Hyper Neutral Beam System for Damage Free Deposition of Indium-Tin Oxide Thin Films at Room Temperature

Suk Jae Yoo[1], Daechul Kim[1], Jong Sik Kim[1], Kyoung Suk Oh[1] and Bongju Lee[1],

Soung Woong Choi[2] and Young Chun Park[2],

Jin-Nyoung Jang[3] and MunPyo Hong[3]

[1]National Fusion Research Center, Deajeon, Korea
TEL:82-42-870-1640, e-mail: sjyoo@nfrc.re.kr.
[2]Dept. of Information Technology, Handong Global University, Pohang, Korea
[3]Dept. of Display and Semiconductor Physics, Korea University, Chungnam, Korea

Keywords : Neutral Beam, Indium-Tin Oxide, Low-Temperature Process

Abstract

A neutral beam system has been developed to produce hyperthermal neutral beams composed of indium, tin, and oxygen atoms. Using these hyper thermal neutral beams with energies in the range of tens of eV, high quality indium-tin oxide (ITO) thin films have been obtained on glass substrates at room temperature. The optical transmittance of the films is higher than 85% at a wavelength of 550 nm and the electrical resistivity is lower than 1×10^{-3} Ωcm .

1. Introduction

High quality thin film deposition of indium-tin oxide (ITO) at low temperature is a key issue in the development of organic flexible displays such as the organic light emitting diodes (OLED). Especially, top-emitting OLEDs[1] require a direct deposition of the ITO film on organic layers.

Magnetron sputtering is the most popular technique to deposit ITO films. However, this technique needs high substrate temperature, typically above 250 ℃, for the film to have good optoelectronic properties such as high transmittance and conductivity. During conventional sputter deposition processing, it is not easy to avoid plasma damage due to the high sensitivity of organic films to radiation and charged particles from plasmas: electrons, ions, and UV photons.

We have developed a neutral beam deposition technique for plasma-damage-free deposition of ITO films with good optoelectronic properties at room temperature. Instead of heating the substrate to supply reaction energies to the reactive atoms on the substrate, we produce reactive atomic beams which are already accelerated enough for the reaction energy in the neutral beam source earlier before they reach the substrate. In order to apply this technique to the deposition of the indium-tin oxide films at room temperature, a neutral beam source has been developed and performed a capability test by the deposition of the ITO thin films on glass substrates at room temperature.

2. Experimental

Our developed neutral beam source consists of an inductively coupled plasma (ICP) source, a magnetron sputter source, reflector, and limiter as shown in figure 1. The magnetron sputter source supplies solid elements such as indium and tin atoms into the plasma in which the solid elements are ionized. The ions are accelerated in the plasma sheath between the plasma and reflector, and then neutralized mainly through the Auger neutralization [2]. The neutralization efficiency depends on the impinging angle, reflector material, surface roughness, etc [3]. We use a polished stainless steel (SUS316L) plate for the reflector. The neutral

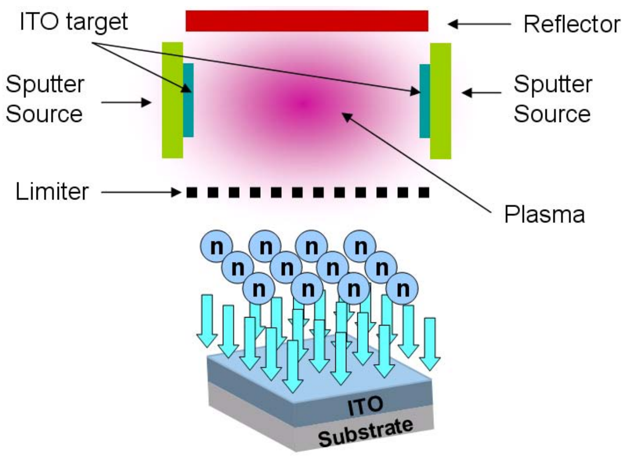

Fig. 1. Conceptual diagram of the neutral beam source.

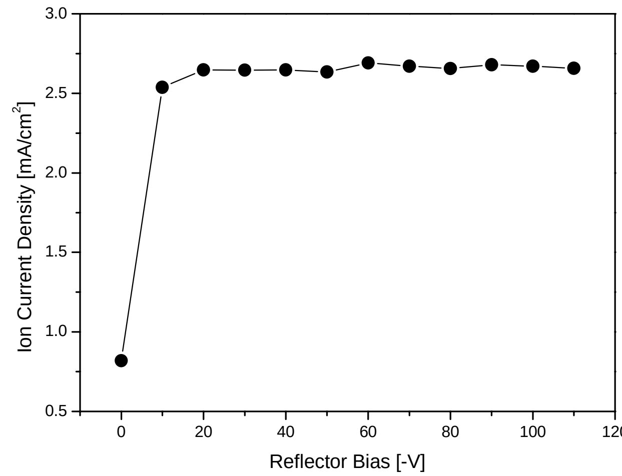

Fig. 2. Ion current density at the reflector surface as a function of the reflector bias.

beam energies are ca. a half of the impinging ion energies [4]. The accelerating potential is the sum of the plasma potential and biased voltage. For instance, in case of a bias voltage of –30 eV with a plasma potential of 10 eV, the impinging ions are accelerated up to 40 eV and then the reflected neutral atoms keep a half of the energy, i.e., ca. 20 eV.

The atoms neutralized at the reflector surface return back into the plasma and can be re-ionized. So, the plasma should be as much thinner as possible compared to the ionization mean free path of the reflected atoms. The plasma volumetric extension is limited by a limiter which is an array of permanent magnets. The limiter prevents charged particles from flowing down to the substrate.

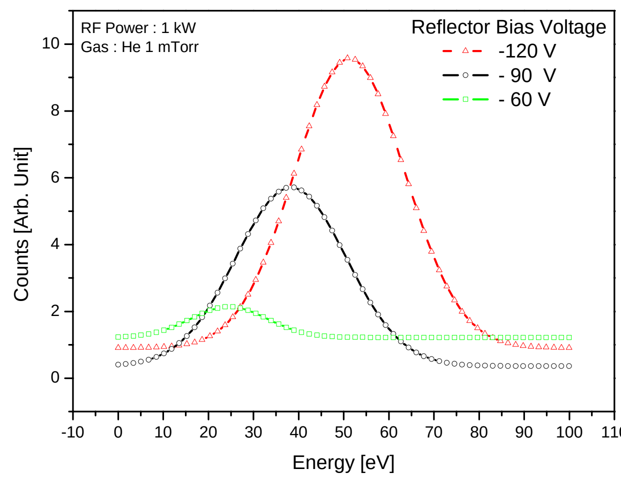

Fig. 3. Measured neutral beam energy distribution as a function of the reflector bias voltage.

3. Results and discussion

The measured ion current density at the reflector surface is larger than 2.5 mA/cm^2 of which about a half may be equivalent to the neutral beam flux reflected on the reflector, i.e., ca. 1.6 × 10^{16} atoms/cm^2 s. The measured ion beam current density is shown in figure 2. The ion current density J_i is not changed as the reflector bias voltage is increased over –20 V due to the relation between the plasma sheath width d and the reflector bias voltage V, i.e., [5]

$$J_i \propto \frac{V^{1.5}}{d^2} = const \quad (1)$$

The sheath width increases as the reflector bias is increased. So, the ion current density keeps a constant value. With this ion current density, the deposition rate is independent of the reflector bias voltage and obtained up to ca. 10 nm/min.

Figure 3 shows the measured neutral particle beam energy distribution as a function of the reflector bias voltage. The peak energies of the neutral particle beam are ca. 45% of the reflector bias voltage and in good agreement with the theoretical estimation.

Figure 4 shows the loss current density through the limiter. The most electrons are confined in the plasma by the limiter but some ions are lost. The ion current is much smaller than plasma current compared to Figure 2.

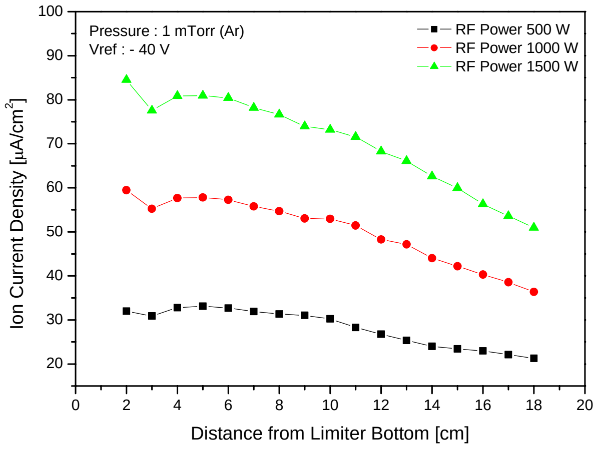

Fig. 4. Resistivity as a function of the reflector bias.

The resistivity of the ITO films deposited on a glass substrate by the neutral beam is shown as a function of the reflector bias voltage in figure 5. The resistivity is very sensitive to the neutral beam energies.

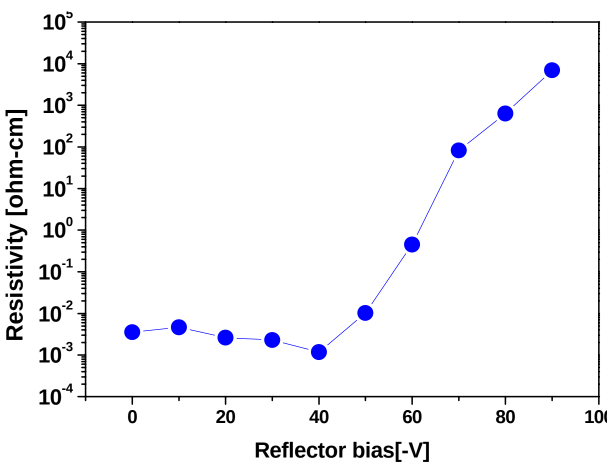

Fig. 5. Resistivity as a function of the reflector bias.

The lowest resistivity of 1 × 10^{-3} Ωcm is obtained at a reflector bias voltage of –40 V which is equivalent to a neutral beam energy of 25 ~ 30 eV. The resistivity does not almost change up to a reflector voltage of 50 V and then increases rapidly over 50 V.

The transmittance of ITO films deposited on glass substrates by neutral beam is shown as a function of the reflector bias in figure 5. The transmittance is very sensitive to the neutral beam energies. The best transmittance is obtained at a reflector bias voltage of–40 V and the transmittance is better than 85 % at a wavelength of 550 nm.

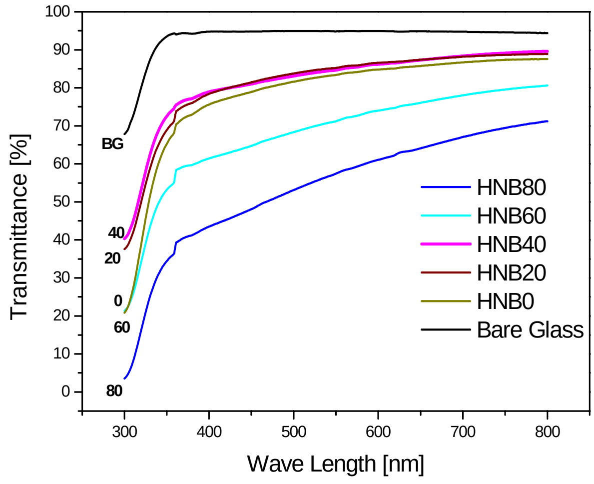

Fig. 6. Transmittance as a function of the reflector bias.

4. Summary

We can make a performance test of the neutral beam system applying it to the deposition of the ITO film at room temperature. The optoelectronic qualities, optical transmittance and electrical conductivity, are as good as those of the ITO films at higher temperature over 250 ℃. We expect also that the film should be free of the plasma damage since most of the charged particles are prevented from flowing down to the substrate. Therefore the neutral beam system can be applied to the ITO film deposition for the OLEDs as well as the flexible displays since the film quality is supposed to meet the requirement of them.

5. References

1. G. Gu, V. Bulovic, P. E. Burrows, S. R. Forrest and M. E. Thompson, Appl. Phys. Lett. **68**, 2606 (1996)
2. M. A. Cazalilla, N. Lorente, R. Diez Muino, J.-P. Gauyacq, D. Teillet-Billy and P. M. Echenique, *Phy. Rev.* B**58**, 13991, (1998).
3. B. A. Helmer and D. B. Graves, *J. Vac. Sci. Technol.* A**16**, 3502 (1998).
4. J. W. Cuthbertson, *J. Nucl. Materials* **196-198**, 113 (1992).
5. M. A. Lieberman and A. J. Lichtenberg, Principles of Plasma Discharges and Materials Processing, A Wiley-Interscience Publication, New York, p165 (1994).