Energy distribution function of substrate incident negative ions in DC magnetron sputtering of metal-doped ZnO target measured by magnetized retarding field energy analyzer

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Abstract: The energy distribution function (EDF) of charged particles incident on a substrate during magnetron sputter deposition of a metal-doped zinc oxide target was measured using a magnetization-reflection field energy analyzer (RFEA). The formation of a perpendicular magnetic field region in front of the RFEA significantly suppresses the inflow of bulk plasma electrons into the RFEA, allowing the measurement of the EDF of oxygen negative ions. An investigation of the optimization of the magnetic filter central flux density is reported.

Keywords: metal-doped zinc oxide, transparent conductive films, magnetron, sputtering, negative ions, retarding field energy analyzer, magnetic filter.

1. Introduction

We have been studying magnetron sputtering deposition processes for metal-doped ZnO films such as Al-doped ZnO (AZO) and Ga-doped ZnO (GZO), which are expected to replace ITO (Indium Tin Oxide) as transparent conducting films. In planar magnetron sputtering deposition using oxide targets, there is a problem of film composition and crystallinity degradation on the substrate surface opposite the target erosion area. This is believed to be due to the incident of high-energy particles emitted from the erosion zone of the oxide target onto the opposite substrate, but the details have not yet been clarified. To understand the sputtering deposition process of oxide targets, it is extremely important to understand the particles and energy flux incident on the substrate, and it is necessary to measure the energy distribution function (EDF) of the charged particles.

In the past, several examples have been reported of the detection of negative ions from sputtering targets using large, expensive energy-resolved mass spectrometers that require differential exhaust [1, 2, 3]. However, there are few examples using the compact, inexpensive, and highly mobile retarding field energy analyzer (RFEA), which by itself cannot separate the incoming fluxes of electrons and negative ions. However, it has been reported by Rafalskyi et al. that an orthogonal magnetic field region of several hundred gauss above the RFEA injection aperture can suppress the inflow of electrons into the RFEA and measure the EDF of negative ions [4, 5]. The purpose of this study is to measure the EDF of positively and negatively charged particles incident on a substrate during sputter deposition using a magnetized RFEA and to clarify the effectiveness and issues involved. For this purpose, we have been developing and applying magnetized RFEA to charged-particle EDF measurements and improving the instrumentation over the past few years [6, 7]. As a result, we have been able to obtain measurement results that are comparable to previously reported negative ion EDF measurements using an energy-resolved mass spectrometer.

In this paper, we report the results of charged-particle EDF measurements in magnetized RFEA during DC magnetron sputtering (DCMS) of a Ga-doped ZnO target. The paper will focus in particular on the influence of the central flux density of the magnetic filter on the measurement results.

2. Experimental Setup and Procedures

A 3-inch diameter 2 wt % Ga-doped ZnO (GZO) sputtering target was used for the experiments, DCMS was performed in pure argon at a pressure of 1 Pa. The distance between the aperture of the RFEA head and the target surface was kept at about 40 mm.

The RFEA head consists of three grid electrodes (ER: electron repeller, D: discriminator, CR: collector repeller) and C: collector electrode. By applying the appropriate voltage to each electrode, the energy of charged particles in the plasma can be discriminated and detected; by differentiating the current waveform of C by the potential of D, the EDF of the ions is obtained. For the EDF measurement of negatively charged particles, ER was set to floating potential, D to -500V to 50V, CR to 60V, and C to 100V.

The magnetic filter is a square ring-shaped iron core with a Nd-based permanent magnet or SmCo permanent magnet mounted inside. It was installed above the aperture of the RFEA head. The presence of a perpendicular magnetic field is expected to suppress the inflow of electrons into the RFEA. Heavy ions have a sufficiently large Larmor radius compared to electrons, so the influx flux of ions into the RFEA is not much affected. If the central magnetic flux density of the magnetic filter is too small, the suppression of bulk plasma electrons will be insufficient, and if it is too large, the magnetron discharge itself may be affected. Therefore, we investigated the optimal flux density for EDF measurements of oxygen negative ions by varying the central flux density of the magnetic filter in several ways.

3. Results and Discussion

In DCMS with a discharge power of 4 W and a target applied voltage of -280 V, the incident aperture position of RFEA was moved radially from the target center axis at 5 mm intervals to investigate the radial position dependence of the energy distribution function of negatively charged particles.

The radial distribution of the EDF of negatively charged particles in DCMS without a magnetic filter is shown in Figure 1. The signal peak near the D voltage of 0 V is due to the inflow flux of bulk plasma electrons and its value is about 0.8 at r = 0 mm. The radial intensity variation reflects the spatial distribution of the bulk plasma electron density. In Figure 1, the inflow flux of bulk plasma electrons is too large and the signal in the high-energy region is too weak to confirm its existence.

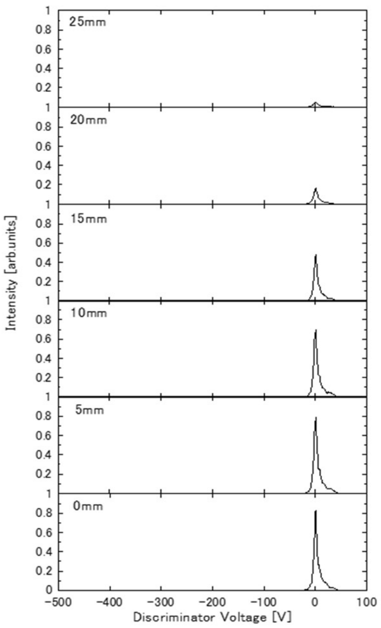

Fig. 1. Radial distribution of EDF of negatively charged particles in DCMS of GZO target with magnetic filter central flux density 0 G.

The EDF of negatively charged particles when the central flux density of the magnetic filter is 180 G is shown in Fig. 2. A signal indicating the inflow flux of bulk plasma electrons is observed near the D voltage of 0 V as in Fig. 1, but the signal peak value is about 0.0015 at r = 0 mm, which is about 1/1000 of that in Fig. 1. The significant reduction of the signal peak in the low-energy part clearly confirms the weak signal in the high-energy part. The signal peak of the high-energy part exists around the D voltage -280V and is maximum at the radial position r = 15mm. It can be seen that energetic negative ions with energy equivalent to the target applied voltage are mainly incident from the target erosion region to its counterpart.

Although not shown in the figure, when the central flux density of the magnetic filter was 550 G, the signal peak intensity of bulk plasma electrons at D voltage around 0 V was not so different from that at 180 G. However, the EDF waveform for the bulk plasma electrons became more complicated, and the radial dependence of the signal peak intensity was different from Fig. 1 and Fig. 2. The radial dependence of the signal intensity from oxygen negative ions in the high-energy region was almost the same as in Fig. 2, although the signal intensity was slightly lower than in Fig. 2. From the above, it was found that the magnetron plasma itself is affected when the central magnetic flux density of the magnetic filter is too large. It was also confirmed that the voltage and current of the magnetron discharge were slightly affected by the radial position of the RFEA. In summary, when measuring the ion energy distribution function during magnetron sputtering with magnetized RFEA, the use of a flux density of about 200 G is considered optimal.

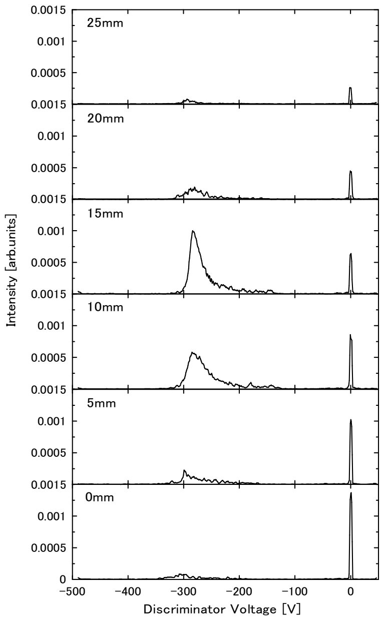

Fig. 2. Radial distribution of EDF of negatively charged particles in DCMS of GZO target with magnetic filter central flux density 180 G.

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