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Layer-dependent Electrical Properties of Graphene-related Nanomaterials Revealed by Atomic Force Microscopy

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Graphene has attracted much attention recently due to their exotic electronic properties. Potential applications of graphene sheets as ultrathin transistors, sensors and other nanoelectronic devices require them supported on an insulating substrate. Therefore, a quantitative understanding of charge exchange at the interface and spatial distribution of the charge carriers is critical for the device design. Here, we demonstrate that atomic force microscopy (AFM)-based technique Kelvin force microscopy (KFM) can be applied as an experimental means to quantitatively investigate the local electrical properties of both single-layer and few-layer graphene films on silicon dioxide. The effect of film thickness on the surface potential of few-layer graphene is observed. For example, a 66 mV increase in the surface potential is detected for a ten-layered film with respect to an eight-layered one. Furthermore, with the introduction of multiple lock-in amplifiers (LIAs) in the electronics for scanning probe microscopes, single-pass kelvin force microcopy and probing of the other electric property such as local dielectric permittivity via the capacitance gradient dC/dZ measurements are allowed by the simultaneous use of the probe flexural resonance frequency ω_{mech} in the first LIA targeting the mechanical tip-sample interactions for surface profiling, and a much lower frequency ω_{elec} (both in the second LIA and its second harmonic in the third LIA) for sample surface potential and dC/dZ measurements, respectively. In contrast to surface potentials, the dC/dZ measurements show that local dielectric permittivity of few-layer graphene films maintain 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 graphene materials.