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Numerical Simulation of O^- Ion Trajectory in RF Magnetron Plasma
RFマグネトロンプラズマ中の酸素負イオン軌道解析

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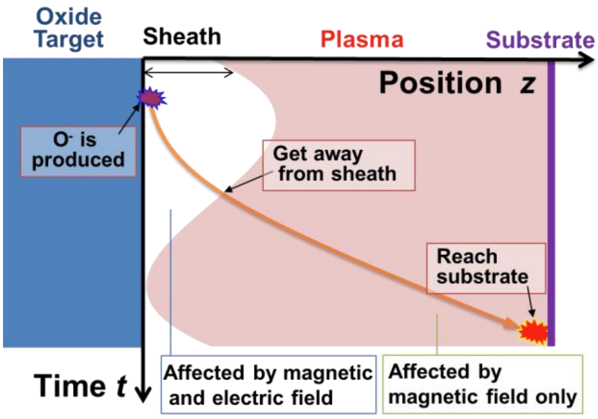
Behavior of high energy nagative oxygen (O^-) ions in RF magnetron plasma is investigated by a numerical simulation in which O^- ions are released from the oxide target surface and are accelarated by the time-varying RF sheath in front of the target. Deflection of O^- ions depends not only on a magnetic field of the magnetron gun but also on the RF phase at the target surface.

1. Introduction

Magnetron plasmas are one of the most important tools for sputter deposition of thin films. However, energetic particles from the sputtered target sometimes induce physical and chemical damages to the deposited film surface during the sputtering processes. For example, magnetic and/or electrical properties of magnetic recording films or magnetic tunneling junction for magnetoresistive random access memory (MRAM) sensitively vary with sputtering conditions, suggesting the damage to the deposited film interface. Therefore, measurement of energetic particles in the magnetron plasma is indispensable to improve the deposition process. So far, we have investigated behavior of O^- ions in an RF magnetron plasma with an insulating target materials (MgO), especially focusing on the O^- energy distribution function (EDF) and its spatial dependence.[1,2] We have found that O^- ions were released from the MgO surface and were accelerated by the sheath electric field up to a few hundred eV. The maximum kinetic energy of O^- ions varied with radial position of the target due to spatial variation of MgO surface potential caused by the variation of the sheath thickness. Furthermore, it has been also pointed out that the O^- energy distribution has fine structure due to energy modulation of time-varying plasma potential. Another interesting feature is that the O^- signal showed drastic change in its intensity depending on the radial position. This result suggests that high energy O^- ions were deflected by magnetic field of magnetron gun and were not detected by a quadrupole mass spectrometer (QMA) with an energy analyzer. In this study, O^- trajectory is numerically simulated with using a model including time-varying sheath electric field, as well as magnetic field distribution of the magnetron gun.

2. Simulation Model

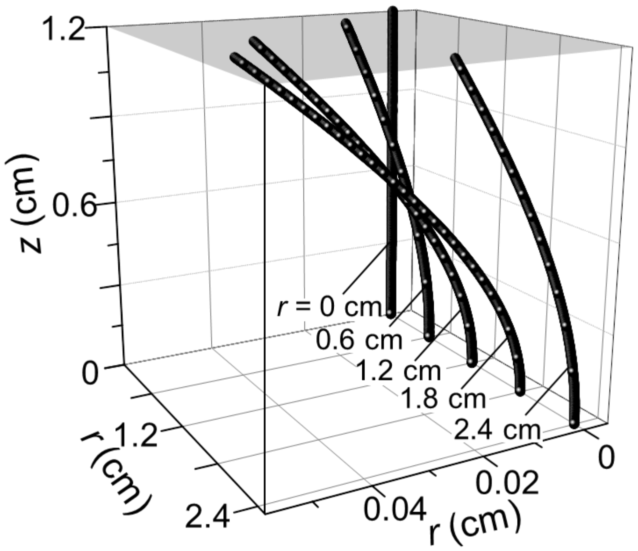
In this simulation, spatial profile of magnetic field strength *B* is experimentally obtained from the field measurement of a pair of magnets used in our previous experiments.[1,2] Origin of cylindrical coordinate is set at the center of the magnet for radial position (*r*) and on the surface of the MgO target for axial position (*z*). The inner (cylindrical) magnet is 1.7 cm in its radius and the outer (ring-structured) magnet is 2.1 cm and 3.1 cm in

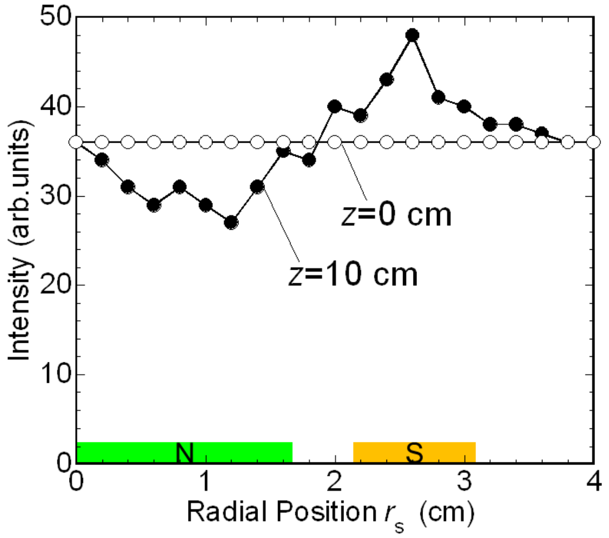


inner and outer radii. Parallel magnetic field B_r has the maximum at r=1.7 cm. Figure 1 shows schematic of the model. In this model, not only axi-symmetric magnetic field of the magnetron gun but also time-varying RF sheath in front of the MgO target, spatial variations of MgO surface potential and the sheath thickness are considered. Uniform ion density is supposed in the sheath, resulting in linear decease in the electric field with the distance from the target surface. O^- ions are released at arbitrary RF phase and arbitrary position of the target and ion trajectories are calculated by Runge-Kutta method. Here, RF phase angle (φ) of 180^o is determined as the minimum spontaneous voltage of the target surface (0 V). In the sheath region, both the electric and the magnetic fields are taken into account. After passing through the sheath, O^- ion trajectories are calculated only by the magnetic field. Plasma-sheath boundary moving with the RF phase is also included in this model. To ensure the calculation accuracy, number of the calculation more than 300 steps is guaranteed for the trajectory calculation inside the sheath region.

3. Calculation Results

Figure 2 shows trajectories of O^- ions in the vicinity of the MgO surface (z<1.2 cm). O^- ions are released at r=0, 0.6, 1.2, 1.8 and 2.4 cm with an RF peak-to-peak voltage of 420, 400, 290, 200 and 340 V, respectively. An RF phase in Fig. 2 is φ=60^o, which corresponds to a spontaneous MgO surface voltage of 110, 100, 70, 50 and 80 V. At r=0, the





O^- ion travels along z axis because there is no parallel magnetic field at r=0. At r=0.6 and 2.4 cm, however, the O^- ions are deflected due to the parallel component of the magnetic field. At r=1.2 and 1.8 cm, where the parallel magnetic field component is much higher, O^- ions at z=1.2 cm are shifted about 0.3 mm away from their initial position due to the deflection. Although the position shift is less than 1 mm at z=1.2 cm, ions travel through the plasma to the substrate, typically positioned at z~10 cm. This means that position shift becomes a few mm on the substrate.

Figure 3 shows O^- flux at the MgO target (z=0) and the substrate (z=10 cm). When O^- flux at the MgO target is assumed to be uniform, O^- flux at substrate is not uniform. Since the calculated O^- fluxes are taken into account the RF sheath oscillation, non-uniform O^- ions distribution is formed owing to not only magnetic field strength but also the RF phase variation. To clarify the RF phase dependence, more detailed analysis will be discussed in the conference.

4. Conclusion

In conclusion, trajectories of O^- ions released from the magnetron target surface were simulated. Strong ion deflection was observed at a position of the maximum parallel magnetic field and at low spontaneous RF voltage phase.

References

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