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Fabrication and Study of Nickel Phthalocyanine based Surface Type Capacitive Sensors

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Abstract**—**Thin films of Nickel phthalocynine (NiPc) of different thicknesses (100, 150 and 200 nm) were deposited by thermal evaporator on glass substrates with preliminary deposited aluminum electrodes to form Al/NiPc/Al surface-type capacitive humidity sensors. The capacitance-humidity relationships of the sensors were investigated at humidity levels from 35 to 90% RH. It was observed that the capacitance value increases nonlinearly with increasing humidity level. All measurements were taken at room temperature.

Keywords**—**Capacitive sensor, Humidity, Nickel phthalocyanine, Organic semiconductor.

I. Introduction

THE humidity sensors play important role for measurement and controlling of humidity in many industrials and medical fields such as food storage, medicine stores, hospitals, electronic devices, computer rooms and all kind of machines. In recent years, the fabrication and study of electric, electronic and photonic devices employing organic semiconductors have attracted much attention [1- 5]. This is mainly due to their advantages of low cost, simplicity of device fabrication, and interesting electrical and optical properties. Organic semiconducting materials are very sensitive to humidity [6, 7], temperature [8, 9], and different types of gases such as ammonia [10].

As far as we know, a few studies have been reported of humidity sensors employing organic semiconductors. Investigations of orange dye (OD), a p-type organic semiconductor, for humidity sensing applications have been carried out by Moiz et al. [11, 12]. Due to the solubility of OD in water this material is not good for high humidity level sensing. Nickel phthalocynine (NiPc) is insoluble in water so it seems reasonable to investigate NiPc as a humidity sensor. NiPc is thermally stable and its thin film can be deposited by thermal evaporation without dissociation [13, 14].

In this work, the fabrication and investigation of Al/NiPc/Al surface-type capacitive humidity sensors of different thicknesses is undertaken and effect of humidity on the capacitance is examined.

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II. Experimental Procedure

Fig.1 shows molecular structure of the NiPc used as an active material. The NiPc powder used in this study was obtained from Sigma Aldrich and used without further purification. Aluminum electrodes of thickness of 160 nm were deposited by vacuum evaporation technique on thoroughly cleaned glass substrate. Thin films of NiPc, of thicknesses 100, 150, 200 nm, were thermally sublimed on glass substrates (25 mm x 25 mm) with preliminary deposited aluminum electrodes. During deposition the chamber pressure was kept at 10^{-5} mbar. The deposition rates were maintained to be 0.1 and 0.2 nm/s for Al and NiPc, respectively. The gap between electrodes and length of the gap was equal to 40 µm and 16 mm. The thickness of each layer was monitored by a crystal-controlled thickness monitor [15]. The surface type capacitive sensor, Al/NiPc/Al was fabricated. Cross-sectional view of the fabricated capacitive sensor is shown in Fig. 2. Measurement of the capacitance was done by conventional instruments at the frequency of 1 kHz, at room temperature (25 ± 0.5 ^{o}C).

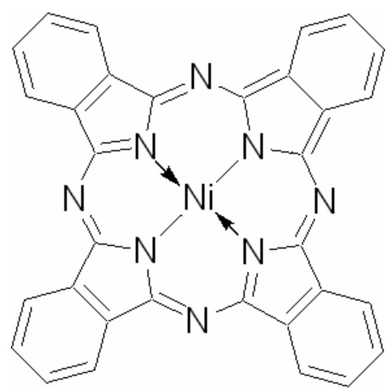

Fig. 1 Molecular structure of NiPc

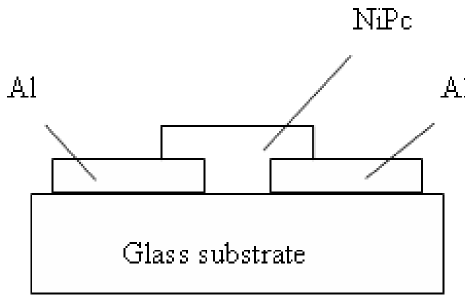

Fig. 2 Cross sectional view of the device

III. Results and Discussion

The measured capacitance-humidity relationships of Al/NiPc/Al surface type humidity sensor are shown in Fig. 3. It is observed that the capacitance value increases with the increase of humidity level from 35 to 90% RH. The capacitance increases from 15, 13, 10 to 506, 445, 340 pF for 100, 150 and 200 nm thick films of NiPc, respectively. The capacitance increases nonlinearly with changing of humidity level. The increase in capacitance of the sensor may be due to absorption of water molecules in the pore of thin films and formation of charge transfer complexes. We know that the capacitance is directly proportional to the dielectric permittivity of organic thin film, with the increase of humidity the value of dielectric permittivity increases and hence the capacitance value increases.

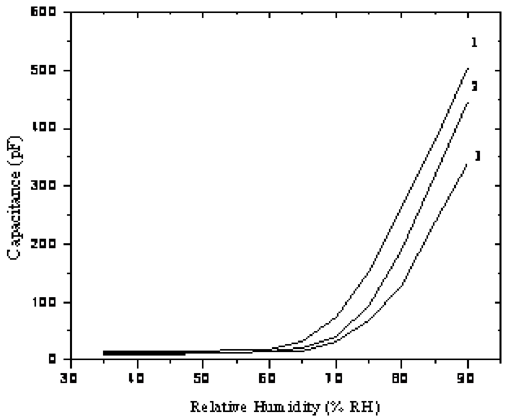

Fig. 3 Capacitance-humidity relationship of capacitive-type sensor: 100 nm (1), 150 nm (2) and 200 nm (3).

Fig. 4 shows the capacitance-thickness relationships of surface-type humidity sensor. It can be observed from this figure that the capacitance decreases as the thickness of the film increases. As we know that diffusion of water molecules inside the film and absorption capacity of the film depends upon thickness of the thin film.

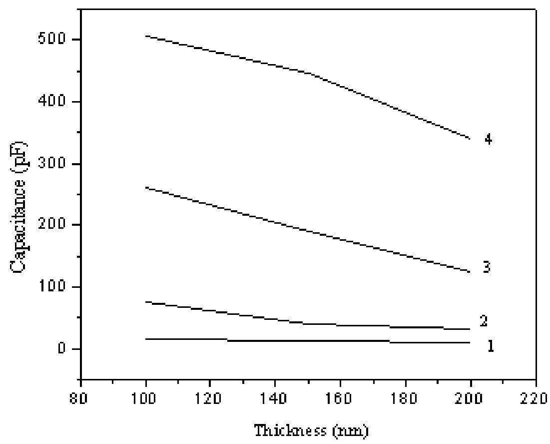

Fig. 4 Capacitance-thickness relationship of sensor: 40% RH (1), 70% RH (2), 840% RH (3) and 90% RH (4).

The changes in the capacitance depend upon the area of the plate, film thickness and dielectric properties of the sensing materials. In general, the relationship between relative dielectric constant and polarizability is determined by Clausius-Mosotti relation [16]:

$$\frac{(\varepsilon_{dry}-1)}{(\varepsilon_{dry}+2)} = \frac{N_{dry}\alpha_{dry}}{3\varepsilon_{O}} \quad (1)$$

where ε_{dry} is relative permittivity , ε_{O} is permittivity of free space.

From the above equation, we can write the expression at 35 %RH humidity:

$$\varepsilon_{dry} = \frac{(1+2N_{dry}\alpha_{dry}/3\varepsilon_{O})}{(1-N_{dry}\alpha_{dry}/3\varepsilon_{O})} \quad (2)$$

Similar equation can be written for the dielectric constant at higher humidity:

$$\varepsilon_{H} = \frac{(1+2N_{H}\alpha_{H}/3\varepsilon_{O})}{(1-N_{H}\alpha_{H}/3\varepsilon_{O})} \quad (3)$$

The value of $N_H\alpha_H$ depend upon the relative humidity level. Therefore, the product $N_H\alpha_H$ can be assumed as:

$$N_H\alpha_H = N_{dry}\alpha_{dry}(1+KH) \quad (4)$$

The equation of dielectric constant and capacitance for humidity can be written as [17]

$$\frac{C_H}{C_{dry}} = \left(\frac{\varepsilon_H}{\varepsilon_{dry}}\right)^n \quad (5)$$

From equations (2), (3), (4) and (5) the relation between the capacitance and dielectric constant of the humidity sensor can be written as:

$$\frac{C_H}{C_{dry}} = \left(\frac{(1+2N_{dry}\alpha_{dry}(1+KH)/3\varepsilon_O)}{(1-N_{dry}\alpha_{dry}(1+KH)/3\varepsilon_O)\varepsilon_{dry}} \right)^n \quad (6)$$

Where H is relative humidity and K is humidity capacitive factor. In this case the value of k is 0.0177 (RH^{-1}). Fig. 5 shows comparison of simulated and experimental results. The simulated result shows reasonable match with experimental results.

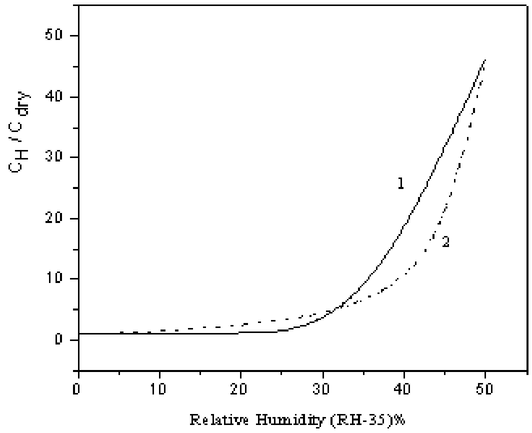

Fig. 5 Relative capacitance-humidity relationships: experimental (1) and simulated (2).

IV. Conclusion

Surface-type capacitive sensors have been fabricated and investigated using NiPc as humidity sensitive material. The change in capacitance is studied by changing relative humidity (RH). It was observed that the capacitance increases with increases of humidity level from 35 to 90% RH. It is observed that the change in capacitance is very small in the low RH range and it increases quickly in the high RH range. At high humidity level the absorbed water vapors increase and the increase in dielectric property makes the capacitance to increase quickly. These surface type sensors are very simple, low cost and ease to fabricate.

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