Electrical characterization of silicon-based OFET substrates spray coated with water-based graphene solution

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Introduction

Graphene has significant functional potential, for example in the battery industry, where its unique properties enable the production of batteries with improved capacity and charging rates. OFET test chips with interdigitated electrode structures (Figure 1) with dimensions in the lower µm range can be used to characterize the electrical properties and the processability of novel materials.

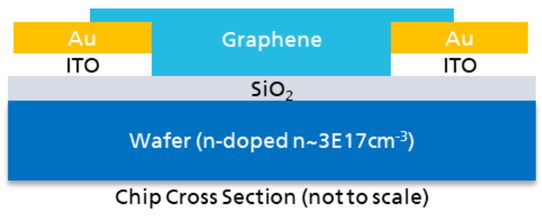

Figure 1: Principle sketch of the cross-section of an OFET test electrode structure with deposited graphene solution

Experimental Setup

A graphene solution that is commercially available was deposited via spray coating for investigating the material properties and the quality of the deposition process. The deposition process was performed at Sixonia Tech GmbH, Germany to ensure reproducible deposition of the graphene solution on the test substrates. The chips were placed on a heat plate (Figure 2)

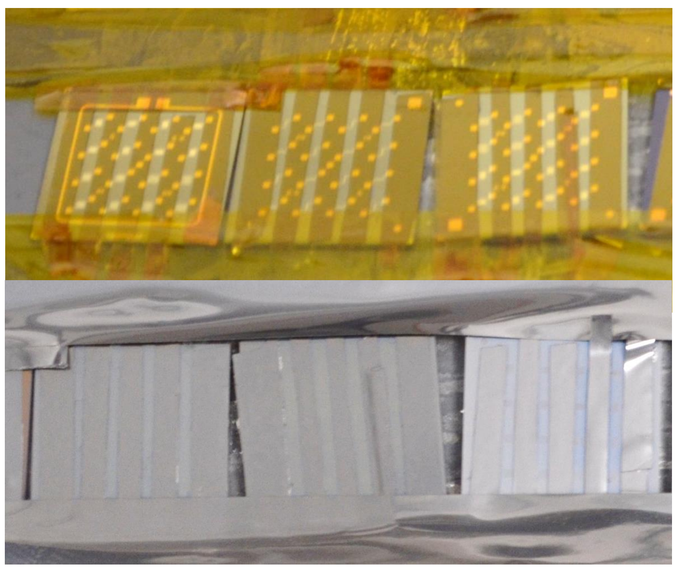

Figure 2: Water-based spray coated graphene solution on OFET test chips with polyimide film (Kapton tape); top: 10 kΩ/sq; bottom: 1 kΩ/sq sheet resistance

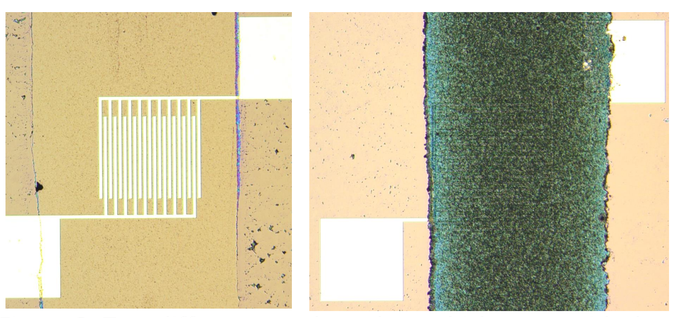

Figure 3: Two different graphene layer thicknesses with sheet resistances of 10 kΩ/sq (left) and 1 kΩ/sq (right)

and the temperature was set to about 250 °C. The electrodes were covered with polyimide film (*Kapton* tape). Graphene was diluted with ethanol (99%) in a ratio of 1:40 and sprayed onto the heated substrates. Two deposition processes with graphene solution were carried out. A sheet resistance of about 10 kΩ/sq was pursued first, and 1 kΩ/sq second.

Results

The thicknesses of the homogeneous deposited graphene layers (Figure 3) were estimated with AFM (Figure 4) between the silicon surface and the graphene. For 1 kΩ/sq the larger area seems to measure up to abound 150 nm in height. For 10 kΩ/sq, the range was exemplarily measured between about 40 to 80 nm. Peaks up to over 800 nm occurred in both specimen.

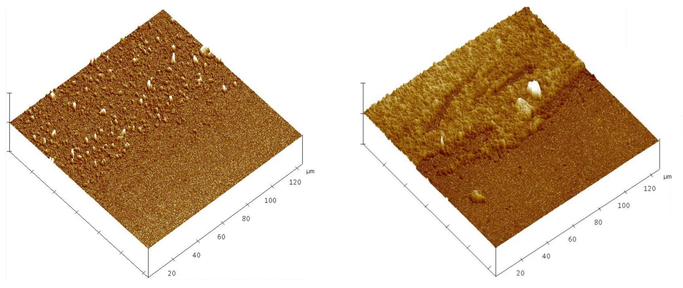

Figure 4: Exemplarily AFM measurements of two OFET test chips with different sheet resistance and layer thickness; left: sheet resistance = 10 kΩ/sq, right: sheet resistance = 1 kΩ/sq

Initial I-V- curves (Figure 5) of 5 µm and 10 µm with 1 kΩ/sq and 10 kΩ/sq graphene showed, that a larger channel length and a larger resistance decreased the current.

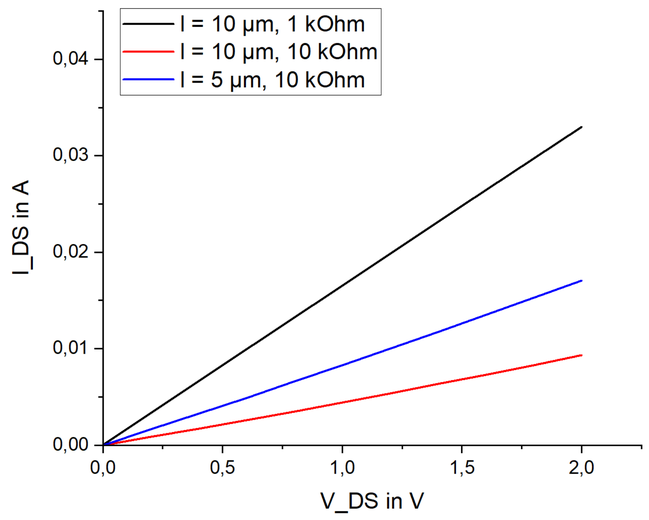

Figure 5: I-V curves I_DS vs. V_GS of three OFETs with 10 µm and 5 µm channel length (all n =1)

Compared to previous work [1], the estimated conductivity led to a higher order of magnitude, which indicates an improvement in graphene flake arrangement due to spray coating.

With the transmission line method [2], the determined contact resistance (Figure 6) led to about 61,2 Ω for 1 kΩ/sq sheet resistance (2.5 µm, 5 µm, 10 µm and 20 µm channel lengths all with n=4). The negative slope shows that the contact resistance dominates the measurements. This could have been caused by an unsufficient contact between graphene and silicone due to inhomogeneous graphene flake deposition. The outlier supports such hypothesis.

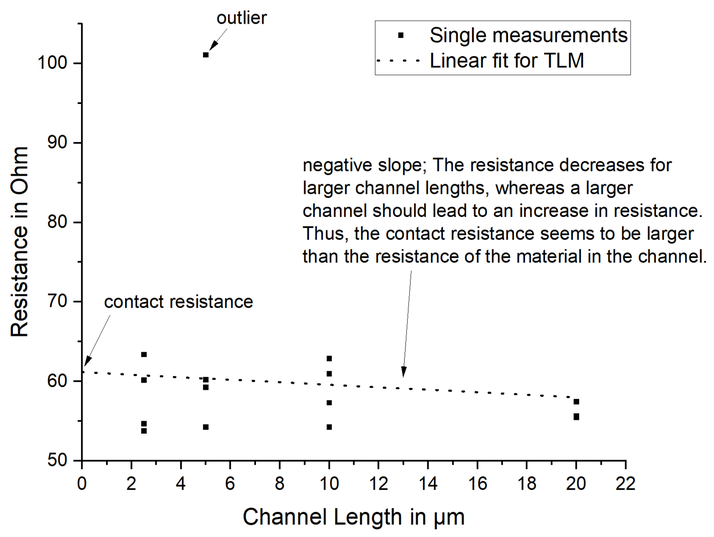

Figure 6: Contact resistance from transmission line method (TLM). The contact resistance is dominating and causes a negative slope, which leads to the assumption, that the contact of the graphene flakes differs for the different channel lengths.

Conclusion

The OFET substrates are a useful tool for investigating organic materials. Despite the spray coating technique resulting in macroscopically homogeneous layers, the graphene flake solution still showed thickness differences in the nanoscale. The influence on the contact resistance for different channel lengths needs to be examined in more detail.

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[1] Stoppe, et al. 2024, Characterization of Organic Semiconductors and Conductors by Means of Conductivity and Field Effect Using the Example of Graphene, ICCC 2024, Cottbus, May 2024

[2] Xu, Yong; Gwoziecki, R.; Chartier, I.; Coppard, R.; Balestra, F.; Ghibaudo, G. (2010): Modified transmission-line method for contact resistance extraction in organic field-effect transistors. In: Applied Physics Letters 97 (6), Artikel 063302. DOI: 10.1063/1.3479476.