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Fabrication of thin film transistor using magnesium zinc oxide (MgZnO) as a semiconductor layer by magnetron sputtering technique

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Inverted staggered thin film transistors (TFTs) using magnesium zinc oxide (MgZnO) material as a channel layer have been fabricated over the glass substrate. A radio frequency magnetron sputtering technique was used to deposit thin films at a very low temperature of 100 °C. The structural and electrical characteristics were investigated. The semiconductor film shows slightly enhanced grain size without any crack with few grain boundaries. For the first time the self heating effect on the TFT fabricated using MgZnO was discussed. The electrical characteristics of MgZnO based device exhibit reduced self-heating effect compared with undoped zinc oxide. The calculated parameters are carrier mobility 1.08 cm^2/V-s, threshold voltage 15 V, leakage current 10^{-10} A and current ratio (on/off) 10^{-5}. The low deposition and processing temperatures make MgZnO-TFTs very promising for the flexible electronics.

Key words: MgZnO, Transistor, Self-heating, Sputtering, Characteristics.

Introduction

Zinc oxide (ZnO) as a semiconductor material in thin film transistor (TFT) has acquiring observation because of its better electrical characteristics, low-temperature process and transparency performance contrasting with conventional silicon TFTs [1-3]. Hence ZnO TFT considered potential next-generation flat panel display devices [4]. These properties are greatly collided by the intrinsic defects formed in the semiconductor layer. Presence of these defects reduces the electrical performance of the transistor. Particularly at very low temperatures, it causes severe current lag instead of channel saturation on applying high drain voltages and gate voltages [5]. In the case of TFTs based on silicon and high mobility transistors based on GaN, reported the lagging of output current in the device was due to self heating effect [6-8]. Thus control of electrical characteristics by reducing the defects of ZnO semiconductor material during deposition process may lead to correct saturation current in the transistor which in turn reduce the arise of self heating effect in the device. More works revealed that the doping of ZnO film with ternary element like Mg, Ga, In, Al etc, obtained the improved electrical properties of film[ref 9-12]. Particularly with Ga and In high mobility was achieved. However due to their rareness and cost we chose Mg material for ZnO TFT. However, to the best of our knowledge no reports were available on the study of self-heating effect on MgZnO based TFT. In MgZnO large bandgap and decrease donor-like defects make it as an emerging active layer material in thin film transistors [13, 14]. The ionic radii of magnesium (Mg^{2+}) are 0.57 Å and that of zinc (Zn^{2+}) are 0.60 Å. This advantage of almost same ionic radii would not create any lattice disorder and wide range solubility was achieved [15]. Apart from this magnesium alloyed with zinc oxide greatly reduces zinc interstitials and oxygen vacancies [16, 17]. The chemical characters of MgZnO make it a better non-toxic material suited for our atmosphere. Several studies on the improved characteristics of MgZnO thin film transistors fabricated at various processing methods and conditions have been reported [18-21]. In the present work radio frequency magnetron sputtering technique was employed to fabricate thin film transistor using MgZnO semiconductor at very low temperature (100 °C) and voltage-current characteristics were studied related to the absence of self-heating effect.

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Materials and Methods

A target in pellet form (MgO: 10 wt % and ZnO: 90 wt %) was used for radio frequency (RF) magnetron sputtering. The RF pressure, power and substrate temperature was maintained at 10 milli torr, 80 W and

100 °C respectively. To reduce the oxygen vacancies defects to achieve smaller background carrier trap density of material oxygen gas along with argon gas was used in the ratio of 3sccm:1sccm. The damage of the films by bombardment of energetic negative oxygen ions can be extenuated by maintaining low deposition rate around 4 nm/min [22].

The glass substrate coated with gate metal Indium Tin Oxide (ITO) was taken. The ITO was used as a bottom gate contact for the MgZnO TFT. After cleaning the substrate, SiNx film was deposited. Chemical vapor deposition process using plasma (PECVD) was employed to form a dielectric layer under the conditions of SiH_4=200 sccm/NH_3 = 800 sccm /N_2=35 sccm with 1 torr pressure, 30W power and 100 °C temperature. The organic impurity was removed over the insulator layer. Before depositing the semiconductor layer, the surface of target was cleaned by a pre-sputtering process. With above sputtering parameters, MgZnO thin films were deposited. The sample was rinsed chemically to remove all particulate matter and was subjected to photoresist coating and soft baking. Then the mask and sample alignment was done, and UV was exposed to it. Development was done to obtain source and drain geometric shapes. Finally by e-beam evaporation the source and drain metal using titanium (Ti) having a thickness of 30 nm and gold (Au) having a thickness of 90 nm was implanted and contacts were made by lifted-off processes.

The surface morphology of MgZnO film and thickness of various layers of the transistor grown at 100 °C was measured using a field-emission scanning electron microscope (FE-SEM). High-resolution x-ray diffraction (XRD) with a Cu Kα radiation (1.540Å) measurement was performed to analyze the crystal quality of the channel layer. We measured the electrical characteristics of the fabricated devices using a semiconductor parameter analyzer (HP 4155A).

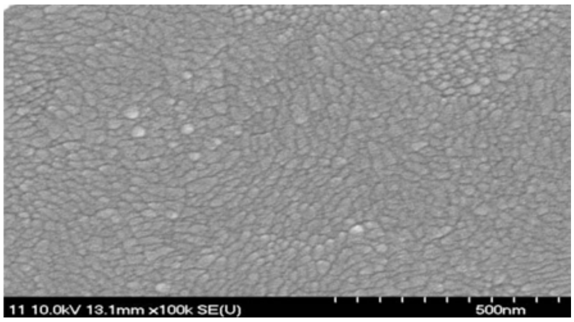

Fig. 1. Surface morphology of MgZnO film grown at 100 °C.

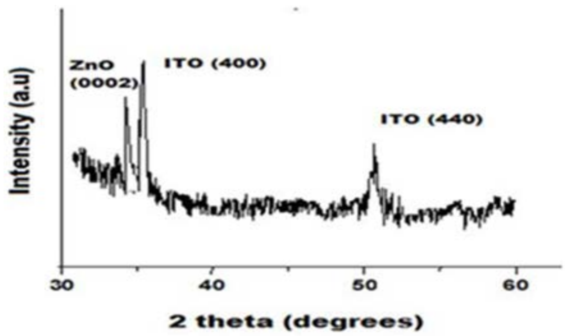

Fig. 2. XRD analysis of MgZnO film grown at 100°C.

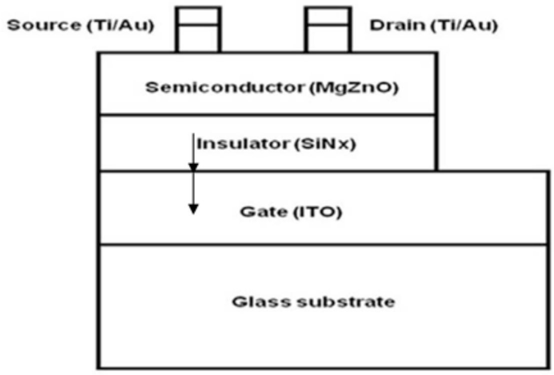

Fig. 3. Structure of fabricated MgZnO TFT.

Result and Discussions

Fig. 1 is the surface analysis of MgZnO film. The film shows polycrystalline structure and larger grain size with fewer grain boundaries when compared with ZnO based TFT as reported elsewhere [23]. Though the surface was rough the two dimensional mode of growth was not seen, thus the presence of Oxygen and Argon gas plays effectively in producing high quality film. Fig. 2 shows the X-ray diffraction pattern of MgZnO thin film. The pattern shows wurtzite structure of ZnO with c-axis orientation. As the peak (0002) occurred at 34.4 °, ZnO material shows strain less crystal [24] and remaining peaks were related to the ITO [25]. No second phase was found in this film. The diffraction peak also revealed better crystalline and the larger grain size in the materials. Thus it indicated the substitution of more Zn by Mg in the ZnO crystals. SEM and XRD results revealed the surface morphology of low T MgZnO film were improved by proper control of growth parameters during sputter.

Fig. 3 shows the structure of fabricated MgZnO thin film transistor possessing an inverted staggered structure with bottom gated. Fig. 4 shows the SEM image of cross-section view of the device. The fabricated TFT devices had a channel layer (MgZnO) at temperatures 100 °C with a thickness of 156 nm, a dielectric layer with 182 nm and a gate layer with 198 nm. The growth rate of MgZnO semiconductor was increased i.e thickness increased as compared with GaZnO [26] grown at similar sputtering conditions. Thus strong ionic bond was results in MgZnO film [27]. Fig. 5 shows the output characteristics of transistor taken between the drain current I_D and drain

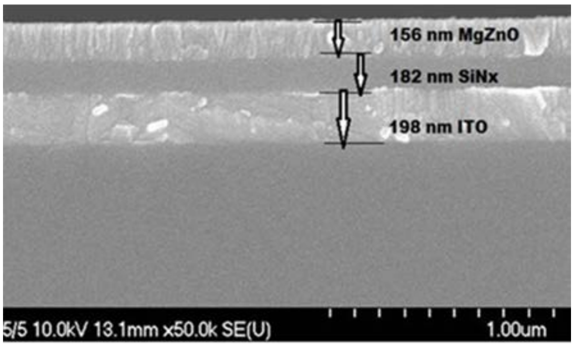

Fig. 4. SEM image of cross section view of the device.

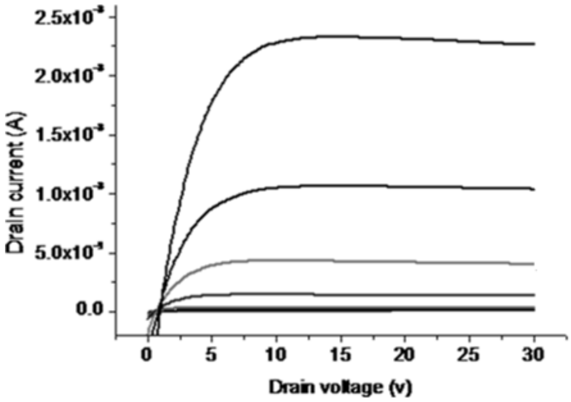

Fig. 5. Output characteristics of a TFT.

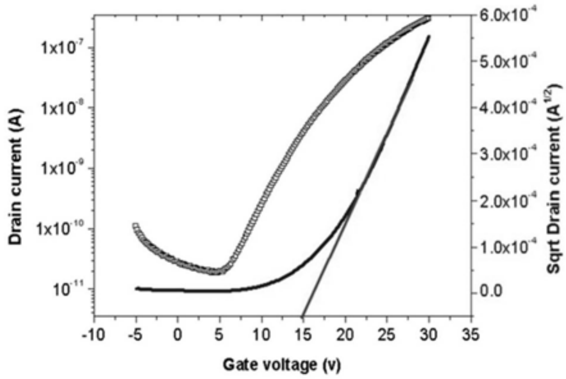

Fig. 6. Input characteristics of a TFT.

voltage V_{DS} at various gate voltage V_{GS} ranging from 0V to 12V. The channel conductance curves showed a smooth current saturation, without any lowers in output current. This indicated that self-heating effect was absent in the channel layer. D.Han et al [10] obtained degraded output characteristics in GaZnO TFT stating the defects present in between the channel and electrodes layer and the same was reduced by annealing treatment. A.K.Sahoo [28] and Y.H.Lin [29] groups produced a-InGaZnO TFT and ZnO:Al TFT with improper saturation and no explanations were given. H.Y.Jung et al [30] fabricated LZTO TFT at RF power of 100W with anomalous behavior of output characteristics due to interfacial trap and bulk trap densities. Manojkumar et al. [31] fabricated ZnO TFT showing the presence of SHE due to interstitials defects of the channel layer and the same effect was reduced by NaF doped ZnO TFT. Weng et al. [32] reported the carrier trap was created in the channel layer because of more grain boundaries and generate further defects while moving from the source to drain electrodes. This cumulative process increase temperature in the channel path results in degradation of output characteristics. Here in MgZnO TFT, we suggested that the absence of heating effect was due to the presence of lesser grain boundaries due to large grain size and reduced intrinsic defects present due to MgZnO materials itself. Hence temperature rise along the channel path is reduced due to the presence of fewer grain boundaries. Also, incorporation of magnesium metal element into zinc oxide suppresses oxygen vacancies and reduces carrier density found in the background of MgZnO TFTs [33]. In addition crowding of current was not seen in the curve due to good ohmic contact between the semiconductor layer and metal electrodes. Fig. 6 is the transfer characteristics (I_D versus V_{GS}, at $V_{DS} = 10$ V) of TFT fabricated at 100 ºC. The current ratio (on/off) and leakage current were calculated as ~10^5 and ~10^{-10}A respectively. A threshold voltage V_T and mobility μ_{FE} was calculated in saturation region from $I_D^{1/2}$ vs V_G curve as 15Vand 1.08 cm^2/V.s respectively. The value of channel width (W) was 300 μm,

Table 1. Comparison of device parameters fabricated by various deposition method.

Deposition method	Dielectric layer material	Temp	Threshold voltage (V_{TH})	Mobility (μ_{FE}) cm^2/V.s	Leakage current (Amp)	On/off ratio	References
Atomic layer deposition	SiO_2	200 ºC	8.1	3.6	~10^{-10}	~10^6	[33]
Pulsed laser deposition	SiO_2	300 ºC	0.7	6.7	-	~10^6	[34]
Spin coating	SiO_2	–	6.0	0.1	~10^{-12}	~10^7	[35]
RF magnetron sputtering	SiNx	100 ºC	15V	1.08	~10^{-10}	~10^5	Present work

the channel length (L) was 10 μm and capacitance per unit area (C_{SiNx}) was 16×10^{-10} Fm^{-2}. These values show the operation of preferable enhancement mode of the TFT. The various device parameters of MgZnO TFTs fabricated by different deposition methods as reported in literature were compared with the current work is given in Table 1.

Conclusions

The study demonstrates the fabrication of TFT device and the characteristics of MgZnO film grown at 100°C. When MgZnO was used as a channel layer, The electrical characteristics of the device showed absence of self-heating effect. MgZnO semiconductor material film showed minimized defects of zinc interstitials and oxygen vacancies and larger grain size with fewer grain boundaries. Because of this carrier trap in the channel path was significantly reduced which in turn minimized the temperature rise along the channel path on applying high voltage. Thus self-heating effect did not affect the device characteristics. The calculated value of transistor parameters revealed good performance of the device. Hence the reduction of heating effect is an important issue for the proper function of TFT device.

References

1. Y. Caglar, M. Caglar, S. Ilican, S. Aksoy, and F. Yakuphanoglu, J. Alloy. Comp. 621 (2015) 189-193.
2. Mazran Esro, George Vourlias, Christopher Somerton, I. Wiliam, Milne, and George Adamopoulos, Adv. Func. Mater. 25 (2015) 134-141.
3. D.Z. Zhou, and B. Li, J. Alloy. Comp. 648 (2015) 587-590.
4. H.C. You, J. Appl. Res. Technol. 13 [2] (2015) 291-296.
5. M. Amutha Surabi, J. Chandradass, Seong-Ju Park, and Leenus Jesu Martin, J. Ceram. Process. Res. 18[1] (2017) 41-44.
6. M.H. Lee, K.H. Chang, and H.C. Lin, J. Appl. Phys. 102 (2007) 054508.
7. S. Inoue, S. Takenaka, and T. Shimodam, Jpn. J. Appl. Phys. 42 (2003) 4213-4217.
8. Y. Zhang, S. Feng, and H. Zhu, IEEE Electron Device Lett. 35 (2014) 345-347.
9. Tae Young Ma, and Mu Hee Choi, Appl. Surf. Sci. 286 (2013) 131-136.
10. Dedong Han, Suoming Zhang, Feilong Zhao, Junchen Dong, Yingying Cong, Shengdong Zhang, Xin Zhang, and Yi Wang, Thin Solid Films 594 (2015) 266-269.
11. B. Alexander Cheremisin, Sergey N. Kuznetsov, and Genrikh B. Stefanovich, AIP Adv. 5 (2015) 117124.
12. Ahmed A. Al-Ghamdi, Omar A. Al-Hartomy, M. El Oksr, A.M. Nawar, S. El-Gazzar, Farid El-Tantawy, and F. Yakuphanoglu, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 131 (2014) 512-517.
13. H.A. Chin, I.C. Cheng, C.I. Huang, Y.R. Wu, W.S. Lu, W.L. Lee, and T.S. Lin, J. Appl. Phys. 108 (2010) 054503.
14. Y. Kwon, Y. Li, Y.W. Heo, M. Jones, P.H. Holloway, D.P. Norton, Z.V. Park, and S. Li, Appl. Phys. Lett. 84 (2004) 2685-2687.
15. A. Ohtomo, M. Kawasaki, T. Koida, K. Masubuchi, H. Koinuma, Y. Sakurai, Y. Yoshida, T. Yasuda, and Y. Segawa, Appl. Phys. Lett. 72 [19] (1998) 2466-2468.
16. A. Onodera, N. Tamaki, K. Jin, and H. Yamashita, J. Appl. Phys. 36 (1997) 6008-6011.
17. Y. Ogawa, and S. Fujihara, Phys. Status Solidi A 202[9] (2005) 1825-1828.
18. J.S. Wrench, I.F. Brunell, P.R. Chalker, J.D. Jin, A. Shaw, I.Z. Mitrovic, and S.Hall, Appl. Phys. Lett. 105 (2014) 202109.
19. C.J. Ku, P. Reyes, Z. Duan, W.C. Hong, R. Li, and Y. Lu, J. Electron. Mater. 44 (2015) 3471-3476.
20. Yi-Shiuan Tsai, Jian-Zhang Chen, I. Chun Cheng, ECS Trans. 50[8] (2013) 173-178.
21. I.C. Cheng, B.S. Wang, H.H. Hou, and J.Z. Chen, ECS Trans. 50 (2013) 83-93.
22. K. Tominaga, S. Iwamura, Y. Shintani, and O. Tada, Jpn. J. Appl. Phys. 32 [1] (1993) 4131.
23. M. Amutha Surabi, J. Chandradass, and Seong-Ju Park, Mater. Manuf. Processes 30[2] (2015) 175-178.
24. P. Sagar, P.K. Shishodia, R.M. Mehra et al, J. Lumin. 126 (2007) 800.
25. M.H. Yang, J.C. Wen, K.L. Chen, S.Y. Chen, and M.S. Leu, Thin Solid Films 484 (2005) 39-45.
26. M. Amuthasurabi, J. Chandradass, Seong-Ju Park and Leenus Jesu Martin, Surf. Eng. 33 (2017) 816-819.
27. T. Sivaraman, A.R. Balu, and V.S. Nagarethinam, Mater. Sci. Semicond. Process. 27 (2014) 915-923.
28. A.K. Sahoo, and G.M. Wu, Thin Solid Films. 605 (2016) 129-135.
29. Yung-Hao Lin, Hsin-Ying Lee, Ching-Ting Lee, and Cheng-Hsu Chou, Mater. Chem. Phys. 134 (2012) 1203-1207.
30. Hong Yoon Jung, Se Yeob Park, Ji-In Kim, Hoichang Yang, Rino Choi, Dae-Hwan Kim, Jong-Uk Bae, Woo-Sup Shin, and Jae Kyeong Jeong, Thin Solid Films. 522 (2012) 435-440.
31. Manoj Kumar, Hakyung Jeong, and Dongjin Lee, RSC Adv. 7 (2017) 27699-27706.
32. Chi-Feng Weng, Ting-Chang Chang, Han-Po Hsieh, Shih Ching Chen, Wei-Che Hsu, Wang-Chuang Kuo, and Tai-Fa Young, J. Electrochem. Soc. 155 (2008) H967-H970.
33. A. Shaw, T.J. Whittlesc, I.Z. Mitrovica, J.D. Jina, J.S. Wrench, D. Hespc, V.R. Dhanak, P.R. Chalker, and S. Halla, Proc. ESSDERC (IEEE) (2015) 206-209.
34. ChangPeng Wang, Dan Tang,Shun Han, PeiJiang Cao, XinKe Liu, YuXiang Zeng, WenJun Liu, Fang Jia, WangYing Xu, DeLiang Zhu, and YouMing Lu, Phys. Status Solidi A. 215 (2018) 1700821-1700826.
35. Chien-Yie Tsay, Hua-Chi Cheng, Min-Chi Wang, Pee-Yew Lee, Chia-Fu Chen, and Chung-Kwei Lin, Surf. Coat. Technol. 202 (2007) 1323-1328.