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A Study of Carbon Nanotube Array for Fabrication of Carbon Nanotube Tip

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***Abstract*— This research is about carbon nanotube(CNT) array for fabrication of CNT tip. CNT tip is useful to image and to manipulate submicrometre-sized, or nano-sized objects. In fabricating a carbon nanotube tip, a method using direct attachment between a single CNT and a probe with nanomanipulator system is more well-defined relative to the one by chemical vapor deposition method. This method using physical attachment needs CNT samples proper to the fabrication process. AC dielectrophoresis(DEP) is a very useful for these CNT samples. This research introduces a modified method for CNTs sample using DEP with peculiar electrode-set like a knife-edge and a channel-type electrode formed by a couple of metal electrode. The Proposed method used these electrodes to purify CNTs from raw material with impurities, and can form CNT array. And this method provide handiness in the fabrication process of CNT sample and of CNT tip.**

I. Introduction

Nanotechnology is rising to fame popularly nowadays. Its rise is based on the techniques of imaging and manipulation for nanometer-sized objects. We have been interested in the manipulations in which typical methods are such as AFM(atomic force microscope) and DEP. The former can directly manipulate objects smaller than 100 nm, and the latter is non-contact method using E-field(electric field) in liquid environment. Particularly, contact-type devices like nanogripper or nanotweezer are more helpful to manipulate several micrometer to several ten nanometer-sized objects.

For the fabrication of the nanotweezer, CNTs are very useful materials since they are chemically stable and have high mechanical and electrical properties. Philip Kim *et al* [1]. researched the CNT nanotweezer for the first time, and Seiji Akita *et al* [2] made the CNT tips for SPM(scanning probe microscope), and J. S. Lee *et al* [3] proposed a nanotweezer system with couple of single CNT tip. In these CNT-used nanomanipualtion devices, the repeatable and easy fabrication techniques are very important. Therefore, we focused on not only the CNT nanotweezer system, but also its fabrication methods using CNT samples made by DEP with simple experimental set-up. There were many researches about the CNT samples by E-field as follows. Y. Nakayama *et al* [4] purified and aligned the CNTs using DC E-field. S. Akita *et al* [2] fabricated the CNT cartridge using AC E-field to make the CNT tips, and J. Tang *et al* [5] made CNT fibers by DEP.

This paper introduced our research about the CNT array for the more precise fabrication of the CNT nanotweezer system. We made the CNT array using a couple of asymmetric metal electrodes and a general function generator without special instruments like RF-amp, which is different from other previous works.

II. Carbon Nanotube Nanotweezer System

Our CNT array are intend to use in the fabrication of the CNT nanotweezer system. This nanotweezer system is composed of a couple of single CNT tip, and is fabricated through the following process. First, W-tip(tungsten tip) is electrochemically etched. Next, a single CNT is attached at the end of W-tip with the nano aligner system[6]. And then carbon nanotube array are used in attachment process between s single CNT and a W-tip. The CNT nanotweezer system[3] is composed of these two single CNT tips. When CNTs bend to each other by electrostatic force between two tips, nanotweezer can grip. This nanotweezer can be also detached each other by mechanical separation.

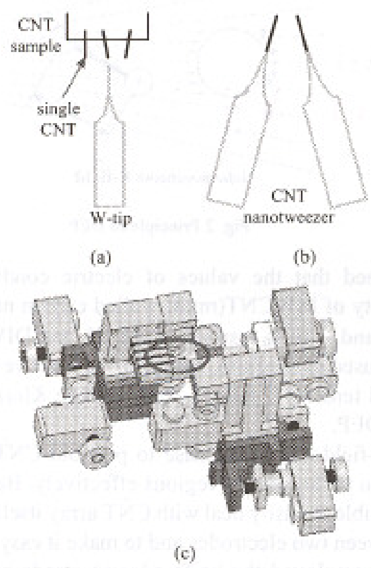

Fig. 1 Schematics about CNT nanotweezer system using CNT array as CNT samples : (a) fabrication of single CNT tip, (b) CNT nanotweezer, (c) nano aligner system (red circle shows (a) as a part of system).

III. Carbon Nanotube Array

This paper will show the CNT array for the fabrication of the CNT nanotweezer system composed of two CNT tips. To became proper samples for the CNT nanotweezer, CNT array have to obtain many parallel aligned single CNTs. In this research, we applied AC DEP to the fabrication of CNT array, and took some basic experiments for this.

Particle surrounded a certain medium in non-uniform AC E-field is attracted or repelled toward the strong E-field region. This effect is called as AC DEP, and the former is positive DEP and the latter negative DEP respectively. In case of CNTs, there happens polarization with the concentrated charges at the both ends of CNT since they have long geometry of high aspect ratio. Therefore CNT has the dielectric moment with the concentrated charges at the both ends of CNT(Fig. 2). But it is assumed that dielectrophoretic force acted on CNTs is such as that of sphere, because they generally entangled with many impurities in CNT suspension like carbon nanocapsules, amorphous carbon, and metal nanoparticles *etc.* And then dielectrophoretic force can be expressed as follows[7].

$$F_{DEP} = 2\pi\varepsilon_m a^3 \mathrm{Re}[K(\omega)]\cdot\nabla E^2$$

$$K(\omega) = \frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*} \quad where\ \varepsilon^* = \varepsilon + j\frac{\sigma}{\omega}$$

$K(\omega)$ is Clausius-Mossoti factor, ω, the frequency of AC E-field, ε^*, complex permittivity, a, the length of CNT, and E, the E-field. Sub-letters p and m mean particle and medium respectively. Here, we can know that ∇E^2 is only dependent of the geometry of metal electrode.

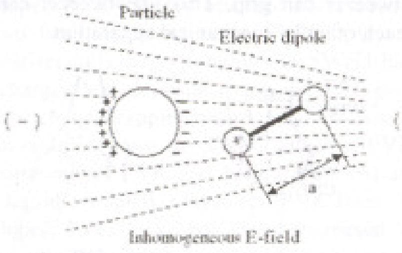

Fig. 2 Principle of DEP

Supposed that the values of electric conductivity and permittivity of MWCNT(multi-walled carbon nanotube) are 10^5 Sm^{-1} and ~ $10^4\varepsilon_0$ respectively[8, 9], and DIW(deionized water) is used as medium, then $K(\omega)$ is positive in the range of several tens MHz below. And positive $K(\omega)$ also means positive DEP.

The E-field had to increase to pull out CNT from CNT suspension to the wanted regions effectively. Besides, it had to be possible to easily deal with CNT array itself. To enlarge DEP between two electrodes and to make it easy to deal with itself, we employed the knife edge electrode and flat electrode as follows for DEP(Fig. 3). As the results, strong E-field is induced at the end of knife edge electrode. Only a general function generator(Agilent, model no. 33220A) supplied AC E-field to the gap between two electrodes under max 10 V_{p-p} at the level of 20 MHz below. Gap size is a few hundreds micrometers to fill the gap with CNT suspension. And we used 2 wt% CNT suspension made by ultrasonication of commercial MWCNTS(Iljin Nanotech Inc., MWCNTs grown on Al_2O_3 substrate by CVD) in DIW.

Experiment process is as follows. Firstly, let the gap maintain the constant size of a few hundreds of nanometer. And then apply the AC E-filed to the gap. Next, fill the gap with CNT suspension. After several seconds, turn off the E-field, and separate the knife edge electrode. This knife edge electrode is used as CNT array.

We found that CNTs were attached at the end of knife edge electrode after AC E-field was induced, and CNTs were aligned comparatively parallel to each other(Fig. 4). At lower AC voltage, the number of attached CNTs was too small to observe them without high magnifications of SEM(scanning electron microscope), but at higher AC voltage, attached CNTs were relatively many enough to easily find out them. But it was difficult to analyze quantitatively the relationship between the number of CNTs and induced AC voltage, and it was possible just to analyze qualitatively like these.

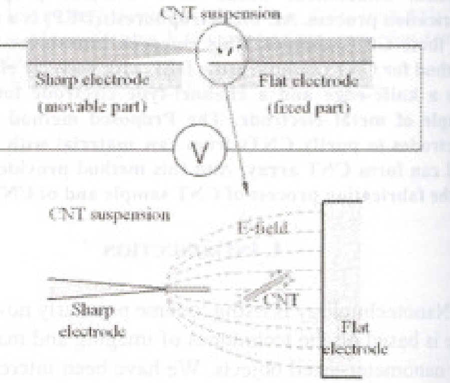

Fig. 3 Schematic of the set-up for the fabrication of the CNT sample, and the movement of CNTs by E-field distribution in CNT suspension

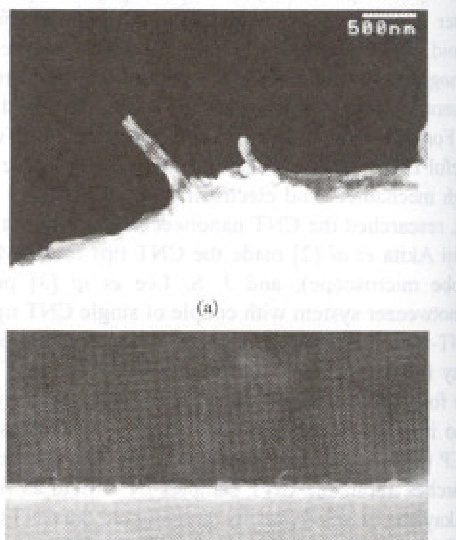

Fig. 4 SEM images for experimental results: (a) 5 V_{p-p} at 10 MHz, (b) 10 V_{p-p} at 10 MHz

IV. Conclusion and Summary

We fabricated the CNT arrays for fabrication of the CNT nanotweezer system composed of two single CNT tips. To fabricate it without special AC source, we employed the asymmetric electrode pair of knife edge electrode and flat electrode, and a common commercial function generator. And we applied AC DEP to make CNT arrays. By DEP theory, we expected that the number of purified CNTs from CNT suspension would be proportional to induced voltage, and through some experiments, we found such a thing qualitatively. Compared with the case that RF-amp was used as the AC source[2], CNTs might be less attached in this research. But this research showed that it was possible to make the CNT arrays for the fabrication of the CNT nanotweezer system just by the employment of proper electrodes instead of special instruments like RF-amp. Also, knife edge electrode was proper for convenient operation through the fabrication process.

V. Acknowledgements

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VI. References

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