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Electrochemical tuning and mechanical resilience of single-wall carbon nanotubes*

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Abstract: Single-wall carbon nanotubes (SWNTs) are fascinating systems exhibiting many novel physical properties. In this paper, we give a brief review of the structural, electronic, vibrational, and mechanical properties of carbon nanotubes. In situ resonance Raman scattering of SWNTs investigated under electrochemical biasing demonstrates that the intensity of the radial breathing mode varies significantly in a nonmonotonic manner as a function of the cathodic bias voltage, but does not change appreciably under anodic bias. These results can be quantitatively understood in terms of the changes in the energy gaps between the 1D van Hove singularities in the electron density of states, arising possibly due to the alterations in the overlap integral of π bonds between the p-orbitals of the adjacent carbon atoms. In the second part of this paper, we review our high-pressure X-ray diffraction results, which show that the triangular lattice of the carbon nanotube bundles continues to persist up to ~10 GPa. The lattice is seen to relax just before the phase transformation, which is observed at ~10 GPa. Further, our results display the reversibility of the 2D lattice symmetry even after compression up to 13 GPa well beyond the 5 GPa value observed recently. These experimental results explicitly validate the predicted remarkable mechanical resilience of the nanotubes.

INTRODUCTION

Carbon nanotubes have unique structural, mechanical, and electronic properties. It is, thus, not surprising that they are being studied very actively ever since their discovery [1] from a basic science point of view, as well as for potential applications [2] such as actuators [3], pressure [4] and flow [5] sensors, nanoscale electron devices [4], catalysts, light-weight batteries, and hydrogen storage. Electrons confined in one dimension behave fundamentally different than in three dimensions. In one dimension, electrons form a correlated liquid, called the Luttinger liquid, which has novel features like separation of spin and charge and a power law dependence of the resistance on the bias voltage and temperature. Recent experiments [3] suggest that signatures of Luttinger liquid are found in single-wall carbon nanotubes (SWNTs).

Carbon nanotubes have been shown to be excellent actuators where the actuating action has been attributed not to the intercalation of ions, but due to the electrochemical double-layer charging [4]. This, in turn, is expected to change the electronic structure of the nanotubes. Our motivation was to quantify the effect of the electrochemical biasing of the nanotubes on the electronic band structure over and above the doping. This has been achieved [6] by employing resonance Raman scattering (RRS), which probes both vibrational and electronic states. Raman spectra of SWNTs show two prominent bands: one near ~180 cm^{-1} associated with the radial breathing mode (RBM) and the other near 1590 cm^{-1} attrib-

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