Transactions of the Materials Research Society of Japan 30[3] 805-808 (2005)

The 3-D Nano-Manipulator Fabrication by FIB-CVD

Reo Kometani[1,2], Takayuki Hoshino[2,3], Kazuhiro Kanda[1,2], Yuichi Haruyama[1,2] and Shinji Matsui[1,2]

[1]University of Hyogo, Graduate School of Science, LASTI, 3-1-2 Koto, Kamigori, Hyogo, 678-1205, Japan
Fax: 81-791-58-0242, e-mail: leo@lasti.u-hyogo.ac.jp
[2]CREST JST, Japan Science and Technology Co.,
Kawaguchi Center building, 4-1-8, Hon-cho, Kawaguchi, Saitama 332-0012, Japan
[3]University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Highly functional nano-tools that can perform operation and analysis in the nano-space are very important in the broad research fields. And it is necessary to make nano-tools the 3-D structure from the 2-D structure for increasing the performance of the nano-tools. So, our research group has performed the development of nano-tools with the three-dimensional (3-D) nano-structure by using Focused-Ion-Beam Chemical-Vapor-Deposition (FIB-CVD). This time, as 3-D nano-tool, the 3-D electrostatic nano-manipulator that can perform operation of nano parts has been developed on the glass capillary by using FIB-CVD. We demonstrated the movement of the 3-D nano-manipulator by using the coulombic attraction induced by plus and minus charges as the driving forces.

Key words: 3-D, Nano-Manipulator, FIB-CVD, Nano-Tool, SiO_2/DLC hetero-structure

1. INTRODUCTION

High-performance nano-tools were required for carrying out the mechanical operation and the manufacturing in the nano-space as shown in Fig. 1. Therefore, we suggested making nano-tools the three-dimensional (3-D) nano-devices by using Focused-Ion-Beam Chemical-Vapor-Deposition (FIB-CVD) for giving the highly performance to nano-tools. FIB-CVD is the key technology for 3-D nano-structure fabrication. Features of FIB-CVD are as follows; 1) it is possible to fabricate the arbitrary 3-D nano-structure in the very simple process, such as wine glasses, bellows and coils [1], 2) various materials (Carbon, Tungsten, SiO_2 and so on) can be deposited by changing the gas source for CVD, 3) 3-D structure can be fabricated on the arbitrary surface.

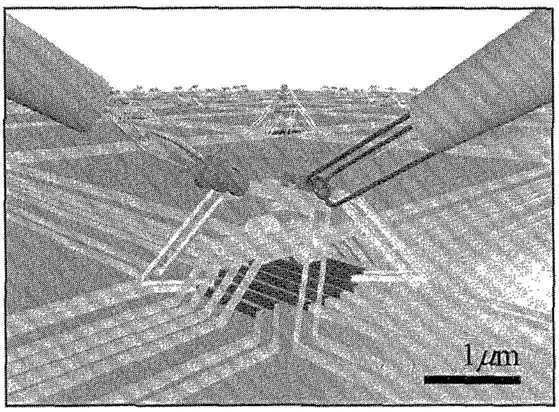


Fig. 1. Mechanical operation and the manufacturing in the nano-space by using 3-D nano-tools.

Thus far, we have reported the 3-D electrostatic nano-manipulator by using the repulsive force for the drive [2, 3]. And we succeeded in the manipulation of the polystyrene micro-sphere with a diameter of 1.0 μm by using that 3-D electrostatic nano-manipulator [4]. However, the nano-manipulator moved by repulsive force had a problem that the applied voltage for the drive was very high.

For solving this problem, we fabricated the 3-D electrostatic nano-manipulator with SiO_2/DLC hetero-structure. Features of the 3-D electrostatic nano-manipulator with SiO_2/DLC hetero-structure are as follows, as shown in Fig. 2; 1) applied voltage is low because the attractive force as the driving force is used, 2) nano-manipulator has 3-D fingers for catching a target firmly, 3) nano-manipulator has the SiO_2 finger for avoiding the electrical short-circuit, 4) it can be used in the broad field because the nano-manipulator is fabricated on the tip of the glass capillary.

In this article, we will report about the fabrication and the movement checks of the 3-D electrostatic nano-manipulator with the SiO_2/DLC hetero-structure.

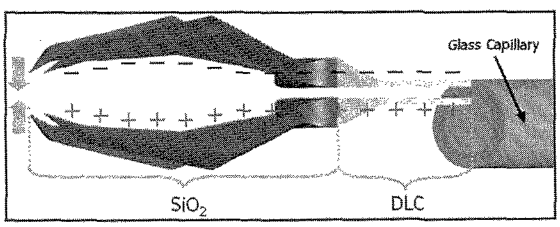


Fig. 2. Features of the 3-D electrostatic nano-manipulator with SiO_2/DLC hetero-structure.

2. FABRICATION PROCESS BY USING FIB-CVD

Fabrication process of 2-terminal electrodes in the glass capillary is very simple as shown in the Fig. 3 (a). First, Al-Ni wire was run through the hole of the glass capillary (Fig. 3 (a)-(i)). And the glass capillary and Al-Ni wire was pulled by using micropipette puller

(PC-10; NARISHIGE Co.). In this process, the 1μm tip of the glass capillary and Al-Ni internal electrode could be obtained in the glass capillary. Second, Au coating was carried out by DC sputtering for the external electrode fabrication (Fig. 3 (a)-(ii)). The Au thickness coated in this experiment was about 30 nm. Finally the tip shape control of the glass capillary was performed by using FIB-etching (Fig.3 (a)-(iii)). In this process, the 2-terminal electrode could be obtained on the tip of the glass capillary as shown in Fig. 3 (b).

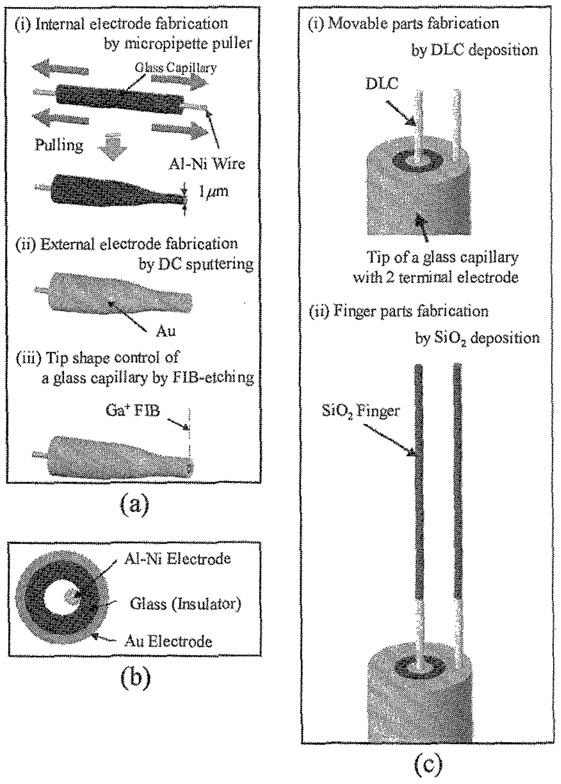


Fig. 3. Schematic drawing of the fabrication process. (a) Fabrication process of the 2-terminal electrodes in the glass capillary, (b) the illustration of the tip of the 2-terminal electrode, (c) fabrication process of the nano-manipulator by FIB-CVD.

And then, we fabricated the 3-D nano-manipulator with SiO_2/DLC hetero-structure on the tip of glass capillary with the 2-terimanal electrodes by FIB-CVD as shown in Fig. 3 (c). First, the movable parts of the manipulator were fabricated by the carbon deposition (Fig. 3 (c)-(i)). At this time, the *phenanthrene* ($C_{14}H_{10}$) gas was used as a source gas for CVD. And the carbon deposited by FIB-CVD is formed DLC. Resistivity of the DLC was about 100 Ωcm measured by the electrical characteristics measurement of a DLC air-wire.[5] And then, we fabricated the SiO_2 finger of the manipulator by using the *1,3,5,7-Tetramethylcyclotetra-siloxane* ([CH_3-(O)SiH]$_4$) as a source gas for CVD (Fig. 3 (c)-(ii)). Resistivity of SiO_2 was measured by the electrical characteristics measurement of a SiO_2 air-wire as shown in Fig. 4. Electrical resistivity was about 2.03 MΩcm. For this reason, even if finger's tips of this manipulator contacts or the material target is caught, it can avoid the short-circuiting electrically.

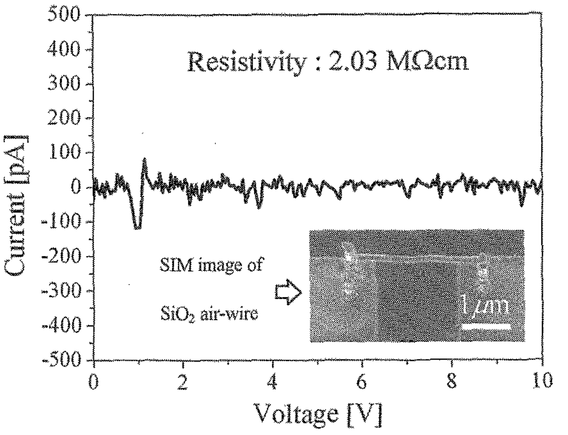


Fig. 4. I-V curve of the SiO_2 air-wire.

This process carried out in a commercially available FIB system (SIM2050MS2: SII Nanotechnolgy Inc.) using a Ga^+ ion beam operating at 30 keV. The beam diameter was about 5 nm. The system was equipped with two gas sources in order to increase the gas pressure. The top of the gas nozzles was set 300 μm from each other and positioned about 150 μm above the substrate surface. The inside diameter of each nozzle was 0.3 mm. Computer pattern generator (CPG) system was added to FIB apparatus to draw any pattern. Using CPG, control of beam scanning and blanking can be performed [6] .

3. RESULTS AND DISCUSSIONS

The electrostatic nano-tweezers with SiO_2/DLC hetero-pillar structure was fabricated by FIB-CVD as shown in Fig. 5. The deposition time of the DLC parts and SiO_2 parts were about 3 min and 24 min at a beam current of 1 pA and 7 pA.

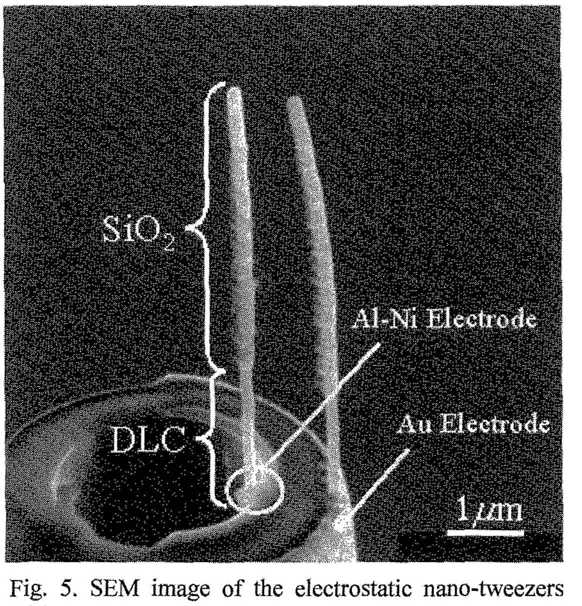
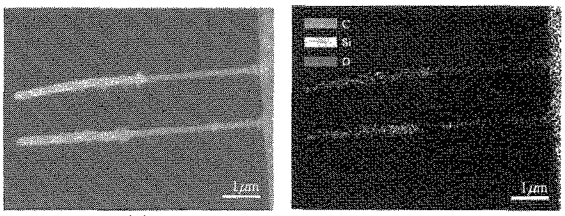


Fig. 5. SEM image of the electrostatic nano-tweezers with SiO_2/DLC hetero-pillar structure.

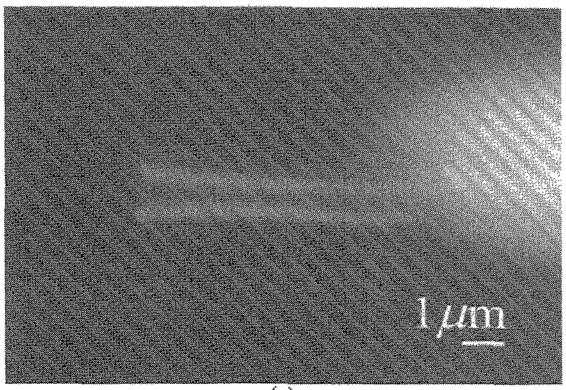
Furthermore, a distribution map of the elements for nano-tweezers with the hetero-pillar structure measured by using the scanning electron microscope – energy dispersive X-ray fluorescence spectrometer (SEM-EDX), as shown in Fig 6.



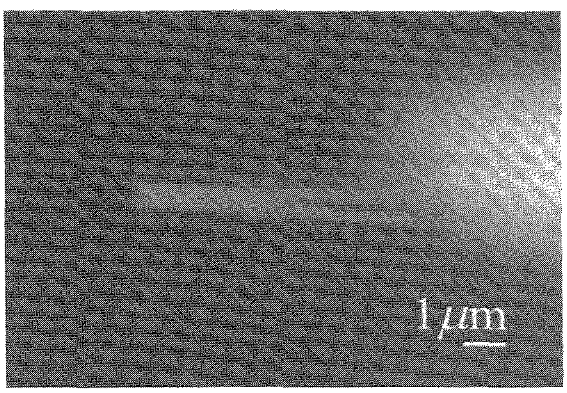
(a) (b)

Fig. 6. Elements distribution of the nano-tweezers with SiO_2/DLC hetero-pillar structure measured by SEM-EDX. (a) SEM image of the nano-tweezers with SiO_2/DLC hetero-pillar structure fabricated on the Si surface, (b) distribution map of the elements on the nano-tweezers with SiO_2/DLC hetero-pillar structure measured by SEM-EDX.

And then, we observed the movement of this nano-tweezers under the optical microscope. Figure 7 (a) shows the optical microscope image of the nano-tweezers before applying voltage. And fingers of the nano-tweezers were closed by applying 14 V as shown in Fig. 7 (b). But, it remained that the pillars were fixed after applying voltage as shown in Fig. 8. We think that pillars were fixed by the surface energy.



(a)



(b)

Fig. 7. Result of the movement check of the nano-tweezers with SiO_2/DLC hetero-pillar structure
(a) Optical microscope image of the nano-tweezers with SiO_2/DLC hetero-pillar structure before applying voltage, (b) optical microscope image of the nano-tweezers with SiO_2/DLC hetero-pillar structure after applying 14 V.

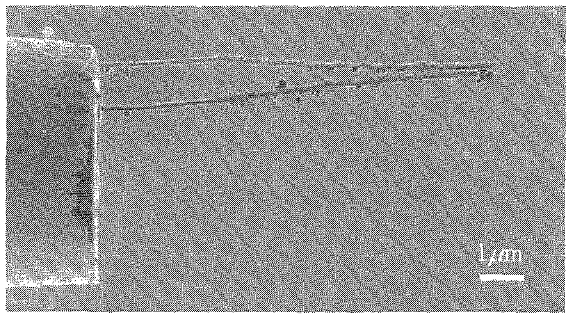


Fig. 8. SIM image of the nano-tweezers with SiO_2/DLC hetero-pillar structure after applying 14 V.

Furthermore, we fabricated the 4-clawed nano-manipulator with SiO_2/DLC hetero-structure by FIB-CVD, as shown in Fig. 9. Deposition time is 20 min at the beam current of 1 pA for carbon movable parts and 45 min at the beam current of 7 pA for SiO_2 finger parts.

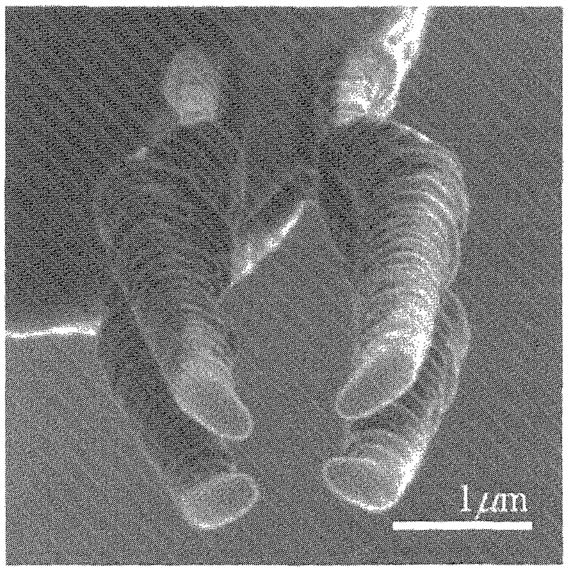
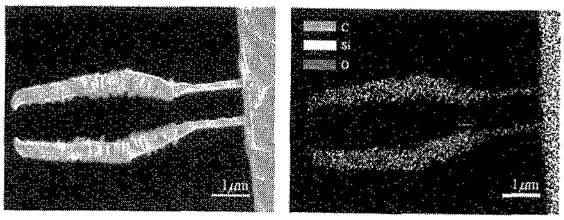


Fig. 9. SIM image of the 4-clawed nano-manipulator with SiO_2/DLC hetero-structure.

And then, the element distribution of the 4-clawed manipulator structure fabricated on Si surface was measured by SEM-EDX as shown in Fig. 10.

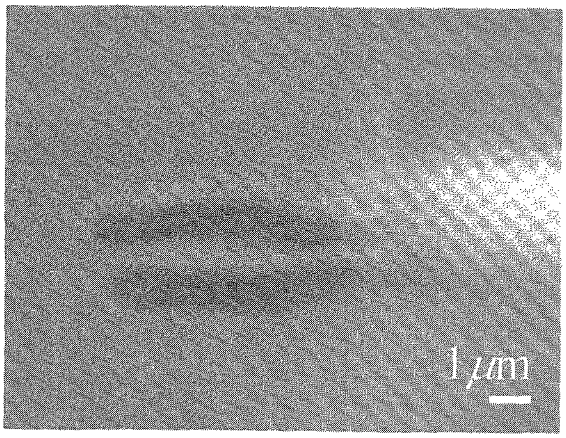
And the movement of the 4-clawed nano-manipulator by applying voltage was observed under the optical-microscope. Figure 11 shows the optical microscope image of the 4-clawed nano-manipulator before applying voltage. This 4-clawed nano-manipulator was moved by the 0.26 V (off-set voltage) as shown in Fig. 11(b). As a result, we could not control the movement of the manipulator by the voltage. The result indicates that the structure design of 4-clawed nano-manipulator should be improved to increase the operation voltage. In other words, the reactivity to the voltage was too high.

After then, the phenomenon that SiO_2 finger was fixed by the surface energy was observed the same as in the case of the nano-tweezers with SiO_2/DLC hetero-pillar structure.

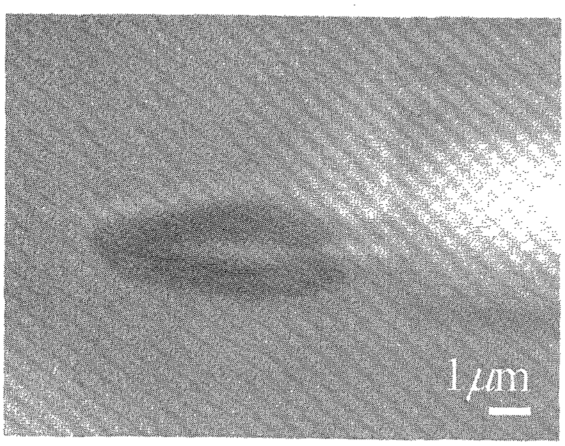


(a) (b)

Fig. 10. Elements distribution of the nano-manipulator with SiO_2/DLC hetero-pillar structure measured by SEM-EDX. (a) SEM image of the 4-clawed nano-manipulator with SiO_2/DLC hetero-structure fabricated on the Si surface. (b) distribution map of the elements on the 4-clawed nano-manipulator with SiO_2/DLC hetero-structure measured by SEM-EDX.



(a)



(b)

Fig.11. The result of the movement check of the 4-clawed nano-manipulator. (a) Optical microscope image of the 4-clawed nano-manipulator with SiO_2/DLC hetero- structure before applying voltage, (b) optical microscope image of the 4-clawed nano-manipulator with SiO_2/DLC hetero-structure moved by 0.26 V (off-set voltage).

4. CONCLUSION

We fabricated the 3-D electrostatic nano-manipulator with SiO_2/DLC hetero-structure by FIB-CVD. And the movement checks of the nano-manipulator was performed. As a result, the nano-tweezers and the 4-clawed nano-manipulator were driven by the low-voltage such as 14 V and 0.26 V (off-set voltage). These results indicate the nano-manipulator with the SiO_2/DLC hetero-structure has the highly reactivity to the voltage as a 3-D nano-structure device. Furthermore, the phenomenon that SiO_2 finger was fixed by the surface energy was observed.

ACKNOWLEDGEMENT

The support of CREST Japan Science and Technology Co. and a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan is acknowledged.

REFERENCES

[1] S. Matsui, T. Kaito, J. Fujita, M. Komuro, K. Kanda and Y. Haruyama, *J. Vac. Sci. & Technol.*, **B 18**, 3181-3184 (2000).

[2] R. Kometani, T. Morita, K. Watanabe, T. Hoshino, K. Kondo, K. Kanda, Y. Haruyama, T. Kaito, J. Fujita, M. Ishida, Y. Ochiai and S. Matsui, *J. Vac. Sci. & Technol.*, **B 22**, 257-263 (2004).

[3] R. Kometani, T. Hoshino, K. Kondo, K. Kanda, Y. Haruyama, T. Kaito, J. Fujita, M. Ishida, Y. Ochiai, and S. Matsui, *J. Appl. Phys.*, **Vol. 43**, No. 10, 7187-7191(2004).

[4] R. Kometani, T. Hoshino, K. Kondo, K. Kanda, Y. Haruyama, T. Kaito, J. Fujita, M. Ishida, Y. Ochiai, and S. Matsui, *J. Vac. Sci. & Technol.*, **B 23**, 298-301(2005)

[5] T. Morita, R. Kometani, K, Watanabe, K. Kanda, Y. Haruyama, T. Hoshino, K. Kondo, T. Kaito, T. Ichihashi, J. Fujita, M. Ishida, Y. Ochiai, T. Tajima and S. Matsui, *J. Vac. Sci. & Technol.*, **B 21**, 2737-2741 (2003).

[6] T. Hoshino, K. Watanabe, R. Kometani, T. Morita, K. Kanda, Y. Haruyama, T. Kaito, J. Fujita, M. Ishida, Y. Ochiai, and S. Matsui, *J. Vac. Sci. & Technol.*, **B 21**, 2732-2736 (2003).

(Received December 24, 2004; Accepted April 18, 2005)