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

Preparation of In_2O_3-ZnO (IZO) Thin Film on Glass Substrate for Organic Light Emitting Device (OLED)

Jeong Soo Hong [a], Sang Mo Kim [a], Sang Joon Park [b], Hyung Wook Choi [a] & Kyung Hwan Kim [a]

[a] Department of Electrical Engineering, Kyungwon University, Seongnam, Korea

[b] Department of Chemical Engineering, Kyungwon University, Seongnam, Korea

Version of record first published: 19 Apr 2010

To cite this article: Jeong Soo Hong, Sang Mo Kim, Sang Joon Park, Hyung Wook Choi & Kyung Hwan Kim (2010): Preparation of In_2O_3-ZnO (IZO) Thin Film on Glass Substrate for Organic Light Emitting Device (OLED), Molecular Crystals and Liquid Crystals, 520:1, 19/[295]-27/[303]

To link to this article: http://dx.doi.org/10.1080/15421401003608287

Mol. Cryst. Liq. Cryst., Vol. 520: pp. 19/[295]–27/[303], 2010

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421401003608287

Preparation of In_2O_3-ZnO (IZO) Thin Film on Glass Substrate for Organic Light Emitting Device (OLED)

JEONG SOO HONG,[1] SANG MO KIM,[1] SANG JOON PARK,[2] HYUNG WOOK CHOI,[1] AND KYUNG HWAN KIM[1]

[1]Department of Electrical Engineering, Kyungwon University, Seongnam, Korea
[2]Department of Chemical Engineering, Kyungwon University, Seongnam, Korea

The low resistivity and excellent surface smoothness of IZO makes it a good candidate for high-quality transparent conducting electrodes in OLEDs. The deposition of IZO thin film by Facing Targets Sputtering system on glass substrate as function of substrate temperature. The device structure of the IZO anode is configuration of Al/LiF/Alq_3/TPD/IZO. The electrical and optical properties of the as-doped IZO thin film were evaluated with UV/VIS spectrometer, Hall Effect measurement, XRD, AFM, FESEM. The resistivity and transmittance of the as-deposited films were 25.3 Ω/sq and above 80% in the visible range. The performance of OLED was evaluated by J-V-L measurements.

Keywords FTS; IZO; OLED

Introduction

Organic light-emitting diodes (OLEDs) have been widely studied because they have many advantages such as simple structure, high brightness, and self-emission. Recently, OLED-based devices have been used in flat panel displays, computer monitors, portable applications, advertising, and other information display devices. To improve the efficiency and stability of OLED, high quality OLED materials are required. Especially important are the transparent conductive oxides (TCOs) with a high transmittance and good electrical conductivity that could be used as OLED electrode materials [1]. Among various TCO materials, indium tin oxide (ITO) has good electrical conductivity ($<10^{-4}$ Ω-cm), wide optical band gap (>3.5 eV) and high transmittance (>80%); so that it has been widely used as anode materials in OLED devices [2]. However, film-cracks caused by the inside stress of the crystalline

Address correspondence to Kyung Hwan Kim, Kyungwon University, Bokjeong-dong, Sujeong-gu, Seongnam 461-701, Korea (ROK). Tel.: (+82)31-750-5491; Fax: (+82)31-750-5491; E-mail: khkim@kyungwon.ac.kr

structure of the ITO thin film and rough surface of ITO thin film resulted in decrease in the efficiency and stability of OLED devices [3]. Therefore the TCO materials for OLED anode should have an good surface smoothness and amorphous structure. Recently, indium zinc oxide (IZO) has been suggested as a condidate substitution materials for OLED anode. The IZO thin film has several advantages such as: good conductivity, high optical transparency, and low deposition temperature. It was also reported that IZO films had improved surface smoothness and high amorphous etching rate as compared to the ITO thin film when applied to OLED device [4–5].

Thin films are deposited using a variety of techniques such as radio frequency sputtering [6], pulsed laser deposition (PLD) [7], and by spray pyrolysis [8]. We deposited an IZO thin film on a glass substrate by a facing target sputtering (FTS) system as a function of various substrate temperatures. The FTS system was designed to array two sheets of targets facing each other. Structurally, the energetic charge particles are restricted by the magnetic force within the plasma and are composed of the high-density plasma that is between the targets. The substrate is located in a plasma-free area apart from the center of plasma. The plasma-free area suppresses the bombardment of the high energy particles to the substrate [9–11]. To confirm the suitability of the IZO thin film for an OLED anode, we investigated an OELD with an anode of IZO thin film deposited by the FTS system.

Experimental

Before the deposition, the substrate was ultrasonically cleaned with de-ionized water (D. I. Water) for 15 minutes and then with isopropyl alcohol (IPA) for 15 minutes. It was then dried with N_2 gas. The deposition chamber was then evacuated to a pressure of 2.2×10^{-6} Torr. The IZO thin film was prepared with a 1 mTorr working pressure and with 0.08A of input current. More details of the sputtering conditions are shown in Table 1.

Figure 1 shows the schematic diagram of the FTS system. The device structure has the configuration of IZO (1500 Å)/TPD (400 Å)/Alq_3 (700 Å)/LiF (10 Å)/Al (700 Å). The substrate was located 90 mm away from the common axis of the targets and at a distance of 50 mm (target to target). The thickness of the

Table 1. Sputtering condition

Deposition parameter	Sputtering condition
Target	IZO (In_2O_3 90 wt%:ZnO 10 wt%)
$D_{T\text{-}S}$	90 mm
$D_{T\text{-}T}$	50 mm
Substrate	Soda-lime Glass
Base pressure	2.2×10^{-6} Torr
Working Pressure	1 mTorr
Ar:O_2 Gas flow ratio	0.3
Input Power	0.08A
Temperature	50–250°C

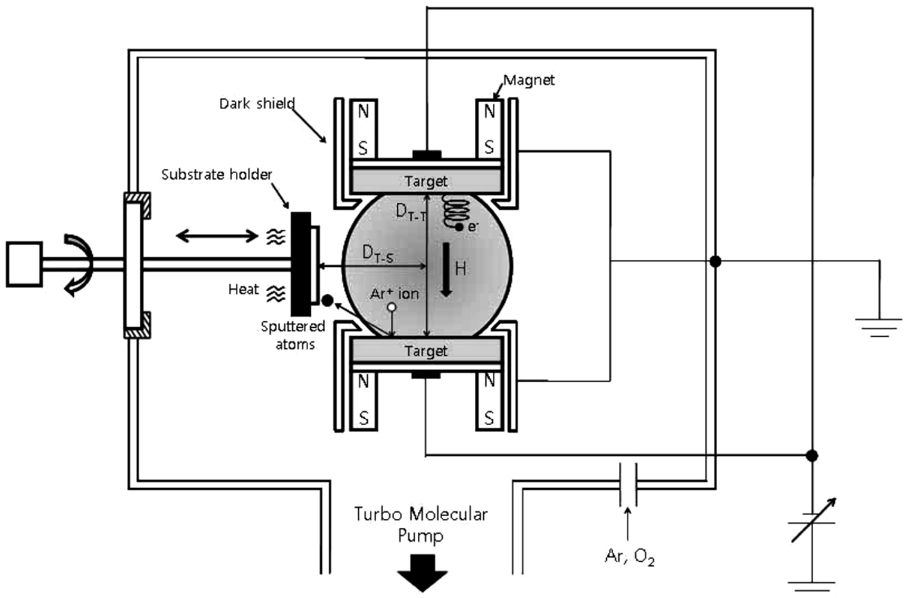


Figure 1. Schematic of facing targets sputtering (FTS) system.

IZO thin film was fixed at 150 nm. The IZO thin film was then deposited on the glass substrate as a function of temperature. The electrical and structural properties of the as-deposited IZO thin films were then examined by a hall-effect measurement, and by using an atomic force microscope (AFM), an X-ray diffractometer (XRD), and a field emission scanning electron microscope (FESEM). The optical property was measured by an UV-VIS spectrometer. The bottom-type OLED structure is shown in Figure 2. The performance of the OLED device such as the operating voltage and its efficiency were evaluated by J-V-L (current density-voltage-luminance) measurements.

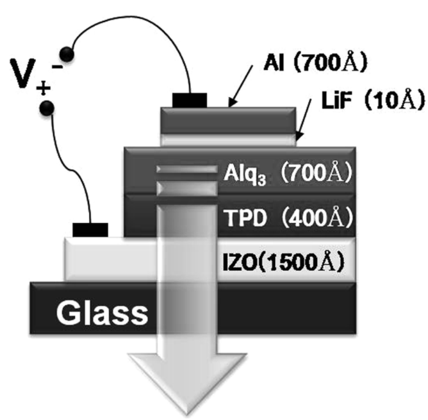


Figure 2. Structure of organic light emitting device (OLED).

Results and Discussion

Figure 3 shows the electrical properties of the IZO thin films as a function of substrate temperature. The lowest sheet resistivity was 25.3 Ω/sq at 150°C. It's little bit higher than conventional ITO-coated glass substrate (20 Ω/sq) [12]. But after preparing the IZO thin film, we expected to be improve the electrical properties by additional process like as plasma treatment and post anealing. The resistivity increased above a 150°C substrate temperature. This is because the resistivity depends upon the carrier mobility. With an increase in the substrate temperature, the intrinsic oxygen of the thin film decreased because of higher vapor pressure and lower boiling point than that of In and Zn. This also lead to an increased number of oxygen vacancies in the films. As a result, the carrier mobility was increased with the increase of the oxygen vacancies [13].

Figures 4 and 5 show the optical transmittance and the optical band-gap energy of the IZO thin films. The transmittance of all of the deposited-IZO films was shown to be at above 80% in the visible range. We observed a slight shifting of the absorption region of the IZO thin films with increasing substrate temperature. This absorption shift is caused by the increased carrier concentration due to the increase (by Burstein-Moss effect) of the oxygen vacancies [14]. As the carrier concentration increases, the band-gap energy of the films is widened [15].

Figure 6 shows the X-ray diffractometer (XRD) patterns of the IZO thin film as a function of substrate temperature. All of the prepared IZO thin films showed a broad pattern without a clear peak until the temperature increased to 250°C. It was reported that Zn^{2+} is the reason for the decreased crystalline attribute in the In_2O_3 [13]. That can be explained by the fact that when the IZO thin film forms its crystalline structure due to the diffusion of atomic, Zn^{2+} interferes with its structural relocation, because of the high-energy barrier inherent to Zn^{2+} [17].

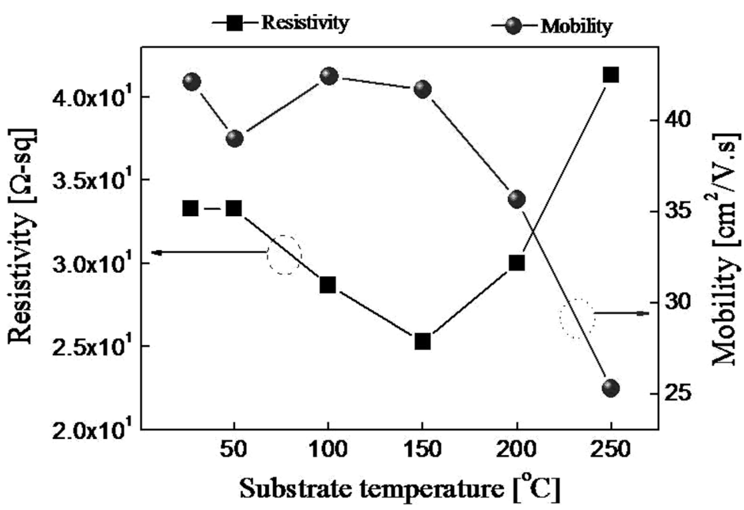


Figure 3. Electrical properties of IZO thin films prepared on glass substrate as function of substrate temperature.

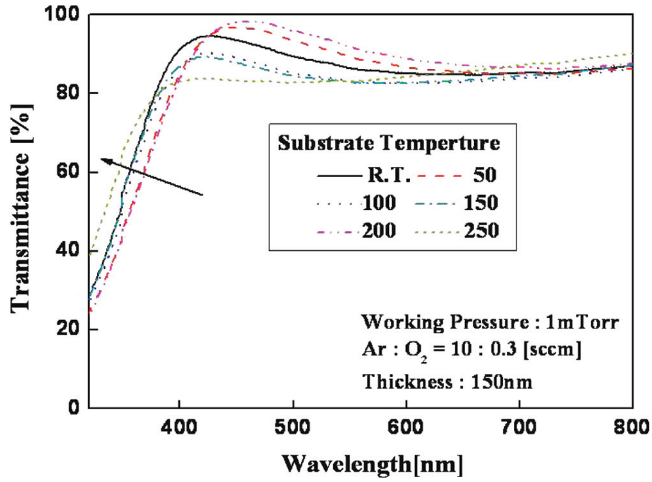


Figure 4. Optical transmission of IZO thin films prepared on glass substrate as function of substrate temperature.

Figure 7 shows the atomic force microscope (AFM) images and RMS (root-mean-square) values of the IZO thin films. A surface roughness (<1 nm) is detrimental to an OLED anode. The localized high electric fields induced by the surface roughness of the film can cause an unexpected current flow leading to a dark spot formation or a short device operation time [18]. Conventional ITO films have a 2 nm surface roughness [19]. But, as stated, the OLED anode needs to be below 1 nm surface roughness. In Figure 7, the RMS values of the IZO thin films were less than the required 1 nm surface roughness, regardless of the substrate temperature.

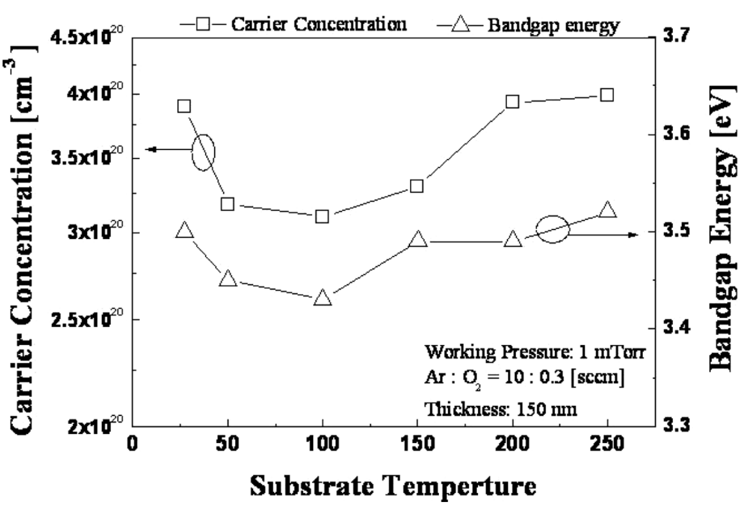


Figure 5. Carrier concentration and band-gap energy of IZO thin films prepared on glass substrate as function of substrate temperature.

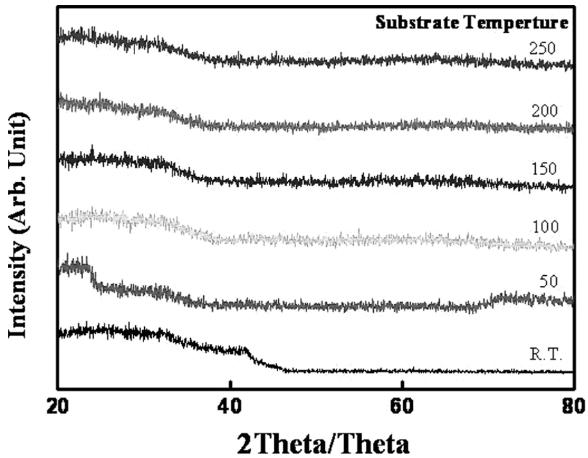


Figure 6. XRD pattern of IZO thin films prepared on glass substrate as function of substrate temperature.

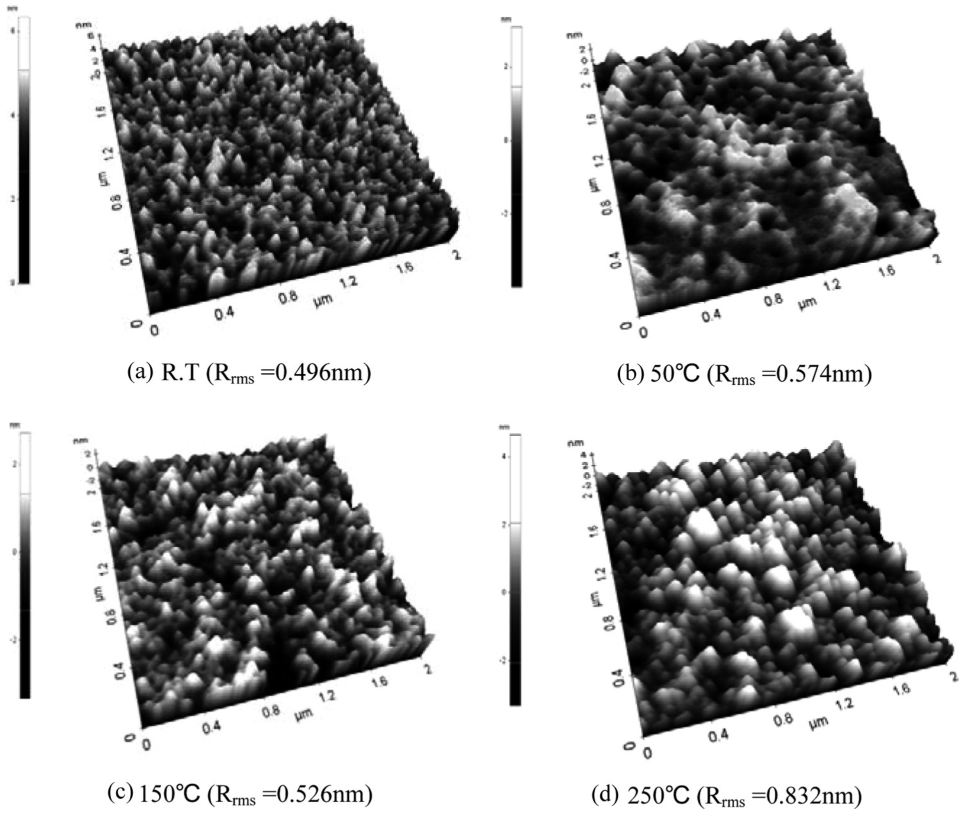


Figure 7. AFM images of IZO thin films prepared on glass substrate as function of substrate temperature.

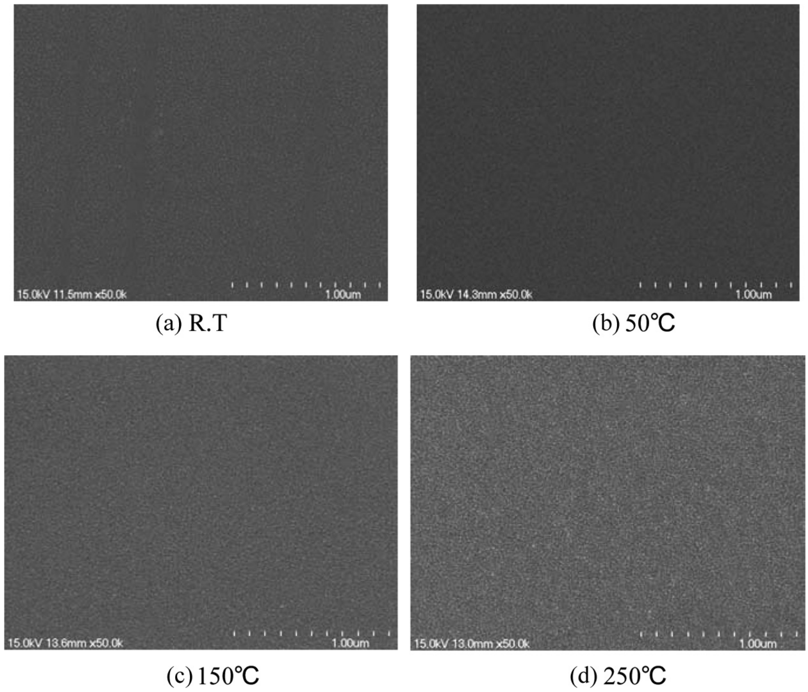
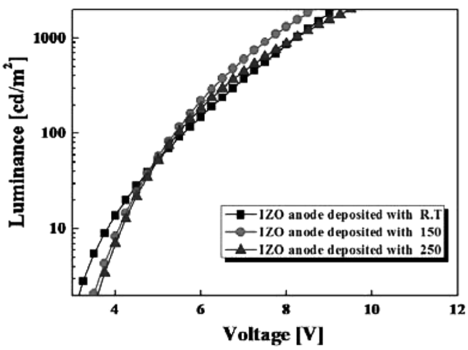


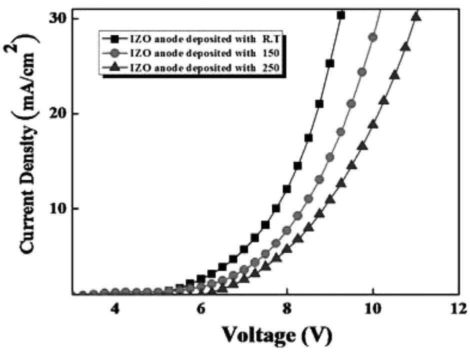
Figure 8. FESEM image of IZO thin film prepared on glass substrate as function of substrate temperature.

Figure 8 shows the FESEM image of IZO thin films as function of substrate temperature. As shown in the figure, prepared IZO thin films with substrate temperature showed very smooth surface without defects such as pinholes and cracks. In the case of ITO thin films, additional process was needed for the surface that became rough due to crystallization to become smoother [20]. However the IZO thin film has a smoother surface than the ITO thin film, therefore additional process is not needed. For this reason, it was known that the IZO thin films, a replacement of ITO, are more suitable for OLED anode.

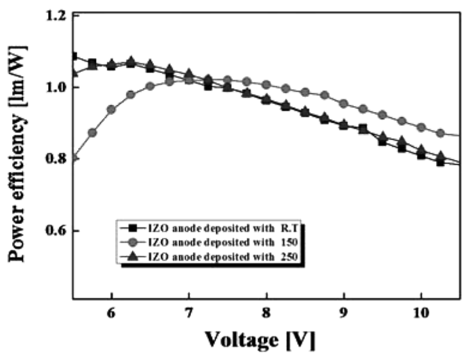
After the evaluation of the IZO thin films properties, we concluded that the IZO thin film deposited at 150°C is suitable for an OLED anode. To compare the performance of OLED based on IZO anode properties, we prepared an OLED and placed it on the IZO thin film, prepared with room temperature, 150°C and 250°C, respectively. We measured the performance of OLED. Figure 9 shows the luminance, current density and power efficiency of OLED fabricated on IZO anode. In the luminance-voltage characteristic, the OLED fabricated on IZO anode prepared at 150°C substrate temperature showed the most excellent performance. And the OLED fabricated on IZO anode deposited at 150°C substrate temperature showed high efficiency in power efficiency-voltage characteristic. The result of the experiment can be explained by the relation between the luminescence efficiency of OLED and the resistivity (Ω-cm) of IZO anode. The decrease in luminescence efficiency is caused by the decrease in the luminescence uniformity due to the high resistivity of IZO anode [21].



(a) Luminance versus Voltage



(b) Current density versus Voltage



(c) Power efficiency versus Voltage

Figure 9. The performance of the OLED fabricated on IZO thin film.

Conclusions

In this study, we prepared IZO thin films for an OLED anode on a glass substrate at various substrate temperatures by the FTS system. The as-deposited IZO thin films showed a high transmittance, above 80%, in the visible range and a low resistivity. Also, the IZO thin film showed an amorphous structure.

The resistivity (25.3 Ω/sq) and the roughness ($R_{rms} = 0.526$ nm) of IZO thin film was most excellent at 150°C substrate temperature. And the result of investigation about the properties of OLED fabricated on IZO anode prepared with substrate temperature is that the properties of OLED was most excellent at 150°C substrate temperature.

Therefore it is concluded that the performance of OLED could be attributed to the properties of the IZO thin film.

Acknowledgment

This study was supported by the kyungwon University Research Fund in 2009.

References

[1] Kim, S. M. & Kim, K. H. (2007). *Jounal of the Korean Physical Society*, *51*, 3.
[2] Jiang, X., Wong, F. L., Fung, M. K., & Lee, S. T. (2003). *Apply. Phys. Lett.*, *83*, 1875.

[3] Hong, J. S., Rhee, B. R., Kim, H. M., Je, K. C., Kang, Y. J., & Ahn, J. S. (2004). *Thin Solid Films*, *467*, 258.
[4] Huang, Z. H., Zeng, X. T., Sun, X. Y., Kang, E. T., Fuh, Jerry Y. H., & Lu, L. (2009). *Thin Solid Films*, *517*, 17.
[5] Rim, Y. S., Kim, S. M., & Kim, K. H. (2009). *Jounal of the Korean Physical Society*, *54*, 3.
[6] Ramamoorthy, K., Kurma, K., Chandramohan, R., Sankaranarayanan, K., Saravanan, R., Kityk, I. V., & Ramasamy, P. (2006). *Optics Communication*, *262*, 1.
[7] Lim, W. T., Stafford, L., Wright, J. S., Vossa, L. F., Khanna, R., Song, J., Park, J. S., Heo, Y. W., Lee, J. H., Kim, J. J., Norton, D. P., & Pearton, S. J. (2007). *Applied Surface Science*, *253*, 30.
[8] Lee, D. Y., Lee, J. R., Lee, G. H., & Song, P. K. (2008). *Surface and Coatings Technology*, *202*, 22.
[9] Kim, K. H. (2007). *J.C.P.R.*, *8*, 1.
[10] Kim, S. M., Rim, Y. S., Keum, M. J., & Kim, K. H. *Journal of Electroceramics*, DOI 10.1007/s10832-008-9452-z.
[11] Rim, Y. S., Kim, S. M., Choi, H. W., Park, S. J., & Kim, K. H. (2008). *Colloids and Surfaces*, 313–314.
[12] Lee, Y. J., Kim, J. H., Jang, J. N., Yang, I. H., Kwon, S. N., Hong, M. P., Kim, D. C., Oh, K. S., Yoo, S. J., Lee, B. J., & Jang, W. G. (2009). *Thin Solid films*, 517.
[13] Minami, T., Yamamoto, T., Toda, Y., & Miyata, T. (2000). *Thin Solid Films*, *373*, 189.
[14] Jung, Y. S., Seo, J. Y., Lee, D. W., & Jeon, D. Y. (2003). *Thin Solid Films*, 445.
[15] Shin, H. H., Kang, S. J., & Yoon, Y. S. (2007). *Journal of the Korean Institute of Electronics SD*, *44*, 5.
[16] Kim, N. O., Kim, H. G., & kim, W. S. (2001). *Journal of the Korean Institute of Electrical and Electronic Material Engineering*, *44*, 8.
[17] Huang, Z. H., Zeng, X. T., Sun, X. Y., Kang, E. T., Fuh, J. Y. H., & Lu, L. (2009). *Thin Solid Films*, *571*, 17.
[18] Liu, G., Kerr, J. B., & Johnson, S. (2004). *Synthetic Metals*, *144*, 1.
[19] Zhang, B., Dong, X., Xu, X., Wang, X., & Wu, J. (2007). *Material Science in Semiconductor Processing*, *10*, 6.
[20] Bae, J. H. & Kim, H. K. (2008). *Thin Solid Film*, *516*, 21.
[21] Mu, H., Li, W., Jones, R., Steckl, A., & Klotzkin, D. (2007). *Journal of Luminescence*, *126*, 255.