Fabrication of single-wall Carbon nanotube STM probe and processing of single nanometer scale pit with high-aspect-ratio for highly oriented pyrolytic graphite

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Abstract

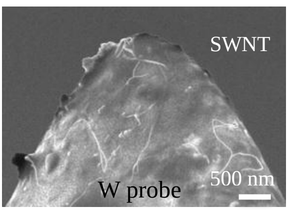
We have successfully developed one of unique fabrication methods of three-dimensional structures scale with about 50 nm using multi-wall carbon nanotube (MWNT) as a scanning tunnelling microscope (STM) probe. In order to develop further ultra-precision systems, it is surely required that a new ultimate processing technology needs fabrication size below 10 nm, i.e. single nanometer scale. This study paid great attention to realize the ultimate processing on engineering of single nanometer scale structures using a single-wall carbon nanotube (SWNT) probe. The much difficulty in fabrication of SWNT probes with high probability could be overcome using by unique phenomena with mixed dispersion liquid with both MWNT and SWNT through the pull-up method that we developed originally. In this process, it was clarified that SWNT with high probability attached to the point of MWNT, which was adhered to the apex of the conventional tungsten (W) needle. The success rate for fabrication of the SWNT probe was increased up to about 17 %. Finally, single nanometer scale pit with diameter of 9 nm and depth of 4 nm was obtained.

1. Introduction

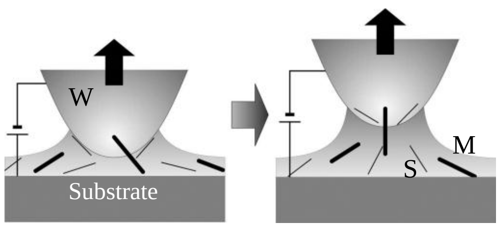
Single nanometer scale devices and electromechanical systems, such as a drug delivery system that will aim at only target cell, are strongly desired for realization. These dream technologies should need an innovative processing method. We have developed unique fabrication methods of high-aspect-ratio nanometer scale three-dimensional structures of pit, line and convex part using a multi-wall carbon nanotube (MWNT) with about 50 nm as a STM probe. It turns out that this method has been applicable to various conducting materials, such as noble metal thin films on silicon wafer, low-resistivity single crystalline silicon wafer and highly oriented pyrolytic graphite (HOPG). In this study, I would challenge to investigate the new method of fabricating SWNT probes with high success probability using the improved pull-up method [1], and clarify the relationship between the CNT diameters and the configuration of the pits fabricated for HOPG.

2. Experimental

The author has ever used only W needle through the pull-up process. It was clarified that SWNTs adhered around a W needle due to its large curvature as shown in Figure 1 (a). In this study, the fabrication of SWNT probes was also challenged using by the same pull-up method with mixed dispersion liquid (isopropyl alcohol) contained of both closed MWNT (diameter of 10-40 nm: Bucky USA) and SWNT (diameter of 1-5 nm: MTR). In this process, I have been verified by the exploratory experiment that the SWNT easily attaches to the point of the MWNT, which is adhered to the apex of the conventional W needle because of much small curvature of MWNT, as shown in Figure 1(b). The concentrations of both SWNT and MWNT were controlled in the ranges of 0.05-0.01 mg/ml and 0-0.1 mg/ml, respectively. Through the pull-up process, I set the constant condition of the probe bias of –14 V and the pull-up speed of 14 µm/s. Nanoscale pits were tried to fabricate on HOPG with atomic-level flatness and application conformity to various fields. The fabrication conditions of pit configuration were investigated under the condition of a bias voltage of 4 V, tunnel current of 1 nA and fabrication time of 180 s.



(a)



(b)

Figure 1. Concept of the pull-up method using mixture dispersion liquid: (a) SEM image using only W probe, (b) process using mixture of SWNT(S) and MWNT(M).

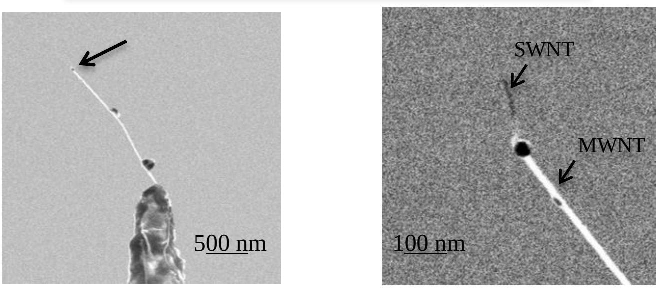
3. Results and Discussion

3.1 Fabrication of SWNT probe

The optimum manufacturing condition of the SWNT probe was investigated by changing the concentration condition of SWNT and MWNT, which was based on the case of fabrication of a MWNT probe. Table 1 shows the relationship between the concentration and the success production rate. It is clearly seen that the optimum condition can be specified with the mixture dispersion liquid concentration of 0.01 mg/mL SWNT and 0.05 mg/mL MWNT. Dramatic increase of success rate up to 17% from 2 % can be identified. Figure 2 shows the typical SEM image of SWNT probe. We can see that the single SWNT attached to the point of the single MWNT, which was adhered to the apex of the W needle, corresponding according to physical phenomena described above.

Table 1. Change of success rates for fabrication of SWNT probe

CNT concentration/mg.mL^{-1}			Success rate/%
No.	SWNT	MWNT	
1	0.005	0	2
2	0.005	0.05	12
3	0.005	0.1	7
4	0.01	0.05	17
5	0.01	0.1	5



(a) (b)

Figure 2. Typical SEM images of SWNT probe: (a) whole image fabricated under the concentration of No.4, (b) high magnification image of the joint part between SWNT and MWNT shown by the arrow in Figure 2(a).

3.2 Fabrication of pit using SWNT probe

Processing of pits was investigated using the SWNT probe obtained in this study, and the feature of the pit size and the configuration was compared with those fabricated using MWNT probes with different diameters. Figure 3 shows the typical pit STM images and their depth profiles with the probes used. We can see the dramatic result that the single nanometer scale pit with diameter of 9 nm and depth 4nm was realized using SWNT probe obtained as shown in Figure 3(a). However, until now the aspect ratios showed variation of values among 0.4-2.7. The variation is considered to be come from the distribution of the electrical field between the tip of SWNT and the surface condition at each processing place. Figure 3(b) and 3(c) show the pit images using MWNT probes with the diameters of 10 nm and 40 nm. The diameter and depth of pits fabricated are 14 nm, 45 nm and 38 nm, 115 nm, respectively. It should be noted that the diameter of the pit using SWNT is much smaller corresponding to the ultimate small diameter of the SWNT probe developed originally by the author.

In summary, this study can demonstrate the fabrication of the SWNT probe and the processing of single nanoscale pit. Moreover, STM fabrication using the SWNT probe can open the dreams to realization of innovative technologies.

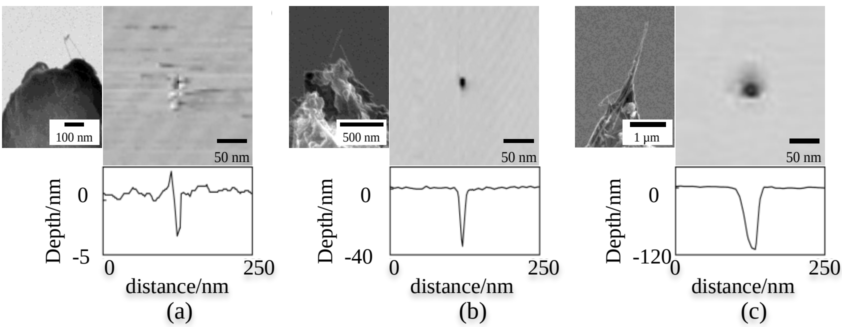


Figure 3. Variation of STM images of pits fabricated using SWNT probe and MWNT probe. SEM image of the probe used is shown in the left-hand side of each figure: (a) SWNT with 7 nm in diameter, (b) MWNT 10 nm in diameter and (c) MWNT with 40 nm in diameter.

References:

[1] A. Matsumuro and M. Takagi, Proc. 10th euspen Int. Conf., Delft, Netherlands. June 2010, Vol.2 282-258.