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Metal-coated Carbon Nanotube Tips for Nanoscale Electrical Measurements

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1. Introduction

The nanometer scale diameter, high aspect ratio and mechanical robustness of carbon nanotubes (CNTs) have made them one of the most promising materials for nanoprobe applications such as a tip of atomic force microscopy (AFM) and scanning tunneling microscopy (STM). The CNT tip has been used in AFM for imaging biological materials with very high resolution, stability, and without damages to both the sample and the CNT tip itself [1].

The CNT tips can also be utilized for the electrical measurement with the multi-probe STM [2]. To characterize the electrical properties of nanotstructures, it is necessary to reduce the spacing between the tips in the multi-probe STM. In the case of the conventional metal tips, the minimum spacing is practically limited to be larger than several hundred nm. This is because the radius of the end of electrochemically etched metal tips is usually larger than 100 nm so that two tips begin to touch with each other at ~200 nm probe spacing. If the CNT tips are used for the multi-probe STM, the probe spacing can be reduced down to approximately 15 nm, the diameter of the CNT.

However, it is difficult to use the CNT tips as conductive probes, because of the presence of the high contact resistance at the interface between the CNT and the supporting metal tip [3].

In order to solve this issue, we have developed the metal-coated CNT tip by using pulsed laser deposition (PLD) [4]. The atom-resolved STM imaging and spectroscopy were demonstrated for silicon surfaces using the metal-coated CNT tip [5]. Moreover, characteristics of metal-coated CNT tips as probes in the multi-probe STM were investigated.

2. Experiments and Results

After a CNT was glued to a W tip by irradiating the contact area with an electron beam in a field emission scanning electron microscope (FE-SEM), the tip ensemble was coated with a metal (W or PtIr) thin-layer with a thickness of 3 to 6 nm by PLD method. We used multi-walled CNTs (MWCNTs) with an average diameter of 20 nm and a length of over 3 μm, which were synthesized by the arc discharge method. From transmission electron microscopy (TEM) observations, the metal layer was found to be uniformly coated on both the end and the side wall of the MWCNT, preserving the shape of the inner MWCNT (Fig. 1(a)).

The metal-coated CNT tip was introduced into an ultra-high vacuum (UHV) single-tip STM, and was used for STM observations of Si(111)-7×7 and Si(100)-2×1 clean surface. Figure 1(b) shows an empty state STM image of the Si(111)-7×7 surface taken with the W-coated CNT tip. The atomic images were stably obtained for both Si(111)-7x7 and Si(100)-2x1 surface for a period of over one hour without the degradation of their clearness by adsorbates from the CNT. Thus, the metal coating effects passivation of the tip as well as good electrical connection to the W tip.

We have also obtained the STS spectra with typical features in the density of states. These spectra conform qualitatively with previous reports [6, 7]. These results indicate high reliability of the metal-coated CNT tip in probing surface electronic states by STM/STS.

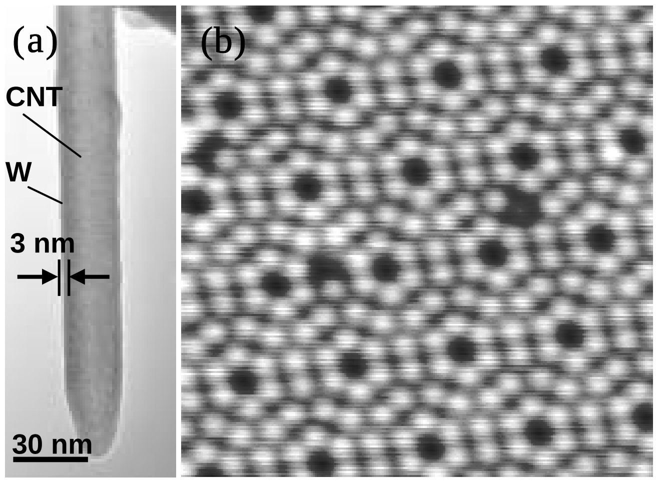

Fig. 1 (a) TEM image of a W-coated CNT. (b) STM image of Si(111)-7x7 taken by a W-coated CNT tip (V_s = 1.55 V, I_t = 0.4 nA, 15 nm × 15 nm).

Next, we demonstrated the potentiality of the metal-coated CNT tips for a multi-probe STM. Two metal-coated CNT tips were installed into a multi-probe UHV-STM combined with FE-SEM to demonstrate the multi-probe operation at a nanometer probe-spacing. It was found that the metal-coated CNT tips could be brought together into approximately 50 nm spacing (Fig. 2(a)), which was not attained with usual W tips.

We also demonstrated the mechanical robustness and flexibility of the tip by pressing against a Mo plate in the SEM. Upon contact with the plate, the tip began to bend flexibly (Fig. 2(b)). However, when the tip was retracted from the contact point, it returned to its initial shape. This result indicates that the metal-coated CNT tips have an advantage over the metal tips when they are used for electrical measurements in a multi-probe STM by repeated direct contacts to the sample. Once a usual metal tip contacts the sample surface, it is broken or its radius of the end becomes larger. However, the metal-coated CNT tips bend flexibly with contact to the sample many times.

The electrical conductivity of the metal-coated CNT tips was measured in the multi-probe STM. The measured resistance of metal-coated CNT tips was much lower (< 50 kΩ) in comparison with the tunnel resistance. It was confirmed that the resistance of the tip did not disturb the probing surface electronic states by STM/STS. The PtIr-coated CNT tip showed lower resistance than the W-coated one. This might be due to the chemical stability of the PtIr layer.

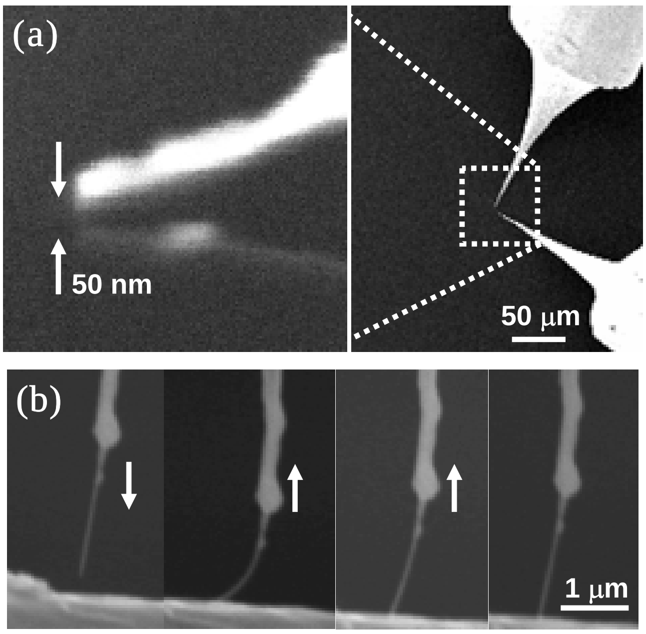

Fig. 2 (a) SEM images of two metal-coated CNT tips in the multi-probe STM. (b) SEM images during the flexibility test of the metal-coated CNT tip.

3. Conclusions

Using the metal-coated CNT tip, the atomic imaging and spectroscopy were stably achieved. The metal-coated CNT tips showed good performance for nanoscale electrical measurements in the probe-spacing of two tips, the mechanical flexibility and the electrical conductivity.

Acknowledgements

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References

[1] S. S. Wong, A. T. Wooly, T. W. Odom, J.-L. Huang, P. Kim, D. V. Vezenov and C. M. Lieber: Appl. Phys. Lett. **73** (1998) 3465.

[2] S. Hasegawa, I. Shiraki, F. Tanabe, R. Hobara, T. Kanagawa, T. Tanikawa, I. Matsuda, C. L. Petersen, T. M. Hansen, P. Boggild and F. Grey: Surf. Rev. Lett. **10** (2003) 963.

[3] T. Shimizu, H. Tokumoto, S. Akita and Y. Nakayama, Surf. Sci. **486** (2001) L455.

[4] T. Ikuno, M. Katayama, M. Kishida, K. Kamada, Y. Murata, T. Yasuda, S. Honda, J.-G. Lee, H. Mori and K. Oura: Jpn. J. Appl. Phys. **43** (2004) L644.

[5] Y. Murata, S. Yoshimoto, M. Kishida, D. Maeda, T. Yasuda, T. Ikuno, S. Honda, H. Okado, R. Hobara, I. Matsuda, S. Hasegawa, K. Oura and M. Katayama: Jpn. J. Appl. Phys. **44**, No. 7B (2005). (in press)

[6] R. Wolkow and Ph. Avouris: Phys. Rev. Lett. **60** (1988) 1049.

[7] J. J. Boland: Phys. Rev. B **44** (1991) 1383.

Appendix

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