DUST COLLECTION AND REMOVAL — NFP-COLLECTOR

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UDC 533.9

A short description of an NFP-Collector (Negatively Charged Fine-Particle Collector) proposed for the collection and removal of fine particles in dusty plasmas is presented. At first, a principle of the Collector is described, together with its experimental confirmation. Then, recent experiments combined with ditch structures formed on plates to guide fine particles are introduced. Measurements have also been made on fine particles sputtered out of a dusty metal plate into a plasma. Finally, the effects of the Collector on silane plasma, in which dusty fine particles are formed, are presented.

Introduction

The NFP-Collector was proposed and has been proved to be useful for the collection and removal of fine-particles of size less than a few tens of μm in dusty plasmas [1] and could be of crucial importance in various kinds of plasma application. The Collector is just a simple electrode with hole(s), which is externally biased higher than the floating potential to collect fine particles in plasmas. Fine particles pass through the hole(s) without impinging the electrode surface into the electrode hole(s). When fine particles near the Collector are collected, fine particles left away from the Collector approach the Collector in the presence of the force balance among fine particles confined by an external potential, being pulled one after another into the Collector. Finally, there is almost no fine particle left in plasmas.

When a metal plate is set for the particle levitation, fine particles levitating in the horizontal plane above the plate show a specific spatial distribution, depending on the electrostatic-potential profile provided by the plate surface. Here, the plate has the surface with ditches for the particle levitation which is shaped to provide such a potential profile that fine particles are guided to flow outsides toward the NFP-Collector [2]. In this situation, the Collector can be located at a position far away from the central plasma region, where the plasma disturbance caused by the Collector is negligibly small. Even if the ditches are filled up with insulator or the surface with ditches is covered by a plane insulator film to yield the plane surface, the fine-particle levitation and flow are quite similar to those mentioned above, and we can have almost the same results for the fine-particle removal.

In the experiments mentioned above, fine particles are externally injected into plasmas. On the other hand, fine particles are sputtered out of a dusty metal plate into a plasma. When their size is smaller than a few tens of μm, they also levitate in a plasma. Then the NFP-Collector is switched on to collect and remove these particles. In this way, the Collector could be used for cleaning dusty metal plates.

It is well known that dusty fine particles are often formed in reactive plasmas used for various kinds of material and device processing. We have applied the NFP-Collector to collection and removal of fine particles formed in a silane plasma which has been employed in the fabrication of amorphous and micro-crystalline silicon films. Measurements have proved that the Collector improves the film quality [3].

The works presented here have been carried out under the research collaboration at Tohoku University and also at Hitachi Kokusai Electric Inc., Japan (see [1—3]).

1. Principle and Confirmation

When we have small electrodes biased electrically in a thin layer of fine-particle clouds levitating in plasmas, there appear vortices of fine particles on the horizontal plane. As shown (top view) in Fig. 1, the directions of vortices depend on the polarity of electric potentials applied. Here we are interested in vortices produced by a positively biased electrode. Their size is observed to be smaller than that in case of the negative potential. Fine particles are attracted toward the electrode, but they do not impinge the electrode, flowing sideways to form vortices. This is because the electrode potential is smaller than the plasma potential even in this situation.

Figure 2 shows vortices (top view) produced by one (left) and two (right) electrodes. In the latter case, the electrode separation is smaller than the size of vortices and then particles are guided to flow into a region between the two electrodes without impinging the

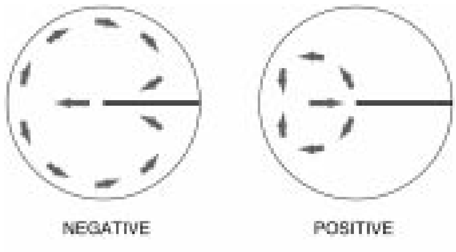

Fig. 1. Vortices depending on bias polarity

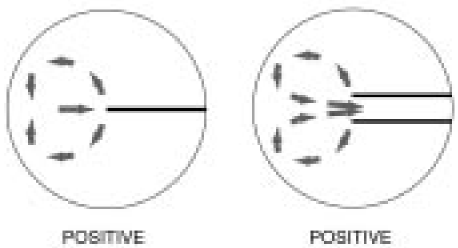

Fig. 2. Vortices produced by 1 and 2 electrodes

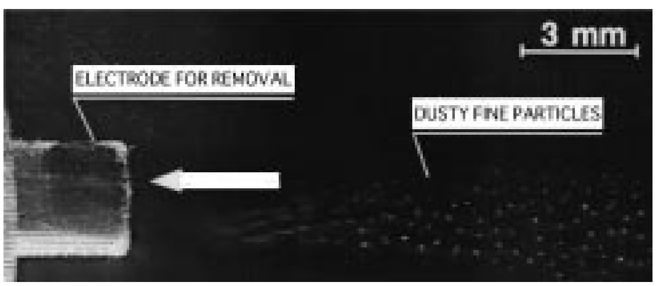

Fig. 3. Fine-particle removal (side view) by tube-typed NFP-Collector

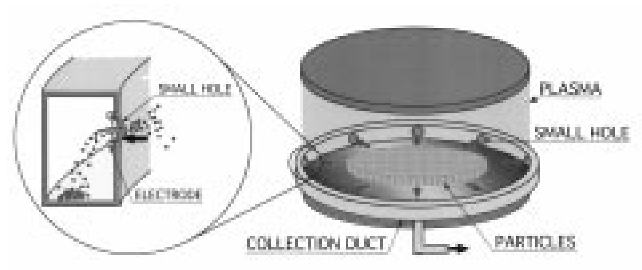

Fig. 4. Duct-typed NFP-Collector

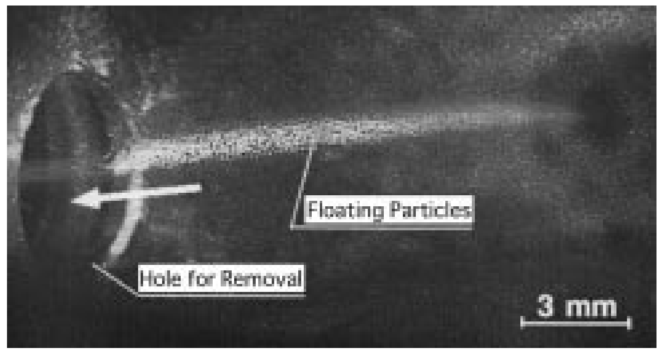

Fig. 5. Removal by duct-type NFP-Collector

electrodes. This behavior of vortices is special for negatively charged particles and is a basic principle of the NFP-Collector. We cannot expect this feature of vortices for positively charged particles when, instead of the positive potential, a negative potential is applied to the two electrodes. In this situation, fine particles flow toward the electrodes, impinging their surfaces.

A simple configuration of the NFP-Collector is provided by a cylindrical tube electrode. It is better to cover the outside wall by insulator (for example, ceramic tube). An action of the Collector is demonstrated in Fig. 3. The Collector collects fine particles which are externally injected into a plasma and levitate above a metal plate for particle levitation. Fine particles are removed into the tube without impinging the inside wall of the tube. The result is consistent with the particle flow in Fig. 2 (right). This mechanism could also be applied to the experiment on particle collection at the HEDRC in Russia [4], which followed our works on the NFP-Collector.

A different configuration of the NFP-Collector is schematically described in Fig. 4. In this case, a duct surrounds fine-particle clouds levitating in a plasma. There are several holes at the inside wall of the duct, behind which electrodes are situated for fine-particle removal. When the electrodes are biased, particles are removed into the duct, as demonstrated in Fig. 5. A pumping system could be connected with the duct to guide fine particles into a region outside the vacuum chamber.

Both of the configurations mentioned above are quite simple for manufacturing. Various ideas could be found for other configurations of the Collector. The configurations should depend on real situations for application. But, the Collector itself is so simple that we could meet no complicated configuration in any case.

It has to be again emphasized here for a specific feature of the particle removal. When fine particles near the Collector are removed, fine particles left away from the Collector approach the Collector in the presence of the force balance among particles, being pulled one after another into the Collector. This feature based on the force balance among fine particles provides an efficient

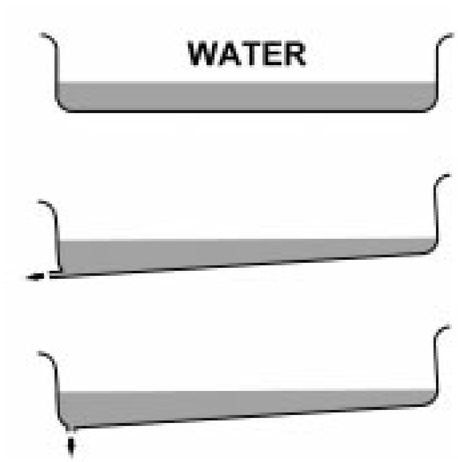

Fig. 6. Water in an inclined vessel

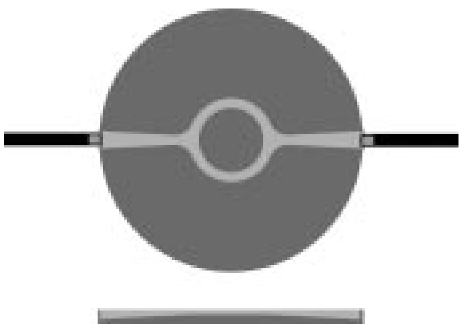

Fig. 7. Ideal ditch structure (top view)

particle removal. We can imagine a similarity between the Collector action and the dynamics of water in a vessel inclined as presented in Fig. 6. This similarity also suggests us to form such a ditch structure on the levitating plate, for example, as shown in Fig. 7 (the ditch depth increases in the radial direction), so as to induce a flow of fine particles along the ditch in the radial direction toward the NFP-Collector, enhancing the Collector action.

2. Related Experiments

2.1. Ditch guidance

When there is a ditch formed on the levitation electrode, negatively-charged fine particles should levitate above the ditch because the potential there is higher than that in the other region. In case of Fig. 7, the ditch has radial paths, and their width and depth increase in the radial direction. Then fine particles levitating above the ditch are guided in the radial direction. The NFP-Collectors are situated at the radial edges, as shown in Fig. 7. In this way, the Collector action becomes more efficient even if the Collector is situated far away from the central region. If we do not like a non-plane structure due to the ditch, we can put a thin plane insulator above the plate, which guarantees a similar potential profile to that without insulator.

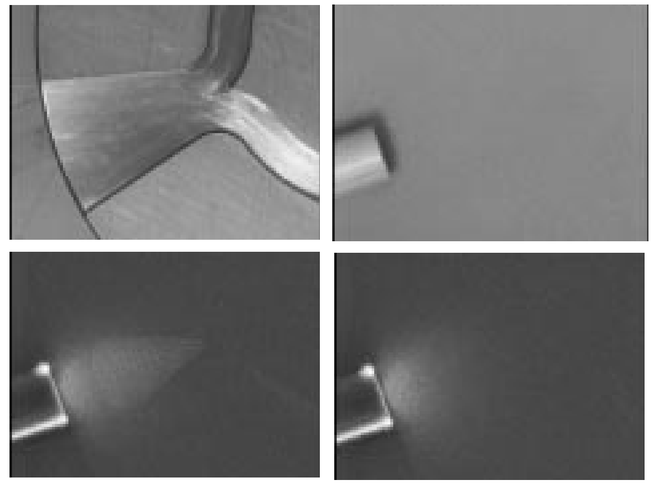

Fig. 8. Ditch-guided fine-particle removal (top view) by tube-typed NFP-Collector

Experimental results are shown in Fig. 8. The ditch (upper, left), which is formed on the plate of 6 cm in diameter, covered by a thin plane insulator (upper, right). When fine-particles are externally injected into a plasma, they are guided along the ditch into its wide region in front of the Collector which is not yet biased (lower, left).

Immediately after the Collector is biased, however, all fine particles are removed into the tube (lower, right) even if the bias potential is quite small. Another shape of the ditch used is presented in Fig. 9 (top view). The ditch depth increases along a spiral toward the plate edge. Figure 10 shows a particle flow in the absence of the Collector. This shape of the ditch is better than that in Fig. 7 for the fine-particle removal. Other shapes of the ditch could be found out, depending on real situations for application.

2.2. Plate cleaning

In the experiments in [1—3], spherical particles (methyl-methacrylate polymer) of 10 μm in diameter are externally injected into plasmas, where they are negatively charged up. In a region above the plate for particle levitation, there is the upward electric force

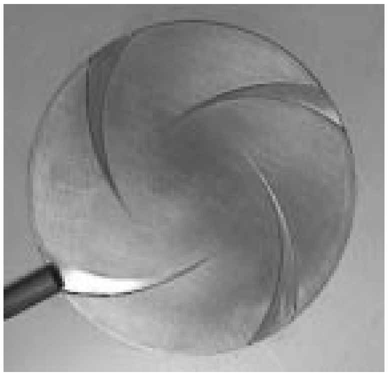

Fig. 9. Spiral-shaped ditch

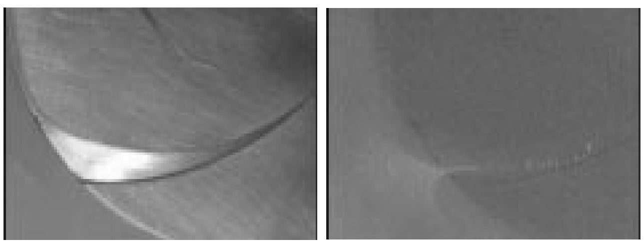

Fig. 10. Ditch shape and corresponding particle flow (top view)

yielding the particle levitation against the gravity force. If there is no plasma, however, fine particles fall down, contaminating the plate.

Here, the dusty plate is cleaned by ion bombardment. In Fig. 11, there is a plate below a coarse grid (left, rf electrode). A region inside a circle is used for the particle levitation. But, when the plasma is switched off, fine particles of 10 μm in diameter fall down on the plate, resulting in the formation of a dusty surface, as found in Fig. 11 (right). Now the method of ion bombardment is employed to clean the dusty plate. A dc negative potential in the range of 100 – 300 V is applied to the plate with respect to the chamber wall in the presence of plasma. Then, many particles with different sizes (100 nm $\sim$ 10 μm) are sputtered out and again levitate above the plate, as found in Fig. 12. Now we use the NFP-Collector to remove these particles. Therefore, the Collector can be also useful to clean the dusty plate. The method used here is applicable to other situations for cleaning dusty plates contaminated.

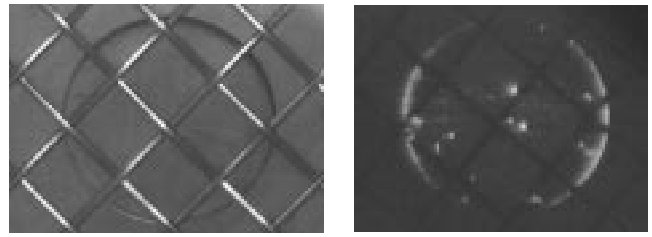

Fig. 11. Surfaces of plate (top view): clean (left) and dusty (right)

2.3. Effects on silane plasma

A silane plasma has been employed in the fabrication of amorphous and micro-crystalline silicon films. But, it is now of crucial importance to solve the problems caused by dusty particles formed in a silane plasma during the fabrication process.

The NFP-Collector has been installed in order to find the effects of particle removal on amorphous silicone films formed on a substrate in a silane plasma. Two different measurements have been performed here. In one of them, the NFP-Collector is switched on after particles grow up so large ($\geq$100 nm in diameter) in a rf silane plasma that they are clearly observed to levitate above the plate (substrate). The Collector is proved to remove these particles in the same way as mentioned up to now. In the other measurement, the Collector is switched on just after the plasma is triggered. Then, even for a long plasma operation, we can observe no appreciable particle growth as far as the particle size is, roughly speaking, larger than 100 nm in our measurements. The results mean that the NFP-Collector is effective not only in the fine-particle removal, but also in suppressing the particle growth in a silane plasma. The suppression is due to the removal of fine particles much smaller than 100 μm. Under this condition, amorphous silicon films formed has been confirmed to be improved for providing better solar-cell batteries. This suppression of the particle growth would be also important in other reactive plasmas used for other material and device fabrication, where dusty fine particles degrade materials and devices fabricated.

Conclusions

The NFP-Collector is very effective for the dust removal from dusty plasmas including fine particles. In addition to its simple principle, the Collector is basically simple in its configuration and could be successfully employed

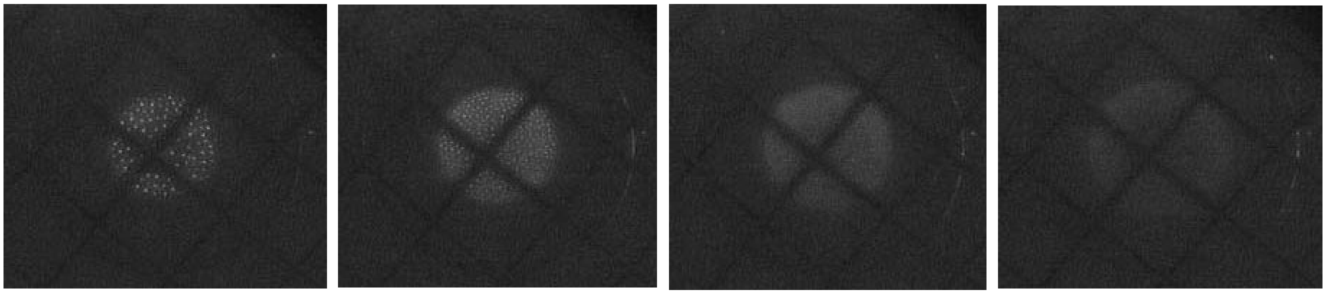

Fig. 12. Particle levitation (top view): particle size depends on the vertical position [from 10 μm (left) to less than 1 μm (right)]. The position is changed upward by a step of 1 mm from left to right

for eliminating the contamination in various kinds of plasma application.

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4. *Winter J., Fortov V.E., Nefedov A.P.* // J. Nucl. Mater. — 2001. — **90**. — P. 509.

ЗБИРАННЯ ТА УТИЛІЗАЦІЯ ПИЛУ — NFP-КОЛЕКТОР

Н. Сато

Р е з ю м е

Представлено NFP-колектор (колектор негативно заряджених дрібнодисперсних частинок), що призначається для збирання та видалення дрібнодисперсних частинок із запорошеної плазми. Описано принцип дії колектора і наведено експериментальні дані. Експериментально досліджено вплив на збирання дрібнодисперсних частинок структури канавок на дисках колектора. Проведено дослідження вкидання в плазму дрібнодисперсних частинок дисками колектора. Наведено результати роботи колектора у плазмі гідриду кремнію, яка формує дрібнодисперсні частинки.