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Electrical characterization of Al/methyl-red/Ag schottky diode

By

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Abstract:

This paper reports the fabrication and electrical characterization of surface type Al/methyl-red/Ag Schottky barrier diode. Electrodes were deposited on glass substrate with a narrow gap between them followed by spin coating of methyl-red (MR). A thin film of MR was deposited from 10 wt% solution in benzene by spin coater at an angular speed of 2000 revolution per minute (RPM) on a glass substrate with preliminary deposited metal electrodes. The thickness of the film was 300 nm. The length and width of the semiconducting channel between metallic electrodes were equal to 30 μm and 17 mm, respectively. The current-voltage (I-V) characteristics of Al/MR/Ag structure showed rectification behavior. The value of rectification ratio was found about 200 at ±4 V. I-V characteristics of Al/MR/Ag structure were also investigated as a function of temperature ranging from 25-55 °C. The sample was also investigated as humidity sensor at room temperature within the relative humidity (RH) range of 30-90%. The impedance changed linearly and approximately reduced 5 orders of magnitude over the whole humidity range. It was observed that under the effect of humidity the capacitance of the MR film increased by 1.5 times over the whole humidity range.

Keywords:

Schottky barrier diode, Current –voltage characteristics, humidity sensor, methyl-red

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1. Introduction:

Study of organic semiconductors have attracted a great deal of interest due to their use in electrical, electronic and optoelectronic devices as such batteries, light emitting diodes, solar cells etc. Organic semiconductors are extensively used in the fabrication of active and passive solid state devices because of their low cost and good performance [1, 2]. A lot of industrial applications of organic semiconductors may be realized by investigating their electrical behavior as a function of device fabrication parameters and techniques [1-3]. Organic semiconductor materials have now been reached at the stage of commercialization with the technological success of thin film devices. This is mainly due to improved efficiency, manufacturing yield and stability [4-8]. Organic semiconductors that show change in their electrical behavior as function of ambient condition e.g. temperature, humidity, radiation and toxic gasses are discussed in [9-11].
Schottky diodes are widely used in electronics industry as general purpose rectifiers. The advantage of Schottky diodes is their high current density and low forward voltage drop in devices. Schottky diodes have been fabricated in variety of forms such as point contact, deposited metal, and deposited metal and oxide film. The current flow in the Schottky diode is primarily due to majority carriers having an inherently fast response [12]. The electrical properties of Schottky diodes are similar to a p-n junction. These diodes are extensively used in, low-noise mixers, switching circuits and for high-frequency applications. Schottky diodes can be switched from one state to another much faster than p-n junction diodes.

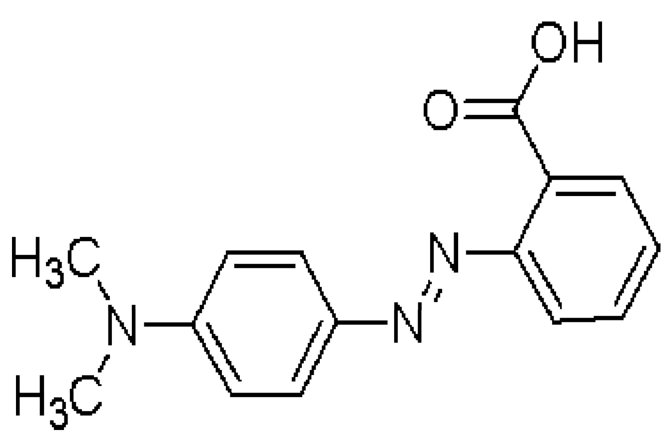

Figure (1)*: Molecular structure of methyl-red*

Methyl-red is chosen as organic semiconductor to form Schottky diode with Al due to its conjugated structure and richness in π-electrons [13]. The molecular structure of MR is shown in Fig. 1. The aim of this work is to investigate and analyze the electrical transport of Al/MR/Ag Schottky diode and determine its essential parameters and electronic conduction properties. It is important to know the parameters of the diode and its characteristics as function of temperature and humidity for its utilization in an environment where temperature and humidity level change.

2. Experimental:

Methyl-red 2-[4-(dimethylamino)phenylazo]benzonic acid with molecular formula $(CH_3)_2NC_6H_4N{=}NC_6H_4COOH$ purchased from Sigma Aldrich was used for the fabrication of the Schottky diode. The 10 wt% solution of MR was prepared in benzene. The solution was stirred for 2 hours at room temperature. A glass substrate was cleaned for 10 min. using distilled water in ultrasonic cleaner and dried. Then the substrate was plasma cleaned for 5 min. followed by deposition of electrodes by thermal evaporator. The thickness of the electrodes was 100 nm and gap between the electrodes was 30 μm. After that the film of MR was deposited by spin coater with angular rotation of 2000 RPM. A thin film was formed with approximate thickness of 300 nm. The fabricated device was kept at 50 °C for 1 hour to evaporate the moisture in the film. Cross sectional view of fabricated device is shown in Fig. 2.

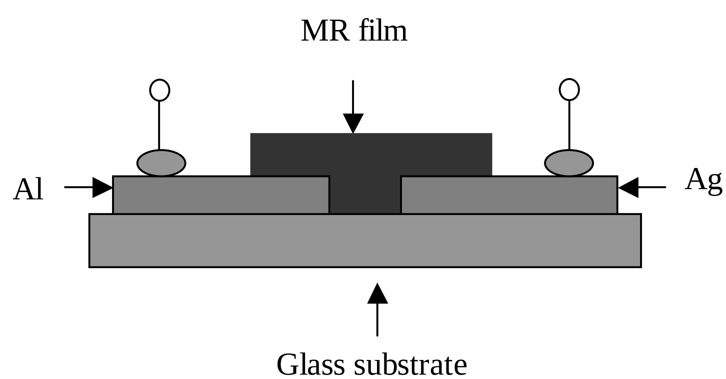

***Figure (2)**: Cross sectional view of Al/MR/Ag Schottky diode*

DC I-V characteristics were measured at temperature range 25-55°C. The temperature dependent I-V characteristics were performed by using a thermo-chuck "Alpha" series system model TP 0315A-TS-2 of Temprotic Corporation, USA. It uses a temperature controlled chuck (the thermo-chuck plate platform) as a surface for inducing a localized temperature. Functional testing on the Schottky diode was done using a KARL SUSS PM5 probe station. The effect of humidity on MR film was investigated in the range of

30-90% RH. The humidity level was controlled by placing the device in the self made humidity controlled chamber. The CEM DT-8860 digital humidity meter was used for *in situ* humidity measurements.

3. Results and discussion:

The measured I-V characteristics of the Al/MR/Ag structure at room temperature are shown in Fig. 3. It is seen that the characteristics are non-linear, asymmetric and show rectification behavior. The rectification ratio (RR) was determined as the ratio of forward to reverse bias current (I_F/I_R) at biasing voltage equal to ±4 V and was found about 200. The value of turn on voltage was estimated from the I-V characteristics of Fig. 3 and it was found about 2 V. In reverse bias, no significant change has been observed in current up to 5 V, but above 5 V there is a sharp increase in current.

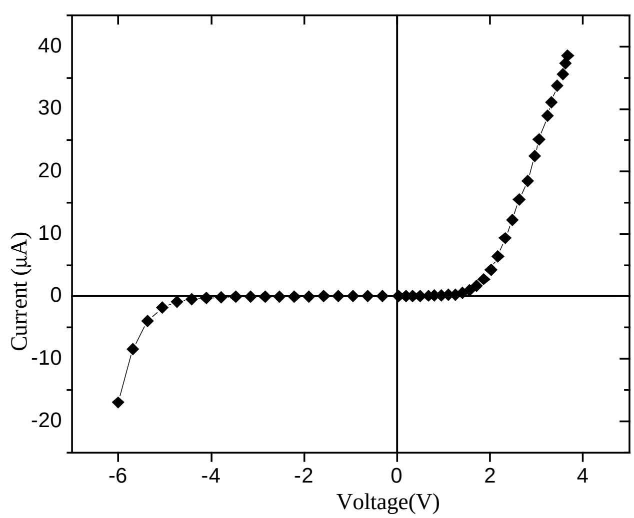

Figure (3): *I-V characteristics of Al/MR/Ag Schottky diode*

I-V characteristic of the Al/MR/Ag structure as the function of temperature is shown in Fig. 4. The high current flow at elevated temperature may be either due to increased bond breaking, and thus generating more free carriers to participate in the conduction process, or due to increased detraping of the carriers from their respective trap centers. It is observed that the barrier height decreases with increase in temperature. It can be seen from the Fig. 4 that the reduction of barrier height is not a linear function of ambient temperature. Thus the change in current is also nonlinear.

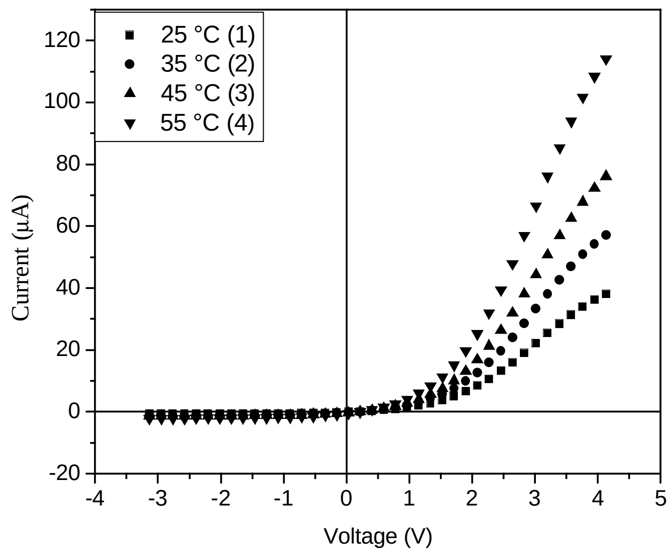

Figure (4): *I-V characteristics of Al/MR/Ag Schottky diode as a function of temperature*

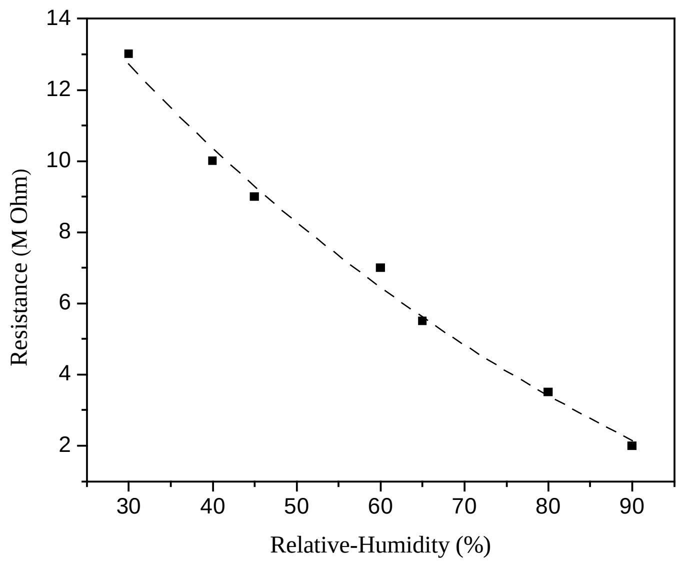

Figure (5)*: Resistance-relative humidity relationships for Al/MR/Ag Schottky diode*

The dependence of DC resistance of the device on the humidity level at room temperature is shown in Fig. 5. From this figure it is clear that the resistance drops significantly with increase in humidity level. Resistance of the sample decreases from 13 MΩ to 2.5 MΩ at relative humidity range from 30-90 %, i.e. the resistance of the junction decreases by 5.0 times over the whole relative humidity range.

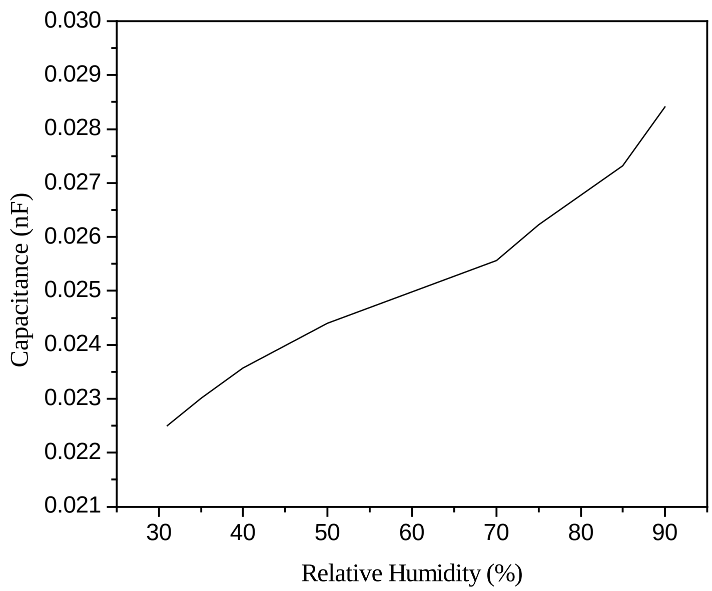

***Figure (6)**: Capacitance-relative humidity relationships for Al/MR/Ag Schottky diode*

Capacitance-relative humidity relationships for the Al/MR/Ag surface-type structure are shown in Fig. 6. It is seen from Fig. 6 that capacitance of the sample increases from 21.5 pF to 29 pF at relative humidity ranging from 30-90% RH, i.e. the capacitance of the junction increases by 1.5 times with increase in humidity. It may be due to direct absorption of water molecules as dipoles and effect of water molecules as impurities in MR play the main role in the increase of dielectric constant of the MR and hence in the capacitance [14].

4. Conclusion:

It has been seen that the Al/MR/Ag structure shows Schottky type behavior. I-V characteristics of the junction showed rectification behavior. The change in characteristics as a function of temperature may be due to increase in the density of free carriers, either by bond breaking or by detraping mechanism. It has been observed that the conduction of MR thin film increases with temperature and humidity. Due to humidity and temperature sensitivity this junction may be used for humidity and temperature sensors.

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References:

[1] F. Gutman, and L. E. Lyon, *Organic Semiconductors, Part A*, Krieger Robert E. Publishing Company, Malabar, Florida, USA, 1981.
[2] F. Gutman, H. Keyzer, L. E. Lyons, and R. B. Smoano, *Organic Semiconductors, Part B*, Kriger Robert E. Publishing Company, Florida, USA, 1983.
[3] C. M. Petty, M. R. Bryce, and D. Bloor, *An Introduction to Molecular Electronics*, St. Edmundsbury Press Limited, London, 1995.
[4] P. E. Burrows, Z. Shen, V. Bulovic, D. M. McCarty, S. R. Forrest, J. A. Cronin, and M. E. Thompson, *Relationship Between Electroluminescence and Current Transport in Organic Heterojunction Light-Emitting Devices* Vol. 79, p. 7991, 1996.
[5] C. D. J. Blades, and A. B. Walker, *Simulation of organic light-emitting diodes*, Synth. Met. Vol. 111-112, p. 335, 2000.
[6] S. R. Forrest, *Simulation of the external quantum efficiency for bilayer organic light emitting devices*, Chem. Rev. Vol.97, p. 1793, 1997.
[7] W. Brutting, S. Berleb, and *A*. G. Muckl, "*Device physics of organic light-emitting diodes based on molecular materials*, Org. Electron. Vol.2, p. 1-36, 2001.
[8] M. Lonergan, *Charge transport conjucated polymer-inorganic semiconductor and conjucated polymer-metal interfaces*, Annu. Rev. Phys. Chem. Vol. 55, p. 257, 2004.
[9] K. S. Karimov, *Electric Properties of Quasi-One Dimensional Crystals of Tetracyanoquine dimethane Complexes*, PhD Thesis, A. F. Ioffe Physical Technical Institute, St. Peterburg, Russia, 1982.
[10] K. S. Karimov, *Electric Properties of Organic Materials under Uniaxial Tension and Complession*, DSc Thesis, Department of Heat Physics, Academy of Sciences, Tashkent, Uzbekistan, 1994.
[11] K. S. Karimov, Kh. M. Akhmedov, A. A. Dzhuraev, M. N. Khan, S. M. Abrarov, and M. I. Fiodorov, *Organic-on-inorganic Ag/n-GaAs/p-CuPc/Ag photoelectric sensor*,Eurasian Chem. Technol. J. Vol. 2, p. 181, 2000.
[12] S. Aydogan, M. Saglam, and A. Turut, *On the some electrical properties of the non-ideal PPy/p-Si/Al structure*, Polymer Vol. 46, p. 10982, 2005.

[13] T. Kilicoglu, M. E. Aydin, and Y. S. Ocak, *The determination of the interface state density distribution of the Al/methyl red/p-Si Schottky barrier diode by using a capacitance method*, Physica B Vol. 388, p. 244, 2007.

[14] K. S. Karimov, I. Qazi, T. A. Khan, P. H. Draper, F. A. Khalid, and M. Mahroof-Tahir, *Humidity and illumination organic semiconductor copper phthalocyanine sensor for environmental monitoring*, Environ Monit Assess, DOI 10.1007/s10661-007-9898-5.