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AFM and KFM Measurements of Semiconductor Surface Using Carbon Nanotube Tip Fabricated by Electrophoresis

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Carbon nanotubes (CNTs) are ideal structures for the tips used in scanning probe microscopies such as AFM and STM, since they have intrinsically small diameters (1-20 nm) with high aspect ratios and can buckle elastically. CNT tips were fabricated by various method such as Si cantilever manipulation[1)], electrophoresis/cantilever manipulation[2)] and CVD[3)]. In this presentation, we studied a simple method to attach the CNTs directly to the Si tip by electrophoresis and applied it to AFM and KFM measurements.

CNTs were synthesized by a conventional DC arc discharge in a helium atmosphere. Nanotubes thus prepared were multiple-wall type. The diameter was about 10 nm and the length was 1-6 μm. The synthesized nanotubes were ultrasonically dispersed in ethyl alcohol about 100 minutes and centrifuged at 5500 rpm for 30 minutes to remove large particles. The top of the centrifuged suspension was used for the electrophoresis.

Nanotubes were directly attached to a Au-coated Si AFM tip using an AC electrophoresis technique. Figure 1 shows the experimental setup. The suspension was dropped onto a glass plate with a hollow. Two electrodes, a conventional Si AFM tip and a metal plate, were dipped into the suspension with a spacing of 50 μm. The frequency and the amplitude of the AC voltage was 5 MHz and 9 V. The electrophoresis was performed for 1 minute.

Figure 2 shows a typical SEM image of a CNT tip attached to the conventional Si AFM tip. Protrusion length of the CNT tips was 20-500 nm. An amorphous carbon layer was deposited on the foot of the CNT tip by irradiating electron beam in an SEM apparatus to fix the CNT tightly on the Si tip.

To explore the resolution of these tips and their applicability to high-resolution imaging of fine structures, we have performed AFM measurement of a surface pit of AlGaN/GaN grown on (1000) sapphire substrate. Figure 3 shows typical images of the pit using (a) a CNT tip and (b) a conventional Si tip. A clear image of the pit with diameter of about 80 nm was obtained in the case of the CNT tip. However, an image obtained by the conventional Si tip was not so good.

Figure 4 shows the depth profiles of the pit measured by both tips. The advantage of the nanotube tip is clearly observed. In the depth profile measured by the CNT tip, a steep wall and a bottom of the pit are recognized as shown in the figure. From this profile, we can identify that the present pit of the AlGaN/GaN surface is not a nanopipe that threads through the buffer layer. In the case of the Si tip, on the other hand, triangular profile is obtained. The pyramidal shape of the conventional Si tip restricts the ability of the tip to access narrow features. The profile obtained by the conventional Si tip does not reflect true profile but the profile of the Si tip. Small-cone-angle CNT protrusion with diameter of about 10 nm on the end of the conventional Si tips significantly improves the spatial resolution.

Figure 5 shows the measured contact potential profile of i-GaAs/i-AlGaAs layered structure with different Al content of 0.3, 0.5 and 0.8 using the CNT tip obtained by KFM. Clear contact potential profile was obtained for both tips.

In summary, the carbon nanotube tips were fabricated by attaching the CNTs directly to the conventional Si cantilever tips by using electrophoresis. Clear profiles have been successfully obtained using a CNT tip for AFM and KFM measurements.

1) H. DaiJ. H. Hafner, A. G. Rinzler, D. T. Colbert and R. E. Smalley: Nature **384** (1996) 147.
2) S. Akita, H. Nishijima, Y. Nakayama, F. Tokumasu and K. Takeyasu: J. Phys. D: Appl. Phys. **32** (1999) 1044.
3) J. H. Hafner, C. L. Cheung and C. M. Lieber: J. Am. Chem. Soc. **121** (1999) 9750.

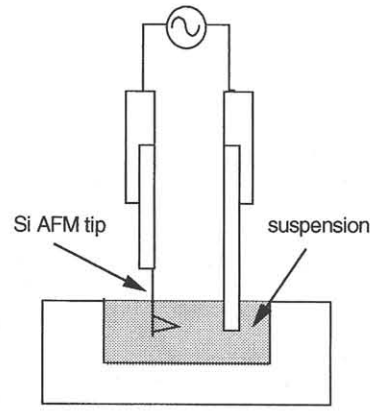


Fig. 1: Schematic drawing of the experimental setup for the electrophoresis.

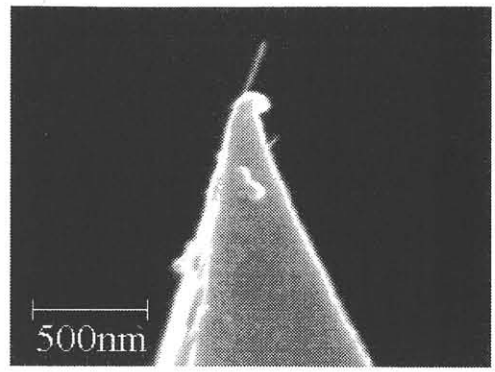
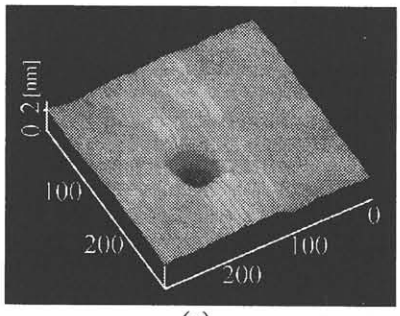
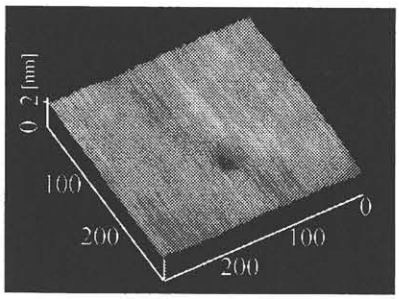


Fig. 2: SEM image of a CNT tip attached to the Si cantilever tip.

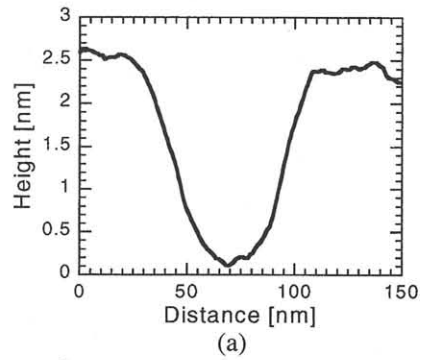


(a)

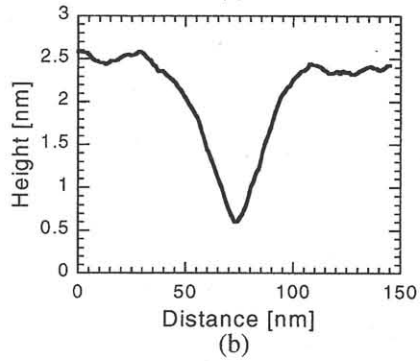


(b)

Fig. 3: Typical AFM images of a pit on an AlGaN/GaN surface using (a) a CNT tip and (b) a Si tip.



(a)



(b)

Fig.4: Depth profiles of the surface pit obtained by (a) a CNT tip and (b) a Si tip.

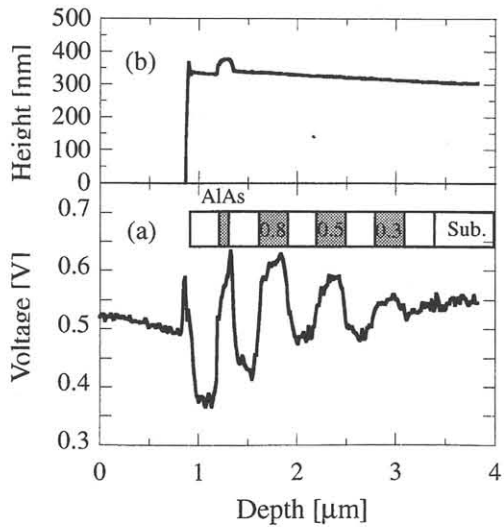


Fig.5: Profile of (a) contact potential and (b) topography of i-GaAs/i-AlGaAs layered structure measured by KFM using a CNT tip. x_{Al}=0.3, 0.5 and 0.8.