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Ring Oscillator Circuit based on ZnO Thin Film Transistors

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1. Introduction

Zinc oxide (ZnO) based thin film transistors (TFTs) are under active research due to their potential application in various display systems. Fabrication processes and electrical characteristics of the ZnO TFTs were studied [1-2] and the reported performances in terms of field effect mobility, on/off current ratio, and the sub-threshold slope are excellent.

However, to estimate the performance of TFTs in the real circuits, it is required to fabricate standard circuits and investigate their dynamic characteristics. Although excellent device parameters of ZnO TFTs have been reported, they are only the characteristics of unit devices. Recently, the dynamic characteristics of ring oscillators (ROs) fabricated by utilizing indium-gallium-zinc-oxide (IGZO) and indium-gallium-oxide (IGO) have been reported [3-4]. According to the reports, the ROs fabricated with IGZO TFTs which had high channel mobility of 18.2 $cm^2V^{-1}s^{-1}$ exhibited the highest oscillation frequency of 410 kHz under the supply voltage (V_{DD}) of 18 V and ROs fabricated with IGO TFTs which had the field effect mobility of 7 $cm^2V^{-1}s^{-1}$ exhibited the oscillation frequency of 2.2 kHz at V_{DD} of 30 V, repectively. There has been no investigation on the dynamic characteristics of ZnO TFTs by fabricating ROs or other integrated circuits.

In this work, ZnO TFTs, inverters, and 5-stage ROs were fabricated on a glass substrate by using RF magnetron sputtering method and their performances were investigated.

2. Experiments

Inverters and 5-stage ROs based on bottom gated ZnO TFTs were fabricated on glass substrates (Corning 1737) coated with 200-nm-thick indium-tin-oxide (ITO). ITO gate electrodes were defined by utilizing photolithography and wet etch. The silicon nitride gate dielectric layer (100 nm) and ZnO channel layer (100 nm) were deposited by plsma enhanced chemical vapor deposition (PECVD) and RF magnetron sputtering, respectively. The ZnO channel layer was subsequently patterned using photolithography and wet etch. Vias for contact to the gate electrode were established by using photolithography and dry etching of silicon nitride. Finally, source and drain contacts and interconnection metal layer composed of Ti/Pt/Au (20/30/200 nm), were deposited by e-beam evaporation and lifted off. The cross-sectional schematic diagram of ZnO TFTs is shown in Fig. 1. The TFTs with W/L=200/20 µm and W/L=800/20 µm were used for the load and drive transistors in the inverters, and 5-stage ROs.

3. Results and Discussions

The output characteristics (I_D-V_{DS}) and the transfer characteristics ($\log(I_D)$-V_{GS}) of the drive TFT are shown in Fig. 2(a) and Fig. 2(b), respectively. The transfer curve in Fig. 2(b) shows the on/off current ratio over 10^5. Considering that the gate current is in picoampere range and it is order of magnitude lower than the off-current, the off current is not limited by the gate leakage current but the surface leakage current between the source and drain of the TFT. The field effect mobility (μ_{FE}) and the threshold voltage of the TFTs operating in saturation region are 0.25 $cm^2V^{-1}s^{-1}$ and 14 V, respectively. Fig. 3 shows the voltage transfer curve of the inverter under the supply voltage of 40 V. The gain at the inversion voltage (V_{inv}=18 V) was 1.3, which is smaller than expected desinged value of 2. It may be attributed to the gate voltage dependence of μ_{FE}, shown in Fig.4, which decrease the square root of geometrical beta ratio $[(\mu W/L)_{drive}^{1/2} / (\mu W/L)_{load}^{1/2}]$.

The dynamic characteristic of the fabricated 5-stage RO is shown in Fig. 5. The fabricated RO exhibited the oscillation frequency of 3.52 kHz under the supply voltage, V_{DD} of 50 V. It corresponds to the propagation delay of 28.4 µs/stage. The performance of the fabricated RO is a little bit worse than those of ROs based on IGO TFTs [3] and IGZO TFTs [4]. By further optimization of the fabrication process, field effect mobility of ZnO TFTs and the oscillation frequency of RO can be improved. Considering that the best field effect mobility of ZnO TFTs reaches up to 70 $cm^2V^{-1}s^{-1}$ [1], the oscillation frequency of RO can reach the status of IGZO TFTs.

4. Conclusions

RF magnetron sputtered ZnO based bottom gate TFTs, inverters, and ROs were fabricated and characterized. It is the first demonstration of RO by utilizing ZnO films deposited by RF magnetron sputtering. The gain of the inverter was 1.3 at V_{DD} of 40 V and the oscillation frequency of the RO was 3.52 kHz under the supply voltage of 50 V. Considering that the field effect mobility of drive transistor of RO was only 0.25 $cm^2V^{-1}s^{-1}$, we expect that ZnO TFTs with better field effect mobility can improve the dynamic performance.

Acknowledgements

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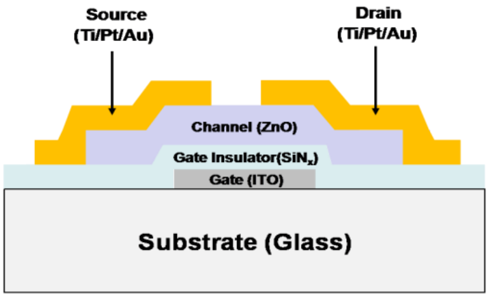
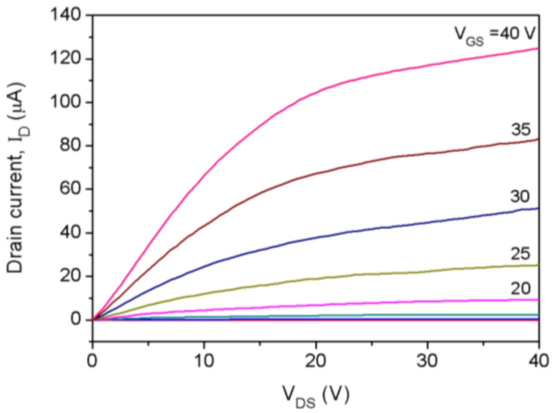
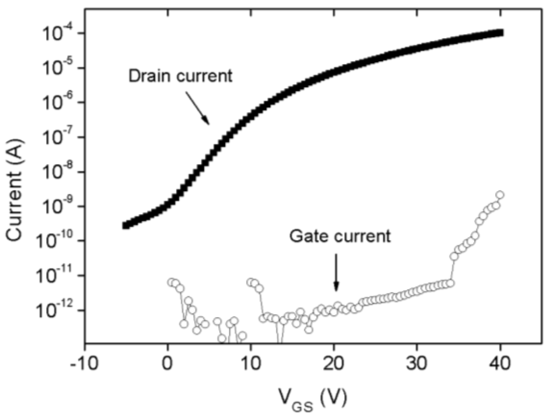


Fig. 1 Cross-sectional schematic diagram of ZnO TFTs



(a)



(b)

Fig. 2 Characteristics of drive TFTs with W/L=800/20 μm (a) output characteristics of TFTs. V_{GS} was changed from 40 V to −5 V in steps of −5 V. (b)Transfer characteristics and gate leakage current of TFTs at V_{DS} of 20 V.

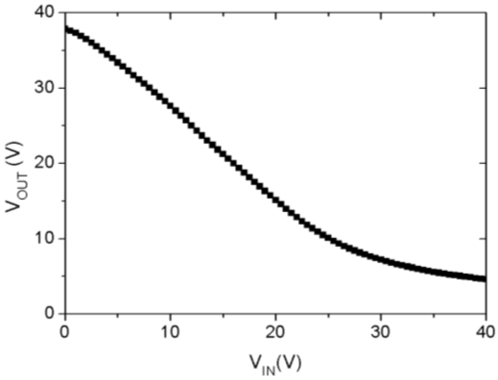


Fig. 3 Voltage transfer curve of the inverter fabricated using ZnO TFTs. The supply voltage of 40 V was used.

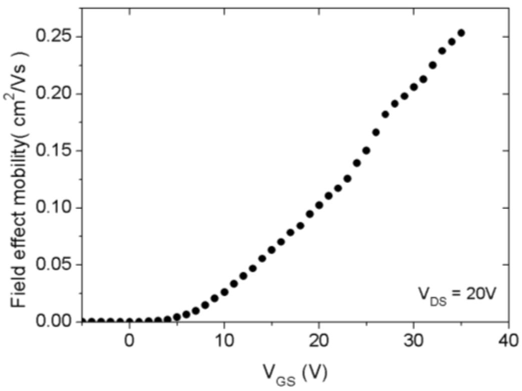
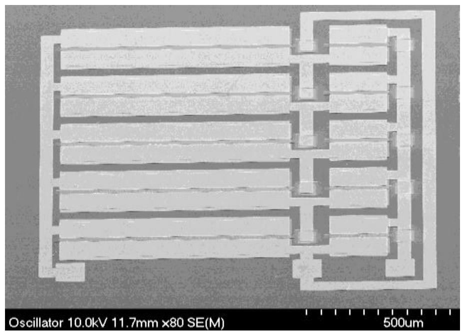
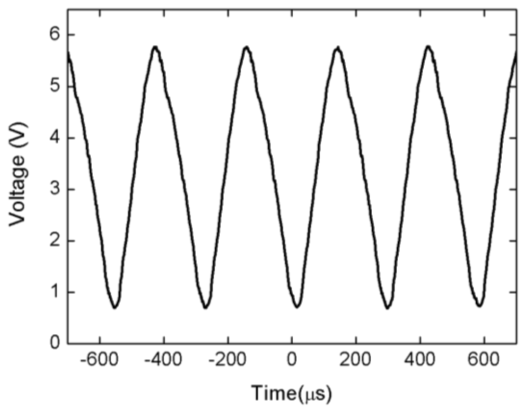


Fig. 4 Field effect mobility versus gate voltage at V_{DS} of 20 V.



(a)



(b)

Fig. 5 (a) SEM top view of the fabricated RO. (b) Output characteristics of the RO at the supply voltage (V_{DD}) of 50 V. The peak to peak voltage and the oscillation frequency of the RO were measured to be 5.08 V and 3.52 kHz, which corresponds to the propagation delay of 28.4 μs/stage.