APPLICATION NOTE

I-V Characterization of Graphene-Based Thin-Film Transistors

Thin-film transistors (TFT) are key components of flat-panel displays, which have become commonplace in today's commercial electronic devices. Nevertheless, TFTs are still widely researched and developed in order to continue growing the fields of applications [1]. Challenges arise in electrical characterization of the TFT due to the small thicknesses of electrodes and potential softness if organic materials are used. One major challenge is in the electrical probes penetrating the thin electrodes, resulting in improper characterization and damage of the device.

In this application note, the device under test is a TFT with a graphene channel. The source and drain consist of 100 nm thick conductive electrodes. The channel, source and drain are all fabricated on a 100 nm thick flexible insulating material deposited on a conductive substrate, acting as the gate dielectric and electrode, respectively [Figure 1]. As is often challenging with other thin-film devices, previous attempts to characterize the transistor using manual probes resulted in the probes penetrating the extremely thin source/drain electrodes and gate dielectric, making it impossible to characterize the current modulation of the device.

To overcome this issue, three miBot micromanipulators were positioned on a miBase and simply placed under the objective of a Nikon Eclipse L200 optical microscope [Figure 2]. Taking advantage of the nanometer positioning resolution of the miBot, probes were quickly placed on the thin electrodes without penetrating to the conductive substrate. The operation of positioning the probes took about 5 minutes before starting the measurements. As the probe is lowered over the target area, the tip comes into the same focal plane as the sample before contact. At this point, the resolution of approach was increased to 100 nm in order to perfectly control the approach and visually detect the contact. Thanks to this, the gate dielectric was not damaged.

Three tests were performed on each transistor to verify the condition of the gate dielectric and probe contact. First, a probe was placed on the drain electrode and another probe on the substrate (gate electrode) then the resistance was measured between the probes. As is required for successful characterization, the resistances were those of an open circuit, meaning that the gate dielectric had not been compromised [Figure 3]. Resistances were then measured between two probes on the same drain electrode and found to be 50 Ω. This value is expected, as it accounts for both contact resistance

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Imina Technologies products in use:

- miBot™ BT-11 micromanipulator
- miBase BS-42 stage
- syDrive SD-10 piezoelectric controller

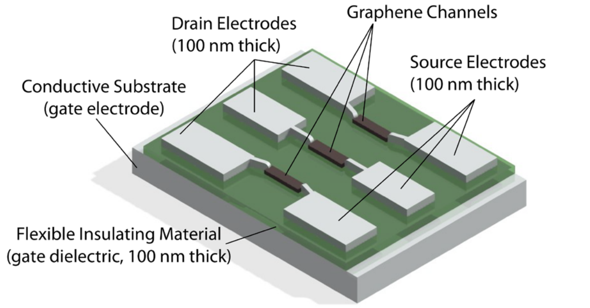

Figure 1. Schematic of the device under test, showing three thin film transistors with graphene channels.

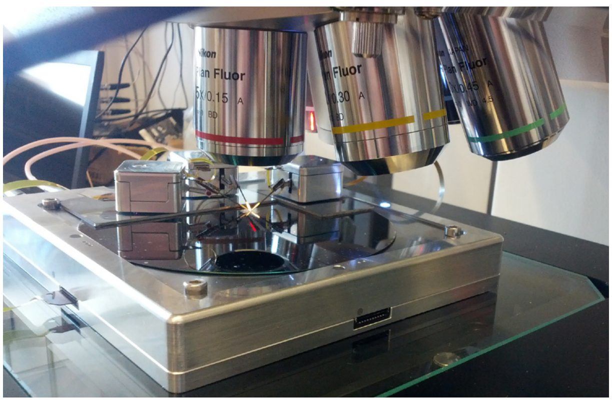

Figure 2. The miBot micromanipulators probing a thin film transistor on the miBase under the objective of an optical microscope.

of the probes and the sheet resistance of the electrode [Figure 4]. The final test to ensure the device and probing setup are functioning properly involved measuring the channel resistance, i.e. between the source and drain electrodes with no gate bias. When channel resistance values were in the range of 2 kΩ, the device was selected to be characterized.

To perform this operation, one probe was placed on the source electrode, another on the drain electrode, and the final one on the conductive substrate, which, in this case, is the gate electrode [Figure 5]. A HP 4156A semiconductor parameter analyzer was used to produce current-voltage sweeps for the gate-source bias (V_{GS}) and the drain-source bias (V_{DS}) then measure the I-V curves.

CONCLUSIONS

This application note reports about the successful use of miBot micromanipulators to overcome one of the key challenges in electrical characterization of thin-film transistors, i.e. landing probes on the film without penetrating it. The open-circuit resistance between the drain electrode and the conductive substrate was measured to support this assertion. Moreover, the resistances measured on the drain electrode and those across the channel proved that the probes were in good electrical contact with the electrodes [Figure 6].

The time to carry out this experiment was also greatly reduced thanks to the virtually-unrestricted range of motion the miBot micromanipulators compared with traditional manual probers. In fact, it was possible to test nine devices on the substrate without having to make any adjustments of the sample relative to the probes, thereby being able to accomplish in less than an hour a task that had been attempted over months of trials with traditional manual probers.

[1] N. V. Cvetkovic, K. Sidler, V. Savu, J. Brugger, D. Tsamados, A. M. Ionescu, Three-level stencil alignment fabrication of a high-k gate stack organic thin film transistor, Microelectronic Engineering, Vol. 88, Issue 8, Aug. 2011, pp 2496-2499

http://dx.doi.org/10.1016/j.mee.2010.12.086

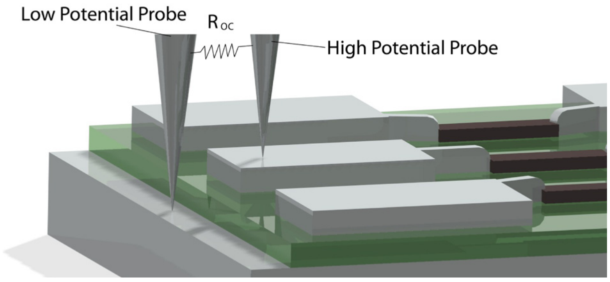

Figure 3. Testing for open circuit behaviour between the drain electrode and the substrate (gate electrode) to verify that the probe has not penetrated through the gate dielectric.

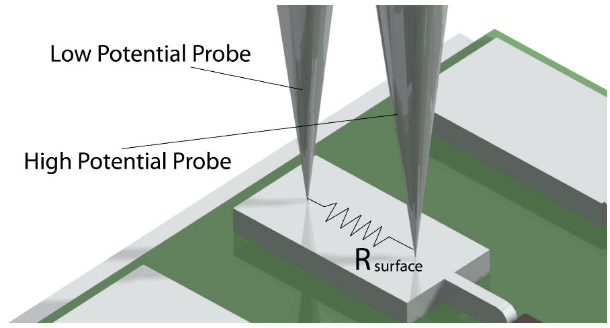

Figure 4. Testing the resistance across a section of the drain electrode to ensure that the probes are making good electrical contact. A low resistance is expected.

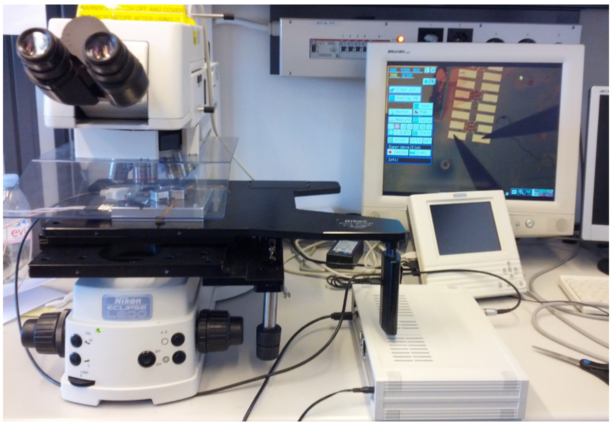

Figure 5. The probing assembly with the miBot probes on the source and drain displayed on the microscope monitor.

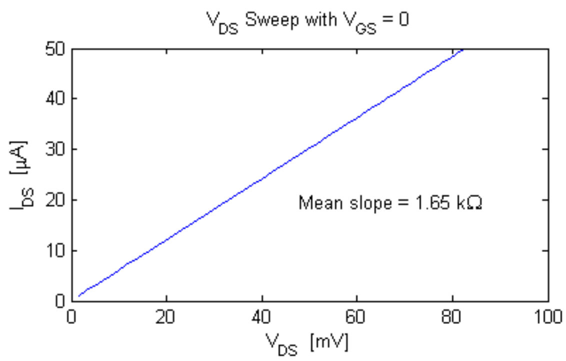

Figure 6. I_{DS} - V_{DS} sweep with V_{GS} = 0. Linear behavior indicates a good Ohmic contact. The slope of this I-V curve yields the channel resistance (plus the contact and electrode surface resistances).

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