# STIFFENING PRISTINE GRAPHENE BY CONTROLLED DEFECT CREATION

**Cristina Gómez-Navarro[1],** Guillermo López-Polín[1], Vincenzo Parente[2], Francisco Guinea[2], Mikhail I. Katsnelson[3], Francesc Pérez-Murano[4], and Julio Gómez-Herrero[1,5]

[1] Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, 28049, Madrid, Spain.

[2] Instituto de Ciencia de Materiales, CSIC, 28049, Madrid, Spain

[3] Radboud University Nijmegen, Institute for Molecules and Materials, Heyendaalseweg 135, NL-6525AJ Nijmegen, The Netherlands

[4] Instituto de Microelectrónica de Barcelona, CSIC, 08193 Bellaterra, Spain.

[5] Centro de Investigación de Física de la Materia Condensada, Universidad Autónoma de Madrid, 28049, Madrid.

cristina.gomez@uam.es

**Abstract**

Defect-free graphene sheets have been shown to exhibit superior mechanical properties: they are very flexible, stiff, and strong [1]. Unfortunately mechanical cleavage of graphene is not a scalable technique, and the current procedures to generate graphene in large amounts still do not yield high quality crystalline graphene. For graphene produced by CVD and chemical reduction of graphene oxide their stiffness and strength are significantly lower than that of pristine graphene [2, 3] and point toward a strong dependence of mechanical properties with defect content in graphene. Unfortunately, the fact that these defects are created during sample preparation in an uncontrolled manner hinders systematic studies. Reliable structure-properties relationship can be obtained starting with a pristine graphene sheet obtained by micro-exfoliation of natural graphite, and subsequently introducing a known quantity of defects.

In this work we focus on the variation of mechanical properties of suspended graphene with a controlled density of defects created by ion irradiation. Stiffness and strength are experimentally determined by indentation experiments with an AFM probe on graphene drumheads. Counter intuitively, we find that the stiffness of graphene increases with defect content up to a vacancy content of ~0.2%, where it doubles its initial value. For higher density of vacancies the elastic modulus slowly decreases with defects inclusion. The initial increase in stiffness can be explained in terms of a power law dependence of the elastic coefficients with the momentum of flexural modes predicted for 2D membranes [4]. In contrast to the elastic trend, the fracture strength decreases with defect density according to standard fracture continuum models.

**References**

[1] C. Lee, X. D. Wei, J. W. Kysar, J. Hone, *Science* **321**, 385 (2008).
[2] C. S. Ruiz-Vargas *et al.*, *Nano Letters* **11**, 2259 (2011)
[3] C. Gomez-Navarro, M. Burghard, K. Kern, *Nano Letters* **8**, 2045 (2008)
[4] J. A. Aronovitz, T. C. Lubensky, *Physical Review Letters* **60**, 2634 (1988)