Intrinsic Mobility, Shallow Traps and Deep Traps in TMTSF Single-Crystal Transistors

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Band transport is believed to be an intrinsic property of organic semiconducting materials, with a clear signature being a mobility increase with lowering temperature. In practice, the realization of intrinsic charge transport in field-effect transistors (FETs) is limited by disorder present at the surface of the organic materials, and rubrene is the only material exhibiting intrinsic transport in FET experiments [1]. More materials are needed to understand the properties of organic semiconductors, as well as to investigate the charge transport mechanism in the low-temperature regime (below 100K), which has hardly been explored using FETs so far. Here we report our study of Tetramethyltetraselenafulvalene (TMTSF) single-crystal FETs, whose room-temperature mobility is reproducibly 4 cm^2/Vs. In these transistors, we observe a mobility increase with lowering temperature, thus demonstrating the intrinsic nature of transport. In the best device, the mobility reaches its maximum value at 160K, and then decreases slowly upon further cooling, so that $\mu > 1cm^2/Vs$ at 40 K. We also observe an interesting correlation, with devices exhibiting higher mobility also showing lower threshold voltage (V_{th}) shift with temperature.

We interpret the data quantitatively, in terms of a phenomenological model, which relies on an assumed density of states. Specifically, we assume the presence of a band where charge carrier are delocalized –contributing to the current flow with a mobility $\mu = \alpha\ T^{-2}$, and of shallow and deep traps, where charge carriers do not contribute to the current flow. Using this model we analyze the role of shallow and deep traps, and we extract their density and energy scale. We find that shallow traps with a characteristic energy of 10-15 meV can account for the measured temperature dependence of the mobility in the range 100-300 K, and that the deep traps are only directly responsible for the threshold voltage shift. We also find that the magnitude of the fluctuations in the Coulomb potential generated by the holes trapped in the deep traps corresponds well to the energy of the shallow traps. We conclude that the presence of shallow traps is "caused" by the charges present in the deep traps, which explains the observed correlation between mobility and the temperature-induced threshold voltage shift (i.e., deeps traps are indirectly responsible for the observed T-dependence of the mobility, because they induce shallow traps).

[1] V. Podzorov et al., Phys. Rev. Lett. 93 086602 (2004)