Properties of ITO (Indium Tin Oxide) Thin Films Prepared by Magnetron Sputtering Using DC and Pulse Modes

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Abstract

We report on the properties of ITO thin films prepared by dc and pulse magnetron sputtering at low temperature. The electrical, optical, and surface properties of the films prepared by dc and pulse magnetron sputtering were compared. We discuss the role the pulse power plays in determining ITO thin film properties that are important in flat panel applications.

1. Objectives and Background

Flat panel displays based on flexible plastic substrates have received a lot of spotlight recently for their application in handheld mobile devices. However, it has been difficult to deposit high quality TCO (Transparent Conducting Oxide) thin films on plastic substrates due to their high temperature processes [1]. In this study we look into low temperature deposition of ITO thin films using a bipolar pulse power supply in DC and unipolar pulse modes. Moreover, we focus on the resistivity and the surface roughness of the films deposited in the pulse mode compared to the films deposited in the DC mode and discusses their application in flat panel displays.

2. Experiment

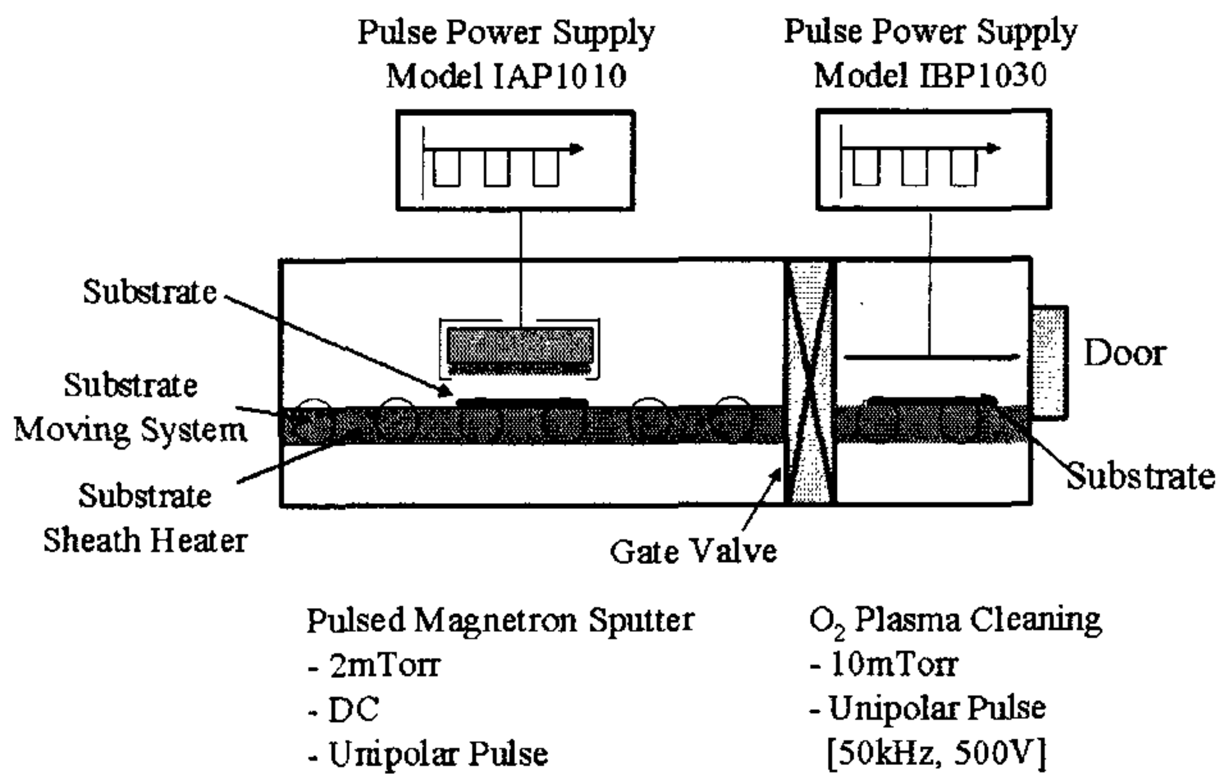
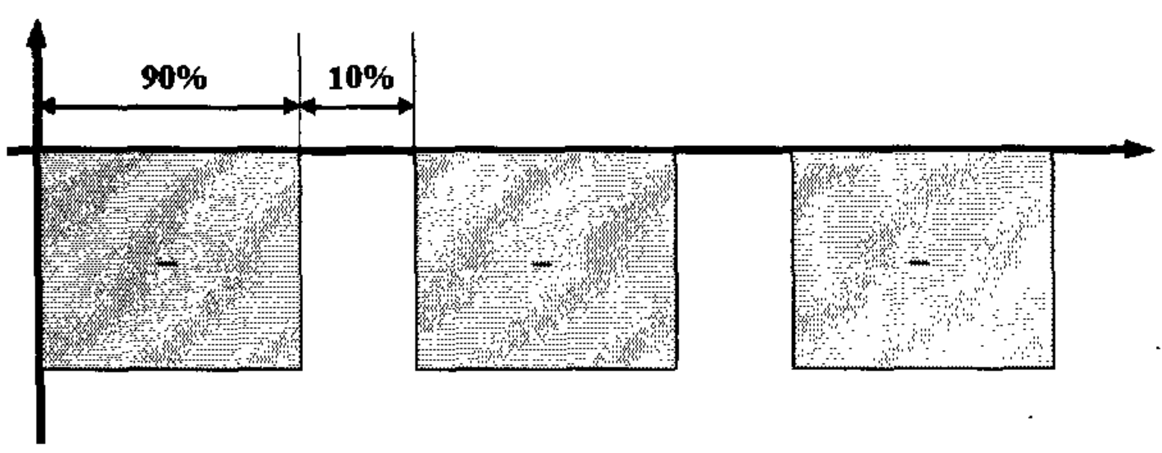
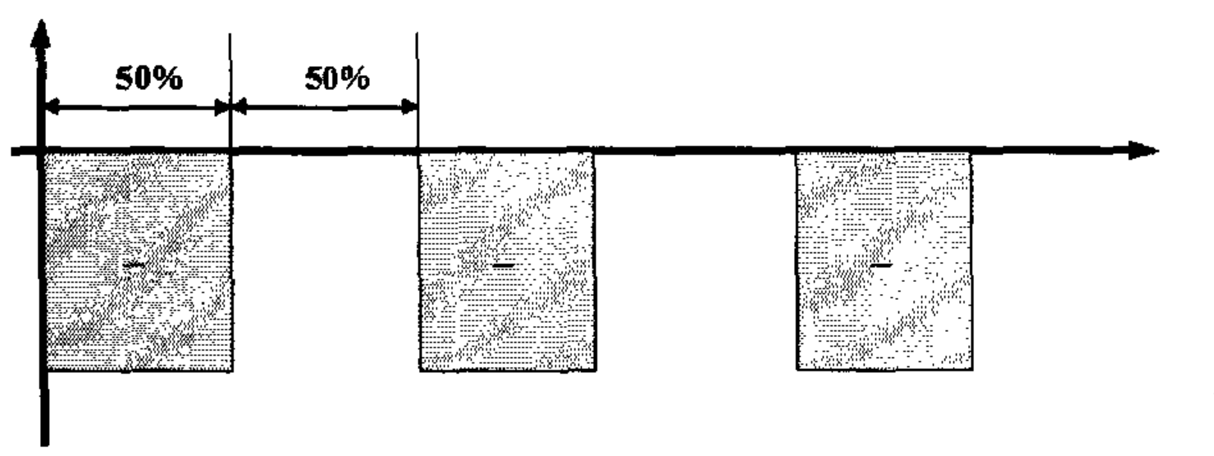


Figure 1. Single ended in-line sputter system

ITO thin films were deposited using a magnetron sputter source at DC and unipolar pulse modes in a single ended in-line sputter system shown in Figure 1. The deposition system is equipped with a substrate heater in the loading chamber, and an O_2 plasma cleaning system in the process chamber. The plasma cleaning system is used to clean the surface of the substrate prior to deposition and increase the adhesion of the film [O_2 plasma, 10mTorr, 50 kHz, 500V, unipolar power supply (IBP1030, ITM, Inc.)]. A 5" × 20"× 0.25" size rectangular ITO target (In_2O_3 90wt% : SnO_2 10wt%) of 99.2% density was used to deposit the ITO films on soda lime glass substrates. The base pressure of the deposition chamber was pumped to 2×10^{-6} Torr with a cryo pump, and the working pressure was kept constant at 2 mTorr with a gas flow rate of Ar 380 sccm and O_2 5 sccm. The effective deposition time was 20sec. The sputtering power was 2kW for all the samples. For the films deposited in the unipolar pulse mode, the frequency was 50 kHz with two different duty cycles as depicted in Figure 2. (IAP1010, ITM, Inc.). The ITO films were deposited at a relatively low substrate temperature of 70°C. The ITO films were analyzed using a surface profiler, spectrophotometer, 4 point probe, XRD (X-Ray Diffraction) and AFM (Atomic Force Microscopy).



(a) 90% (-) duty unipolar pulse



(a) 50% (-) duty unipolar pulse

Figure 2. Voltage waveforms used in this study

3. Results and Discussion

The electrical resistivity of the deposited ITO films is shown in Figure 2. All the ITO films showed specific resistivity values between 6.4×10^{-4} Ω cm and 7.6×10^{-4} Ω cm. The films deposited in the unipolar pulse mode at 50 kHz frequency with 90% (-) duty cycle exhibited the lowest resistivity.

Figure 3. shows the surface roughness of the ITO films. The pulse mode deposited films showed a much lower surface roughness than the DC mode deposited films, with the ITO film deposited in the 50 kHz, 90% (-) duty pulse mode showing the lowest surface roughness of 2.63 nm, making it the most desirable for OLEDs [2].

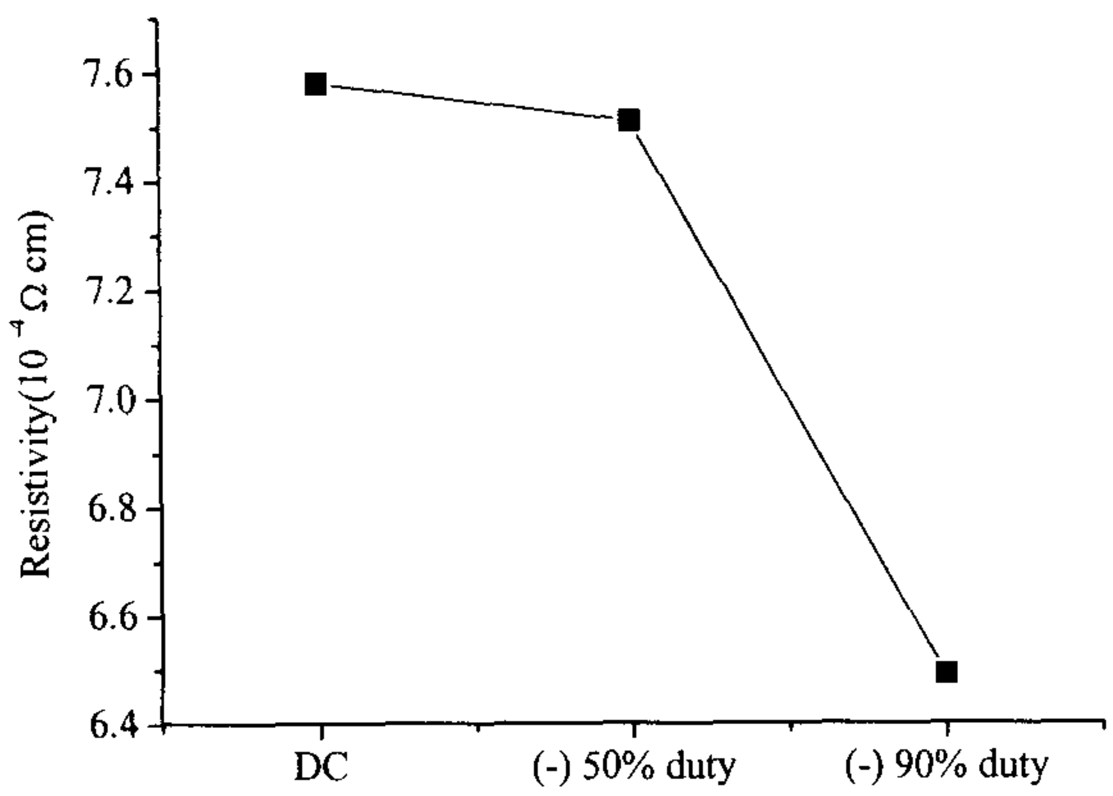
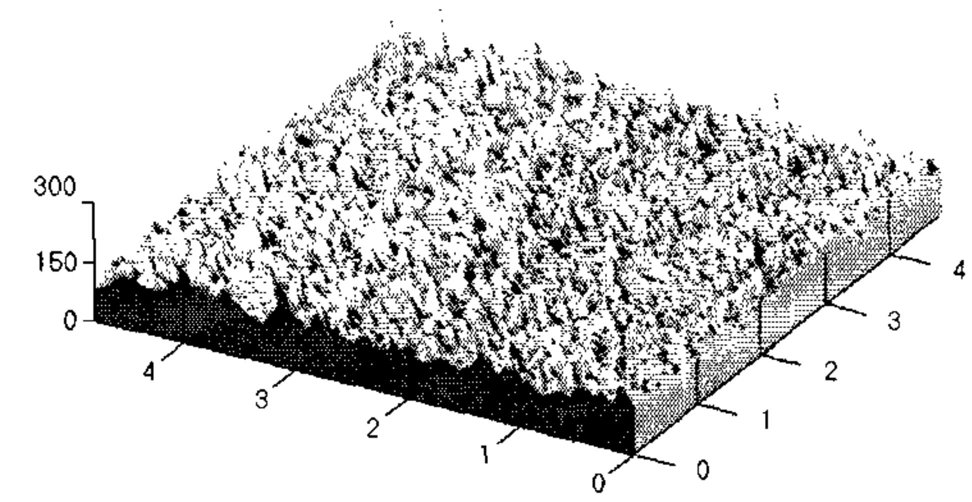
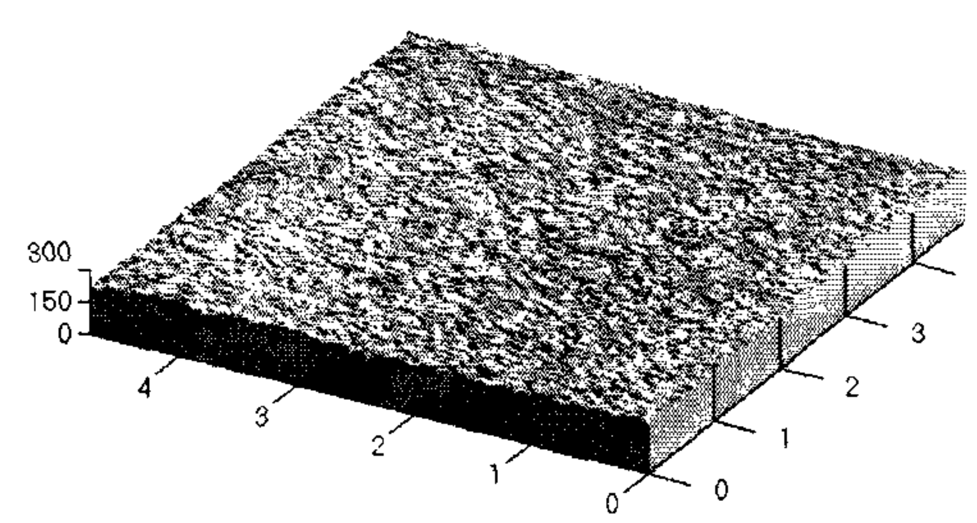


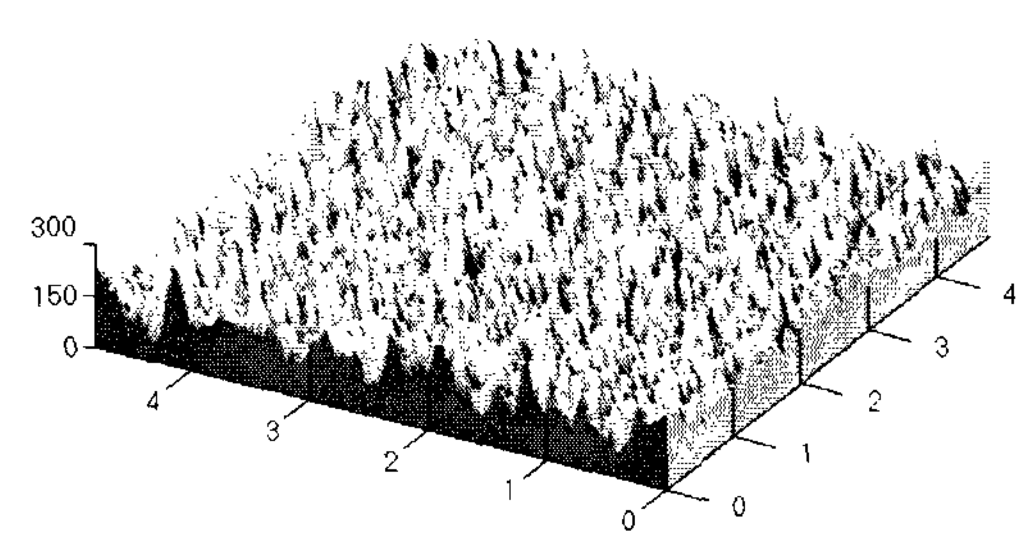
Figure 3. Resistivity of the ITO films



(a)Unipolar 90% duty, 2.63nm rms roughness



(b)Unipolar 50% duty, 2.65nm rms roughness



(c)DC, 4.37 rms roughness

Figure 4. Surface roughness of the ITO films

Quite a few of the film properties, such as packing density, adhesion, and structure depend on the adatom mobility during the deposition process. In general, high adatom mobility during the deposition process of ITO films results in a film with lower resistivity by phase transition from the amorphous state to the poly-crystalline state [2]. Typically this high adatom mobility is achieved through heating of the substrate to temperatures of 150℃ and more. However with our restriction of low substrate temperatures, we had to find another way to increase the adatom mobility for better film properties. This can be achieved by the flux of energetic particles to the substrate. By using a pulsed power supply for the sputtering process we were able to increase the potential difference between the plasma and the grounded substrate which enhances the energy transfer to the substrate by ion bombardment [3]. This means that the increase in the adatom mobility due to the ion bombardment enabled the growth of a denser, amorphous film for lower resistivity and surface roughness. The DC mode deposited films, with weaker ion bombardment than the pulse mode deposited films, would have formed a more porous film, thus exhibiting a higher resistivity and surface roughness.

Figures 5. shows the XRD spectrum of the deposited films. All the films deposited in the pulse mode seem to be almost amorphous like with very weak intensity peaks. This can be expected since ITO films make the transition from the amorphous phase to the crystalline phase with rising deposition temperature, while the ITO films in this study were deposited at a relatively low substrate temperature of 70°C. However the films deposited in the DC mode show intensity peaks which are a little bit stronger than the pulse mode deposited films. This is because the more energetic ion bombardment in the pulse mode deposition restricted the growth of micro crystalline structures and resulted in a more densely packed amorphous like film.

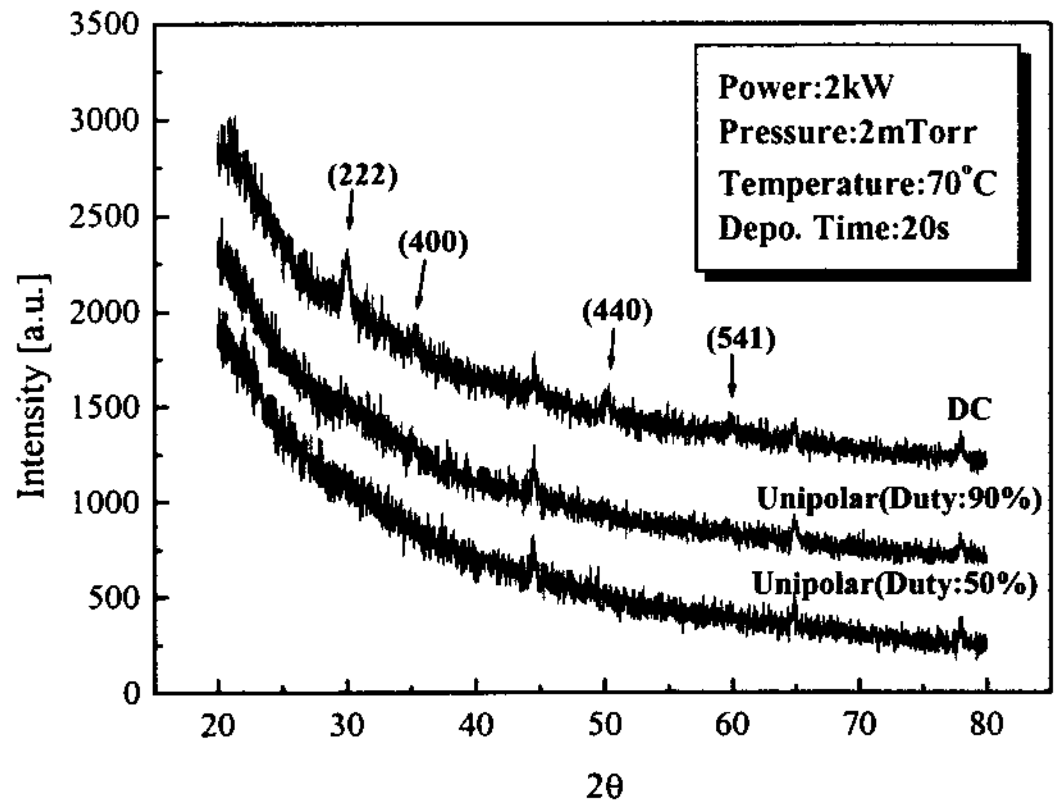


Figure 5. XRD spectrum

Figure 6. shows the optical transmittance graph for the deposited films. The films show typical transmittance curves of transparent conducting oxides, with the film deposited in the unipolar pulse mode with a 90% duty cycle exhibiting the highest transmittance at 550 nm [5].

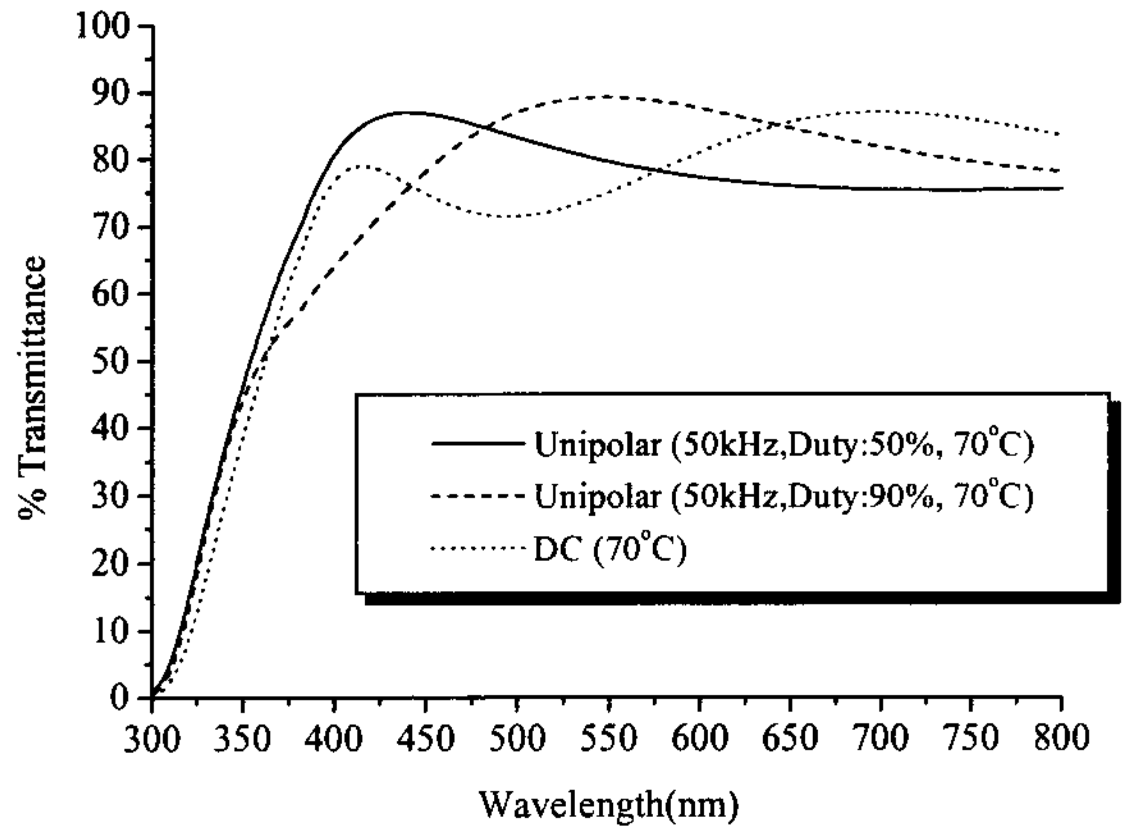


Figure 6. Optical transmittance

4. Conclusion

ITO thin films were deposited on glass substrates at 70°C substrate temperature using a single ended in-line sputter system with a magnetron sputter using DC and unipolar pulse mode power. The ITO film deposited in the 50 kHz unipolar pulse mode with 90% (-) duty had the best specific resistivity and surface roughness characteristics making it the best candidate for use in flat panel display applications.

5. Acknowledgement

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6. References

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