Stresses Induced Piezoelectric Response in Monolayer Graphene

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A piezoelectric response of monolayer graphene (MLG) deposited on silicon SPM calibration grating has been revealed by Piezoresponse Force Microscopy (PFM). A strong correlation between the topography and piezoelectric response was found (Figure 1). Piezoresponse value on the grating depressions (suspended graphene) appeared close to 0, whereas essentially negative values were observed on the ridges. The observed piezoresponse can be attributed to stresses appeared at the grating ridges. Raman spectroscopy was used for estimation of the stress spatial distribution in MLG.

Raman spectroscopy is a widely used technique for examination of various properties of the graphene [1]: the number and orientation of layers, the quality and types of the edges, the effects of perturbations, such as electric and magnetic fields, strain, doping, disorder and functional groups etc. The typical Raman spectrum of monolayer graphene (MLG) consists of 3 main lines: D, G and 2D bands. The D-band (at about 1350 cm^{-1}) is due to the breathing vibrations of sp^2 carbon rings and requires defects for its activation in the spectrum. The doubly degenerated G-band (at about 1580 cm^{-1}) corresponds to in-plane vibration of sp^2 carbon atoms and is ideal for studies of in-plane stress and strain in different graphitic. The 2D-band (at about 2672 cm^{-1}) is a second order of the D-band. This is a single peak in MLG and splits into 4 peaks in bilayer graphene [1-3].

Raman spectroscopy was applied for the examination of tensile and compressive stresses existed in monolayer graphene deposited on a silicon SPM calibration grating. Variations of G-band position in Raman spectrum allowed estimating the stress values from -78 GPa up to +78 GPa. Positive sign corresponds to the tension of the graphene sheet, whereas the negative one – to the compression. Tensile stresses periodically occurred at the ridges of the silicon grating, while the compressive stresses were mainly localized around graphene holes and wrinkles.

The studied MLG were grown via CVD technique on copper substrates, and then were transferred onto the Si/SiO_2 grating substrate by a wet process. The grating consists of periodical stripes with a height of about 1.3 μm and a period of 3 μm.

Confocal Raman microscope Alpha 300AR (WiTec GmbH, Germany) was used for mapping of MLG. Periodic changes of the integrated intensity, position and full width at half-maximum of both G and 2D-bands has been revealed. The period of these changes coincides with the period of Si grating (3 μm). The G-band position increased at grating ridges and decreases at depressions. The maximum range of these variations was about 1.4 cm^{-1}.

Observed shift of G-band allowed estimating the stresses in MLG [4]. Spatial distribution of the stresses (stress map) is shown in Figure 2a. Stress values vary in wide range from -78 GPa up to +78 GPa. Positive sign here corresponds to the tension of the graphene sheet, whereas the negative one shows the compression. Tensile stresses periodically were occurred at the ridges of the silicon grating, while the compressive stresses were mainly localized around graphene holes and wrinkles (Figure 2b).

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Figures:

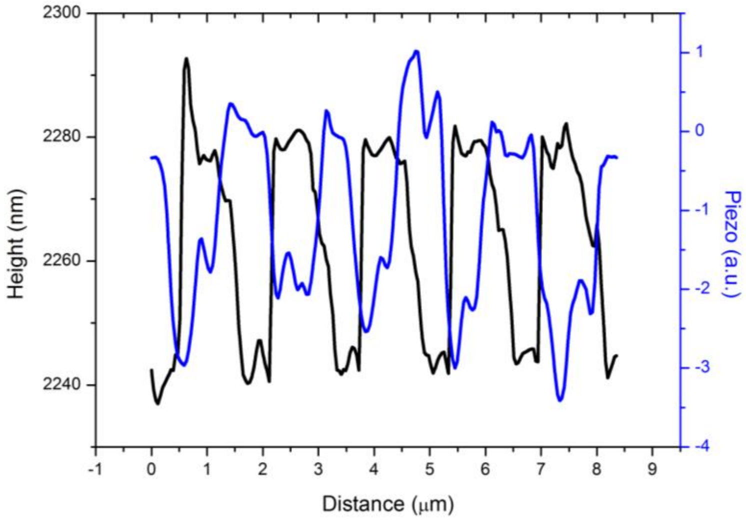

Figure 1. Superposition of cross-sections of topography and piezoresponse signal.

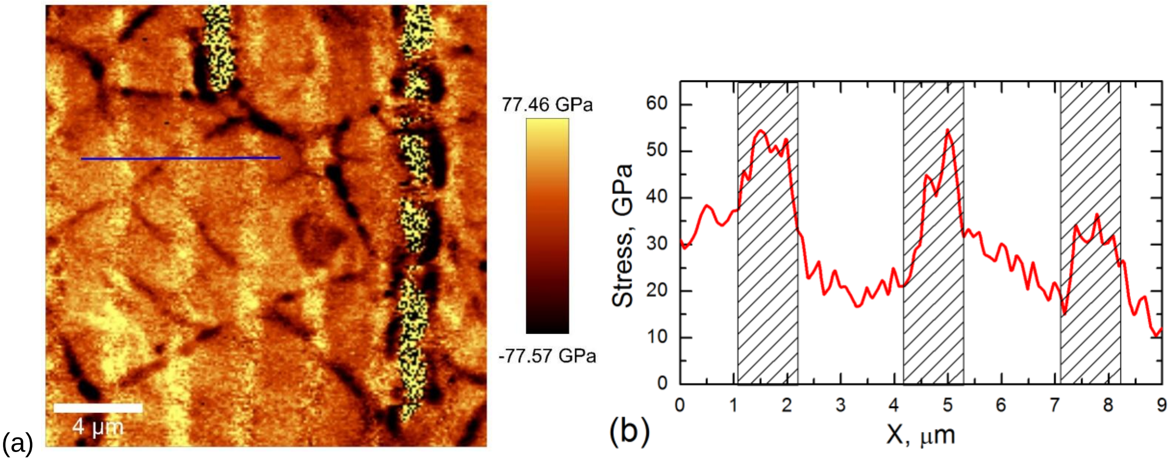

Figure 2. (a) Stress map of SLG on the silicon grating and (b) variations of stress across the grating (blue line). Shaded rectangles correspond to grating ridges.