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Short communication

Electrochemical properties of Zn/orange dye aqueous solution/carbon cell

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Abstract

An investigation is made of the electrochemical properties 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 a cylindrical glass vessel and has a length and a diameter of 4 and 2 cm, respectively. 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 open-circuit voltage and short-circuit current of the fully charged cell is 1.5 V and 0.45 mA, respectively. The efficiency of current discharge/charge is 67%. The discharge voltage/current–time characteristics exhibit stable and constant behaviour.

Keywords: Rechargeable cell; Electrochemical sensor; Orange dye; Charge–discharge process; Organic semiconductor; Energy storage and conversion

1. Introduction

The study of the electric and electrochemical properties of organic materials remains an area of frontier research and is influencing the modern and future technologies of solid-state and electrochemical devices. This is mainly due to low cost, simplicity of device fabrication, interesting electrical, electrochemical and optical properties, and environmentally harmless or friendly technology. Many potential applications of organic semiconductors may be realized via investigation and modification of their conductivity [1–4]. Organic semiconductors have been investigated very intensively during the past decade and, as a result, a number of different types of devices have been fabricated. Presently, some organic semiconductors are used in commercially-produced light emitting diodes.

Undoubtedly, organic semiconductors will find more niches among electronic appliances in the near future and, therefore, the search for new organic materials is expected to continue. Some organic semiconductors are very sensitive to humidity [1,2], temperature [5,6], infra-red, visible and ultraviolet radiation [7], and different types of gases such as ammonia [8]. Obviously, investigation of electrochemical behaviour and fabrication of electrochemical cells and sensors with liquid and solid electrolytes on the base of organic materials is very promising area [9,10]. For example, Panozzo et al. [11] have described a high-efficiency light-emitting electrochemical cell on the base of organic salt and Arnold [3] has reported an electrochemical glucose sensor. Organic-based transistors that are able to detect charged/uncharged chemical species in aqueous media via the electric field have been developed by Bartic et al. [12]. It is shown that the

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transistor is sensitive to protons and glucose. A number of ion-selective electrode devices, semi-conducting oxide sensors and electrochemical ones based on liquid and solid electrolytes have also been described [3,13].

Orange dye (OD) is a p-type organic semiconductor and is a potential candidate for use in electronic devices. In an earlier study [14], we reported a poly-*N*-epoxipropylcarbazole/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. This paper reports an investigation of the electrochemical properties of a Zn/orange dye aqueous solution/carbon cell.

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 and zinc and carbon rods with length of 4 cm and diameter of 4 mm as electrodes were used. The cell was assembled in a cylindrical glass vessel (Fig. 2) and cell's length and diameter were 4 and 2 cm, respectively. The separation between the Zn and carbon electrodes was 3.5 mm and the volume of electrolyte was 6 cm^3.

The discharge voltage–current, charge voltage/current–time and discharge voltage/current–time characteristics of the cell were measured at room temperature by conventional digital meters.

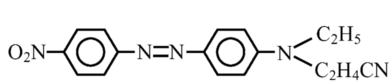

Fig. 1. Molecular structure of orange dye (OD).

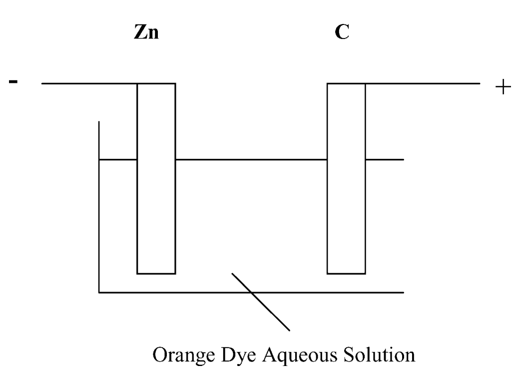

Fig. 2. Schematic diagram of Zn/orange dye aqueous solution/carbon cell.

3. Results and discussion

The discharge voltage–current (*V–I*) relationship of the Zn/orange dye aqueous solution/carbon electrochemical cell is shown in Fig. 3. The *V–I* relationship is typical for electrochemical cells [15]. The zinc electrode's potential has a negative polarity with respect to the carbon electrode of the cell. The charge voltage/current–time and discharge voltage/current–time curves of the cell are presented in Figs. 4 and 5, respectively. It is found that the cell is rechargeable. The measured values of the open-circuit voltage and short-circuit current of the fully charged cell are 1.5 V and 0.45 mA, respectively (Fig. 3). The current efficiency, i.e., the ratio of the quantity of electricity obtained from the cell and that used to charge it (Figs. 4 and 5) for a fixed time of 4 h is 67%. The discharge voltage/current–time characteristics exhibit stable and constant behaviour (Fig. 5), unlike the Leclanche cell [15].

Probably, the cell reactions are a follows:

$$\text{Anode}: \quad Zn \rightarrow Zn^{2+} + 2e^- \tag{1}$$

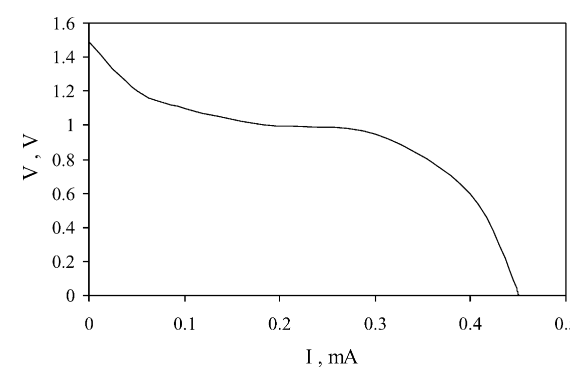

Fig. 3. Voltage of Zn/orange dye aqueous solution/carbon cell as function of discharge current.

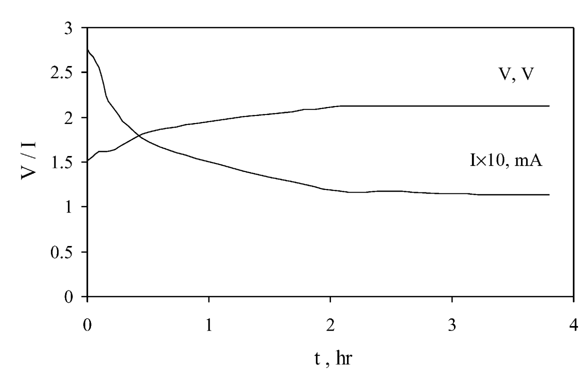

Fig. 4. Charge voltage/current–time curves for Zn/orange dye aqueous solution/carbon cell.

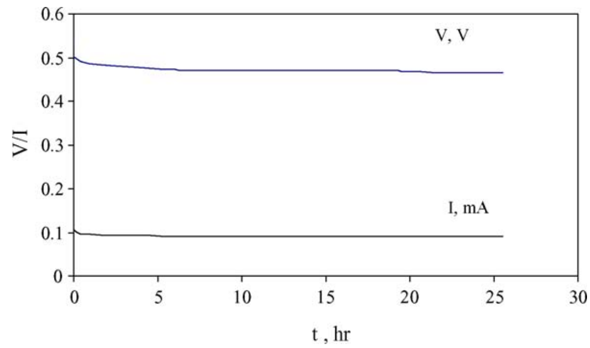

Fig. 5. Discharge voltage/current–time curves for Zn/orange dye aqueous solution/carbon cell.

$$\text{Cathode}: \quad 2(C_{17}H_{17}N_5O_2) + 2H_2O + 2e^- \rightarrow 2(C_{17}H_{17}N_5O)(OH) + 2OH^- \tag{2}$$

$$\text{Cell}: \quad 2(C_{17}H_{17}N_5O_2) + 2H_2O + Zn \rightarrow Zn^{2+} + 2(C_{17}H_{17}N_5O)(OH) + 2OH^- \tag{3}$$

In the Zn/orange dye aqueous solution/carbon cell, we replaced the Zn electrode by carbon, charged the cell and found that in the discharge mode the operation voltage and current dropped from 0.2 to 0.003 V and from 0.036 to 0.0006 mA, respectively, during 12 h. This means that in the Zn/orange dye aqueous solution/carbon version, the Zn electrode is active with respect to that of carbon.

The electrical energy of the cell as a change of free energy (ΔG) was found to be $-290\ \text{kJ mol}^{-1}$ by using the following expression [15]:

$$\Delta G = -nFE \tag{4}$$

where n is the number of electrons transferred per mole (it is equal to 2); F the Faraday constant (96487 C); and E is the cell voltage (1.5 V).

The capacity of the cell (C) was calculated using the expression [15]:

$$C = nF(W/\text{MW}) \tag{5}$$

where W is the weight of active electrode material (Zn in this case: its weight is equal to 3.57 g); MW the molecular weight of the material (for the Zn it is equal to 65.37). The calculated value of C is 10.54 kC = 2.93 Ah.

The conductivity of the orange dye aqueous solution was investigated and it increases with increases in the concentration of $C_{17}H_{17}N_5O_2$. This means that the Zn/orange dye aqueous solution/carbon cell may be used as electrochemical sensor of moisture and water precipitation, as well as in instruments for measuring environmental parameters.

4. Conclusions

An electrochemical Zn/orange dye aqueous solution/carbon cell has been fabricated and its electrochemical properties have been investigated. The cell is found to be rechargeable. The open-circuit voltage and short-circuit current of the fresh and fully charged cell are 1.5 V and 0.45 mA, respectively.

The current discharge/charge efficiency is 67%. The discharge voltage/current–time characteristics exhibit stable and constant behaviour. The cell may be used as a source of electric power for low power applications, as an electrochemical sensor of moisture or water precipitation, and for measuring environmental parameters.

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References

[1] F. Gutman, L.E. Lyons, Organic Semiconductors, Part A, Krieger Robert E. Publishing Company, Malabar, Florida, USA, 1981, p. 125.
[2] F. Gutman, H. Keyzer, L.E. Lyons, R.B. Somoano, Organic Semiconductors, Part B, Krieger Robert E. Publishing Company, Malabar, Florida, USA, 1983, p. 35.
[3] E. Arnold, in: C.M. Petty, M.R. Bryce, D. Bloor (Eds.), An Introduction to Molecular Electronics, St. Edmundsbury Press Limited, London, 1995, p. 142.
[4] T. Mikayama, H. Matsuoka, K. Uehara, A. Sugimoto, K. Mizuno, N. Inoue, Trans. IEEE Jpn. 118 (1998) 1435.
[5] Kh.S. Karimov, PhD Thesis, A.F. Ioffe Physical Technical Institute, St. Peterburg, Russia, 1982.
[6] Kh.S. Karimov, DSc Thesis, Department of Heat Physics, Academy of Sciences, Tashkent, Uzbekistan, 1994.
[7] Kh.S. Karimov, Kh.M. Akhmedov, A.A. Dzhuraev, M.N. Khan, S.M. Abrarov, M.I. Fiodorov, Eurasian Chem. Technol. J. 2 (2000) 251–256.
[8] M.I. Fiodorov, Patent #2124719, Moscow, Russia (1999) 3.
[9] J.R. Stetter, W.R. Penrose, Sh. Yao, J. Electrochim. Soc. 150 (2003) S11.
[10] B. Oh, D.R. Vissers, Z. Zhang, R. West, H. Tsukamoto, K. Amine, J. Power Sources 119–121 (2003) 442–447.
[11] S. Panozzo, M. Armand, O. Stephan, Appl. Phys. Lett. 80 (2002) 679–681.
[12] C. Bartic, A. Campitelli, S. Borghs, Appl. Phys. Lett. 82 (2003) 475–477.
[13] A.R. Blythe, Electrical Properties of Polymers, Cambridge University Press, USA, 1979, p. 91.
[14] Kh.S. Karimov, M.M. Ahmed, R.M. Gul, M. Mujahid, Kh.M. Akhmedov, J. Valiev, Proceedings of the Advanced Materials – 2001, Dr. A.Q. Khan Research Laboratories, Rawalpindi, Pakistan, 2002, pp. 329–333.
[15] D.B. Hibbert, Introduction to Electrochemistry, Macmillan Press Ltd., London, UK, 1993, p. 294.