Graphene-derived Materials for NEMS

M.K. Zalalutdinov, J.T Robinson, C.D. Cress , J.C. Culbertson, A.L. Friedman, E.S. Snow, B.H. Houston

Naval Research Laboratory, Washington, DC 20375
maxim.zalalutdinov@nrl.navy.mil

The ability to engineer a new "artificial material" as a heterostructure comprised of a few hand-picked monolayers of 2D materials (e.g., graphene, BN, MoS_2 etc…) greatly expands the pallet of materials available for a NEMS designer and opens new opportunities for the functionality of nanomechanical devices. We demonstrate that from the point of view of mechanical properties, such heterostructures can offer more than just ultra-thin, chemically stable films. Defects introduced within individual monolayers can drastically alter the mechanics of the heterosystem and can be manipulated in real time due to reduced activation energies of the atoms, a result of the "all-surface" nature of 2D materials.

In our experiments with drum-type nanomechanical resonators a sharply focused laser beam can initiate rapid re-arrangement of defects, which manifests itself as a high stress induced in the suspended film. A side-by-side comparison will be provided for the mechanical response of multilayer graphene films deposited as a stack of graphene platelets versus heterostructures formed through a layer-by-layer transfer of graphene and boron nitride. A dramatic increase in the resonant frequency of the laser-irradiated drums indicates the presence of a high tensile stress that extends beyond the value associated with thermal expansion. We demonstrate that depending on the type of structure, the laser induced stress can become permanent or it can exhibit a relaxation time up to approximately 100 sec, which we attribute to the evolution of the defects. Overall, this process provides a basis for a cycling mechanical action (e.g. "nanomuscle"). We view such *in-situ* control over mechanical stiffness and stress as an example of the new capabilities afforded by 2D materials that are unavailable in conventional 3D materials. Our demonstrated mechanical tunability can be viable for numerous NEMS devices, ranging from nanomechanical resonators to applications like "nano-muscle" or mechanical energy storage. Furthermore, the underlying physics of atom re-arrangement within the monolayers and of defects themselves forming sophisticated structures can provide guidance for designing new man-made materials.

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