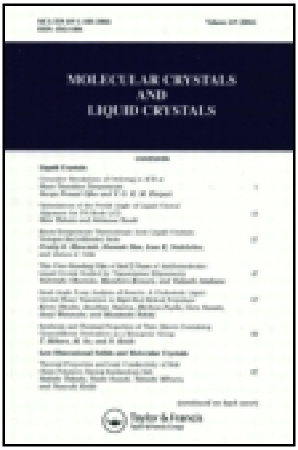

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 10 Nov 2009

Mol. Cryst. Liq. Cryst., Vol. 513, pp. 277–284, 2009

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400903217009

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The sheet resistance of the ITO films after oxygen and nitrogen plasma treatments was investigated, based on the change in the lattice characteristics such as the grain size and the lattice strain. The plasma treatment yields an increase in the grain size thence the electrical conductivity in addition to better surface morphology. The decrease in lattice strain is attributable to the increase in the grain size. The experimental results imply that the grain boundary scattering limited mobility plays an important role in the conductivity of ITO films.

Keywords: conductivity; grain size; indium tin oxide; lattice strain; plasma treatment; surface morphology

INTRODUCTION

Indium tin oxide (ITO) films have been an important material in optoelectronic devices such as solar cells and flat panel displays because of high optical transmittance in the visible region and high electrical conductivity [1,2].

Recently, many studies have been reported on modifying the surface properties of ITO in a chemical or physical method in order to improve the sheet resistance, the surface morphology and the work function [3,4].

This research was financially supported by the Ministry of Commerce, Industry and Energy (MOCIE) and Korea Industrial Technology Foundation (KOTEF) through the Human Resource Training Project for Regional Innovation.

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Physical surface treatment by oxygen, hydrogen or nitrogen has been known to be an effective way to modify the surface of ITO for optoelectronic devices [5,6].

It has been reported the carrier concentration decreases a bit by oxygen plasma treatment while it increases slightly by nitrogen plasma treatment and that this is attributed to the increase (or decrease) in the surface oxygen concentration replacing (or producing) the oxygen vacancies [3,4].

On the other hand, the decrease in mobility by the oxygen plasma treatment has been explained simply by the oxygen content in the film.

Up to date, the changes of the electro-optical properties of ITO films after plasma treatment has been explained, based on the change in the carries concentration and the mobility, due to the surface oxidation or simple oxygen addition to the ITO surface [3].

In this paper, we report that the average grain size and the lattice strain are playing an important role in the mobility and thence the electrical conductivity after the surface treatment by oxygen or nitrogen plasma.

EXPERIMENTAL

The ITO coated glass substrates used in this work were purchased from Samsung Corning Co.. The Soda lime float glass with 1.1 mm thickness was coated with a 200 Å SiO_2 buffer layer and a 1500 Å ITO film at the room temperature and 550°C, respectively. ITO was sputtered from an In_2O_3:SnO_2 (90 wt%:10 wt%) target in at ambient Ar (100 sccm)/O_2(1.2 sccm) using DC (3.26 kW) magnetron sputtering system. The sheet resistance, transmittance and the root mean square value of surface roughness (σ_{rms}) as-received ITO films was $10\,\Omega/\gamma$, 86% and ~3.09 nm, respectively.

Prior to the plasma treatment, the substrates were ultra sonically cleaned in diluted detergent for 20 min, followed by rinsing in de-ionized water. For the plasma treatment, the cleaned ITO substrate were exposed to oxygen or nitrogen plasma in a parallel plate type plasma reactor biasing with a RF power of 50 Watt corresponding to a power density of 1.5 Watt/cm^2. Following the surface treatment in the oxygen atmosphere of 100 ~ 900 m Torr or in the nitrogen atmosphere of 700 ~ 1100 m Torr, each sample was subjected to several thin film analysis.

The structural morphology was investigated using AFM (Digital Instrument, Nanoscope βa) and SEM (HITACHI, S-4200). Also we investigated the average grain size and the lattice strain by help of the X-ray diffractometer (PHILIPS, X'Pert PRO-MRD) using Cu-K_α radiation ($\lambda = 0.154$ nm). The sheet resistance and the mobility were

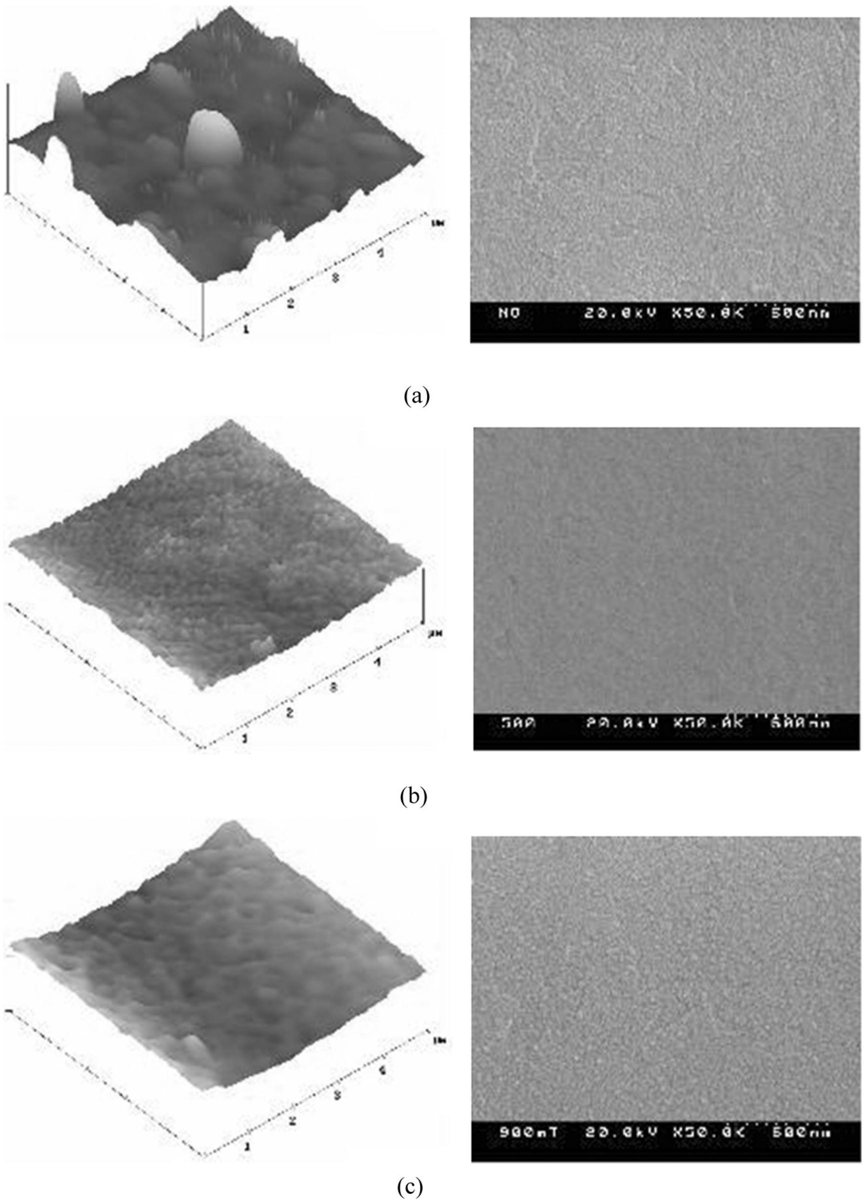

FIGURE 1 AFM and SEM images before and after plasma treatment: (a) as-deposited (b) 500 m Torr O_2- plasma treatment (c) 900 m Torr N_2-plasma treatment.

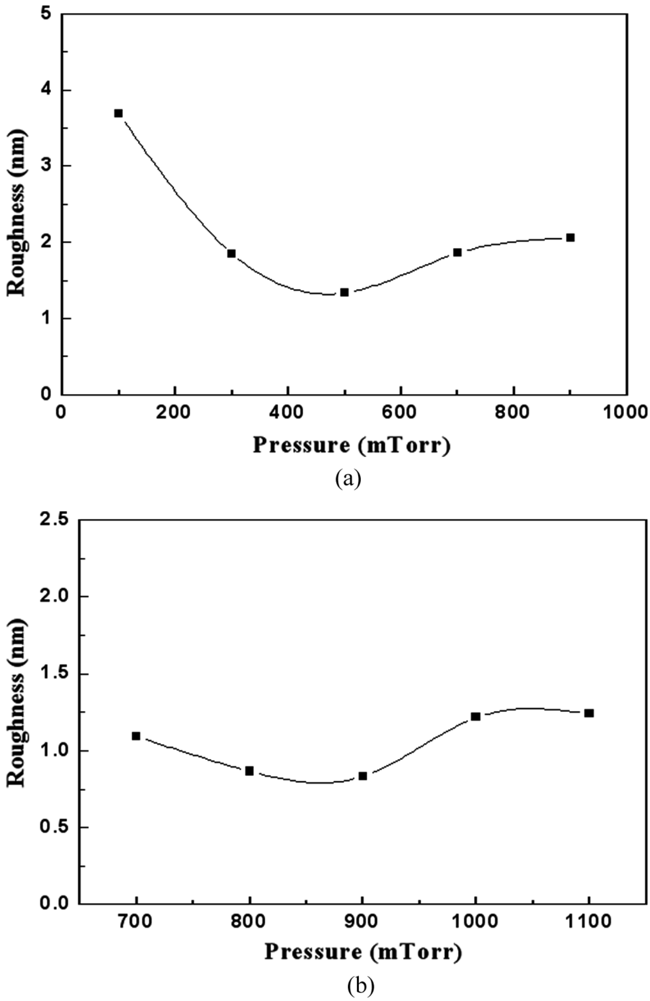

FIGURE 2 The surface roughness (σ_{rms}) of ITO films treated in (a) the O_2 plasma, (b) N_2 plasma.

measured by the four-point probe (Mitsubishi, MCP-T360) and the Hall effect measurement system (BIO-RAD, HL 55 win).

RESULTS AND DISCUSSION

Figure 1 represents AFM and SEM images before and after the plasma treatment. From the images, the surface morphologies of ITO films are

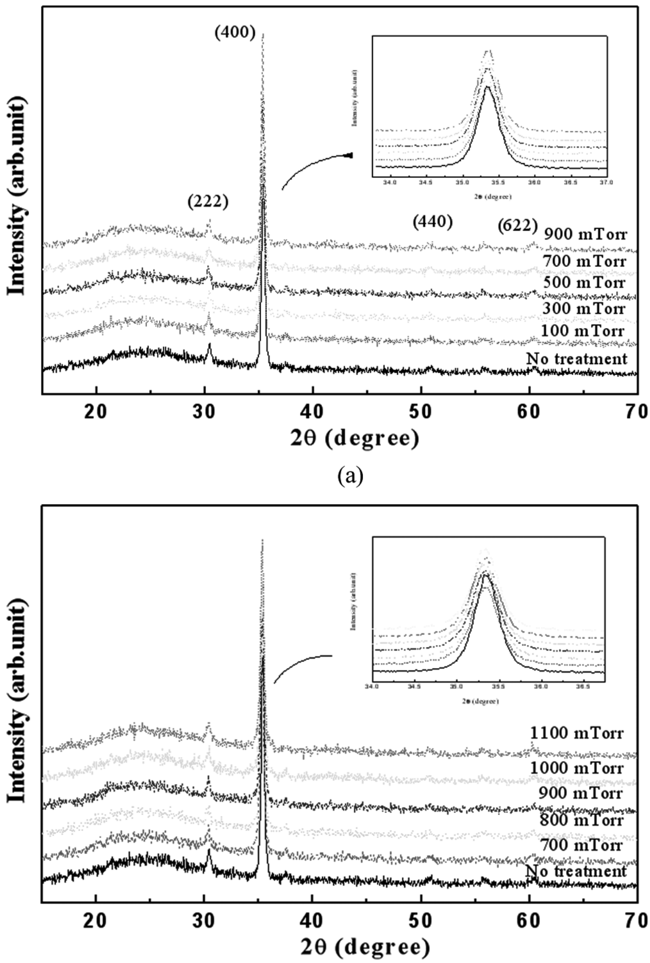

FIGURE 3 XRD patterns for ITO thin films before and after (a) O_2 plasma treatment, (b) N_2 plasma treatment.

known to be more smooth with more fine granular structure by the plasma treatment. The root mean square value of roughness (σ_{rms}) 3.09 mn of as-deposited ITO changed to 1.34 nm by oxygen plasma treatment. σ_{rms} decreased drastically to 0.83 nm in the case of the nitrogen plasma treatment.

Figure 2 show the surface roughness (σ_{rms}) of ITO films treated in (a) the oxygen and (b) the nitrogen plasma. In both cases, σ_{rms} changed

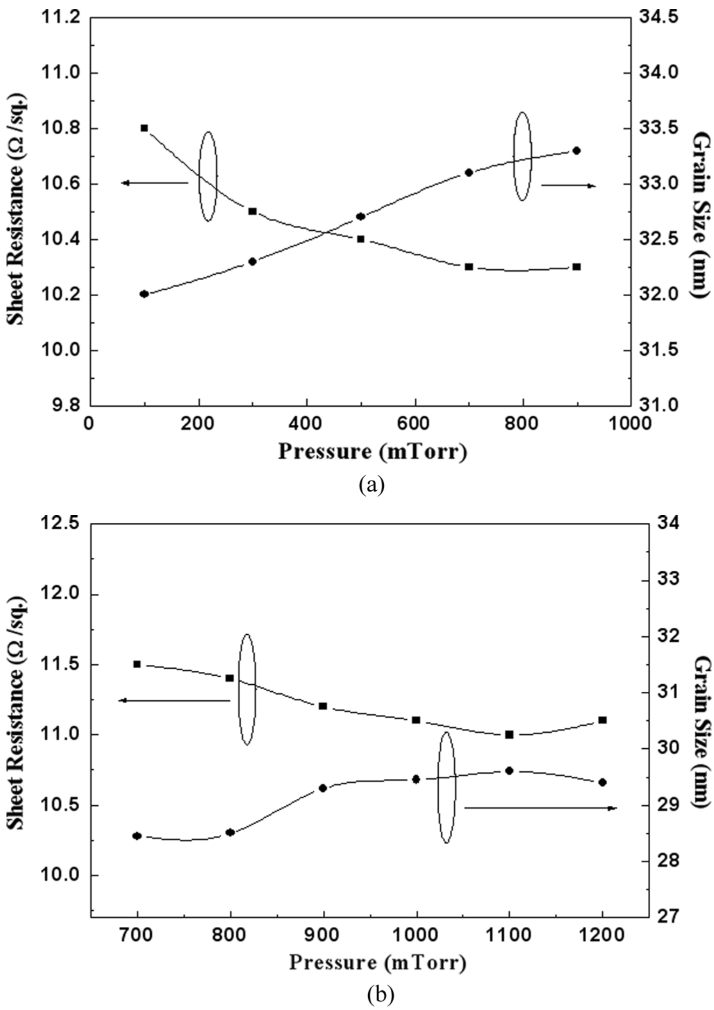

FIGURE 4 Sheet resistance and average Grain size of ITO thin films after (a) O_2 plasma treatment, (b) N_2 plasma treatment.

with gas pressures, indicating the existence of a pressure to give the minimum σ_{rms}.

XRD patterns of the plasma treated ITO films are plotted in Figure 3. The insert indicates the (400) peak from cubic ITO which is known to appear in the ITO films grown at a high power input and a low oxygen partial pressure [7]. XRD patterns reveal that the (400) peak changes little in the diffracted peaks position angle 2θ

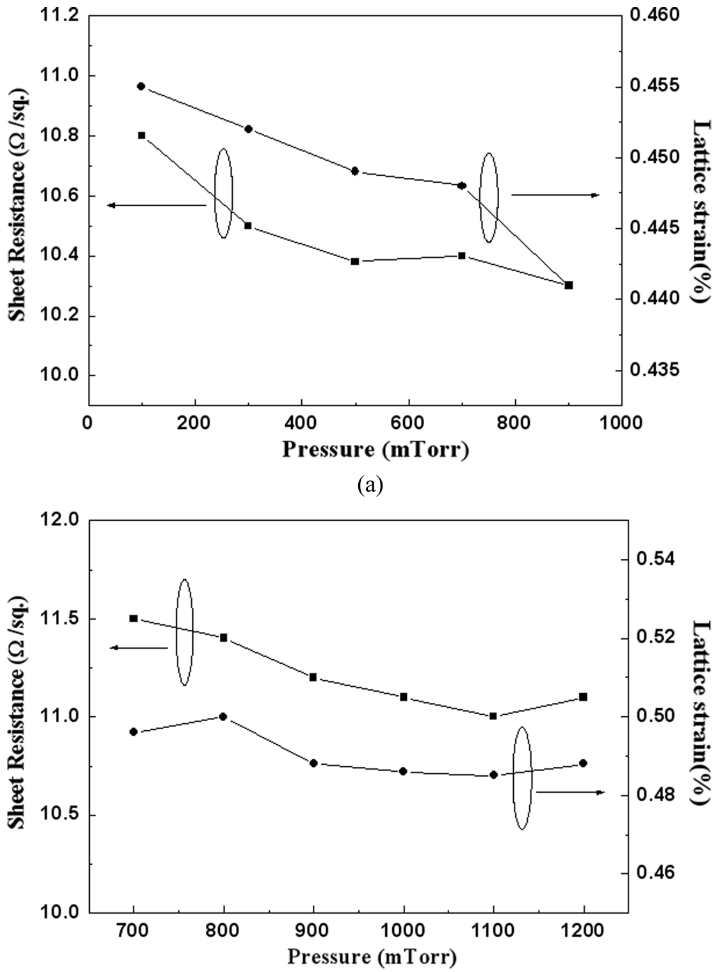

FIGURE 5 Sheet resistance and Lattice strain of ITO thin films after (a) O_2 plasma treatment, (b) N_2 plasma treatment.

and intensity after the plasma treatment. This implies no change in the bulk lattice constant and crystalline orientation of ITO films by plasma surface modification. But, as seen in the insert of Figure 3, The full width at half maximum (FWHM) has a tendency to decrease with increasing gas partial pressures of the plasma treatment. This suggests that the average grain size of polycrystalline ITO films increases by a plasma treatment.

Figure 4 represents the average grain size δ and the sheet resistance R_s after (a) oxygen plasma treatment and (b) nitrogen plasma treatment. δ obtained by using the Sherrer's formula [7] from the peak positions, form factor and FWHM data. It is evident from Figure 4 that R_s is approximately inversely related to δ. This can be explained, based on a grain boundary scattering limited mobility: if the grain boundary scattering is assumed to be the predominant scattering mechanism affecting the mobility, R_s has an inverse relationship with δ, i.e., $R_s \propto \delta^{-1}$ [7]. Thus, one would expect the change in δ by a surface modification using plasmas.

Figure 5 is plots of the lattice strain Δ and sheet resistance R_s after plasma treatment, which are obtained from an analysis of the XRD data. As seen in Figure 5, R_s is proportional to Δ. Compare with data in Figure 4, Δ has an inverse relation with δ, indicating strongly that the change in the grain size affecting the mobility and thence the sheet resistance of ITO films is due to mitigation of the lattice strain after the plasma treatment.

CONCLUSIONS

ITO films were grown by a dc magnetron sputtering system have been suffered with the surface modification using the oxygen and the nitrogen plasma with several partial pressures and the electrical properties was investigated, with regard to the lattice characteristics such as the average grain size and the lattice strain.

Experiential data suggest strongly that the decrease in the sheet resistance of the plasma treated ITO films has a deep relation with an increase in the average grain size, resulting from the reduction of the lattice strain after the plasma treatment.

In conclusion, the change in grain size related to the lattice strain after plasma treatment is an important factor affecting the electrical conductivity as much as the change in the carrier concentration.

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