

Characteristics of plasma parameters in sputtering deposition using a powder target

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Abstract. Fabrication mechanisms of functional thin films prepared using a sputtering deposition method with metal-based powder targets were examined and profiles of electron density and emission intensity in the processing plasma were investigated. The electron density and electron temperature were 0.5×10^9 to $3 \times 10^9 \text{ cm}^{-3}$ and 0.5 to 1.5 eV, respectively. The radial profiles of the electron density were almost uniform, but the electron density and temperature at the edge of the electrode were higher than those at the center near the powered electrode. Axial profiles suggested that the electron density was the highest at the plasma/sheath boundary. The profile shape using a powder target was almost the same as that using a bulk target.

1. Introduction

Sputtering deposition is a method for preparation of thin films using an ion sputtered material from a bulk target; that is, deposition onto a substrate. This method has been used to prepare uniform amorphous and crystalline thin films with large areas. Based on the versatility of the sputtering method, we have developed several kinds of functional thin films, including those made from tungsten carbide, silicon carbide, chromium carbide, titanium carbide, cubic boron nitride, carbon nitride and silicon nitride [1-7]. High density bulk targets ($>3 \text{ g/cm}^3$ and $>95\%$ density) are generally used in this method. Therefore, when producing a thin film with certain elemental ingredients using this method, it is necessary to make a new target compared to that used for other methods, such as spark plasma sintering. However, target preparation can be time-consuming and expensive. Thus, sputtering deposition would become more attractive if powder material targets can be used.

Kajima et al. prepared ferromagnetic nanocomposite oxide sputtered films with a $\text{Bi}_2\text{O}_3\text{-Fe}_2\text{O}_3\text{-PbTiO}_3$ ternary system using powder targets [8] and suggested that the prepared films worked well as thin film capacitors. We have also prepared TiO_2 films using a Ti powder target [1-2] and found that the deposition rate, Ti atom emission intensity and electron density in the processing plasma using the powder target were higher than those found using a bulk target. These parameters also slightly increased with an increase in the powder size. In contrast, electron temperatures in the plasma using a powder target were almost the same as those using a bulk target. These results suggest that the net-cathode surface area of the powder target is larger than that of the bulk target. However, spatial profiles of the plasma parameters, such as the electron density, electron temperature and emission species, were not investigated.

In this paper, functional thin films were prepared by a sputtering deposition method using



metal-based powder and bulk targets. The characteristics of the sputtering plasma were studied based on measurements of electron density, electron temperature, and Ti atoms emission intensity in the plasma. Based on the results, the mechanisms of thin film deposition using powder targets were explored.

2. Experimental

A schematic illustration of the experimental apparatus has been presented elsewhere [2]. The deposition chamber was fabricated from stainless steel with a diameter of 400 mm and a length of 370 mm. The metal powder targets were set up on a stainless steel target holder. Rutile Ti powders of 45 μm diameter were used as the powder targets and a Ti metal target was used as a bulk target. The purity of the powder target in the target holder was similar to that in the bulk target (99.9%). The chamber was evacuated to 1 Pa using a rotary pump and then to a base pressure of 1×10^{-2} Pa using a turbomolecular pump. A deposition total pressure (P) of 10 Pa was produced using a mixture of oxygen (O_2 : 99.99%) and argon (Ar: 99.99%) at a flow rate of 10 sccm. RF non-magnetron sputtering plasmas were generated at 13.56 MHz discharge frequency and 30-70 W discharge RF power. The Si(100) substrates were located 5.0 cm from the target. The substrates were cleaned by repeated bathing in an ultrasonic agitator and then rinsed in high-purity deionized water prior to loading into the deposition chamber. The electron density and temperature of the processing plasma were measured using a Langmuir probe of size 0.3 mm ϕ and a 0.5 mm tungsten wire. The optical emission intensity of Ti atoms and the laser light scattering intensity were recorded through a spectrometer (Hamamatsu C5095) equipped with an ICCD camera (Hamamatsu C7164-03) after integrating 16 times.

3. Results and discussion

Radial distributions of electron density in the processing plasma using powder and bulk targets at different RF powers are shown in figure 1. Measurements were made using a Langmuir probe at 10 mm above the cathode surface. The electron density ranged from 0.5×10^9 to $3 \times 10^9 \text{ cm}^{-3}$ and increased with increasing RF power. The profiles suggest that the electron density at the edge of the electrode (-5 and +5 cm in figure 1) was higher than that at other positions. The radial electron density profile using a Ti bulk target at 70 W RF power (figure 1) was almost the same as that obtained with the powder target at the same RF power. However, the electron density using a powder target was almost 3 times higher than that using a bulk target. In our previous work, the deposition rate increased with increasing RF power using a powder target. These results are consistent with those in figure 1.

Radial distributions of electron temperature 10 mm above the substrate at different RF powers are shown in figure 2. The electron temperatures ranged from 0.5 to 1.5 eV and were almost independent of the RF power. The radial electron temperature profile using the Ti bulk target at 70 W RF power (figure 2) and the absolute electron temperature with the bulk target were almost the same as those obtained with the powder target.

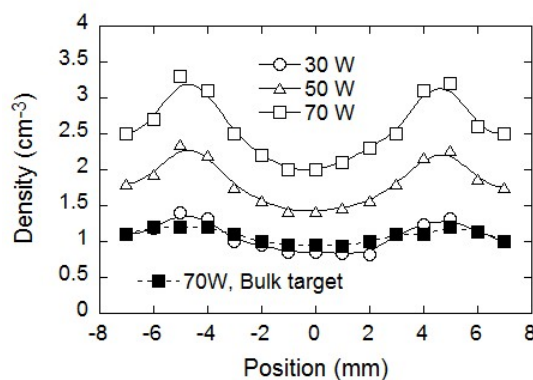


Figure 1. Radial distributions of electron density 5 mm above the substrate at different RF powers.

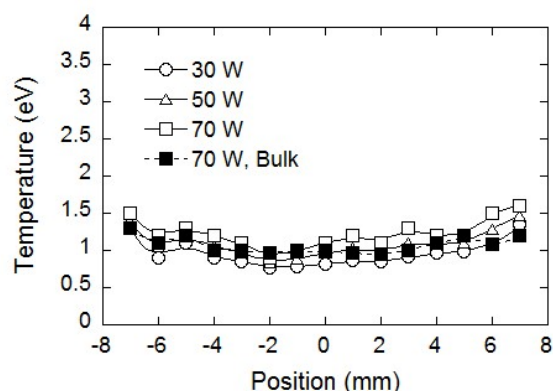


Figure 2. Radial distributions of electron temperature 5 mm above the substrate at different RF powers.

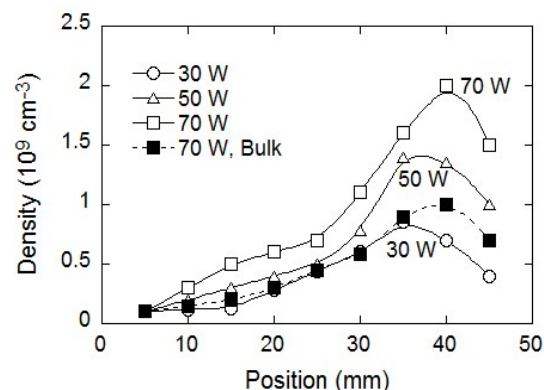


Figure 3. Axial distributions of electron density at the center of the electrode.

Axial distributions of electron density in sputtering plasma using a powder target at different RF powers are shown in figure 3. The electron density ranged from 0.5×10^9 to $3 \times 10^9 \text{ cm}^{-3}$. The maximum electron density occurred at 35 to 40 mm from the anode surface, at the plasma/sheath boundary region.

Emission profiles of Ti atoms (337 nm) measured by a monochromator using a powder target at different RF powers are shown in figure 4. The profiles of Ti emission intensity were similar to the profiles of the electron density.

Axial profiles of the electron density, Ti emission intensity and laser light scattering (LLS) intensity using a powder target are shown in figure 5. LLS intensity was measured by 532 nm laser light and light scattering was measured using a photodetector. All the profiles have a sharp peak at the plasma/sheath region. The peak position of the LLS profiles was 5 mm shifted to the cathode. Small particle generation and growth were related to the high energy electrons near the sheath area. No LLS signal in the sputtering plasma was obtained using the bulk target.

In our previous work, the quality of films prepared by plasma processing was decreased by particle generation, which was detected by LLS methods [6]. LLS intensity was detected at the plasma/sheath region, but not on the anode surface.

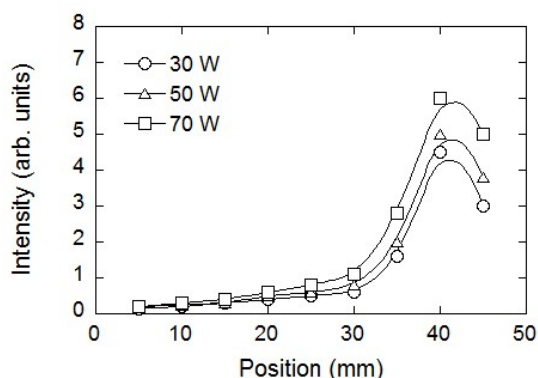


Figure 4. Axial distributions of Ti (337nm) emission at the center of the electrode.

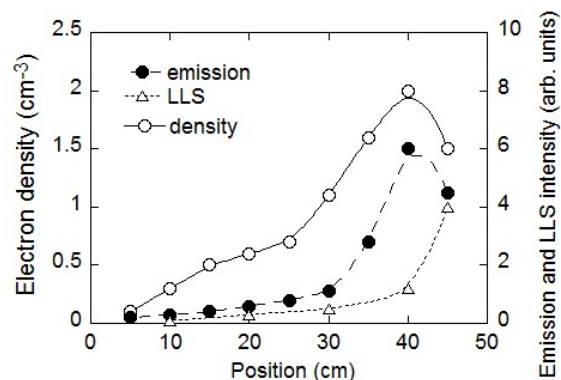


Figure 5. Axial distributions of electron density, Ti (337 nm) emission and LLS intensity at the center of the electrode.

4. Conclusion

Radial and axial profiles of electron density, electron temperature and LLS intensity were investigated in sputtering plasma using a powder target. The electron density and electron temperature were 0.5×10^9 to $3 \times 10^9 \text{ cm}^{-3}$ and 0.5 to 1.5 eV, respectively. The profiles of these parameters were uniform, which suggests that uniform thin films with large areas can be prepared. Small particle generation and growth were related to the high energy electrons near the sheath area at a particle size of 45 μm .

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References

- [1] Kawasaki H, Ohshima T, Arafune K, Yagyu Y and Suda Y 2012 *Trans. Mater. Res. Soc. Jpn* **37** 147
- [2] Kawasaki H, Kanazawa T, Aoqui S, Ohshima T, Yagyu Y and Suda Y 2011 *Trans. Mater. Res. Soc. Jpn* **36** 455
- [3] Kawasaki H, Shigematsu T, Imasaka K, Ohshima T, Yagyu Y and Suda Y 2011 *Trans. Mater. Res. Soc. Jpn* **36** 479
- [4] Ohshima T, Murakami Y, Kawasaki H, Suda Y and Yagyu Y 2011 *Jpn. J. Appl. Phys.* **50** 08JD09
- [5] Kawasaki H, Shibahara K, Ohshima T, Yagyu Y and Suda Y 2010 *Jpn. J. Appl. Phys.* **49** 08JF01
- [6] Kawasaki H, Ohshima T, Yagyu Y and Suda Y 2008 *Trans. Mater. Res. Soc. Jpn* **33** 655
- [7] Kawasaki H, Matsunaga T, Guan W, Ohshima T, Yagyu Y and Syda Y 2009 *J. Plasma Fusion Res. Series* **8** 1431
- [8] Kajima A, Arita T, Tsuji Y, Inoue M and Fujii T 2006 *J. Magn. Soc. Jpn.* **30** 174