

Temperature sensitivity of Zn/orange dye aqueous solution/carbon cell

K. S. KARIMOV^{a,b}, M. SALEEM^{c,*}, M. MEHRAN BASHIR^a, T. ALI^a

^aGIK Institute of Engineering Sciences and Technology, Topi, District Swabi-23640, Pakistan

^bPhysical Technical Institute of Academy of Sciences, Rudaki Ave.33, Dushanbe-734025, Tajikistan

^cGovernment College of Science, Wahdat Road, Lahore-54570, Pakistan

An investigation is made of the resistance and capacitance temperature sensitivity of a Zn/orange dye aqueous solution/carbon cell. In this cell, a solution of 3 wt.% orange dye ($C_{17}H_{17}N_5O_2$) in distilled water is used as the electrolyte and zinc and carbon rods serve as electrodes. The cell is fabricated in organic glass box and has a height, width and thickness of 35, 30 and 14 mm, respectively. The resistance and capacitance-temperature studies are made in the interval of 35-80 °C. It is found that the resistance and capacitance of the cell depend on temperature: temperature sensitivity of the cell was $-1.2\%/^{\circ}C$ and $1.5\%/^{\circ}C$ for the resistance and capacitance respectively. The Zn/orange dye aqueous solution/carbon cell can be used as solution based resistive and capacitive temperature sensor.

(Received February 6, 2015; accepted April 5, 2016)

Keywords: Capacitance, Electrochemical cell, orange dye, Aqueous solution, Resistance sensitivity

1. Introduction

At present, a rapid advancement is observed in the development of the sensors for application in monitoring various parameters such as humidity, temperature, illumination and concentration of different kinds of gases. Temperature measurement is important not only for the comfort of human being but also essential for other living organisms, agriculture, industrial processes, storage and transportation etc. Temperature sensors are normally categorized as contact and non-contact type sensors. The former type includes resistance temperature detectors (RTDs) and thermocouples. The RTDs may also be classified as thermal sensitive resistors (thermistors) and resistance wire RTDs. For the fabrication of temperature sensors, the commonly used sensing materials are the platinum and gold, which are very expensive [1-2]. Research is being carried out to replace expensive sensing materials with cheaper, low density, flexible and easy to fabricate materials. For this purpose organic materials are considered potentially very promising [3-6]. The resistance-temperature devices are considered highly sensitive and accurate. For some cryogenic applications, currently carbon based resistance-temperature sensors are being used.

In the last few years, not only solid but solution based organic semiconductor devices as a temperature sensors were fabricated and investigated. As a potential material for a solution based temperature sensor an organic compound Nickel (II) phthalocyanine-tetrakisulfonic acid tetrasodium salt (NiTSPc) has been studied [7]. Using NiTSPc, an ITO/NiTSPc solution/ITO cell has been made and characterized in the temperature range of 20–85 °C. It

was observed the change in the resistance and capacitance of the cell caused by the temperature variation.

Orange dye (OD) is a p-type organic semiconductor and is a potential candidate for use in electronic devices. In an earlier study [8], we have reported a poly-N-epoxypropylcarbazole/OD heterojunction that was deposited from aqueous solution under high gravity conditions by centrifugation. This two layer structure exhibited rectification behaviour. Actually, orange dye has excellent solubility in water, good absorption in visible spectrum. It is also stable in normal conditions and harmless. Therefore, it would be useful to use this material in electrochemical devices that could be used for storage and conversion of energy and as sensors in instrumentation as well. An investigation of the electrochemical properties of a Zn/orange dye aqueous solution/carbon cell was done [9] and the discharge voltage-current, charge voltage/current-time and discharge voltage/current-time studies are made. It is found that the cell is rechargeable. The electrical conductivity of OD aqueous solutions were investigated [10]. Aluminum electrodes were used in the conductance cell. It was found that the electrical conductivity of the OD solution increased with temperature, frequency and the applied voltage. Conductivity-concentration relationship showed a maximum conductivity at 0.05 mol/dm^3 . In continuation of our efforts for investigation of the Zn/orange dye aqueous solution/carbon cell, in this paper an investigation is made for the temperature sensitivity of a Zn/orange dye aqueous solution/carbon cell's parameters.

2. Experimental

Commercially produced organic semiconductor orange dye, $C_{17}H_{17}N_5O_2$ (Fig. 1) with a molecular weight of 323 g and a density of 0.9 g cm^{-3} was used for preparation of the electrolyte for a Zn/orange dye aqueous solution/carbon electrochemical cell. Using a 'hot-probe' method, it was confirmed that orange dye is a p-type semiconductor. In this cell, a solution of 3 wt.% orange dye in distilled water as electrolyte was used. The schematic diagram of the cell is shown in Fig. 2. The sizes of zinc and carbon electrodes were $34 \times 17 \times 1.5 \text{ mm}$ and $34 \times 26 \times 3 \text{ mm}$, respectively. The cell was assembled in an organic glass box, cell's sizes were equal to $35 \times 30 \times 14 \text{ mm}$. The separation between the Zn and carbon electrodes was 7 mm and the volume of electrolyte was 5 ml. The resistance and capacitance of the cell were measured by LCR meter Agilent U1732A at 100 Hz. Temperature was measured by liquid in glass thermometer and FLUKE 87V multimeter. The experiments were conducted in the standard laboratory chamber for investigation of temperature sensitivity of the parameters of the devices.

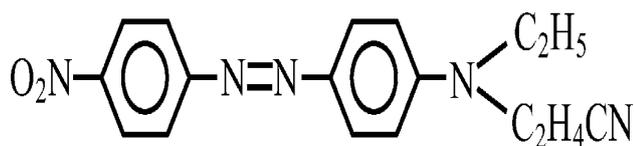


Fig. 1. Molecular structure of orange dye (OD).

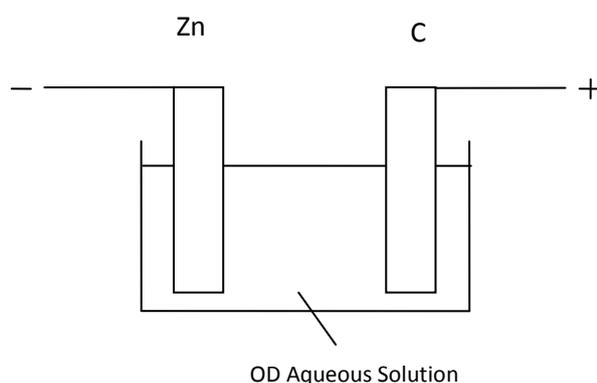


Fig. 2. Schematic diagram of Zn/orange dye aqueous solution/carbon cell.

3. Results and discussion

Fig. 3 shows resistance-temperature and capacitance-temperature relationships measured at 100 Hz for Zn/orange dye aqueous solution/carbon cell. It is seen that the resistance decreases and capacitance increases with rise in temperature. The dependences are quasi-linear. The

average resistance temperature coefficient (S) of the cell calculated by using Eq. 1 [11] was $-1.2\%/^{\circ}\text{C}$.

$$S = \left(\frac{\Delta R}{R_0 \Delta T} \right) \times 100\% \quad (1)$$

where R_0 is the initial resistance, ΔR is the change in resistance and ΔT is the change in temperature. By the same way the average capacitance temperature coefficient was found that was equal to $1.5\%/^{\circ}\text{C}$. Fig. 3 shows that the temperature coefficient of the resistance is negative and temperature coefficient of the capacitance is positive for the Zn/orange dye aqueous solution/carbon cell.

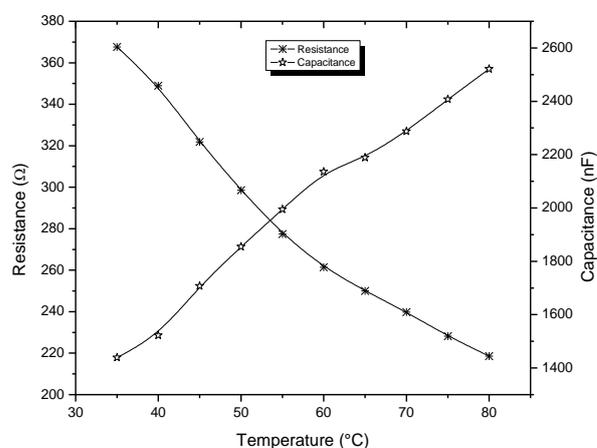


Fig. 3. Resistance-temperature and capacitance-temperature relationships for the Zn/orange dye aqueous solution/carbon cell.

The conductivity of the electrolytes depends on the concentration of the ions and their velocity. The conductivity (σ)-concentration relationships are determined by the following expression [12]:

$$\sigma = 10^{-3} \alpha c F (v_c + v_a) \quad (2)$$

where F is constant, α is dissociation constant, c is concentration of the solution (in mol/dm^3), v_c and v_a are velocities of the cations and anions, respectively. The conductivity-temperature relationship is described by the formula [12]:

$$\sigma_2 = \sigma_1 [1 + A(T_2 - T_1)] \quad (3)$$

where σ_1 and σ_2 are conductivity values at T_1 and T_2 , respectively, A is temperature conductance coefficient.

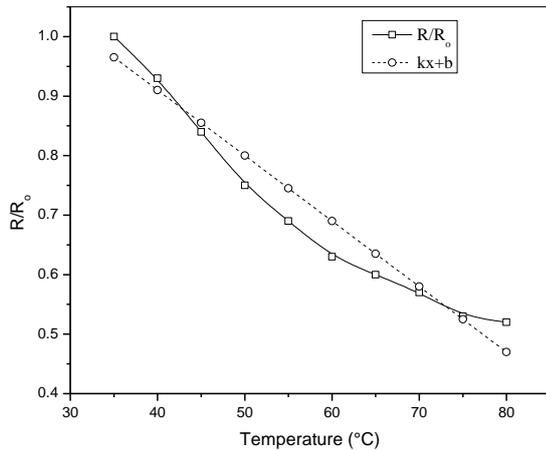


Fig. 4. Experimental (solid line) and simulated (dashed line) relative resistance-temperature relationships for the Zn/orange dye aqueous solution/carbon cell: R_0 is initial value of the resistance at 35 °C.

The resistance temperature coefficients (S) of the samples are lower than in solid semiconductor thermistors, but they are much larger than in metals [11].

Using a linear function [13]:

$$y = kx + b \quad (4)$$

The relative resistance can be represented as:

$$\frac{R}{R_0} = kT + b \quad (5)$$

where R , R_0 and k are resistance, initial resistance and temperature coefficient, respectively.

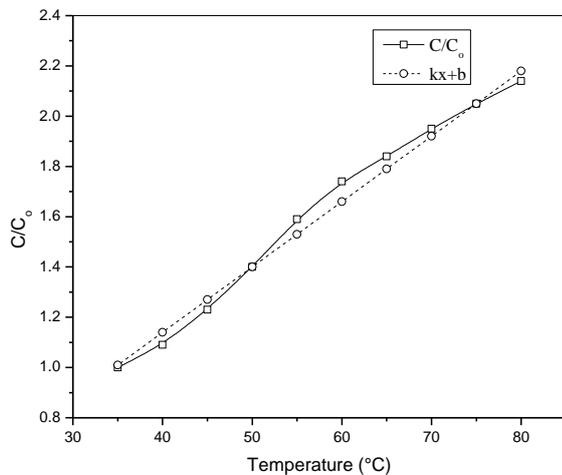


Fig. 5. Experimental (solid line) and simulated (dashed line) relative capacitance-temperature relationships for the Zn/orange dye aqueous solution/carbon cell: C_0 is initial value of the capacitance at 35 °C.

Experimental (solid line) and simulated (dashed line) by using Eq. 5 results are plotted in Fig. 4 and are observed in good agreement with experimental results at k and b in Eq. 5 equal to $-0.011 \text{ } ^\circ\text{C}^{-1}$ and 1.35, respectively. By the same way the capacitance-temperature relationships were simulated. The simulated and experimental graphs of capacitance vs temperature are presented in Fig. 5 for $k = 0.026 \text{ } ^\circ\text{C}^{-1}$ and $b = 0.1$.

The resistance-temperature relationships observed from the investigation of the Zn/orange dye aqueous solution/carbon cell can be explained by considering the effect of heating on the orange dye and water molecules in the solution. The decrease of the resistance with increase of the temperature may be due to increase of the concentration of the charges due to dissociation, first of all, [14].

Secondly, it may be due to contribution of displacement current of bound charges of dipoles of molecules [15]. The capacitance-temperature relationships can be explained by the same manner: the increase of total polarizability due to increase of ions concentration and polarizability of the dipole molecules definitely increases the capacitance.

The investigated temperature dependences of the resistance and capacitance of the Zn/orange dye aqueous solution/carbon cell can be potentially used for measurement of the temperature as dependences, firstly, are quasi-linear, can be easily linearized by using linear circuits, secondly, the value of the temperature coefficient, especially capacitance temperature coefficient, is sufficiently high for practical applications, and thirdly, availability of opposite signs of the temperature coefficients of resistance and capacitance, in principle, allows to fabricate low frequency oscillators [16] on the base of temperature sensitive cell.

4. Conclusion

The resistance and capacitance-temperature studies of a Zn/orange dye aqueous solution/carbon cell made at 100 Hz showed that the resistance and capacitance of the cell depend on temperature: temperature sensitivity of the cell was equal to $-1.2\%/^\circ\text{C}$ and $1.5\%/^\circ\text{C}$ for the resistance and capacitance, respectively. The resistance and capacitance-temperature dependences are simulated by the linear function and showed good agreement. The dependences are quasi-linear that make potential application of these cells as temperature sensor.

Acknowledgement

We are thankful to GIK Institute of Engineering Sciences and Technology of Pakistan for the support extended to this work.

References

- [1] C. Y. Lee, G. W. Wu, W. J. Hsieh, *Sensors Actuat. A* **147**, 173 (2008).
- [2] J. J. Park, M. Taya, *J. Electronic Packaging* **127**, 286 (2005).
- [3] S. Cho, L. Piper, A. DeMasi, A. Preston, K. Smith, K. Chauhan, P. Sullivan, R. Hatton, T. Jones, *J. Physical Chem. C* **114**, 1928 (2010).
- [4] J. Drechsel, B. Mannig, D. Gebeyehu, M. Pfeiffer, K. Leo, H. Hoppe, *Org. Elect.* **5**, 175 (2004).
- [5] J. Reboun, A. Hamacek, T. Dzigan, M. Kroupa, *IEEE*, 40 (2010).
- [6] S. Mathew, C. S. Menon, *OAM-RC* **4**, 63 (2010).
- [7] Z. Ahmad, Sh. M. Abdullah, Kh. Sulaiman, *Sensors Actuat. A* **179**, 146 (2012).
- [8] Kh. S. Karimov, M. M. Akhmed, R. M. Gul, M. Mujahid, Kh. M. Akhmedov, J. Valiev, *Proceedings of ISAM-2001, Rawalpindi, Pakistan*, 329 (2002).
- [9] Kh. S. Karimov, M. H. Sayyad, M. Ali, M. N. Khan, S. A. Moiz, Kh. B. Khan, H. Farah, Z. M. Karieva, *J. Power Sources* **155**, 475 (2006).
- [10] Kh. S. Karimov, I. Qazi, Z. M. Karieva, T. A. Khan, I. Murtaza, *Electrical properties of orange dye aqueous solution*, *Kuwait J. Sci. Eng.* **35**, 1 (2008).
- [11] J. W. Dally, W. F. Riley, K. G. McConnell, *Instrumentation for Engineering Measurements*, 2nd ed., John Willey & Sons, Inc., New York, U.S.A., 1993.
- [12] K. S. Krasnov, *Physical Chemistry*, published by "Visshaya Shkola", Moscow, Russia, 1982.
- [13] A. Croft, R. Davison, M. Hargreaves, *Engineering Mathematics. A Modern Foundation for Electronic, Electrical and Control Engineers*. Addison-Wesley Publishing Company, Great Britain, 1993.
- [14] D. B. Hibbert, *Introduction to Electrochemistry*, Macmillan Press Ltd., London, Great Britain, 1993.
- [15] D. V. Sivukhin, *Physics*, Vol. 3, *Electricity*, Nauka, Moscow, Russia, 1977.
- [16] I. T. Sheftel, *Thermistors*, Nauka, Moscow, USSR, 1973.

*Corresponding author: msaleem108@hotmail.com;
drsaleem@ymail.com