Single-pass Kelvin force microscopy and dC/dZ imaging in intermittent contact mode: its applications for high-resolution and high-sensitivity probing of the local properties of graphene materials

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Abstract:

The past three decades have witnessed a rapid growth of scanning probe microscopy (SPM) technique and its evolution from a tool to merely acquire sample's morphology to a much enhanced one with various derived imaging modes for probing materials local electric, magnetic or mechanical properties. Nevertheless, further development of advanced imaging strategies that could either expand the breadth of what is measurable in material sciences or break the current limits on detection sensitivity and spatial resolution is still highly desired for SPM-associated technologies. One particular approach toward such goals is the multi-frequency technique with the introduction of multiple lock-in amplifiers (LIAs) in SPM electronics. Here, we report that successful implement of single-pass Kelvin force microscopy (KFM) and simultaneous capacitance gradient dC/dZ measurements can be achieved with a delicately designed triple LIA setup, i.e., the combined use of both probe flexural resonance frequency ω_{mech} (in the first LIA with a feedback loop for surface profiling), and a much lower frequency ω_{elec} (in the second LIA with a second feedback control to null the tip/sample electrostatic interactions for quantitative measurements of sample surface potentials) as well as its second harmonic $2\omega_{elec}$ (in the third LIA to monitor the tip oscillation at this frequency caused by the electrostatic interactions for extraction of dC/dZ signal). Furthermore, traditional Kelvin force microcopy in cases without multiple LIAs is operated in a two-pass approach known as lift mode, in which a first scan is taken to obtain the surface morphology, followed by positioning the tip at a certain distance above the sample. Quantitative mapping of a sample's surface potential is obtained in the second pass by guiding the tip along the surface contour acquired in the first scan. Instead of the sensing the electrostatic forces at a remote tip-sample separation, the single-pass KFM & dC/dZ imaging at Agilent is operated in the intermittent contact mode regime while the tip is always brought in intermediate vicinity of to the sample surface, thus significantly improving both the detection sensitivity and spatial resolution. Using single-layer or few-layer graphene films as an example, the ultrahigh detection sensitivity associated with single-pass KFM and dC/dZ will be demonstrated and the effect of film thickness on the surface potential is observed. In contrast to surface potentials, the dC/dZ measurements show that local dielectric permittivity of few-layer graphene films maintains at the same level regardless of the film thickness. Such simultaneous monitoring of multiple electronic properties that exhibit different behaviors in response to the graphene layers provides us a technique to achieve both a comprehensive characterization and a better understanding of grapheme materials. In

addition, new results on investigations of other graphene-related systems such as white graphene (Boron Nitride) and graphene oxide (GO) will be presented.