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Investigation for hafnium oxide as an insulator layer of organic thin film transistor

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Introduction

Thin-film transistors based on molecular and polymeric organic materials are of interest for a lot of applications, such as displays, radio-frequency identification tags as well as sensing detector [1]. The use of organic materials to development of organic transistors is most attractive for their lower cost and simpler packaging, relative to conventional inorganic electronics, and their compatibility with flexible substrate. However high operating voltage required for current device is main obstacle to develop practical devices. At present, the high dielectric-constant materials are used to lower operating voltage of organic transistors, such as Al_2O_3 [2-3], Ta_2O_5 [4] and TiO_2 [5]. The pure HfO_2 gate insulator that exhibits a good chemical, thermal stability and relatively high dielectric constant of 20–25 [6] has been studied in this paper for organic thin film transistors.

Experimental

The experimental process of MIM capacitor

The HfO_2 film with 180 nm was deposited on the cleaned ITO glass by DC sputtering. During the deposition process, a substrate temperature was kept at 300°C and chamber pressure of ($Ar+O_2$) gases were maintained 5mTorr, respectively. (1) In order to change the oxygen content in the HfO_2 film, the ratio of $O_2/(Ar+O_2)$ was varied at 5%~35%. (2) In order to improve leakage current of the HfO_2 film, the substrate temperature was varied at 27°C, 200°C, 300°C, respectively. After the HfO_2 film was deposited, the Al top electrode with 300 nm was deposited by thermal evaporation method. The electrical characteristic of I-V, C-V, were measured by HP4156B, HP4284. Material properties were analysis by Atomic force microscopy, and X-ray diffraction respectively.

The experimental process of OTFT device

In this report, the structure of device is shown in Fig.1. The glass substrate were cleaned by acetone, IPA, and DI water in the ultrasonic bath and dried by nitrogen. The Al with 100 nm was evaporated for gate electrode by thermal evaporation system. Then the gate oxide of HfO_2 layer with 250 nm was sputtered by the aforementioned deposition condition. This Source and drain electrode with Al (5nm)/Au (100nm) were deposited by thermal evaporation and the channel width/length with 4000/25 um was patterned by lift-off process. The surface of insulator was treated by RF power 100W O_2 plasma. Active layer was solution-base RR-P3HT 0.8wt% and dissolved in P-xylene. The polymer film was deposited by spin coater and baked at 120°C for 2 hours in glove box. Finally, the samples were encapsulated with a protective glass cover and UV-epoxy seal. The characteristics of OTFT device will be reported in this letter such as I_D-V_D and I_D-V_G curve.

Result and discussion

Fig.2. shows the relationship between the leakage current density and the oxygen content of HfO_2 thin film. It can be observed that the oxygen content at 20% shows the lowest leakage current density than the others. Fig.3. exhibits the J-E characteristic of 5%-20% that shows the leakage current density reduction as increasing the oxygen content. This result can be explained by oxygen deficiency. The higher oxygen content will cause the dielectric layer like the insulator and lower the leakage current density [7]. Fig.4. exhibits the J-E characteristic of 20%-35% indicates that leakage current density was raised as the enhancement of oxygen content. This result can be attributed to grain boundary by AFM measurement. Fig.5. shows the surface roughness of different oxygen content. It can be observed that the more rugged surface will be formed while the increasing of oxygen content that will induce the serious leakage current density. Fig.6. shows the I-V relationship from 27°C to 300°C. It can be observed that the HfO_2 thin film prepared at 200°C shows the lowest leakage current density than the others and the worst leakage current density at 300°C. It can be explained by XRD and AFM measurements. Fig.7. shows the XRD pattern of HfO_2 thin films and surface roughness deposited at 27°C, 200°C, and 300°C. The monoclinic peak appears at $2\theta=28.3^o$ for most films. The intensity of this peak increases for higher substrate temperature during sputtering. This is undesirable for gate dielectric application as grain boundaries produce leakage path. The HfO_2 thin film deposited at 300°C show the worst leakage current density. The results agree with XRD result and AFM measurement. Surface morphology maybe another important property to influence the electrical characteristic of dielectric thin films [8]. Fig.7. also exhibits the surface roughness of HfO_2 thin films change with substrate temperature. However, the different leakage current density of the HfO_2 samples deposited at 27°C and 200°C that may be explained the oxide film at higher temperature of substrate temperature at 200°C can reduce the surface roughness in summary the XRD results and AFM data indicate the HfO_2 films deposited at 200°C have better electrical performance. From Fig.8, the increasing oxygen concentration would cause the measured dielectric constant to be small.

From the aforementioned experiment, the optimal deposition condition of HfO_2 thin film can be found to design the OTFT device. In addition, the O_2 plasma treatment was used to improve the surface roughness of hafnium oxide and improve the characteristic of the device. According to Fig.9 (a) (b), the device channel width/length with 4000/25 um exhibits good I_D-V_D and I_D-V_G curves. From the $(I_D)^{1/2}$-V_G curve, 1.03×10^{-3} cm^2/Vs of carrier mobility, 2V of threshold voltage and 119 on/off current

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ratio can be calculated.

Conclusion

Hafnium oxide thin films with different oxygen concentration and substrate temperature by sputter system were studied. The optimal processing parameter can be used to form the high quality gate dielectric layer of HfO_2. The oxide insulator performs low leakage current density and high dielectric constant property. The low operating voltage polymer thin film transistors are fabricated successfully by using the high-k material, HfO_2.

References

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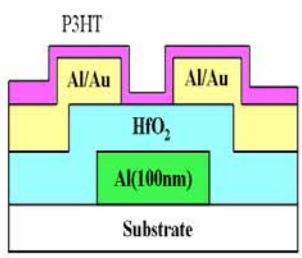

Fig. 1. The bottom-contact organic thin film transistor.

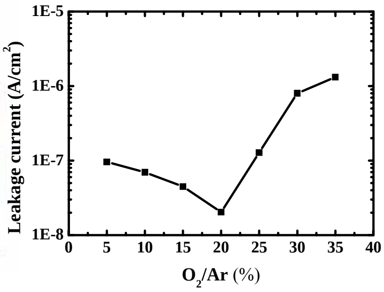

Fig. 2. The relationship between leakage current and O_2/Ar+O_2 is in MIM structure.

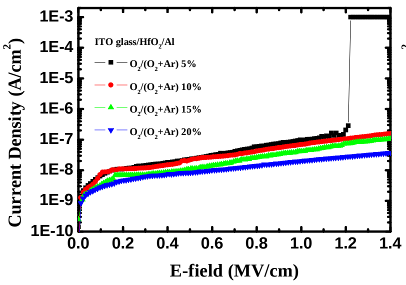

Fig. 3. The J-E characteristics of 5%~20%.

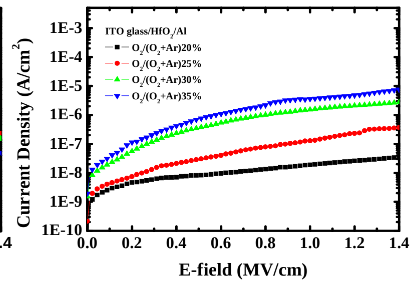

Fig. 4. The J-E characteristics of 20%~35%.

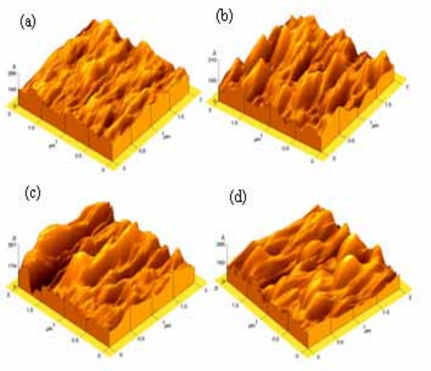

Fig. 5. Three dimension AFM image of HfO_2 thin films deposited on ITO substrate
(a) O_2/O_2+Ar = 20%; Rms = 32.4Å
(b) O_2/O_2+Ar = 25%; Rms = 53.5Å
(c) O_2/O_2+Ar = 30%; Rms = 76.4Å
(d) O_2/O_2+Ar = 35%; Rms = 77.4Å.

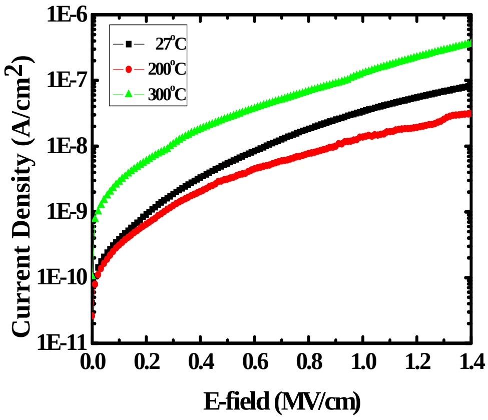

Fig. 6. Current-voltage characteristics of HfO_2 MIM prepared at 27,100.200, and 300°C respectively.

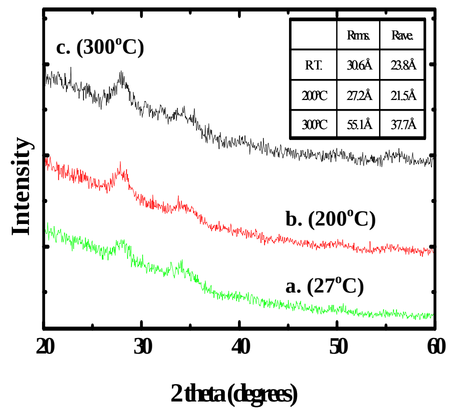

Fig. 7. XRD patterns and AFM image of HfO_2 thin films at various substrate temperature.

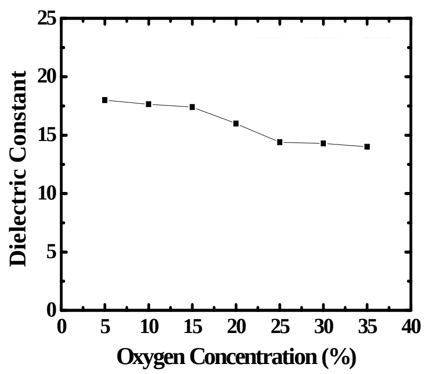

Fig. 8. The relationship between dielectric constant and oxygen concentration.

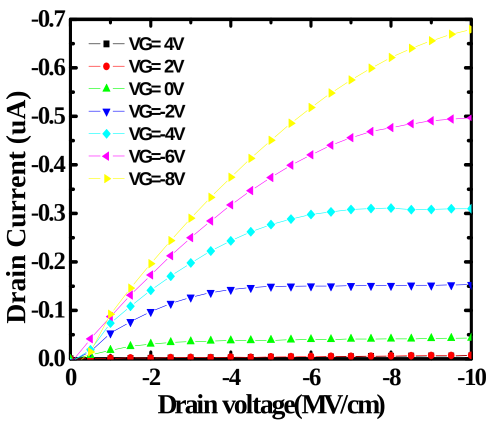

Fig. 9. (a) I_D-V_D characteristic of the sample with O_2 plasma treatment.

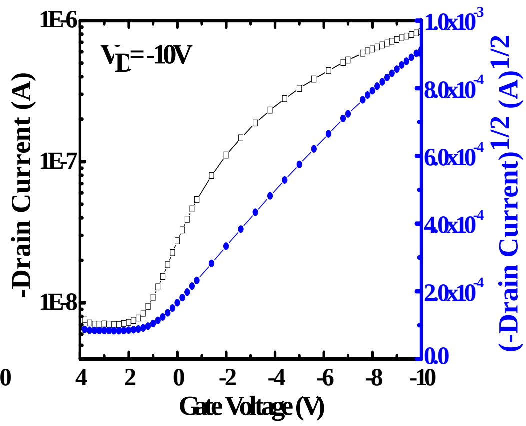

Fig. 9. (b) I_D-V_G characteristic of the sample with O_2 plasma treatment.

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