G1

Basic Plasma Research – Proposals for Applications
プラズマの基礎的研究－応用への提案

Noriyoshi Sato
佐藤徳芳

Professor Emeritus, Tohoku University
Home: *Kadan 4-17-113, Sendai 980-0815, Japan*
東北大学名誉教授
自宅：〒980-0815 仙台市青葉区花壇 4-17-113

Some basic experiments are presented for next-stage intelligent plasma applications. They include works on productions of large-scaled discharge plasmas for uniform plasma processing, controls of electron temperature for finding processing conditions, and removal of dust particles for clean processing.

1. Introduction

The author has been interested in basic plasma research to establish “intelligent” plasma processing for device and material manufacturing.

Here some basic experiments [1] are introduced on plasma productions for large-scaled uniform plasma processing under different pressure ranges, electron-temperature controls for finding conditions required in plasma processing, and dust-particle removal necessary for a new clean technology. Several drastic results obtained are presented to show that the methods proposed could be useful in many kinds of plasma processing in the future.

2. Plasma Productions

2-1. *Under Pressure < 0.1 Torr*

In the experiments here, non-uniform plasmas are produced for large-scaled uniform plasma processing at a distance not far from the position of plasma production. A part of the vacuum chamber is used as an electrode or an antenna. Microwave and *rf* plasmas have been produced on this line of research. The density profiles are controlled by permanent magnets. They provide also magnetic fields for ECR in case of the microwave plasmas and for modified magnetron typed (MMT) discharge in case of the *rf* plasmas. A feedback control could be effective for meter-size uniform processing.

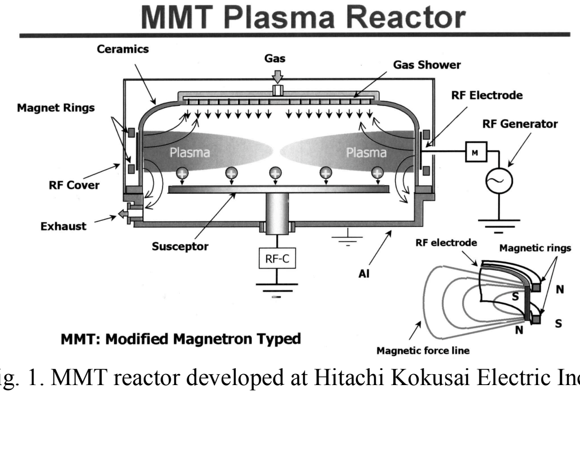

Fig. 1. MMT reactor developed at Hitachi Kokusai Electric Inc.

The MMT reactor developed for semiconductor manufacturing [2] is demonstrated in Fig. 2.

2-2. *Under Pressure of 0.1 ~ 10 Torr*

A parallel-plate *rf* discharge under this pressure range has been widely used for plasma productions in applications. Multi-hollows formed in the *rf* powered electrode is effective for increasing the plasma density. But, the discharge is often localized in the special hollow(s). There is also a possibility of dust-particle trapping in the isolated hollows.

To eliminate these problems in the isolated-hollow cathode, the hollows are connected by ditch [3]. Gas-feed holes are made in the bottoms of the hollows and/or between the hollows in the hollow cathodes. The plasma density has been confirmed to increase with no localization of the discharge in case of the connected-hollow cathode.

2-3. *Under Atmospheric Pressure*

Plasma processing using atmospheric plasmas is now quite useful for various applications. So-called “barrier discharges” are well known as a method of plasma production under the atmospheric pressure.

We have proposed a quite simple method of the atmospheric plasma production [4]. This is called CCMD (Capacity-Coupled Multi-Discharges, see Fig. 2). Needle-typed electrodes are set near a metal plate, which are coupled with external capacitors. Being different from the barrier discharges, the discharge power can be controlled to increase by increasing the capacity of the capacitors.

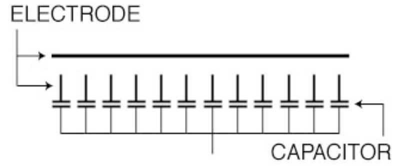

Fig. 2. Circuit for CCMD.

3. Electron-Temperature Control

We have proposed two methods for electron-temperature (*Te*) control. They were established by varying local plasma structures to yield high and low *Te* regions.

One of them employs a pin-hollow cathode. A radial discharge structure is varied by the length of pins installed axially near the inside wall of the hollow cathode. With an increase in the length, the ionization localizes gradually near the pins, being followed by the *Te* decrease in the central region.

A grid is employed in the other method, which separates the discharge region (I) from a region (II) for plasma processing. In the presence of a negative potential applied to the grid, most electrons in the region I are reflected by the grid except high-energy tail electrons. But, there occurs ionization due to the tail electrons in the region II. Electrons produced there are not responsible for maintaining the discharge, having a low *Te*. Therefore, *Te* in the region II decreases with an increase in the negative grid potential. *Te* is controlled also by varying the grid mesh size or the size of hole(s) made in the grid even at a floating grid potential.

Both of the methods yield continuous *Te* controls over one to two orders of magnitude. Drastic effects of *Te* on reactive plasmas have been observed in the experiments. A lot of negative hydrogen ions (more than 90%) are produced in the low *Te* region in hydrogen and methane plasmas, suggesting a possibility of efficient negative ion source.

Figure 3 presents an effect of *Te* on formation of diamond particles in hydrogen-methane plasmas. High-quality diamonds are formed with a decrease in *Te* even at low gas pressure around 0.1 Torr.

The *Te*-control is also useful for producing a high-quality a-Si:H film for solar-cell battery [5].

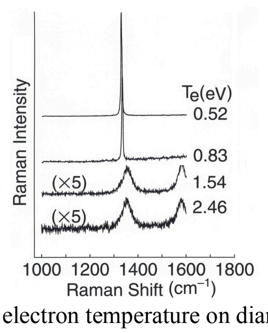

Fig. 3. Effect of electron temperature on diamond formation.

4. Dust Removal

As an extension of experiments on negative-ion plasmas and fullerene plasmas, the author was engaged in various basic works on fine-particle plasmas. On the basis of the physics clarified, the NFP-Collector (Negatively-Charged Fine-Particle Collector) has been proposed for collection and removal of fine particles in dusty plasmas. The Collector is just a simple electrode with hole(s), which is biased higher than the floating potential in plasmas. Particles (<50μm) pass through the hole(s) without impinging the electrode surface into the hole(s). When particles near the Collector are collected, particles left away approach the Collector in the presence of force balance among particles, being pulled one after another into the Collector.

Fine particles levitating in the horizontal plane above a metal plate show a spatial distribution, depending on the potential profile above the plate surface. We can prepare the surface with ditches shaped to yield a potential profile for particles to be guided toward the NFP-Collector. Then, the Collector can be located at a position far away from the central plasma region, as shown by its example in Fig. 4. Even if the ditches are filled up with insulator or the plate is covered with an insulator film to yield the plane surface, we can have almost the same results for the particle removal.

Since the NFP-Collector removes fine particles before they grow large, the Collector is also useful to suppress the particle growth in reactive plasmas.

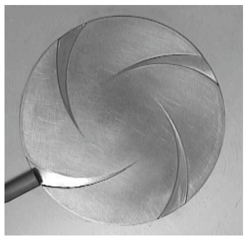

Fig. 4. Ditches for guiding particles toward the NFP-Collector.

4. Conclusions

Basic plasma experiments have been extended to propose new methods for plasma applications. They are expected to be useful in the future.

Acknowledgments

The author appreciates the collaborations at Tohoku University, ANELVA Corporation, Hitachi Kokusai Electric Inc., SHARP Corporation, and ADTEC Plasma Technology Co., Ltd.

References

[1] N. Sato, *Proc. of 28th Annual Meeting of Institute of Electrostatics Jpn.*, 2004, p. 35 [in Japanese]; *Dust Plasmas in Application* (Odessa, 2004), p. 11.

[2] U. Ogawa, N. Sato, K. Shino, and R. Furukawa, Hitachi Hyoron **85** (2003) 41 [in Japanese].

[3] T. Koshimizu, U. Ogawa, O. Kasahara, and N. Sato, *Proc. of 63th Annual Meeting of Jpn. Soc. Appl. Phys.*, No.1, 2002, p. 87 [in Japanese].

[4] H. Mase, T. Fujiwara, and N. Sato, Appl. Phys. Lett. **83** (2003) 5392.

[5] Y. Kurimoto, T. Shimizu, S. Iizuka. M. Suemitsu, and N. Sato, Thin Solid Film **407** (2002) 7.