ZrO_2 게이트 절연막을 이용한 산화물 박막 트랜지스터의 전기적 특성

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Electrical properties of oxide thin film transistor with ZrO_2 gate dielectrics

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Abstract - In this paper we have presented recent studies concerning the high performance oxide thin film transistor (TFT) with a-IGZO channel and ZrO_2 gate dielectrics. The a-IGZO TFT is fully fabricated at room-temperature without any thermal treatments. The ZrO_2 is one of the most promising high-*k* materials with high capacitance originated from the high dielectric constant. The a-IGZO TFT with ZrO_2 shows high performance exhibiting high field effect mobility of 39.82 cm^2/Vs and high on-current of 2.52 mA at 10V.

1. Introduction

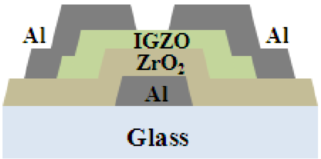
Recently, oxide semiconductors have attracted much attention, because of their superior electrical properties that include wide band gap, high field effect mobility and high uniformity over large areas compared to that of the conventional Si TFTs. [1-3]. In particular, IGZO has n-type semiconductor characteristics with a high mobility of more than 10 cm^2/Vs, a high on/off ratio of more than 10^6 and the process availability at room-temperature.[4-8] The a-IGZO TFTs can be obtained significantly high field effect mobility of 12cm^2/Vs, even in the amorphous phase.[8] In order to obtain a high on current at low gate voltage, we can either use a high-*k* material or reduce the thickness of the gate dielectric layer. However, the thickness reduction of the gate dielectric layer is limited due to the electron tunneling. While in high-*k* materials, the increase of the film thickness reduce the electron tunneling and keep a high capacitance. Among many candidate materials, ZrO_2 has expected to be one of the most promising high-*k* materials due to its desirable properties: high dielectric constant (~25), high breakdown field intensity (~ 15 MV/cm), large band gap (~5.6 eV) and relatively low leakage current.[9-11] In this work, we report on the fabrication of high performance a-IGZO thin film transistor with ZrO_2 gate dielectrics and Al electrodes. The a-IGZO and ZrO_2 thin films are deposited by rf-magnetron sputtering at room temperature. The device has exhibited a high field effect mobility of 39.82cm^2/Vs and a high on current of 2.56 mA at V_{GS} of 10V, demonstrating that the ZrO_2 is an attractive candidate materials gate dielectrics for thin film transistor.

2.Experimental

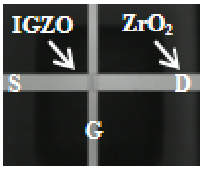
Gate-electrode of 100 nm is deposited on glass substrate by thermal evaporation method. Aluminum (4N purity) is used as electrode source. ZrO_2 thin film is deposited at room temperature by rf-magnetron sputtering method. The sputtering is carried out at a working pressure of 5×10^{-3}Torr in only Ar ambient. And then a-IGZO thin films are deposited by rf-magnetron sputtering and their thickness is maintained to 30nm. The deposition of the channel layer is performed at room temperature in a mixture of argon and oxygen. The working pressure and rf-power are fixed at 5×10^{-3} Torr and 100W, respectively. The carrier concentration of the active layer is controlled by oxygen partial pressure. Finally drain-source electrodes of 100nm are deposited by thermal evaporation method. Figure 1(a) shows the schematic diagram of a-IGZO TFT. All of the fabrications are performed at room temperature. In order to reduce the damage at the channel surface during the deposition, bottom gate structure is used. Figure (b) shows top view of the a-IGZO TFT with ZrO_2 taken by optical microscopy. The a-IGZO TFT has a dimension of channel length(L) = 30μm, width(W)=300μm and gate length = 70μm. Aluminum electrodes are used as gate and source/drain electrodes. Figure 1(c) shows a cross sectional scanning electron microscope(SEM) image of a-IGZO/ZrO_2 on glass.

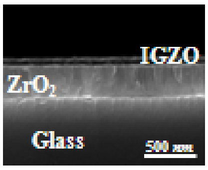
3. Result and Discussion

Figure2 shows the typical drain current versus drain-source voltage at various gate voltages. The device well operates in n-channel enhancement mode with little drain current at zero gate voltage. This TFT exhibits clear pinch-off voltages and current saturation at higher drain voltage, which shows the good electrical ohmic quality of the source and drain contacts and prove that, the TFT meets the standard field effect transistor characteristics. Figure 3 shows the transfer characteristics of the a-IGZO TFT with ZrO_2 gate dielectrics at the drain voltage of 5V. The gate voltage is swept from -10 to 15 V. The TFT exhibits the high on-current of 2.56mA at V_{GS}=10V. The on-to-off ratio is measured about 10^7. The threshold voltage (V_{th}=3.49V) is calculated by



(a)





(b) (c)

Figure1: (a):schematic diagram of a-IGZO TFT; (b): top view of the a-IGZO TFT; (c): cross sectional scanning electron microscope(SEM) image of a-IGZO/ZrO_2 on glass.

linearly fitting the square root of drain current versus gate voltage curve. The subthreshold swing is estimated to 0.56 V/decade. The low subthreshold swing shows the good interface between the a-IGZO channel layer and ZrO_2 gate dielectric layer.[12] Figure 4 shows the field-effect mobility of the a-IGZO TFT as function of the gate-voltage. The a-IGZO TFT with ZrO_2 gate dielectric has a large transconductance(g_m) due to asmall subthreshold swing, a high on-to-off ratio and a high on current. The apparent maximum field-effect mobility of the a-IGZO TFT is estimated about 39.82 cm^2/Vs. The a-IGZO TFT with ZrO_2 gate dielectric has high field effect mobility due to the high transconductance(g_m) which represents a promising application of the TFTs for switching devices. As a result, the remarkable improvement of the device performance is observed for the TFT with the a-IGZOchannel and ZrO_2 gate dielectric.

4. Conclusion

In summary, we demonstrated a high performance amorphous oxide thin film transistor with a-IGZO channel and ZrO_2 gate dielectrics. The TFT shows a high field effect mobility of 39.82 cm^2/Vs and high on-current of 2.02mA at V_{GS} of 10V. Note that the field effect mobility and on-current are the exceptionally higher than ever shown in the previous researches. The subthreshold swing and threshold voltage are 0.56 V/decade and 3.49 V, respectively. These results demonstrated the potential use of ZrO_2 thin film as a promising gate dielectric material for the fabrication of a-IGZO TFTs.

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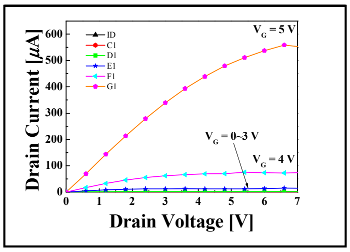

Figure2: Output Characteristic

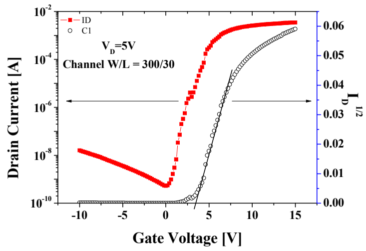

Figure 3: Transfer Characteristic

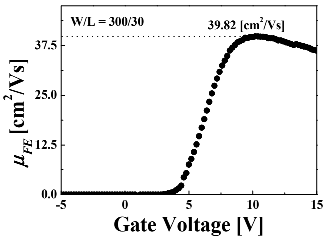

Figure4: Mobility vs Gate Voltage

References

1. H. Hosono, J. Non-Cryst. Solids **352**,851(2006)
2. Y. Shimura, K. Nomura, H. Yanagi, T. Kamiya, M. Hirano, H. Hosono, Thin Solid Films **516**,5899(2008)
3. B. D. Ahn, J. H. Kim, H. S. Kang, C. H. Lee, S. H. Oh, K. W. Kim, G. Jang, S. Y. Lee, Thin Solid Films **516**,1382(2008)
4. E. M. C. Fortunato, L. M. N. Pereira, P. M. N. Barquinha, A. M. B. Rego, G. Goncalves, A. Vila, J. R. Morante, and R. F. P. Martins, Appl. Phys. Lett. **92**,222103(2008)
5. J. Park, S. Kim, C. Kim, S. Kim, I. Song, H. Yin, K. K. Kim, S. Lee, K. Hong, J. Lee, J. Jung, E. Lee, K. W. Kwon, and Y. Park, .**93**,053505(2008)
6. J. H. Na, M. Kitamura, and Y. Arakawa, Appl. Phys. Lett. **93**,063501(2008)
7. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, Nature (London) **432**,488(2004)
8. H. Yabuta, M. Sano, K. Abe, T. Aiba, T. Den, H. Kumomi, K. Nomura T. Kamiya, and H. Hosono, Appl. Phys. Lett. **89**,112123(2006)
9. R. Mahapatra, Je-Hun Lee, S. Maikap, G. S. Kar, A. Dhar, Nong-M. Hwang, Doh-Y. Kim, B. K. Mathur and S. K. Ray, Appl. Phys. Lett. **82**,2320(2003
10. D. Fischera, and A. Kersch, Appl. Phys. Lett. **91**,242101(2007)
11. D. C.Hsu, M. T. Wang, and J. Y. Lee, J. Appl. Phys.**101**,094105(2007)
12. D. C. Hsu, I. Y. Chang, M. T. Wang, P. C. Juan, Y. L. Wang, and J. Y. Lee, Appl. Phys. Lett. **92**,202901(2008)