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Potential Distribution in Functionalized Graphene Devices Probed by Kelvin Probe Force Microscopy

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Abstract. Kelvin probe force microscopy was used to study the impact of contacts and topography on the local potential distribution on contacted, individual functionalized graphene sheets (FGS) deposited on a SiO_2/Si substrate. Negligible contact resistance is found at the graphene/Ti interface and a graphene resistance of 2.3 kΩ is extracted for a single sheet with sub-µm size. Pronounced steps in the topography, which we attribute to a variation of the spacing between graphene and substrate, result in a significant change of the local resistivity.

Keywords: Functionalized graphene sheets, Kelvin probe force microscopy, electrical potential, local resistance
PACS: 68.37.-d, 68.65.Pq, 61.48.Gh, 72.80.Vp

INTRODUCTION

Chemically derived graphene with functional groups called functionalized graphene sheet (FGS) [1] can be utilized in sensor technology, batteries and supercapacitors because of the unique combination of high specific area, excellent electronic conductivity and structural stability [2-4]. The large density of functional groups and lattice defects of FGSs is expected to strongly influence their electrical properties and to affect the performance of FGS-based devices. In addition, graphene-metal contact resistances are crucially important for the development and optimization of graphene-based electronics. Further pushing the development towards applications, however, requires a nanoscale insight into such electronic properties. While there are a variety of studies available in the literature concerning the electronic properties of pristine and epitaxially grown graphene, for FGSs, the local electrical properties of individual sheets have not been studied with an appropriate high spatial resolution up to now. In this work we made contacts to an individual FGS and performed Kelvin probe force microscopy (KPFM) measurements under external DC bias, allowing local voltage drops across the contacted FGS to be derived.

EXPERIMENTAL DETAILS

The process to derive FGS is described in detail elsewhere [1]. FGSs suspended in ethanol (< 0.1 mg/ml) were deposited on 300 nm thick SiO_2 grown on a Si substrate. Electron beam lithography was used to make contacts to FGS, which requires high accuracy in locating any graphene sheets of typically sub-µm in size. Metal contacts are 100 nm thick Au, with an additional 10 nm thick Ti adhesion layer. We utilized our own home built Kelvin controller, which was integrated into a Vecco diInnova AFM system, allowing topography and Kelvin voltage to be measured simultaneously with a spatial resolution of few nanometers and a potential resolution of millivolts, respectively [5]. All the measurements were done in non-contact mode under ambient conditions. The one-pass method used is expected to have a higher spatial resolution for Kelvin measurements than the two-pass method used by others [6], because the tip oscillates at a much closer distance above the sample surface. The tips were silicon AFM probes with a Pt/Cr coating. External biases U_{ext} ranging from -1.5 V to +2.0 V with an interval of 0.5 V were applied to study the local electrical potential in an electrode configuration. The current through the device was recorded by a source meter when scanning.

RESULTS AND DISCUSSION

Figure 1 (a) and (b) are topography and Kelvin voltage images of the contacted FGS with an applied voltage of U_{ext} = +2.0 V. Wrinkling features are clearly observed in the graphene sheet, which are caused by the linear clusters of epoxy sites [1] due to thermal treatment of epoxy groups [7]. The large wrinkles were also seen to result in uneven metal

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contacts with the graphene sheet underneath. As can be seen in Figure 1 (b), the Kelvin voltage changes when going from the left to the right contact reflecting the local drop of the externally applied voltage. Note the black points partly observed on top of the wrinkles are most likely measurement artifacts.

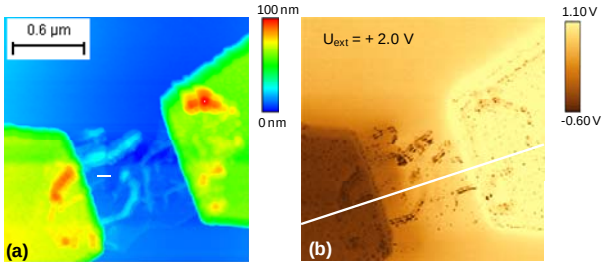

FIGURE 1. KPFM measurements on the FGS: (a) Topography and (b) Kelvin voltage of the FGS at an external bias of +2.0 V.

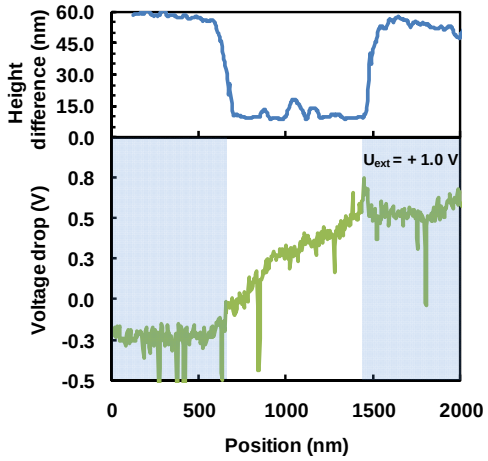

FIGURE 2. Line scans of topography (top) and voltage drops (bottom) at an external bias of +1.0 V.

Figure 2 shows line scans of the topography and voltage drop along the position which is perpendicular to the metal electrodes as indicated in Figure 1 (b). The areas of constant voltages (shaded) are stemming from the metal contacts. Apparently, at the Au/Ti–graphene interface there is no obvious voltage drop, indicating negligible contact resistance. This is different to what has been observed in Cr-contacted pristine graphene [6]. The line scan of the voltage drop along the FGS shows a pronounced non uniform behavior. This is likely due to the different local thickness (e.g. the locally varying graphene-substrate distance) and the randomly located wrinkles throughout the graphene. Considering the value obtained for the voltage drop across the graphene and the measured current, we are able to extract an internal resistance of 2.3 kΩ for this special FGS. Although the measurement accuracy has to be improved further, the data plotted in Figure 2 indicate a change of the local resistance in the wrinkled area.

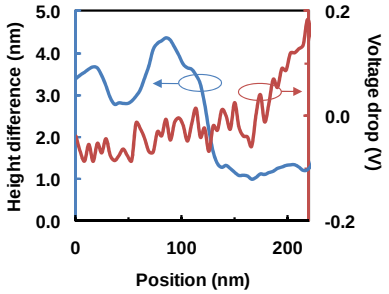

FIGURE 3. Line scan of voltage drop and height at the height step as marked by the white line in Figure 1 (a).

In Figure 3, we show correlated topography and KPFM data in a small section close to the left contact of the device (see white line in Figure 1 (a)). An obvious height step in topography of about 3 nm, most likely caused by an increased distance between the graphene and the substrate [1], results in a distinct change of the voltage drop. This may suggest that the local resistivity of the graphene could be dependent on its distance from the substrate, probably caused by a change in the carrier density induced by the SiO_2 layer.

CONCLUSION

A single contacted functionalized graphene sheet of sub-µm size was investigated by one pass KPFM with high spatial resolution. From the Kelvin voltage maps with different bias, the local electric potential across graphene in relation to the contacts was studied. We extract an internal resistance of the graphene sheet of 2.3 kΩ and a negligible contact resistance. The detailed line scan across a height step suggests that the local resistivity of the graphene decreases with increasing distance between graphene and substrate.

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