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Mobility enhancement of $InGaZnO_x$ thin-film transistor by hetero-channel with a different composition.

Mamoru Furuta[1], Daichi Koretomo[1], and Ryunosuke Higashi[1]

[1] Kochi University of Technology
185, Miyanokuchi, Kami
Kochi 782-8502, Japan
Phone: +81-887-57-2521 E-mail: furuta.mamoru@kochi-tech.ac.jp

Abstract

An IGZO hetero-channel thin-film transistor was demonstrated to enhance a field effect mobility (μ_{FE}). The μ_{FE} of hetero-channel IGZO TFT increased to 23.7 cm^2/Vs which is twice as high as a conventional IGZO TFT. Carrier transport mechanism in an IGZO hetero-channel is discussed by using a device simulation.

1. Introduction

An $InGaZnO_x$ (IGZO) thin-film transistor (TFT) [1] has been received considerable attention for use in next-generation displays owing to their excellent electrical properties. Although a field effect mobility (μ_{FE}) of IGZO TFT (10~15 cm^2/Vs) is over ten times larger than that of an amorphous silicon TFT, further enhancement of the μ_{FE} is desired to expand their applications. Several approaches have been proposed to improve the μ_{FE} of oxide TFT. Among them, it is known in the IGZO material system that an increase of In content is effective to enhance the μ_{FE} of IGZO TFT since a conduction band (E_C) of the IGZO is mainly composed of an In 5s orbital. However, high In composition leads to an increase carrier concentration (oxygen vacancy) in the film, result in a degradation of TFT properties such as a negative shift of threshold voltage with hump in transfer characteristics. There are many reports of a stacked channel to improve the μ_{FE} of oxide TFT [2, 3]; however, only a few reports discussed an effect of hetero-channel on electrical properties of the IGZO TFT [4, 5].

In this study, the enhancement of μ_{FE} in IGZO TFT was demonstrated by using a hetero-channel consisting of an In-rich-IGZO on the IGZO-111 (In:Ga:Zn= 1:1:1 atm.%). In addition, carrier transport in the IGZO hetero-channel TFT is also discussed based on the results obtained by a device simulation.

2. Experiments

A bottom gate IGZO TFT was fabricated on a heavily-doped p-type Si wafer with a 100-nm-thick thermally grown SiO_2, as shown in Fig. 1. The conductive Si substrate and thermally grown SiO_2 were served as a gate electrode and a gate insulator (GI), respectively. An IGZO hetero-channel consist of a 10-nm-thick In-rich-IGZO on a 10 nm-thick IGZO-111 [IGZO-In-rich/111] was deposited by RF magnetron sputtering at room temperature. The TFT with a single-layer channel of IGZO-111(45 nm) was also fabricated as a reference. A Mo/Al/Mo (50/50/20 nm) stacked film was deposited as source/drain (S/D) electrodes. Shadow mask was used to form both the IGZO channel and the S/D electrodes. A 100-nm-thick SiO_2 film was further deposited by plasma-enhanced chemical vapor deposition. Finally, the measurement pads were opened by photolithography and plasma etching. After the whole process, fabricated TFTs were post-annealed in air at 350°C for one hour. The channel length (L) and width (W) were 350 and 1400 μm, respectively.

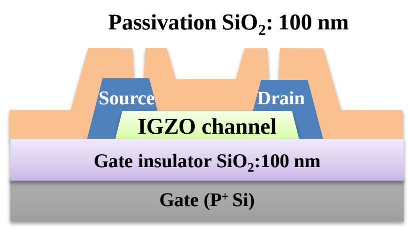

Fig. 1 Schematic cross-sectional view of the TFT.

3. Results and discussion

Figure 2 showed a comparison of transfer characteristics of the IGZO111 and IGZO-In-rich/111 TFTs. Table I summarizes electrical properties of both TFTs.

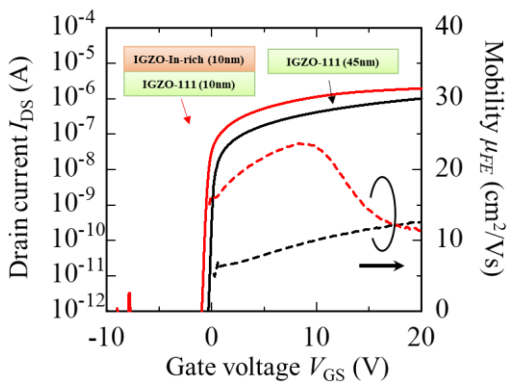

Fig. 2 Transfer characteristics of the IGZO111 and IGZO-In-rich/111 hetero-channel TFTs (V_{DS}=0.1 V). Solid and dotted lines represent a drain current and a field effect mobility, respectively.

The reference TFT (IGZO-111) exhibited good electrical properties with a μ_{FE} of 12.5 cm^2/Vs. The μ_{FE} of IGZO111 TFT (black dotted line in Fig. 2) gradually increased with increasing a gate voltage (V_{GS}). By the optimization of IGZO-

In-rich layer, similar threshold voltage (V_{th}) and sub-threshold swing (S.S.) were able to achieve for the IGZO-In-rich/111 hetero-channel TFTs. On the other hand, the on-current of the hetero TFT obviously increased at a positive V_{GS} region. The μ_{FE} of hetero-channel TFT (red dotted line in Fig. 2) exhibited 23.7 cm^2/Vs at V_{GS}~10 V. It is worth noticing that the V_{GS} dependence of the μ_{FE} showed different tendency. Although a channel/GI interface of both TFTs was formed by IGZO111, a transconductance of the hetero-channel TFTs exhibited single peak at V_{GS}~10 V, whereas that of IGZO TFT gradually increased up to V_{GS} of 20 V.

Table I Summary of the electrical properties

	IGZO-111 TFT	IGZO-In-rich/111 TFT
Mobility (cm^2/Vs)	12.5	23.7
V_{th} (@I_{DS}=1nA) (V)	0.1	-1.2
S.S. (V/dec.)	0.11	0.11

To understand the carrier transport in the hetero-channel TFT, transfer characteristics were reproduced by a device simulation (ATLAS, Silvaco). Conduction band discontinuity (ΔE_C) at an IGZO-In-rich/111 hetero-interface was estimated to be 0.39 eV from an electron affinity model using optical band gap and ionization potential measurements of each film.

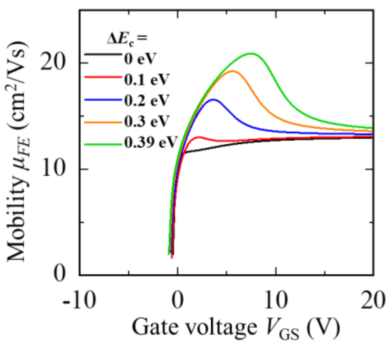

Fig. 3 Simulation result of the μ_{FE} of the hetero-channel TFT with ΔE_C varied from zero to 0.39 eV as a function of V_{GS}.

Figure 3 depicts simulation result of the μ_{FE} of hetero-channel TFTs as a function of V_{GS} with the ΔE_C varied from zero to 0.39 eV. When the ΔE_C was set at 0.39 eV (experimental value), the experimental V_{GS} dependence of the μ_{FE} (red dotted line in Fig. 2) was able to reproduce well by a device simulation. On the other hand, simulation results suggest that the peak μ_{FE} gradually declined by decreasing ΔE_C. In this experiments, high-mobility In-rich IGZO was deposited on an IGZO-111. To enhance the μ_{FE} of the IGZO-In-rich/111 hetero-channel TFT, the ΔE_C has to be formed at the IGZO-In-rich/111 hetero-interface. In other words, single peak of a transconductance is one experimental evidence for forming ΔE_C at a hetero interface.

3. Conclusions

In summary, we demonstrated IGZO hetero-channel TFT used an In-rich IGZO on IGZO-1114 stacked channel. The μ_{FE} of the IGZO-In-rich/111 hetero-channel TFT (23.7 cm^2/Vs) is two times higher than conventional IGZO TFT. The experimental results have been reproduced by a device simulation including a conduction band discontinuity at a hetero interface. Thus, an IGZO hetero-channel is effective to improve the μ_{FE} of the IGZO TFT.

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