M-6-1

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp1078-1079

Improved performance of α-IGZO Thin-Film Transistors with an Au/HfSiO/IGZO(O_2-rich) Schottky Source

Chien-Hsiung Hung[1], Shui-Jinn Wang*[1, 2], Yen-Han Chen[1], Chien-Hung Wu[3], Chieh Lin[1], Pang-Yi Liu[1], Yung-Chun Tu[1], and Tseng-Hsing Lin[1]

[1] Institute of Microelectronics, Dept. of Electrical Eng., National Cheng Kung Univ., Tainan, Taiwan.
[2]Advanced Optoelectronic Technology Center, National Cheng Kung University, Tainan, Taiwan
[3] Department of Electronics Engineering, Chung Hua University, Hsinchu, Taiwan.
*Phone: +886-6-2763882, E-mail: sjwang@mail.ncku.edu.tw

Abstract:

Amorphous Indium gallium zinc oxide (α-IGZO) Schottky barrier thin-film transistors (SB-TFTs) with IGZO(O_2-rich) interlayer (IL) and HfSiO/IGZO(O_2-rich) bilayer stack are fabricated. Significant improvement in device characteristics obtained from Schottky contact source is investigated. With stacking a 10-nm-thick IGZO(O_2-rich) and 5-nm-thick HfSiO bilayer in the source region, experimental results show that the turn-off voltage of SB-TFTs increases from -0.7 V to about 0 V, the turn-off current decreases from 10^{-10} A to 10^{-11} A, the on/off current ratio increases from 10^5 to 10^6, and the subthreshold swing decreases from 0.204 V/dec to 0.097 V/dec. Therefore, the α-IGZO SB-TFTs provide the better performance than a conventional α-IGZO TFTs.

1. Introduction

Amorphous indium gallium zinc oxide thin-film transistors (α-IGZO TFTs) have been considered as the potential candidate for the next-generation applications of display industry due to their advantages of the higher mobility, higher uniformity, lower cost, and lower temperature process compared to amorphous silicon-based TFTs [1]. In regular α-IGZO TFTs, metal contacts to α-IGZO are Ohmic owing to low work function (3.9-4.1 eV), high carrier concentration and abundant oxygen vacancies in α-IGZO. Recently, TFTs with Schottky contact with better performance compared to conventional TFTs [2-3] have been demonstrated. Schottky barrier is attained to restrict current flow at low negative bias and make possible to control current less influenced by the imperfection of semiconductor film [2]. In this study, the α-IGZO Schottky barrier TFTs (SB-TFTs) were fabricated. The insertion of a HfSiO/IGZO(O_2-rich) bilayer at the source region is proposed to alleviate Fermi-level pinning caused by interface states and to offer a suitable potential barrier to reduce off current. Effects of the bilayer insertion on Schottky barrier height and device performance of SB-TFTs are examined.

2. Experimental

P-type silicon wafer with a 500-nm-thick SiO_2 layer were used. All metal layers were deposited by electron-beam evaporator. HfSiO layer and α-IGZO layer were deposited by RF sputtering. A 50-nm-thick TaN film was initially deposited as bottom gate electrode on insulating substrate. Subsequently, a 50-nm-thick HfSiO dielectric layer was formed using a HfSi target (Hf:Si=1:1) in ambient with a mixture of $O_2/(Ar+O_2)$ = 33%. After a 400°C annealing in O_2 ambient for 5 min, a 25-nm-thick α-IGZO active layer was deposited using an α-IGZO target (In_2O_3:Ga_2O_3:ZnO=1:1:1) in Ar ambient. A 10-nm-thick IGZO(O_2-rich) and a 5-nm-thick HfSiO layer were deposited in sequence on the source region of the α-IGZO active layer. Finally, a 150-nm-thick Au and Ti layer was formed using an E-beam evaporator for the Schottky source and Ohmic drain contact electrodes, respectively. The schematic cross section view of the proposed SB-TFTs with an Au/HfSiO/IGZO(O_2-rich) Schottky contact source is shown in Figure 1.

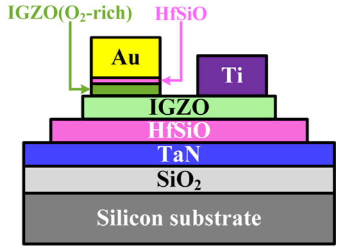

Fig. 1 Device structure of SB-TFTs with HfSiO/IGZO(O_2-rich) bilayer.

3. Results and Discussion

Figure 2 shows the J-V characteristics of the Schottky contact source with/without the HfSiO/IGZO (O_2-rich) bilayer. As revealed in the figure, without the HfSiO/IGZO(O_2-rich) bilayer, the source contact shows Ohmic behavior. Current rectifications were observed only from the samples with the IGZO(O_2-rich) IL and HfSiO/IGZO(O_2-rich) bilayer. The extracted Schottky barrier heights (ϕ_{Bn} in V)/ideal factor (n)/current rectification ratio (I_F/I_R) are 0.52/1.51/10, 0.64/1.62/10^2, respectively for the Schottky source with the IGZO(O_2-rich) IL and HfSiO/IGZO(O_2-rich) bilayer.

According to the composition analysis by X-ray photoelectron spectrum (XPS) for samples with/without IGZO(O_2-rich)/HfSiO bilayer, considerable improvement in Schottky contact performance could be ascribed to (a) increasing the oxygen content in IGZO could also lower the carrier concentration (n~10^{17} cm^{-3} at $O_2/(Ar+O_2)$=20%) and widen the depletion width to reduce junction tunneling, (b) Fermi-level pinning due to the abundant defects could be alleviated as well with the compensation of the oxygen vacancies [4-6], and (c) HfSiO IL insertion could prevent the inter-diffusion of ions (In^{3+}, Zn^{2+}, and Ga^{3+}) across the HfSiO/IGZO interface and avoid the formation of a eutectic interface [4-6].

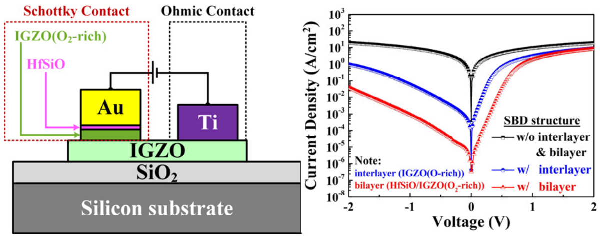

Fig. 2 J-V characteristics of the Schottky contact property.

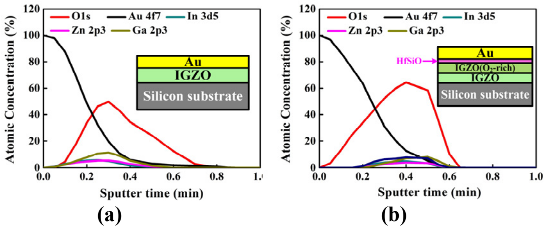

Fig. 3 XPS depth profile of IGZO (a) w/o and (b) w/ HfSiO/IGZO(O_2-rich) bilayer.

The α-IGZO SB-TFTs is composed of the Au/HfSiO/IGZO(O_2-rich) structure as the Schottky source contact and Ti metal electrode as the Ohmic contact drain. Figure 4 shows the transfer characteristics of α-IGZO SB-TFTs with/without IGZO(O_2-rich) IL and HfSiO/IGZO(O_2-rich) bilayer compare with conventional α-IGZO TFTs (Ohmic contact source/drain). It is seen that the α-IGZO SB-TFTs with the HfSiO/IGZO(O_2-rich) bilayer show the lower I_{off} and better SS than α-IGZO TFTs with the proposed Schottky source. Note that the Schottky source contact provides a Schottky barrier height (ϕ_{Bn}) lead to the V_{off} shift from -0.7 V to 0 V.

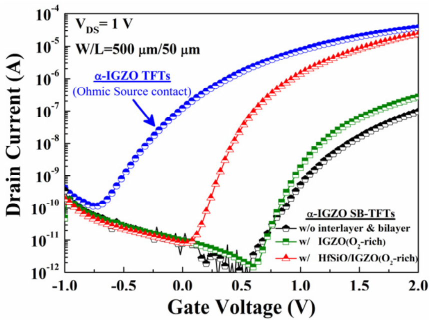

Fig. 4 The I_{DS}-V_{GS} characteristics of α-IGZO SB-TFTs with/without the IGZO(O_2-rich) IL and HfSiO/IGZO(O_2-rich) bilayer compare with α-IGZO TFTs (Ohmic source contact).

The extracted device electrical parameters are shown in Table I. It shows that V_{TH}, I_{off}, and μ_{FE} changes from 0.07 V, 1.14×10^{-10} A, and 5.89 cm^2/V-s for the α-IGZO TFTs to 0.62 V, 7.88×10^{-12} A, and 7.02 cm^2/V-s for the α-IGZO SB-TFTs, respectively. The reduced I_{off} and voltage shift of V_{off} are attributed to the Schottky contact source, it provides a Schottky barrier height (ϕ_{Bn}) to suppress the off current and cause a shift of V_{TH} ($\Delta V_{TH} \propto \phi_{Bn}$) [7-8]. In addition, the SS decreases from 0.204 V/dec to 0.097 V/dec after the use of Schottky source. Our experimental results show that the α-IGZO SB-TFTs without HfSiO/IGZO(O_2-rich) bilayer have a poor performance, which could be due to the existence of a considerable interface states at the interface between the α-IGZO active layer and Au (Schottky source contact) leading to Fermi level pinning.

Table I The TFT device performance comparison

Structure	V_{TH} (V)	V_{off} (V)	SS (V/dec)	μ_{FE} (cm^2/V-s)	I_{on}/I_{off}
α-IGZO TFTs (Ohmic source)	0.07	-0.7	0.204	6.53	10^5
α-IGZO SB-TFTs (w/ bilayer)	0.62	**0**	**0.097**	7.76	10^6
[2]	-	-	-	0.1	10^5
[3]	3.57	-2	0.35	11.2	10^6
[10]	0.91	-0.8	0.192	3.9	10^7

Figure 5 shows the possible energy band diagram of the SB-TFTs under thermal equilibrium and gate biasing (V_G>V_{TH}). Current transport in α-IGZO SB-TFTs is determined by the effective Schottky barrier height ($\phi_{Bn(eff)}$) at source, which is controlled by gate voltage through modulating the Schottky barrier width in associated with the Schottky barrier lowering effect. Shrinkage in the Schottky barrier width would enhance carrier tunneling from source to channel region [9], as a result, the effective barrier height at source is lowered by V_G and voltage controlled drain currents can be obtained. The improved SS suggests that the subthreshold current could be also controlled by Schottky barrier.

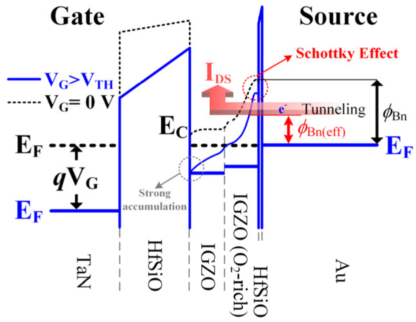

Fig. 5 The transport mechanisms of the SB-TFTs.

4. Conclusions

α-IGZO SB-TFTs with an Au/HfSiO (5 nm)/IGZO(O_2-rich) (10 nm) Schottky source structure have been successfully fabricated and improved device performance have also been demonstrated. The results reveal that the Schottky barrier creates an extra barrier to the channel carriers, which leads to a reduced leakage current (I_{off}) and a shifted turn-off voltage (V_{off}). The α-IGZO SB-TFTs with the proposed Schottky Source show a much better performance (I_{on}/I_{off} = 10^6, SS = 0.097 V/dec, V_{off} = 0 V, and μ_{FE} = 7.76 cm^2/V-s) as compared with those of conventional α-IGZO TFTs. It is expected that the source engineering proposed in this work might have potential applications in IGZO-related devices.

Acknowledgements

This work was supported by the Ministry of Science and Technology (MOST), Taiwan, under contract No. NSC 102-2221-E-006-217-MY2, and MOST 103-2221-E-006 -132. The authors would like to thank the Advanced Optoelectronic Technology Center, National Cheng Kung University, Taiwan, for equipment access and technical support.

References

[1] T. Kamiya et al., Sci. Technol. Adv. Mater. 11 (2010) 044305.
[2] A.M. Ma et al., Solid-State Elec. 76 (2012) 104.
[3] Trinh et al., J. Appl. Phys. 116, 214504, 2014.
[4] D. H. Lee et al., IEEE Electron Device Lett. 32 (2011) 1695.
[5] A. Chasin et al., IEEE Trans. Electron Devices 60 (2013) 3407.
[6] L. J. Brillson et al., J. Appl. Phys. 109 (2011) 121301.
[7] S. F. Feste et al., Solid-State Elec. 53 (2009) 418.
[8] R. H. Yan et al., IEEE Trans. Electron Devices 39 (1992) 1704.
[9] R. Jhaveri et al., IEEE Trans. Electron Devices 56 (2009) 93.
[10] A.M. Ma et al., Appl. Phys. Lett. 103 (2013) 253503.