Interference of electron waves on single wall carbon nanotubes

A. Hassanien[*,1], P. Umek[†], A. Mrzel[†], D. Vrbanic[‡], M. Mozetic[#], P.Venturini[§], M. Tokumoto[*], D. Mihailovic[†] and S. Pejovnik[‡]

[*]Nanotechnology Research Institute
1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan
[†]Jozef Stefan Institute
Jamova 39, 1000 Ljubljana, Slovenia
[‡]Faculty of Chemistry, University of Ljubljana,
Askerceva 5, 1000 Ljubljana, Slovenia
[#]Institute of Surface Engineering and Optoelectronics,
Teslova 30, 1000 Ljubljana, Slovenia
[§]National Institute of Chemistry
Hajdrihova 19, 1000 Ljubljana, Slovenia

Abstract. We report on the structure and electronic properties of single wall carbon nanotubes (SWNTs) tips with atomically spatial resolution. Scanning tunneling microscopy (STM) show topographic images of closed tips with a variety of geometrical structure; these include round, conical, as well as tips with a messy shape. Standing wave pattern of the charge density is observed at the tube cap which is formed due to constructive interference between the electronic states and its reflection on the nanotube tips. Atomically resolved images show asymmetry in the charge density that decay out within 6 nm away from the cap. These distinctive tip states do not exist elsewhere on the tube and are related to the presence of topological defects at tube ends.

Experimental Results and discussion

In this study, two methods of purification are carried out in order to remove metal nanoparticles and other unwanted species. The first one involves a chemical purification (1). The second method utilizes hydrogen plasma technique (2). A mat of purified soot was sonicated in ethyl alcohol for a few minutes prior to being cast on freshly cleaved highly oriented pyrolytic graphite (HOPG) substrates for STM experiments. In Fig. 1 we show an STM topographic image of a 6.5 nm × 6.5 nm area taken with 30 mV bias voltage and 200 pA current. In this image two armchair nanotubes laying on HOPG substrate are clearly visible; one nanotube marked A, has a closed end of a round shape while the other, marked B, is a longer nanotube, its tip is not shown in this image. Near the end of tube A, complex corrugation is clearly visible which is different from armchair lattice (6 nm away from the tube end). The pattern has asymmetric features, which reflects the shape of charge density on the nanotube lattice. At low bias voltage the STM topographic image can be thought of as the spatial variation of the electronic charge density near the Fermi level. The later is proportional to square of the wavefunctions. Topological defects, such as pentagons at the tube caps, disrupt the nanotube potential, which in turn reflect the electronic wavefunctions (3). Near these scattering centers constructive interference between incident and reflected Wavefunctions Fig. 2(a) shows a larger view of the same nanotubes. A line profile of the topography is taken along the highlighted line. Two different periods of oscillations are detected; see Fig. 2(b). Close to the cap an oscillation of nonequidistant peaks is clearly observed. A period 0.74 nm is seen (dashed arrows) which differs significantly from the lattice constant of 0.25 nm. At distance larger than 6 nm away from the cap an oscillation of equidistant peaks is observed. The period of the oscillation is 0.25 nm (solid arrows) which compares nicely with the lattice constant of armchair nanotube lattice. Apparently at these distances the tip is following the atomic corrugations and the cap has undetectable effects beyond this range. Therefore the distance (6 nm) could be assigned as the range of disturbance of the electronic charge density due to reflection of electron waves from nanotube ends.

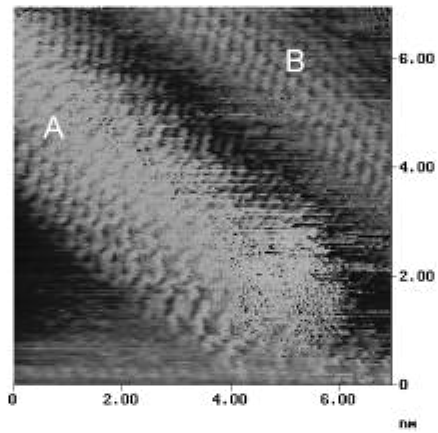

FIG 1. STM topographic image of armchair SWNT taken near the tube cap. CDW are clearly visible. The oscillations damp out within 6 nm away from the cap. In this region the effects of scattering is small enough and the STM tip is following the atomic corrugation due to nanotube lattice.

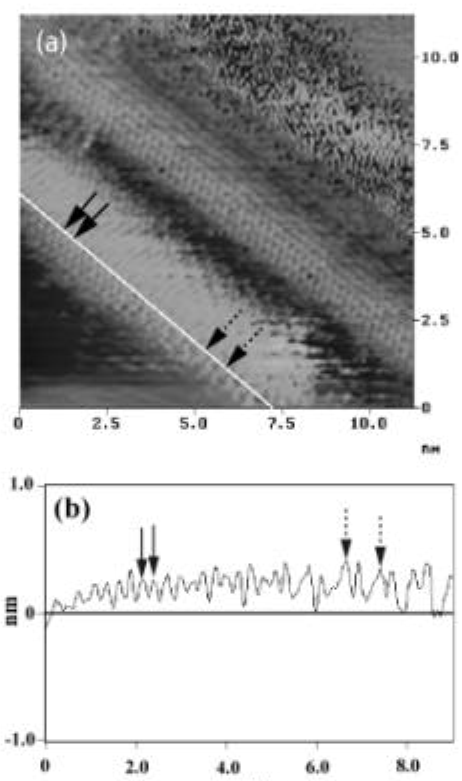

FIG 2. (a) STM image of two armchair SWNT. (b) Shows section analysis along the highlighted line in (a). Two types of periodicity are marked by the arrows: Near the tube cap, peak pairing features are dominant with period 0.74 nm (dashed arrows); Nearly 6 nm away from the cap, an oscillation with period 0.25 nm due to SWNT topography (solid arrows) is dominant.

References:
1. P. Umek, *et. al;* 38: (11-12) 1723 (2000).
2. A. Hassanien *et. al*; proceeding of the International Winterschool, Kirchberg, Tirol, Austria 2001.
3. A. Hassanien *et. al*; Appl. Phys. Lett. 78, 808, 2001.

[1] Author to whom correspondence should be addressed. Electronic mail: Abdou.Hassanien@aist.go.jp