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# Fiber Optic Relative Humidity Sensor

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Submitted by:

Dr. Farhad Ansari*
Professor

Submitted to:

Patrick J. Szary**
Research Engineer

*Civil & Materials Engineering
University of Illinois at Chicago
Chicago, IL 60607

**Center for Advanced Infrastructure & Transportation (CAIT)
Rutgers, The State University
Piscataway, NJ 08854-8014

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16. Abstract

The objective for this study was to investigate and to perform a detailed survey of available sensors for quantification of relative humidity. The importance of relative humidity measurements becomes apparent in geotechnical applications, including in hydrogeologic characterization of contaminated sites, and creation of contaminant transport models. Survey of literature developed here includes all the recent advances in the development of relative humidity sensors using myriads of technologies including electrical optical, and chemical basis. Moreover, the survey includes basic research for development of the sensors as well as applications. Applications in all disciplines are considered for completeness. It turns out there is a need for fiber optic sensors as there has been very limited (one to two) sensors that have been developed using optical fiber sensor technology. These sensors have not been packaged for practical applications and therefore there is a need to start a project for packaging and fiber optic sensor for specific applications in geotechnical engineering.

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## Background

Accurate hydrogeologic characterization of contaminated sites, along with the nature and extent of contamination must be determined in order to perform risk assessments, create contaminant transport models, and optimize remedial alternatives such as soil venting and bioremediation. Pore pressure is a critical parameter for flow and transport modeling that can be used with stratigraphic information to correlate geologic units. For this reason, it is important to develop technologies for practical measurement of relative humidity in soils. A desirable approach corresponds to engineer the sensors either as a standalone unit or packaged into a cone-penetrometer-push technology. A promising technology has been the use of fiber optic sensors for this purpose. The basic design for any Relative Humidity (RH) sensor pertains to quantification of the capillary pore pressure in unsaturated soils. These sensors allow for real-time, continuous measurement.

## Objectives

The objective for this study was to investigate and to perform a detailed survey of available sensors for quantification of relative humidity. The importance of relative humidity measurements becomes apparent in geotechnical applications, including in hydrogeologic characterization of contaminated sites, and creation of contaminant transport models. Survey of literature developed here includes all the recent advances in the development of relative humidity sensors using myriads of technologies including electrical optical, and chemical basis. Moreover, the survey includes basic research for development of the sensors as well as applications. Applications in all disciplines are considered for completeness. It turns out there is a need for fiber optic sensors as there has been very limited (one to two) sensors that have been developed using optical fiber sensor technology. These sensors have not been packaged for practical applications and therefore there is a need to start a project for packaging and fiber optic sensor for specific applications in geotechnical engineering.

## Structure of the Report

As per earlier discussions, the objective of the technology transfer project was to perform an exhaustive literature search pertaining to the state-of-the art in Relative Humidity sensor technology as related to geotechnical engineering. Main focus was on fiber optics, but then it was realized that the extent of the work has been limited to few worth citing. The search results are presented in this report in the following format:

1. Search was limited to the recent literature (2003-2006).
2. Summary of the results for each cited work is presented directly from the abstract. Therefore, the original authors of the cited work are credited with the full abstracts presented here (abstracts extracted from th literature and copied in here). This approach provides a quick and direct evaluation of each sensor/sensor category for future application and research. This approach is especially very

advantages since the abstracts for each cited work describes advantages, shortcomings, applications and the state of the developed technologies. Some of the cited work do not directly correspond to relative humidity sensors, but are indirectly related either through similarity in application or indirect correspondence. As discussed earlier, results from this survey indicates that hardly any work has been accomplished in fiber optic sensor technology and the final recommendation of this technology transfer project calls for a one year research for packaging a fiber optic relative humidity sensor.

List of Literature and Corresponding Abstracts

Abe, H. and H. Kitano (2006). "Development of humidity standard in trace-moisture region: Characteristics of humidity generation of diffusion tube humidity generator." Sensors and Actuators a-Physical **128**(1): 202-208.

The characteristics of humidity generation of a diffusion tube humidity generator (DTG) have been studied by the real-time mass measurement of evaporating water using a magnetic suspension balance and by humidity measurement using a moisture analyzer based on cavity ring-down spectroscopy in the amount-of-substance fraction range of water between 20 nmol/mol and 600 nmol/mol. The observed mass-change rates of a diffusion cell due to water evaporation agree well with the evaporation rates calculated on the basis of Fick's law of diffusion. The stable generation of trace-moisture in nitrogen gas is realized by precisely controlling temperature and pressure. The relative standard uncertainty of the stability of trace-moisture generation of the DTG is 0.006 (0.6%). The effect of temperature on the stability of humidity generation of the DTG is smaller than that of a frost-point generator. (c) 2006 Elsevier B.V. All rights reserved.

Agus, S. S. and T. Schanz (2005). "Comparison of four methods for measuring total suction." Vadose Zone Journal **4**(4): 1087-1095.

This study assessed four methods for measuring soil total suction in laboratory: the noncontact filter paper method, the psychrometer technique, the relative humidity ( RH) sensor, and the chilled- mirror hygrometer technique. Our aim in this study was to compare the four total suction measurement techniques, especially the psychrometer method and the RH sensor, which may be used for field total suction measurements. While field application of the sensors is the eventual concern, no field measurements were performed in the study. Assessment was made using two bentonite - sand mixtures, which can be used as clay liner for landfills. A discussion of factors influencing measurement accuracy is also provided. The chilled- mirror hygrometer technique appears to give the most accurate results, and therefore may used as a benchmark for assessing the accuracy of the three other methods. For the bentonite - sand mixture used in this study, the total suction measured using the noncontact filter paper technique represents values at a quasi-equilibrium state after redistribution of water in the specimen, instead of the total suction at as- compacted state. The RH sensor provided a faster response than the psychrometer technique However, the RH sensor exhibited a systematic error in the small suction range.

Ahn, K., B. W. Wessels, et al. (2005). "Spinel humidity sensors prepared by thermal spray direct writing." Sensors and Actuators B-Chemical **107**(1): 342-346.

Ceramic humidity sensors consisting of MgAl2O4 dielectric layer and Ni-5

wt.%Al electrodes were prepared by plasma spray processing and their electrical properties were investigated as a function of the relative humidity. The complex impedance of the sensor was measured at different humidity levels, using impedance spectroscopy. The resistance and the capacitance of the sensor were determined from the impedance plots using equivalent circuit simulations. The resistance of the sensor decreased from 2.4 x 10(9) to 9 x 10(5) Omega with increasing the relative humidity from 11 to 98% due to the increase of surface electrical conductivity resulting from water adsorption. The capacitance increased 1-7 nF in the humidity range. 

Airaksinen, S., M. Karjalainen, et al. (2004). "Comparison of the effects of two drying methods on polymorphism of theophylline." International Journal of Pharmaceutics **276**(1-2): 129-141.

Processing-induced transformations in drug formulation may induce adverse biopharmaceutical changes in the finished product. During the drying phase of wet granulation, theophylline monohydrate transforms either the stable (form I), ora polymorphic, metastable (form I*) form of anhydrous theophylline. We investigated the effect of two drying methods (multichamber microscale fluid bed dryer MMFD) or variable temperature X-ray powder diffractometer (VT-XRPD) on the relative amounts of the different theophylline forms remaining in the dried granules. Granules were analyzed using XRPD and near-infrared spectroscopy. Form I* was the predominant form of theophylline after drying at 40-50degreesC with both drying techniques. Although drying at temperatures over 50degreesC produced mostly form I, more than 20% of form I-* remained even at 90degreesC when drying in MMFD. In these conditions, humidity had little influence on the amount of form I* in the granules. In contrast, drying in a VT-XRPD at 60degreesC produced form I already during the first 15 min. Using additional drying methods, including MMFD, during the preformulation stage can be more informative about the possible polymorphic transformations and their underlying mechanisms, such as triboelectrification or recrystallization, in drug ingredients during the manufacturing process. 

Alexy, M., G. Voss, et al. (2005). "Optochemical sensor for determining ozone based on novel soluble indigo dyes immobilised in a highly permeable polymeric film." Analytical and Bioanalytical Chemistry **382**(7): 1628-1641.

An optochemical ozone sensor is described that has been manufactured by immobilisation of novel soluble indigo derivatives in permeable transparent polymeric films of polydimethylsiloxane-polycarbonate copolymer. From a number of investigated indigo derivatives, 4,4',7,7'-tetraalkoxyindigo 9 has been selected for optimal sensitivity and specificity of ozone detection. A linear calibration for ozone can be obtained in the range between 0.01 and 0.5 ppm. The limit of quantitation is 0.03 ppm, and the accuracy exceeds 8%. It takes about 134 s to measure the

relatively low occupational exposure concentration of 0.1 ppm. A reduction of the sensor response time could be achieved through application of double-sided coated sensors instead of single-sided variants. The stability of the sensors and the effect of external parameters like relative humidity (RH), temperature and gas flow on the sensor response have been investigated. The sensor response is affected by varying the gas flow or temperature; however, humidity in the range between 0 and 90% RH does not affect sensor response. The indigo derivative 9 remained stable inside the polymeric film and no chemical reaction, crystallisation or leaching occurred during 10 months of observation. Proper choice of indicator dye and polymeric material and successful application of kinetic evaluation method for the exposure experiments determine the desired features of the sensor.

Alexy, M., M. Hanko, et al. (2006). "Disposable optochemical sensor chip for nitrogen dioxide detection based on oxidation of N,N '-diphenyl-1,4-phenylenediamine." Sensors and Actuators B-Chemical **114**(2): 916-927.

We report on a novel optochemical sensor chip for nitrogen dioxide (NO2) based on the indicator reagent N,N'-diphenyl-1,4-phenylenediamine (DPPD). The sensor chip was manufactured by immobilising DPPD in a highly permeable polymeric layer made from polydimethylsiloxane-polycarbonate block copolymer (PDMS-PC). The presence of NO2 causes oxidation of DPPD, which thereby changes its visible spectrum. The best wavelength for determining NO2 was 480 nm. To realise short measuring times (e.g. 23 s to determine 5 ppm NO2), a measuring procedure was chosen that enables a linear correlation between the rate of change of the transmission of DPPD and the concentration of NO2. A linear calibration function was obtained in the range from 0.1 to 25 ppm NO2. The limit of quantitation (LOQ) was 0.12 ppm and the accuracy exceeds 6%. The stability of the sensor chips, the effect of internal parameters (indicator reagent concentration and thickness of the polymeric layer) and the effect of external parameters (relative humidity (RH), temperature and gas flow) on the sensor chip response were investigated.No cross-sensitivities were observed at concentrations lower than 0.1 ppm ozone (03), 0.2ppm chlorine (Cl-2) and 250ppm nitrogen monoxide (NO).The application area of the developed sensor chips is environmental and working place analysis of NO2. For this purpose, the sensor chips will be integrated into a lightweight portable photometer made of semiconductor components. 

Alvarez-Herrero, A., H. Guerrero, et al. (2004). "High-sensitivity sensor of low relative humidity based on overlay on side-polished fibers." Ieee Sensors Journal **4**(1): 52-56.

A low relative humidity (RH) sensor based on overlay on side-polished fiber is presented. The evanescent field from a single-mode optical fiber is coupled to a TiO2 waveguide overlay. The transmission response exhibits

sharp resonances whose central wavelengths are linearly shifted with RH. This behavior is due to the porous columnar nanostructure of the TiO2 film. The water is adsorbed in the pores of the nanostructure changing the refractive index of the layer and causing a shift of the wavelength resonances. The response of the sensor is determined by the shape and size of the pores.The optical fiber evanescent field sensor developed has a linear response and high sensitivity (0.5 nm/% RH) for low RH (RHsimilar to0%-15%) at 26.1 degreesC +/- 0.6 degreesC. The lack of hysteresis in the adsorption-desorption cycle has been checked. The development of a sensor with tailored response is envisaged using properly techniques to control the porosity of the material.

Ankara, Z., T. Kammerer, et al. (2004). "Low power virtual sensor array based on a micromachined gas sensor for fast discrimination between H-2, CO and relative humidity." Sensors and Actuators B-Chemical **100**(1-2): 240-245.

A micromachined metal oxide gas sensor operated with temperature modulation allows discrimination between air, H-2 and CO in less than 1 s. Furthermore, the actual humidity level and gas concentration can be estimated. We tested gas concentrations of 3-12 ppm H-2 and 12-100 ppm CO at five relative humidity levels between 30 and 70%. While H-2 can be identified for all concentrations, certain identification of CO requires concentrations above 20 ppm and also determination of the relative humidity level from the sensor data. 

Ansari, Z. A., T. G. Ko, et al. (2004). "Humidity sensing behavior of thick films of strontium-doped lead-zirconium-titanate." Surface & Coatings Technology **179**(2-3): 182-187.

PS(x)Z(0.3)T(0.7)O(3) (x = 0.1-0.5) nano-particles were prepared using sol-gel technique from alkaoxides. The powders were calcined at different temperatures from 500 to 700 degreesC. The optimum calcination temperature of 600 degreesC was chosen based on the differential thermal analysis and XRD analyses. The structural and morphological analyses of powders were carried out using XRD and scanning electron microscope. The particle size found to be approximately 30-45 nm, varies as an inverse function of Sr doping concentration. Sensors were fabricated in the form of thick film resistors (of similar to25-mum thickness) on the alumina substrate having pre-printed Ag electrodes. The I-V characteristic of these resistors was obtained by varying voltage from -5 to +5 V. The band gap is found to vary from 2.7 to 3.7 eV which decreases with increasing Sr doping level. The samples were tested for sensing relative humidity (RH) in the range of 20-100% RH. The sensitivity, measured as a function of d.c. resistance, increases with increasing Sr concentration. The sensitivity and barrier height are correlated. 

Armento, P., M. Casciola, et al. (2004). "Silica-zirconium phosphate-phosphoric acid composites: preparation, proton conductivity and use in gas sensors." Solid State Ionics **166**(1-2): 19-25.

Mesoporous composites made of silica and alpha-zirconium phosphate (SiO2.xZrP) were synthesized starting from mixtures of delaminated ZrP dispersions and tetrapropylammonium oligosilicate solutions. The surface area of the composites reaches a maximum of 700 m(2)/g for x approximate to 0.02, while the average pore diameter is about 40 A for x in the range 0.05-0.35. In order to increase proton conductivity at low relative humidity (r.h.), SiO2.xZrP.yH(3)PO(4) composites were prepared and characterised by Si-29 and P-31 MAS NMR and conductivity measurements. At 100 degreesC and 6%, r.h., the conductivity of the composites, with H3PO4 loadings of 80% of the pore volume, rises from 5 x 10(-4) to 2 x 10(-2) S/cm for x decreasing between 0.35 and 0.05, as a consequence of the concomitant increase of pore volume. For the composite with x=0.18, the dependence of conductivity on H3PO4 loading was also investigated at different temperatures and r.h. values. The combined increase of humidity, temperature and H3PO4 loading results in an increase of conductivity from 1 x 10(-7) S/cm (y=0.09, T=25 degreesC, 0% r.h.) to 4 x 10(-2) S/cm (y=0.61, T=100 degreesC, 30% r.h.). SiO2.0.18ZrP.0.61H(3)PO(4) was also tested as a proton electrolyte in an oxygen sensor consisting of a disk of the composite sandwiched between a platinum sensing electrode and a reference electrode based on Ni1-xO. The sensor is able to detect O-2 at room temperature in a dry environment with a response time of 20-30 s. (C) 2003 Elsevier B.V. All rights reserved.

Arregui, F. J., I. R. Matias, et al. (2003). "Optical fiber gas sensors based on hydrophobic alumina thin films formed by the electrostatic self-assembly monolayer process." Ieee Sensors Journal **3**(1): 56-61.

Optical fiber gas sensors have been fabricated by deposition of Al2O3 and polymer ultra-thin films on the ends of optical fibers using the electrostatic self assembly monolayer process. These sensors are designed to operate at the standard transmission wavelengths with no cross sensitivity to temperature from at least 10 to 70degreesC Experimental results of the response of these sensors to organic volatile compounds such as acetone, dichloromethane, or ethanol, are presented. In addition, a thermal curing process is proposed for achieving a humidity cross sensitivity of less than 1.4% from 11% to 85% of relative humidity, this cross sensitivity was still negligible after one year of the thermal curing process.

Arregui, F. J., Z. Ciaurriz, et al. (2003). "An experimental study about hydrogels for the fabrication of optical fiber humidity sensors." Sensors and Actuators B-Chemical **96**(1-2): 165-172.

A study about the optical sensitivity of four different hydrogels to the humidity is presented. The investigated hydrogels were poly-hydroxyethyl

methacrylate, poly-acrylamide, poly-N-vinyl pyrrolidinone and agarose. These hydrogels were deposited on optical fiber by means of direct polymerization on the optical fiber surface. In addition, these materials were examined with different light sources, temperature and relative humidity conditions. The conclusion deducted from the experiments is that increasing the pore size of the hydrogels, the sensitivity and response time of these materials with the humidity is remarkably improved. 

Arshak, K., E. Jafer, et al. (2005). "Design of a new thick film capacitive pressure and circuitry interface." Composites Science and Technology **65**(5): 757-764.

In recent years, number of studies investigating the use of capacitance effects in mechanical transducers has been undertaken. It was found that changing the dimensions of the chemical constitution of the dielectric material could change the nominal value of the parallel plate. This fact has been used to develop sensors that measure quantities such as strain, acceleration, gas concentration, humidity, etc. [1].This paper is focused on developing a low-cost pressure sensitive device using thick film technology. The paper illustrates the original design specifications and how the sensor and signal conditioning circuitry performed against expectations. One of the design constrains was ensuring the operation of the sensor in a hostile operating conditions. Several device configurations were made based on both commercial Cermet and a PZT pastes. The relative performance of these materials as a dielectric-sensing element is compared in terms of their sensitivity, repeatability, and hysteresis.An efficient signal conditioning circuitry has been developed. The purpose of the circuitry is to allow the interface to make control decisions based on accurate stable pressure readings obtained by at the circuit. In this paper, the full system design of the pressure sensor and compensation circuitry was considered. 

Baratto, C., G. Sberveglieri, et al. (2004). "Low temperature selective NO2 sensors by nanostructured fibres of ZnO." Sensors and Actuators B-Chemical **100**(1-2): 261-265.

We studied the gas sensing properties of Zn nanopowders synthesised by an aerosol route. Two different powder morphologies were obtained: fibre-mats and cauliflower structure. Both sensors showed a great sensitivity against sub-ppm concentration of NO2 at low working temperature. The fibre powders relative response towards 0.4 ppm of NO2 is 50, while relative response of the cauliflower structure is 8 at 100degreesC. Both sensors were also selective, since no resistance variation was observed for CO, and ethanol. On the contrary resistance variations were observed with relative humidity changes. Sensors behaviour was studied at different working temperatures in the range 20-150degreesC. 

Barillaro, G., A. Diligenti, et al. (2006). "Low-concentration NO2 detection with an adsorption porous silicon FET." Ieee Sensors Journal **6**(1): 19-23.

Adsorption porous silicon FET (APSFET) is a porous silicon (PS)-based device constituted of a FET structure with a porous adsorbing layer between drain and source. Adsorbed gas molecules in the porous layer induce an inverted channel in the crystalline silicon under the PS itself. The mobile charge per unit area in the channel depends on the molecular gas concentrations in the sensing layer so that adsorbed gas molecules play a role similar to the charge on the gate of a FET. In this work, NO2 detection by using the APSFET is demonstrated for the first time. NO2 concentration as low as 100 ppb was detected. Devices with both as-grown and oxidized PS layers were fabricated and compared in order to investigate the effect of a low-temperature thermal oxidation on the electrical performances of the sensor. Nonoxidized sensors show a high sensitivity only for fresh devices, which reduces with the aging of the sample. Oxidation of the PS layer improves the electrical performance of sensors, in terms of stability, recovery time, and interference with the relative humidity level, keeping the high sensitivity to nitrogen dioxide.

Bedoya, M., M. T. Diez, et al. (2006). "Humidity sensing with a luminescent Ru(II) complex and phase-sensitive detection." Sensors and Actuators B-Chemical **113**(2): 573-581.

A simple, inexpensive optode for relative humidity (RH) monitoring in air has been fabricated using the water-sensitive luminescent dye [Ru(phen)(2)(dppz)](2+) (where phen and dppz stand for 1,10-phenanthroline and dipyrido[3,2-a:2',3'-c]phenazine, respectively) immobilized on poly(tetrafluoroethylene). When interrogated with a tailored emission lifetime-based instrument, the novel device outperforms humidity optosensors reported so far for environmental monitoring. The operational range of the optode is from 4 to 100% RH at 20 degrees C. Its response time (t(90)) is shorter than 1.4 min (recovery time < 1.2 min), and it shows repeatability and reproducibility of the RH measurements better than 1 and 4%, respectively. Furthermore, the robust optode can even be dipped in water with full recovery of its analytical features and its stability has been verified for more than 2.5 years (discontinuous measurement). The sensor has been validated in the 10-30 degrees C temperature range using a NIST-traceable humidity generator. It has been applied successfully to water activity measurements in food and relative humidity monitoring in a weather station using a ruggedized fiber-optic phase-sensitive fluorometer. 

Belysheva, T. V. and L. P. Bogovtseva (2006). "Determination of low chlorine concentrations in air using semiconductor chemical sensors." Journal of Analytical Chemistry **61**(5): 494-497.

Comparative studies of electophysical gas-sensitive properties of semiconductor metal oxides (NiO, WO3, and In2O3) in detecting trace

concentrations of chlorine in air at 250-300 degrees C were performed. WO3 and In(2)O(3) film sensors were found to have the best sensitivity, selectivity, and stability. However, WO3 films are characterized by a longer relaxation time (3 min) compared to In2O3 films, for which it is no longer than 30 s. The kinetic and steady-state relative conductivity values of In2O3 films as functions of the chlorine concentration in air fall on the same curve in the range 0.01-0.7 ppm. This suggests that the concentration of chlorine in air can be determined from the initial rates of the variation of the relative conductivity of films, which significantly decreases the time of analysis (from 40 to 5 s at a sensor working temperature of 300 degrees C). Changes in air humidity in the range from 40 to 80% have no effect on the initial rates of the variation of the relative conductivity of In2O3 films under kinetic conditions. The mechanism of the variation of In2O3 film conductivity in detecting chlorine in air was discussed.

Bernardi, A., F. Becherini, et al. (2006). "Condensation on ancient stained glass windows and efficiency of protective glazing systems: two French case studies, Sainte-Chapelle (Paris) and Saint-Urbain Basilica (Troyes)." Journal of Cultural Heritage **7**(1): 71-78.

The multidisciplinary EC VIDRIO project has the purpose of providing a better understanding of the effect of the environment on glass surfaces and paint (grisaille) and to evaluate the efficiency of the protective glazing system, in order to find sustainable solutions to protect ancient stained glass windows from the main causes of glass weathering, in particular the condensation phenomenon. Hence, a new device, named "dew point sensor", was built and patented to protect the stained glass windows by detecting the condensation on the glass surface. The research was focused on laboratory tests and experimental campaigns: two important French monuments, Sainte-Chapelle in Paris and Saint-Urbain Basilica in Troyes, were monitored, while the study in Cologne Cathedral (Germany) is still in progress. Three different systems were used to detect the phenomenon of condensation in order to evaluate and compare their accuracy and reliability: the indirect measurement through mathematic calculations using air temperature and relative humidity, and two direct measurements by means of the dew point and the leaf wetness sensors, The laboratory tests and research in the field made evident the errors associated with the measurements of the condensation process, and the accuracy and reliability of the new device. The efficiency of the protective glazing system, as regards to the weathering of the stained glass windows, has been confirmed. In fact, the presence of a protective glazing reduces the danger of condensation on the internal side of the ancient window and also the total time of the high relative humidity values of the air in contact with the protected window. 

Bertolo, J. M., A. Bearzotti, et al. (2003). "Sensoristic applications of self-assembled mesostructured silica films." Sensor Letters **1**(1): 64-70.

Electrochemical sensors developed from mesostructured silica film have been fabricated through evaporation-induced self-assembly via dip-coating on various substrates with interdigitated electrodes. The silica films exhibited ordered mesoporous phases that were maintained after the copolymer removal. A large current variation (up to four orders of magnitude) has been observed during relative humidity changes in the testing chamber. The performance of the sensors has been found to be dependent on the film preparation method, especially on the calcination temperature and the length of time it is maintained. A different response as a function of the surfactant used as templating agent has been obtained. The electrical response of the devices was studied at various concentrations of alcohol vapor (methanol, ethanol, isopropanol, and n-butanol).

Bishop, A. and P. Gouma (2005). "Leuco-emeraldine based polyaniline-poly-vinyl-pyrrolidone electrospun composites and bio-composites: A preliminary study of sensing behavior." Reviews on Advanced Materials Science **10**(3): 209-214.

The responsive nature of polyaniline (PANI) to gaseous pollutants is highly dependant on the film composition and processing. In initial studies LEB-PANI was used to develop a room temperature sensor for NO2 detection. It has been observed that the relative response to NO2 in constant humidity is dependant on the concentration of polyaniline in electrospun films of PANI and poly-vinyl-pyrrolidone (PVP). In subsequent studies analysis of exposed bio-doped PANV PVP matrices reveal PANI particles self assembling into hollow fibrous structures. In this paper the results from initial efforts for the development of a PANI based bio/chem sensor are discussed.

Bjorkqvist, M., J. Salonen, et al. (2004). "Characterization of thermally carbonized porous silicon humidity sensor." Sensors and Actuators a-Physical **112**(2-3): 244-247.

We report the properties of a capacitance type thermally carbonized porous silicon (TC-PS) humidity sensor at room temperature. Several constructions to use porous silicon as a miniaturized humidity sensor material have been introduced earlier. In these applications, poor long-term stability of PS is most often improved by thermal oxidation. However, thermally carbonized PS surface has been found to be at least as stable in humid atmosphere, and in addition to that, the thermal carbonization also maintains the originally large specific surface area of PS. Indeed, our sensor shows good sensitivity over a wide range of relative humidity. The repeatability is excellent but the hysteresis above 60% of relative humidity should be reduced. The effect of measurement frequency on the sensitivity is also demonstrated. 

Bjorkqvist, M., J. Salonen, et al. (2004). "Humidity behavior of thermally carbonized porous silicon." Applied Surface Science **222**(1-4): 269-274.

We have studied the humidity behavior of thermally carbonized (TC) p+-type porous silicon (PS) samples as a function of carbonization temperature. The Fourier transform infrared (FTIR) spectroscopy and gas adsorption measurements indicate that the bond configuration and structure of thermally carbonized porous silicon surface are highly dependent on carbonization temperature. Moreover, the surface affects on the stability of porous silicon but also significantly on its humidity behavior. The porous silicon samples carbonized at or below 650 degreesC remain hydrophobic, while the temperature of 730 degreesC was high enough to produce a hydrophilic surface. The water sorption rate in thermally carbonized porous silicon samples was quite slow, however, this was interpreted to be mostly a consequence of a thick sample. Hygroscopicity was studied by measuring the weight of the sample under various relative humidity values, and also by using isothermal microcalorimeter (IMC). For humidity sensor purposes, we also studied the effect of water adsorption on electrical parameters of thermally carbonized porous silicon layer. The changes of resistance and capacitance were observed both for hydrophobic and hydrophilic surface. 

Bjorkqvist, M., J. Paski, et al. (2005). "Temperature dependence of thermally-carbonized porous silicon humidity sensor." Physica Status Solidi a-Applications and Materials Science **202**(8): 1653-1657.

Thermal carbonization of porous silicon (PS) at 820 degrees C under acetylene atmosphere is an appropriate method for humidity sensing purposes. It produces stable and hydrophilic surface still maintaining originally large specific surface area of PS. We report the temperature dependence of various electrical parameters measured for the thermally-carbonized PS humidity sensor. Capacitance of the sensor in dry air (6 RH%) is almost constant at various temperatures, whereas in higher relative humidity values, the temperature dependence becomes evident. The resistance variation of the sensor is less dependent on RH as the temperature increases. While the capacitance showed linear behavior as a function of temperature, the resistance had a clear non-linear temperature dependence. In order to get information about the effects of frequency on capacitance values, we measured a phase angle and admittance of the sensor as a function of frequency at three different temperatures in low and high humidity. According to these results, it is preferable to operate this sensor construction using low frequency (< 1 kHz). 

Bjorkqvist, M., J. Paski, et al. (2006). "Studies on hysteresis reduction in thermally carbonized porous silicon humidity sensor." Ieee Sensors Journal **6**(3):

542-547.

Different ways to reduce hysteresis in a capacitive-type thermally carbonized porous silicon (TC-PS) humidity sensor are studied and compared. Modification of the contact angle of the dielectric surface, enlargement of the pore size of dielectric, and operating the sensor at elevated temperature proved all to be possible ways to reduce hysteresis in a TC-PS humidity sensor. By variation of the carbonization temperature, we produced TC-PS surfaces of different contact angles. Although the hydrophobic surface prevents hysteresis, it also decreases considerably the sensitivity of the sensor. Enlargement of the pore size reduces and tunes the hysteresis loop into the higher relative humidity (RH) values. Also operation of the sensor only few degrees above room temperature was found to be a workable method to prevent hysteresis. However, a constant temperature is crucial for exact humidity measurement using a TC-PS sensor.

Bruno, P., G. Cicala, et al. (2004). "High relative humidity range sensor based on polymer-coated STW resonant device." Sensors and Actuators B-Chemical **100**(1-2): 126-130.

A polymer-coated surface transverse acoustic wave (STW) resonator is used in high sensitivity relative humidity (RH) sensors ranging from 60 to 100%. The STW device is designed to resonate at 316 MHz and is realized on AT-cut quartz substrate to minimize thermal dependencies. Two kinds of polymeric films, HMDSO and a-C:H, produced by plasma enhanced chemical vapor deposition at room temperature, are tested. The resonant frequency shift of the coated device due to the sorbed water vapor mass is measured at controlled relative humidity and temperature. The most stable and sensitive a-C:H coating is obtained at 50% CH4 of feeding CH4-Ar mixture. Average sensitivities for HMDSO and a-C:H coated device are found to be about 15 and 7.5 ppm/% RH, respectively. The response time to a step of 90% RH for both coatings is less than 30s. 

Bruzzi, M., S. Miglio, et al. (2004). "First study of humidity sensors based on nanostructured carbon films produced by supersonic cluster beam deposition." Sensors and Actuators B-Chemical **100**(1-2): 173-176.

We have investigated the feasibility of humidity sensors based on nanostructured carbon (ns-C) films produced by supersonic cluster beam deposition (SCBD). The ns-C films have been obtained using pure He as the buffer gas in the pulsed microplasma cluster source (PMCS). Films of different thickness (1-10 mum) were deposited on Au contacts: resistive- and capacitive-type devices were manufactured. Resistive sensor show a flat response for relative humidity (%RH) up to 60%. Preliminary measurements performed on capacitive-type devices at room temperature in the relative humidity range 10-70% showed a linear dependence of the capacitance on RH%. Fast rise times and a sensitivity of the order of 0.1-

0.5 pF/%RH favourably compare with standard commercial sensors and other advanced capacitive devices made with polymers. (C) 2003 Elsevier B.V. All rights reserved.

Cambaz, G. and M. Timucin (2004). "Compositional modifications in humidity sensing MgAl2O4 ceramics." Euro Ceramics Viii, Pts 1-3 **264-268**: 1265-1268.

The MgAl2O4 powders were synthesized using the mixed oxide technique. The powders were doped with Na+ ion to modify the sintering behavior and the response characteristics of the spinel ceramics. The variations in electrical impedance were determined at room temperature under relative humidity (RH) values ranging from 21 to 98%. The effect of Na2O addition and sintering temperature on the microstructure and humidity sensitivity of MgAl2O4 were investigated.

Canhoto, O., F. Pinzari, et al. (2004). "Application of electronic nose technology for the detection of fungal contamination in library paper." International Biodeterioration & Biodegradation **54**(4): 303-309.

Studies were carried out in vitro on a cellulose based agar at two water activities (a(w),0.975,0.995) and on three types of paper at two relative humidities (75, 100% RH) for the potential for differentiation of contamination and colonisation by Aspergillus terreus, A. holandicus and Eurotium chevalieri. In vitro studies showed that conducting polymer sensor array gave different responses to each of these species when grown on cellulose agar at both a, levels. Discriminant function analyses of the data showed differentiation of the controls from the spoilage fungi. Cluster analysis gave a significant (P = 0.05) separation of the control and each spoilage fungus. In situ studies on three types of paper showed that using natural substrates the volatile patterns produced by each of these fungi was different from each other and from the control. The results obtained were better at the higher humidity. The three paper types could be successfully differentiated into clusters. For a single paper type, differentiation of controls from spoilage fungal treatments was better at the higher humidity. This study has shown that this technology has potential for the early detection of fungal contamination in library materials and archives for the improved protection of cultural heritage. (C) 2004 Elsevier Ltd. All rights reserved.

Cantalini, C., L. Lozzi, et al. (2003). "The comparative effect of two different annealing temperatures and times on the sensitivity and long-term stability of WO3 thin films for detecting NO2." Ieee Sensors Journal **3**(2): 171-179.

We have deposited 150-nm-thick WO3, films on Si3N4/Si substrates provided with platinum interdigital electrodes and annealed in static air at 300 degreesC and 500 degreesC temperatures for 24 h and 200 h. The morphology, crystalline phase, and chemical composition of the films have been characterized using AFM, grazing incidence XRD and high resolution XPS techniques. The sensor resistance response curve has

been obtained in the 0.2 -4 ppm NO2 gas concentration range in humid air (50% relative humidity), varying the operating temperature between 25 and 250 degreesC. By plotting both sensor resistance and gas concentration logarithmically, the response is linear over the investigated dynamic range. Sensor sensitivities, here defined as the ratio of sensor resistance in gas to that in air (i.e., S = R-Gas/R-Air), have been compared at a given NO2 gas concentration (0.2 ppm). The long-term stability properties have been evaluated by recording film sensitivity for I yr under standardized test conditions. Increasing the annealing temperature from 300 to 500 degreesC causes the sensitivities to decrease. The 300/24h film is shown to be the most sensitive at S = 233, but with poor long-term stability properties. The 300/200h film with S = 32 is stable over the examined period. The 500/24 and the 500/200 films are shown to be less sensitive with S = 16 and S = 14, respectively. The longer the annealing time and the higher the temperature, the poorer the sensitivity, but with positive effects upon the long-term stability of the electrical response. The influence of the annealing conditions on sensitivity and long-term stability has been correlated with the concentration of surface defects, like reduced WO3 phase (i.e., W4+), which resulted in a strong effect on the sensors' response.

Casalbore-Miceli, G., A. Zanelli, et al. (2005). "A model of polyelectrolyte conductance in moist solvents as a basis of water sensors." Langmuir **21**(21): 9704-9708.

The conductance of interpenetrated polymer networks (IPNs) containing quaternary amino groups was studied in cyclohexane, toluene, ethyl ether, ethyl acetate, and tetrahydrofurane as a function of water content by electrochemical impedance spectroscopy. IPNs were then used as sensitive materials to detect water traces in organic solvents with promising results for the construction of a moisture sensor. The detection onset for water concentration increased with the dielectric constant of the solvent. Different IPN-based sensors in the same solvent showed a detection limit at lower water concentration if their characteristic plot [conductance/relative humidity (RH%) in air] was shifted toward lower RH%. This suggests that the composition of this class of polymers can be tuned to achieve the best performance for each solvent.

Chachulski, B., J. Gebicki, et al. (2006). "Properties of a polyethyleneimine-based sensor for measuring medium and high relative humidity." Measurement Science & Technology **17**(1): 12-16.

In this paper a method of preparing polyethyleneimine films, which improves the water resistance of polymer humidity sensors, is proposed. The polyethyleneimine was cross-linked at elevated temperature using 1,4-butanediol diglycidyl ether, both being dissolved in dimethylsulfoxide. The optimum composition of polymer and optimum reaction temperature were obtained. Resistive-type sensors have been prepared by dip coating.

The sensor preserves excellent durability in high humidities or even after immersion in water. The electrical properties of the sensors were investigated by impedance spectroscopy.

Chang, W. Y., Y. C. Lin, et al. (2006). "Combined TiO2/SnO2 material with adding Pt by sol-gel technology for humidity sensor." Progress on Advanced Manufacture for Micro/Nano Technology 2005, Pt 1 and 2 **505-507**: 397-402.

In this work, the sensitivity of the humidity sensor based on hybrid thin films of TiO2/SnO2 nanostructure with Pt dopant was successfully increased. The humidity-sensitive materials, TiO2/SnO2, were prepared by sol gel technology. The microstructure of the sensing film after calcination was investigated by Field Emission gun Scanning Electron Microscopy (FESEM) and revealed that the metal oxide hybrid had about 10 rim grain size. On order to study the effect of Pt dopant on the humidity-sensitive responses, 1 to 10 ml of Pt standard solution was added into the colloidal solution. To compare the humidity sensor of Pt dopant with that of no Pt dopant, operational frequencies and electrode spacings were set under the relative humidity from 30 % to 95 % at the ambient temperature of 22 degrees C. We demonstrated that adding Pt dopant remarkably enhances the sensitivity of TiO2/SnO2 humidity sensor, and further decreased the TiO2/SnO2 resistance, which was 3.3 times lower than that without Pt dopant at high humidity.

Chen, C. C. (2004). "Humidity in plant tissue culture vessels." Biosystems Engineering **88**(2): 231-241.

The relative humidity within the culture vessels is usually very high, resulting in poorly developed epicuticular wax layer and malfunctioning stomata of the plantlets. In this study, the humidity profile in the plant culture vessel was measured by the high polymer humidity sensor. The accuracy of these sensors was improved by calibration equations established using several saturated salt solutions. The tension of the medium was measured by a piezoresistive silicon tension meter. A vapour transfer model was proposed to describe the factors affecting relative humidity in the vessel. The evaporation model of the medium was established to quantify these factors. Several techniques that had been applied for reducing the relative humidity were evaluated by the vapour transfer model. 

Chen, Z. and C. Lu (2005). "Humidity sensors: A review of materials and mechanisms." Sensor Letters **3**(4): 274-295.

We have reviewed humidity sensors based on various materials for both relative and absolute humidity, including ceramic, semiconducting, and polymer materials. In the majority of publications, there are few papers dealing with absolute humidity sensors, which have extensive applications in industry. We reviewed extensively absolute humidity sensors in this

article, which is unique comparing with other reviews of humidity sensors. The electrical properties of humidity sensors such as sensitivity, response time, and stability have been described in details for various materials and a considerable part of the review is focused on the sensing mechanisms. In addition, preparation and characterization of sensing materials are also described. For absolute humidity sensors, mirror-based dew-point sensors and solid-state Al2O3 moisture sensors have been described. As the major problem in Al2O3 moisture sensors, long-term instability, has been solved, alpha-Al2O3 moisture sensors may have promising future in industry.

Cho, J. H., J. B. Yu, et al. (2005). "Sensing behaviors of polypyrrole sensor under humidity condition." Sensors and Actuators B-Chemical **108**(1-2): 389-392.

The influence of temperature (0, 25, and 40 degrees C and relative humidity (5, 10, and 20%) of polypyrrole (PPy) sensor were studied. The PPy sensors were prepared by chemical oxidative method. Initial resistance of the PPy sensor was increased with increase of humidity and decrease of temperature, respectively. Each sensitivity to methanol, water vapor, and mixture gas (methanol and water vapor) was measured, and then compared. Methanol and water vapor were recognized to different type gases in PPy sensors, and adsorption of methanol and water vapor was competed on the surface of sensors. The sensitivity was increased under low humidity and low temperature. The fastest response and recovery time was shown at 25 degrees C. The reproducibility of PPy sensor was excellent at various humidity conditions. The best operating temperature was investigated at 25 degrees C. 

Cole, I. S., W. D. Ganther, et al. (2004). "A study of the wetting of metal surfaces in order to understand the processes controlling atmospheric corrosion." Journal of the Electrochemical Society **151**(12): B627-B635.

This paper explores the simple principle that a metal surface wets when the surface relative humidity (RH) exceeds the deliquescent RH (DRH) of any salts on the surface. Data from field exposures across 19 sites in China, the Philippines, Indonesia, and Australia is used to determine the conditions under which openly exposed surfaces wet. At each site, surface temperature (of a zinc plate), ambient RH, sensor wetness, airborne salinity, and gaseous SOx and NOx were determined over a one-year period. In conjunction with these microclimate measures, the chemistry of airborne and deposited aerosols, as well as rainwater, were measured. Complimentary data from an environmental scanning electron microscope are presented in which salts derived from the evaporation of sea salt are rewetted. Using all of this data, an assessment of the probable contaminants controlling sensor wetting at each site is made. It is found that sites with similar International Standard Organization, (ISO) 9223, classifications in terms of industrial and marine airborne pollutants show

similar surface contaminants and wetting characteristics. It is proposed that dominant contaminates can be identified for each ISO classification that are consistent with the general principle that wetting occurs when surface RH exceeds the DRH of the salts making up the contaminates. These salts can change from day to day due to the continual change in the composition of the contaminates and the ongoing homogenization of previously deposited salts through chemical reaction between salts and with the surface. Rain events usually clean the surface and start the cycle over again. The application of these findings to process models of corrosion is discussed, while generalized rules for predicting surface wetting based on climate data are proposed. It is found that these generalized rules predict total time of wetness to a high degree of accuracy. (C) 2004 The Electrochemical Society.

Connolly, E. J., H. T. M. Pham, et al. (2004). "Relative humidity sensors using porous SiC membranes and Al electrodes." Sensors and Actuators B-Chemical **100**(1-2): 216-220.

There is a need for humidity sensors that can operate in harsh chemical environments. In this respect SiC is a very promising material. Membrane humidity sensors using porous. SiC as the (membrane) sensing element have been fabricated and tested. Earlier work established optimal anodisation conditions to make riotous SiC (optimised for humidity sensing) to be: electrochemical etching in 73% HF, using an anodisation current density J(A) = 1 mA/cm(2). Due to the very low etch-rate of Al in 73% HF, we are able to use Al electrodes instead of Au, making the fabrication process of our sensors more cleanroom friendly. The response of porous SiC membrane devices, with sensitivities up to similar to200% will be discussed. Also, we will discuss the effects on sensor response of accelerated aging in an environmental test furnace and harsh environments such as the outlet of a car exhaust. SEM images are used to examine the membrane structures and porous SiC surfaces. (C) 2004 Elsevier B.V. All rights reserved.

Covington, J. A., J. W. Gardner, et al. (2004). "Conductive polymer gate FET devices for vapour sensing." Iee Proceedings-Circuits Devices and Systems **151**(4): 326-334.

The development of ultra low-power CMOS compatible gas sensors has been the goal of many research groups for a number of years. Such sensors benefit from both a low fabrication cost and an ease of integration with any associated transducer or signal processing circuitry. A sensor with these attributes is proposed comprising a novel chemFET sensor, with a conducting polymer gate, that operates at ambient temperature. Both electrochemically deposited and polymer composite materials have been deposited to form the gate electrode of an n-channel enhanced MOSFET (ECFET and PCFET, respectively). The authors present the first full characterisation of these sensors in terms of their response to pulses

of ethanol and toluene vapour in air. In addition, environmental effects of temperature and humidity on both the baseline signal (i.e. zero vapour) and vapour response have been investigated. The PCFET and ECFET vapour sensitivities (operating at constant current) were found to be up to 5.5 muV/ppm and -2.3 muV/ppm for toluene and 0.6 muV/ppm and 4.5 muV/ppm for ethanol, respectively. The relative selectivity of the chemFET sensors was observed to be up to 564 for these two organics, with an observed sign change with certain polymers. In addition, the detection limits have been estimated to be below 1 ppm of toluene and ethanol vapour in air. It was also found that increasing temperature resulted in a reduction in both baseline and response signals, which the authors postulate is due to a reduction in the bulk solubility of the polymer. The authors believe that the low power of operation, range of polymers and integration with standard electronics makes these sensors ideal for a new range of hand-held electronic noses.

Daanen, H. A., E. M. van Es, et al. (2006). "Heat strain and gross efficiency during endurance exercise after lower, upper, or whole body precooling in the heat." International Journal of Sports Medicine **27**(5): 379-388.

The maximal power that muscles can generate is reduced at low muscle temperatures. However, in prolonged heavy exercise in the heat, a high core temperature may be the factor limiting performance. Precooling has been shown to delay the attainment of hyperthermia. It is still unclear if the whole body should be cooled or if the active muscles should be excluded from cooling in order to maintain muscle power. An experiment was performed to compare thermal strain and gross efficiency following whole body or partial body cooling. Eight well-trained participants performed 40 min of 60% VO2max cycling exercise in a 30 degrees C, 70% relative humidity climatic chamber after four different precooling sessions in a water perfused suit: N (no precooling), CC (45 min whole body precooling), WC (45 min lower body precooling), and CW (45 min upper body precooling). The uncooled body part was Warmed in such a way that the core temperature did not differ from that in session N. Gross efficiency was used to compare performance between the sessions since it indicates how much oxygen is needed for a certain external load. The gross efficiency did not differ significantly between the sessions. Differences in heat loss and heat storage were observed during the first 20 min of exercise. The evaporative heat loss in session WC (305 +/- 67W) and CW (284 +/- 68W) differed from session N (398 +/- 77 W) and CC (209 +/- 58 W). More heat was stored in session CC (442 +/- 125 W) than in sessions WC (316 +/- 39 W), CW (307 +/- 63 W), and N (221 +/- 65 W). It was confirmed that precooling reduces heat strain during exercise in the heat. No differences in heat strain and gross efficiency were observed between precooling of the body part with the exercising muscles and precooling of the tissues elsewhere in the body.

Dabhade, R. V., D. S. Bodas, et al. (2004). "Plasma-treated polymer as humidity sensing material - a feasibility study." Sensors and Actuators B-Chemical **98**(1): 37-40.

Plasma treatment of polymers (surface modification) has been carried out for a long time namely for adhesion improvement and biomedical applications, as it is known to improve the wettability (increase in hydrophilicity) of the polymer surface. It was noted that although extensive work in this area has been carried out, no literature is available on the possible use of plasma-treated/modified polymers for use as humidity sensors. With this in mind, work has been carried out to study the possible use of plasma surface treatment of polymers for humidity sensing. In this communication, we report to the best of our knowledge for the first time humidity sensing by argon plasma-treated polymer namely PMMA with encouraging results. The argon plasma-treated PMMA was characterized by FTIR, XPS, SEM, and contact angle measurements. A capacitive RH sensor was fabricated using the argon plasma-treated PMMA as the dielectric for relative humidity sensing. The sensors fabricated from argon plasma-treated PMMA showed improvement in their sensitivity in 0-40% RH range. (C) 2003 Elsevier B.V. All rights reserved.

Dacres, H. and R. Narayanaswamy (2006). "Highly sensitive optical humidity probe." Talanta **69**(3): 631-636.

A highly sensitive optical humidity probe based on reflectance measurements has been developed using Nafion (R)-crystal violet (CV) films. This sensor can be used to calibrate relative humidity (RH) in the range 0-0.25% with a detection limit (blank signal +3 sigma(b), where sigma(b) = the standard deviation (S.D.) of the blank signal) of 0.018% RH (similar to 4.37 ppm) and exhibited low hysteresis. The sensor films were fully reversible in dry nitrogen and reversal times were shown to be dependent on exposure time and % RH. The response to 1 % RH was highly reproducible (S.D. = 1.67%, number of samples (n)=5). Hydrogen chloride gas did not interfere with the response of the sensor to RH but did reduce sensor reversal times. This sensor displayed sufficient sensitivity that it could be used to detect ppm levels of moisture in process gases such as nitrogen and HCl. (c) 2005 Elsevier B.V. All rights reserved.

Dammgen, U., L. Grunhage, et al. (2005). "The precision and spatial variability of some meteorological parameters needed to determine vertical fluxes of air constituents." Landbauforschung Volkenrode **55**(1): 29-37.

Measurements of meteorological parameters are normally reduced to one set of instruments without replication. If the data are used to generate flux data for the modelling of momentum, heat and matter fluxes between atmosphere and vegetation, the order of magnitude of errors has to be known. Errors arise both from the fact that many instruments are not calibrated individually, as well as from patchiness of vegetation and soil even in ecotopes which are normally considered horizontally

homogeneous. In order to quantify the overall errors, experiments were performed with sets of equal or similar instruments whose results were compared under otherwise identical conditions. We concluded that for wind velocities, an overall error a of 0.1 m center dot s(-1) should be assumed for high resolution cup anemometers; 0.2 m center dot s(-1) are adequate for standard instrumentation. Vertical gradients of wind velocities near the canopy can be resolved with a precision of 15 to 20 %. Air temperature measurements are normally performed using instrumentation with a (nominal) resolution of 0.1 K. Air temperature measurements are much more sensitive against spatial inhomogeneities of the canopy than wind velocity measurements. Air temperature gradients require a resolution of 0.01 K which presupposes careful intercalibration of the sensors. The potential to establish air temperature gradients in one location must not lead to the conclusion that these measurements are representative in space; the gradients assessed are in the order of magnitude of the errors, especially at noon. Measurements of relative air humidity are afflicted with an error of 2 %. For precipitation measurements, the overall error is in the order of 0.1 mm per half hour or 5 to 10 for monthly sampling, provided that a flow distortion correction has been performed. Even measurements of entities which are independent of the patchiness of the plant/soil system such as global radiation are not necessarily representative in space if one sensor only is exposed.

Das, J. O., S. Dey, et al. (2003). "A hygrometer comprising a porous silicon humidity sensor with phase-detection electronics." Ieee Sensors Journal **3**(4): 414-420.

A novel hygrometer is presented, comprising a capacitive humidity sensor with a porous silicon (PS) dielectric and electronics. The adsorption of water vapor by the PS layer leading to change of its effective dielectric constant is modeled with an effective medium approximation (EMA). A simple, but precise, phasesensitive electronic circuit has been developed. This detects any change of phase of a sinusoidal signal transmitted through the PS dielectric and correlates to ambient humidity. It is outlined how the nonlinear response of the sensor is compensated through piecewise linearization. The sensor is tested in combination with the phase detection circuitry. Excellent linearity over the entire range of relative humidity is achieved. Experimental results show a resolution better than 0.1% and an accuracy of 2% (near the transition region) and better than 0.1% (otherwise). The response time is less than 10 s with good stability.

Davis, G. D., S. Mani, et al. (2005). "Electrochemical impedance spectroscopy inspection of composite adhesive joints." Journal of Adhesion Science and Technology **19**(6): 467-492.

Lap shear joints comprised of aluminum-aluminum, aluminum-glass fiber-reinforced polymer (GFRP), aluminum-carbon fiber-reinforced polymer

(CFRP), CFRP-CFRP, CFRP-GFRP and GFRP-GFRP, were exposed to 95% relative humidity (RH) at 50 degrees C, 70 degrees C and 90 degrees C, to salt fog and to a 90 degrees C/95%RH freeze cycle. Electrochemical impedance spectroscopy (EIS) spectra were taken across the whole bonded assembly using an EIS corrosion sensor. Periodically, some specimens were pulled to obtain bond strength as a function of exposure. As expected, the higher the temperature, the faster the bond degradation. The low-frequency impedance correlated with bond strength of the humidity-exposed specimens and showed the same Arrhenius dependence, suggesting that moisture absorption by the adhesive was the limiting factor in bond performance and that EIS has the potential to nondestructively track bond health and warn of deterioration.

De Paepe, K., E. Houben, et al. (2005). "Validation of the VapoMeter, a closed unventilated chamber system to assess transepidermal water loss vs. the open chamber Tewameter((R))." Skin Research and Technology **11**(1): 61-69.

Background/aim: Transepidermal water loss (TEWL) is one of the most important biophysical parameters for evaluating the efficiency of the human skin water barrier. Different approaches exist to measure TEWL. The most commonly used methodology consists of the open chamber diffusion technique in which the water vapor pressure gradient is measured in g/h m(2) according to Fick's law. A typical apparatus is the Tewameter((R)). Recently, a portable device - the VapoMeter - became available with a humidity sensor in a closed chamber.Methods: In the present work, the closed chamber VapoMeter is compared with the open chamber Tewameter((R)) for its applicability to assess TEWL. A comparative study - including parallel in vivo measurements with both devices - was carried out on human forearm skin.Results: It could be concluded that both instruments are reliable tools. A good correlation between recordings (r=0.503-0.966) was found with a consistent feature of measuring higher TEWL values for the Tewameter((R)) than for the VapoMeter. Probe pressure, probe temperature and relative humidity were revealed to be important parameters inducing significant differences in data outcome.Conclusions: From skin barrier damage experiments it became clear that the Tewameter((R)) is able to detect significantly smaller differences than the VapoMeter. In addition, the closed chamber device is currently not sensitive enough to discriminate for the effects induced by diurnal rhythm and fluctuations as a function of time. On the other hand, the small and handy VapoMeter allows more flexibility in measuring protocols and in in-use performance.

DeHennis, A. D. and K. D. Wise (2005). "A wireless microsystem for the remote sensing of pressure, temperature, and relative humidity." Journal of Microelectromechanical Systems **14**(1): 12-22.

This paper presents a microsystem that utilizes inductive power and data transfer through a backscatter-modulated carrier and a transducer

interface that monitors its environment through embedded capacitive transducers. Formed on a single chip, transducers for temperature, pressure, and relative humidity are realized using a silicon-on-glass process that combines anodic bonding and a silicon-gold eutectic to realize vacuum-sealed cavities with low-impedance (6 Omega) electrical feedthroughs. Temperature is sensed capacitively using a row of Si/Au bimorph beams that produce a sensitivity of 15 fF/degreesC from 20 to 100 degreesC. The absolute pressure sensors have a sensitivity of 15 fF/torr and a range from 500 to 1200 torr, while the relative humidity sensor responds with 39 fF/%RH from 20 to 95%RH. A relaxation oscillator implements low-power capacitance-to-frequency conversion on a second chip with a sensitivity of 750 Hz/pF at 10 kHz, forming a 341 muW transducer interface. The system is remotely powered by a 3-MHz carrier and has a volume of 32 mm(3), including the hybrid antenna wound around the perimeter of the system.

Delpha, C., M. Lumbreras, et al. (2004). "Discrimination and identification of a refrigerant gas in a humidity controlled atmosphere containing or not carbon dioxide: application to the electronic nose." Sensors and Actuators B-Chemical **98**(1): 46-53.

Atmospheric pollution and green house effects are now one of the major preoccupations to improve the general quality of life. With an electronic nose application we propose a system dedicated to the main detection of refrigerant Forane 134a (R134a) gas leakage in air conditioned systems and atmospheres. For our application based on a metal oxide type gas sensor array (six TGS elements) mainly coupled with discriminant factorial analysis (DFA) for the pattern recognition, we propose to study the effect of the relative humidity and an antagonist gas carbon dioxide as interfering gases on the R134a gas and concentration discrimination. We show that the relative humidity in a wide range (18-85%) has a more important influence on the target gas and concentrations discrimination than carbon dioxide. We present the discrimination results for the gases and afterwards for the R134a concentrations. Then we show the ability of our system to identify correctly a test data set composed of unknown gas samples. For the gases concentrations identification we also show that a correct identification rate can be obtained specially when the relative humidity rate range is reduced. (C) 2004 Elsevier B.V. All rights reserved.

Di Francia, G., A. Castaldo, et al. (2005). "A very sensitive porous silicon based humidity sensor." Sensors and Actuators B-Chemical **111**: 135-139.

A relative humidity (RH) sensor device based on n-type porous silicon has been designed, fabricated and characterized. The simple device is a diode reverse dc biased, exhibiting an extremely high sensitivity in ambient air and a large operating range (30-70% RH). Aging and NO2 interference on the sensor performance have been also investigated. (c) 2005 Elsevier B.V. All rights reserved.

Ding, B., J. H. Kim, et al. (2004). "Electrospun nanofibrous membranes coated quartz crystal microbalance as gas sensor for NH3 detection." Sensors and Actuators B-Chemical **101**(3): 373-380.

A novel gas sensor composed of electrospun nanofibrous membranes and quartz crystal microbalance (QCM) was successfully fabricated. The electrospun nanofibers with diameter of 100-400 nm can be deposited on the surface of QCM by clectrospinning the homogenous blend solutions of cross-linkable poly(acrylic acid) (PAA) and poly(vinyl alcohol) (PVA). A series of nanofibrous membranes with various weight percentage of PAA to PVA were fabricated and characterized regarding their morphology and sensitivity to NH3. Sensing experiments were examined by measuring the resonance frequency shifts of QCM which due to the additional mass loading. The results showed that the sensing properties were mainly affected by the content of PAA component in nanofibrous membranes, concentration of NH3, and relative humidity. Additionally, the sensitivity of nanotibrous membranes coated (NMC) QCM sensor was much higher than that of continuous films coated QCM sensor. (C) 2004 Elsevier B.V. All rights reserved.

Ding, B., M. Yamazaki, et al. (2005). "Electrospun fibrous polyacrylic acid membrane-based gas sensors." Sensors and Actuators B-Chemical **106**(1): 477-483.

Electrospun fibrous polyacrylic acid (PAA) membranes were studied as sensing material coated on quartz crystal microbalance (QCM) for ammonia detection at ppb level. The fibrous membranes with different morphology can be deposited on the electrode of QCM by electrospinning the PAA solutions with various solvent composition of H2O and ethanol. The results of sensing experiments indicated that the sensitivity of :he fibrous membranes coated QCM (FM-QCM) sensors was four times higher than that of the casting films coated QCM (CF-QCM) sensors. Meanwhile, the FM-QCM sensors exhibited high sensitivity towards low concentration of ammonia, as low as 130 ppb at the relative humidity of 40%. The pre-sorbed water in fibrous membranes was proved to be the key factor to affect the sensitivity of FM-QCM sensors for ammonia. The sensor performance has been found to depend on the morphology of the fibrous membranes, concentration of ammonia, coating load of the fibrous membranes on QCM, and relative humidity. Preliminary study of the stability investigation was also presented. © 2004 Elsevier B.V. All rights reserved.

Drew, S. M., J. E. Mann, et al. (2004). "A humidity sensor based on vapoluminescent platinum(II) double salt materials." Sensors and Actuators B-Chemical **97**(2-3): 307-312.

The vapoluminescent characteristics of platinum(II) double salt materials in the presence of varying levels of relative humidity (RH) have been

investigated. Luminescence spectra for three different platinum(II) double salt materials showed that the intensity and the wavelength maximum depend on the concentration of water vapor surrounding the material. Partial least squares (PLS) analysis of the data demonstrated that two of the double salts responded linearly to changes in RH. A single-channel dip probe sensor was constructed and used to evaluate changes in RH. Different methods for attaching the platinum(II) double salt material to the dip probe were also investigated. Simple adsorption of the material onto the probe produced a sensor with superior performance compared to a Teflon AF support matrix. The PLS analysis of simultaneous three-channel cross-reactive sensor array data from three different platinum(II) double salt materials yielded a much more reproducible RH sensor. In addition, the three-channel cross-reactive array produced a more linear PLS model compared to a single-channel sensor composed of a simulated mixture of the same three platinum(II) double salt materials. 

Edwards, R., K. R. Smith, et al. (2006). "An inexpensive dual-chamber particle monitor: Laboratory characterization." Journal of the Air & Waste Management Association **56**(6): 789-799.

In developing countries, high levels of particle pollution from the use of coal and biomass fuels for household cooking and heating are a major cause of ill health and premature mortality. The cost and complexity of existing monitoring equipment, combined with the need to sample many locations, make routine quantification of household particle pollution levels difficult. Recent advances in technology, however, have enabled the development of a small, portable, data-logging particle monitor modified from commercial smoke alarm technology that can meet the needs of surveys in the developing world at reasonable cost. Laboratory comparisons of a prototype particle monitor developed at the University of California at Berkeley (UCB) with gravimetric filters, a tapered element oscillating microbalance, and a TSI DustTrak to quantify the UCB particle monitor response as a function of both concentration and particle size and to examine sensor response in relation to changes in temperature, relative humidity, and elevation are presented here. UCB particle monitors showed good linearity in response to different concentrations of laboratory-generated oleic acid aerosols with a coarse (mass median diameter, 2.1 mu m) and fine (mass median diameter, 0.27-0.42 mu m) size distributions (average r(2) = 0.997 +/- 0.005). The photoelectric and ionization chamber showed a wide range of responses based on particle size and, thus, require calibration with the aerosol of interest. The ionization chamber was five times more sensitive to fine rather than coarse particles, whereas the photoelectric chamber was five times more sensitive to coarse than fine. The ratio of the response between the two sensors has the potential for mass calibration of individual data points based on estimated parameters of the size distribution. The results demonstrate the significant potential of

this monitor, which will facilitate the evaluation of interventions (improved fuels, stoves, and ventilation) on indoor air pollution levels and research on the impacts of indoor particle levels on health in. developing countries.

Elizalde-Torres, J., H. L. Hu, et al. (2004). "NO2-induced optical absorbance changes in semiconductor polyaniline thin films." Sensors and Actuators B-Chemical **98**(2-3): 218-226.

Chemically deposited semiconductor polyaniline (PANI) thin films have been exposed to detect nitrogen dioxide gas. Because of the high electron receptor behavior, NO2 molecules oxidize the conjugated polymer during the sensing process, leading to the modification of the electronic structure and consequently the change of the optical absorbance of PANI as a function of the toxic gas concentration. NO2-induced optical transmittance changes of the polymer films can be varied between 5 and 80% for a NO2 gas concentration of 3-50 ppm. By using a parametric method, the heat of adsorption (Q) as well as the activation energy of adsorption (EA) for NO2 molecules on PANI surface are obtained from the corresponding adsorption kinetic curves. It is found that Q is of the order of 0.50-0.58 eV, and EA of 0.28-0.50 eV, depending on the type of the PANI films and the NO2 gas concentration. We show that the same kinetic expression can also be obtained from a reaction-diffusion coupled problem reported in literature by assuming a couple of the relations between the thermodynamic variables and kinetic reaction rates of the two models. The desorption process of NO2 from PANI samples is kinetically irreversible in a dried air or N-2 during the experimental time, and slowly reversible if they have been kept in ambient air with a relative humidity greater than zero. 

Ellis, R. A., A. P. Sandford, et al. (2006). "New laser technology to determine present weather parameters." Measurement Science & Technology **17**(7): 1715-1722.

Present weather sensors are becoming increasingly important as a means to augment networks of automated weather stations and extend the capability of manned observations. The classification of hydrometeors is one of the principal tasks that is addressed by present weather sensors. In this paper, we discuss a new laser-based technology for this purpose. The system improves upon current precipitation monitors by using a derivative of phase Doppler anemometry techniques to accurately determine particle speed and size. The instrument is also capable of distinguishing between liquid droplets and solid polycrystalline hydrometeors and can be used to estimate visibility. The incorporation of this technology into a meteorological station with other sensors, such as temperature and relative humidity probes, leads to the accurate classification of particle type. The example data shown are taken from tests in Leicestershire, England and Utah, USA and show the differences between solid and liquid precipitation events.

Faia, P. M., C. S. Furtado, et al. (2004). "Humidity sensing properties of a thick-film titania prepared by a slow spinning process." Sensors and Actuators B-Chemical **101**(1-2): 183-190.

A ceramic thick film humidity sensor was produced from an emulsion of titania powders by a spin coating technique using a low speed. Electrical measurements were taken between interdigital electrodes obtained by depositing silver paste on the oxide, then cured at 500 degreesC for 15 min. Different relative humidities of a dynamic atmosphere were obtained by mixing dry and 23 degreesC saturated synthetic air in convenient proportions. Complex impedance spectra of the titania sensor at various relative humidities (RH) and different temperatures were measured and compared. The humidity sensing behaviour is due to surface water molecules adsorption and capillary condensation. The proposed sensing mechanisms, explaining the registered impedance spectra, are a combination of proton hopping, hydronium electrical drift and diffusion, and electrolytic conduction. In the frequency range 1-400 Hz, resistance and capacitive reactance show variations of three to four-order magnitude over the RH range 10-100%. The curves representing the variations of resistance and capacitive reactance versus RH show clearly the existence of two dominant electrical charge transport mechanisms. A parameter called characteristic humidity is defined to represent the sensitive response of the sensor. It was found that the sensitivity was highly dependent on the frequency. This work also shows that, for the same RH both resistance and capacitive reactance vary with the atmosphere temperature. 

Faia, P. M., C. S. Furtado, et al. (2005). "AC impedance spectroscopy: a new equivalent circuit for titania thick film humidity sensors." Sensors and Actuators B-Chemical **107**(1): 353-359.

The variation of the electrical signal with humidity in ceramic sensors is originated by the chemical and physical sorptions of water molecules existing in the atmosphere. The aim of the work described in the present paper is to establish an equivalent electrical circuit for the case of two titania thick-film samples. It is shown, at least for the temperature of 23 degrees C, that the same type of circuit represents adequately these two samples for various relative humidities. Chemisorption and physisorption are responsible for the different charge transport mechanisms - ion hopping, ion diffusion and electrolytic conduction. Complex impedance data were obtained at the temperature of 23 degrees C and various relative humidities, in the frequency range 0.1 Hz-40 MHz. The best and simpler circuit representation we found, which gives the best fitting for the Cole-Cole and Bode plots, consists of two RC parallel circuits in series with two constant-phase elements (CPEs). The values of the electrical components are tabled and, as an example, the Cole-Cole and Bode plots fitting obtained for one of our samples, the sample B, for 87.5% RH, in the

frequency range 0.1 Hz-40 MHz is shown. (c) 2004 Elsevier B.V. All rights reserved.

Falcaro, P., J. M. Bertolo, et al. (2004). "Ordered mesostructured silica films: Effect of pore surface on its sensing properties." Journal of Sol-Gel Science and Technology **32**(1-3): 107-110.

An electrochemical resistive-type sensor device, with a mesoporous silica thin film as sensitive membrane, has been developed and characterised. The silica film has been obtained via evaporation-induced self-assembly (EISA) using a tri-block copolymer (Pluronic F-127) as templating agent. It has been deposited by dip-coating on a silicon substrate with metallic interdigitated electrodes. Fast, reversible and reproducible electrical responses to relative humidity changes have been observed for the sensor device. The conduction mechanism has been related to chemical properties, structural order and surface morphology of the porosity in the silica film, confirming the dependence on the film preparation method and overall the importance of calcination temperature.

Gaston, A., I. Lozano, et al. (2003). "Evanescent wave optical-fiber sensing (temperature, relative humidity, and pH sensors)." Ieee Sensors Journal **3**(6): 806-811.

Sensitive and versatile evanescent wave-sensing systems featuring polished optical fiber-based sensor designs with low-cost light sources have been developed for temperature, relative humidity, and pH measurements. The work herein contained describes the fabrication of three types of sensors based on standard silica, single-mode fibers previously subjected to a lateral polishing of the cladding. Temperature sensing through oils whose refractive index varied linearly with temperature showed applicability with up to 5 dB/degreesC for a 50 range. Polyvinyl alcohol films on the fibers showed almost 10-dB linear variation from 70% to 90% relative humidity. Sol-gel trapped dyes as thin films on the polished surface were capable of performing 15-dB output variation (although not linearly) for pH ranging from 2 to 11.

Gaston, A., F. Perez, et al. (2004). "Optical fiber relative-humidity sensor with polyvinyl alcohol film." Applied Optics **43**(21): 4127-4132.

We describe a fiber-optic relative-humidity (RH) sensor comprising a moisture-sensitive overlay on a single-mode side-polished fiber. The hygroscopic polymeric material deposited was polyvinyl Alcohol (PVA), which proved to have good adherence and stability. The film reached a fast equilibrium with atmospheric moisture (in less than 1 min), inducing changes in the output optical power of similar to10 dB for the 70%-90% RH range. To yield a low-cost device, single-mode standard communication fibers were used; therefore all the components of the sensor can be commercial, mass-produced telecommunication devices. The experimental results obtained are consistent with the expected

behavior of the system; the output power decreases because of losses in the polished region of the fiber as the refractive index of its external medium approaches the fiber core value. Because the external medium is PVA film, its refractive index changes in response to its water content. (C) 2004 Optical Society of America.

Gu, L., Q. A. Huang, et al. (2004). "A novel capacitive-type humidity sensor using CMOS fabrication technology." Sensors and Actuators B-Chemical **99**(2-3): 491-498.

This paper reports a novel capacitive humidity sensor integrated on a polysilicon heater. The sensor was fabricated with the industrial standard CMOS process to achieve a cost-effective solution for accurate and reliability. The sensing material polyimide was obtained by a post-processing step after the standard CMOS fabrication. The sensing principle of the sensor is based on the dielectric constant change of deposited polyimide due to absorption/desorption of vapor. The passivation (silicon nitride) layer with no limitations to the electrode selection is between the electrode and sensing material in order to improve the reliability of the relative humidity for the sensors. The humidity sensor was measured to show a linear dependence on the relative humidity in the range of 20-70%, the maximum hysteresis is 3%. 

Guerova, G., E. Brockmann, et al. (2005). "An integrated assessment of measured and modeled integrated water vapor in Switzerland for the period 2001-03." Journal of Applied Meteorology **44**(7): 1033-1044.

In this paper an integrated assessment of the vertically integrated water vapor (IWV) measured by radiosonde, microwave radiometer (MWR), and GPS and modeled by the limited-area mesoscale model of MeteoSwiss is presented. The different IWV measurement techniques are evaluated through intercomparisons of GPS to radiosonde in Payerne, Switzerland, and to the MWR operated at the Institute of Applied Physics at the University of Bern in Switzerland. The validation of the IWV field of the nonhydrostatic mesoscale Alpine Model (aLMo) of MeteoSwiss is performed against 14 GPS sites from the Automated GPS Network of Switzerland (AGNES) in the period of 2001-03. The model forecast and the nudging analysis are evaluated, with special attention paid to the diurnal cycle. The results from the GPS-radiosonde intercomparison are in agreement, but with a bimodal distribution of the day-to-night basis. At 0000 UTC, the bias is negative (-0.4 kg m(-2)); at 1200 UTC, it is positive (0.9 kg m(-2)) and the variability increases. The intercomparison of GPS to MWR shows better agreement (0.4 kg m(-2)), with a small increase of the daytime bias with 0.3 kg m(-2). The intercomparison of MWR to the radiosonde gives a bimodal distribution of the bias, with an increase in the standard deviation at the daytime measurement. The relative bias is negative (-3%) at 0000 UTC and is positive (3%) at 1200 UTC. Based on

this cross correlation, it can be concluded that the bimodal distribution is a result of radiosonde humidity measurements. Possible reasons are the solar-heating correction or sensor errors. The monthly bias and standard deviation of aLMo exhibit a strong seasonal dependence with a pronounced dry bias during the warm months of May-October 2002. The diurnal IWV cycle in 2001 shows good model performance between 0000 and 0900 UTC but IWV underestimation by up to 1.5 kg m(-2) for the rest of the day. In 2002 the diurnal cycle shows a systematic dry bias in both the analysis and forecast that is more pronounced in the analysis. This substantial underestimation of IWV was found to correlate with overestimation of aLMo precipitation, especially light precipitation up to 0.1 mm (6 h)(-1) in 2002. There is strong evidence that this underestimation can be related to the dry radiosonde bias in midday summer observations. The aLMo dry bias is about 1.0-1.5 kg m(-2) greater in the nudging analysis as compared with the forecast initialized at 0000 UTC.

Gunter, R. L., W. D. Delinger, et al. (2005). "Hydration level monitoring using embedded piezoresistive microcantilever sensors." Medical Engineering & Physics **27**(3): 215-220.

A new MEMS based sensor technology, embedded piezoresistive microcaritilever (EPM) sensors, may be useful in the real-time monitoring of hydration levels in athletes or other individuals whose activities may result in dehydration. In these devices, organic polymers or functionalized polymeric materials respond to osmolality changes in a person's saliva by expanding or contracting volumetrically. These volumetric changes are measured by tiny piezoresistive microcantilevers embedded in the polymeric material. In this report, we have tested a prototype device utilizing UV crosslinked poly(vinyl acetate) as the active sensing material. This device was able to reliably respond to 1% changes in sodium chloride concentration in solution or alternately to 1% changes in relative humidity. 

Han, S. D., I. Singh, et al. (2004). "Effect of inorganic electrolytes on the sensing behaviour of polyvinyl alcohol-co-styrene sulphonate as a humidity sensor." Indian Journal of Chemistry Section a-Inorganic Bio-Inorganic Physical Theoretical & Analytical Chemistry **43**(1): 67-70.

Polyvinyl alcohol (PVA), a common hydrophilic polymer shows a significant impedance with changing relative humidity and may be chosen as a base material for humidity sensing devices. However, fabricating simply a polyvinyl alcohol film shows high impedance and lacks durability. Cross-linking PVA with sodium salt of 4-styrene sulphonate (SS) makes the fabricated films water insoluble retaining its humidity sensing capabilities. If PVA and SS are cross-linked in presence of inorganic electrolytes, the sensitivity of the fabricated films as humidity sensors increases tremendously especially in presence of transition metal salts. Mixture of the materials are cured on alumina substrate printed with gold

electrodes at a temperature between 120 to 140degreesC. Taking into concentration the sensitivity and stability of the films both, the best compromising results are obtained when PVA, SS and metal chlorides are taken in a ratio of 5:2:2 for ferrous and ferric and 10:43 for cupric and cobalt chlorides.

Han, K. S., A. A. Viau, et al. (2005). "Statistical estimate of the hourly near-surface air humidity in eastern Canada in merging NOAA/AVHRR and GOES/IMAGER observations." International Journal of Remote Sensing **26**(21): 4763-4784.

Estimates of the relative humidity near the ground are frequently requested by scientific communities concerned about weather forecasting, disease prediction, and agriculture. To face the dearth of meteorological observations provided by synoptic networks, remote sensing measurements are particularly useful, specifically because they can provide coherent information at a regional representative scale. The present investigation gives an update on the potential for using satellite data to estimate the near-surface relative humidity. The IMAGER sensor on board the Geostationary Operational Environmental Satellite (GOES) is used to obtain the hourly infrared datasets. In addition, data from the Advanced Very High Resolution Radiometer (AVHRR) flown on the National Oceanic and Atmospheric Administration (NOAA) Sun-synchronous satellite series is used to calculate the daily normalized difference vegetation index (NDVI). Estimates of the relative humidity are assessed using various variables like the surface temperature, NDVI, the precipitable water, the digital elevation model, the date and local time. The study approach combines empirically these variables into third-order polynomial multiple regressions with stepwise functions. The data are split in two parts: the algorithm development dataset and the validation dataset. The estimation model is developed by a stepwise function, which selects independent variables and decides corresponding coefficients. The model validity is further assessed by employing a comparison with the results obtained from the model output using a validation dataset. The accuracy achieved using the validation dataset is in a good agreement with development dataset accuracies. The relative humidity accuracy derived from the present method is within 10% compared to field measurements. The largest discrepancies between model and measurements were observed over forested areas. One outcome from this study is that the difference in results between forested and non-forested targets is enhanced with the topography.

Hoa, P. L. P., G. Suchaneck, et al. (2005). "Influence of polycrystalline silicon as electrical shield on reliability and stability of piezoresistive sensors." Sensors and Actuators a-Physical **120**(2): 567-572.

In this paper, the influence of polycrystalline silicon as a protective field shield on the reliability and stability of piezoresistive silicon sensors is

investigated. For this purpose, the behaviour of piezoresistive sensors with and without polycrystalline silicon shield is observed under changes of environmental condition, such as relative humidity and temperature. The obtained sensor-offset change under humidity stimulation is smaller than that observed by temperature excitation. The samples with polycrystalline silicon shield exhibit a lower humidity and temperature coefficients as compared to the samples without this shield. The values of uncertainties in measurement are evaluated according to the ISO "Guide to the Expression of Uncertainties in Measurement" (GUM). The uncertainty contribution caused by internal disturbing of the sensors can be neglected. Comparing two types of piezoresistive sensors investigated, the samples with polycrystalline silicon shield produce a considerably reduction of all measurement uncertainty contributions. The results show that an additional polycrystalline silicon shield between two insulating layers connected to the supply voltage, which provides a determined potential distribution inside the passivation layer stack, improves the device reliability and the accuracy of measurement. 

Hobson, R. S., A. Clausi, et al. (2003). "Temperature correction to chemoresistive sensors in an e-NOSE-ANN system [1]." Ieee Sensors Journal **3**(4): 484-489.

The influence of the temperature coefficient of resistance in the chemoresistive response of inherently conductive polymer (ICP) sensors in the performance of an artificial neural network (ANN) e-natural olfactory sensor emulator(1) (e-NOSE) system is evaluated. Temperature was found to strongly influence the responses of the chemoresistors, even over modest ranges (ca. 2 degreesC). An e-NOSE array of eight ICP sensor elements, a relative humidity (RH +/- 0.1%) sensor, and a resistance temperature device (RTD +/- 0.1 degreesC) was tested at five different RH levels while the temperature was allowed to vary with the ambient. A temperature correction algorithm based on the temperature coefficient of resistance beta for each material was independently and empirically determined then applied to the raw sensor data prior to input to the ANN. Conversely, uncorrected data was also passed to the ANN. The performance of the ANN was evaluated by determining the error found between the actual humidity versus the calculated humidity. The error obtained using raw input sensor data was found to be 10.5% and using temperature corrected data, 9.3%. This negligible difference demonstrates that the ANN was capable of adequately addressing the temperature dependence of the chemoresistive sensors once temperature was inclusively passed to the ANN.

Hu, Y., O. K. Tan, et al. (2005). "Fabrication and characterization of nano-sized SrTiO3-based oxygen sensor for near room-temperature operation." Ieee Sensors Journal **5**(5): 825-832.

Nano-sized SrTiO3-based oxygen sensors were fabricated from synthesized SrTiO3 and commercial SrTiO3 using the high-energy ball milling and the thick-film screen-printing techniques. The particle sizes, microstructural properties, oxygen-sensing properties, and humidity effects of the synthesized nano-sized SrTiO3-based oxygen sensors were characterized using X-ray diffraction (XRD), transmission electron microscope, scanning electron microscope (SEM), and gas sensing measurements. Experimental results showed that. the particle size of the powders was milled down to be around 27 nm. The effect of different annealing temperatures (400 degrees C, 500 degrees C, 600 degrees C, 700 degrees C, and 800 degrees C) on the gas sensing properties of the synthesized SrTiO3 sensor from nitrogen to 20% oxygen was characterized. The commercial SrTiO3 devices annealed at 400 degrees C, both with 0-h and 120-h milling time, were used for comparison. The optimal relative resistance (R-nitrogen/R-20% oxygen) value of 6.35 is obtained for the synthesized SrTiO3 sample annealed at 400 degrees C and operating at 40 degrees C. This operating temperature is much lower than that of conventional metal oxide semiconducting oxygen gas sensors (300 degrees C-500 degrees C) and SrTiO3 oxygen gas sensors (> 700 degrees C). The response and recovery times are 1.6 and 5 min, respectively. The detected range is 1-20% oxygen. The impedance of the synthesized SrTiO3 sensor with annealing at 400 degrees C and operating at 40 degrees C (from 1 mHz to 10 MHz) in 20% oxygen ambient was found to be independent of the relative humidity (dry, 20% RH, 80% RH, near 100% RH).

Innocenzi, P., P. Falcaro, et al. (2005). "Electrical responses of silica mesostructured films to changes in environmental humidity and processing conditions." Journal of Non-Crystalline Solids **351**(24-25): 1980-1986.

Silica mesoporous films with orthorhombic Fmmm mesostructure have been produced using evaporation induced self-assembling via dip-coating. A block copolymer, Pluronic F-127, has been used its the organic template and hits been removed from the films by thermal calcination. The block copolymer templated films have been characterized as a function of the calcination temperature, in the range 150-550 degrees C by grazing incidence small angle X-ray scattering (GI-SAXS) and Fourier transform infrared spectroscopy. Thermal dehydroxylation formed isolated and geminal silanols on the pore Surface and the removal (if the organic template has increased the water absorption within the pores. The calcination has induced a shrinkage of the pores in the direction normal to the substrate, as it has been observed by GI-SAXS. Humidity sensors based on the mesostructured silica films as sensing membrane have been fabricated using alumina substrates with interdigitated gold fingers. The electrical response of the sensors in different relative humidity (RH) conditions has been measured. In the considered RH range the sensor revealed a high sensitivity with more than 4 orders of magnitude change in

the current. Little hysteresis loop has been observed in the electrical response recorded increasing and reducing the RH value. The films calcined between 350 and 450 degrees C showed the best performances in term of stability. hysteresis and reproducibility of the response. The current response hits been correlated with the beater absorption within the pores. (c) 2005 Elsevier B.V. All rights reserved.

Ishizuka, M., M. Mikami, et al. (2005). "Measurements of soil water content using time domain reflectometry sensor and water vapor in surface soil at the gobi site in the Taklimakan Desert." Journal of the Meteorological Society of Japan **83**(6): 987-999.

Measurements of soil water content, relative humidity of soil air, and soil temperature in surface soil at 0.01 m and 0.05 m depths were carried out at a gobi site near Qira in the southern part of the Taklimakan Desert, China from the end of March 2001 to April 2004. By calibrating Time Domain Reflectometry (TDR) sensors at the site, the applicability of TDR sensors for use in natural hyper-arid conditions was shown. In the wetting process, soil water infiltrated in the liquid phase, while the soil water was in the vapor phase during the drying process. As the first step of the drying process, the surface ground at both depths rapidly and thoroughly dried by evaporation due to the daytime soil temperature increase. As the second step, the soil water evaporated predominantly from the shallower depth. However, because of the supply of water vapor from deeper soil, saturated conditions continued at 0.01 m depth. As the third step, the surface ground gradually dried, repeated diurnal variations in humidity of soil air resulted from the decreased supply of water vapor from deeper soil. Once soil water was supplied in the soil at the gobi site, soil water and water vapor of soil air at 0.05 m depth were not easy to remove.

Islam, T., K. K. Mistry, et al. (2004). "Measurement of gas moisture in the PPM range using porous silicon and porous alumina sensors." Sensors and Materials **16**(7): 345-356.

This paper reports the performance of a porous silicon (PS) sensor for detecting ppm level moisture and compares its relative performance with that of porous alumina (PA) sensors. The porous alumina sensor is fabricated by the sol-gel technique. It is found experimentally that in measuring ppm level moisture the sensitivity of the PA sensor appears to be greater than that of the PS sensor while the response time of the PS sensor is much shorter than that of the PA sensor. A simple but precise technique for the electronic measurement of sensor capacitance, which minimizes the parasitic earth capacitances, has been developed to study the response of both PS and PA gas moisture sensors. The detection electronics can be utilized for an integrated sensor unit. However, initial characterizations of both PS/PA sensors are carried out using a standard LCR meter (HP-4284A) to establish the electronic circuit.

Islam, T., C. Pramanik, et al. (2005). "Modeling, simulation and temperature compensation of porous polysilicon capacitive humidity sensor using ANN technique." Microelectronics Reliability **45**(3-4): 697-703.

The porous polysilicon capacitive sensor used for measuring relative humidity has the advantages of low cost, ease of fabrication and CMOS compatibility. However, the capacitance of the sensor, which is a function of concentration of water vapour, also depends on ambient temperature. Thus, variation of ambient temperature causes error in the performance of sensor outputs. In this paper, two ANN models have been developed. The first model is used to simulate the behavior of the capacitive humidity sensor (CHS). This model can also be used for on line monitoring of the fault of the sensor. The second model is based on inverse modeling, which can be used to compensate the effect of ambient temperature error. It is found from the simulation studies that the error of the direct model is within +/-2% of full scale and for the inverse model the error is within +/- 0.5% of full scale over a temperature range from 20 to 70degreesC. A hardware implementation scheme for realization of the CHS model is also proposed. 

Islam, T. and H. Saha (2006). "Hysteresis compensation of a porous silicon relative humidity sensor using ANN technique." Sensors and Actuators B-Chemical **114**(1): 334-343.

This paper presents a simple technique based on well-known multilayer perceptron (MLP) neural network with back propagation training algorithm for compensating the significant error due to hysteresis in a porous silicon relative humidity sensor. The porous silicon humidity sensor has been fabricated, and its hysteresis with increasing and decreasing relative humidity has been determined experimentally by a novel phase detection circuit. Simulation studies show that the artificial neural network (ANN) technique can be effectively used to compensate the hysteresis of the porous silicon sensor for relative humidity (%RH) measurement. A hardware implementation scheme of the hysteresis compensating ANN model using a micro-controller is also proposed. Simulation studies show that the maximum error is within +/- 1% of its full-scale value. 

Jackson, D. L., G. A. Wick, et al. (2006). "Near-surface retrieval of air temperature and specific humidity using multisensor microwave satellite observations." Journal of Geophysical Research-Atmospheres **111**(D10): -.

A new method for instantaneous retrievals of near-surface specific humidity (Q(a)) and air temperature (T-a) over the oceans was developed by combining satellite microwave observations from Advanced Microwave Sounding Unit-A (AMSU-A), Special Sensor Microwave Imager (SSM/I), and Special Sensor Microwave Temperature Sounder (SSM/T-2). Several retrieval methods based on linear regression are presented that include both single-sensor and multisensor approaches. The most accurate linear

regression algorithms combined AMSU-A and SSM/I observations. The Q(a) and T-a retrieval methods had RMS differences of 0.83 g/kg and 1.53 degrees C, respectively, relative to direct surface observations. These differences were found to be significantly lower than those computed from previously published algorithms applied to daily values. An independent validation data set showed that the current Q(a) retrieval method led to a reduction in RMS error of 0.5 g/kg and reduced bias at the lowest and highest Q(a) values. Likewise, the current T-a retrieval method had a reduction in RMS errors of 1.0 degrees C from previously published methods. Improvements in both retrievals can be attributed to inclusion of the AMSU-A 52.8 GHz channel, which helps distinguish variations near the surface from those at higher levels of the atmosphere. Selection of a retrieval approach represents a trade-off between accuracy, coverage, and temporal extent. Global coverage every 6 hours is approximately 80% using two NOAA satellites; however, such coverage would rely on use of a single-sensor AMSU-A approach with somewhat degraded accuracy. A multisensor approach using AMSU-A and SSM/I on the current NOAA and DMSP satellites will at best provide global coverage over 1 day.

Jain, S., S. Chakane, et al. (2003). "Humidity sensing with weak acid-doped polyaniline and its composites." Sensors and Actuators B-Chemical **96**(1-2): 124-129.

In this paper, we report the behaviour of humidity sensors with polyaniline-based conducting polymers doped with different weak acidic dopants. Changes in surface resistivity of films were monitored as a function of relative humidity. The acidic dopants used were camphosulphonic acid (CSA), diphenyl phosphate (DPPH), and maleic acid (Mac) blends of these were formed with styrene-butyl acrylate copolymer for improving the mechanical stability. The sensitivity of responding the level of relative humidity was compared for three composites wherein, although low sensitivity the Mac-doped films were found to be repeatable and more stable compared to the others. Films prepared out of styrene-butyl acrylate copolymer with different concentrations of PANI-Mac were used for sensing humidity ranging between 20 and 95% relative humidity. The films exhibited almost linear behaviour within a chosen range of humidity. 

Jin, X. L., W. Li, et al. (2005). "Fabrication of relative humidity optical fiber sensor based on nafion-crystal violet sensing film." Spectroscopy and Spectral Analysis **25**(8): 1328-1331.

With two kinds of sensing methods for relative humidity based on fluorescence and visible absorption respectively, crystal violet was opted as the molecule probe for humidity. The optical chemical sensing film for humidity was prepared when crystal violet was embedded in the Nafion gel. The relative humidity sensor was fabricated after the sensing film had been coupled with other components, such as optical fiber and detector,

which possessed short response time (< 2 min), high sensitivity (<= 5% RH), wide dynamic range (30%-100%) and good reversibility (RSD <= 2.6%) for relative humidity at 640 run wavelength.

Jin, X. L., M. Jing, et al. (2005). "Effect of temperature on sensing performance of optical fiber relative humidity sensor based on nafion-crystal violet film." Chemical Journal of Chinese Universities-Chinese **26**(5): 844-845.

The optical fiber relative humidity sensor based on Nafion-crystal violet film was developed. The effect of sample's temperature in the range from 299.15 K to 324.15 K on the sensing performance of the sensor was investigated. The mathematical function between temperature and the sensitivity of the sensor was established according to the reactive theory of sensor to the relative humidity, which was validated with the experiment. With the research, the application range of the sensor was extended, which made the sensor keep a good veracity when it was used in situ.

Jorgensen, A. C., P. Luukkonen, et al. (2004). "Comparison of torque measurements and near-infrared spectroscopy in characterization of a wet granulation process." Journal of Pharmaceutical Sciences **93**(9): 2232-2243.

The purpose of this study was to compare impeller torque measurements and near-infrared (NIR) spectroscopy in the characterization of the water addition phase of a wet granulation process. Additionally, the effect of hydrate formation during granulation on the impeller torque was investigated. Anhydrous theophylline, alpha-lactose monohydrate, and microcrystalline cellulose (MCC) were used as materials for the study. The materials and mixtures of them were granulated using purified water in a small-scale high-shear mixer. The impeller torque was registered and NIR spectra of wet samples were recorded at-line. The torque and the NIR baseline-corrected water absorbances increased with increasing water content. A plateau in the NIR baseline-corrected water absorbances was observed for wet masses containing MCC. This was at the region of optimal water amount for granulation according to the torque results. In the case of anhydrous theophylline, the slope of baseline-corrected water absorbance values increased at the same water amount as the impeller torque started to increase. The hydrate formation of theophylline during granulation was observed as a slight decrease in the impeller torque. In addition, the hydrate formation during granulation affected the granulation liquid requirement. The liquid requirement was different for monohydrate formed during granulation compared to one formed in high relative humidity before the granulation. The results suggest that NIR spectroscopy may be applicable to process monitoring of wet granulation, also in cases where monitoring of impeller torque is difficult to apply. (C) 2004 Wiley-Liss, Inc. and the American Pharmacists Association.

Kalkan, A. K., H. D. Li, et al. (2004). "A rapid-response, high-sensitivity

nanophase humidity sensor for respiratory monitoring." Ieee Electron Device Letters **25**(8): 526-528.

A novel ionic-type humidity sensor based on a plasma-deposited nanophase Si thin film was developed. Detection of relative humidity cycles between 20% and 90% was possible in less than or equal to0.2 s with similar to5 orders of magnitude variation in conductance. Such superior performance is attributable to the unique arrayed column-void network structure and ultrafine thickness (e.g., 50 nm) of the Si film as well as to the lateral electrode configuration. Our sensor can be miniaturized, integrated with signal processing circuits, and fabricated on plastics. A crucial implementation, where our sensor would be very suitable and beneficial, is respiratory monitoring.

Kariduraganavar, M. Y., R. K. Nagarale, et al. (2006). "Electrodialytic transport properties of heterogeneous cation-exchange membranes prepared by gelation and solvent evaporation methods." Journal of Applied Polymer Science **100**(1): 198-207.

The heterogeneous cation-exchange membranes were prepared by employing two different methods: immersing the cation-exchange resin-loaded membranes in gelation bath; evaporating the solvent upon casting a uniform solution of cation-exchange resin on a glass plate. The effect of resin loading on the electrochemical properties of the membranes was evaluated. The permselectivity of these heterogeneous membranes and transport number of calcium ions relative to sodium ions was evaluated with respect to the extent of resin loading and the methods of preparation. It is found that the membrane potential, transport number, permselectivity, and relative transport number are prominently high in the solvent evaporation method compared with the gelation method. The transport number of calcium ions relative to sodium ions in the solvent evaporation method increased monotonously with increasing resin loading. However, the increase of resin loading did not influence much on the relative transport numbers in the gelation method. (c) 2006 Wiley Periodicals, Inc.

Kavasoglu, N., A. S. Kavasoglu, et al. (2006). "Comparative study of ZnCr2O4-K2CrO4 ceramic humidity sensor using computer controlled humidity measurement set-up." Sensors and Actuators a-Physical **126**(2): 355-361.

A home-made ZnCr2O4-KCrO4 ceramic humidity sensor was studied using a commercially available reference humidity sensor, SHT75 from Sensirion. The main advantages of our developed set-up for humidity measurements are low cost and high resolution yielding a full set of information on the variation of humidity. Air moisture sensitive ceramic body prepared using K2CrO4 (20%) in ZnCr2O4 was produced from the solid-state reaction between zinc oxide and chromite oxide at high temperatures. The dc resistance as a function of relative humidity (RH) showed a strong dependence, decreasing over several orders of magnitude with increasing humidity being a smooth exponential. The air

moisture dependent resistance of the ceramic sensor is converted into voltage signals using a circuitry. Basically it consists of an operational amplifier and an A/D converter. Long-term stability measurements showed that ZnCr2O4-K2CrO4 ceramic system has potential use as an active material in humidity sensors. (C) 2005 Elsevier B.V. All rights reserved.

Kerlau, M., O. Merdrignac-Conanec, et al. (2006). "Preparation and characterization of gallium (oxy)nitride powders - Preliminary investigation as new gas sensor materials." Sensors and Actuators B-Chemical **115**(1): 4-11.

Highly reactive gallium oxynitride powders have been prepared by thermal nitridation under ammonia of a gallium oxide precursor synthesized via a soft chemistry process (citrate method). For the first time, thick film sensors were prepared from the oxynitride powders and subsequently compared to GaN thick film sensors prepared from nitride powders obtained by the conventional nitridation of commercial gallium oxide beta-Ga2O3. The former showed large ethanol response in comparison to that of the GaN sensors in the 220-320 degrees C temperature range. The effects of water vapour and sensitive layer thickness on ethanol sensing were also examined. The sensing behaviour of the two materials and the influences of the two parameters - relative humidity and layer thickness - on the latter appeared to be quite different. (c) 2005 Elsevier B.V. All rights reserved.

Khijwania, S. K., K. L. Srinivasan, et al. (2005). "Performance optimized optical fiber sensor for humidity measurement." Optical Engineering **44**(3): -.

A comprehensive experimental study of a fiber optic relative humidity (RH) sensor is carried out in terms of characterization and performance optimization against various parameters that affect the sensor response and sensitivity e.g., film composition, film thickness, fiber core diameter, and the sensor geometry. The sensor is based on evanescent wave absorption spectroscopy and utilizes a specific reagent immobilized permeable polymer membrane cladding on a declad U-bend optical fiber. An optimum film thickness and an optimum film composition exist. In addition, a fiber with a smaller core diameter was observed to be more sensitive, unlike the previously reported results. The sensitivity further increases with a decrease in the bending radius. The sensor is found to be sensitive to RH ranging from similar to 1.6 to similar to 92%, exhibiting a very fast response time, an extremely good degree of reversibility, repeatability, and a large dynamic range. (c) 2005 Society of Photo-Optical Instrumentation Engineers.

Khijwania, S. K., K. L. Srinivasan, et al. (2005). "An evanescent-wave optical fiber relative humidity sensor with enhanced sensitivity." Sensors and Actuators B-Chemical **104**(2): 217-222.

We report a fiber optic relative humidity (RH) sensor based on the evanescent wave absorption spectroscopy using a single U-bend plastic-

clad silica fiber with high dynamic range and high sensitivity. The sensor is fabricated using a CoCl2 doped thin polymer film coated on the bare fiber core. A comprehensive study of the sensor was made in terms of performance optimization. Sensor response was investigated in terms of the chemically synthesized cladding thickness over the centrally de-cladded U-bent probe. The effect of fiber core diameter on the sensitivity was also studied and the fiber with smaller core diameter was observed to be more sensitive unlike the previously reported results. In addition, we observed that the sensor was having a very fast response to the relative humidity, and was fully reversible, repeatable with a large dynamic range. 

Kim, J. H., S. H. Kim, et al. (2004). "Fabrication of nanoporous and hetero structure thin film via a layer-by-layer self assembly method for a gas sensor." Sensors and Actuators B-Chemical **102**(2): 241-247.

Nanoporous and hetero structure thin film consisted of weak polyelectrolytes and TiO2 nanoparticles was fabricated by the sequential depositions of oppositely charged solutions via a layer-by-layer self assembly (LBL-SA) method on a quartz crystal microbalance (QCM) at room temperature and then by an immersion in acidic water (pH 1.8) for 2 min and neutral water for 10 s subsequently. Because in this process, the ionic bonds of weak polyelectrolytes between poly(allylamine hydrochloride) and poly(acrylic acid) were broken, which contributed to separate the agglomerated TiO2 nanoparticles in thin film. In order to measure the gas sensitivity of hetero structure thin film with a high surface area, the frequency shifts of a QCM were monitored as functions of the concentration of ammonia gas and relative humidity. The QCM immersed in acidic water showed larger frequency shifts than the QCM, without an immersion. As the concentration of gas and relative humidity were increased, the frequency shifts of a QCM were also increased gradually. 

Kim, I. J., S. D. Han, et al. (2005). "Polyvinyl alcohol-co-styrene sulfonate/FeCl2 composite as humidity sensing material." Sensors and Materials **17**(4): 219-226.

Polyvinyl alcohol shows a significant impedance response with changing relative humidity (RH) only above 60% RH. Simply fabricated polyvinyl alcohol film as a humidity sensor lacks durability and also shows high impedance. To overcome this problem, polyvinyl alcohol was crosslinked with 4-styrene sulfonate (sodium salt) in the presence of ferrous ions. The best results with the material as a humidity sensor were obtained when polyvinyl alcohol was crosslinked with 4-styrene sulfonate in the presence of ferrous ions at a temperature of 140 degrees C for about 1 h and when polyvinyl alcohol, 4-styrene sulfonate (sodium salt hydrate) and FeCl(2)center dot 4H(2)O were used in a weight ratio of 10:2:3, respectively. The polymeric mixture of the three materials in water was cast on an alumina substrate (7.5 mm x 7.2 mm x 0.38 mm in size)

prefabricated with interdigitized gold electrodes and was cured at a temperature of 140 degrees C for 1 h. The results demonstrate that the logarithm of the impedance decreased linearly with increasing %RH in the range from 30 to 92% RH. Other factors, such as stability, sensitivity and response time for the fabricated sensor, were also determined.

Kizhakkemadam, S. N., K. G. Ong, et al. (2004). "An active circuit for wireless broadcast of sensor information: Application to humidity monitoring." Sensor Letters **2**(3-4): 175-178.

A wireless, inexpensive, active transmitter circuit is described for broadcast of ambient humidity levels. The radio-frequency transmitter is comprised of a square-wave, inverter-type 68 MHz RC relaxation oscillator circuit the output frequency of which depends on the sensor impedance. A spiral antenna operates at the third harmonic frequency of the oscillator is used to broadcast the sensor information to minimize the physical size of the circuit. Application to humidity monitoring is demonstrated with a nanoporous titania sensor. The oscillator circuit showed a frequency shift of 2.2 MHz when the relative humidity changed from 5% to 70%.

Klassen, R. D. and P. R. Roberge (2003). "Surface film resistance as an environmental sensor." Corrosion Reviews **21**(5-6): 433-444.

Although not the only reason that electronics fail, environmental corrosion is the principal reason in the majority of cases. Therefore an elementary approach to controlling the corrosion of electronic parts is to control the environment. The combination of relative humidity (RH) and deposited ionic species cause corrosion damage as well as current leakage on insufficiently protected parts of integrated circuits. An analysis based on mixed potential theory illustrates that the surface film resistance between anodic and cathodic sites has a major influence on the corrosion current. Surface film resistance depends on both the concentration of ionic species and on the thickness of an adsorbed moisture layer, which is a function of relative humidity. The presence of one without the other prevents significant corrosion current from flowing. Electrochemical impedance spectroscopy results indicated that the modulus of impedance at 100 kHz is a meaningful measure of the solution resistance between surface electrodes. Measurements of surface film resistance could be used in an environmental control system by indicating conditions where leakage current is significant and/or the periods of time where corrosion current is significant, i.e. as a time-of-corrosion sensor.

Klassen, R. D. and P. R. Roberge (2006). "Technical note: Measuring corrosiveness with a dual galvanic/surface film resistance sensor." Corrosion **62**(3): 195-198.

A galvanic sensor system designed to measure atmospheric corrosiveness within an aircraft was modified to also measure surface film resistance. Its response to four laboratory conditions was compared to the

mass loss of an aircraft alloy, UNS A92024. The experimental factors were relative humidity (RH) and level of sodium chloride (NaCl). The amount of salt added was equivalent to the cumulative deposition of salt aerosols at a marine site for one week. The four conditions were (a) low RH with no salt added, (b) high RH with no salt added, (c) low RH with salt added, and (d) high RH with salt added. The mass loss of UNS A92024 plates was above that due to cleaning alone for conditions (b), (c), and (d), whereas the galvanic sensor only responded to the most severe condition (d). The galvanic current declined with time when exposed to the same environment in a manner consistent with the development of mass-transfer limitations of oxygen for the cathodic reaction. Implications for improving the design of a galvanic sensor to minimize both of these deficiencies were discussed.

Konstantaki, M., S. Pissadakis, et al. (2006). "Optical fiber long-period grating humidity sensor with poly(ethylene oxide)/cobalt chloride coating." Applied Optics **45**(19): 4567-4571.

A long-period fiber grating (LPFG) humidity sensor is reported utilizing poly(ethylene oxide)/cobalt chloride (PEO/CoCl2) as a hybrid hygrosensitive cladding coating. A thin overlay of the material is deposited on the LPFG and with exposure to different ambient humidity levels, its spectral properties are modified. The material parameters associated with the sensing mechanism may include those of refractive index, absorption, and morphological alterations of the overlaid material. Relative humidity variations in the range from 50% to 95% have been detected with a resolution better than 0.2%. The response time constant of the fiber sensor is of the order of a few hundred milliseconds. (c) 2006 Optical Society of America.

Kribich, K. R., R. Copperwhite, et al. (2005). "Novel chemical sensor/biosensor platform based on optical multimode interference (MMI) couplers." Sensors and Actuators B-Chemical **107**(1): 188-192.

We present a novel platform for chemical sensing and biosensing. The working principle is based on the interference properties of an optical multimode interference coupler. A humidity sensor has been implemented as a proof of principle. It has been realised using hybrid sol-gel planar technology to allow integration on a silicon substrate.Firstly, we describe the theory of multimode interference and we model the sensor response to the change of the sensing layer refractive index. Then, the sensing material is described and characterised regarding optical and sensing properties. Finally, the prototype device is characterised. A linear response to relative humidity is obtained and it is shown that sensitivity can be tuned using the MMI design technique. (c) 2005 Published by Elsevier B.V.

Kulkarni, M. V. and A. K. Viswanath (2005). "Spectroscopic, thermal and

electrical properties of sulphonic acids doped poly(o-anisidine) and their application as humidity sensor." Sensors and Actuators B-Chemical **107**(2): 791-797.

Poly(o-anisidine), P(o-anis) doped with camphor sulphonic acid (CSA) and p-toluene sulphonic acid (p-TSA) was synthesized by in situ chemical polymerization method using ammonium persulphate as an oxidizing agent. This is a single step polymerization process for the direct synthesis of emeraldine salt phase of the polymer. The polymers were characterized by using UV-vis and FT-IR spectroscopy, TGA and conductivity measurements. Formation of mixed phases of polymer together with conducting emeraldine salt phase are confirmed by spectroscopic techniques. Thermal analysis shows that poly(o-anisidine) has three stage decomposition pattern similar to unsubstituted polyaniline. The lower conductivity in poly(o-anisidine) compared to polyaniline is due to the cumulative steric as well as electronic effects of the bulky methoxy substituent present on the benzene ring. High temperature conductivity measurements show 'thermal activated behaviour'. The change in resistance with respect to % relative humidity (RH) is observed, when pressed pellets of the polymer were exposed to the broad range of humidity (ranging between 20-100% RH). © 2005 Elsevier B.V. All rights reserved.

Kulkarni, M. V., A. K. Viswanath, et al. (2006). "Synthesis and humidity sensing properties of conducting poly(N-methyl aniline) doped with different acids." Sensors and Actuators B-Chemical **115**(1): 140-149.

Poly(N-methyl aniline) (PNMA), doped with different acids (viz. HCl, HClO4, H3PO4, H3BO3 and acetic acid) was synthesized by a chemical polymerization method using ammonium persulphate as an oxidizing agent. This is a single step polymerization process to synthesize directly the conducting emeraldine salt phase of the polymer. The synthesized polymers were characterized by UV-vis, TGA/SDTA and conductivity measurements. These polymers were then successfully utilized as humidity sensors. The change in resistance with respect to % relative humidity (% RH) was observed, when pressed pellets of the polymers were exposed to a broad range of humidity (20-100% RH). Among the different acids used for the doping purpose of the polymer, the H3PO4-doped polymer showed the best sensing response and was found to be the best candidate for a humidity sensor. (c) 2005 Elsevier B.V. All rights reserved.

Lee, J. G. and S. P. Lee (2004). "Nano-structured carbon nitride film for humidity sensor applications." Journal of the Korean Physical Society **45**(3): 619-622.

Nano-structured carbon-nitride films (ca. 20 similar to 40-nm grain size) have been deposited for application in humidity sensors. The surface morphology, surface roughness and bonding structures of the films were investigated by scanning electron microscopy (SEM), atomic force

microscopy (AFM) and Fourier transform infrared (FTIR) spectroscopy. In the interdigitated-electrodes (IDE) type, the resistance of the film changed from 8283.30 kOmega to 827.63 kOmega. In the sandwich type, the resistance decreased from 577.41 kOmega to 24.95 kOmega, however, the capacitance increased from 504.31 nF to 1.30 nF in the relative humidity range of 10 to 90%.

Lee, C. W., H. S. Park, et al. (2004). "Humidity-sensitive properties of polyelectrolytes containing alkoxysilane crosslinkers." Macromolecular Research **12**(3): 311-315.

We have prepared new polyelectrolytes containing trialkoxysilyl groups by copolymerizing 3-(trimethoxysilyl)propyl methacrylate (TSPM) with either [2-(methacryloyloxy)ethyl]trimethyl ammonium chloride (METAC), [2-(methacryloyloxy)ethyl]dimethyl propyl ammonium bromide (MEDPAB), or [2-(acryloyloxy)ethyl]trimethyl ammonium chloride (AETAC). The copolymers TSPM/METAC, TSPM/MEDPAB, and TSPM/METAC having compositions of 15/85, 10/90, and 5/95, respectively, were self-crosslinkable polyelectrolytes that possess humidity-sensitive properties. We measured the impedances of the copolymers at various relative humidities (RHs) and found that the resistance was dependent on the content of METAC, MEDPAB, or AETAC. The impedance changed from 10(7) Omega at 20% RH to 10(3) Omega at 95% RH, which is quite a suitable range for a humidity sensor that is to be utilized at ambient humidity. We also performed tests of the materials temperature dependence, hysteresis, response time, and water durability.

Lee, C. Y. and G. B. Lee (2005). "Humidity sensors: A review." Sensor Letters **3**(1): 1-15.

Humidity is one of the most commonly measured physical quantities and is of great importance in a wide variety. This paper reviews the transduction techniques of various state-of-the-art humidity sensors, including (1) optical, (2) gravimetric, (3) capacitive, (4) resistive, (5) piezoresistive, and (6) magnetoelastic sensors. Starting from the fundamental operation principles, critical issues about design, fabrication, characterization and applications of these humidity sensors were reviewed. It is notable that promising technologies has been applied to revolutionize the design of the humidity sensors. Smaller, faster, cheaper humidity sensors have been reported in the published literatures. However, it still remains challenging to develop a humidity sensor which provides a complete set of favorable characteristics, e.g., good linearity, high sensitivity; low hysteresis and rapid response time.

Lee, J. G. and S. P. Lee (2005). "Surface analysis and humidity-sensing properties of carbon nitride films for microsensors." Journal of the Korean Physical Society **47**: S429-S433.

Carbon nitride films were deposited on silicon substrate by a reactive RF

magnetron sputtering system with DC bias for microsensors. Surface analysis of deposited films was performed by XRD, SEM, and TEM. The film had good uniformity and small grain size of about 30 nm. EDS analysis revealed that the chemical state of the carbon nitride film was C2N. The impedance of a CNx humidity sensor which had micro-holes decreased from 249.4 k Omega to 14.2 k Omega in the relative humidity, range from 5 % to 95 %. As the sensing area of the sensor decreased, the sensitivity slope increased proportionally. Hysteresis was about 8 % FSO, and adsorption and desorption time were about 79 see and 90 see, respectively. Experimental results indicate that CNx films can be a new candidate for Si-based micro-humidity sensors.

Lee, C. W., D. H. Nam, et al. (2005). "Humidity sensors fabricated with polyelectrolyte membrane using an ink jet printing technique and their electrical properties." Sensors and Actuators B-Chemical **109**(2): 334-340.

Humidity-sensitive membranes made of ionene oligomer have been fabricated on the electrode substrate using a commercial drop-on-demand ink-jet printing system using a 15 mu m diameter nozzle driven by a piezoelectric device. After deposition and evaporation of the solvent, the humidity sensors have been cross-linked by heating. Their humidity-sensitive properties have been determined by using a thermostatic humidity chamber. Electrical measurements under various relative humidity were performed. The humidity-sensitive characteristics of sensors obtained by ink-jet printing technique were compared with that of dip-coating method. Humidity sensors showed a decrease in impedance as an increase of relative humidity and their impedance characteristics are in a close agreement. (C) 2005 Elsevier B.V All rights reserved.

Lee, C. W., J. G. Kim, et al. (2005). "Humidity-sensitive properties of self-assembled polyelectrolyte system." Macromolecular Research **13**(3): 265-272.

Polyelectrolyte membranes for humidity-sensing were fabricated using a layer-by-layer adsorption process based on the spontaneous self-assembly of alternating layers of cationic and anionic polymers on a silanized ITO patterned glass substrate. The substrate is dipped successively into dilute solutions of a polyanion and a polycation. The homopolymers and copoymers of diallyldimethylammonium chloride (DDA), allylamine hydrochloride (AA), 2-[(methaeryloyloxy)ethyl]trimethyl ammonium chloride (METAC) and vinylbenzyl tributyl phosphonium chloride(VTBPC) were used as the polycations. In this experiment, it was found that the resistance varied according to the chemical structure of the polycation. The resistance varied from 10(7) to 10(5) Omega, as the humidity was increased from 60 (relative humidity) to 95%RH, which is the range of RH values required for a dew sensor operating at high humidity.

Lee, C. W., H. S. Park, et al. (2005). "Humidity sensitivity of hybrid polyelectrolytes prepared by the sol-gel process." Macromolecular Research

**13**(2): 96-101.

Thin-film humidity sensors were prepared using inorganic/organic hybrid polyelectrolytes, which were prepared from the sol-gel reaction of copolymers of [2-(methacryloyloxy)ethyl]dimethylpropylammonium bromide (MEPAB), n-butyl methacrylate (BMA), and 3-(trimethoxysilyl)propyl methacrylate (TSPM) with tetraethyl orthosilicate (TEOS). The humidity-sensitive polyelectrolytes were composed of the copolymers having the following mole ratios of MEPAB, BMA, and TSPM: 60/30/10, 55/30/15, and 50/30/20. We found that the impedance varied with the content of MEPAB or TEOS; it ranged from 10(7) to 10(3) &UOmega; between 20 and 95% relative humidity, which is the range required for a humidity sensor operating at ambient humidity. In addition we investigated a number of characteristics of these humidity sensors, such as their hysteresis, response time, temperature dependence, frequency dependence, water durability, and long-term stability.

Lee, C. W., S. W. Joo, et al. (2005). "Polymeric humidity sensor using polyelectrolytes derived from alkoxysilane cross-linker." Sensors and Actuators B-Chemical **105**(2): 150-158.

New reactive amine-containing polyelectrolytes were prepared for the humidity.-sensitive membranes. The copolymers were mixed with 3-chloropropyl trialkoxysilane and simultaneously fabricated on the sensor electrode by the cross-linking reaction of both halide and alkoxysilane group. The copolymers were composed of different contents of vinylbenzyltributylphosphonium chloride (VTBPC), [2-(methacryloyloxy)ethyl]trimethyl ammonium chloride (METAC), 2-ethylhexylacrylate (2-EHA) and 4-vinylpyridine (4-VP) (VTBPC/METAC/2-EHA/VP = 2/2/2/4, 3/2/2/3, 2/2/3/3 and 2/3/2/3). And trialkoxysilyl group-containing polyelectrolytes were prepared by copolymerization of [2-(methacryloyloxy)ethyl]dimethyl propyl ammonium bromide (MEDPAB) with 3-(trimethoxysilyl)propyl methacrylate (TSPM). When the resistance dependences on the relative humidity of the copolymers were measured, it was found that the resistance decreased with an increase in the content of VTBPC and METAC. The resistance varied three-orders of magnitude between 20% RH and 95% RH, which was required for a humidity sensor operating at ambient humidity. Temperature dependence, hysteresis, response time, water durability and long-term stabilities under various environments were also measured. 

Leiterer, U., H. Dier, et al. (2005). "Correction method for RS80-A humicap humidity profiles and their validation by lidar backscattering profiles in tropical cirrus clouds." Journal of Atmospheric and Oceanic Technology **22**(1): 18-29.

Routine radiosonde relative humidity ( RH) measurements are not reliable as they are presently used in the global upper-air network. The new Lindenberg measuring and evaluation method, which provides RH profile

measurements with an accuracy of +/-1% RH in the temperature range from 35degrees to -70degreesC near the tropical tropopause is described. This Standardized Frequencies (FN) method uses a thin-film capacitive polymer sensor of a modified RS90-H Humicap radiosonde. These research humidity reference radiosondes (FN sondes) are used to develop a correction method for operational RS80-A Humicap humidity profiles. All steps of correction and quality control for RS80-A radiosondes are shown: ground-check correction, time-lag and temperature-dependent correction, and the recognition of icing during the ascent. The results of a statistical comparison between FN sondes and RS80-A sondes are presented. Corrected humidity data of operational RS80-A sondes used in Lindenberg ( 4 times daily) show no bias when compared to FN radiosondes and have an uncertainty of about +/-3% RH at the 1 sigma or 68% confidence level from 1000 to about 150 hPa. Only a small dry bias of at most -2% RH remains in the lowest part of the boundary layer (up to 500-m height). Finally, some examples of corrected RS80-A RH profiles in cirrus clouds validated by lidar backscattering profiles in a region of the intertropical convergence (Maldive Islands) are demonstrated. The soundings indicate that ice-saturated and ice-supersaturated air above 10-km height were connected with cirrus clouds in all 47 investigated cases, and, second, that the corrected RS80-A RH profiles also provide good quality information on water vapor in the upper troposphere.

Ling, Z. and C. Leach (2004). "The effect of relative humidity on the NO2 sensitivity of a SnO2/WO3 heterojunction gas sensor." Sensors and Actuators B-Chemical **102**(1): 102-106.

The sensitivity of a heterojunction sensor, formed between WO3 and 3 wt.% Nd2O3 doped SnO2, to humidity and NO2 has been investigated using forward bias resistance measurements at 300degreesC. The sensor showed high sensitivity and a pseudo-linear response to NO2 in the range 0-5 ppm in dry air. The response to variations in relative humidity (RH) was small at RH levels below 40%, with the sensor becoming saturated at higher values of RH. Cross-sensitivity measurements were carried out to assess the influence of RH variations on the sensor response to 2.5 and 5 ppm NO2. Strong interference effects were observed, with the sensitivity of the sensor to NO2 decreasing rapidly as the RH of the atmosphere increased. 

Liu, J. F., X. Wang, et al. (2005). "Vanadium pentoxide nanobelts: Highly selective and stable ethanol sensor materials." Advanced Materials **17**(6): 764-+.

Ethanol sensing has important applications, including breath alcohol checkers. A highly selective and stable ethanol sensor-see Figure-based on single-crystalline divanadium pentoxide nanobelts is described, representing a new strategy for the design of novel practicable gas sensors. Potential problems caused by changes of relative humidity or the presence of other gases are ruled out.

Lukaszewicz, J. P. and M. Skompska (2006). "A novel carbon-based ionic conductor for humidity sensors." Sensors and Actuators B-Chemical **113**(2): 970-977.

Carbon films modified by means of Na2CO3 were tested as a novel material for the construction of humidity sensors. On the contrary, to "virgin" carbon films and carbon films modified by some alkali metal compounds like hydroxides, acetates or chlorides, the Na2CO3-modified materials exhibit a mixed conduction mechanism. Beside hole/electron conduction the novel carbon, films behave as ionic conductor provided relative humidity is high enough. During carbonisation, the applied modifier forms nano-crystals of Na2CO3 on the surface and in the bulk of semiconductor carbon matrix. The inorganic nano-crystals dissolve and dissociate in the layer of adsorbed water. Ions produced in this way increase electric conductivity of the system contributing significantly to total electric current passing through the carbonate-modified carbon films. The novel carbon material is highly sensitive to water vapour. Water adsorption induced resistance changes of the film are reversible and therefore the material may be applied to the construction of humidity sensors. Carbon films obtained by means other alkali metal carbonates as modifiers behave in a similar way. 

Makkonen, L. and T. Laakso (2005). "Humidity measurements in cold and humid environments." Boundary-Layer Meteorology **116**(1): 131-147.

Recent studies have shed new light on humidity conditions in the polar atmospheric boundary layer, and cast doubt on the reliability of humidity measurements above the frost point humidity. These issues are addressed herein by considering the processes that affect humidity and its measurement in cold climate conditions and by analyzing observations from two sites, at which the relative humidity is frequently above 100% at sub-freezing temperatures, as shown by repeatedly observed in-cloud icing events. Humidity measurements were made at these two sites by the commonly used Vaisala HMP35 probe and HMP233 capacitance probes respectively and simultaneously by the same manufacturer's HMP243 probe that determines the frost point by a heated capacitance sensor. The results confirm that the relative humidity is frequently well above the frost point, both due to radiative cooling and to the advection of moist air, and that the conventional humidity measurements are unable to detect these events. Furthermore, after such events, the iced sensors show too high a humidity. The false values occur due to ice growth on the probe and cannot be corrected by any algorithm. Our results indicate that these problems, inherent to conventional humidity measurements in cold and humid environments, are avoided by the use of HMP243, which has a heated humidity probe.

Masuda, H. and H. Katayama (2005). "Development of portable device for measuring accumulation rate of sea salt particles." Corrosion Science **47**(10): 2411-2418.

We have developed a new portable device for measuring the accumulation rate of sea salt particles. This device is composed of two sets of handy QCM devices, a handy vacuum desiccator and a handy moistening. QCM sensor used was Ag-coated one with 30 MHz in resonant frequency. The resonant frequency change with the relative humidity was measured under different size and amount of attached sea salt particles. The result shows that the resonant frequency was decreased as the relative humidity increased. The decrease of resonant frequency was caused by the weight increase of MgCl2 solution in the sea salt particles. QCM sensor was exposed on outdoor and the amount of attached sea salt was estimated by the resonant frequency change with the relative humidity. (c) 2005 Elsevier Ltd. All rights reserved.

McGaughey, O., J. V. Ros-Lis, et al. (2006). "Development of a fluorescence lifetime-based sol-gel humidity sensor." Analytica Chimica Acta **570**(1): 15-20.

A sol-gel-based optical sensor for the measurement of relative humidity has been developed. It is based on the changes in fluorescence intensity and/or lifetime of the ruthenium complex, ruthenium(II)diphenylphenanthroline-dipyridophenazinehexafluorophosphate. Sensitivity to relative humidity has been demonstrated over the range 0-100% relative humidity. This sensor has been developed for application in the field of indoor air-quality monitoring and displays a limit of detection of 0.35% relative humidity and a resolution of 1.13% over the concentration range of interest (0-50% relative humidity). The effects of varying process parameters on the sensor performance were studied along with the effects of cross-sensitivity to molecular oxygen. (c) 2006 Elsevier B.V. All rights reserved.

McGovern, S. T., G. M. Spinks, et al. (2005). "Micro-humidity sensors based on a processable polyaniline blend." Sensors and Actuators B-Chemical **107**(2): 657-665.

Polyaniline was blended with either polyvinyl alcohol or a butyl acrylate/vinyl acetate copolymer and used as a sensing medium in the construction of a resistance-based humidity sensor. The design utilised 125 μ m polyester-insulated platinum wire as conducting electrodes that were dip-coated in conducting polymer. The sensors had an overall final thickness of less than 150 μ m and showed high sensitivity, low resistance, and good reversibility without hysteresis. Some drift in the response was attributed to slow oxidation of the polyaniline that could be reduced by the application of appropriate barrier coatings. © 2004 Elsevier B.V. All rights reserved.

Miglio, S., M. Bruzzi, et al. (2005). "Development of humidity sensors based on

nanostructured carbon films." Sensors and Actuators B-Chemical **111**: 140-144.
Humidity sensors based on cluster assembled nanostructured carbon films in capacitive configuration have been fabricated and characterized. An electronic read-out system has been designed and implemented in order to measure the complex impedance of the device under operation. The sensor and read-out electronics provide a fully integrated and cost-effective system. Devices under test show a fast dynamic response and a good sensitivity compared to capacitive commercial systems. A linear response is observed for relative humidity in the range up to 70%. Hysteresis is practically absent in this range, while for higher values it is at most in the order of 2%. (c) 2005 Elsevier B.V. All rights reserved.

Miloshevich, L. M., A. Paukkunen, et al. (2004). "Development and validation of a time-lag correction for Vaisala radiosonde humidity measurements." Journal of Atmospheric and Oceanic Technology **21**(9): 1305-1327.
This study presents a method of improving the accuracy of relative humidity ( RH) measurements from Vaisala RS80 and RS90 radiosondes by applying sensor-based corrections for well-understood sources of measurement error. Laboratory measurements of the sensor time constant as a function of temperature are used to develop a correction for a time-lag error that results from slow sensor response at low temperatures. The time-lag correction is a numerical inversion algorithm that calculates the ambient ("true") humidity profile from the measured humidity and temperature profiles, based on the sensor time constant. Existing corrections for two sources of dry bias error in RS80 humidity measurements are also included in the correction procedure: inaccuracy in the sensor calibration at low temperatures, and chemical contamination of sensors manufactured before June 2000 by nonwater molecules from the radiosonde packaging material.The correction procedure was evaluated by comparing corrected RS80-H measurements with simultaneous measurements from the reference-quality NOAA/Climate Modeling and Diagnostics Laboratory balloon-borne cryogenic hygrometer. The time-lag correction is shown to recover vertical structure in the humidity profile that had been "smoothed" by the slow sensor response, especially in the upper troposphere and lower stratosphere, revealing a much sharper troposphere - stratosphere transition than is apparent in the original measurements. The corrections reduced the mean dry bias in the radiosonde measurements relative to the hygrometer from 4% RH at -20degreesC and 10% RH at -70degreesC to about +/-2% RH at all temperatures, and the variability at low temperatures is substantially reduced. A shortcoming of the existing contamination correction is also uncovered, and a modification is suggested. The impact of the corrections on several radiosonde datasets is shown.

Miloshevich, L. M., H. Vomel, et al. (2006). "Absolute accuracy of water vapor measurements from six operational radiosonde types launched during AWEX-G

and implications for AIRS validation." Journal of Geophysical Research-Atmospheres **111**(D9): -.

[1] A detailed assessment of radiosonde water vapor measurement accuracy throughout the tropospheric column is needed for assessing the impact of observational error on applications that use the radiosonde data as input, such as forecast modeling, radiative transfer calculations, remote sensor retrieval validation, climate trend studies, and development of climatologies and cloud and radiation parameterizations. Six operational radiosonde types were flown together in various combinations with a reference-quality hygrometer during the Atmospheric Infrared Sounder ( AIRS) Water Vapor Experiment-Ground (AWEX-G), while simultaneous measurements were acquired from Raman lidar and microwave radiometers. This study determines the mean accuracy and variability of the radiosonde water vapor measurements relative to simultaneous measurements from the University of Colorado (CU) Cryogenic Frostpoint Hygrometer (CFH), a reference-quality standard of known absolute accuracy. The accuracy and performance characteristics of the following radiosonde types are evaluated: Vaisala RS80-H, RS90, and RS92; Sippican Mark IIa; Modem GL98; and the Meteolabor Snow White hygrometer. A validated correction for sensor time lag error is found to improve the accuracy and reduce the variability of upper tropospheric water vapor measurements from the Vaisala radiosondes. The AWEX data set is also used to derive and validate a new empirical correction that improves the mean calibration accuracy of Vaisala measurements by an amount that depends on the temperature, relative humidity, and sensor type. Fully corrected Vaisala radiosonde measurements are found to be suitably accurate for AIRS validation throughout the troposphere, whereas the other radiosonde types are suitably accurate under only a subset of tropospheric conditions. Although this study focuses on the accuracy of nighttime radiosonde measurements, comparison of Vaisala RS90 measurements to water vapor retrievals from a microwave radiometer reveals a 6 - 8% dry bias in daytime RS90 measurements that is caused by solar heating of the sensor. An AWEX-like data set of daytime measurements is highly desirable to complete the accuracy assessment, ideally from a tropical location where the full range of tropospheric temperatures can be sampled.

Mineiro, S. L., M. C. A. Nono, et al. (2005). "Humidity sensitive characteristics of ZnO-TiO2-Ta2O5 ceramic." Advanced Powder Technology Iv **498-499**: 293-298.

The humidity sensing behavior of a ceramic oxide based on the ZnO-TiO2-Ta2O5 system was analyzed. Samples were uniaxially pressed and sintered at temperature range from 1000 to 1200 degrees C. Electrical impedance and capacitance measurements were realized in different values of relative humidity (from 11 to 100%). The microstructures of the sintered samples were characterized by X-ray diffractions and SEM observations. Mercury porosimetry analyses were carried out to determine

the open porosity and the surface area was measured by using the BET nitrogen method. The obtained results were correlated and discussed.

Minnis, P., Y. H. Yi, et al. (2005). "Relationships between radiosonde and RUC-2 meteorological conditions and cloud occurrence determined from ARM data." Journal of Geophysical Research-Atmospheres **110**(D23): -.

Relationships between modeled and measured meteorological state parameters and cloudy and cloud-free conditions are examined using data taken over the ARM (Atmospheric Radiation Measurement) Southern Great Plains Central Facility between 1 March 2000 and 28 February 2001. Cloud vertical layering was determined from the Active Remotely Sensed Cloud Location product based on the ARM active sensor measurements. Both temperature and relative humidity (RH) observations from balloon-borne Vaisala RS80-15LH radiosonde (SONDE) and the Rapid Update Cycle (RUC) 40-km resolution model are highly correlated, but the SONDE RHs generally exceed those from RUC. Inside cloudy layers, the RH from SONDE is 2-14% higher than the RH from RUC at all pressure levels. Although the layer mean RH within clouds is much greater than the layer mean RH outside clouds or in clear skies, RH thresholds chosen as a function of temperature can more accurately diagnose cloud occurrence for either data set than a fixed RH threshold. For overcast clouds (cloud amount greater than or equal to 90%), it was found that the 50% probability RH threshold for diagnosing a cloud, within a given upper tropospheric layer, is roughly 90% for the SONDE and 80% for RUC data. For partial cloud cover (cloud amount is less than 90%), the SONDE RH thresholds are close to those for RUC at a given probability in upper tropospheric layers. Cloud probability was found to be only minimally dependent on vertical velocity. In the upper troposphere, SONDE ice-supersaturated air occurred in 8 and 35% of the clear and cloudy layers, respectively. The RH was distributed exponentially in the ice supersaturated layers as found in previous studies. The occurrence of high-altitude, ice-supersaturated layers in the RUC data was roughly half of that in the SONDE data. Optimal thresholds were derived as functions of temperature to define the best RH thresholds for accurately determining the mean cloud cover. For warm clouds the typical SONDE threshold exceeds 87%, while the RH thresholds for cold clouds are typically less than 80% and greater than 90% with respect to liquid and ice water, respectively. Preliminary comparisons with satellite data suggest that the relationships between cloudiness and RH and T determined here could be useful for improving the characterization of cloud vertical structure from satellite data by providing information about low-level clouds that were obscured by high-level clouds viewed by the satellite. The results have potential for improving computations of atmospheric heating rate profiles and estimates of aircraft icing conditions.

Miszczyk, A., K. Darowicki, et al. (2004). "Evaluation of relative humidity effects

on interfacial impedance at inter-coat interfaces." Polish Journal of Chemistry **78**(9): 1823-1831.

Impedance spectroscopy has been applied as potentially non-destructive method for the evaluation of adhesion at the interface between two polymer layers in protective coating system. The aim was to examine the effect of the outdoor humidity on the interfacial impedance. A automotive basecoat/clearcoat system has been investigated. Anew electrode sensor has been employed to detect the changes caused by adhesive debonding and accumulation of water at the interface. The electrode comprising two thin stripes of an electroconductive ink was placed between two coating layers. Large changes in the impedance were observed when humidity conditions were altered. The obtained data were indicative for strong sensitivity of the interlayer impedance to the outdoor humidity. Water accumulation in the interlayer and the formation of conductive paths led to the worsening of adhesion and deamination of the coating layers.

Moghavvemi, M., K. E. Ng, et al. (2005). "A reliable and economically feasible remote sensing system for temperature and relative humidity measurement." Sensors and Actuators a-Physical **117**(2): 181-185.

Sensing and recording of relative humidity and temperature plays an important role in many industries. In the past analogue devices were used for measurement of relative humidity and temperature. A simple technique combining analogue and digital circuit theory together with programming techniques has been used in this paper to design a remote temperature and relative humidity sensing system. The sensors analogue signal is applied to a micro-controller based data logger for storage purposes. The data is then transferred to the computer through standard RS232 serial port using the user interface program. The program also allows the user to input some of the important parameters such as sampling interval as well as starting date and time for the logging operation. A back-up power supply is also included to enable the system to remain functional in the event of a power failure. The proposed system has added advantages compared with existing systems, namely, in its low cost and high memory capabilities and the ability to perform in both real-time as well as off-line. 

Moran, D. S., K. B. Pandolf, et al. (2004). "Evaluation of the environmental stress index (ESI) for different terrestrial elevations below and above sea level." Journal of Thermal Biology **29**(6): 291-297.

The purpose of this study was to evaluate the recently developed environmental stress index (ESI) for different climatic conditions and terrestrial elevations below and above sea level and to evaluate a new and relatively small (5 mm) infra-red (IR) light sensor for reliability and for measuring global radiation (GR). Meteorological measurements were taken in 3 different climatic zones (hot/wet, hot/dry and extremely hot/dry) at 6 different terrestrial elevations (-386, -200, 35, 375, 960 and 1640m)

for 9 days between 09:00 and 17:00. Meteorological data included ambient temperature, relative humidity, wet bulb temperature, black globe temperature and GR from two instruments: an IR light sensor and a pyranometer. In general, ESI successfully evaluated the impact of climate from the various locations at different terrestrial elevations. Global radiation measurements revealed no significant ($P < 0.05$) differences between measurements by the pyranometer or the IR light sensor. High correlation was found between ESI and the wet bulb globe temperature index when GR was calculated from both the pyranometer (R-2 = 0.933) and the light sensor (R-2 = 0.939). In conclusion, ESI is a valid measure for different terrestrial elevations, and the IR sensors have the potential to measure GR for use in heat stress assessment incorporated in the index. 

Nakamura, H., H. Seko, et al. (2004). "Dry biases of humidity measurements from the Vaisala RS80-A and Meisei RS2-91 radiosondes and from ground-based GPS." Journal of the Meteorological Society of Japan **82**(1B): 277-299.

During the Tsukuba GPS (Global Positioning System) Dense Network Campaign Observations in the autumn of 2000, we performed 3 hourly upper air soundings using two types of radiosondes. One was the Meisei RS2-91, operational sonde of the Japan Meteorological Agency (JMA) made by Meisei Electric Co. Ltd. with an independent thin-film capacitive sensor, and the other was Vaisala RS80-15G with A-type Humicap humidity sensor (RS80-A hereafter). It was found that the Precipitable Water Vapor (PWV) measured by Vaisala RS80-A were clearly smaller (dry bias) by 3-4 mm (about 4-6%) than those by JMA RS2-91 and those analyzed from GPS observations. The dry bias error of Vaisala RS80-A was also confirmed with dual sonde balloon flights equipped with both Vaisala RS80-A and JMA RS2-91 instruments, and near simultaneous flights of two types of radiosondes. It was found that the dry bias error was reduced by the new tight protective cap for the humidity sensor, but substantial amount of dry bias error still remained.We further compared humidity measurements by the two radiosondes to a chilled-mirror dew-point hygrometer using a two-pressure type humidity calibration chamber. The experiment was conducted under room temperature conditions. It showed that relative humidity as measured by the Vaisala RS80-A was about 5 to 15% smaller than that of the dew-point hygrometer. The bias was larger in high humidity conditions. Although the dry bias of Vaisala RS80-A radiosondes has been pointed out in several other studies, the dry bias revealed in this study is much larger than previously reported, indicating that a problem still exists in RS80-A humidity measurements taken in moist air conditions such as Japan.The RS2-91 showed only small dry bias relative to the dew-point hygrometer (less than 4%). However, the Aerological Observatory of the JMA reported that they improved the RS2-91 humidity sensor since 1999 (Shibue et al. 2000). RS2-91 sondes manufactured before and in 1999 had a dry bias with the

same order of magnitude as the Vaisala RS80-A.There have been several reports (e.g., Ohtani et al. 2000) that the PWV derived by GEONET (Japanese nationwide GPS array) and other campaign GPS observations agreed well with those by JMA or Vaisala radiosondes. The implication of the dry bias errors of the radiosonde to the previous GPS studies is that the past GPS analysis in Japan produced a drier atmosphere than actual conditions. It is recommended that the past GPS data, including the GEONET data, be reanalyzed using the most advanced GPS analysis methods.

Neri, G., A. Bonavita, et al. (2004). "A study of water influence on CO response on gold-doped iron oxide sensors." Sensors and Actuators B-Chemical **101**(1-2): 90-96.

A temperature programmed desorption (TPD) study of the water- and CO-interaction with the surface of gold-doped iron oxide sensors is presented. TPD data has shown that CO does not adsorb in the absence of water. The adsorption of CO occurs when water is present as coadsorbate, through the formation of a surface formate intermediate. TPReaction of CO with oxygen in both dry and wet air has shown that water also promotes CO oxidation, likely via the same formate intermediate.The effect of water on the CO sensing of Au/Fe2O3 Sensors was also investigated. Current response data at different temperatures and relative humidity were fitted by the equation S = I-CO/I-air = k[CO](beta), with the sensitivity (k) and exponential (beta) factors dependent on the temperature and relative humidity (RH). Moreover, in wet air, the maximum of response, T-M, shifts to higher temperature with respect to dry air.To explain the results of electrical tests two different sensing mechanisms which operate in dry and wet air, respectively, have been suggested. 

Nishikawa, H., R. Kurihara, et al. (2006). "Measurements of humidity and current distribution in a PEFC." Journal of Power Sources **155**(2): 213-218.

Voltage decreases of polymer electrolyte fuel cells (PEFC) are affected by the relative humidity of the reaction gas inside the cells. A study was conducted to establish a method for measuring relative humidity and current distribution inside PEFC cells in order to identify the factors affecting the voltage decay of such fuel cells. The humidity distribution was measured using a humidity sensor for directly monitoring the relative humidity of the reaction gas flowing through the air flow channel of the cathode separator. The current distribution was measured directly by attaching a current sensor to the rib of the cathode separator. Typical results of relative humidity and current distribution are described and interpretations are discussed. 

Noda, K., M. Takahashi, et al. (2005). "Measurement of methane gas concentration by detecting absorption at 1300 nm using a laser diode

wavelength-sweep technique." Optical Engineering **44**(1): -.

We develop a simple piece of equipment for measuring methane (CH4) gas concentration based on IR absorption by sweeping the wavelength of light emitted from a laser diode (LD). The principle of IR absorption enables the selective measurement of CH4 gas by detecting an absorption line that appears around 1300 nm in the specific absorption spectrum of CH4. Our method is simpler and more user-friendly than existing measurement methods that involve a measurement system equipped with a cell filled with a known concentration of CH4 gas and a lock-in amplifier. The results of measurements using 220- and 660-mm measurement cells show that CH4 gas concentration is proportional to absorbance within a concentration range of 5 to 90 vol %. It is also found that our measurement system can selectively measure only the concentration of CH4 in city gas, which is composed of a mixture of flammable gases. Moreover, a simple technique for removing humidity using silica gel and calcium chloride reduces the influence of relative humidity. These results represent performance superior to other CH4 measurement methods currently in use. (C) 2005 Society of Photo-Optical Instrumentation Engineers.

Nohria, R., R. K. Khillan, et al. (2006). "Humidity sensor based on ultrathin polyaniline film deposited using layer-by-layer nano-assembly." Sensors and Actuators B-Chemical **114**(1): 218-222.

In this paper, we use layer-by-layer (LbL) nano-assembly for deposition of ultrathin poly(anilinesulfonic acid) (SPANI) films for fabrication of highly sensitive and rapid response humidity sensors. Spin coating was also used for fabrication of SPANI based humidity sensors for comparison. The change in electrical sheet resistance of the sensing film was monitored as the device was exposed to humidity. For 5% change in relative humidity, the sensitivity was measured to be 11 and 6% from layer-by-layer based and the spin coated humidity sensors, respectively. An intended application for these layer-by-layer assembled devices is in disposable handheld instruments to monitor the presence of humidity in humidity sensitive environments. (c) 2005 Elsevier B.V. All rights reserved.

Oliveira, A. P., J. Soares, et al. (2006). "An application of neural network technique to correct the dome temperature effects on pyrgeometer measurements." Journal of Atmospheric and Oceanic Technology **23**(1): 80-89.

This work describes an application of a multilayer perceptron neural network technique to correct dome emission effects on longwave atmospheric radiation measurements carried out using an Eppley Precision Infrared Radiometer (PIR) pyrgeometer. It is shown that approximately 7-month-long measurements of dome and case temperatures and meteorological variables available in regular surface stations (global solar radiation, air temperature, and air relative humidity) are enough to train the neural network algorithm and correct the observed

longwave radiation for dome temperature effects in surface stations with climates similar to that of the city of Sao Paulo, Brazil. The network was trained using data from 15 October 2003 to 7 January 2004 and verified using data, not present during the network-training period, from 8 January to 30 April 2004. The longwave radiation values generated by the neural network technique were very similar to the values obtained by Fairall et al., assumed here as the reference approach to correct dome emission effects in PIR pyrgeometers. Compared to the empirical approach the neural network technique is less limited to sensor type and time of day (allows nighttime corrections).

Palummo, L., I. Fratoddi, et al. (2004). "Resistive type sensor for humidity and short alcohols detection." Sensor Letters **2**(3-4): 205-210.

Rh (I) and Pd (II) catalysts were used to prepare humidity sensitive organometallic polymers prepared from N,N-dimethylproparylamine (DMPA) or the corresponding chlorohydrate (DMPA center dot HCl) as monomers. Pristine and iodine doped polymers were characterized and their sensing properties were investigated and here discussed. The responses to relative humidity and short alcohols variations of sensors based on these polymeric membranes were investigated. An interesting response towards methanol and ethanol was found. Long term stability, fast response time and resistance to high humidity atmosphere, were achieved.

Pang, P. F., Z. D. Guo, et al. (2005). "Humidity effect on the monolayer-protected gold nanoparticles coated chemiresistor sensor for VOCs analysis." Talanta **65**(5): 1343-1348.

Two gold-thiolate monolayer-protected nanoparticles were synthesized and used as interfacial layers on chemiresistor sensors for the analysis of violate organic compounds (VOCs). Toluene, ethanol, acetone and ethyl acetate were chosen as the target vapors. Both the resistance and capacitance were measured as the function of analyte concentrations. The effect of humidity on the sensor sensitivity to VOCs was investigated. The sensitivity decreases with humidity increasing, depending on the hydrophobicity of the target compounds. Less effect was observed on the higher hydrophobic compounds. While the relative humidity (RH) increased from 0 to 60%, the sensitivity to acetone decreased by 39 and 37%, respectively on the Au-octanethiol (C8Au) and Au-2-phenylethanethiol (BC2Au) coated sensors, while the sensitivity to toluene decreased by 12 and 14%, respectively. These results show that the sensors coated with hydrophobic compounds protected-metal nanoparticles can be employed in high humidity for hydrophobic compounds analysis. The resistance responses to VOCs are rapid, reversible, and linear. while the capacitance response is not sensitive and consequently not applicable for VOCs analysis. The response mechanism was also discussed based on the sensor response to water vapor. The

capacitance response is not sensitive to the film swelling in dry environment. (c) 2004 Elsevier B.V. All rights reserved.

Parvatikar, N., S. Jain, et al. (2006). "Electrical and humidity sensing properties of polyaniline/WO3 composites." Sensors and Actuators B-Chemical **114**(2): 599-603.

Conducting polyaniline/tungsten oxide (WO3) composites have been synthesized by 'in situ' deposition technique by placing fine graded WO3 in polymerization mixture of aniline. This is a single step polymerization process for the direct synthesis of emeraldine salt phase of the polymer. The results were also well supported by FTIR spectral analysis, scanning electron microscope (SEM), XRD and conductivity measurements. High temperature conductivity measurements show thermal activated behavior. The change in resistance with respect to percent relative humidity (RH) is observed. The composites in the pellet form exhibit almost linear behavior within a chosen range of humidity (ranging between 10 and 95% RH). (c) 2005 Elsevier B.V. All tights reserved.

Paun, V. (2004). "The reference metrological standard for the relative air humidity." Revista De Chimie **55**(6): 402-405.

The paper presents fundamental issues on hygrometry and metrological standard for relative air humidity. Experimental results by working with an electronic psihrometer with aspiration, used as humidity sensor were discussed. Its metrological performance was expressed by estimation of uncertainty in various forms, although the measurand (relative humidity, in this case) was not directly determined being estimated from input quantities.

Pinzari, F., C. Fanelli, et al. (2004). "Electronic nose for the early detection of moulds in libraries and archives." Indoor and Built Environment **13**(5): 387-395.

The development of sensor technology has stimulated interest in the use of characteristic volatile and odorous compounds produced by fungi as early indicators of deterioration in materials. Sensor arrays to measure traces of volatile chemicals could detect early fungal growth in libraries and archives.In this study we tested an electronic nose to detect fungi actively growing on paper samples. The main aim was to verify whether or not a device, currently used to detect fungal activity in stored grain, might be suitable for detecting mould activity on paper. The findings indicate that it is possible to discriminate "in vitro" between paper samples affected by moulds and those unaffected, both at 100% RH (relative humidity), and at 75% RH, simply by measuring their odour fingerprint with an electronic nose. The sensors used in this study discriminated for each paper type three different species of actively growing fungi. Cluster analysis (CA) showed it was possible to differentiate between specific species. Different. paper types influenced the emission of odorous signals by moulds. When considering data from all the paper types, principal component analysis

(PCA) indicated that only samples analysed at 100% RH could be separated.This study suggests that, before electronic-nose technology can be applied to the early detection of mould growth in libraries, archives, museums or in display cases, more information will be required on the influence of substrata and of other environmental parameters in the production of volatile chemicals by fungi.

Popescu, V. (2004). "Humidity sensors based on PbS nanostructured films." Revista De Chimie **55**(10): 797-799.

The paper presents the influence of humidity on the electrical resistance of PbS films, obtained by chemical bath deposition (CBD), on the glass substrate. By keeping of samples in air, containing 0.15 or 19 mg H2O/L, electrical resistance R decreased. After thermal treatment at 90(0)C, electrical resistance, reverts at initial values. The sorption/desorption of water vapors being reversible, these films could behave as humidity sensors. It was observed a decreasing of log R on the increase of relative humidity at ambient temperature. The experimental data prove the possibility of using these films as sensors for hygrothermometers, simultaneously with temperature sensor (PbSfilm). These devices could be applied for digital monitoring of humidity and temperature of environment.

Potyrailo, R. A., A. W. Szumlas, et al. (2005). "A dual-parameter optical sensor fabricated by gradient axial doping of an optical fibre." Measurement Science & Technology **16**(1): 235-241.

There is a general need for optical sensors that respond to multiple substances or physical parameters. Multiple-parameter sensing is not only more efficient, but also permits interacting or interdependent parameters to be individually determined. In this paper, we describe a novel approach to the fabrication of an optical sensor, sensitive to two separate atmospheric conditions, but made from a single fibre optic. The optical fibre is drawn from polycarbonate, with a temperature-sensitive phosphor (La2O2S:Eu3+) incorporated directly into the core. Thus, the light-guiding portion of the fibre is responsible for determining the first parameter of measurement, ambient temperature. A thin fibre cladding is subsequently added to the temperature-sensitive core and serves as a chemically sensitive component. This cladding is made from Nafion(R), and is doped with rhodamine 800. Fluorescence at 750 run from the rhodamine 800 is shown to be enhanced by the presence of atmospheric moisture, and is used in conjunction with a ratiometric means of measuring temperature provided by the phosphorescence from the fibre core. This scheme provides a simple and potentially inexpensive way to manufacture fibre-optic sensors capable of multicomponent determinations. In addition, the temperature-sensitive core material provides a built-in normalization factor for the temperature-dependent response of the chemically sensitive cladding. The developed dual sensor was evaluated over the temperature

range from 20 to 95degreesC and demonstrated better than 1% relative standard deviation (RSD). The humidity sensor component was evaluated over the range of relative humidity (RH) from 0 to 20% RH over temperatures up to 56degreesC. The detection limits for the humidity sensor were 0.17 and 2.35% RH at 20 and 56degreesC, respectively.

Quinn, R. C., A. P. Zent, et al. (2005). "Detection and characterization of oxidizing acids in the Atacama Desert using the Mars Oxidation Instrument." Planetary and Space Science **53**(13): 1376-1388.

We have performed field experiments to further develop and validate the Mars Oxidation Instrument (MOI) as well as measurement strategies for the in situ characterization of oxidation mechanisms, kinetics, and carbon cycling on Mars. Using the Atacama Desert as a test site for the current dry conditions on Mars, we characterized the chemical reactivity of surface and near-surface atmosphere in the dry core of the Atacama. MOI is a chemiresistor-based sensor array that measures the reaction rates of chemical films that are sensitive to particular types of oxidants or that mimic chemical characteristics of pre-biotic and biotic materials. With these sensors, the chemical reactivity of a planetary environment is characterized by monitoring the resistance of the film as a function of time. Our instrumental approach correlates reaction rates with dust abundance, UV flux, humidity, and temperature, allowing discrimination between competing hypotheses of oxidant formation and organic decomposition. The sensor responses in the Atacama are consistent with an oxidative attack by strong acids triggered by dust accumulation, followed by transient wetting due to an increase in relative humidity during the night. We conclude that in the Atacama Desert, and perhaps on Mars, low pH resulting from acid accumulation, combined with limited water availability and high oxidation potential, can result in oxidizing acid reactions on dust and soil surfaces during low-moisture transient wetting events (i.e. thin films of water). These soil acids are expected to play a significant role in the oxidizing nature of the soils, the formation of mineral surface coatings, and the chemical modification of organics in the surface material. (c) 2005 Published by Elsevier Ltd.

Raible, I., M. Burghard, et al. (2005). "V2O5 nanofibres: novel gas sensors with extremely high sensitivity and selectivity to amines." Sensors and Actuators B-Chemical **106**(2): 730-735.

Chemiresistor-type gas sensors were fabricated by depositing vanadium pentoxide (V2O5) nanofibres from aqueous suspension onto silicon substrates. Electrical contact was made through gold electrodes. Due to the sufficiently high conductivity of the fibres, the sensors could be operated at room temperature. Extremely high sensitivity was measured for 1-butylamine (limit of detection (LOD) below 30 ppb) and moderate sensitivity for ammonia. In contrast, only very little sensitivity was observed for toluene and 1-propanol vapours. The sensitivity to 1-

butylamine increased linearly when increasing the relative humidity (rh) of the carrier gas from 0 to 60%. Contacting the fibres with either top or bottom electrodes dramatically changed the response characteristics. Based on these results, the sensing mechanism is discussed in terms of intercalation of the amine into the layered structure of the nanofibres and sorption at the nanofibre/electrode interface. © 2004 Elsevier B.V. All rights reserved.

Rosini, S. and E. Siebert (2004). "Solid-state internal reference electrode based on quinhydrone for hydrogen sensor with acid-doped polybenzimidazole." Electrochimica Acta **49**(4): 525-536.

An electrode consisting of a mixture of quinhydrone (QH) and polybenzimidazole (PBI) with carbon was investigated as a solid reference electrode for hydrogen sensors. The vibrational behaviour of the polybenzimidazole/quinhydrone blend was investigated by infrared spectroscopy. The results suggest the existence of hydroquinone in the blend. The quinone/hydroquinone redox couple was evidenced by cyclic voltammetry. The potential of the solid-state reference electrode was found to be very stable over a period of 700 h. The drift was less than 0.1 mV per day. This electrode was successfully implemented in a potentiometric sensor. The standard potential was of the order of -550 mV at room temperature and increased as a function of the temperature with a slope of 1 mV/degreesC. The standard potential was also insensitive to changes in relative humidity (rh) in the sample gas over a period of I day. (C) 2003 Elsevier Ltd. All rights reserved.

Rout, C. S., A. R. Raju, et al. (2006). "Hydrogen sensors based on ZnO nanoparticles." Solid State Communications **138**(3): 136-138.

Hydrogen sensing characteristics of thick films of nanoparticles (similar to 35 nm diameter) of ZnO, 3% Co doped ZnO, 1% Pt-impregnated ZnO and 1% Pt-impregnated 3% Co-ZnO have been investigated. The last composition exhibits the highest sensitivity for 10-1000 ppm H-2, reaching values upto 1700 as well as good response and recovery times at 125 degrees C or lower. The sensor is not affected significantly upto 50% relative humidity. (c) 2006 Elsevier Ltd. All rights reserved.

Ryan, M. A., H. Y. Zhou, et al. (2004). "Monitoring space shuttle air quality using the jet propulsion laboratory electronic nose." Ieee Sensors Journal **4**(3): 337-347.

A miniature electronic nose (ENose) has been designed and built at the Jet Propulsion Laboratory (JPL), Pasadena, CA, and was designed to detect, identify, and quantify ten common contaminants and relative humidity changes. The sensing array includes 32 sensing films made from polymer carbon-black composites. Event identification and quantification were done using the Levenberg-Marquart nonlinear least squares method. After successful ground training, this ENose was used in a demonstration

experiment aboard STS-95 (October-November, 1998), in which the ENose was operated continuously for six days and recorded the sensors' response to the air in the mid-deck. Air samples were collected daily and analyzed. independently after the flight. Changes in shuttle-cabin humidity were detected and quantified by the JPL ENose; neither the ENose nor the air samples detected any of the contaminants on the target list. The device is microgravity insensitive.

Saevels, S., A. Z. Berna, et al. (2004). "Characterisation of QMB sensors by means of the BET adsorption isotherm." Sensors and Actuators B-Chemical **101**(1-2): 242-251.

A calibration protocol was established for a quartz microbalance-based electronic nose (QMBE-nose) that was used for apple aroma measurements. A gas-mixing panel was built to generate a broad concentration range of single apple volatile compounds and of mixtures of two compounds. The response of each QMB sensor was modelled with BET adsorption isotherms. Results show that the affinity of the different sensors to relative humidity can be described well with the BET parameters. The sensors could also be characterised with this model for affinity towards single apple volatites and mixtures of two apple volatile compounds. By means of multivariate analysis on all sensor responses, the different compounds could be discriminated well and also quantified accurately. The results showed the potential of the QMBE-nose to quantify and discriminate different apple volatile compounds. Also, the established calibration protocol offers an easy and fast tool to characterise new sensors or investigate new application possibilities. 

Sattler, M. L. and R. S. Rosenberk (2006). "Removal of carbonyl sulfide using activated carbon adsorption." Journal of the Air & Waste Management Association **56**(2): 219-224.

Wastewater treatment plant odors are caused by compounds such as hydrogen sulfide (H2S), methyl mercaptans, and carbonyl sulfide (COS). One of the most efficient odor control processes is activated carbon adsorption; however, very few studies have been conducted on COS adsorption. COS is not only an odor causing compound but is also listed in the Clean Air Act as a hazardous air pollutant. Objectives of this study were to determine the following: (1) the adsorption capacity of 3 different carbons for COS removal; (2) the impact of relative humidity (RH) on COS adsorption; (3) the extent of competitive adsorption of COS in the presence of H2S; and (4) whether ammonia injection would increase COS adsorption capacity. Vapor phase react (VPR; reactivated), BPL (bituminous coal-based), and Centaur (physically modified to enhance H,S adsorption) carbons manufactured by Calgon Carbon Corp. were tested in three laboratory-scale columns, 6 in. in depth and 1 in. in diameter. Inlet COS concentrations varied from 35 to 49 ppm(v) (86-120 mg/m(3)). RHs

of 17%, 30%, 50%, and 90% were tested. For competitive adsorption studies, H2S was tested at 60 ppm(v). with COS at 30 ppm(v). COS, RH, H,S, and ammonia concentrations were measured using an International Sensor Technology Model IQ-350 solid state sensor, Cole-Parmer humidity stick, Interscan Corp. 1000 series portable analyzer, and Drager Accuro ammonia sensor, respectively. It was found that the adsorption capacity of Centaur carbon for COS was higher than the other two carbons, regardless of RH. As humidity increased, the percentage of decrease in adsorption capacity of Centaur carbon, however, was greater than the other two carbons. The carbon adsorption capacity for COS decreased in proportion to the percentage of H,S in the gas stream. More adsorption sites appear to be available to H2S, a smaller molecule. Ammonia, which has been found to increase H2S adsorption capacity, did not increase the capacity for COS.

Schroder, C. R. and I. Klimant (2005). "The influence of the lipophilic base in solid state optical pCO(2) sensors." Sensors and Actuators B-Chemical **107**(2): 572-579.

Solid-state optical pCO(2) sensors comprise mostly a pH indicator dye and a quaternary ammonium hydroxide incorporated in a hydrophobic polymer membrane. In this study we investigated a solid-state optical pCO(2) sensor in which the quaternary ammonium ion was replaced by the neutral phosphazene base P-1-t-Oct (PBO) and compared it with a conventional system containing tetraoctylammonium hydroxide (TOA(+)OH(-)). The basic character of PBO is due to the unshared electron pair of the tertiary nitrogen atom linked to the phosphorus atom by a double bond. The phosphazene base forms together with water the buffer system of the sensor. Both sensor types have dynamic ranges between 0 and 50 hPa pCO(2). They show a completely reversible sensor response. A strong cross-sensitivity towards relative humidity (RH) of the analyte gas was found for the PBO-containing sensor. The ratio protonated form/deprotonated form (HD/D) of the indicator dye increases continuously with decreasing RH. At the same time the sensitivity towards pCO(2) decreases. In the case of the TOA(+)OH -containing sensor the ratio HD/D- stays nearly constant at RH values above 20%. At lower RH. however. it decreases significantly as well as the sensitivity towards pCO(2). The deviant behaviour of the two sensor types at the removal of water is due to the nature of the respective Organic base and the resulting influence on the polarity within the sensor matrix. © 2004 Published by Elsevier B.V.

Schuck, P., S. Mejean, et al. (2005). "Thermohygrometric sensor: A tool for optimizing the spray drying process." Innovative Food Science & Emerging Technologies **6**(1): 45-50.

The introduction of a thermohygrometer into the outlet air of a spray-drying chamber allows measurement and observation of absolute and relative

humidities. As an example, there is no powder stuck in a spray-drying chamber of a three-stage pilot plant when the difference between calculated and measured absolute humidity of the outlet air is below 2 g of water kg(-1) dry air. To obtain a whole milk, skim milk or whey powder at 0.20 +/- 0.02 of water activity (at 25 degrees C), the relative humidity of the outlet air must be equal to 11%+/- 1 for whole milk powder and 7%+/- 1 for whey and skim milk powders. (c) 2004 Elsevier Ltd. All rights reserved.

Sears, W. M. (2005). "The effect of DC polarization on the humidity sensing characteristics of bismuth iron molybdate." Sensors and Actuators B-Chemical **107**(2): 623-631.

A pellet of bismuth iron molybdate, compressed to contain gold wire electrodes, was used to confirm protons or hydronium ions as the dominant carriers in a humid atmosphere, by DC polarization measurements. To do this a step voltage was applied to the electrodes for 50 min, followed by a short circuit for an additional 50 min. The time dependence of the charge and discharge currents were measured in both cases. This was done for a number of relative humidity values as set by the flow of humid air (5, 10, 19, 36, and 76% RH). At 76% RH the effect of bias was measured for 0.25, 0.5, 1, 2, 4, and 10 V, while only 0.5 V was used for the remaining humidity values. The charging curves were analyzed using the Logistic fitting routine in the software package Origin, while the discharging curves were analyzed using a simple power law function. The bias dependence showed a change over from a current dominated by DC polarization to one dominated by electrolyses at 2 V. The ratio of electronic current through the semiconductor bulk to the total current, which includes ionic polarization, varied from 56% at 5% RH to 0.68% at 76% RH at 0.5 V bias. The humidity dependent measurements confirmed the Grotthuss chain reaction, or at least proton migration, as the dominant conduction mechanism for porous pellet humidity sensors, even at low humidity. In most studies using DC polarization it is assumed that the current decay is exponential with time, but as clearly shown here this is not the case. The power law current discharge mechanism suggested by Jonscher is seen instead, with a log-log slope near 0.5 as is common with non-Debye capacitance. © 2004 Elsevier B.V. All rights reserved.

Sedenger, B. D., D. R. Suiter, et al. (2006). "German cockroach, Blattella germanica (L.) (Blattaria : Blattellidae), feeding activity in apartment kitchens." Journal of Entomological Science **41**(1): 49-56.

German cockroach, Blattella germanica (L.), distribution within two low-income apartment kitchens was determined by monitoring feeding activity with capacitive proximity sensors for four consecutive days. Six sensors were placed in each kitchen in the cabinets below and above the sink, beside the stove, behind the refrigerator, on the counter and on top of the

upper cabinet. In both apartments, cockroach feeding activity was as follows: in the cabinet below the sink>beside the stove behind the refrigerator>in the cabinet above the sink=on the countertop next to the sink on top of the upper cabinet. Environmental loggers that recorded light intensity, relative humidity and temperature were placed beside each proximity sensor. Areas with the greatest feeding activity were dark and humid. Areas of less feeding activity were most often well-lit, dry, and exposed to human activity.

Sen, S. K. (2005). "A novel concept in the design of a psychrometer." Indian Journal of Engineering and Materials Sciences **12**(6): 498-504.

A novel psychrometric method for measurement of humidity of a process is proposed. The design of a psychrometer is a complex one due to simultaneous introduction of two variables at the same time, viz., the meter current is dependent on both the relative humidity and ambient temperature. The circuit design has been so made that the said current would depend only on the relative humidity of air and independent of temperature variations at the place of measurement. Theoretical calculations show that the maximum error in the measurement of the meter current would be limited to within +1.6% at 120 degrees F and -2% at 60 degrees F for 100% relative humidity while the same would be within +/- 1.75% for the entire temperature range 60 degrees-120 degrees F for 0% relative humidity.

Sentelhas, P. C., J. E. B. A. Monteiro, et al. (2004). "Electronic leaf wetness duration sensor: why it should be painted." International Journal of Biometeorology **48**(4): 202-205.

The purpose of this study was to compare and evaluate the performance of electronic leaf wetness duration (LWD) sensors in measuring LWD in a cotton crop canopy when unpainted and painted sensors were used. LWD was measured with flat, printed-circuit wetness sensors, and the data were divided into two periods of 24 days: from 18 December 2001 to 10 January 2002, when the sensors were unpainted, and from 20 January to 13 February 2002, when the sensors were painted with white latex paint (two coats of paint). The data analysis included evaluating the coefficient of variation (CV%) among the six sensors for each day, and the relationship between the measured LWD (mean for the six sensors) and the number of hours with dew point depression under 2degreesC, used as an indicator of dew presence. The results showed that the painting markedly reduced the CV% values. For the unpainted sensors the CV% was on average 67% against 9% for painted sensors. For the days without rainfall this reduction was greater. Comparing the sensor measurements to another estimator of LWD, in this case the number of hours with dew point depression under 2degreesC, it was also observed that painting improved not only the precision of the sensors but also their sensitivity, because it increases the ability of the sensor to detect and measure the

wetness promoted by small water droplets.

Seyama, M., Y. Iwasaki, et al. (2005). "Discriminative detection of volatile sulfur compound mixtures with a plasma-polymerized film-based sensor array installed in a humidity-control system." Analytical Chemistry **77**(13): 4228-4234.

We demonstrated the discrimination of volatile sulfur compound mixtures with different mixing ratios by using an array of the plasma-polymerized film (PPF)-coated quartz crystal resonators. The PPF sensor array, which contains PPFs prepared from amino acids and synthetic polymers, exhibited different response patterns to mono or mixed volatile sulfur compounds (VSCs) (hydrogen sulfide and methanethiol) under a dry environment. The sensor array was installed in a desktop-size relative humidity controller. The relative humidity and temperature conditions of the sample flow to the sensor cell were equalized to those of the inner atmosphere of the sensor cell based on the concept of the two-separate-temperatures method. In this way, the baseline drift of PPF sensor response caused by the introduction of a highly humid sample was successfully suppressed. We compared the sensor array responses under the controlled humidity conditions. Presorption of water molecules by PPFs caused a decrease of sensor sensitivity, but the films still had the ability to discriminate sub-ppmv VSC mixtures having 6:1, 1:1, and 1:6 mixture ratios of hydrogen sulfide and methanethiol.

Shamala, K. S., L. C. S. Murthy, et al. (2004). "Studies on optical and dielectric properties of Al2O3 thin films prepared by electron beam evaporation and spray pyrolysis method." Materials Science and Engineering B-Solid State Materials for Advanced Technology **106**(3): 269-274.

Al2O3 thin films find a number of applications in optoelectronics, sensors and tribology. In this paper, we report the preparation and characterization of alumina films prepared by both electron beam evaporation and spray pyrolysis method. The electrical properties of alumina films were determined by measuring (C-V) and (I-V) characteristics in a metal oxide semiconductor (MOS) structure. A relative dielectric constant (epsilon(r)) of 9.6 for spray pyrolysed films and 8.3 for evaporated films was obtained. The breakdown electric field was found to be around 5 and 1 MV/cm, respectively for spray pyrolysed and evaporated films. The refractive index of alumina films by evaporation was found to be 1.71 and 1.61 at 275 and 500 nm, respectively. The optical band gap of spray pyrolysed films deposited at 300 degreesC was found to be in the range of 5.40-5.55 eV. Structural, elemental analysis and stoichiometry of the films was studied by scanning electron microscope (SEM), energy dispersive X-ray analysis (EDAX), Auger electron spectroscopy (AES) and Rutherford back scattering (RBS) spectra. 

Shinohara, T., S. Motoda, et al. (2005). "Evaluation of corrosivity in atmospheric environment by ACM (Atmospheric Corrosion Monitor) type corrosion sensor."

Pricm 5: The Fifth Pacific Rim International Conference on Advanced Materials and Processing, Pts 1-5 **475-479**: 61-64.

An ACM (Atmospheric Corrosion Monitor) type corrosion sensor, consisting of a Fe-Ag galvanic couple was developed and applied for the evaluation of corrosivity of atmospheric environments. The sensor was designed considering mass-production and good reproducibility of results, making it convenient for long-term corrosion data acquisition. Besides the sensor output, I, temperature, relative humidity (RH) were also recorded by a microcomputer. By analyzing the magnitude and time variation of I, the occurrence and duration of rain, dew and dry periods, T-rain, T-dew and T-dry, respectively, could be distinguished and determined. And by referencing to the empirical I-RH calibrating curve, the amount of deposited sea salt, Ws, could also be estimated. It was also found that the corrosion loss could be estimated in both indoor and outdoor sites by analyzing sensor output. Corrosivities of some kinds of exposure sites, not only outdoor environments but also indoor environments, were evaluated by using the ACM sensor.

Skuratovsky, I., A. Glot, et al. (2004). "The effect of humidity on the voltage-current characteristic of SnO2 based ceramic varistor." Journal of the European Ceramic Society **24**(9): 2597-2604.

Tin dioxide based ceramics in the SnO2-Bi2O3-CO3O4-Nb2O5-Cr2O3 system exhibit highly non-linear voltage-current characteristics (non-linearity coefficient reaches 55-60 in electric fields of about 3500 V cm(-1)) in parallel with high humidity sensitivity in low electric fields (humidity sensitivity coefficient reaches 10(5)). Such ceramics can be used for the fabrication of a device with combined varistor and humidity sensor properties. Voltage-current characteristics of ceramics with different amounts of bismuth oxide are studied in air with different relative humidity contents. 

Skuratovsky, I., A. Glot, et al. (2006). "Modelling of the humidity effect on the barrier height in SnO2 varistors." Materials Science and Engineering B-Solid State Materials for Advanced Technology **128**(1-3): 130-137.

Tin dioxide based SnO2-Bi2O3-Co3O4-Nb2O5-Cr2O3 ceramic device with combined varistor and humidity-sensitive properties is studied. This varistor-sensor has high humidity sensitivity coefficient of about 420 at low electric field and high non-linearity coefficient of about 50 at electric field 3500 V cm(-1). Current-voltage characteristics of the samples with separate electrodes for the central and the peripheral parts are studied in air with different relative humidity. It is shown that current through the peripheral part of a sample is increased much stronger than through the central part. The observed increase of low-field current on relative humidity is explained by the decrease of the barrier height. The estimations of the lowering of the barrier height in a humid air is performed using the suggested models. 

Sobel, A. H., S. E. Yuter, et al. (2004). "Large-scale meteorology and deep convection during TRMM KWAJEX." Monthly Weather Review **132**(2): 422-444.

An overview of the large-scale behavior of the atmosphere during the Tropical Rainfall Measuring Mission (TRMM) Kwajalein Experiment (KWAJEX) is presented. Sounding and ground radar data collected during KWAJEX, and several routinely available datasets including the Geostationary Meteorological Satellite (GMS), NOAA outgoing longwave radiation (OLR), the Special Sensor Microwave Imager (SSM/I), and ECMWF operational analyses are used. One focus is on the dynamical characterization of synoptic-scale systems in the western/central tropical Pacific during KWAJEX, particularly those that produced the largest rainfall at Kwajalein. Another is the local relationships observed on daily time scales among various thermodynamic variables and areal average rain rate. These relationships provide evidence regarding the degree and kind of local thermodynamic control of convection.Although convection in the Marshall Islands and surrounding regions often appears chaotic when viewed in satellite imagery, the largest rain events at Kwajalein during the experiment were clearly associated with large-scale envelopes of convection, which propagated coherently over several days and thousands of kilometers, had clear signals in the lower-level large-scale wind field, and are classifiable in terms of known wave modes. Spectral filtering identifies mixed Rossby-gravity (MRG) and Kelvin waves prominently in the OLR data. "Tropical depression - type" disturbances are also evident. In some cases multiple wave types may be associated with a single event. Three brief case studies involving different wave types are presented.Daily-mean sounding data averaged over the five sounding sites show evidence of shallow convective adjustment, in that near-surface moist static energy variations correlate closely with lower-tropospheric temperature. Evidence of thermodynamic control of deep convection on daily time scales is weaker. Upper-tropospheric temperature is weakly correlated with near-surface moist static energy. There are correlations of relative humidity ( RH) with deep convection. Significant area-averaged rainfall occurs only above a lower-tropospheric RH threshold of near 80%. Above this threshold there is a weak but significant correlation of further lower-tropospheric RH increases with enhanced rain rate. Upper-tropospheric RH increases more consistently with rain rate. Lag correlations suggest that higher lower-tropospheric RH favors subsequent convection while higher upper-tropospheric RH is a result of previous or current convection. Convective available potential energy and surface wind speed have weak negative and positive relationships to rain rate, respectively. A strong relationship between surface wind speed ( a proxy for latent heat flux) and rain rate has been recently observed in the eastern Pacific. It is suggested that in the KWAJEX region, this relationship is weaker because there are strong zonal gradients of vertically integrated water vapor. The strongest surface

winds tend to be easterlies, so that strong surface fluxes are accompanied by strong dry-air advection from the east of Kwajalein. These two effects are of opposite sign in the moist static energy budget, reducing the tendency for strong surface fluxes to promote rainfall.

Soddell, J. R., K. McGuffie, et al. (2004). "Intercomparison of atmospheric soundings from the Aerosonde and radiosonde." Journal of Applied Meteorology **43**(9): 1260-1269.

This paper presents a preliminary evaluation of meteorological measurements made by the Aerosonde ( using Vaisala, Inc., RS90 sensors) by comparing them with closely correlated measurements made using traditional balloonborne sondes ( Vaisala RS80-A/-H). Eighteen comparisons were completed in temperatures ranging from -20degrees to 10degreesC. Although the Aerosonde generally performed well in comparison with the radiosonde, calibration errors and time-lag errors similar to those observed between radiosonde and dropsonde observations were evident in some of the temperature and relative humidity profiles. The average temperature differences between the Aerosonde and radiosonde profiles varied between 0.01degrees and 1.2degreesC, with the Aerosonde observations being consistently warmer than the radiosonde measurements. A dry bias was also generally present in the radiosonde relative humidity observations relative to the Aerosonde observations. Wind observations were comparable. Mean wind magnitude differences ranged from 0.02 to 1.7 m s(-1), with the mean wind direction differences between 0.1degrees and 19.1degrees. After application of ground-check corrections, the most prominent causes of disparity between the Aerosonde and radiosonde profiles are the inevitable temporal and spatial dislocation between the Aerosonde and radiosonde soundings and aerodynamic factors that influence the Aerosonde sensor measurements. These differences are inherent in this very different observing platform. Kinetic heating, the different sensor types, chemical contamination, storage and handling inconsistencies, and sensor age are likely to play a lesser role.

Star, A., T. R. Han, et al. (2004). "Sensing with Nafion coated carbon nanotube field-effect transistors." Electroanalysis **16**(1-2): 108-112.

Sequential CVD and CMOS processes were used to make a FET that has single walled carbon nanotubes to serve as the conducting source to drain channel. This structure can be decorated to provide gas and liquid responses and herein is evaluated as a humdity sensor. The Na+, K+, and Ca2+ ion-exchanged Nafion polymer acts as the chemically sensitive layer in this electrochemical sensor. The effect of gate voltage on the charge-sensitive NT structure was found to be RH dependent over the range of 12-93% RH with msec response time.

Steele, J. J., J. P. Gospodyn, et al. (2006). "Impact of morphology on high-speed

humidity sensor performance." Ieee Sensors Journal **6**(1): 24-27.
Capacitive-based humidity sensors were fabricated using unique nanostructured aluminum-oxide thin films. These sensors exhibited extremely fast desorption response times as short as 42 ms. In this paper, we present the effects of varying the thin-film porosity on sensor performance. Specifically, we look at the capacitive response and the desorption response time of the sensors. It was found that increased porosity tends to decrease the desorption response time and increase the relative humidity where the devices become sensitive.

Stukalov, O., C. A. Murray, et al. (2006). "Relative humidity control for atomic force microscopes." Review of Scientific Instruments **77**(3): -.
We describe the design and performance of a relative humidity (RH) control chamber for use with atomic force microscopes (AFM) in which the tip is scanned across the stationary sample. The small volume (similar to 9 cm(3)) chamber encloses the sample, the cantilever holder, and a commercial humidity/temperature sensor. The RH is controlled by passing a controlled ratio of dry and humid nitrogen gas across the sample. This unique design prevents exposure of the scanner assembly to humid gas and maintains all of the functionalities of the AFM system with no measurable degradation of its performance. Using this system, the RH at the sample position can be varied between 5% and 95% and controlled to within +/- 0.2% during an AFM measurement. To demonstrate the performance of the RH control chamber in imaging and force spectroscopy modes, we have characterized the RH-dependent swelling of small chitosan droplets with diameters of 3-40 mu m, and the RH dependence of capillary forces between the AFM tip and a mica surface. (c) 2006 American Institute of Physics.

Su, P. G. and R. J. Wu (2004). "Uncertainty of humidity sensors testing by means of divided-flow generator." Measurement **36**(1): 21-27.
In our laboratory a simple home-made standard humidity generator (divided-flow system) was used for the testing of humidity sensors. The divided-flow system consists of dry flow devices and wet flow devices and connected with a constant temperature mixing flow chamber. The flow-rate and accuracy of the system are controlled by the mass flow controller and standard hygrometer, respectively. The generating relative humidity range is 30-90% RH at the temperature extending from 15 to 35 degreesC. The calibration uncertainty of humidity sensors testing by means of divided-flow humidity generator was evaluated following the ISO GUM at three working temperature points (15, 25 and 35 degreesC) at relative humidity 60% RH. (C) 2004 Elsevier Ltd. All rights reserved.

Su, P. G. and W. Y. Tsai (2004). "Humidity sensing and electrical properties of a composite nano-sized SiO2 and poly(2-acrylamido-2-methylpropane sulfonate)." Sensors and Actuators B-Chemical **100**(3): 417-422.

A composite material of nano-sized SiO2 and poly (2-acrylamido-2-methylpropane sulfonate) (poly(AMPS)) was used to make a humidity sensor. The infrared (IR) spectra and microstructure of the material were analyzed, and the humidity sensing and electrical properties of the sensor were measured. The sensor well responded to humidity with a relative good linearity, though it depended on the applied frequency. The temperature influence between 15 and 35 degreesC was -0.71 and -0.15% RH/degreesC at 30 and 90% RH, respectively. The sensor showed a negligible hysteresis and fast response time upon humidification and desiccation. The stability of the sensor in a highly humid and alcoholic environment increased with increasing the SiO2 content. The activation energy for conduction reduced with water adsorption. The different impedance plots observed at low and high relative humidity suggested different sensing mechanisms of the SiO2/poly(AMPS) composite material. (C) 2004 Elsevier B.V. All rights reserved.

Su, P. G. and C. L. Uen (2005). "A resistive-type humidity sensor using composite films prepared from poly(2-acrylamido-2-methylpropane sulfonate) and dispersed organic silicon sol." Talanta **66**(5): 1247-1253.

A composite material of dispersed organic silicon sol and poly(2-acrylamido-2-methylpropane sulfonate) (poly-AMPS) was used to make humidity sensor without protective film or complicated chemical procedures. The organic silicon sol was dispersed well in the poly-AMPS without using dispersion agent. Parameters that may affect the water-resistive but humidity-sensitive characteristic of composite material, the adding amount of organic silicon sol solution and the film of thermal treatment time, were investigated. The microstructure of the material was analyzed, and the humidity sensing and electrical properties of the sensor were measured. The sensor well responded to humidity with a relatively good linearity, though it depended on the applied frequency. The temperature influence between 15 and 35 degrees C was within -0.17% relative humidity (RH)/degrees C in the range of 30-90% RH. The activation energy was maximum around 40% RH. The sensor showed the hysteresis within 5.9%, fast response time, long-term stability (75 days at least) and satisfactory resistance to high humidity atmosphere (97% RH) and chemical environment (20% C2H5OH vapor). Analyzing the structure and complex impedance plots of organic silicon sol/poly-AMPS was used to explain improvement in humidity sensing properties in comparison with nano-sized SiO2 powder/poly-AMPS films. (c) 2005 Elsevier B.V. All rights reserved.

Su, P. G. and S. C. Huang (2005). "Humidity sensing and electrical properties of a composite material of SiO2 and poly-[3-(methacrylamino)propyl] trimethyl ammonium chloride." Sensors and Actuators B-Chemical **105**(2): 170-175.

In this present work, humidity sensors were prepared using in situ synthesized composite of hydrolytic tetraethyl orthosilicate (TEOS) and

poly- [3-(methacrylamino)propyl] trimethyl ammonium chloride (poly-MAPTAC). The infrared spectra of the material were analyzed, the humidity sensing and electrical properties of the sensor were investigated by measuring the complex impedance spectra at different humidities. The sensor based on composite film showed better sensing properties than poly-MAPTAC film, such as satisfactory resistance to high humidity atmosphere (97% RH) and chemical environment (20% C2H5OH vapor), high sensitivity (three orders), better linearity over humidity range (10-90% RH), negligible hysteresis and quicker response and recovery (humidification: 60 s, desiccation: 120 s). The sensor's linearity depended on the applied frequency. The temperature influence between 15 and 35 degrees C; found to be -0. 11 and -0.05% RH/degrees C at 10 and 90% RH, respectively. The activation energy for conduction reduced with water adsorption. The different impedance plots observed at low and high relative humidity suggested different sensing mechanisms of poly-MAPTAC/SiO2) composite material. (c) 2004 Elsevier B.V. All rights reserved.

Su, P. G., Y. L. Sun, et al. (2006). "Humidity sensor based on PMMA simultaneously doped with two different salts." Sensors and Actuators B-Chemical **113**(2): 883-886.

The humidity-sensing properties of poly(methyl methacrylate) (PMMA) were enhanced by doping with two alkali salts (KOH and K2CO3), whose dissociation constants were distinctly different from each other. The electrical properties of PMMA doped with different amounts of KOH or a mixture of KOH and K2CO3 were examined in detail as a function of relative humidity (RH), to elucidate the contribution of the salts to the sensing properties (linearity and sensitivity). The PMMA doped only with KOH had a high sensitivity but low linearity. The poor linearity of the PMMA/KOH complex was improved by further doping of K2CO3. The PMMA doped with a mixture of KOH (0.6%, w/w) and K2CO3 (0.6%, w/w) was optimal in both sensitivity and linearity in the range of 30-90%RH. (c) 2005 Elsevier B.V. All rights reserved.

Su, P. G. and S. C. Huang (2006). "Electrical and humidity sensing properties of carbon nanotubes-SiO2-poly (2-acrylamido-2-methylpropane sulfonate) composite material." Sensors and Actuators B-Chemical **113**(1): 142-149.

Alkali salts of poly(2-acrylamido-2-methylpropane sulfonate) (PAMPS)-SiO and single-walled carbon nanotubes (SWCNTs)-SiO,PAMPS were used as composite materials to make a humidity sensor. The impedances of these composite materials were measured at various humidities and temperatures in the frequency range of 1-100 kHz. The results indicated that the H+ form of the PAMPS-SiO2 composite film had the highest electrical conductance. For practical use, a humidity sensor which was a low-resistance device. commonly required for electronic circuit compatibility, was prepared from SWCNTs-SiO2-PAMPS composites, The

sensing mechanism of the SWCNTs-SiO2-PAMPS composite films were explained by considering the observed impedance plot and activation energy compared with a SiO2-PAMPS composite film. At low relative humidity (RH), new conductive paths were formed. Whereas with increasing RH. the ionic contribution became prevalent. Other sensing properties of the SWCNTs-SiO2-PAMPS composite films such as effects of applied frequency, ambient temperature and hysteresis were also investigated. (c) 2005 Elsevier B.V. All rights reserved.

Sundaram, R. and K. S. Nagaraja (2004). "Solid state electrical conductivity and humidity sensing studies on metal molybdate-molybdenum trioxide composites (M = Ni2+Cu2+ and Pb2+)." Sensors and Actuators B-Chemical **101**(3): 353-360.

Metal molybdates, prepared by the solution route, were sintered at 750 degreesC in the form of cylindrical discs. The humidity sensing characteristics Of Composites MMoO4 (MM; M = Ni2+, Cu2+ and Pb2+) and MoO3 materials are described. Sintered polycrystalline discs Of MMoO4 (MMMO-10) and MoO3 (MMMO-01) Composites in the mole ratios of 80:20, 60:40, 40:60 and 20:80 designated as MMMO-82, MMMO-64, MMMO-46 and MMMO-28, respectively, are doped with 2 mol% of Li+. The composites were subjected to dc conductance measurements over the temperature range 100-300degreesC in air atmosphere from which activation energies were determined. The current was found to increase linearly with the applied field and exponentially against temperature indicated the ohmic contact and semiconductive nature of the electrode samples, respectively. The activation energy for dc conductance was found to be in the range of 0.20-1.82 eV for different composites and terminal phases. The scanning electron microscopy studies of NMMO-28 composite indicated pores structure of the sensor materials. The surface adsorption studies (BET) of NMMO-28 composite showed that the radius of the pores was found to be distributed from 10 to 65 Angstrom with pore specific volume of 0.27 cm(3) g(-1). As the micropore structures are preferred for the humidity sensing properties, the composites were subjected to dc resistance measurements as a function of relative humidity in the range of 5-98% relative humidity, achieved by different water vapour buffers thermostated at room temperature. The sensitivity factor, S-f (R-5%/R-98%) measured at ambient temperature revealed that NMMO-28, CMMO-28 and PMMO-28 composites have the highest humidity sensitivity factors of 16,543 2800, 6945 80 and 4814 300, respectively, when compared to undoped composites. The response and recovery characteristics for these humidity sensing composites were studied. (C) 2004 Elsevier B.V. All rights reserved.

Sundaram, R., E. S. Raj, et al. (2004). "Microwave assisted synthesis, characterization and humidity dependent electrical conductivity studies of perovskite oxides, Sm-1-xSrxCrO3 (0 <= X <= 0.1)." Sensors and Actuators B-Chemical **99**(2-3): 350-354.

The perovskite oxides, Sm1-xSrxCrO3 (0 less than or equal to X less than or equal to 0.1) were synthesized by a microwave assisted combustion route from the constituent metal nitrates and urea. The single-phase oxides were characterized by X-ray diffraction (XRD) and the lattice parameters were evaluated. The perovskite oxides were subjected to DC conductance measurements over the temperature range 100-300 degreesC in air atmosphere from which activation energies were determined. The current was found to increase linearly with the applied field and exponentially against temperature indicating the ohmic nature of the electrode contacts. The activation energy values for DC conductance were found to be in the range of 0.38-0.56eV. DC resistance measurements as a function of relative humidity in the range of 5-98% RH were carried out on sintered discs at 25 degreesC under static conditions from which the sensitivity factor, S-f (R-5%/R-98%) for SmCrO3, SM0.95Sr0.05CrO3 and Sm0.90Sr0.10CrO3 were calculated to be 2198, 2971, 4510, respectively. The response and recovery characteristics were studied for Sm0.90Sr0.10CrO3, which exhibited good linearity and very narrow hysteresis loop. 

Sundaram, R. and K. S. Nagaraja (2004). "Electrical and humidity sensing properties of lead(II) tungstate-tungsten(VI) oxide and zinc(II) tungstate-tungsten(VI) oxide composites." Materials Research Bulletin **39**(4-5): 581-590.

Lead(II) tungstate and zinc(II) tungstate were prepared by a solution route and sintered at 973 K in the form of cylindrical discs. Experimental results on PbWO4 (PW) and WO3 (WO) composites for humidity sensing are described. Sintered polycrystalline discs of PbWO4 (PWWO-10), WO3 (PWWO-01), ZnWO4 (ZWWO-10) and composites of PW or ZW and WO in the mole ratios 8:2, 6:4, 4:6, 2:8 designated as PWWO and ZWWO-82, 64, 46 and 28, respectively and doped with 2 mol% of Li+ were studied. The composites were subjected to dc conductance measurements over the temperature range 373-673 K in air atmosphere from which activation energies were determined. The activation energy values for dc conductance were found to be in the range of 1.09-1.30 eV. The composites were identified by powder XRD data. The scanning electron microscopy (SEM) studies were carried out to study the surface and pores structure of the sensor materials. The composites were subjected to dc resistance measurements as a function of relative humidity in the range of 5-98% RH, achieved by different water vapor buffers thermostated at room temperature. The sensitivity factor (S-f = R-5%/R-98%) measured at 298 K revealed that PWWO-28 and ZWWO-46 composites have the highest humidity sensitivity factor of 17615 +/- 3000 and 2666 +/- 550, respectively. The response and recovery time for these humidity sensing composites were good. 

Sundaram, R. and K. S. Nagaraja (2004). "Solid state electrical conductivity and humidity sensing properties of WO3-Y2O3 composites." Physica Status Solidi a-

Applied Research **201**(3): 529-535.

Experimental results on the composites made from WO3 (WO) and Y2O3 (YO) for electrical and humidity sensing properties are described. The compound and composites of WO3 and Y2O3 in mole ratios (1: 1, 1:2, 2:1, 1:3, 3:1 and 3:2%) were sintered in the form of a disc of 10 mm diameter were subjected to do conductance measurements over the temperature range 373-673 K from which the activation energies were determined. The composites were identified by powder XRD data. The scanning electron microscopy (SEM) studies were carried out to study the surface and pores structure of the sensor materials. The Brunauer-Emmett-Teller (BET) surface adsorption studies showed that the radius of the pore sizes were found to be distributed from 10-45 Angstrom. The pore specific volume was calculated to be 0.01 cm(3) gm(-1). As the composites having micropores are preferred for humidity sensing properties, the composites were subjected to do resistance measurements as a function of relative humidity in the range of 5-98% RH, achieved by different water vapour buffers thermostated at room temperature. The sensitivity factor S-f (R-5%/R-98%) measured at 25 degreesC revealed that WOYO-31 (WO3 and Y2O3 in 3:1 mole ratio) has the highest humidity sensitivity factor of 1535 (+/-80). The response and recovery time for this humidity sensing composite was also studied. (C) 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Tai, W. P., J. G. Kim, et al. (2003). "Humidity sensitive properties of nanostructured Al-doped ZnO : TiO2 thin films." Sensors and Actuators B-Chemical **96**(3): 477-481.

Nanostructured Al-doped ZnO(AZ):TiO2 films are prepared using a sol-gel process and the humidity sensitive properties of the films are investigated. The films possess nanostructure. Nanostructured-bilayered TiO2/AZ film exhibits improved linearity with narrow hysteresis loop in the resistance variation for relative humidity than single layered film. The resistance of the bilayered TiO2/AZ film changes by nearly three orders of magnitude during the relative humidity variation of 30-90%. The humidity sensitive properties in the nanostructured AZ:TiO2 films are discussed. 

Tai, W. P., J. G. Kim, et al. (2005). "Preparation and humidity sensing behaviors of nanostructured potassium tantalate: titania films." Sensors and Actuators B-Chemical **105**(2): 199-203.

Nanostructured-bilayered potassium tantalate (KT): titania (TiO2)) films are prepared by the sol-gel process, and the humidity sensing behaviors of the films are investigated. The films possess nanosized grains and nanoporous structure. Bilayered KT/TiO2, and TiO2/KT films exhibit improved linearity with narrow hysteresis loop in the resistance variation for relative humidity compared to monolayered TiO2,) and KT films. The bilayered KT/TiO2) and TiO2/KT films show over three orders of change in

the resistance during the relative humidity variation from 20 to 90%. The humidity sensing properties in the nanostructured KT: TiO2 films are discussed. (c) 2004 Elsevier B.V. All rights reserved.

Takato, K., N. Gokan, et al. (2005). "Effect of humidity on photoluminescence from Ru(bpy)(3)(2+) incorporated into a polysaccharide solid film and its application to optical humidity sensor." Journal of Photochemistry and Photobiology a-Chemistry **169**(1): 109-114.

The effects of humidity on photoluminescence from Ru(bpy)(3)(2+) dispersed in polysaccharide solid films have been investigated. In a K-carrageenan solid film, peaks of relative emission intensity (I-R) and lifetime (T) appeared around 20% (under Ar) and 30% (under air) relative humidity (RH). In a chitosan solid film, only small changes were observed in I-R and tau of the photoluminescence up to 20% RH. However, over 20% RH, the I-R and tau decreased with the increase in RH These results were interpreted by mobility of Ru(bpy)(3)(2+) as well as electrostatic and hydrophobic interactions between polysaccharide and Ru(bpy)(3)(2+). Larger effect of humidity was observed under air than under Ar depending on the polysaccharide used, which was explained by the quenching reaction by the O-2 dissolved in water phase in the polysaccharide domain. (C) 2004 Elsevier B.V. All rights reserved.

Tan, K. M., C. M. Tay, et al. (2005). "High relative humidity measurements using gelatin coated long-period grating sensors." Sensors and Actuators B-Chemical **110**(2): 335-341.

A long-period grating (LPG) coated with gelatin was developed as a high relative humidity (RH) sensor. The resonance dip or coupling strength of the LPG spectrum varies with RH. Experimental investigations on the sensor yield a sensitivity of 0.833%RH/dB with an accuracy of +/- 0.25%RH, and a resolution of +/- 0.00833%RH. The LPG RH sensor also offers repeatability, hysteresis and stability errors of less than +/- 0.877, +/- 0.203 and +/- 0.04%RH, respectively. In addition to the characterization of the LPG RH sensor, further studies were conducted to determine the effect of grating periodicities on the sensitivity of the sensor. Results show that higher order cladding modes from smaller grating periods enable the sensor to achieve higher sensitivity to humidity. This method is proposed to be more cost effective as compared to more complex spectroscopic methods based on wavelength detection. This sensor can also help to solve problems in measuring high humidity with existing relative humidity measurement systems. (C) 2005 Elsevier B.V. All rights reserved.

Tandon, R. P., M. R. Tripathy, et al. (2006). "Gas and humidity response of iron oxide - Polypyrrole nanocomposites." Sensors and Actuators B-Chemical **114**(2): 768-773.

Nanocomposites of PPY-Fe3O4 have been synthesized using an

emulsion polymerization method in aqueous solution. The resulting polymer composites possessed much higher conductivity as compared to pure polypyrrole (PPY) and the conductivity decreased with increasing the PPY content. The composite exhibited fairly high sensitivity to relative humidity and some commonly used gases (N-2, O-2 and CO2). Changes in resistance for nitrogen and oxygen gas have also been reported. Based on these results, it is expected that these composites may furnish a simple means of humidity and gas sensing. (c) 2005 Elsevier B.V. All rights reserved.

Tay, C. M., K. M. Tan, et al. (2004). "Humidity sensing using plastic optical fibers." Microwave and Optical Technology Letters **43**(5): 387-390.

The use of plastic optical fibers (POFs), curved at the sensing point and coated with cobalt chloride (CoCl2) and gelatin as the overlay material, for relative humidity sensing is demonstrated in this paper. The fiber-core diameter and bending radius of the sensing point affects the sensitivity of the sensor to a great extent. (C) 2004 Wiley Periodicals, Inc.

Teixeira, M. F. S., E. T. G. Cavalheiro, et al. (2004). "Use of a carbon paste electrode modified with spinel-type manganese oxide as a potentiometric sensor for lithium ions in flow injection analysis." Electroanalysis **16**(8): 633-639.

A potentiometric sensor constructed from a mixture of 25% (m/m) spinel-type manganese oxide (lambda-MnO2), 50% (m/m) graphite powder and 25% (m/m) mineral oil is used for the determination of lithium ions in a flow injection analysis system. Experimental parameters, such as pH of the carrier solution, flow rate, injection sample volume, and selectivity for Li+ against other alkali and alkaline-earth ions and the response time of this sensor were investigated. The sensor response to lithium ions was linear in the concentration range 8.6 x 10(-5) - 1.0 x 10(-2) mol L-1 with a slope 78.9 +/- 0.3 mV dec(-1) over a wide pH range 7 - 10 (Tris buffer), without interference of other alkali and alkaline-earth metals. For a flow rate of 5.0 mL min(-1) and a injection sample volume of 408.6 muL, the relative standard deviation for repeated injections of a 5.0 x 10(-4) mol L-1 lithium ions was 0.3%.

Tran, T. U., K. Suzuki, et al. (2005). "Detection of changes in taste of japonica and indica brown and milled rice (Oryza sativa L.) during storage using physicochemical analyses and a taste sensing system." Journal of Agricultural and Food Chemistry **53**(4): 1108-1118.

Changes in the taste of japonica, hybrid, and indica brown and milled rice, stored for 10 months at low (5 degreesC, 65-70% relative humidity) and room temperatures were observed by physicochemical analyses and a novel method using a taste sensing system. During storage, some properties increased or decreased while others were fairly constant. The main taste components of cooked rice such as sweetness (sucrose) and umami tastes (glutamic acid and aspartic acid) were reduced during

storage, whereas glucose and fructose increased. The increase of fat acidity and consequent decrease of the pH value of the cooking solution may contribute to the off-taste of cooked stored rice. A taste sensing system with 10 lipid membrane sensors was also used to classify new and old rice samples using principal component analysis, Fresh and room temperature stored japonica and indica rice could be clearly distinguished; however, it was not possible to differentiate the samples stored at low temperature.

Trenberth, K. E., J. Fasullo, et al. (2005). "Trends and variability in column-integrated atmospheric water vapor." Climate Dynamics **24**(7-8): 741-758.

An analysis and evaluation has been performed of global datasets on column-integrated water vapor (precipitable water). For years before 1996, the Ross and Elliott radiosonde dataset is used for validation of European Centre for Medium-range Weather Forecasts (ECMWF) reanalyses ERA-40. Only the special sensor microwave imager (SSM/I) dataset from remote sensing systems (RSS) has credible means, variability and trends for the oceans, but it is available only for the post-1988 period. Major problems are found in the means, variability and trends from 1988 to 2001 for both reanalyses from National Centers for Environmental Prediction (NCEP) and the ERA-40 reanalysis over the oceans, and for the NASA water vapor project (NVAP) dataset more generally. NCEP and ERA-40 values are reasonable over land where constrained by radiosondes. Accordingly, users of these data should take great care in accepting results as real. The problems highlight the need for reprocessing of data, as has been done by RSS, and reanalyses that adequately take account of the changing observing system. Precipitable water variability for 1988-2001 is dominated by the evolution of ENSO and especially the structures that occurred during and following the 1997-98 El Nino event. The evidence from SSM/I for the global ocean suggests that recent trends in precipitable water are generally positive and, for 1988 through 2003, average 0.40 +/- 0.09 mm per decade or 1.3 +/- 0.3% per decade for the ocean as a whole, where the error bars are 95% confidence intervals. Over the oceans, the precipitable water variability relates very strongly to changes in SSTs, both in terms of spatial structure of trends and temporal variability (with regression coefficient for 30 degrees N-30 degrees S of 7.8% K-1) and is consistent with the assumption of fairly constant relative humidity. In the tropics, the trends are also influenced by changes in rainfall which, in turn, are closely associated with the mean flow and convergence of moisture by the trade winds. The main region where positive trends are not very evident is over Europe, in spite of large and positive trends over the North Atlantic since 1988. A much longer time series is probably required to obtain stable patterns of trends over the oceans, although the main variability could probably be deduced from past SST and associated precipitation variations.

Tsai, W. Y., H. C. Chen, et al. (2005). "An ultrasonic air temperature measurement system with self-correction function for humidity." Measurement Science & Technology **16**(2): 548-555.

This paper proposes an ultrasonic measurement system for air temperature with high accuracy and instant response. It can measure the average temperature of the environmental air by detecting the changes of the speed of the ultrasound in the air. The changes of speed of sound are computed from combining variations of time-of-flight (TOF) from a binary frequency shift-keyed (BFSK) ultrasonic signal and phase shift from continuous waves [11]. In addition, another proposed technique for the ultrasonic air temperature measurement is the self-correction functionality within a highly humid environment. It utilizes a relative humidity/water vapour sensor and applies the theory of how sound speed changes in a humid environment. The proposed new ultrasonic air temperature measurement has the capability of self-correction for the environment variable of humidity. Especially under the operational environment with high fluctuations of various humidity levels, the proposed system can accurately self-correct the errors on the conventional ultrasonic thermometer caused by the changing density of the vapours in the air. Including the high humidity effect, a proof-of-concept experiment demonstrates that in dry air (relative humidity, RH = 10%) without humidity correction, it is accurate to 0.4 degreesC from 0 degreesC to 80 degreesC, while in highly humid air (relative humidity, RH = 90%) with self-correction functionality, it is accurate to 0.3 degreesC from 0 degreesC to 80 degreesC with 0.05% resolution and temperature changes are instantly reflected within 100 ms.

Uddin, M. S., P. R. Armstrong, et al. (2006). "Accuracy ofgrain moisture content prediction using temperature and relative humidity sensors." Applied Engineering in Agriculture **22**(2): 267-273.

Grain temperature and moisture content (MC) are considered to be principal factors for safe storage of grain. Continuous monitoring of temperatures within grain masses is relatively easy using thermocouples, but monitoring of MC is limited by availability of sensors. However, temperature and relative humidity (RH) can be used to predict grain MC based on equilibrium moisture content (EMC) equations such as the Modified Henderson, Chung-Pfost, or Oswin. These models are limited to quasi-static thermodynamic conditions but do provide a method to predict MC with commercial sensors. Error analysis was performed using EMC relationships for wheat to determine the error in grain MC prediction due to sensor error EMC prediction errors were found to be +/- 0.25% to +/- 0.65% MCdb between the RH ranges of 20% to 70% RH. At higher RH levels, prediction error increased substantially. Sensor error was set to +/- 2% RH and +/- 0.4 degrees C, for the error analysis. The sensor error was adopted from a commercial sensor that could be potentially used for a cabled monitoring system. At higher levels of sensor error (+/- 3% RH, +/-

0.4 degrees C and +/- 4% RH, +/- 0.4 degrees C), prediction error increased from +/- 0.38% to +/- 0.96% MCdb and from +/- 0.65% to +/- 1.29% MCdb, respectively, for the same RH range. Prediction error due to sensor error was found to be of the same magnitude as the standard errors of regression models developed for wheat. Measurements of sensor accuracy were also performed and accuracy was found to be within or better than rated manufacturer specifications for RH but temperature accuracy was less than rated accuracy.

Valentini, L., C. Cantalini, et al. (2004). "Highly sensitive and selective sensors based on carbon nanotubes thin films for molecular detection." Diamond and Related Materials **13**(4-8): 1301-1305.

In the present work, the electrical response of carbon nanotubes (CNTs) thin films to NO2, CO, NH3, H2O and C2H5OH for gas sensing applications is reported. The sensor design is a CNT serpentine resistor, fabricated by photolithography defining Pt electrodes upon Si3N4, and then growing CNTs upon the Si3N4 structure The electrical response has been measured exposing the films to the interfering gases at different operating temperatures between 25 and 250 degreesC. Upon exposure to NO2 (10-100 partsper-billion (ppb)) the electrical resistance of CNTs is found to decrease. The nanotube sensors exhibit a fast response and a substantially higher sensitivity than that of existing solid-state sensors at room temperature. Sensor reversibility is achieved by a fast recovery at 165 degreesC. No response has been found by exposing the films to CO in the investigated working temperature range. On the contrary, NH3, ethanol as well as 80% relative humidity, have resulted to increase the electrical resistance of the films. The experimental findings revealed that p-type semiconductor behaviour is present in our CNTs. 

Virmani, J. I. and R. H. Weisberg (2005). "Relative humidity over the west Florida Continental Shelf." Monthly Weather Review **133**(6): 1671-1686.

Observed relative humidity variations on the coastal ocean of the West Florida Continental Shelf (WES) are examined over the 5-yr period 1998-2003. Despite considerable daily variability within seasons, the monthly mean values are nearly constant at about 75%. Summertime specific humidity is twice that during winter, so high air temperatures are responsible for the low summer monthly mean relative humidities. Winter has the greatest relative humidity variability; values range from less than 50% to over 100% as extratropical fronts move over the WFS. Saturation (and fog) occurs as warm moist air passes over colder water. Two different sensors, mounted on multiple moorings, were used to make these observations. Monthly mean values from the Rotronics MP-100F are higher than the Hygrometrix 1020SHT. In addition to sensor differences, a contributing cause to this offset appears to be the locations chosen for sensor deployment. NCEP reanalysis climatology over the WES and land-

based coastal data both show an annual cycle in monthly mean relative humidity, with higher values in summer, suggesting that the reanalysis field is influenced by land. Air-sea fluxes over the WFS are sensitive to small spatial variability in the coastal ocean and atmosphere. The large grid spacing of the NCEP reanalysis does not capture this variability. The lack of coastal ocean data for assimilation biases the NCEP reanalysis fields toward land-based measurements. Increased spatial coverage via evolving Coastal Ocean Observing Systems should remedy this problem by providing required information for describing and understanding the complicated ocean-atmosphere interactions that occur on continental shelves.

Wagner, T., C. D. Kohl, et al. (2006). "Gas sensing properties of ordered mesoporous SnO2." Sensors **6**(4): 318-323.

We report on the synthesis and CO gas-sensing properties of mesoporous tin(IV) oxides (SnO2). For the synthesis cetyltrimethylammonium bromide (CTABr) was used as a structure-directing agent; the resulting SnO2 powders were applied as films to commercially available sensor substrates by drop coating. Nitrogen physisorption shows specific surface areas up to 160 m(2) . g(-1) and mean pore diameters of about 4 nm, as verified by TEM. The film conductance was measured in dependence on the CO concentration in humid synthetic air at a constant temperature of 300 degrees C. The sensors show a high sensitivity at low CO concentrations and turn out to be largely insensitive towards changes in the relative humidity. We compare the materials with commercially available SnO2-based sensors.

Wang, J., F. Q. Wu, et al. (2004). "Humidity sensitivity of composite material of lanthanum ferrite/polymer quaternary acrylic resin." Sensors and Actuators B-Chemical **99**(2-3): 586-591.

The sensing properties of the humidity sensor made of composite material of nanocrystalline lanthanum, ferrite (LaFeO3) and polymer quaternary acrylic resin are investigated and compared with those of nanocrystalline lanthanum ferrite, including the sensitivity, the hysteresis, and the response and recover times. The measurement frequency influences both the linearity of the curves of resistance via relative humidity (RH) and the relation between capacitance and RH. By coating the ethyl cellulose on the humidity sensor as protecting films, the water resistance property of the sensor is improved. Humidity sensing mechanisms of the sensors are discussed. 

Wang, J., F. Q. Wu, et al. (2005). "Complex impedance property of humidity sensing material lanthanum orthoferrite." Ferroelectrics **323**: 71-76.

Resistive type humidity sensor is fabricated using nanometer lanthanum ferrite. The impedance property of the sensor is measured in relative humidity (RH) range 11% to 98%, and in frequency range 10 Hz to 100

kHz. The complex impedance plots (Cole-Cole plots) are drawn. A circuit with resistors and capacitors is used as an equivalent circuit of the conduction process of the sensor. With the changing of the resistance and capacitance in the circuit, the shape of the complex impedance curve changes gradually from one semicircle to two semicircles, and finally only the second semicircle remains. This coincides with what happens in the Cole-Cole plots of our experiment. The mechanism of the humidity sensor is analyzed in terms of the complex impedance plots and the equivalent circuit. In low RH range, the conduction process is dominated by the decomposition and polarization of the grains of the sensing material, and in high RH range, by the decomposition and polarization of the adsorbed water.

Wang, J., X. H. Wang, et al. (2005). "Study on dielectric properties of humidity sensing nanometer materials." Sensors and Actuators B-Chemical **108**(1-2): 445-449.

Resistive- (surface-) and capacitive- (sandwich-) types of humidity sensors of nanometer barium titanate were fabricated. The impedance, capacitance and dielectric loss properties of the sensors were tested under different temperatures. In the frequency range of 10-10(5) Hz, both types of sensors got the dielectric loss nearly in all the relative humidity range, and the peaks of the dielectric loss moved to the high frequency direction as the relative humidity (RH) or temperature increased, respectively. The results indicated that not only the conduction carriers but also the polarizations of the sensing material and/or the adsorbed water existed for both types of the humidity sensors. It is mainly the sensing material rather than the structure or the electrode form that determines the properties of the humidity sensors. 

Wang, Y. F., M. Nishikawa, et al. (2005). "A smart thermal environment monitor based on IEEE 1451.2 standard for global networking." Ieee Transactions on Instrumentation and Measurement **54**(3): 1321-1326.

A temperature and relative humidity (RH) monitor using a thermistor and a polyimide-film RH Sensor is developed for global assessment of thermal environments. The smart transducer interface module includes the relaxation oscillators for signal conditioning and a one-chip 16-bit microcomputer for networking. The microcomputer accommodates the calibration tables as well as the mandatory transducer electronic data sheets specified by the IEEE 1451.2 standard. The online calibration using the calibration table and the ratiometric signal conditioning allow +/- 0.1.4 degrees C accuracy over the temperature range from -20 degrees C to 50 degrees C and 2.5 % RH accuracy over the RH range from 20 %RH to 90 %RH. Beside these high-accuracy measurements using low-cost sensors, the monitor features an adaptive architecture for global networking.

Wang, J. H. (2005). "Evaluation of the dropsonde humidity sensor using data from DYCOMS-II and IHOP_2002." Journal of Atmospheric and Oceanic Technology **22**(3): 247-257.

The dropsonde humidity data have not been fully utilized due to lack of knowledge on performance of the dropsonde humidity sensor. This study evaluates the performance of the dropsonde humidity sensor using data collected from two field experiments, the Dynamics and Chemistry of Marine Stratocumulus Phase 11: Entrainment Studies (DYCOMS-II) and the International H2O Project (IHOP)(-)2002. During DYCOMS-II, 63 dropsondes were dropped above marine stratocumulus clouds. It provides a unique opportunity to evaluate the performance of the dropsonde humidity sensor within clouds. Relative humidity (RH) inside clouds did not reach 100% all the time, but the maximum RH reached 100% for 28% of soundings and was within the sensor accuracy range (94%-100%). This suggests that the dropsonde humidity sensor displays no systematic dry bias near saturation. The dropsonde humidity sensor experienced large time-lag errors when it descended from a dry environment above clouds into clouds. The mean estimated time constant of the sensor is 5 s at 15 degrees C, which is much larger than 0.5 s at 20 degrees C given by the manufacturer. The humidity sensor still reported near-saturation RH after it exited clouds because of water on the sensor. The approximately coincident dropsonde and aircraft temperature data during DYCOMS-II show that the dropsonde underestimates temperatures inside and below clouds by averages of 0.21 degrees and 0.93 degrees C, respectively. Seventy-one pairs of dropsonde and radiosonde soundings during IHOP(-)2002 were launched within a half hour and 50 km and sampled the same air mass based on the visual examination. The comparisons show that the dropsonde and radiosonde RH data agree with each other within +/- 2% RH, suggesting no systematic dry bias in dropsonde humidity data. However, dropsonde-measured temperature is consistently colder than that by radiosonde by similar to 0.4 degrees C.

Wang, X. H., Y. F. Ding, et al. (2006). "Humidity sensitive properties of ZnO nanotetrapods investigated by a quartz crystal microbalance." Sensors and Actuators B-Chemical **115**(1): 421-427.

ZnO nanotetrapods were prepared and studied for the humidity detection application. The humidity sensors developed were featured by combination of a quartz crystal as a transducer and ZnO nanotetrapods as a sensing element. The ZnO nanotetrapods were synthesized by evaporating highly pure zinc pellets (99.999%) at 900 degrees C in air and then distributed onto the electrode surfaces of the quartz crystal at room temperature. The synthesized ZnO nanotetrapods were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The experimental results indicated that the response of the sensors varied with the thickness of the ZnO nanotetrapods layer. The maximum frequency sensitivity was nearly similar to 100 Hz/% relative humidity (RH) in the

humidity range of 40-80% relative humidity (RH). The ZnO nanotetrapods sensors also had a good frequency stability and reproducibility. Thus it was found that ZnO nanotetrapods were a potential humidity sensing material. (c) 2005 Elsevier B.V. All rights reserved.

Wang, C. T. and C. L. Wu (2006). "Electrical sensing properties of silica aerogel thin films to humidity." Thin Solid Films **496**(2): 658-664.

Mesoporous silica aerogel thin films have been fabricated by dip coating of sol-gel derived silica colloid on gold electrode-patterned alumina substrates followed by supercritical drying. They were evaluated as the sensor elements at relative humidity 20-90% and temperature 15-35 degrees C under ail electrical field of frequency 1-100 kHz. Film thickness and pore structure were two main parameters that determined the sensor performance. The film with a greater thickness showed a stronger dielectric characteristic when moisture abounded, and presented a smaller hysteresis loop and a higher recovery rate, due to the large size of pore throats. As the film thickness decreased, at low humidity the surface conductivity enhanced and the response rate increased. The silica aerogel based humidity sensor can be modeled as an equivalent electrical circuit composed of a resistor and a capacitor in parallel, and is driven by ionic conduction with charged proton carriers. (c) 2005 Elsevier B.V All rights reserved.

Webborn, N., M. J. Price, et al. (2005). "Effects of two cooling strategies on thermoregulatory responses of tetraplegic athletes during repeated intermittent exercise in the heat." Journal of Applied Physiology **98**(6): 2101-2107.

Athletes with spinal cord injury (SCI), and in particular tetraplegia, have an increased risk of heat strain and consequently heat illness relative to able-bodied individuals. Strategies that reduce the heat strain during exercise in a hot environment may reduce the risk of heat illness. To test the hypotheses that precooling or cooling during intermittent sprint exercise in a heated environment would attenuate the rise in core temperature in tetraplegic athletes, eight male subjects with SCI ( lesions C-5 - C-7; 2 incomplete lesions) undertook four heat stress trials (32.0 +/- 0.1 degrees C, 50 +/- 0.1% relative humidity). After assessment of baseline thermoregulatory responses at rest for 80 min, subjects performed three intermittent sprint protocols for 28 min. All trials were undertaken on an arm crank ergometer and involved a no-cooling control ( Con), 20 min of precooling (Pre), or cooling during exercise (Dur). Trials were administered in a randomized order. After the intermittent sprint protocols, mean core temperature was higher during Con (37.3 +/- 0.3 degrees C) compared with Pre and Dur (36.5 +/- 0.6 degrees C and 37.0 +/- 0.5 degrees C, respectively; $P < 0.01$). Moreover, perceived exertion was lower during Pre ( 13 +/- 2; $P < 0.01$) and Dur ( 12 +/- 1; $P < 0.01$) compared with Con (14 +/- 2). These results suggest that both precooling and cooling during intermittent sprint exercise in the heat reduces thermal

strain in tetraplegic athletes. The cooling strategies also appear to show reduced perceived exertion at equivalent time points, which may translate into improved functional capacity.

Wolfbeis, O. S. (2006). "Fiber-optic chemical sensors and biosensors." Analytical Chemistry **78**(12): 3859-3873.

Won, J., S. H. Choa, et al. (2006). "An integrated sensor for pressure, temperature, and relative humidity based on MEMS technology." Journal of Mechanical Science and Technology **20**(4): 505-512.

This paper presents an integrated multifunctional sensor based on MEMS technology, which can be used or embedded in mobile devices for environmental monitoring. An absolute pressure sensor, a temperature sensor and a humidity sensor are integrated in one silicon chip of which the size is 5 mm x 5 mm. The pressure sensor uses a bulk-micromachined diaphragm structure with the piezoresistors. For temperature sensing, a silicon temperature sensor based oil the spreading-resistance principle is designed and fabricated. The humidity sensor is a capacitive humidity sensor which has the polyimide film and interdigitated capacitance electrodes. The different piezoresistive orientation is used for the pressure and temperature sensor to avoid the interference between sensors. Each sensor shows good sensor characteristics except for the humidity sensor. However, the linearity and hysteresis of the humidity sensor can be improved by selecting the proper polymer materials and structures.

Wu, R. J., Y. L. Sun, et al. (2006). "Composite of TiO2 nanowires and Nafion as humidity sensor material." Sensors and Actuators B-Chemical **115**(1): 198-204.

Homogeneous TiO2 nanowires were fabricated by hydrothermal method. SEM pictures proved the yield of nanowires to be more than 90%. Composite humidity sensing films were made by using TiO2 nanowires, TEOS and Nafion. FTIR absorption spectroscopy was used as a semiquantitative method to get information about the protonation. The sensing films were prepared by a dip-coating method. The composite films coated on a pair of gold electrodes were tested for humidity sensors of resistance type. The measurement was carried out at five fixed humidity points in the range of 12-97% relative humidity, which were controlled by employing five different salt solutions. Resistance changes were about three orders of magnitude. The nanowires-based humidity sensors showed moderate sensitivity, short response and recovery time (< 2 min) at relative humidity less than 76%, and good long-term stability. (c) 2005 Elsevier B.V. All rights reserved.

Xu, Y. Y., X. H. Li, et al. (2005). "Capacitive humidity sensing properties of hydrothermally-etched silicon nano-porous pillar array." Sensors and Actuators B-Chemical **105**(2): 219-222.

Hydrothermally-etched silicon nano-porous pillar array (Si-NPPA) was

studied as a sensing material to detect humidity. Room temperature capacitance sensitivity of Si-NPPA sensor was investigated at a relative humidity (RH) ranging from 11 to 95 % under different signal frequencies. As a result, the measured capacitance showed an increase over 1500% at the low frequency of 100 Hz. The response time was about 15 and 5 s in RH-increasing process and RH-decreasing process, respectively. These excellent sensing characteristics indicate that Si-NPPA might be a practical sensing material. (c) 2004 Published by Elsevier B.V.

Yang, K. L., K. Cadwell, et al. (2005). "Use of self-assembled monolayers, metal ions and smectic liquid crystals to detect organophosphonates." Sensors and Actuators B-Chemical **104**(1): 50-56.

Smectic liquid crystals form stable, micrometer-thick films when deposited onto the surfaces of solids. In this paper, we report that orientational transitions of thin films of the smectic liquid crystal (LC), 4'-octyl-4-biphenyl-carbonitrile (8CB) supported on surfaces presenting copper ions can be exploited to detect the presence of organophosphonate compounds at parts-per-billion (ppb) levels in gas phases. The orientational transition of the 8CB is driven by the competitive binding of the nitrile groups of 8CB and dimethyl methyl phosphonate (DMMP) for the surface-immobilized copper ions. Because the orientational transition of the LC can be observed by using a polarizing film and the naked eye, this detection scheme does not require complex instrumentation to transduce the signal. The film of LC responds to 10 ppbv of DMMP and the initial response time is approximately 20 s. The system is also demonstrated to exhibit molecular specificity. The LC does not respond to gaseous streams containing 1% of the saturated vapor concentrations of ethanol (770 ppm), hexane (1990 ppm) and acetone (3020 ppm) and 75% relative humidity of water. (C) 2004 Elsevier B.V. All rights reserved.

Yang, B. Z., B. Aksak, et al. (2006). "Compliant and low-cost humidity nanosensors using nanoporous polymer membranes." Sensors and Actuators B-Chemical **114**(1): 254-262.

This paper proposes non-fragile compliant humidity nanosensors that can be fabricated inexpensively on various types of nanoporous polymer membranes such as polycarbonate, cellulose acetate, and nylon membranes. The nanosensor contains a pair of interdigitated electrodes deposited on the nanoporous polymer membranes. The resistance and/or capacitance between these electrodes vary at different humidity levels with a very high sensitivity due to the water adsorption (capillary condensation) inside the nanopores. The proposed sensors are low-cost in both material and fabrication. Due to its compliance, the sensors can be suitable for certain applications such as in situ water leakage detection on roofs, where people can walk on top of them. Testing results demonstrated that the sensor changes resistance within large range of relative humidity (RH) values (40-100% RH) with very high sensitivity.

Design A and B sensors exhibit high sensitivities, 2.5 and 1.3 G Omega/% RH, respectively, to relative humidity changes but are not linear in response till 55% RH is reached (R-2 similar to 0.7391 for design A, R-2 similar to 0.8824 for design B). For the design C sensors, sensitivity is around 20 G Omega/% RH and the response is highly linear (R-2 Omega 0.96) for 40-100% relative humidity range. These results showed the feasibility of the proposed compliant and low-cost nanopore polymer membrane based humidity nanosensors which could be used for in situ water leakage and humidity level detection on three-dimensional and complex surfaces such as roofs and airplane bodies in the near future. 

Yeo, T. L., T. Sun, et al. (2005). "Characterisation of a polymer-coated fibre Bragg grating sensor for relative humidity sensing." Sensors and Actuators B-Chemical **110**(1): 148-155.

This paper presents a detailed study of the characteristics of a polymer-coated fibre Bragg grating (FBG) sensor for relative humidity (RH) detection. The sensing scheme used in this work builds upon previous research and extends the application of FBGs in chemical sensing by employing a moisture sensitive polymer coating to induce a mechanical strain on the device through volume expansion. The swelling of the polymer coating as a result of the moisture absorption changes the Bragg wavelength of the FBG, thus giving a direct indication of the humidity level. Sensors with different coating thicknesses were evaluated through a series of experiments carried out over a range of values of RH and temperature to investigate various sensing characteristics which include the RH and temperature sensitivity, the time response and the hysteresis effect. All the sensors tested show a linear and reproducible response with a small degree of hysteresis. 

Yeo, T. L., T. Sun, et al. (2005). "Polymer-coated fiber Bragg grating for relative humidity sensing." Ieee Sensors Journal **5**(5): 1082-1089.

A fiber-optic-based humidity sensor has been fabricated using a fiber Bragg grating (FBG) coated with a moisture-sensitive polymer. The sensing concept exploits the inherent characteristics of the FBG and is based on the strain effect induced in the Bragg grating through the swelling of the polymer coating. A direct indication of the humidity level is given by the shift of the Bragg wavelength caused by the expansion of the sensing material. The FBG sensor used in this work has an approximate coating thickness of 33 mu m and was exposed to different humidity levels at room temperature. The sensitivity of the sensor was estimated to be about 4.5 pm/% RH at a wavelength of 1535 nm, this being obtained through a process of linear regression. The resulting uncertainty in the measurement is +/- 4%RH and the response time of the sensor and the moisture expansion coefficient of polyimide were obtained from a series of experimental investigations and cross compared with the results of

previous work.

Zampolli, S., I. Elmi, et al. (2004). "An electronic nose based on solid state sensor arrays for low-cost indoor air quality monitoring applications." Sensors and Actuators B-Chemical **101**(1-2): 39-46.

The occurrence of illnesses related with poor ventilation has driven an increasing attention towards indoor air quality monitoring. In buildings equipped with climate control systems, the diseases related to the air quality can be significantly reduced if smart intervening procedures. aiming to control the concentration of pollutants in the indoor air, can be implemented in the heating, ventilation air conditioning unit. When reliable information about both the indoor and outdoor air quality is made available, the climate control system can provide the most appropriate amount of ventilation, ensuring safe and comfortable living conditions.In this paper, a dedicated, miniaturized, low-cost electronic nose based on state-of-the-art metal oxide sensors and signal processing techniques was developed. The proposed device is targeted to the quantification of carbon monoxide and nitrogen dioxide in mixtures with relative humidity and volatile organic compounds by using an optimized gas sensor array and highly effective pattern recognition techniques. The electronic nose was tested in an environment reproducing real operating conditions. Exploiting the unique response patterns of the different sensors in the array and the capability of a simple fuzzy-logic system it was possible to identify and discriminate concentrations as low as 20 ppb for NO2 and 5 ppm for CO in the test gas environment, allowing to reach the necessary sensitivity towards the target pollutants together with the selectivity towards the typical interfering gas species. (C) 2004 Elsevier B.V. All rights reserved.

Zanjanchi, M. A. and S. Sohrabnezhad (2005). "Evaluation of methylene blue incorporated in zeolite for construction of an optical humidity sensor." Sensors and Actuators B-Chemical **105**(2): 502-507.

A novel dye incorporated into microporous material is introduced for optical humidity sensing. Methylene blue (MB) was encapsulated into the protonated mordenite zeolite (HMOR) via ion exchange reaction. The dye molecules are strongly retained in the channels of the zeolite and take part in the protonation/deprotonation reactions reversibly. The mechanism of the sensor is based on the protonation or deprotonation of the dye molecules which are associated with the desorption or adsorption of water molecules by the zeolitc, respectively. The spectral changes due to different humidity levels are probed by diffuse reflectance spectroscopy. Discs prepared from 200 mg of the dye-loaded zeolite provide a thickness of Pz approximate to 0.8 turn and show good characteristics for an optical humidity sensor. They showed a linear response range from 9 to 92% relative humidity ($r(2) > 0.99$), and good stability and reversibility. The sensor operates at either of the two 650 or 745 nm bands but it exhibits a higher sensitivity for the measurements performed at 650 nm. The sensor

demonstrates relatively fast response and recovery times about 2 min in the direction of adsorption and about 4 min in the direction of desorption of water. (c) 2004 Elsevier B.V. All rights reserved.

Zhang, Y. S., K. Yu, et al. (2005). "Detection of humidity based on quartz crystal microbalance coated with ZnO nanostructure films." Physica B-Condensed Matter **368**(1-4): 94-99.

The possibilities and properties of ZnO nanorod and nanowire films-coated quartz crystal microbalance (QCM) as a humidity sensor have been investigated. The morphology and crystal structures of ZnO nanorods and nanowires were characterized with X-ray diffraction (XRD) and scanning electron microscopy (SEM). It can be found that the frequency shift of the ZnO nano structures-coated QCM linearly decreases with increasing relative humidity over the range of 5-97% RH. The experimental results demonstrated that ZnO nanostructures-coated QCM are usable as a humidity sensor and as an analytical device. It appears that the ZnO nanomaterial films can be used as efficient humidity sensors. (c) 2005 Elsevier B.V. All rights reserved.

Zhang, Y. S., K. Yu, et al. (2005). "Quartz crystal microbalance coated with carbon nanotube films used as humidity sensor." Sensors and Actuators a-Physical **120**(1): 142-146.

The possibilities and properties of multi-wall carbon nanotube (MWNT)-coated quartz crystal microbalance (QCM) as a humidity sensor are presented. In order to enhance effectively sensitivity of the sensor, the MWNTs coated on QCM are treated by means of ball milling and hydrogen plasma technique, respectively. The morphology and microstructure of MWNT films were characterized with SEM and TEM. It can be found that the frequency shift of the MWNT-coated QCM linearly decreases with increasing relative humidity over the range of 5-97% RH. The sensors have a response and recovery time of about 60 and 70 s, respectively. The experimental results prove that MWNT-coated QCM are usable as a humidity sensor and as an analytical device. (c) 2004 Elsevier B.V. All rights reserved.

Zhang, Y. S., K. Yu, et al. (2005). "Zinc oxide nanorod and nanowire for humidity sensor." Applied Surface Science **242**(1-2): 212-217.

ZnO nanorod and nanowire films were fabricated on the Si substrates with comb type Pt electrodes by the vapor-phase transport method, and their humidity sensitive characteristics have been investigated. These nanomaterial films show high-humidity sensitivity, good long-term stability and fast response time. It was found that the resistance of the films decreases with increasing relative humidity (RH). At room temperature (RT), resistance changes of more than four and two orders of magnitude were observed when ZnO nanowire and nanorod devices were exposed, respectively, to a moisture pulse of 97% relative humidity. It appears that

the ZnO nanomaterial films can be used as efficient humidity sensors. (C) 2004 Elsevier B.V. All rights reserved.

Zhao, Z., M. A. Carpenter, et al. (2006). "All-optical hydrogen sensor based on a high alloy content palladium thin film." Sensors and Actuators B-Chemical **113**(1): 532-538.

Optical reflectance measurements were performed to determine the hydrogen response characteristics of 20 nm thick Pd0.6Au0.1 films. The response time and signal change characteristics were determined as a function of hydrogen concentrations ranging from 0.05% to 4% in a balance of dry CO2 free air. The detection limit was determined to be 0.05% with a corresponding response time of 130s, while at 4% hydrogen concentrations the response time was 5 s at ambient temperatures. A linear decrease of both the signal change and response time was measured within an operating temperature range between 25 C and 100 C for a 1% hydrogen in air gas mixture, The sensor response dependence of the Pd0.6Au0.4 film with a change in humidity was determined between ambient levels and 95% relative humidity (RH). While the signal change was independent of humidity the response time increased due to water adsorption on the Pd alloy sensing layer. A similar increase in response time was shown for 100 ppm of background CO mixed with 1% hydrogen in nitrogen at room temperature. At an elevated operating temperature of 80 C, 100 ppm of CO did not affect the sensor response towards 1% hydrogen in a balance of nitrogen. Reliability tests have been performed over a 1-year time period and the sensing specifications have not drifted beyond 2% and 13% of the calibrated signal change and response time, respectively. A response time on the order of seconds and the proven stability of the high alloy content Pd thin film demonstrate the promising attributes of this material for use in an all-optical hydrogen sensor (c) 2005 Elsevier B.V. All rights reserved.

Zou, J., H. Y. He, et al. (2004). "A guest/host material of LiCl/H-STI (stilbite) zeolite assembly: preparation, characterization and humidity-sensitive properties." Journal of Materials Chemistry **14**(15): 2405-2411.

The novel zeolite guest/host material, LiCl/H-STI (stilbite) assembly was synthesized by a thermal dispersion method, and characterized in detail by powder XRD, Li-7 MAS NMR, SEM/EDX, DTA and FT-IR. The loading threshold of LiCl was confirmed by XRD to be 0.14 g/g. The Li-7 MAS NMR spectra were measured for a solution of LiCl, LiCl crystallites, LiCl/H-STI assembly, Li+ ion-exchanged STI (Li-STI) as well as LiCl dispersed on supports of zeolite ZSM-39, zeolite ZSM-5, silica gel and quartz. According to the chemical shifts, the states of Li+ can be identified as Li+ ions in solution, LiCl isolated in zeolite channels, Li+ cations balancing the framework charges and LiCl as a crystalline phase or cluster. Characterization results proved the LiCl guest was highly dispersed into the channels of the host at the threshold assembly loading. The

interactions of LiCl with the zeolite framework and H2O are also discussed. The threshold loading LiCl/H-STI material was found to possess optimum humidity-sensitive performance with a linear change of 4 orders of magnitude in electrical conductivity over the whole range of relative humidity. In addition, it also shows satisfactory reversibility and fast responses to environmental moisture changes.

Zuo, X., Z. M. Wang, et al. (2005). "Microstructure and humidity-sensing mechanism of both Ca2+-doped and Li+-modified PbTiO3 nano-film." Journal of Inorganic Materials **20**(1): 158-162.

A good humidity-sensitive Li+-modified and Ca2+-doped PbTiO3 nano-film (Li+-CaxPb1-xTiO3, x=0.35, Li/Ti=1/100 mol/mol, sintered at 850degreesC/1h; abbreviated as Li-CPT) was prepared by the sol-spin-coating process using Ca(OAc)(2), Pb(OAc)(2), Li2CO3 and Ti(O-Bu-n)(4) as starting materials. Li-CPT microstructure was studied by means of AFM. AFM observation of both morphology and linear surface roughness indicates marked reticulate grain boundaries, the linear surface roughness is within (+0.5mum)similar to (-1.2mum), and hence. large surface area: The film surface shows the presence of polycrystalline grains with an average area of 51mum x 10mum. Such a microstructure is favorable for having a good humidity sensitivity. The crystal geometry and electron structure will change greatly after the equate-valence substitution of Ca2+ with smaller Pauling ion radius for Pb2+. The substitution decreases the lattice distortion (c/a), the non-symmetry and film cracks. There is a probable mechanism for electrical resistance-humidity sensitivity. H2O molecules polarized and adsorbed on the Li-CPT film surface, due to the doping of Li+ ions with smaller radius, dissociate into H+ and OH-, H+ ions combine with lattice oxygen, OH- ions fill up the oxygen hole (defect site) and release free electrons which participate in electric conduction in the external electric field; hence electrical resistance will decrease with the increase of relative humidity.