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Polycarbazole-based electrochemical transistor

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Abstract A polycarbazole conducting polymer transistor has been constructed having the dimensions 1 cm × 2 cm × 1 mm. Polycarbazole film used here has a redox potential of 1.30 V. Polymer-coated platinum plates were used as the source and drain. The inter-electrode spacing of the device is typically of the order of 200–500 μm to minimise the internal resistance. The high saturation current region of the transistor in the most positive bias voltage (1.3 V), with negligible hysteresis and greater stability, appears to give a device that is superior to other conducting polymer transistors.

Key words Transistor · Conducting polymer · Polycarbazole

Introduction

Recent interest in developing organic conducting polymers for several molecular electronics applications has led to the discovery of polymer-based transistors [1–5]. The first organic polymer-based transistor was reported by Wrighton et al. [1] in 1984, and this led to the examination of the suitability of other conducting polymers for transistor applications; these include polypyrrole [1], polyaniline [2], polythiophene [3–4] etc. Since then, many types of transistors were made which can be broadly classified as electrochemical transistors [1–2] and field effect transistors (FETs) [3–5]. Recently, Garnier et al. [5] reported an all-polymer field effect transistor, using α,ω-dihexylsexithiophene, which had high field effect mobility ($\mu_{FET} = 7 \times 10^{-2}$ cm^2 V^{-1} s^{-1} and $g_m = 61$ nA/V); the high mobility was attributed to the ordered structure formed by self-assembly. The polymer-based transistor would be expected to be superior to conventional inorganic transistors. Furthermore, the sophisticated technology required for constructing the inorganic transistors can be replaced by a simpler technology involving organic conducting polymers. Although mass transport aspects of polycarbazole conducting polymer have been investigated [7–10], its use in battery [11] and biosensor applications has only recently been reported [12, 13]. Since this polymer has a high redox potential ($E^\circ = 1.33$ V) compared to the other polymers, a transistor made of polycarbazole would be expected to have better transfer and saturation characteristics. In this paper we report the construction and performance characteristics of a polycarbazole transistor.

Experimental

The polycarbazole films were formed on Pt-coated glass (1 cm × 2 cm) by using a PAR 273 potentiostat/galvanostat interfaced with an IBM-compatible computer. A Pt gauze counter electrode was used in the experiment. A Ag/AgCl electrode was used as the reference electrode. The deposition was carried out at 1.6 V from 60 mM carbazole containing 0.1 M tetra-*n*-butylammonium perchlorate in methylene chloride. The polymer was deposited for a period of 300 s. The polycarbazole deposit was washed with methylene chloride and later with water.

The transistor was fabricated using Pt-coated glass electrodes; for this purpose, the plate was cleaned with trichloroethylene and etched chemically to obtain a smooth surface. In the middle of the plate, a slit (200 and 500 μm) was masked, black wax being deposited on the unmasked area. The mask was removed and the plate was dipped in boiling aqua regia to remove the Pt on the unexposed surface. The black wax was removed by boiling tetrachloroethylene. The ohmic contacts were made by depositing and curing silver paint on each end of the Pt on the glass plate. The ohmic contacts were masked by lacquer and teflon tapes. Polycarbazole was deposited on both Pt electrodes by the procedure described earlier. One half of the polycarbazole-deposited Pt

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plate was used as the source and the other half as the drain. The gate electrode was constructed using a Ag plate. The three electrodes were contacted by a filter paper wetted with 1 M KCl. The contact between polycarbazole (p-type) and metal is ohmic [14, 15]. The transistor characteristics were measured using a Tacussel dual potentiostat (Type B1-PAD). All measurements were carried out at 25 °C.

Results and discussion

The polycarbazole transistor designed and constructed for this study is shown in Fig. 1. The gate voltage and drain voltage are marked as V_G and V_D in the figure. Figure 2 describes the output characteristics of the polycarbazole triode, I_D vs V_G, for drain voltages (V_D) of 0.5–1.0 V. From these curves an important fundamental parameter, trans conductance of the device, g_m [16] defined as

$$g_m = \frac{\delta I_D}{\delta V_G} (V_D = \text{constant})$$

was evaluated as about 0.54 mA/V (average value). This value is about five times the value obtained for the polyaniline transistor reported by Paul et al. [2]. If this parameter is converted into the conventional parameter in units of S/cm, the g_m value obtained here corresponds to 10.8 mS/cm. The lower value obtained with the polycarbazole transistor is partly caused by the greater inter-electrode separation of 500 μm. The performance of this transistor compares well with the MOSFET devices reported in the literature [16]. To examine the effect of the inter-electrode separation on the performance of the transistor, a transistor with a 200-μm gap was constructed. The experimental results are shown in Fig. 3. This device gave a value of g_m = 9.45 mA/V, corresponding to 472 mS/cm. Thus, the transistor trans conductance increases with decreasing gate width. With a view to comparing the performance of the polycarbazole transistor with a polyaniline transistor, experiments similar to the one described here have been performed under our conditions, and the trans conductance was measured; in these experiments, 0.55 mA/V was obtained for a 500-μm width (V_D = 0.3 V). In comparison to the previous report [2], the corresponding g_m value is higher, and this is attributed to the smaller inter-electrode separation used in the earlier studies.

Remarkable features of the polycarbazole transistor include the low hysteresis of the device in scanning forward and reverse directions of the drain voltage and the maximum positive voltage needed for the saturation of the drain current. With polyaniline, the saturation region is ill-defined and occurs at about 0.2 V, with a sharp decrease in the current beyond this value. With polycarbazole, the saturation region starts at 0.5 V and extends up to 1.3 V. The hysteresis is typically greater at the low drain voltage than at a higher drain voltage. The transistor reproducibly gave the same result even after subjecting it to several cycles of the gate voltage versus drain current. The experiments were also conducted after leaving the transistor in an oven at 50 °C for 24 h, which did not lead to any significant change in the transistor characteristics.

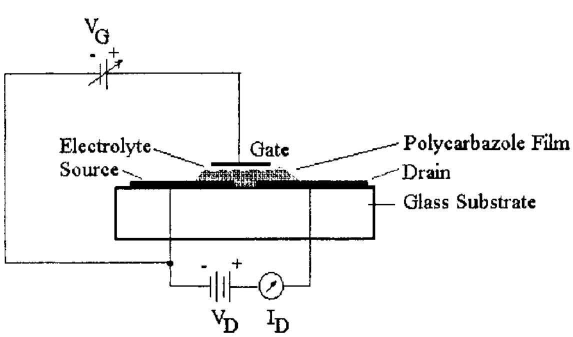

Fig. 1 Schematic diagram for the characterisation of the device

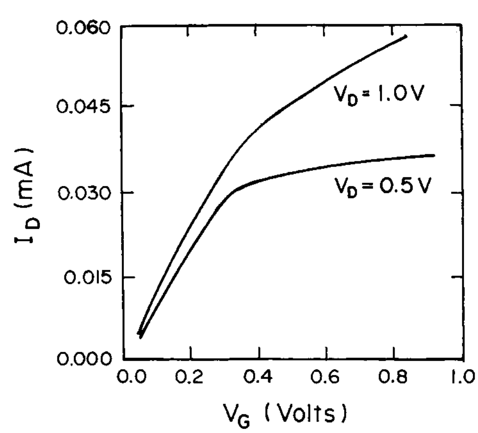

Fig. 2 *VG* vs. I_D characteristics of the device at various bias voltages V_D at inter-electrode spacing 500 μm

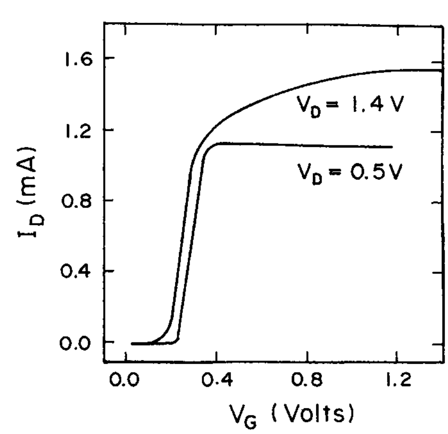

Fig. 3 *VG* vs. I_D characteristics of the device at various bias voltages V_D at inter-electrode spacing 200 μm

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