A Study on AFM Manipulation of Single-Wall Carbon Nanotube

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Abstract. As single-wall carbon nanotube (SWCNT) has special electrical and physical property, it can be used as excellent material to construct various nano electronic device. However, in the fabrication process, the modification of size, shape and even the electronic property, especially to the metallic SWCNT, is a key problem to be overcome. Here a modified nanomanipulation technology based on atomic force microscope (AFM) is utilized to perform various kinds of SWCNT manipulation, such as SWCNT separation, catalyst remove, continual nano buckles fabrication and even stretch to break, thus to modify the size, shape and eventually the electrical property of the SWCNT. In addition, the manipulation results are analyzed based on the mechanical mechanism.

1. Introduction

Since single-wall carbon nanotube (SWCNT) was successfully synthesized in 1993 [1], much research has been done on it for its special electrical and physical property, and it has been used to fabricate various nano electronic device, such as transistor, sensor and even simple logic circuit [2][3]. With the development of SWCNT based nano electronic device, the modification of SWCNT’s size, shape and electrical property has been one of a excited research fields. And limited by the SWCNTs synthesizing technology, the raw SWCNTs material consists of both semi-conducting SWCNTs and metallic SWCNTs, while the metallic SWCNTs are unnecessary in nano electronic device. For that, di-electrophoresis technology is utilized to separate the metallic from semi-conducting SWCNTs [4], and also the manipulation through a probe of an atomic force microscope (AFM) is a feasible way to modify the electrical property of the metallic SWCNT.

However, limited by dispersion technology of SWCNT bundles, most of the manipulation objects are MWCNT [5] or SWCNT bundles [6], little has been reported about the manipulation of single SWCNT. Aimed to overcome the barrier described above, here a modified AFM manipulation technology is utilized to perform various kinds of manipulation to modify the size,
shape and electrical property of the SWCNT, thus to eventually develop a method to modify the electrical property of the nano device.

2. Materials and methods
Before the alignment process, SWCNTs raw materials produced by arc discharge, is dispersed according to the following steps. Di-ionized water with sodium dodecyl sulfate (SDS) as additives is used as solvent[7], after accurate mass weighing with 0.1% SWCNT and 1% SDS proportion, the mixture solution in test tube is sonicated (40kHz) for about two hours. During sonication, the position and tilt angle of test tube in ultra-sonicator is adjusted to keep SWCNT solution ‘boiling’ in order to mix them uniformly and sufficiently, and at the same time the solution is heated to 40~60 centigrade degree for improving the dispersion effect. After the sonication, the solution keeps unmoved for sedimentation for about 6 hours.

After the dispersion of SWCNTs, a modified AFM based nanomanipulation system (AFM system, model Dimension3100 of Veeco Co., is modified according to the same method previously presented in[8]) is used for imaging and manipulating the SWCNT at room temperature and atmosphere condition. During imaging, the AFM system is working in tapping mode with frequency 312.5kHz, and the AFM probe used here is model MPP-11100 with rectangle Si cantilever, tip radius less than 10nm and force constant 40N/m. After imaging, the manipulation with force feedback is performed without changing the probe, and as force applied on the tip can be online controlled, wear or destroy of the AFM probe is significantly reduced, which can be verified by the fact that the resolution of the image keeps unchanged even after manipulation.

3 Results and Discussion
After the dispersion, the modified AFM based manipulation was performed to the SWCNT in the array with several kinds of results shown in the following.

3.1 Stretch to break of SWCNT
After the dispersion, scan area is reduced step by step and two SWCNTs are clearly imaged as shown in Fig. 1. Note here that as the scan size of the AFM system is 90um*90um*7um, which is relatively large at the nanometer scale, the effective signal is at the same scale of background noise when object less than 1 nm is imaged, thus parameters, such as setting point, vibration frequency, proportional gain and integer gain, have to be continually adjusted for obtaining image with acceptable resolution, and even thus the resolution of the scanned image is still deteriorated.
As shown in Fig. 1(a), two SWCNTs are parallel aligned and also straightened after the alignment process, and the left SWCNT with larger diameter actually consists of two single SWCNTs grown from the same catalyst. And we can also see that the height of the SWCNT consisted of two single SWCNTs is 1.8nm, which is close to the sum of the heights of two single SWCNTs with diameter of 1.2nm shown in the section curve shown in Fig. 15(a). In Fig. 5 it is noted that the height of the slim SWCNT on the right side is only 0.26nm as shown in the section curve of Fig. 1(a), and for verifying its repeatability the sample is rotated 45 degree and then scanned, after that the characterized height value of the slim SWCNT are still 0.24nm and 0.26nm as shown in Fig. 1(b). With the consideration of the push-down effect by probe during scanning by tapping mode, which means that the measured height of SWCNT is a little less than the original diameter due to the push force of the probe and the height value changes a little with the setting point changing.

After the imaging, the SWCNT is manipulated to bend and then break by controlling the probe trajectory of the AFM based nanomanipulation system, and the manipulation result and its stretch stress analysis is shown in Fig. 2.

3.2 Other manipulation results of SWCNT

By the proposed alignment method, another SWCNT is aligned and various kinds of manipulation are
performed with results shown in Fig. 3.

Fig. 3 Various AFM manipulation of SWCNT
(a) SWCNT image before manipulation, (b) separation of SWCNT from ‘Y’ CNTs, (c) bend of SWCNT, (d) removal of catalyst at one end of SWCNT and form of three nano bucklings, (e) SWCNT image after manipulation

In the image of SWCNT shown in Fig. 3(a), the height of the slim SWCNT is 1.5nm, and after the local scan the manipulation is performed by controlling the probe trajectory to successfully separate the SWCNT from the ‘Y’ CNTs as shown in Fig. 3(b), where the trace at the original position of the SWCNT is the left amorphous carbon particle. And the manipulation results in Fig. 3(c) and (d) show that although the catalyst strongly bonds to SWCNT [10], the catalyst particle is still removed by several steps of manipulation. And by three continual manipulations, three nano buckles are also formed on the SWCNT to change its electron transport property. Besides, small nano particles in Fig. 3 (a) and (e) are mainly nano particles of amorphous carbon without exclusion of possible nano bubbles [11].
In addition, compared with the motion mode of multi-wall carbon nanotube (MWCNT) during manipulation [22][27], the experimental results shown in Fig.6 and 7 demonstrate that the motion mode of the SWCNT is no longer the rotation around a rotation center under the manipulation of the AFM probe. On one side, due to the stronger quantum effect with size at the nanometer scale, SWCNT will suffer relatively stronger adhesion force with the consideration of its nanometer size. On the other side, different from polycarbonate or silicon substrate with relatively rougher surface, here SWCNT aligns on mica substrate with atomic flatness and thus the contact area between the SWCNT and mica is relatively larger. Dependent on both adhesion force and contact area [9], the nano frictional force is relatively much larger and the push force applied by the probe is not enough to move the whole SWCNT, which results in the local deform and local move of the small SWCNT section in essence, or the break of the SWCNT when the deform caused by the push force is overlarge.

4. Conclusions
In summary, a modified AFM based nanomanipulation technology is utilized to perform various kinds of manipulation on the SWCNT after the SWCNT raw materials is dispersed, such as SWCNT separation, catalyst remove, continual nano buckles fabrication and even stretching to break, which are used to control the size or shape and the electrical property of the SWCNT eventually. This manipulation technology shows a feasible way to perform the modification of the SWCNT’s size, shape and eventually the electrical property.

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