An Infrared Study of the Humidity Sensing and Electrical Properties of a Composite Material of Nano-sized SiO_2 and Poly(2-acrylamido-2-methylpropane Sulfonate)

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Many kinds of ceramics and polymers have been studied to develop humidity sensors for measurement and control of humidity in human comfort and a myriad of industrial processes. The advantages and disadvantages of both ceramics and polymer humidity sensors were evaluated in the literatures. Basic requirements for humidity sensing ceramics are a porous body and both chemical and thermal stability. For example, the TiO_2, Al_2O_3, SiO_2 and $BaTiO_3$, etc. are the most successful ceramic materials for humidity sensing. The ceramics humidity sensors record changes in surface conductivity and dielectric constant due to water vapor adsorption, which are classified as conductive and capacitive humidity sensors, respectively. The humidity sensors fabricated with polymeric materials are divided into two categories, resistive- and capacitive-type. The resistive- and capacitive-type humidity sensors are fabricated with polymer electrolytes and hydrophobic polymers, respectively. Polyimides are the most studied polymer materials based on the dielectric constant changes. Poly (2-acrylamido-2-methylpropone sulfonates) (poly(AMPS)) with acidic groups or their salts such as –SO_3–H+ or –SO_3–M+, where M is an alkali metal, are electrolytic- or resistive-type humidity sensing polymers. The conductivity of the polymer electrolytes usually increase with increasing humidity since the polymer electrolyte ionizes and produces conductive ions which migrate inside the material. However, one of serious shortcomings of the hydrophilic electrolytic-type polymer's sensing material is that when exposed to a highly humid atmosphere for a long time, then the humidity-sensing layer is liable to swell, shrink or peel off from the substrate.The humidity sensing properties of some composite materials of inorganic–polymer have been reported, such as SiO_2/Nafion, $BaTiO_3$/RMX and $BaTiO_3$/poly(styrene) sulfonic sodium. To improve the water-resistive but humidity-sensitive characteristic of poly(AMPS), the nano-sized SiO_2 particles were composed with poly(AMPS) and the humidity sensing and electrical properties of the composite films were investigated in this study.

Instruments and analysis – The mid-infrared spectra of the composite material were measured using a Nicolet Magna-IR 860 spectrometer fitted with a IR microscopy with a liquid-nitrogen-cooled mercury-cadmium-telluride detector. The complex impedance of the sensor as a function of relative humidity were measured with an LCR meter (Philips PM6304) in a cell, in which humidity was controlled by mixing dry and wet air using mass flow controllers (Hastings) as described elsewhere. The frequency ranged from 1 to 100 kHz and RH varied from 10 to 90% RH at the temperature of 15, 25, and 35℃. The stability test was controlled by a saturated K_2SO_4 solution in a 97% RH environment.

IR spectra –The IR spectra of the composite material are shown as Fig. 1. The spectra looked like the combination of those of nano-sized SiO_2 and poly(AMPS). A characteristic absorption peak of the AMPS units is seen at 1046 cm^{-1} due to the SO group. The peaks between 1090 and 1250 cm^{-1} were a mixture of SiO_2 and poly(AMPS) due to the asymmetric stretching mode of O–Si–O at 1000-1250 cm^{-1}.

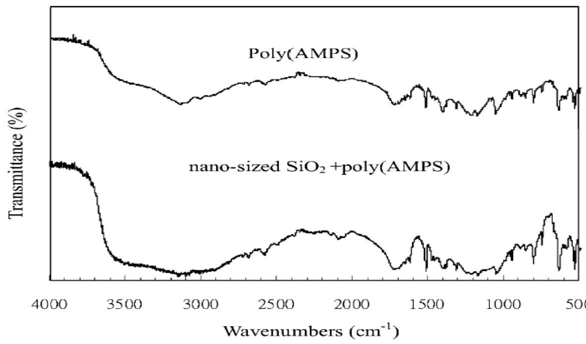

Figure 1. IR spectra of poly(AMPS) and the composite of nano-sized SiO_2/poly(AMPS).

Discussion - Nano-sized SiO_2 and AMPS polymer were mixed to form composite films as a humidity sensor. The IR spectra of the composite were the combination of those of SiO_2 and poly(AMPS). The impedance and capacitance of the sensor varied with frequency and RH. At low RH, the frequency influence on the impedance was bigger than that at high RH. The lower the frequency, the larger the range of capacitance change with increasing humidity. The sensor exhibited good sensitivity, good linearity, negligible hysteresis, low temperature dependence and excellent stability in a high RH atmosphere and even in an alcoholic environment. The response and recovery time of the sensor were 60 s and 120 s, respectively. The activation energy for conduction reduced with water adsorption. This behavior suggested that the conductivity of the SiO_2/poly(AMPS) composite is controlled by ions. The complex impedance plots in different RH showed that the shapes of the curves changed from a semicircle to a line with increasing RH, indicating different sensing mechanisms at low and high RH.