Structured MgO Coated Electrodes to Reduce the Inception Voltage

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Abstract: In this study, structured MgO films were synthesized on stainless steel electrodes to reduce the glow discharge inception voltage in a diode type discharge system under 6%Xe+94%Ne atmosphere. The relationship between the MgO surface configuration and the discharge inception voltage was investigated. We prepared two types of MgO films, namely, those with a flat surface and those with a structured surface. The structured surface appeared similar to a desert-rose-like structure. The discharge inception voltage was varied with the surface configuration of the MgO film. The inception voltages in the structured MgO-coated electrodes were lower than those in the MgO films with a flat surface of 0.4-10 KPa. One of the causes of the suppression of inception voltage in a structured MgO-coated electrode is considered to be the field enhancement effect at the tip of the MgO-coated electrode.

Keywords: MgO, Glow plasma, Surface structure, Inception voltage

1. Introduction

Paschen's law explains that the inception voltage for plasma is changed by the pressure and distance of a pair of electrodes. Although a high voltage is required to generate plasma at a relatively low pressure, the inception voltage increases with pressure after a minimum voltage under a constant electrode configuration. To maintain a low inception voltage for discharge plasma at a relatively high pressure, one of the methods used is the supply of electrons from electrodes coated with materials of high secondary electron emission coefficient. The secondary electron emission phenomenon of the nature of MgO affects the glow discharge characteristics. Hence, MgO-coated electrodes have already been applied to a plasma display panel with a relatively high pressure to maintain a low power consumption. To supply many secondary electrons from electrodes to the plasma, metal electrodes should be completely covered with MgO.

To maintain a lower power consumption, the use of the field enhancement effect at an electrode surface coated with microstructures was proposed in this study. When these microstructures were composed of magnesium oxide, both the high secondary electron emission and the field enhancement effects were expected. Up to now, MgO films have been fabricated by reactive unbalanced planar magnetron sputtering, oxygen ion-beam-assisted deposition, inductively coupled plasma-assisted evaporation and electron beam evaporation methods. These general deposition systems are difficult to use in the deposition of structured MgO film because it is generally difficult to control the precursor condition at these physical vapor depositions. On the other hand, we have developed a chemical vapor deposition (CVD) technique that can possibly be carried out under atmospheric pressure. This technique is fundamentally thermal CVD and can deposit MgO whiskers or structured MgO films.

In this study, a structured MgO film was employed to reduce the discharge inception voltage in a diode-type discharge system. First electrodes were completely coated with flat MgO layer. Subsequently, the structured MgO film was synthesized on the flat MgO layer by CVD.
2. Experimental

Stainless steel (SUS304L) substrates of the super smooth surface were used and cut into dimensions of 10×10×2 mm³. To cover the SUS304L substrate surface with MgO, flat MgO films were deposited by a metal organic deposition method that can easily prepare flat films by spin coating with a metal organic solvent (Kojundo Chemical Lab. Co., Mg-03). The rate of rotation was higher than 500 rpm, and two drops of the solvent were applied. To remove organic components, the samples are annealed at 400 °C for 30 min. This sample is called “Spin-MgO” in this report. Subsequently, structured MgO films were prepared using an atmospheric CVD apparatus. The raw material Mg(C₅H₇O₂)₂ (Tokyo Kasei Co., quoted purity of 99.9%), was loaded into a vaporizer and vaporized using an electric heater. The reactant vapor was first carried by nitrogen gas flowing at a rate of 1.5 L/min and then sprayed from the metallic nozzle directly onto the SUS304L substrate mounted on the electric heater. The reactant, Mg(C₅H₇O₂)₂ was immediately decomposed by the heat from the substrate heater to form the films. The deposition duration was 30 min. The substrate was heated to 620 °C using the electric heater. The distance between the nozzle and the substrate was maintained at 15 mm. Here, the coated MgO is called “CVD-MgO” in this report.

X-ray diffraction (XRD) analysis using M03XHF (Mac Science Co.) were conducted to reveal the crystal structure of the sample. The X-ray source was Cu Kα (0.154 nm). The surface morphology and roughness of the film was observed by scanning electron microscopy (SEM, JEOL, JSM-6700F). The electrical behavior of the sample was examined using a diode-type plasma discharge system. This system consists of vacuum chamber, 20 kHz A.C. power supply and digital multi-meter. For measurement, a couple of SUS304L electrodes with, or without coated structured, or flat MgO was fixed in 6%Xe+94%Ne atmosphere. The glow discharge was obtained by applying electric power to the diode electrode under the gas pressure of 100 Pa-1000 Pa. The discharge inception voltage was measured by the digital multi-meter.

3. Results and Discussion

Figure 1 shows XRD patterns of the SUS304L substrate, Spin-MgO and CVD-MgO. The Spin-MgO showed no clear diffraction line except substrate peaks, implying the presence of an amorphous phase. On the other hand, the CVD-MgO showed a clear diffraction line at 2θ=43°, corresponding to a (200) diffraction line for the cubic rock salt structure of MgO crystals. The crystalline orientation was kept constant among the samples except the amorphous material. The other diffraction lines were indexed as those from the SUS304L substrate. The XRD profile of the CVD-MgO suggested a preferred (100) orientation, because the intensities of the peaks assigned to (111) and (220) were lower than that of the peak assigned to (100).

The SEM images shown in Fig. 2 indicate surface configuration changes of the substrate and samples. The SUS304L substrate and Spin-MgO surfaces were smooth and flat. Holes with nanometer diameters on the Spin-MgO surface were observed in the high-magnification SEM image. On the other hand, the image of the CVD-MgO surface showed many plate-like grains. The CVD-MgO surface configuration change may reduce the discharge inception voltage produced by the field enhancement effect, and sharp tips may also work as the emission
sites of electrons. From the XRD results for the CVD-MgO suggested preferred (100) orientation, it was considered that the roughness change corresponded to the crystalline growth of [100] direction observed in XRD patterns.

The discharge inception voltage was measured for 3 types of electrodes, namely, SUS304L, Spin-MgO, and CVD-MgO, as indicated in Fig. 3. The lowest inception voltages of all the electrodes were observed at approximately 2000 Pa. They were 103, 85, and 78 V for the SUS304L, Spin-MgO, and CVD-MgO, respectively. The inception voltage varied with gas pressure and the type of electrode used. Both MgO coatings reduced the discharge inception voltage, and the CVD-MgO indicated the lowest inception voltage among these three samples. The discharge condition also varied with gas pressure and the type of electrode used, and the pressure for maintaining the glow discharge was increased to 6000 Pa by the MgO coating, since the glow discharge of the SUS304L changed to streamer discharge at 1200 Pa. Hence, the structured MgO coating on the electrodes for discharge maintains the glow discharge and reduces the inception voltage.

Fig. 2. The surface SEM images of samples. Low- and high-magnification images are left and right side, respectively.

a) SUS 304L

b) Spin-MgO

c) CVD-MgO

Fig. 3. The relationship between the discharge inception voltage and gas pressure for three types of electrodes, SUS304L, Spin-MgO, and CVD-MgO.

4. Conclusion

MgO coating is effective for reducing the discharge inception voltage of an A.C. discharge diode-type system in 6%Xe+94%Ne atmosphere. A structured MgO film is essential for reducing the discharge inception voltage. The pressure for the glow discharge was increased to 6000 Pa by the MgO coating.
References


