

The Origin of Linear and Nonlinear Damping in  
Graphene Nanomechanical Resonators

Marc Bockrath,<sup>1</sup> Tengfei Miao,<sup>1</sup>

<sup>1</sup>University of California, Riverside, Department of  
Physics and Astronomy, University of California,  
Riverside, California 92521

The origin of dissipation in nanoelectromechanical systems (NEMS) remains unresolved. Graphene and carbon nanotubes have emerged as excellent materials to investigate linear and nonlinear damping[1-2] in NEMS. Here we demonstrate that the quality factor of electrically-driven few-layer graphene drumhead resonators is inversely proportional to temperature for drives sufficiently small to probe the linear damping regime. At larger drives, the nanomechanical resonance broadens due to nonlinear damping.[2] The linear and nonlinear damping in graphene resonators can be understood by a model of thermally fluctuating high frequency modes that broaden the spectral response of the measured fundamental mode through nonlinear coupling, similar to a model recently proposed for carbon nanotubes.[3] A model for thin membranes explicitly accounting for the nonlinearities is given, yielding good agreement to experiment. Our results provide a general framework for understanding the origin of linear and nonlinear damping in nanoscale resonators based on ultrathin membranes.

1. Bunch, J. S. et al. Electromechanical resonators from graphene sheets. *Science* **315**, 490–493 (2007).
2. Eichler, A. et al. Nonlinear damping in mechanical resonators made from carbon nanotubes and graphene. *Nat. Nanotechnol.* **6**, 339–342 (2011).
3. Barnard, A. W., Sazonova, V., van der Zande, A. M. & McEuen, P. L. Entropic spectral broadening in carbon nanotube resonators. *arXiv1110.1517* (2011).