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BI-LAYER CAPACITIVE TYPE LIGHT AND HUMIDITY SENSORS

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In this work, we have investigated the capacitive type light and humidity sensors fabricated by using cellulose and copper phtalocyanine (CuPc). Films of cellulose were deposited on glass substrates with preliminary deposited metallic electrodes followed by deposition of CuPc films. The capacitances of the samples were evaluated under the effect of light and humidity. It was observed that the capacitance of the sensor increases with increase in light intensity and relative humidity level. Comparison of the samples with different electrodes shows that the light sensitivity of the sample having Al electrodes is 2 times greater than the Ag one.

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1. Introduction

Organic semiconductors have made it possible to fabricate highly sensitive sensors at low cost due to the reason that these materials are very sensitive to humidity [1, 2], temperature [3, 4], infra-red, visible and ultraviolet radiation [5], and different types of gases [6]. No doubt, organic materials will find more suitable place among the electronic materials in near future and research on new organic materials is expected to prolong.

Light is among the most commonly measured quantities in measurement science. Due to very broad spectrum of electromagnetic radiation and different measuring and sensing requirements there is no single solution for the measurement of entire spectral range in different conditions. There is always need for exploring and developing new materials and sensors, respectively. An increasing number of papers deal with the investigation of sensing properties of organic materials. Karimov *et al.* [7] have investigated light sensing properties CuPc based surface-type photocapacitor in visible region of spectrum. Surface type organic capacitor represents a simple, low cost and versatile alternative to the devices built in sandwich configuration. Because of these advantages, there is a growing interest in the fabrication and study of surface type optoelectronic devices employing organic semiconductors as active materials [8-10].

Very recently, we have investigated the light sensing properties of organic semiconductor Cu(II) 5,10,15,20-tetrakis(4′-isopropylphenyl) porphyrin (CuTIPP) [11]. In this work, CuTIPP was employed as an active material in surface-type photocapacitive detectors. With the increase in illumination, the increase in capacitance of the sensor was observed.

As far as the humidity sensors are concerned, different types of humidity sensors are available in market and most of these sensors are capacitive type [12, 13]. Currently the most commercially available humidity sensors have LiCl as sensing element [14, 15], in which a mixture of lithium chloride and carbon is used between the electrodes. Operating principle of this device is based on the ionic conductivity [16]. Organic materials that are insoluble in water such as cellulose acetate butyrate and polyimide have been used as humidity sensors [17]. Cellulose and

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CuPc are also insoluble in water, so in this work, we have undertaken the fabrication and study of sensors employing cellulose and CuPc which are sensitive to humidity and light, respectively. Cellulose is one of the organic materials that is found in nature. Cellulose is abundantly found in plants and is extracted from cotton or wood. The aim of this research is to develop a reliable, accurate and cheap light and humidity sensors using organic materials.

2. Experimental

Commercially available cellulose with molecular formula $(C_6H_{10}O_5)_n$ and CuPc purchased from Sigma Aldrich were used without further purification for the fabrication of the bi-layer capacitive type light and humidity sensors. Density of the cellulose was 1.592 g/cm^3. Molecular structures of the cellulose and CuPc are shown in Fig. 1. The 5 wt% suspension of cellulose was prepared in water while the CuPc was dissolved in methanol. Glass substrates were cleaned for 10 min. using distilled water in ultrasonic cleaner and dried. Then the substrates were also plasma cleaned for 5 min. The metallic electrodes on cleaned substrate were deposited, keeping the 50 μm gap between them. The thickness of the electrodes was 100 nm where as the gap lengths were 5 mm. Films of cellulose and CuPc were deposited by drop casting method with approximate thickness of 50 μm and 10 μm, respectively. The CuPc film was deposited on cellulose to make these sensors light sensitive. The fabricated devices were kept at room temperature for one night to evaporate the moisture from the films. Measurements were carried out in self made light and humidity measurement setups, which have been developed in our device testing laboratory using conventional digital instruments.

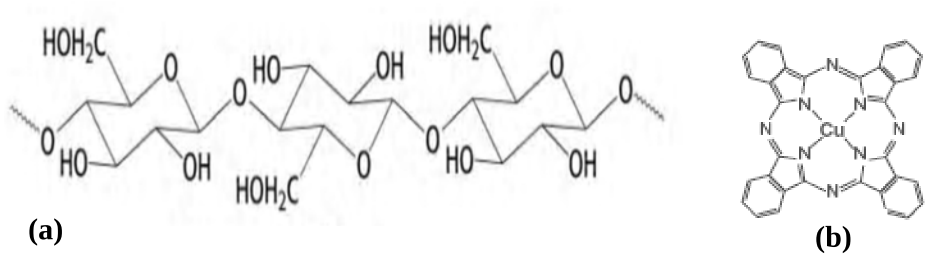

Fig. 1. Molecular structure of cellulose (a) and CuPc (b)

3. Results and discussion

In surface-type capacitor light falls on the active medium employed and capacitance of the sensor increases. The capacitance-illumination relationship for the Al/cellulose/CuPc/Al and Ag/cellulose/CuPc/Ag surface-type photocapacitive detector is shown in Fig. 2. Where, C_{ph} and C_d are the capacitances under illumination and dark conditions, respectively. In dark condition the value of capacitance was 10 pF. The ratio of C_{ph}/C_d for the Al/cellulose/CuPc/Al and Ag/cellulose/CuPc/Ag sensors at 8000 lx illumination increased up to 2.4 and 1.2 times of dark, respectively. The illumination effects the concentration of ions, dipoles, electrons and holes which increase the polarizability in the films. Electronic polarization is universal whereas ionic polarization takes place due to charge-transfer complexes. Therefore, polarization under dark (α_d) conditions can be represented by the equation:

$$\alpha_d = \alpha_i + \alpha_e + \alpha_{td} \tag{1}$$

where, α_i, α_e and α_{td} are the polarizations in dark condition due to ions, electrons and transfer of charge carriers, respectively. Under illumination polarizability can be written as:

$$\alpha = \alpha_i + \alpha_e + \alpha_t \tag{2}$$

where α_t is polarizability under illumination due to the transfer of charge carriers. Here we assume that concentration of charge carriers and total polarizability (α) is light dependent. The relationship between molecular concentration, dielectric permittivity constant and polarizability can be determined by [18]:

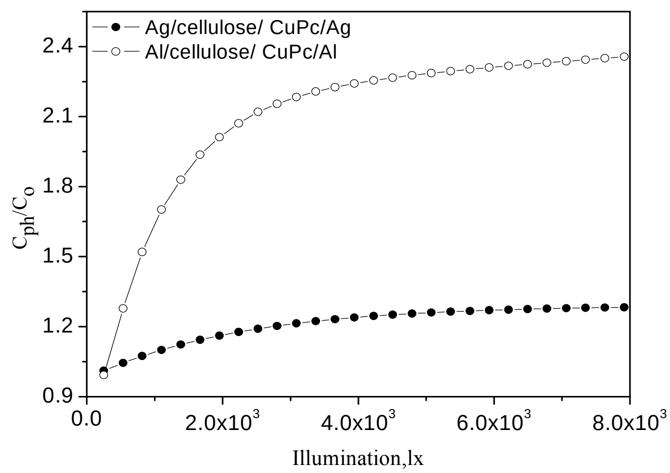

Fig. 2. Relative capacitance vs. Illumination relationship for Ag/cellulose/CuPc/Ag and Al/cellulose/ CuPc/Al light sensors.

$$\frac{(\varepsilon_d - 1)}{(\varepsilon_d - 2)} = \frac{N_d \alpha_d}{3\varepsilon_\circ} \tag{3}$$

where, ε_d and N_d are relative permittivity and concentration of the charge carriers (in dark condition) respectively.

Most of humidity sensors determine relative humidity level using capacitive technique. The sensors are made of a thin film capacitor. The active material absorbs or releases water molecules and thus changes the capacitance of the capacitor. The capacitance depends upon the polarization [19], dielectric permittivity constant of the sensing material, gap between the electrodes and electrode geometry [20]. To determine the dielectric constant, we considered an approximation, the metallic electrodes and gap between the electrodes with deposited cellulose as parallel plate capacitor. Using this approximation the relative permittivity constant of cellulose can be calculated by following expression:

$$C = \frac{\varepsilon_r \varepsilon_\circ A}{d} \tag{4}$$

where, A is the area of plates and d is the distance between the plates.

Fig. 3 shows the capacitance-relative humidity relation of Ag/cellulose/CuPc/Ag and Ag/cellulose/Ag surface type humidity sensors. The capacitance of the Ag/cellulose/CuPc/Ag and Ag/cellulose/Ag sensors increases about 2.23 and 2.12 times on the logarithmic scale at relative humidity ranging from 30 to 80%. In initial condition the value of capacitance was 17-18 pF for both samples. The increase in capacitance with increase in humidity can be explained as; the humidity level effects the concentration of ions, dipoles, electrons and holes and thus increases the polarizability in the organic materials. The increase in capacitance with humidity may also be due to the porous nature of the films. Dielectric constant of the organic material increases with absorption of water molecules due to higher dielectric constant value of water. Both the Ag/cellulose/CuPc/Ag and Ag/cellulose/Ag humidity sensors have almost same sensitivity.

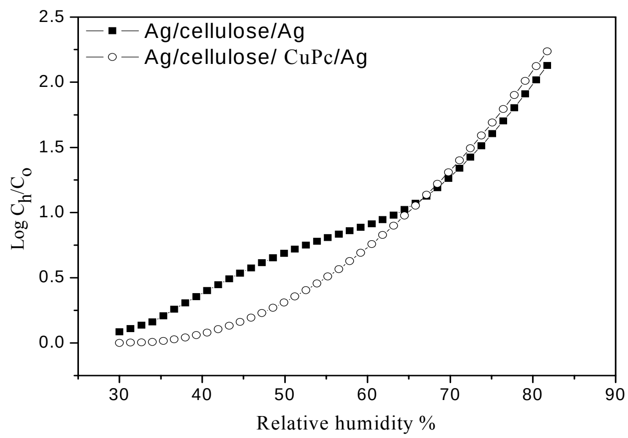

Fig. 3. Relative capacitance vs. relative humidity relationship for Ag/cellulose/Ag and Ag/cellulose/ CuPc/Ag humidity sensors.

4. Conclusions

The investigations made on surface-type Al/cellulose/CuPc/Al, Ag/cellulose/CuPc/Ag and Ag/cellulose/Ag sensors showed good sensitivity of these materials for light and humidity sensors. It was observed that under filament lamp illumination up to 8000 lx, Al/cellulose/CuPc/Al and Ag/cellulose/CuPc/Ag sensors increased up to 2.4 and 1.2 times of dark, respectively. Whereas, the capacitance of Ag/cellulose/CuPc/Ag and Ag/cellulose/Ag humidity sensor increased 170 and 132 times over the whole humidity range, respectively. From technological point of view the surface type photocapacitive sensors are much simple and easy to fabricate than sandwich type.

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