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Usage of Carbon Nanotubes in Scanning Probe Microscopes as Probe

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Abstract: Carbon Nanotubes (CNT) are one of the most popular materials studied as a subject in nanotechnology. There are lots of areas that CNTs can be used for scientific, technological and commercial purposes. One of the important scientific uses of CNTs are probes used in "Scanning Probe Microscopy" because of their mechanical and electrical properties. In this study, our aim was to give information and present examples from different types of scanning probe microscoby studies published before and emphasize CNT's importance in resolution of image taken by "Atomic Force Microscope" (AFM) and "Scanning Tunneling Microscope" (STM) that are types of "Scanning Probe Microscopes". Also assembly process and remarkable situations in assembly is going to be presented in this paper.

Keywords: Carbon Nanotube, Scanning Probe Microscope

1. Introduction

Nowadays, technology is developing to answer needs of human being. The important one of these developments is nanotechnology. The technology smaller than microtechnology (Akdoğan A., Küçükyıldırım B.O., 2006).

Studies related to nanotechnology are important for material science and improvement of materials. Imaging, evaluating and fabricating in atomic size will be improved by developing nanotechnology studies and by these improvements nanomaterials will be synthesized.

Examination of nanomaterials revives lots of technical method such as electron microscopes and scanning probe microscopes. Especially scanning probe microscobes are very important for examinations.

2. Carbon Nanotubes

Carbon nanotubes (CNTs) are allotropes of carbon (Wikipedia – Carbon Nanotube, 2009). These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors.

Because of the symmetry and unique electronic structure of graphene, the structure of a nanotube strongly affects its electrical properties. By the type of a nanotube which is related with the wrapping of cylindrical structure, it's electrical properties are changed. Thus all armchair nanotubes are metallic, so conductive. In theory, metallic nanotubes can carry 1,000 times greater electrical current density than metals such as copper (Hong, Seunghun; Sung Myung, 2007).

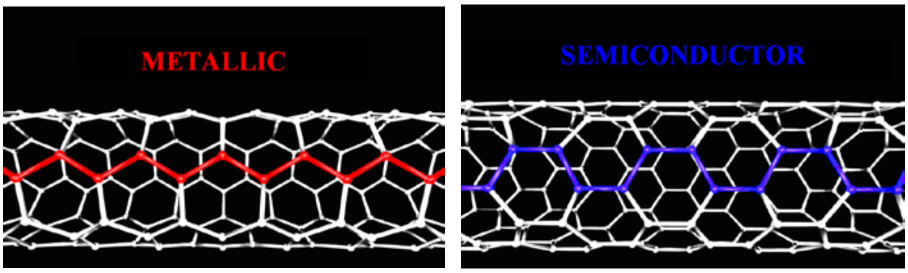

Figure 1. Metallic and semiconductor carbon nanotube structures (Wikipedia – Metallic nanotube, 2007, Wikipedia – Semiconducting nanotube, 2007)

3. Scanning Probe Microscopes

Nano surface investigations are usually made bu "Scanning Electron Mıcroscopes" (SEM) and/or "Transmission Electron Microscopes" (TEM). Because of some difficulties such as difficulties of imaging non-conductives by SEM and preperation of TEM specimens by destructive and expensive methods makes us to search for another method to investigate nano scale properties of materials. Therefore, "Scanning Probe Microscopy" provides us cheaper, easier surface investigation facility that can be used for all kinds of materials.

Scanning Probe Microscopy (SPM) is a branch of microscopy that forms images of surfaces using a physical probe that scans the specimen (Wikipedia – Scanning probe microscopy, 2009). An image of the surface is obtained by mechanically moving the probe in a raster scan of the specimen, line by line, and recording the probe-surface interaction as a function of position. SPM was founded with the invention of the "Scanning Tunneling Microscope" in 1981. Of these techniques "Atomic Force Microscopy" (AFM) and "Scanning Tunneling Microscopy" (STM) are the most commonly used followed by "Magnetic Force Microscopy" (MFM) and "Near-field Scanning Optical Microscopy" (NSOM/ SNOM).

3.1 Usage of Carbon Nanotubes in Scanning Probe Microscopes as a Probe

High-resolution imaging in SPM's is based on short-range interactions between the tip apex and the atomic-sized features of the surface (Chien-Chan Su, 2005). Therefore, minimizing the long-range forces between the tip and the surface is highly desirable. Much effort has been made to improve the sharpness of AFM probing tips. Reason of this process is to enhance their wear-resistance properties by releasing the wear and bump of the tip to the material surface. However, problems still remain in obtaining consistent high-resolution images since the conventional silicon or silicon nitride tips quickly become worn during operation and then tip profile changes occur, particularly when crashing the surface.

An ideal AFM probing tip should be mechanically elastic and chemically inert such that changes of the tip profile and chemical reaction are minimized during the scanning process. The resolution of an AFM is governed by the geometry of its tip apex and the aspect ratio of the cantilever tip. Specifically, to obtain a high resolution, the tip apex should be sharp and the radius of curvature should be small.

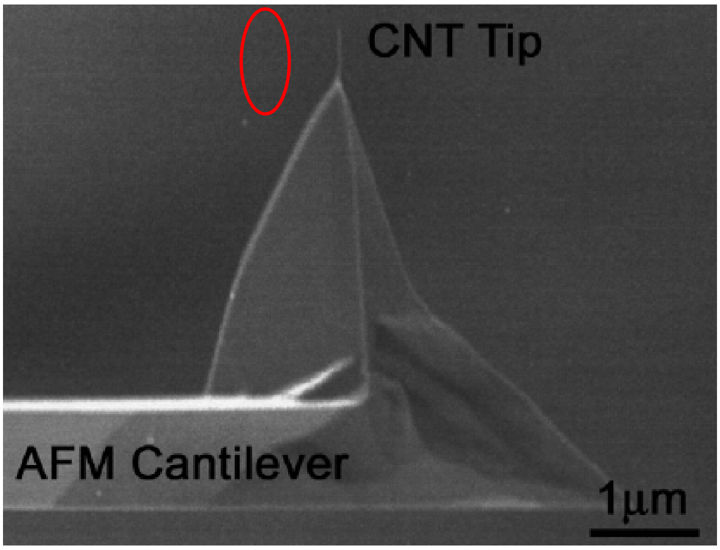

Figure 2. AFM Cantilever with a CNT tip

Since carbon nanotubes (CNTs) were first discovered, researchers have proposed many potential applications for these nanometer scale structures, including field emitters, sensors, scanning probe microscopy tips, molecular wires and high strength composites. Since the imaging resolution of an AFM is determined by the diameter of the scanning probe tip, CNT tips offer the potential for resolution at the nanoscale. Furthermore, the long characteristic length of CNT tips permits the tracing of rough surfaces with steep and deep features. A high CNT tip aspect ratio is also advantageous in reducing the long-range forces between the tip and the surface in the tip sample interactions, there by further improving the imaging resolution.

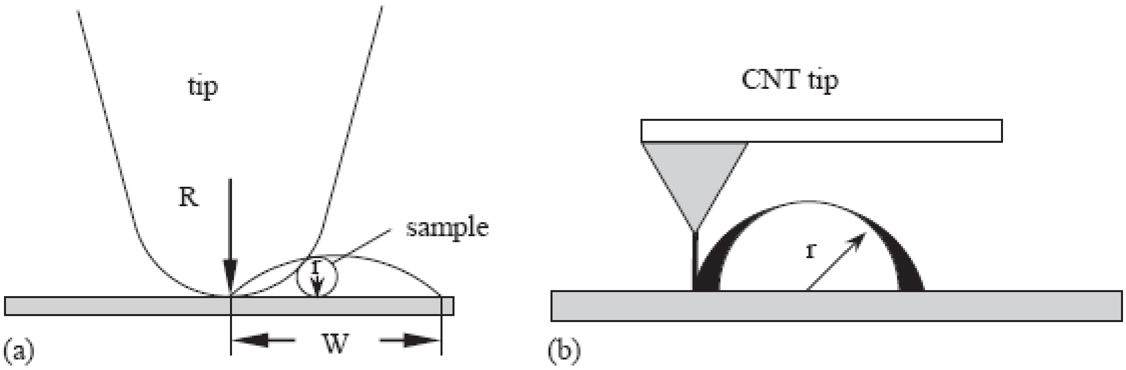

Figure 3. Standard (a) and CNT tip (b) deconvolution model (Liqiu Guo et. al., 2005).

As you may see in deconvolution model shown in Figure 3, by using standard tip you may obtain an image different from the original sample geometry but by using CNT tip this image can be obtained well-matched with the geometry of the sample. If we look for the rough surfaces as seen on Figure 4, image taken by a CNT tip probe will be as the same with the surface.

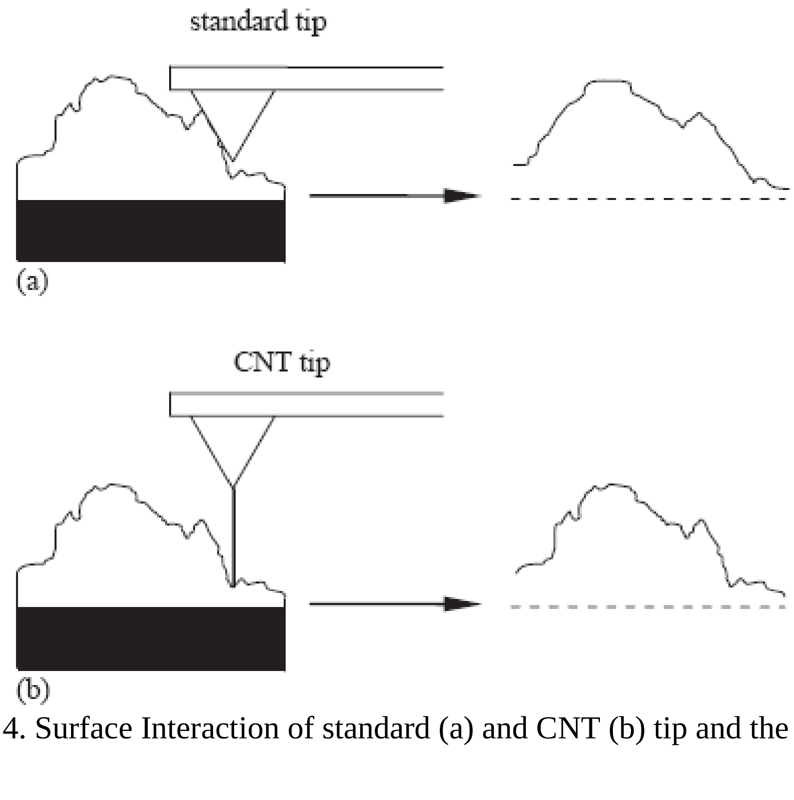

Figure 4. Surface Interaction of standard (a) and CNT (b) tip and the sample.

In studies about CNT tip usage, orientation and smoothness of CNT are the most important facts (June-Ki Park et. al., 2006). At first CNT is attached to probe by electrophoresis method. As shown in Fig. 5, dielectrophoresis is the motion of a particle produced by the interaction of a non-uniform electric field with the induced effective dipole moment of the particle. Polarized CNT moves to the AFM probe tip where is the strongest area in the electric field and eventually assebly of the CNT actualized.

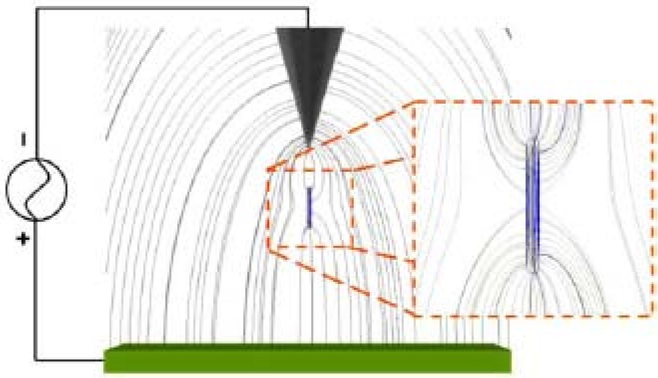

Figure 5. A schematic diagram that shows the electric field line of electrophoresis.

In some situations curled or bent CNTs would be assembled to the tip apex. So we have to amend the directionality and straightness of the CNTs, because the morphology of these CNT would degenerate the imaging quality of the tip. Focused-ion-beam (FIB) is introduced by June-Ki Park et. al. to solve this problem (June-Ki Park et. al., 2006, Wikipedia – Focused ion beam, 2009). When the ion beam was focused to the CNT tip, CNT's angle is quickly changed according to the beam direction and in a few minutes CNT will have it's most smooth shape (Figure 6).

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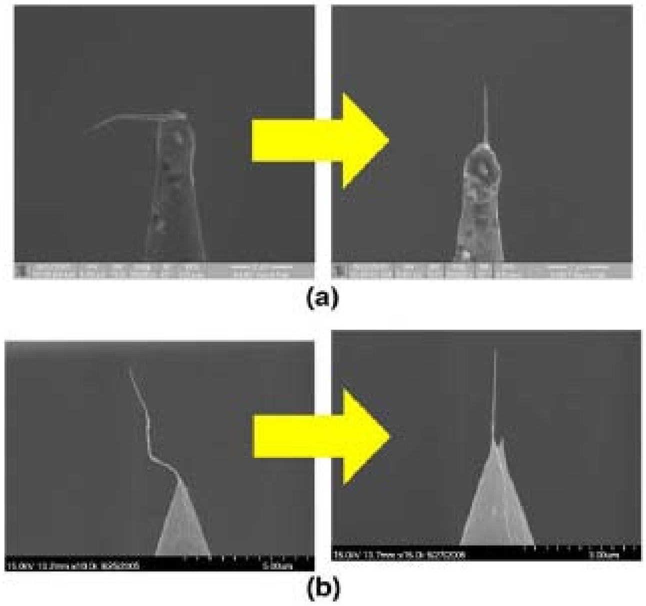
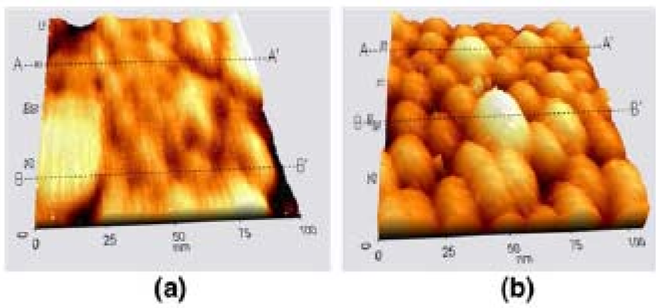


Figure 6. Directionality and straightness control of the CNT tip by FIB: (a) fully bent CNT is changed to the erected form, (b) highly curled CNT is straightened after a dose of ion beam.

4. Results and Discussion

We may evaluate these investigations by looking results of some images taken by both CNT tip and conventional tip. When June-Ki Park et. al. measured the sample surface in an area of 100x100 nm^2, the conventional tip produced an unclear image as shown in Fig. 7(a), because the radius of the tip was too large for the Au particles. With respect to the fabricated CNT tip, they could obtain a very clean image for the Au, as shown in Fig. 7(b). After scanning the sample several times with the CNT tip, they have checked the CNT tip again in an FE-SEM. As a result, they have found no change from the original CNT tip. The results show that the adhesion strength of the CNT is enough to measure the sample in non-contact mode AFM.



Şekil 7. AFM images taken in non-contact mode obtained with (a) a general tip and (b) a CNT tip for a 15 nm Au ball on an Si substrate.

At the same time, the image taken in the study of Liqiu Guo et. al. shows that, the resolution of AFM image which is taken by using CNT tip is more satisfying (Liqiu Guo et. al., 2004).

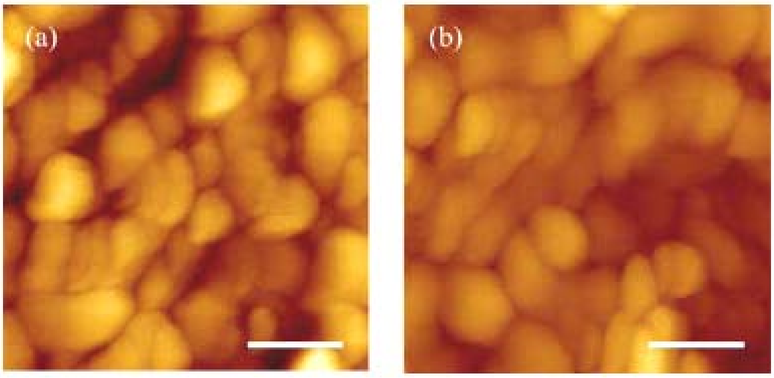


Figure 8. Image resolution comparison when using CNT probe (a)and silicon probe (b) (bar = 500 nm).

Another example is the study of Hyung Woo Lee et. al.(H.W. Lee et al., 2005). In the study, standard specimen with a 100 nm tall grating have been investigated by two types of AFM tips which are conventional and CNT tip. Fig. 9 shows that images taken by using CNT tip displays the sorface condition much more correct than the conventional one.

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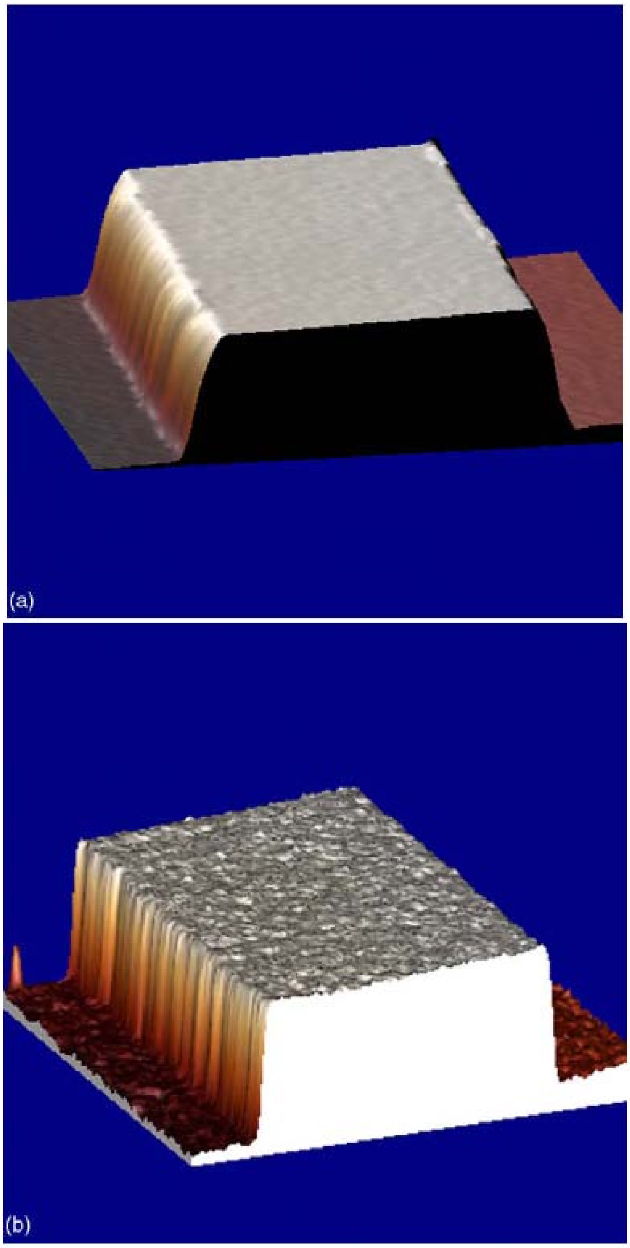

Figure 9. Standard specimen with a 100 nm tall grating investigated by a conventional tip (a) and CNT tip (b).

Consequently, CNT tips have an significance in scanning probe microscopy results. CNT tips have to be used to obtain more detailed and true results about nano surfaces so investigations, fabrications and maintenance of nano materials can be done succesfully.

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