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Nanomechanical properties of metallic thin-films reinforced by carbon nanotube network from flexural measurements

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Abstract – Mechanical properties of nanolaminates– metallic thin-film and carbon nanotubes– are characterized by flexural measurements. From quasi-static flexural measurements– using an AFM cantilever– and dynamic flexural measurements, we find the elastic modulus of the CNT reinforced metallic thin-films to be nearly twice as large. Large amplitude quasi-static flexural measurements indicate the relative Yield strengths of nanolaminates to be significantly enhanced. Simultaneous dynamic flexural measurements while applying Joule heating show suppression of thermal-elastic effects in the nanolaminates, attributable to enhanced thermal conductivities and suppression of thermal expansion with the CNT reinforcement. Finally, long-cycle dynamic flexural measurements indicate significant reduction in anelastic effects.

A promising application of carbon nanotubes (CNTs) is their use as a functional component in nanocomposite material systems [1]. With unmatched electrical, mechanical, and thermal properties, CNTs have been employed to enhance the properties of various ceramic-, polymer-, and metallic-based nanocomposites [2]. With their high conductivities- both electrical and thermal-, high optical reflectance, and high biocompatibility metallic thin-films possess high-functionality and are attractive for certain micro- and nanomechanical sensing and high-frequency applications. For mechanical resonant device applications, resonator materials with high elastic modulus and high thermal-elastic stability are highly desirable. Herein, we characterize mechanical properties metallic thin-film/CNT nanolaminates by flexural measurements. For flexural measurements, we fashion the nanolaminate material into a freestanding nanobeam structures [3].

Quasi-static flexural measurements are conducted by a commercially available atomic force microscope (AFM). We find CNT network reinforced Al thin-films (Al-CNT) elastic modulus to be nearly twice that of Al thin-film nanomechanical beams. Furthermore, high deflection measurements indicate a drastic increase in Yield strengths of Al-CNT nanolaminates. For dynamic flexural measurements, by fitting measured resonant frequencies and nanomechanical beam resonator dimensions, we can surmise both the elastic modulus and internal stress. Similar to quasi-static flexural measurements, we find the elastic modulus of Al-CNT beam resonators to be twice that of Al. For large amplitude dynamic flexural measurements, we find the Al-CNT nanomechanical beam resonators to be less susceptible to nonlinear effects.

Beyond elastic properties, nanoscale materials– such as nanocomposites and nanolaminates– and their nanomechanical properties may be affected by extrinsic factors beyond applied stress. One is the thermal-elastic effect. By simultaneously conducting the dynamic flexural measurements while applying Joule heating, we observe the resonant response of the Al-CNT nanomechanical beam resonators to be substantially less affected than those without CNT reinforcement. The other is anelastic effect. By conducting extremely long-cycle dynamic flexural measurements, we again observe the resonant response of the Al-CNT nanomechanical beam resonators to be less affected.

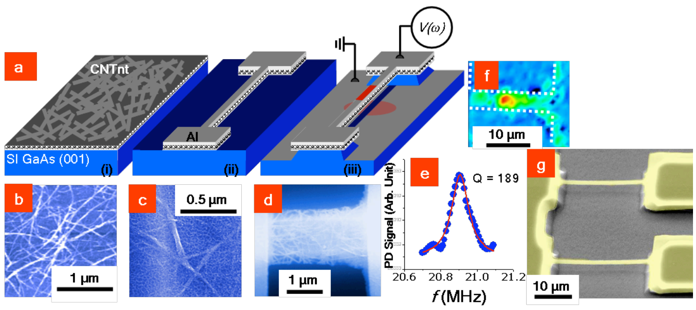

Figure 1: (a) schematic of the Al-CNT nanomechanical beam fabrication; (b-c) AFM image of the CNT network self-assembled on the substrate (b) and after UHV sputter deposition of Al thin-film (c); (d) FE-SEM image of free-standing CNT network, exposed after selectively removing the Al thin-film; (e-f) fundamental flexural mode resonant response of Al-CNT nanomechanical beam resonators; (g) SEM image of the freestanding Al-CNT beam resonators.

References

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