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Fabrication of Indium-Tin-Oxide Channel Ferroelectric-Gate Thin Film Transistors using Yttrium Doped Hafnium-Zirconium Dioxide by Chemical Solution Process

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Abstract

We have fabricated and characterized a ferroelectric gate thin film transistor (FGT) using ferroelectric yttrium doped hafnium-zirconium (Y-HZO) as a gate insulator and conductive indium-tin-oxide (ITO) as a channel layer. Both layers were prepared by the chemical solution process. The fabricated device showed normal ferroelectric-gate transistor operation with good electrical properties.

1. Introduction

Ferroelectric thin film materials such as $Pb(Zr,Ti)O_3$ (PZT), $(Bi,La)_4Ti_3O_{12}$ (BLT), and $SrBi_2Ta_2O_9$ (SBT) have been widely used for various types of application such ferroelectric random access memory (FeRAM) and ferroelectric-gate transistors [1,2]. However, these conventional ferroelectric films have poor compatibility with Si CMOS technology. On the other hand, HfO_2 has been used as the gate dielectric in advanced CMOS devices due to its high permittivity, and ferroelectricity of HfO_2-based materials was discovered recently [3]. A promising application of HfO_2-based ferroelectrics is ferroelectric-gate FET, because the materials show good ferroelectric properties even when the thickness is as thin as 10 nm. However, it must be noticed that when ferroelectric material is used as a gate insulator in Si-MOSFET, the available charge is limited because of the charge mismatch between ferroelectric polarization and channel [4]. One of the ways to use full polarization of the ferroelectric-gate insulator is to use an oxide channel. We have previously demonstrated even a conductive oxide, indium-tin-oxide (ITO), can be used as a channel due to the large charge controllability of ferroelectric BLT film used as a gate insulator [5], and a few paper reported the combination of HfO_2-based ferroelectric gate insulator and In-Ga-Zn-O [6] and In-Zn-O [7] channel.

In addition, the most widely used deposition technique for the ferroelectric HfO_2-based gate insulator is atomic layer deposition (ALD). There are only a few reports on chemical solution deposition (CSD) for these materials [8-10] and no report on ferroelectric-gate transistor with HfO_2-based ferroelectric gate insulator fabricated by CSD.

In this work, bottom gate ferroelectric-gate thin film transistors (FGTs) with yttrium doped hafnium zirconium dioxide (Y-HZO) as a gate insulator and ITO as a channel were fabricated and characterized. Both Y-HZO and ITO layers were fabricated by CSD.

2. Experimental

Y-HZO films were fabricated by the procedure we previously reported [11]. The source solution of Y-HZO was prepared by mixing $Hf(acac)_4$, $Zr(acac)_4$ and $Y(acac)_3$ in propionic acid (PrA). ITO source solution was prepared by mixing $In(acac)_3$ and $Sn(acac)_2$ in PrA. First, the source solution of Y-HZO was spin-coated on the platinized substrate ($Pt/Ti/SiO_2/Si$) followed by drying on a hot plate at 225 ºC for 3 min in air. The crystallization step of Y-HZO films was done by rapid thermal annealing (RTA) at 800 ºC for 3 min in a vacuum environment. The thickness of Y-HZO film is 33 nm. Next, ITO source solution was spin-coated on Y-HZO followed by drying at 100 ºC for 3 min in air. Then, the samples were annealed at 600 ºC in an oxygen environment for 15 min. Pt source and drain electrodes were formed by sputtering and patterned by the lift-off process. Next, the device region was isolated by wet etching. The channel length and width are 5 and 100 μm, respectively. Finally, the bottom gate electrode is accessed by photolithography and etching. Pt/ITO/Y-HZO/Pt metal-ferroelectric-semiconductor (MFS) structure capacitors were also fabricated to measure the ferroelectric properties.

3. Results and Discussion

Figure 1 shows XRD pattern of the Y-HZO film annealed at 800 ºC in a vacuum environment. Diffraction peaks around 30.5° and 35.4° were observed, which suggests the formation of o(111)/c(111) and o(200)/c(200), respectively where o and c mean orthorhombic and cubic phases. It is interesting to note that a peak from the monoclinic phase (m-phase) was not observed.

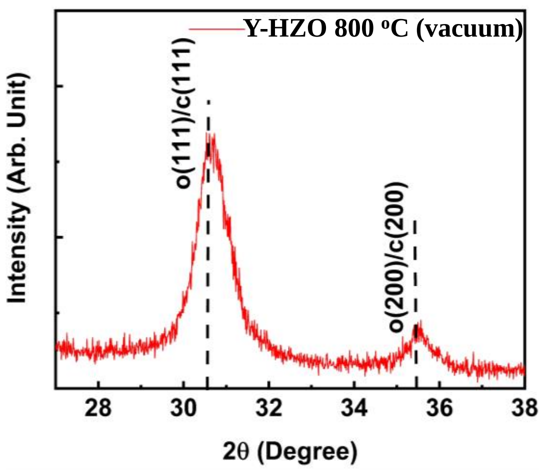

Fig. 1. XRD pattern of CSD Y-HZO film.

In order to confirm ferroelectric properties, polarization-voltage (P-V) and capacitance-voltage (C-V) characteristics were measured for vacuum annealed Y-HZO films fabricated by CSD. Figures 2(a) and 2(b) show P-V loop and C-V curve of the Y-HZO film, respectively. Ferroelectric nature is observed in the P-V loop with clear switching current. The remnant polarization, P_r deduced from Figure 2(a), is approximately 10 μC/cm^2. As shown in Figure 2(b), C-V curve with clear butterfly-shaped loop was obtained with a decrease in capacitance on the positive voltage side. Since the positive voltage is applied to the top electrode in this measurement (which corresponds to the negative gate bias in the device), the decrease in capacitance shows the depletion of ITO.

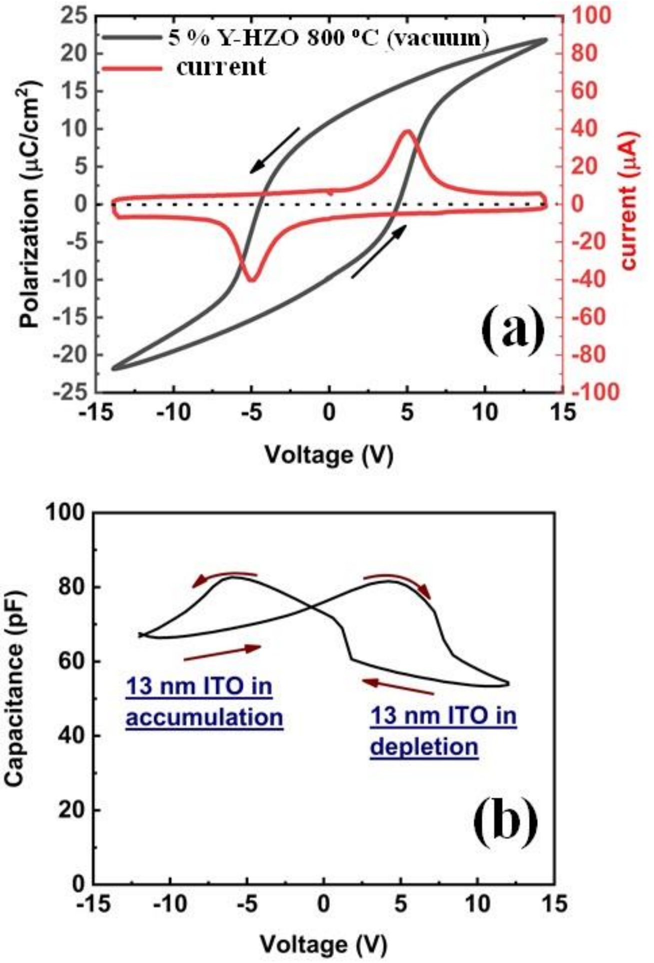

Fig. 2. Electrical properties of ITO/Y-HZO MFS structure, (a) P-V and I-V loop and (b) C-V curve.

Figure 3(a) shows drain current-drain voltage (I_D-V_D) characteristics of an FGT with Y-HZO gate insulator and 13-nm-thick ITO channel. I_D-V_D exhibits a clear pinch-off and current saturation, confirming standard field-effect transistor operation. A large saturated drain current of 16 mA was observed for V_G=3V, which corresponds to 0.16 mA/μm. Figure 3(b) shows drain current–gate voltage (I_D–V_G) characteristics. Counter-clockwise hysteresis due to the ferroelectric nature was confirmed with a memory window of 3.8 V. The subthreshold voltage swing (SS) of 193 mV/decade and an on/off drain current ratio of approximately 10^6 were obtained. Electrical properties of FGT with different channel thickness will be presented at the conference.

4. Conclusion

Ferroelectric properties were confirmed by P-V and C-V measurements for the ITO/Y-HZO MFS structure fabricated by CSD. Next, bottom gate FGTs with ferroelectric Y-HZO gate insulator and 13 nm thick ITO channel which were formed by CSD have been demonstrated. Normal n-channel transistor operation was obtained with low SS and high on/off drain current ratio.

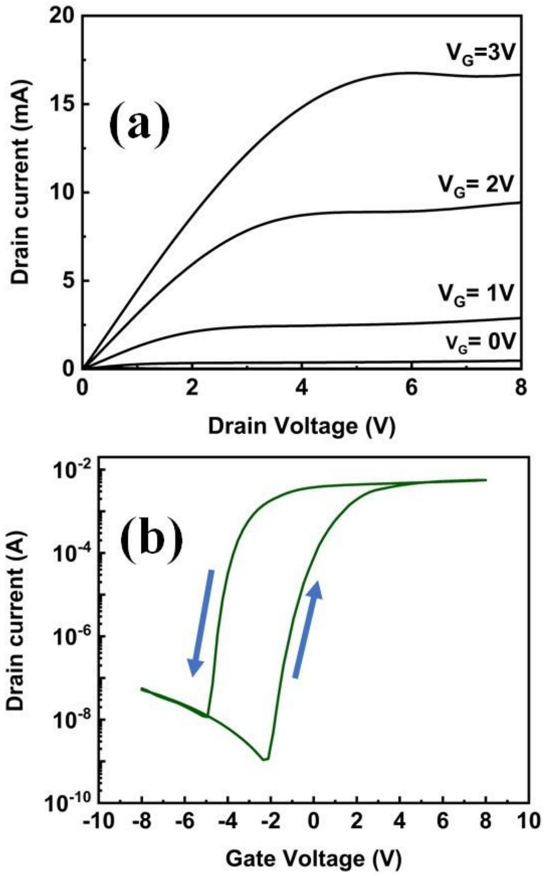

Fig. 3 Electrical properties of FGT with Y-HZO gate insulator and 13 nm thick ITO channel, (a) I_D-V_D and (b) I_D–V_G characteristics.

Acknowledgements

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