Application of guided particles in dusty plasmas for carbon nanotube syntheses

Kazuo Takahashi, Ryo Miyama, Masanari Kuroda

Department of Electronics, Kyoto Institute of Technology

Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan

Introduction

Dust particles in plasmas have been a target as the impurities for a quarter of a century, which should be removed from ULSI fabrication processes. Conversely, physical phenomena of the dust particles in plasmas have attracted considerable scientific interest since exploring Coulomb crystals in 1994. The dust particles, especially micrometer-sized, have been distributing research topics, however, never been materials positively used for any research and industrial fields. Handling dust particles in plasmas should be a key issue bringing technological break-through. Here it reminds metal catalyses to be used for carbon nanotube syntheses. The carbon nanotube is often required to be trimmed as a shape of devices and patterns. For patterning process, it is necessary to manufacture the metal of catalyses in microelectronics scale. The metal is hardly etched in dry process without volatile products, and control of the process is difficult in the precise scale. This work shows an example to construct a pattern of dust particles on surfaces[1]. The example suggests a method to possibly form patterns with metal particles. Finally, the carbon nanotube is tried to be grown on the patterns.

Experimental

The Ar plasmas were generated in an apparatus with parallel-plate electrodes configuration (Fig. 1). The apparatus was modified in a chamber for dusty (complex) plasmas in space (PK-3 plus) [2]. The Ar gas was introduced at 1.0 sccm, and pressures were set from 13 to 200 Pa. The 13.56 MHz rf voltage was supplied to bottom electrode. The input power was varied between 2 and 10 W. The silica or Si substrates covered with stainless grid (mesh) as patterning mask were set on the electrode. The silica and Ni-coated melamine-formaldehyde particles were injected to plasmas. The diameters of the particles were 1.6 and 1.0 μm, respectively.

Another apparatus was employed for synthesizing carbon nanotubes. The CH_4 and H_2 gases were used and their flow rate were 64 and 16 sccm, respectively. The Si substrates containing the Ni-coated particles were set on the stage supplied another 13.56 MHz rf power of 200 W and heated at 650°C.

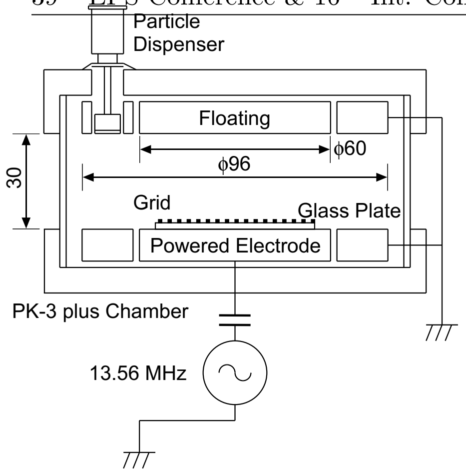


Figure 1: (a) Schematic of the apparatus modified in a chamber for dusty (complex) plasmas in space (PK-3 plus) [2].

Results and Discussion

After injecting the particles to plasmas, they were levitated around the plasma-sheath boundaries near the top and bottom electrodes. The particles were distributed 4 mm above the bottom electrode in 2.5 mm thick at 40 Pa and 3.5 W. When the plasmas were turned off, the particles dropped and were transported to the substrate. In after-glow where charges remained on the particles, electrostatic force and gravity acted on the particles upward and downward, respectively. The particles were falling down at speed slower than that in free falling. They got closer to the bottom electrode and the speed exceeds that in free falling. It seems that the particles were accelerated by static charge on surface. The particles, consequently, looked to be evacuated to holes of grid and were located at the center of opening parts of the grid, not forming shadows of the grid (Fig. 2). The spots of 25 μm in diameter were arranged with regulated by the grid of 170 μm interval. The diameter of spots and number of particles included by a spot were controlled by powers and pressures.

For synthesizing carbon nanotubes, particles coated by the Ni as a catalytic metal were injected to the plasmas at 200 and 4.0 W. In Fig. 3 (a), 4 spots of the particles are found to be patterned and the diameter of spots ranges around 70 μm. The carbon nanotubes were found to be growing on the particles.

Conclusion

After-glow plasmas transported dust particles to surface in balance of forces of electrostatic and gravitational. The grid on surface distributed static charge and modifies potential. The particles

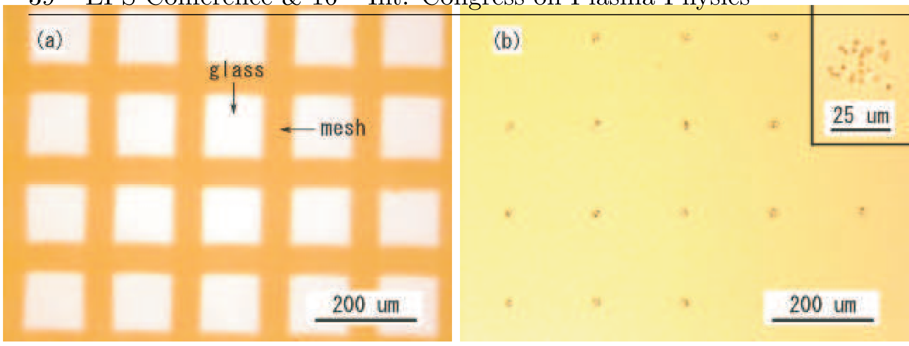
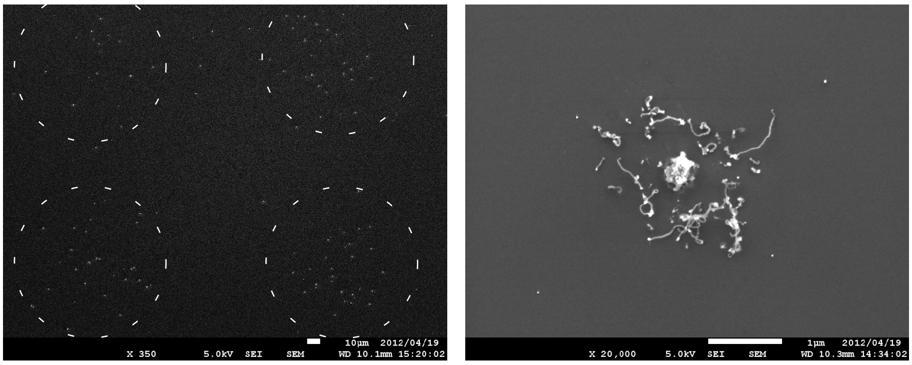


Figure 2: (a) Grid (mesh) of stainless steel used for patterning, (b) patterns of dust particles on a substrate after removing the grid.



(a) (b)

Figure 3: Images of scanning electron microscopy on the Si substrate which passed through the plasmas for pattering of particles and synthesizing carbon nanotubes. (a) 4 spots of particles are indicated by circles of broken-line, (b) a magnified image of (a) including a few particles on which carbon nanotubes is found.

were evacuated to the holes of the grid which seems to be positive to the negatively-charged particles. Particles coated by Ni catalysis were employed to synthesize carbon nanotubes. The carbon nanotubes were found to be growing on the particles.

The metal particles controlled to be placed on surface are useful for selective growth of carbon nanotubes. In case that pattern of the carbon nanotube is necessary in microelectronics, e.g., for interconnecting of Si through via, the pattern formation of particles transported from plasmas to surfaces can be a candidate for one of tools in controlled processes.

Acknowledgement

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