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ORANGE DYE BASED TEMPERATURE SENSOR

Kh.S. KARIMOV[1,2], M. SALEEM[3], Kh.M. AKHMEDOV[2], M.M. AHMED[4], A. HASSAN[1], S. SHAFIQUE[4]

[1] GIK Institute of Engineering Sciences and Technology, Topi, District Swabi, KPK, 23640, Pakistan
[2] Center for Innovative Development of Science and Technologies of Academy of Sciences,
Aini 299/2, Dushanbe, 734063, Tajikistan
[3] Government College for Boys, Gulberg Lahore- 54000, Pakistan
[4] Capital University of Science and Technology, Islamabad, Pakistan

Corresponding author: M. Saleem, E-mail: `msaleem108@hotmail.com; muh.saleem@gmail.com`

Abstract. In this study, organic semiconductor orange dye (8 wt.%) and sugar (8 wt.%) aqueous solution was prepared. The temperature sensors were fabricated by drop-casting of the solution on the surface-type, interdigitated silver electrodes, deposited on ceramic alumina sheet. In the result, it was fabricated sol-gel elastic films of orange dye-sugar blend samples. Two kinds of samples were investigated as temperature sensors: opened surface (1) and encapsulated (2). It was observed that the properties of these samples were entirely different: sample (1) showed positive temperature coefficient, as posistor, whereas sample (2) showed negative temperature coefficient, as thermistor. Temperature coefficient of impedance at 100 Hz of the posistor and thermistor were equal to +150% /°C and -9.7% /°C, respectively. The transistors can be used as temperature sensors.

Key words: organic semiconductor, complex, film, deposition, drop-casting, orange dye, sugar, sol-gel film, aqueous, impedance, posistor, thermistor, sensor, temperature.

1. INTRODUCTION

Temperature sensors are used widely in automatic control systems. Majority of the temperature sensors is based on electrical properties of materials. Temperature is the most often-measured environmental parameter. Temperature affects to the physical, electronic, chemical, mechanical, and biological systems. It is known that many processes work well only within specific temperature range. Temperature sensors and analog-to-digital converters based on p-type and n-type organic semiconductor transistors were described in [1], where it was presented an organic temperature detector that consists of an organic temperature sensor and an organic complementary read-out circuit. The temperature sensor was a Wheatstone bridge composed of temperature sensitive polymer films and metal films. Flexible thermal sensors based on organic field effect transistors with polymeric channel/ gate-insulating and light-blocking layers were described in [2]. This flexible OFET-based thermal sensors exhibited typical p-type transistor characteristics at a temperature range of 25–100 °C while the hole mobility of devices was linearly increased with temperature. In [3], the effect of temperature on hysteresis of dipolar dielectric layer based organic field effect transistors, in particular, temperature sensing mechanism was studied. Organic field effect transistor (OFET) based ultrafast, flexible, physiological–temperature sensors with hexagonal barium titanate nanocrystals in amorphous matrix as sensing material was discussed [4] and it was shown that the sensors are highly stable around of body temperature and work at various extreme conditions, such as under water and in solutions of different pH values and various salt concentrations. Ravariu et al. [5], reported the fabrication of organic transistors based on para-aminobenzoic acid (PABA) grafted to ferrite nanoparticles, at room temperature. The measurement of output characteristics in the saturation regime and transfer characteristics at negative gate voltages proved the synthesis of an organic transistor based on PABA-NCS. In [6], the simulation results showed that if the source/drain regions are semiconductors, the Nothing On Insulator (NOI) devices worked as a transistor.

In [7], an organic temperature sensor based on asymmetric metal insulator semiconductor capacitor with electrically tunable sensing area was discussed. It was shown that an area-asymmetric organic metal-insulator (AMIS) capacitor exhibits strong temperature dependence. The gate electrode in the device was made much larger than the top electrode so that a significant fraction of the capacitance comes from the channel. Tactile and temperature sensors based on organic transistors for e-skin fabrication was described in [8]: a systematic review of organic transistor-based sensors was presented to summarize the latest progress in these devices. Printable, highly sensitive flexible temperature sensors for human body temperature monitoring: a review was published in [9]. This article reviews the current research status of highly sensitive patterned flexible temperature sensors used to monitor body temperature changes. Fully printed PEDOT:PSS based temperature sensor with high humidity stability for wireless health care monitoring was described in [10]. This sensor exhibits excellent stability in environmental humidity ranged from 30% RH to 80% RH, and high sensitivity of ($-0.77\%\ ^{o}C^{-1}$) for temperature sensing between 25 °C and 50 °C. Moreover, a wireless temperature sensing platform was obtained by integrating the printed sensor to a printed flexible hybrid circuit, which performed a stable real-time health care monitoring. In [11], we investigated aluminum phthalocyanine chloride thin films for temperature sensing. Impedimetric humidity and temperature sensing properties of chitosan-$CuMn_2O_4$ spinel nanocomposite were investigated by us as well [12].

In this study, we continue the investigation of temperature sensitive devices based on organic semiconductors [13–15]. We are presenting the properties of the organic semiconductor orange dye-based temperature sensor which have actually, structure of the organic thin film transistor.

2. EXPERIMENTAL

In this study, aqueous solution of commercially available organic semiconductor orange dye (8 wt.%) and sugar (8 wt.%), was prepared. As orange dye (OD) and sugar (disaccharides) both are well dissolved in water, we can assume that these both ingredients blend solution will form here some complex. Figure 1 shows molecular structure of orange dye [13] and Fig. 2 represents molecular structure of sugar. The sugar was used for fabrication of conducting coating. It was observed by us that sugar makes adhesion of the deposited film much better with respect to only OD films deposited from aqueous solution. As a solvent, distilled water was used. Commercially available surface-type interdigitated silver electrodes coated with ceramic alumina sheet fabricated by screen printing and chemical etching technology [13] were used as the substrates. Sizes of substrate were equal to 14 mm: 7 mm: 0.5 mm with width of electrodes and interelectrode distances as well, of 200 μm. Length of the electrodes was equal to 7 mm.

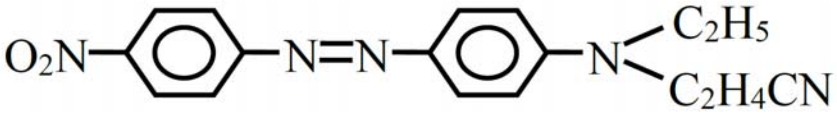

Fig. 1 – Molecular structure of orange dye (OD).

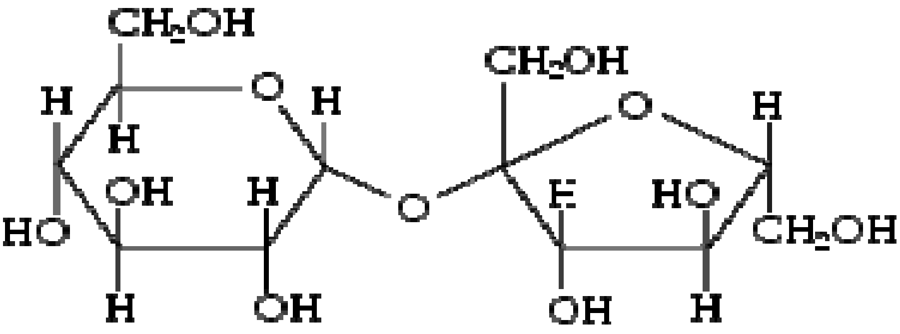

Fig. 2 – Molecular structure of sugar.

The samples were fabricated by drop-casting of the solution. Figure 3 shows atomic force microscope (AFM) images of the OD-sugar sample. Figure 4 shows cross section of the sensor which has some similarity with organic thin film transistor-based temperature sensor (opened sensor (a) and encapsulated sensor (b)).

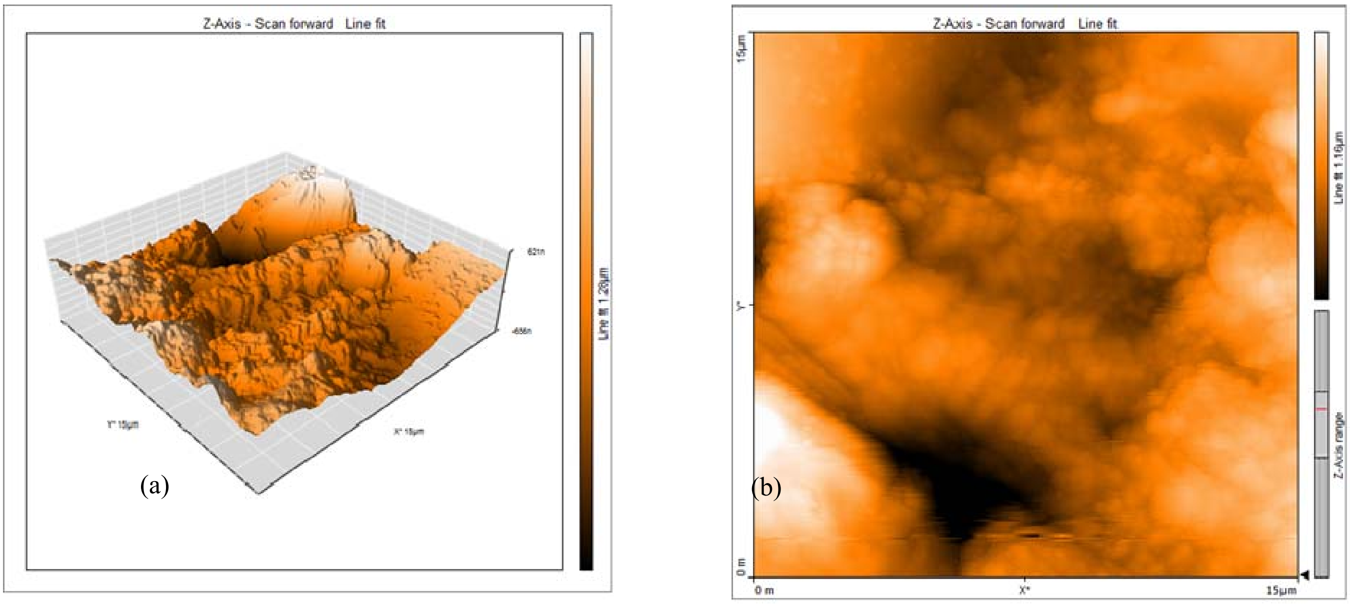

Fig. 3 – Atomic force microscope image of the OD-sugar film: 3D (a) and 2D (b) images.

The thickness of the OD-sugar thin films were in the range of 810–930 nm. The OD-sugar samples were deposited by drop-casting on flexible dielectric substrates as well and it was found that OD-sugar films are actually, gel showing good flexibility and softness. This technology is called sol-gel technology which was developed earlier and used for the fabrication of silicate thin films on silicon [11]. We measured thermoelectric (Seebeck) effect in the OD-sugar samples and found that the samples were p-type semiconductors. The orange dye molecular structure (Fig. 1) shows the presence of double bond or pai-electrons as well that can bring to the generation of electrons and holes at thermal excitation of the electrons. According to mobility of electron and holes, the semiconductor may show p-type or n-type conductivity and accordingly, the properties that were observed in our paper. The sugar itself is not semiconductor but used as filler can affect to the conductivity as well.

For measurements of voltage and current, digital multimeters HIOKI DT4252 and HIOKI DT4253 were used. For measurement of the temperature, FLUKE87 multimeter with built-in thermocouple was used. For heating of the samples, Torrey Pines Scientific hot plate was used.

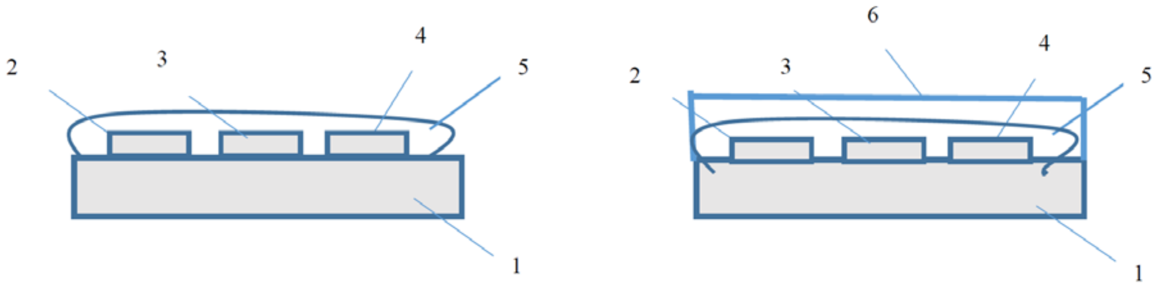

Fig. 4 – Cross section of OD-Sugar based, open (a) and encapsulated (b) temperature sensor like to an OFET having substrate (1), source (2), gate (3), drain (4), orange dye complex film (5), capsule (6).

3. RESULTS AND DISCUSSIONS

Figure 5 shows impedance Z (100 Hz) and temperature relationship for the OD-sugar based sensor operating as opened device. It is seen that as temperature increases, impedance increases as well. This behavior is attributed to the temperature sensor which is called posistor [12]. At temperature equal to 28 °C, the temperature coefficients of impedance (α) is equal to:

$$\alpha = \frac{\Delta Z}{Z(\Delta T)} \times 100[\%], \tag{1}$$

where ΔZ, Z and ΔT are increment of impedance, impedance and increment of temperature, respectively. It was found that $\alpha = +150\%/^{\circ}\mathrm{C}$.

Figure 6 shows impedance Z (100 Hz) and temperature relationship for the OD-sugar based temperature operating as encapsulated temperature device. It is seen that as temperature increases, impedance decreases as well. This behavior is attributed to the temperature sensor which is called thermistor [13]. At 28 °C, temperature coefficients of impedance is equal to $-9.7\%/^{\circ}\mathrm{C}$.

The results which demonstrated in Fig. 5 and Fig. 6 can be explained by the following way. It can be assumed that in the case of the opened temperature sensor (Fig. 5), where the sensitive film was opened with respect to the environment, heating of the sample brings to the evaporation of the humid and accordingly, to decrease of the concentration of water molecules in the OD-sugar film. Our investigations showed that at decrease of the humidity, the impedance and resistance of the OD-sugar films increased. Therefore, impedance of the OD-sugar sample (Fig. 5) is increasing at the heating as humid in the body of the samples decreased. In the contrary, in the case of OD-sugar based device operating as encapsulated (Fig. 4b) temperature sensor, the humidity in the body of the sample should be approximately constant. Therefore, heating of the sample can bring to increase of the conductivity of the OD-sugar sample (Fig. 6), as it is organic semiconductor, due to increasing of the concentration and, probably, of mobility of charge carriers due to hopping mechanism of conduction which is common in the organic semiconductors [14, 15].

As relationships shown in Fig. 5 and Fig. 6 are actually, non-linear, that may be due to presence of the metal-semiconductor Schottky junctions with depletion region in the Ag-OD-Ag structures. From electronic point of view, these junctions can be represented as oppositely connected semiconductor diodes. Presence of depletion region definitely influence to the sensitivity of the device positively. We are presenting here short version of the paper. All characteristics and schematic diagrams of the devices will be submitted for publication in the “Applied Physics A Materials Science & Processing”. Presented in the paper, information and Figs. 4, 5, and 6 show that the temperature sensor actually, can be used in two modes of operation: in open and in encapsulated structure, which showed entirely different mechanism of operation and properties.

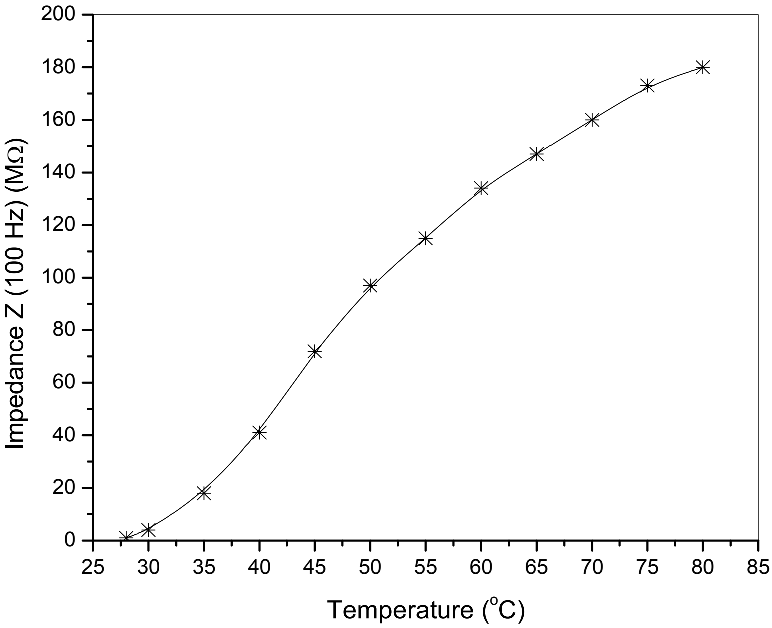

Fig. 5 – Impedance Z (100 Hz) and temperature relationship
for the OD-sugar based temperature sensor operating as opened device.

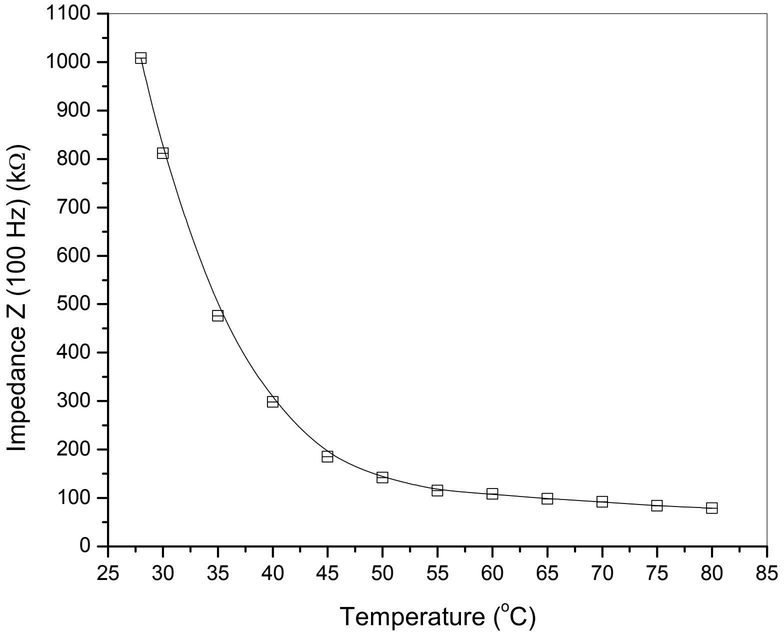

Fig. 6 – Impedance Z (100 Hz) and temperature relationship
for the OD-sugar based temperature sensor operating as encapsulated device.

Recently [16], a highly sensitive capacitive cell, based on a novel CuTsPc-TiO_2 nanocomposite electrolytic solution for low-temperature sensing applications, was investigated. Organic semiconductor temperature sensors based on conductive polymers, patterned by a selective-wetting method was presented in [17]. The properties of newly fabricated devices, in principle can be explained by physical approaches which are well-known in literature [18, 19]. At the same time, concrete data obtained by researches in last few years finally allow to bring the commercialization of the data obtained in the research laboratories.

4. CONCLUSION

Orange dye and sugar-based temperature sensors having structure of organic thin film transistor was fabricated. All terminals, of the sensor were placed in the bottom plane unlike to traditional configurations. The impedance-temperature relationships of the temperature sensor were investigated. It was observed that opened surface and encapsulated samples showed, respectively positive and negative temperature coefficients. It was shown that the sensors are highly sensitive to the influence of the temperature and can be used as thermistors and as posistors as well, including for demonstration purposes in education.

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