Properties of the Metallic Phase in Conjugated Polymer Field-Effect Transistors: Dependence on Temperature and Magnetic Field

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Introduction

We have studied the carrier transport in conjugated polymer field-effect transistors (FETs) using electrolytes and SiO2 as the gate dielectrics from 298 K to 260 mK and at various magnetic fields.

Experimental

We have used a He3 cryostat to cool a sample at various magnetic fields up to 15 Tesla for studying the dependence of the conductivity in the channel of a field effect transistor made of conjugated polymer. The liquid crystalline thiene[3,2-b]thiophene polymer, pBTTT-C14 - molecular structure shown in the inset of the figure, functions as the semiconducting polymer in the channel of the FET; pBTTT-C14 has been previously shown to exhibit high carrier mobilities, $\mu \sim 1$ cm$^2$/Vs, in SiO2-gated FETs.

Results and Discussion

We have studied the carrier transport in conjugated polymer field-effect transistors (FETs) using electrolytes and SiO2 as the gate dielectrics from 298 K to 260 mK. With polyelectrolyte gate dielectric, a very high field-induced carrier densities, $\sim 10^{22}$ charges/cm$^3$, present in the device channel, lead to high conductivity, typically $\approx 10^2$-10$^4$ S/cm at room temperature. At 4.2 K, this device exhibits metallic conductivity and a remarkable current-carrying capacity without any noticeable degradation; the current density in the transistor channel exceeds $2 \times 10^7$ A/cm$^2$. At low temperatures, device conductivity is strongly nonlinear in the source-drain electric field, suggestive of delocalised carrier transport by charge density waves. Although the carrier density in the SiO2 gated device was significantly lower (1.5x10$^{20}$ charges/cm$^3$), it exhibited similar general behaviour, i.e. a thermally activated mobility at $T>10$ K and $T$-independent mobility between 10 K – 260 mK. The figure below shows the T-dependence of the conductivity.

Conclusions

Our studies of the carrier transport in conjugated polymer field-effect transistors (FETs) using polyelectrolyte and SiO2 as the gate dielectrics, in a wide temperature range clearly demonstrate a metallic behavior at the low temperature regime from $\sim 10$ K to 260 mK. The data exhibit a thermally activated mobility at $T>10$ K and $T$-independent mobility between 10 K – 260 mK. At low temperatures, device conductivity is strongly nonlinear in the source-drain electric field, suggestive of the possibility of carrier transport by partially mobilized charge density waves that were incrementally unpinned by the drain-source bias. No magneto resistance was observed up to a magnetic field of 15 Tesla.

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