Effect of Hafnium Oxide on ALD Grown ZnO Thin Film Transistor

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Abstract

The TFTs from ZnO semiconductor with hafnium oxide dielectrics were prepared by atomic layer deposition to characterize the electrical properties. Good electrical properties of oxide TFT was obtained with channel mobility of 2.1 cm^2/Vs*, threshold voltage of 0 V, the subthreshold slope of 0.9 V/dec, and on to off current ratio of* 10^6*.*

1. Introduction

Research efforts on ZnO thin film have driven by its characteristic and potential applications. ZnO has a wide band and direct band gap II-VI semiconductor. The various applications include transparent conductor [1], solar cell window [2], ultraviolet light emitter [3], gas sensors [4], photovoltaic devices [5], and surface acoustic wave devices [6]. Its wide applications owes to its its properties such as wide direct band gap of 3.4 eV at room temperature (RT), large exciting binding energy of 60 meV at RT, high optical transparency in the visible region, good electrical conductivity and outstanding piezoelectricity. ZnO thin films have been prepared by various technologies such as sputtering [7], metal oxide chemical vapor deposition [8], pulse laser deposition [9], sol-gel process [10], spray pyrolysis [11], and atomic layer deposition (ALD) [12].

Hafnium dioxide is considered as a potential gate insulator due to its relatively high dielectric constant around 30 and large band gap around 5.68eV [13]. Atomic layer deposition (ALD) for semiconductor industry is used for the fabrication of uniform and dense nano films due to the easy control of thickness and improved film quality at relatively low temperature. Plasma enhanced (PE) ALD with shower head reactor and ALD with traveling-wave reactor were used for ZnO film fabrication on silicon wafer by using plasma and water as reactants, respectively [14]. Recently, there was a report on the HfO_2 as a potential substitute for SiO_2 gate insulator, however, they reported the interfacial properties of HfO_2 as a ALD film on the silicon wafer [15].

In this paper, ZnO and HfO_2 thin films were prepared by PEALD. The oxide TFT from ZnO semiconductor with hafnium dielectrics was prepared by ALD for the first time to characterize the electrical properties.

2. Experimental

ZnO films were deposited on 100X100mm glass after cleansing by ALD using injection type source delivery system at the temperature of 150 °C. As a source of Zn diethylzinc was used. Oxygen plasma was used as oxygen precursor for ZnO fabrication. The reactor pressure was maintained 0.7 Torr with the Ar purging of 100 sccm. During the reaction diethylzinc and oxygen plasma were sequentially injected into the reactor chamber to form ZnO monolayer on the substrate.

HfO_2 films were deposited on the glass after cleansing by ALD at the temperature 200 °C. The source delivery system for ALD is using bubbler type delivery system. As a source of hafnium tetrakis(ethylmethylamino) hafnium (TEMAH) was used. Water was used as oxygen precursor for thin film fabrication. The reactor pressure was maintained 0.6 Torr with the Ar purging of 100 sccm. During the reaction TEMAH and oxygen precursor were sequentially injected into the reactor chamber to form HfO_2 monolayer on the substrate.

In order to make oxide TFT, ITO as gate metal was patterned by photolithography on the glass. On the gate hafnium oxide was deposited by ALD, and patterned by lift off process. Gold, as a source and drain metal, was deposited by thermal evaporator, and patterned by lift off process. Zinc oxide as an active channel material was deposited and patterned by photolithography.

3. Results and Discussion

The growth rate of thin film (average film thickness per cycle) was examined as a function of process condition, such as process temperature and reaction cycle. The growth rates were about 2 A°/cycle and 1.2 A°/cycle for zinc oxide and hafnium oxide, respectively. The structure of oxide TFT in this experiment is bottom gate and bottom contact. The thickness of hafnium prepared by ALD is about 660A°. Gold was used for source and drain metal. Zinc oxide was deposited to 200A° by ALD. No special treatment was used in this experiment. The structure of oxide TFT was shown in Figure 1.

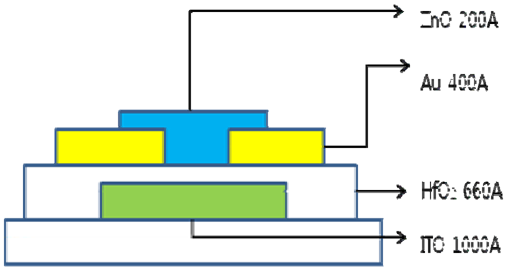

Fig. 1 Structure of Oxide TFT by ALD

Even though, there were few reports on the zinc oxide TFT by ALD technology. It is not easy to find the effect of hafnium oxide as gate dielectric on the oxide TFT. ALD is a recommended process to make hafnium thin film with good uniformity and conformability. We prepared a relatively narrow channel length oxide TFT with the dimension of width of 50 μm and length of 10 μm.

The transfer curve of zinc oxide TFT is shown as in Fig. 2 The electrical property of zinc oxide TFT was measured with the logId vs. gate voltage of the transfer curve of the transistor. This oxide TFT operates as an n-channel enhancement mode device. The positive gate voltage is required to induce a channel in the zinc oxide layer. The channel conductivity increases with gate bias voltage increasing. The on to off current ratio exhibits around 10^6 with good result. The on to off ratio is higher than the previous result of around 10^3 and the transfer characteristic shows fairly good. [16] The channel mobility, threshold voltage and subthreshold slope were calculated by a linear fit of the $Id^{1/2}$ vs gate voltage curve. The obtained channel mobility of oxide TFT is about 0.8 cm^2/Vs and threshold voltage is almost 0 V. The subthreshold slope is 0.9 V/dec. Carcia reported that ZnO TFT with hafnium oxide on heavily doped n-type Si wafers by magnetron sputtering, and showed a mobility of 12.2 cm^2/Vs, with a threshold voltage of 2.6V and subthreshold slope of 0.5V/decade. [17] He prepared relatively thin hafnium oxide of 250 A thick with the dimension of W/L = 200 μm /20 μm. The report did not mention the detailed experimental and TFT structure, however. He also mentioned that the gate leakage current with 250 A thickness of hafnium oxide was 10^{-7}A at Vg =10V. From our result we also obtained the gate leakage current of 10^{-7}A at Vg = 10V to 30V. We obtained that thicker hafnium dielectric shows similar leakage current with broad gate voltage regions. The gate leakage current is quite reasonable and can be reduced by decreasing the gate area.

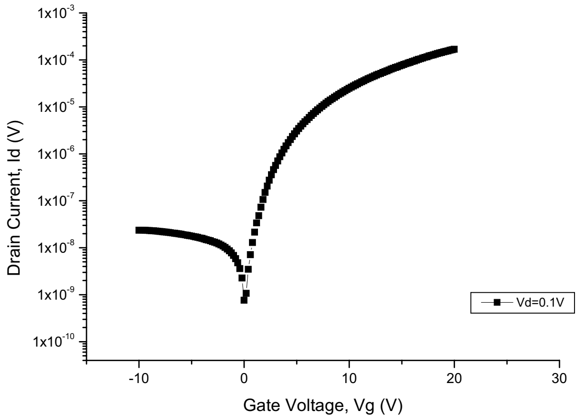

Fig. 2 Transfer curve of zinc oxide TFT with hafnium gate dielectric on glass substrate.

The drain current (Id) as a function of drain voltage (Vd) with hate voltage Vg of 30 V is shown in Fig. 3. The output characteristic shows pinchoff behavior and current saturation. The zinc oxide channel can be depleted of free electron in the saturation region. However, this oxide TFT shows output property with poor saturation at gate voltage of 30 V. This is due to the contact problem with voltage stress, and due to the weak gate dielectric with a relatively thin layer. It is critical to understand the gate dielectric growth mechanism and its chemical reactivity with the electrical performance. Because the hafnium oxide is deposited rather than crystal growth, the thickness issue with equivalent oxide thickness (EOT) plays an important role. More experimental results related oxide TFTs characteristics will be discussed in the near future.

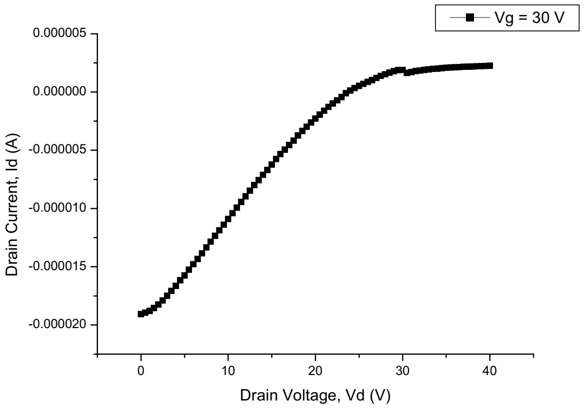

Fig. 3 Output curve of zinc oxide TFT with hafnium gate dielectric on glass substrate.

4. Summary

We prepared ZnO TFT with hafnium oxide gate dielectric by ALD technology. Good electrical characteristics of oxide TFT was obtained with channel mobility of 2.1 cm^2/Vs, threshold voltage of 0 V, the subthreshold slope of 0.9 V/dec, and on to off current ratio of 10^6.

5. References

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