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Nanoscale Raman imaging and analysis of strain distribution in carbon nanotube

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Tip-enhanced Raman scattering (TERS) microscopy is one of most successful applications of plasmonics to nano-imaging and nano-analysis of a variety of advanced nanomaterials. TERS microscopy employs a metallic nano-tip which plays important roles in confining and enhancing the probing light field due to the excitation of localized modes of surface plasmon polaritons (SPP) at the apex [1, 2]. Combination of a scanning SPP tip with Raman spectroscopy has so far enabled us to perform analytical nano-imaging of nano-carbon materials as well as semiconductors and biomolecules with spatial resolution far beyond the classical diffraction limit [3-7].

Here in this presentation, we show practical application of TERS to imaging and characterizing local strain distribution in carbon nanotube (CNT) at spatial resolution of ~20 nm [5]. TERS spectral mapping was performed along an isolated CNT that was dragged from just two inner locations, marked by points *A* and *B* in the AFM image in Fig. 1**a**. The yellow arrows indicate the directions of dragging. As shown in Fig. 1**b**, TERS spectra of the locally-dragged CNT exhibited clear variation in Raman frequency of the G-band (C-C stretching vibrational mode) along the length of the CNT. Sharp up-shifts corresponding to torsional strain were seen near the points (points *A* and *B*) where the CNT was dragged by the tip apex. In addition, up-shifts were also be seen at the other corner points, such as at point *C* in the figure, where the CNT was locally rolled even without a push at that location. On the other hand, the peak position in the non-manipulated straight part of the CNT remains stable at about 1591 cm^{-1}. This result leads us to the conclusion that the nanotube used in this particular experiment had stronger frictional force on the substrate that provided rotational torque to the CNT during manipulation, thus the resultant strain was a combination of tensile and torsional strains, with torsional strain being stronger in magnitude. Further, we spectroscopically investigated that depending upon the tip-positioning and the amount of tip-applied lateral force during the dragging process, CNTs were locally stretched, rolled, moved or went through a combination of all changes. Such optical-based analytical mapping of localized strains along a nanotube is not possible by any other methods.

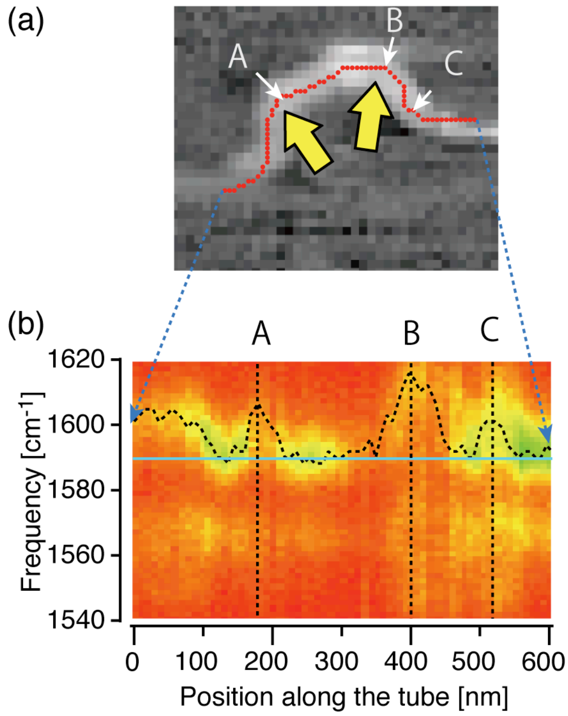

Fig. 1 (a) An AFM image of a nanotube, which was dragged along the yellow arrows from two distinct points marked by *A* and *B*. **(b)** The frequency positions of G^+-mode in TERS spectra obtained along the length of the manipulated part of the CNT (corresponding to the red dotted path shown in **(a)**).

References

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