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博　士　論　文　の　要　旨

専攻名　　システム創成科学専攻

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博士論文題名

Development of Magnetized Plasma Sputtering Source for Effective Target Utilization with Various Magnet Setups

（ターゲット有効利用のための様々な磁石配置を用いた磁化プラズマスパッタ源の開発）

要旨（２，０００字程度にまとめること。）

A high-density radio frequency (RF) magnetized sputtering plasma source with a rotational square-shaped magnet arrangement for uniform target utilization has developed. Eight neodymium rod magnets of 30 × 5 × 3 mm, where the connection between N-pole and S-pole magnets is one side of the square, are mounted on a circular iron yoke disc and an iron cover of 5 × 3 × 1 mm is also used for magnetic shielding of otiose magnetic fields from the permanent magnets. The magnetic field simulation, the measurement of the target erosion and the time-averaged ion flux to the target have been investigated for case (a) without iron cover, no air gap between N-pole and S-pole magnets, case (b) with iron cover, no air gap, and case (c) with iron cover, 5 mm air gap, respectively. It is found that the iron covers suppress the horizontal magnetic flux density and the copper target utilization percentage increases from 74.15 % to 87.49 %. Moreover, by decreasing the air gap between the shielded magnets, the copper target utilization percentage rises from 83.85 % to 87.49 %. The target utilization as well as the time-averaged ion flux to the target are optimum for case (b).

A gyratory square-shaped capacitive radio-frequency (RF) discharge plasma sputtering source is proposed for materials processing and functional film preparation, composed of magnet arrangements consisting of eight neodymium bar magnets of dimensions 30 mm × 5 mm × 3 mm. In order to evaluate its performance, two square-shaped magnetic arrangements were investigated: case (a) without iron shielding and case (b) with iron shielding of dimensions 5 mm × 3 mm × 1 mm. The magnetic field simulation is analyzed, while the plasma discharge characteristics and the film properties are measured. The film thickness and the resistivity profiles of case (b) are more uniform than their corresponding profiles in case (a). The lowest electrical resistivity of the film is 4.33×10^{-8} Ω·m at r = 30 mm for case (b), which is of the same order as the bulk resistivity of the copper. The roughnesses of the film thickness profile for cases (a) and (b) are ± 24.4% and ± 7.2%, respectively. Using atomic force microscopy (AFM) analysis, the film surface for case (b) was observed to show an improved smooth surface with reduced needle-shaped grain size, as well as a lower surface roughness than that of case (a). The surface roughness of the films is approximately 3.73 nm and 2.49 nm for case (a) and case (b), respectively. From the X-ray diffraction (XRD) patterns, the film texture, the relative intensity ratios of the (111) peak to the (200) [$I_{(111)}/ I_{(200)}$] were found to be 13.76 and 4.08 for the cases (a) and (b), respectively.

To improve the target erosion near the edge, the outer ring-shaped RF magnetized plasma is produced near the chamber wall by a monopole magnet scheme. Three monopole magnet schemes such as the setups (a) R = 5 mm, (b) R = 20 mm and (c) R = 35 mm has been investigated are chosen, where “R” is the gap distance between magnets in consecutive circles. Distributions of the 2D magnetic flux lines, absolute value of the horizontal magnetic flux density and discharge voltage are investigated for the proposed setups to produce outer

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ring-shaped plasma. A high luminous ring-shaped plasma is observed for (b) R = 5 mm, whereas multi-ring discharges are observed for (b) R = 20 mm and (c) 35 mm. It is found that the electron temperature decreases with increasing gas pressure for the all cases. The electron temperatures were 2.42, 1.71 and 1.15 eV at Ar gas pressure of 4 Pa for the setup (a), (b), and (c), respectively. The plasma density is approximately same for the setups (b) and (c) at all gas pressure. The highest plasma densities were 6.26×10^{15}, 1.06×10^{16} and 1.11×10^{16} m^{-3} at 5 Pa for the setups (a), (b), and (c), respectively. It is found that, the electron mean free path is 41.4, 63.17 and 84.66 mm at Ar gas pressure of 5 Pa for the setups (a), (b), and (c), respectively. Electron neutral collision frequency for case (a) R = 5 mm is higher than that for case (b) R = 20 mm and case (c) R = 35 mm at a constant RF power of 40 W and z = 13 mm axial distance from the target surface. Radial profile of ion saturation current for case (b) R =20 mm is more uniform than that for case (a) R = 5 mm and case (c) R = 35 mm set up.

The capacitively coupled RF outer ring-shaped magnetized plasma discharge is developed with a concentrically monopole arrangement of magnets to erode the target in a specific area, in especial, near the chamber wall. The three concentric monopole magnet arrangements with a center magnet, and magnets in setups (a) three circles, (b) two circles, and (c) one circle were investigated. From the magnetic flux lines profiles, it was found that the magnetic flux density in component parallel to the target surface has a peak magnitude in the outer circle of magnets for all setups. Ring-shaped plasma in the specific outer area was observed. The ion saturation current, I_{isat} were 0.6 mA, 0.79 mA, and 0.46 mA, for setups (a), (b), and (c), respectively at r = 47 mm, where r = 0 mm is the center of the target. It was found that, I_{isat} is very high in the outer target region near the chamber wall for setups (a) and (b), where I_{isat} for setup (c) decreases slowly. The results showed that the target utilization could be controlled in the outer specific area near the wall.

A pulsed direct current (DC) discharge ring–shaped plasma source has been proposed using single pole magnet arrangements, including a center magnet, with magnets in the setups (a) one circle, (b) two circles, and (c) three circles. The 2D magnetic flux lines profiles, larmor–radii and Hall parameters of the electrons and ions, electrical discharge characteristics, ion saturation current profiles were investigated to characterize the proposed plasma. The electron larmor–radii, r_e were 0.17, 1.64, 5.82 mm for setups (a), (b), and (c), respectively. It was found that the highest electron Hall parameters are approximately 561 at r = ±21 mm for setup (a), 544 at r = ±36 mm for setup (b), and 297 at r = ±50 mm for setup (c). The strong ring–shaped plasma discharges was observed for all setups. The typical discharge voltages were 1.0, 0.6, and 0.6 kV for setups (a), (b), and (c), respectively. The ion saturation currents, I_{isat} were 1.44, 2.88, and 2.2 mA for setups (a), (b), and (c), respectively at r = 45 mm and t = +10 µs. The I_{isat} of setup (b) is less fluctuating, whereas I_{isat} of setup (c) is highly variable in all radial positions. Setup (b) has the best profile among the three setups.