# Keysight Technologies
# Single Pass KFM Study of Current Transport in Graphene and Graphene to Metal Contacts

Application Note

# Introduction

Recently the methods for Atomic Force Microscopy (AFM) based measurements of local surface potentials (SP) have been considerably advanced. Frequency Modulation Kelvin Force Microscopy (FM KFM) has been shown to improve resolution and fidelity of the SP values[1].

The improved method is employed for measuring electronic transport properties of few layer graphene — a material which attracted attention due to its (theoretically) outstanding mechanical and electrical properties[2]. Unfortunately to date it has been difficult to produce large defect free samples of graphene so that graphene devices do not match the expectations. Their properties are often governed by microscopic behavior and distribution of imperfections. Thus methods for local measurement of graphene properties are required.

For this transport study a scanning probe potentiometry technique is used rather than applying a fixed tip-sample bias and recording the resulting tip current. For the potentiometry method a current is injected to a thin conducting layer via macroscopic contact patches (Figure 1) which leads to a gradient of the electrical potential along the film and is also present at its surface. The local electrical potential ($V_{Kelvin}$) can be probed by single pass Kelvin Force Microscopy (KFM)[3]. KFM is an AFM technique which excites the AFM cantilever via two paths simultaneously: Mechanically at frequency $\omega_1$ and electrically with a modulated tip sample bias at frequency $\omega_2$. The cantilever response to the mechanical excitation is used for topography imaging. A feedback loop detecting the cantilever response to the excitation at $\omega_2$ tunes the tip potential to the surface potential at all times while imaging the surface. Thus the surface potential (SP) data are acquired simultaneously to surface topography. For better lateral resolution and better fidelity of the SP data the frequency modulation method of KFM must be employed. (For a detailed description of Single Pass KFM FM mode please refer to[1].)

The sample under investigation was few layer graphene which was epitaxially grown on semi-insulating silicon carbide (SiC) by thermal decomposition[4].

Gold contacts were evaporated onto the graphene and a power supply applying Vbias between the contacts is used to drive the sample current.

# Abstract

In this study advanced Atomic Force Microscopy (AFM) techniques are employed to investigate local current transport in epitaxially grown few-layer graphene as well as graphene to metal junctions. The microscopic sheet resistance and the contact resistivity are deduced from the distribution of the local surface potential in current carrying thin films of graphene and in the vicinity of the current injecting contacts.

# Results

Figure 2 shows topography and surface potential distribution of the graphene sample without a current flow. The topography (Figure 2(a)) shows terraces of 200 nm typical width, as well as pits and wrinkles which are frequently found for graphene grown from SiC. The surface potential map (Figure 2(b)) exhibits discrete surface potential values which is due to variations in the number of graphene layers[5].

Figure 3 shows a larger region of the surface while a current is driven through the graphene by applied biases of ±12 V. Accordingly the SP maps exhibit average gradients superimposed on the native, discrete SP distribution. The potential gradient can be fitted to the SP data and is on the order of 6.2 kV/m which converts to a sheet resistance of $R_{microscopic}$ = 1.04 kΩ/□. This is slightly smaller than the macroscopic value $R_{macroscopic}$ = 1.3 kΩ/□. This could be due to local variation of the sheet resistance caused by fluctuation of the averaged layer thickness on a µm scale and the distribution of localized defects as e.g. steps on the atomic scale.

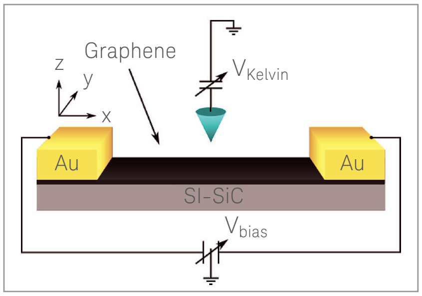

Figure 1. Schematic of the experimental setup. $V_{bias}$ drives a current through the thin graphene layer (dark grey), the potential gradient in the graphene film is measured by tuning the potential of the AFM tip (blue cone) to the local electrical potential at the tip position.

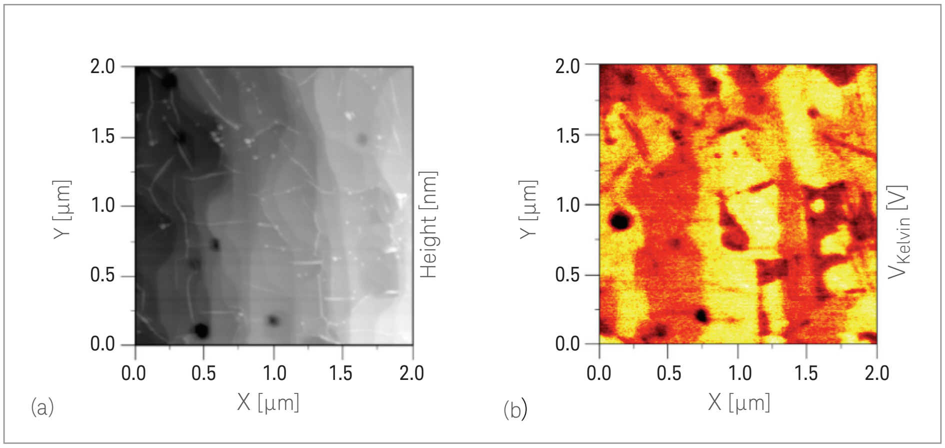

Figure 2. (a) topography and (b) surface potential of epitaxial graphene on SiC. Wrinkles (bright lines) and pits (dark holes) are visible in the topography.

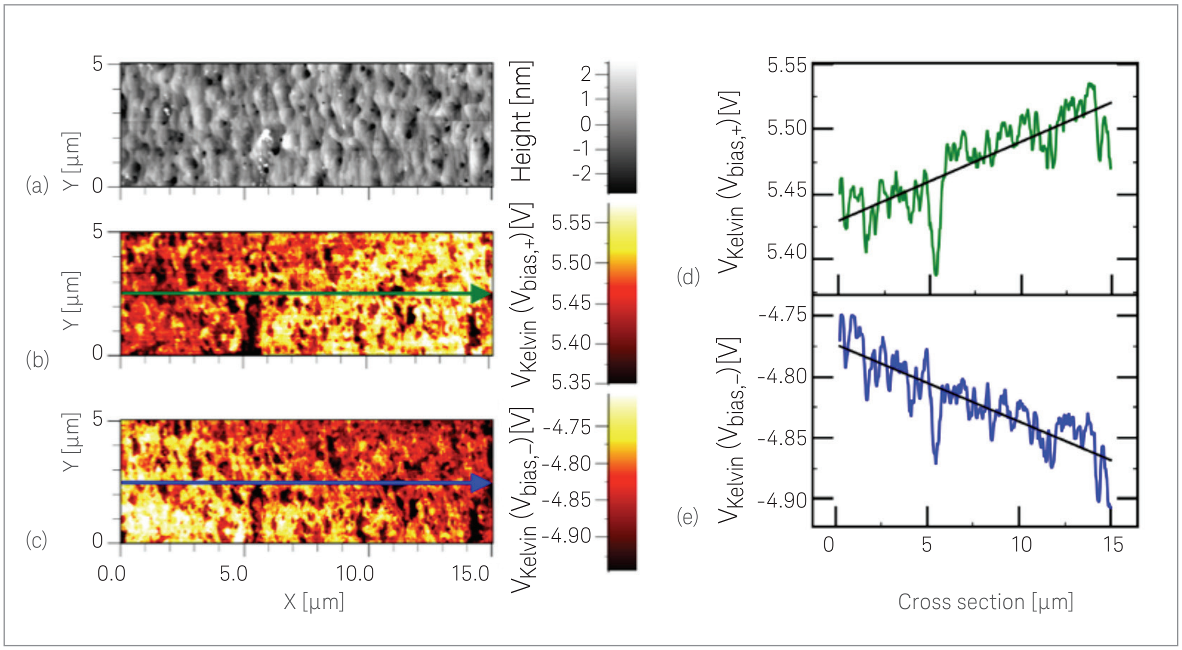

Figure 3. (a) larger area topography, b) and c) SP distribution with +12V and -12V bias applied respectively between the gold contacts. (d) and e) show the cross section along the green and blue lines in (b) and (c). Black lines indicate linear fits of the average voltage gradients of -6.3 ·103 V/m and 6.1·103 V/m. Note that the fluctuations in the cross sections are not noise but the native, discrete SP levels caused by the varying layer thickness of the graphene.

In a second experiment the contact resistivity between the gold contacts and the graphene film is investigated by mapping the SP distribution in the vicinity of a gold contact with applied $V_{bias}$ = ± 8V. Figure 4 displays topography (a) and SP maps (b), (c). Figure 4 (d) shows the cross sections along the orange, blue, and green lines. The gold contact forms a sharp step of 100 nm height. The SP on graphene and gold exhibit a difference of 0.3V consistent with earlier investigations of the respective work functions [6]. Due to the high conductivity of gold the SP distribution on the contact is independent of the bias polarity. The SP map of the graphene in front of the contact is superimposed with the potential gradient.

The SP data at the edge of the gold contact can be used to estimate the contact resistance between the two materials. The SP distribution of the current carrying contact can be calculated in a numerical simulation of a model contact using experimental data as input parameters. The details of the numerical analysis can found in ref[7]. The contact resistivity can be estimated to be better than $1\cdot 10^{-6}\ \Omega cm^2$. The details of evaluation and modeling can be found in ref [3].

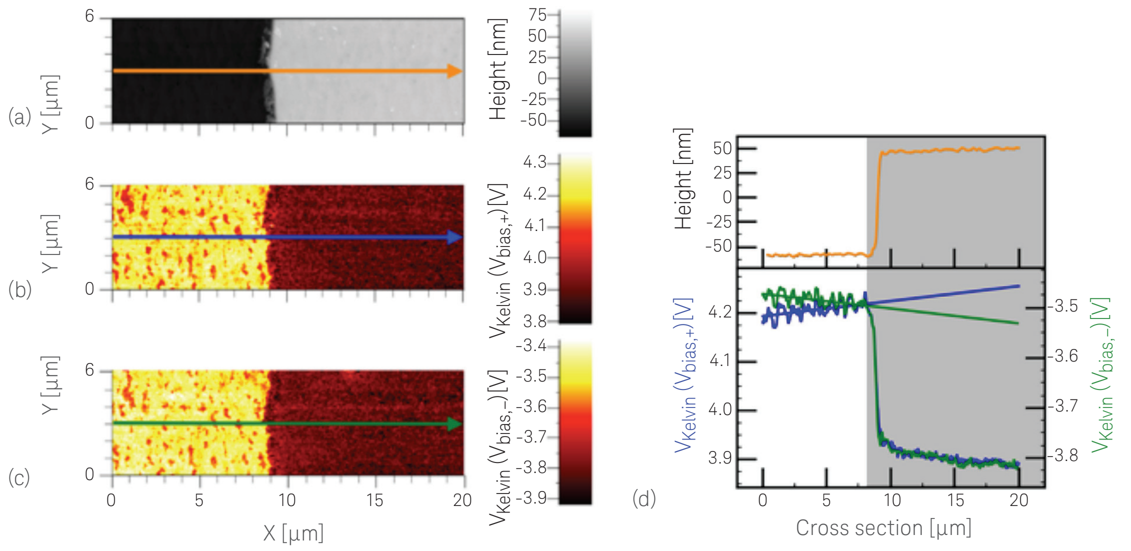

Figure 4. (a) topography showing the edge of a gold contact and (b), (c) SP maps of the same region acquired at ±8V respectively. (d) cross sections along the orange, blue, and green lines.

## Summary

Single Pass KFM using the frequency modulation method is a versatile tool yielding very good quantitative surface potential data at a high spatial resolution. The high quality KFM FM data can be compared to numerical results from modeling to give deeper insight to sample properties which are not accessible for direct probing on a microscopic length scale. In the present application KFM FM was used in a potentiometry setup to investigate electrical transport properties of graphene and graphene to metal contacts. The resulting microscopic sheet resistance $R_{mic}$ = 1.3kΩ/☐. and the contact resistivity of $1e{-}6\Omega m^2$ is consistent with values from other techniques.

# References

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