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Carbon Nanotube Strain Sensor by Using Micro-Raman Spectroscopy

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Micro-Raman Spectroscopy is regarded as is an effective, precise, noncontact technique with micrometer spatial solution for strain measurement,[1] but is restricted to those so-called Raman-active materials whose spectra have typical and visible Raman modes (peaks) sensitive enough to strain.[2] This limitation may be break by using some Raman-active materials as strain sensing media. As a new Raman-active material, carbon nanotube is potential for sensing strain[3-5] because of its outstanding mechanical[6-7] and spectral[8-10] properties.

In this work, we present a theoretical and experimental study of carbon nanotube (CNT) strain sensor in terms of micro-Raman spectroscopy for the micro-mechanical measurement of both Raman-active and Raman-inactive materials. The CNTs uniformly dispersed on the surface of (or inside) the measured body are taken as sensors (as Fig.1 shows). The theoretical model of CNT strain sensor is developed by applying the resonant and polarized Raman properties of CNTs and quantificationally calculating the synthetic contributions from individual CNTs in random directions to the entire Raman spectrum. The proposed model provides an analytic relationship between the in-plane strain components (ε_X, ε_Y and γ_{XY}) to be measured and the Raman-shift increment ($\Delta\Omega$) detected through polarized Raman tests.

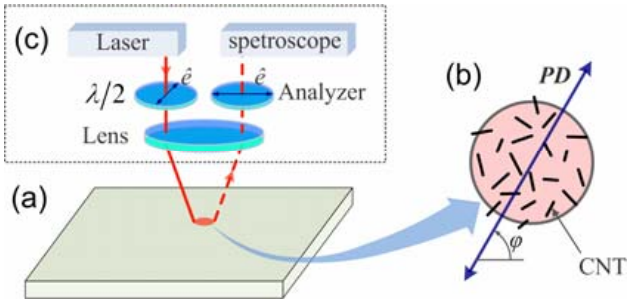

Figure 1. Diagrammatic sketches of CNT strain sensors by polarized Raman spectroscopy. (a) Measured body, (b) CNTs dispersed uniformly and stochastically on the surface of the measured body, where ***PD*** is the polarizing direction of incident light. (c) Polarized Raman spectroscope, where straight and segment lines are incident and scattering lights, respectively, and $\hat{e}$ denotes the fast axis direction of half-wave plate or the polarizing direction of analyzer plate.

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Based on this model, we introduce a novel noncontact technique of strain measurement named Raman Strain Rosette, which detects the Raman-shift increments of the spectra from a same sampling spot with three different polarized directions (as Fig.2 shows), and then substitute them into the analytic relationship of the theoretical model to compose a simultaneous equations set. By solving this equations set, the strain components are achieved. This proposed technique is applied in several experiments to confirm the validity of the CNT strain sensor in this work. The experimental results reached by Raman Strain Rosette are consistent with the actual values as a whole, which verifies that Raman Strain Rosette is practicable to quantitative measuring all the in-plane components of the strain tensor (including both normal and shear strains) and it is further applicable to achieving the strain fields through Raman mapping. (PACS numbers: 81.70.Fy, 81.05.Tp, 07.10.Pz)

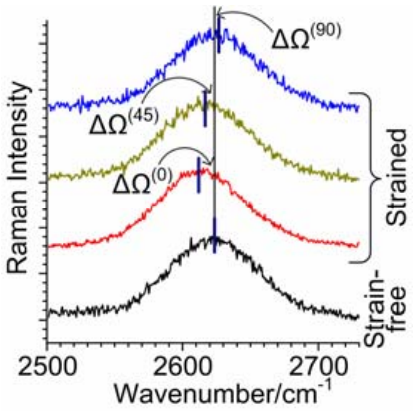

Figure 2. G' band spectra with different loading and polarization directions.

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