SPUTTERING DEPOSITION OF ITO THIN FILMS BY ECR PLASMA SOURCE

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Abstract

ITO thin film was deposited by sheet shaped electron cyclotron resonance (ECR) plasma. The plasma source is composed of slot antennas on a rectangular waveguide, permanent magnets around the slots and a target within the discharge chamber. Microwaves of 2.45 GHz are radiated from the slots and generated plasma along the waveguide. With Ar sputtering, ITO thin films were deposited with thickness uniformity of ±4.4 % within 120 nm and deposition rate of 2.75 nm/min. Its resistivity was about 4×10⁴ • cm, and its transparency was above 70 % at 550 nm without glass substrate.

I. Introduction

Indium tin oxide (ITO: ln₂O₃+SnO₂) has high transparency and low resistivity superior to other materials. It utilized as transparent electrodes for flat panel display, solar cell and electrochromic devices. Especially, rapid growth of market for flat panel displays demands for deposition of ITO thin films with large area. Magnetron sputtering is widely used to deposit ITO thin films. It achieves low resistivity by substrate heating and high deposition rate by high sputtering voltage. However, it is difficult to deposit on low temperature substrate, and to get smooth surface. Substrate heating produces large grain in the film by crystallization, and roughens the surface. High sputtering voltage induces the damage of film surface by reflected negative ion bombardment. These worsen the morphology of the film. Moreover, target utilization efficiency is not high due to its nature. Hence, magnetron sputtering is difficult to adapt large area deposition process for ITO thin films. Then, deposition method of ITO thin films with large area is extensively studied [1,2].

Electron cyclotron resonance (ECR) plasma sputtering is an attractive method for depositing indium tin oxide (ITO) thin films with smooth surface. ECR plasma produce abundant reactive species, thus it is viable to deposit ITO thin films without substrate heating. Also, the high-density plasma achieves high deposition rate with low sputtering voltage. Consequently, it reduces damage to the deposited films. High quality ITO thin films were able to deposited by plasma sputtering using a bucket type ECR plasma source [3]. However, the diameter of the ECR plasma source limits the deposited area. Hence, plasma sputtering using the bucket type ECR plasma source was difficult to deposit with large area.

On the other hand, a sheet shaped ECR plasma source is viable to deposit with large area by a linear substrate motion on a conveyor system. We developed the sheet shaped ECR plasma source for plasma sputtering [4-7]. We applied it for reactive sputter deposition of titanium nitride [4-7] and titanium oxide [8] films. In the present work, we deposited ITO thin films by this plasma source. For deposition of ITO thin films, the plasma source was partially changed from the previous work. We investigated spatial distribution of the generated plasma and the deposited film properties. Then, we estimated the possibility to ITO thin film deposition process.
2. Experimental Apparatus

Figure 1 shows the configuration of the sputtering source using ECR plasma. It has a discharge chamber \((L268 \times H45 \times D30 \text{ mm})\) with permanent magnets, slot antennas on a rectangular waveguide, a sputtering target on the discharge chamber center and a substrate holder at the downstream of the discharge chamber. Microwaves of 2.45GHz are radiated from the slot antennas on a rectangular waveguide and generated plasma along the waveguide. Radiated fields are adjusted by a T-shaped ridge on the waveguide and a plunger at the end of waveguide. Two rows of SmCo magnets are settled on the side wall of the discharge chamber. This arrangement produces ECR layer (87.5 mT) near the side wall and ring-cusp shaped magnetic fields for plasma confinement. Each magnets is cooled by water from its behind for stable operation.

The sputtering target is placed on the discharge chamber center along the waveguide for achieving high deposition rate by dense plasma. The target surface faces to the downstream substrate holder. This arrangement prevents the microwave window contamination by sputtered particles, and achieves high deposition rate due to high-density plasma and the substrate facing to the target. The target is isolated from the discharge chamber wall by ceramic target holder, and cooled by distilled water from its behind. Target with the composition of 90 wt%In_2O_3 + 10 wt%SnO_2 is used. Its size is 200mm wide and 10mm high. By biasing the target to chamber wall, target is sputtered by dense plasma around the target. Excess sputtering voltage induces local discharge between the target and holder. Then, the sputtering voltage was limited under 100V in this experiment. However, the dense plasma achieves high sputtering current density with respect to low sputtering voltage.

A substrate holder is placed on downstream with facing the target. Though the substrate did not heated externally, it heated by incoming heat flux from the plasma. The substrate temperature is controlled distance between target and substrate. In this experiment,
Table 1 Deposition condition.

<table>
<thead>
<tr>
<th>Target</th>
<th>In$_2$O$_3$ + 10 wt% SnO$_2$</th>
</tr>
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<tbody>
<tr>
<td>Working gas</td>
<td>Ar (125ccm)</td>
</tr>
<tr>
<td>Pressure</td>
<td>0.0973 Pa</td>
</tr>
<tr>
<td>Microwave power</td>
<td>400W</td>
</tr>
<tr>
<td>Target bias voltage</td>
<td>-60V</td>
</tr>
<tr>
<td>Substrate</td>
<td>Pyrex Glass</td>
</tr>
<tr>
<td>Deposition Time</td>
<td>8 hours</td>
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</tbody>
</table>

substrate holder was placed at the position where the substrate temperature did not exceed crystallization temperature of ITO.

The discharge plasma profiles at downstream of plasma source was diagnosed by single Langmuir probe method. Plasma profiles above the substrate effect on the substrate temperature. Also, excess voltage drop between plasma and substrate damage the film surface by ion bombardment. Hence, plasma properties and its spatial profile were important for the film deposition with large area.

Then, the properties of deposited films were characterized by following methods. Atomic composition and chemical bonding of the films were analyzed by X-ray photoelectron spectroscopy (XPS). Thickness and surface morphology of the films were observed with scanning electron microscope (SEM). Optical transmittance of the films in visible range was measured with multichannel spectroscope under normal incidence of xenon lamp. Electrical resistivity of the film was measured by Van der Pauw method.

3. Results and Discussion

The deposition conditions are shown in Table 1. In the present experiment, ITO thin films were deposited with only argon gas (with no oxygen flow). In this experiment, we did not optimize oxygen content in the deposited films. Also, target bias voltage was $-60$V for stable operation.

Figure 2 shows the substrate temperature dependence on distance from the target. Substrate temperature decreases with increasing distance from the target. Beyond 60 mm, substrate temperature did not exceed 140°C during 8 hour deposition. It was under the crystallization temperature of ITO. Thus

Fig.2 Substrate temperature with various distance from the target.

Fig.3 Spatial profile of plasma at 50mm downstream from the target.
the ITO thin films were deposited on this position in this experiment.

Figure 3 shows the plasma profile at the 50 mm downstream from the target surface (10 mm upstream from the substrate). The plasma density is slightly lower than that of previous study [6-8] due to the change of magnet arrangement. Electron temperature is around 5 eV within 180 mm. However, plasma profile is uniform within 180 mm at the discharge chamber exit. The difference between space potential and floating potential, i.e. substrate potential, is below 20 V. It is expected that ion bombardment effect on the depositing film surface was low in this experiment.

Figure 4 shows the spatial profiles of deposited film properties. The bottom graph shows the thickness distribution of the film. The thickness uniformity of the film is ±4.4 % within 120 mm. The deposition rate is 2.75 nm/min. The middle graph shows the transmittance and the resistivity of the film. The resistivity is about 4×10⁻³ • cm on the center and uniform within 200 mm. Also the transmittance is above 70 % in the whole area. The top graph shows the atomic concentration ratio of the film. The atomic ratio of O/In is slightly lower than the stoichiometric value of 1.5 within 120 mm.

4. Conclusions

Sheet shaped ECR plasma source was applied to the deposition of ITO thin film. With Ar sputtering, the deposited ITO thin film was thickness uniformity of ±4.4 % within 120 mm and deposition rate of 2.75 nm/min. Its resistivity was about 4×10⁻³ • cm, and its transparency was above 70 %.

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References
