Correlated AFM/STEM study on the Mechanical Stiffness of Defect-Engineered Graphene

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The first isolation of a single layer graphene sheet from graphite via the adhesive tape method in 2004 [1] triggered an avalanche of experiments studying this two-dimensional (2D) material, including investigations on the unique electronic as well as mechanical properties. Since these macroscopically observed properties are a result of elemental composition and atomic structure, the 2D nature of graphene allows for a direct correlation by linking atomic resolution scanning transmission electron microscopy (STEM) images to the observed macroscopic properties. Moreover, this structure-to-property correlation permits investigations on alterations of material properties through defect-engineering. In this study, the in-plane mechanical stiffness of graphene in its pristine state is compared to a defective state in the form of vacancies by correlating atomic force microscopy (AFM) nano-indentation measurements to atomic resolution STEM images. Both instruments, as well as the target chamber where the vacancies are created, are part of the Controlled Alteration of Nano-materials in Vacuum down to the Atomic Scale (CANVAS) system at the University of Vienna, which provides an ultra-high vacuum environment permitting direct correlation. The vacancy density is precisely determined by 2D STEM scan maps, which combine individual small FOV atomic resolution images into one large area, followed by processing of the data set by a convolutional neural network [2]. With a vacancy density of around 1 x 10^{13} cm^{-2} the 2D elastic modulus decreases by approximately 40%. The STEM images reveal strain-induced surface corrugation caused by the vacancies [3], which might play a role in the weakening mechanism.

References

[1] K. S. Novoselov et al., Science, 5696 (2004) 666-669
[2] A. Trentino et al., Nano Letters, vol. 21 (2021) 5179-5185
[3] J. Kotakoski, F. R. Eder, J. C. Meyer, Phys. Rev. B, 20 (2014) 201406

Figures

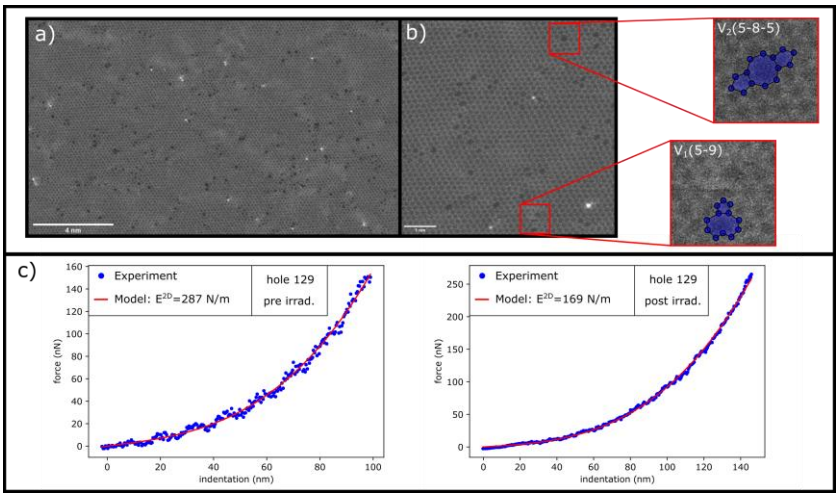

Figure 1: Atomic resolution STEM image (a) and corresponding magnification (b) revealing the introduced vacancies. AFM nano-indentation curves of the same graphene drumhead before and after irradiation (c).