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Application of Formyl-TIPPCu (II) for Temperature and Light Sensing

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***Abstract*—**Effect of temperature and light was investigated on a thin film of organic semiconductor formyl-TIPPCu(II) deposited on a glass substrate with preliminary evaporated gold electrodes. The electrical capacitance and resistance of the fabricated device were evaluated under the effect of temperature and light. The relative capacitance of the fabricated sensor increased by 4.3 times by rising temperature from 27 to 187^{0}C, while under illumination up to 25000 lx, the capacitance of the Au/formyl-TIPPCu(II)/Au photo capacitive sensor increased continuously by 13.2 times as compared to dark conditions.

***Keywords*—**formyl-TIPPCu(II), Organic semiconductor, Photocapacitance, Polarizability.

I. Introduction

FOR the utilization of renewable energy sources, the assessment of environmental conditions is an important factor which can be done by monitoring temperature, humidity barometric pressure, wind speed and direction, rain fall and air pollution [1, 2]. The organic semiconductors based sensors can be used for sensing application of these environmental parameters because organic materials are very sensitive to temperature [3, 4], radiations [5], humidity [6, 7] and various gases [8, 9].

Porphyrin is the heterocyclic organic compound which is found in nature in the form of chlorophyll, which is thought to be the best photo acceptor in nature. The free base porphyrin can be changed into metalloporphyrin by inserting the metals into its core [10]. Due to its attractive properties, porphyrin has been used for the fabrication of different organic devices such as junction diodes [11], sensors [7, 12] and solar cells [13].

In this research work, copper based porphyrin i.e. 2-formyl-5,10,15,20-tetrakis(4´-isopropylpheny)prophyrinatocopper(II) or formyl-TIPPCu(II) has been used to fabricate the organic sensor for temperature and light sensing application.

II. Experimental

Thin film of organic semiconductor formyl-TIPPCu(II) is used as a sensing element for the fabrication of Au/formyl-TIPPCu(II)/Au organic sensor. The synthesis of formyl-TIPPCu(II) has been described elsewhere [14]. The molecular structure of formyl-TIPPCu(II) is given in Fig. 1. Microscope glass slides were used as substrates. The substrates were cleaned ultrasonically in acetone for 25 minutes followed by thorough rinsing with distilled water. After drying, the substrates were plasma cleaned for 5 minutes. The gold electrodes of 100 nm thickness were thermally deposited on the substrates by keeping 40 µm gaps between them by using the mask. Then the thin film of formyl-TIPPCu(II) of thickness 140 nm was thermally sublimed on the substrates. For these thermal depositions, the Auto 306 vacuum coater with diffusion pumping system (Edward) was used under a chamber pressure of 5.5×10^{-5} mbar. The thickness of formyl-TIPPCu(II) and gold films were measured by an FTM5 crystal controlled thickness monitor. The cross-sectional view of the fabricated Au/formyl-TIPPCu(II)/Au sensor is shown in Fig. 2.

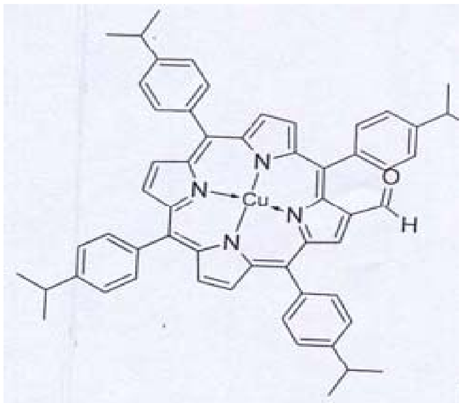

Fig. 1 Molecular structure of formyl-TIPPCu(II).

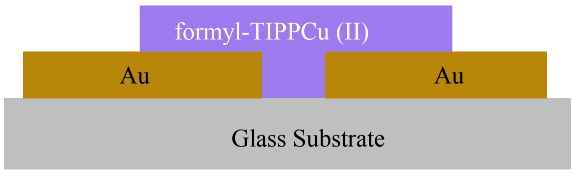

Fig. 2 Cross-sectional view of the Au/formyl-TIPPCu(II)/Au organic sensor

The electrical capacitance and resistance were measured by using DVM 890L and Kiethley 196 digital multimeters. The temperature dependence measurements of the device were made using Karl Suss PM5 probe station with a thermo chuk ‘Alpha’ series system, model TP 0315A-TS-2 of Temprotic Corporation, USA. The fabricated sensor was illuminated by a tungsten filament lamp at room temperature, and the

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illumination measurements were made by CEM DT-1300 light meter.

III. Results And Discussion

Fig. 3 shows the capacitance-resistance versus temperature plots of Au/formyl-TIPPCu(II)/Au surface type sensor. The measurements were made under the dark conditions at 40% RH. It has been observed from these curves that capacitance increases by 4.3 times while resistance decreases by 4.4 times with an increase in temperature from 27 to 187^{0}C. The polarization and conductance of sensing film cause the change in the magnitude of capacitance and resistance of the device [15]. With increasing temperature, the molecular thermal movement becomes stronger, which increases the polarization and causing the enhancement in the capacitance of the fabricated sensor. While the resistivity of the sensing material decreases with the increase in temperature, according to the relation.

$$\rho_T = \rho_0 \exp\left(\frac{E}{kT}\right) \quad (1)$$

Where ρ_T is the resistivity at absolute temperature T, ρ_0 is pre exponential factor, k is the Boltzmann's constant and E is the activation energy of conduction.

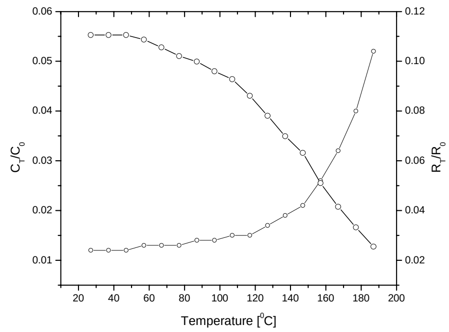

Fig. 3 Capacitance/resistance temperature relationships for the Au/formyl-TIPPCu(II)/Au organic sensor.

It can be observed from Fig. 4 that the capacitive and resistive measurements have the hysteresis of 3.2 and 5.1%, which may be caused by polarization of the material.

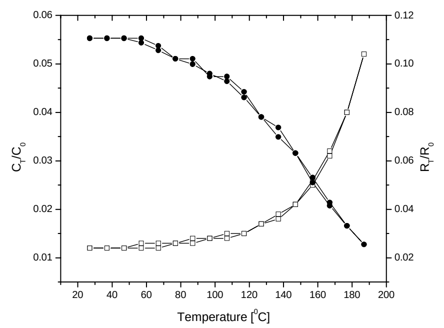

Fig. 4 Hysteresis in the capacitive and resistive measurements of Au/formyl-TIPPCu(II)/Au organic sensor.

Fig. 5 shows the relationship between relative capacitance and illumination for Au/formyl-TIPPCu(II)/Au surface type photocapacitive sensor. Where C_d and C_{ph} are capacitances under dark conditions and illumination respectively. This plot shows that the photocapacitance of fabricated sensor increases about 13.2 times with the increase in illumination from 0 to 25000 lx. The concentration of charge carriers, i.e. electrons, holes, ions and dipoles increases with increasing illumination, which causes the increase in polarizability in the film which results in the increase in the capacitance of the sensor [16, 17]. The total polarizability (α) can be written as

$$\alpha = \alpha_{dip} + \alpha_i + \alpha_e + \alpha_t \quad (2)$$

Where α_{dip}, α_i, α_e and α_t are polarizability under illumination due to dipoles, ions, electrons and the transfer of charge carriers, respectively.

The change in capacitance of the device may be due to electronic and ionic polarizability. The electronic polarizability arises due to the relative displacement of orbital electrons, while the ionic polarizability is due to charge-transfer complexes in the formyl-TIPPCu(II). The capacitance is actually depending on the relative permittivity (ε_r) of the material who depends on the polarizability according to Clausius-Mossotti equation [18].

$$\left(\frac{\varepsilon_r - 1}{\varepsilon_r - 2}\right) = \frac{N\alpha}{3\varepsilon_0} \quad (3)$$

Where N is the concentration of charge carriers, ε_r is the relative permittivity and ε_0 is the permittivity of free space.

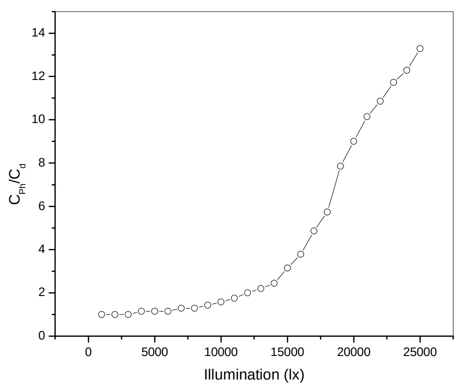

Fig. 5 Capacitance- illumination relationship for the Au/formyl-TIPPCu(II)/Au organic sensor.

IV. Conclusions

The organic semiconductor formyl-TIPPCu(II) has been successfully used for the fabrication of surface type Au/formyl-TIPPCu(II)/Au organic sensor. The changes in capacitance and resistance of the sensor with temperature and light have been observed. The capacitance has increased by 4.3 times while resistance of the fabricated sensor decreased by 4.4 times by rising temperature from 27 to 187^{0}C. An acceptable hysteresis for capacitive and resistive measurements was found. The rise of 13.2 times in capacitance due to illumination was also observed. The association of photocapacitive response of the organic sensor was assumed with polarization due to the transfer of photo – generated electrons and holes.

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REFERENCES

[1] A. Joyce, J. Adamson, B. Huntley, T. Parr, R. Baxter, "Standardization of temperature observed by automatic weather stations," *Environmental Monitoring and Assessment*, vol. 68, pp. 127-136, 2001.

[2] W. Qihao, Y. Shihong, "Urban air pollution patterns, land use and thermal landscape: an examination of the linkage using GIS," *Environmental Monitoring and Assessment*, vol. 117, pp. 463-489, 2006.

[3] S. A. Moiz, M. M. Ahmed, Khasan S. Karimov, "Effects of Temperature and Humidity on Electrical Properties of Organic Semiconductor Orange Dye Films Deposited from Solution," *Japanese Journal of Applied Physics*, vol. 44, pp. 1199-1203, 2005.

[4] M. M. Ahmed, Kh.S. Karimov, S.A. Moiz, "Photoelectric behavior of n-GaAs/orange dye, vinyl-ethynyl-trimethyl-piperidole/conductive glass sensor," *Thin Solid Films*, vol. 516, pp. 7822-7827, 2008.

[5] P. Bhattacharya, *Semiconductor Optoelectronic Devices*. New Jersey: Prentice Hall International, 1994.

[6] F. Gutman, L. E. Lyons, *Organic semiconductors, Part A*. Malabar, Florida, U.S.A: Krieger Robert E. Publishing Company, 1981.

[7] M. Saleem, M. H. Sayyad, Khasan S Karimov, Muhammad Yaseen Mukhtar Ali, "Synthesis and application of Ni(II) 5,10,15,20-tetrakis(4´-isopropylphenyl)porphyrin in a surface-type multifunctional sensor," *Phys. Scr*, vol. 82, pp. 015703 (6pp), 2010.

[8] H. Bai, Gaoquan Shi, "Gas Sensors Based on Conducting Polymers," *Sensors*, vol. 7, pp. 267-307, 2007.

[9] I. Muzikante, Vicente Parra, Rorijs Dobulans, Egils Fonavs, Janis Latvels, Marcel Bouvet, "A Novel Gas Sensor Transducer Based on Phthalocyanine Heterojunction Devices," *Sensors*, vol. 7, pp. 2984-2996, 2007.

[10] X. Zhou, "Synthesis and Characterization of Novel Discotic Liquid Crystal Porphyrins for Organic Photovoltaics," vol. PhD. Kent, Ohio, USA: Kent State University, 2009.

[11] T. J. Savenije, Ellen Moons, Gerrit K. Boschloo, and Albert Goossens, Tjeerd J. Schaafsma, "Photogeneration and transport of charge carriers in a porphyrin p/n heterojunction," *Physical Review B*, vol. 55, pp. 9585-9592, 1997.

[12] M. Saleem, M. H. Sayyad, K. S. Karimov, M. Yaseen, Mukhtar Ali, "Cu(II) 5,10,15,20-tetrakis (4´-isopropylphenyl) porphyrin based surface type resistive - capacitive multifunctional sensor," *Sensors and Actuators B*, vol. 137, pp. 442-446, 2009.

[13] T. Oku, Akihiro Takeda, Akihiko Nagata, Tatsuya Noma, Atsushi Suzuki, Kenji Kikuchi, "Fabrication and Characterization of Fullerene-Based Bulk Heterojunction Solar Cells with Porphyrin, CuInS2, Diamond and Exciton-Diffusion Blocking Layer," *Energies*, vol. 3, pp. 671-685, 2010.

[14] M. Yaseen, Mukhtar Ali, Muhammad NajeebUllah, Munawar Ali Munawar, Irshad Khokhar, "Microwave-Assisted Synthesis, Metallation, and Duff Formylation of Porphyrins," *J. Heterocyclic Chem.*, vol. 46, pp. 251-255, 2009.

[15] J. Wang, Wang X-H, Wang X-D, "Study on dielectric properties of humidity sensing nanometer materials," *Sensors Actuators B*, vol. 108, pp. 445-449, 2005.

[16] F. Gutman, L.E. Lyon, *Organic Semiconductors*: Krieger Robert E. Publishing Company, Malabar, Florida, USA, 1981.

[17] M. Iwamoto, Manaka. T, "Organic films and control of current–voltage characteristics by the surface polarization," presented at Proc Int. Symp. on Super-Functionality Organic Devices (IPAP Conf. Series vol 6), 2005.

[18] M. A. Omar, *Elementary Solid State Physics: Principles and Applications*: Pearson Education, Singapore, 2002.