A field effect transistor based on an n-type dibenzothiophene derivative

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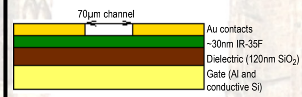
Introduction

Although *p*-type organic semiconductors (e.g. pentacene) are well known and can be made into reliable air-stable devices with high mobilities[1], *n*-type semiconducting molecules have not reached the same level of development[2,3]. These materials are therefore attracting considerable research interest. Good *n*-type behaviour is necessary to make devices containing complementary integrated circuits and p—n junctions.

The dibenzothiophene moiety has already been exploited in the design of *p*-type FETs, providing hole mobilities of 0.15 cm^2 V^{-1} s^{-1} [4]. Incorporating the electron deficient dibenzothiophene-*S*-*S*-dioxide group increases the electron affinity[5] and offers a strategy for the design of *n*-channel devices.

FET structure



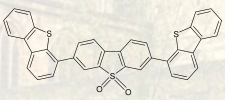
Although in-plane DC measurements did not show conductivity significantly greater than that of the underlying substrate, it was found that the conductivity could be changed by the field effect, which indicated an *n*-type device

The FET was made in a top-contact configuration, using a conductive silicon wafer (10^{-3} Ω cm resistivity) with 120 nm thermally grown silicon dioxide as the gate dielectric. The SiO_2 was treated with a silanising solution before the IR-35F and gold contacts were thermally evaporated. The gate was formed by exposing the silicon at the back of the wafer and attaching aluminium foil to the silicon with silver paste.

Material

Thin films of 3,7-bis(dibenzothiophene-4-yl)-dibenzothiophene-*S*-*S*-dioxide (IR-35F) were prepared on glass slides and silicon wafers using vacuum sublimation at a pressure of approximately 10^{-5} mbar.

A purpose-built evaporator for organic materials was used to prepare the films, and a commercial metal evaporator was used to evaporate metals through a shadow mask to create contacts for the devices.



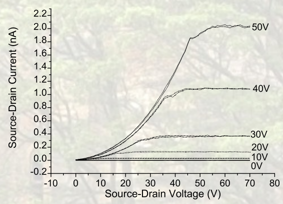
Molecular Formula = $C_{36}H_{20}O_2S_3$
Formula Weight = 580.7378

Molecular structure of 3,7-bis(dibenzothiophene-4-yl)-bibenzothiophene-*S*-*S*-dioxide (IR-35F)

Transistor characteristics

The transistor characteristics were measured in air, and confirm that the IR-35F was an *n*-type semiconductor.

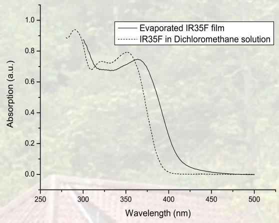
The non-saturation region shows a non-linear increase in current – this has been attributed to contact effects between the metal contact and organic semiconductor[6].



Source-drain current against source-drain voltage characteristics as a function of gate voltage

Absorption spectra

The UV-visible absorption spectrum for the thermally evaporated film is similar to that measured in dichloromethane solution, indicating the material had not dissociated on vacuum sublimation.

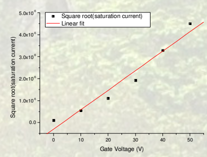


Mobility

In the simplest transistor model, the saturation source-drain current (I_D) is dependent on the gate voltage (V_{GS}) with the relationship

$$I_D = \mu \frac{w}{L} C''_{ox} \frac{1}{2} \left(V_{GS} - V_{th}\right)^2$$

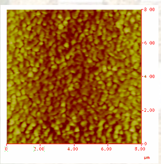
where μ is the mobility, w and L are the channel width and length, C''_{ox} is the insulator capacitance per unit area and V_{th} is the threshold voltage



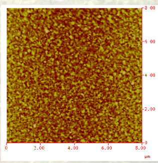
The fact that the square root of the saturation current against gate voltage does not exhibit a linear relationship is currently the subject of further study. However, using the simple model with a linear fit yields a mobility of 1.75×10^{-6} cm^2 V^{-1} s^{-1}

Film morphology

Under an atomic force microscope, the evaporated film appears polycrystalline, with an average grain size of about 300nm. In comparison, pentacene, under similar conditions, has been observed to have a grain size of around 100-200nm.



AFM image of a thermally evaporated film of IR-35F on glass



AFM image of a thermally evaporated film of pentacene on glass

Conclusions and further work

Good quality thin films of IR-35F were produced by thermal evaporation. The in-plane conductivity could be changed by the field effect, and air-stable transistors were fabricated.

Work is ongoing into investigating the effects of alternative functional groups on the molecule, to increase the electron affinity of the material and hence increase the mobility of the FETs.

References

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