5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Time-resolved Measurement of Charge Density at the Bottom of High-aspect-ratio Holes in a Pulsed Capacitively Coupled Plasma

Haruka Suzuki[1,2], Makoto Moriyama[1], Naoya Nakahara[1], Keita Ichikawa[1], and Hirotaka Toyoda[1,2,3]
[1] Department of Electronics, Nagoya University, [2] Center for Low-Temperature Plasma Sciences, Nagoya University, [3] National Institute of Fusion Science
e-mail (speaker): hsuzuki@nuee.nagoya-u.ac.jp

In recent years, the demand for 3D-NAND memory device is dramatically increasing. For the manufacturing, high aspect ratio (HAR) hole etching is one of the essential processes, and reactive ion etching (RIE) using capacitively coupled plasma (CCP) is indispensable. However, in the HAR-RIE, electric positive charge accumulated at the bottom of the etching hole reduces the energy of incident ions, which causes abnormal profile and decrease in the etching rate. To solve the problem, pulsed power is used for charge relaxation from the holes during pulse off timing. One of the approaches to understand charge-up phenomena inside the holes in pulsed CCP is the use of capillary plate (CP) as a model of etching hole and the measurement of voltages on the top and the bottom of CP. So far, several researches based on this approach have been reported [1,2]. However, there is no report on charging-up phenomena of HAR hole, more than 30, using pulsed plasma with absolute charge measurements. We have applied the CP model method to investigate temporal change of charge-up in pulsed-VHF CCP plasmas to evaluate the absolute value of charge density at the bottom surface of CPs with aspect ratios greater than 30. In this study, absolute density measurement of the positive charge accumulated at the bottom of the hole [3,4] is demonstrated with time variation during the pulsed VHF discharge.

In the experiment, a typical-narrow gap CCP chamber with an electrode diameter of 11 cm and an electrode gap of 3 cm is used. The top electrode is grounded and discharge gas of Ar or Ar/C_4F_8 (perfluorocyclobutane) is introduced to the vessel through a mass flow controller and a gas manifold at a pressure of 2 Pa. 40 MHz VHF power (<600 W) is applied to the powered electrode through the matching box with a pulse modulation frequency of 1 kHz and a duty cycle of 50%. As a model of the hole pattern, a lead-glass CP (thickness: 0.3 mm, aspect ratio (AR): 12, 30, and 50) with a metal electrode at the bottom of the CP is placed on the powered electrode through an insulated alumina plate. A high voltage probe (HVP) is connected to the electrode on the CP bottom through a vacuum feedthrough. Before the experiment, the frequency characteristics of HVPs are carefully calibrated, including the feedthrough structure.

The temporal change of charge density was evaluated from a one-dimensional equivalent circuit model using the measured voltage, plasma potential, and plate capacitance. Figure 1 shows a schematic diagram of electric field and an equivalent circuit model from the plasma to the RF electrode. To simplify the model, accumulated charge is considered to be only on the surface of the sheath edge,

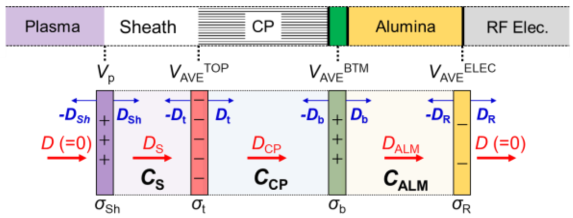

Figure 1. Electric field and surface charge density in the vicinity of the CP.

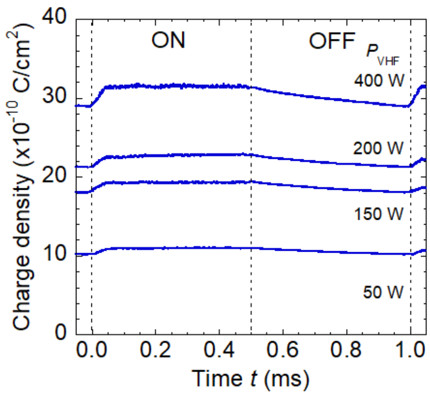

Figure 2. Temporal variation of surface charge density at the CP bottom with the AR of 30.

the top and bottom of the CP, and the powered electrode surface. Based on the model, electric flux density in each space can be calculated from the surface charge density. Thus, the voltage generated in each part can be obtained from line integration of the electric field. Based on this, the charge density can be estimated from the measured capacitance and the potential differences.

Figure 2 shows the temporal variation of charge density at the CP bottom with the CP of AR=30 in Ar plasma. The surface charge density increases with increasing the VHF power (P_{VHF}) from 50 to 400 W. When the VHF power is turned ON, the charge density immediately increases, and then saturates within about 0.1 ms. On the other hand, when the VHF power is turned off, the charge density slowly decreases. The experimental results clearly show charging and discharging during the VHF pulse operation.

References

[1] Kurihara, et al., Proc. 3rd ICRP, II-3, 1997.
[2] Negishi et al., J. Vac. Sci. Technol., **B35**, (2017) 051205.
[3] M. Moriyama, et al., Jpn. J. Appl. Phys., **59** (2020) SJJB03.
[4] M. Moriyama, et al., Jpn. J. Appl. Phys., **60** (2021) 016001.