Direct observation of individual defects on carbon nanotubes by dynamic force microscopy

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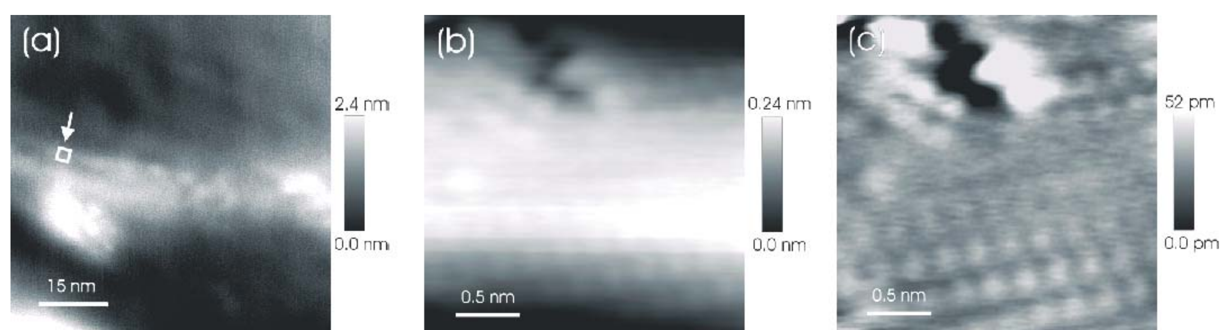
Single-walled carbon nanotubes (SWNTs), consisting of single graphene sheets rolled up to form hollow tubes with nanometer diameter and over micrometer length, show metallic or semiconductive properties, depending on their helicity. The SWNTs have attracted much attention due to their unusual mechanical and unique electronic properties which can provide great opportunity for fabricating nanoscale devices [1]. Actual implementation of the SWNT devices demands a thorough understanding of the structural and electronic properties not only of perfect SWNTs but also of defective SWNTs because some kinds of defects are naturally included and can cause drastic changes of their properties [2].
Recently, we have successfully achieved atomic resolution for imaging SWNTs by dynamic force microscopy (DFM) in ultrahigh vacuum and at low temperature [3]. The DFM, operated by the frequency modulation technique in non-contact regime, has enabled atomic resolution for imaging non-periodic features and point defects. Here, we present atomic resolution imaging of individual defects in the SWNTs. As in the case of Ref. 3, we observed the SWNTs on a graphite substrate under feedback control to maintain a constant frequency shift (Δf) of the cantilever oscillation (eigenfrequency: $f_0 \approx 159$ kHz) with a constant amplitude. Figure (a) ($\Delta f \approx -11.9$ Hz) shows surface topography of a bundle of nanotubes. Figures (b) ($\Delta f \approx -127$ Hz), corresponding to the open square in Fig. (a), shows surface topography of an individual SWNT. The image contrast of the upper middle part in Fig (c), where a parabolic curvature is subtracted for better visualization, suggests the existence of localized defects. By detailed analysis of the image contrasts, we will topologically characterize those defects.



[1] C. Dekker, Phys. Today **52**, 22 (1999); T. Rueckes et al., Science **289**, 94 (2000).
[2] A.J. Lu and B.C. Pan, Phys. Rev. Lett. **92**, 105504 (2004); A.V. Krasheninnikov et al., Phys. Rev. B **63**, 245405 (2001).
[3] M. Ashino, et al., Phys. Rev. Lett. **93**, 136101 (2004).