

# IN-SITU CHAMBER WALL CLEANING IN PROCESSING PLASMAS

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## **Abstract**

Fundamental properties of an in-situ chamber wall cleaning in a reactive electron cyclotron resonance (ECR) plasma have been investigated using a poly-Si wafer on the wall, to which a dc or radio-frequency (RF) surface voltage is induced externally. Plasma parameters are measured by a heated Langmuir probe. To keep the wall condition clean during the plasma processing, we have found an optimum dc and RF sheath voltages without giving serious surface damage. Our method proposed here for the in-situ chamber wall cleaning is quite effective for keeping the wall condition constant during the plasma processing.

## **1. Introduction**

Interactions between charged particles and a chamber wall have been of crucial importance in processing plasmas as well as fusion plasmas, where impurities from the chamber wall cause serious problems, resulting in an unstableness of plasma parameters [1]. Especially, in processing plasmas, it is quite important to establish a wall cleaning technique for maintaining the chamber wall condition constant during the processing. The cleaning technique gives rise to not only a reduction of production cost but also a quality improvement.

We have presented a new method for cleaning the chamber wall by inducing radio-frequency (RF) surface voltage [2],[3]. In order to control the wall surface condition, the energy of ions accelerated by the sheath potential toward the wall plays a key role in the cleaning, because those ions impinging on the wall give rise to chemical and/or physical sputtering effect on removing the impurities from the surface [2], [4].

In this paper, we investigate basic characteristics of an in-situ chamber wall cleaning in a reactive electron cyclotron resonance (ECR) plasma [3],[4],[5]. The ECR plasma is generated by a plane slotted antenna [6] with 6 circular arrays of permanent magnets. Here, we mainly study the surface condition of the metal side wall, antenna, and substrate. The mechanism of metal surface cleaning is as follows. A vacuum chamber is separated into several parts which are insulated electrically. By applying RF power directly to each of them in rotation, a negative sheath potential is induced on the surface of each part. The surface is cleaned by the sputter-etching of positive high energy ions, in order to keep the wall condition constant without giving much influences to plasma parameters [3].

## 2. Experimental apparatus

A schematic of the experimental apparatus is shown in Fig. 1. A microwave of 2.45 GHz traveling through a rectangular waveguide is converted into a coaxial mode, which is fed to the antenna. An impedance matching is adjusted by E-H tuner between the rectangular waveguide and the coaxial one. The plane antenna consists of an azimuthally 4-segmented slot of 5 mm in width and 309 mm in diameter at the radial position corresponding to the 4th magnet ring position as shown in Fig. 1. Cylindrical permanent magnet pieces of 25 mm in diameter and 20 mm long with the maximum magnetic field of about 0.5 Tesla at their surface center are attached to the back plate of the antenna to form 6 magnet rings with a magnetic field strength of 0.4 : 0.8 : 0.8 : 1.0 : 1.0 : 0.8 ratio on the antenna surface, where 1.0 corresponds to about 0.5 Tesla. The ratio can be varied by either changing magnet species or adjusting magnet positions under the conditions that the axial magnetic field  $B_z$  has to be reduced less than 10 Gauss on the substrate which is located at 12 cm away from the antenna and that the plasma parameters in the radial direction have to be uniform in front of the substrate.

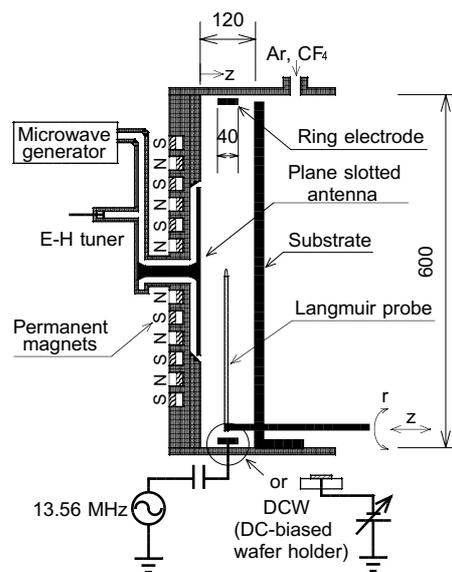


Figure 1. Experimental apparatus.

Working gases is Ar,  $\text{CF}_4$ , and  $\text{H}_2$  with pressure range of 0.67 ~ 2.0 Pa. The flow rate ratio of  $\text{CF}_4$  and  $\text{H}_2$  in the total working gases, i.e.,  $\text{CF}_4, \text{H}_2 / (\text{Ar} + \text{CF}_4 + \text{H}_2)$ , is 0~20 %. A microwave power of 1,000 W is fed to the antenna. Spatial profiles of plasma parameters are measured by a Langmuir probe[5] which is movable in the  $(r, z)$  plane, where  $r$  is a radial distance from the center and  $z$  is an axial distance from the antenna surface. The cleaning rate of the vacuum chamber wall is evaluated by measuring the thickness of polymer film deposited on a stainless-steel layer covering a  $1 \times 2$  cm conductive poly-Si wafer, which is supposed as a metal chamber wall. Chamber wall cleaning is established by either applying a dc bias to the wafer on the wafer holder (DCW) or applying a radio-frequency(RF) bias to the wafer on the ring electrode of 4 cm long and 54 cm in diameter as shown in Fig. 1. A surface temperature of the wafer is measured by a thermocouple. Cleaning rate  $C_R$  and deposition rate  $D_R$  are measured after the ECR plasma discharge during 60~180 minutes.

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## 3. Experimental results and discussion

Figure 2 shows radial and axial profiles of the ion saturation current  $I_{is}$ . Near the antenna,  $I_{is}$  has two broad peaks with small humps, which are almost symmetrical with respect to  $r = 0$  cm. With an increase in  $z$ , a distance between the peaks decreases gradually, being accompanied by

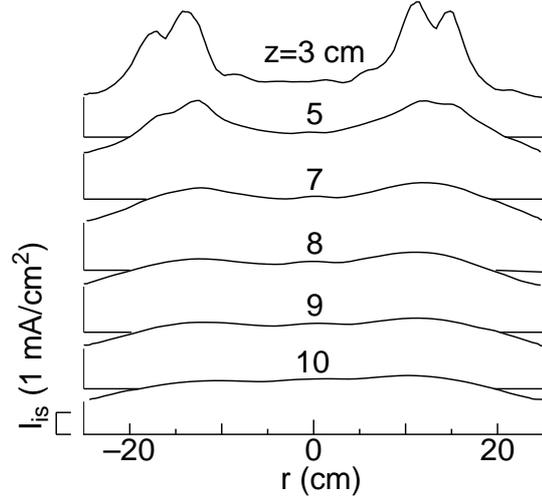
a decrease in the peak height. As a result, quite homogeneous ( $\leq \pm 5\%$ ) radial profiles are formed at  $z \simeq 10$  cm over 30 cm in diameter.

Using this ECR plasma source, we measure radial and axial profiles of the deposition rate  $D_R$  before the cleaning as shown in Fig. 3. It is confirmed that fluorocarbon like  $C_xF_y$  compounds are deposited on the whole inner chamber wall surface. The deposition rate  $D_R$ , however, drastically changes about 1 to 22 Å/min with the flow ratio of  $H_2/CF_4$  as shown in Fig. 4. That is, the deposition rate is markedly enhanced by increasing  $H_2$ . This dependence is supposed by a decrease of the amount of fluorine atoms through the following reaction,

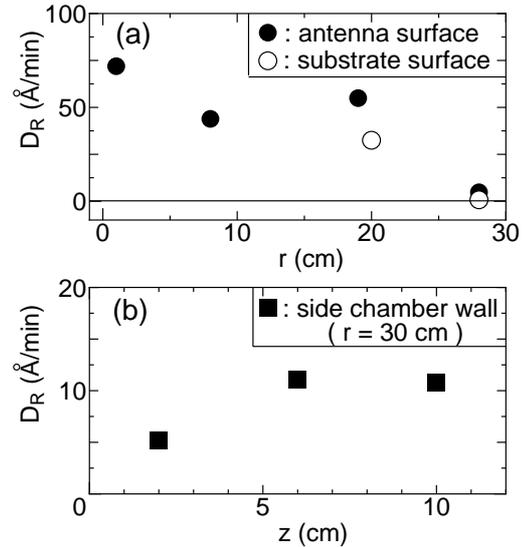


The deposition of fluorocarbon film is necessary for getting a high etching selectivity between two layers of different materials on the substrate. However, the deposition on the other wall except substrate causes a source of needless radicals, fine particles and temporal changes of plasma parameters. Therefore, the development of cleaning technique in a  $CF_4/Ar$  plasma with  $H_2$  gas is practically important.

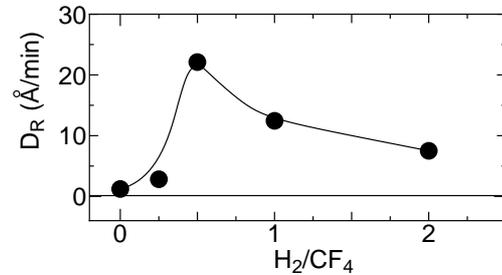
Figure 5(a) shows dependencies of the cleaning rate  $C_R$  and surface temperature  $T_t$  on the surface dc sheath voltage  $V_{sh}$  measured at  $z = 6$  cm.  $V_{sh}$  is defined as  $V_{sh} \equiv V_s - V_t$ , where  $V_s$  is a space potential at  $(r, z) = (25, 6)$  cm ( $V_s \simeq 25$  V in this experiment) and  $V_t$  is dc biased surface voltage. We have found that an optimum value of the dc sheath voltage for  $C_R \simeq 0$  is  $V_{sho} = -45$  V for keeping the wall surface clean. On the other hand,  $T_t \simeq 40$  °C and  $T_t$  has only a weak dependence on  $V_{sh}$ .



**Figure 2.** Radial and axial profiles of ion saturation current  $I_{is}$ . Working gas is argon. Gas pressure is  $P_r = 2.0$  Pa and microwave power is  $P_\mu = 1$  kW.



**Figure 3.** (a) Radial and (b) axial profiles of deposition rate  $D_R$ . Working gas is  $Ar/CF_4/H_2 = 8/1/1$ . Total gas pressure is  $P_r = 0.67$  Pa and microwave power is  $P_\mu = 1$  kW.



**Figure 4.** Dependence of  $D_R$  on the flow rate ratio  $H_2/CF_4$ . Working gas ratio is  $Ar/(Ar + CF_4 + H_2) = 0.8$ .  $P_r$  and  $P_\mu$  are the same as in Fig. 3.

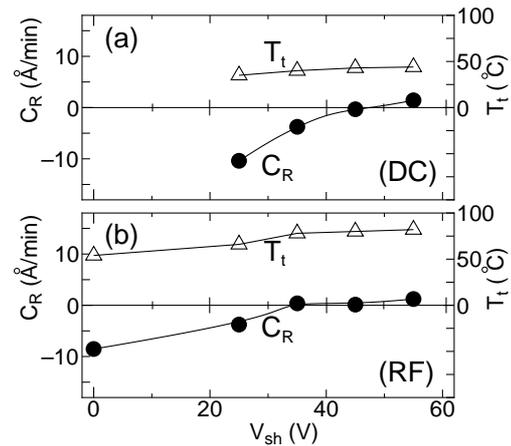
In Fig. 5(b), we also measure dependencies of  $C_R$  and  $T_t$  on the time-averaged surface RF sheath voltage  $V_{sh}$ , which is induced by radio-frequency (RF) power at the frequency of 13.56 MHz supplied to the ring electrode. It is found that an optimum value of  $V_{sh}$  for  $C_R \simeq 0$  is  $V_{sho} = -35$  V. Two effects are considered for this decrease of  $V_{sho}$  in case of RF bias: the one is an existence of ions with energy higher than that in dc-bias case because of an expansion of the ion energy distribution function, the other is an increase of surface temperature from 40 °C to 78 °C. It is also noted that no remarkable wall surface damage is observed during the cleaning. This implies an existence of high selectivity of sputter-etching between deposited impurities and metal wall. Therefore, our cleaning technique is quite useful for in-situ chamber wall cleaning in the processing plasmas.

#### 4. Conclusion

We have observed basic characteristics of in-situ chamber wall cleaning in a high-density processing plasma, where the ion current density toward the substrate is higher than 1 mA/cm<sup>2</sup>. It is found that an optimum sheath voltage on the wall enables to keep the wall condition constant during the processing without undergoing serious surface damage. These experimental results confirm a quite usefulness of our method for the in-situ chamber wall cleaning in the reactive processing plasmas.

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**Figure 5.** Dependencies of cleaning rate  $C_R$  and surface temperature  $T_t$  on (a) surface dc sheath voltage  $V_{sh}$  at  $z = 6$  cm and RF (13.56 MHz) sheath voltage  $V_{sh}$ (time-averaged) at  $z = 5$  cm. Experimental conditions are the same as in Fig. 3.