Construction of ZnO devices : electric and magnetic properties

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Zinc oxide is one of the wide band gap semiconductors. By using the ZnO-layer as an active channel layer, transparent transistors (ZnO-TFTs) have been constructed. The ratio I_{on}/I_{off} of ZnO-TFTs fabricated on Si-wafers is about 10^6 and the optical transmittance of ZnO-TFTs fabricated on glass is more than 80%. It is also performed that the magnetic properties of ZnO thin films are controlled by V or Co doping under the non-equilibrium condition. Ferromagnetic properties of Co-ZnO films are confirmed by not only SQUID but also MCD and core-level XAS. Relatively weak signal of ferromagnetics suggests that a part of the film shows ferromagnetic character due to the inhomogeneous of the doped exotic cations (V, Co etc.). These results show that it is possible to fabricate a transparent spin-FET that can be operated even in the presence of visible light

I. INTRODUCTION

ZnO is one of the 2-6 compound semiconductors with a wide band gap of 3.3eV [1]-[6]. If we can control p-type and n-type conductivity of this material, it is expected that light emitting devices operating in the short-wavelength range, from blue to ultraviolet, such as LED based on GaN devices. Furthermore, ZnO is one of the rare materials which can be well crystallized even on the amorphous substrates such as glasses, SiO_2/Si and plastics. Using these characteristics, it is expected that transparent Thin Film Transistors (TFTs) using ZnO as the active channel layer. It is expected that the characteristics of ZnO-TFTs will not degrade on exposure to visible light due to the wide band gap of its active channel layer, whereas the characteristics of amorphous Si TFTs and poly Si TFTs do degrade. Therefore, there is no need to shield the active channel layer from visible light. This makes the TFT structurally-simple and transparent to visible light. This can allow the aperture ratio of active matrix arrays to be increased.

Here, we have described the construction and characteristics of bottom-gate-typeTFTs using ZnO as the active channel layer and a two-layer gate insulator, and discuss the reduction in the leakage current, the drain current characteristics, and the transparent TFT[7].

It is important to control both the electric properties and the magnetic properties of Zn O thin for the practical applications in opto-electronic and opto-magnetic devices at room temperature. We have also fabricated transparent magnetic materials with oxide semiconductors, such as V and Co substituted ZnO films.

II. EXPERIMENTAL

ZnO ZnO thin films were deposited by a pulsed laser deposition using ArF excimer laser which can deposit high quality oxide thin films. The target was a single crystal ZnO substrate (99.9999%) which is the highest-purity oxide available at present. Because of its broad application, an amorphous glass (Corning #1737), SiO_2/Si and sapphire were used as the substrates. The ZnO thin films of about 250nm thickness were deposited on the substrate at a temperature of 300-550℃ in an oxygen atmosphere. The oxygen gas pressure (P_{O2}) was changed from $6x10^{-4}$ to $1x10^{-1}$ Torr. For constructing the TFTs, SiO_2 and SiN are used as gate insulating layer.

Transition metal (TM) substituted for Zn in ZnO ($Zn_{1-x}TM_xO$ (x = 0 to 0.15)) films were formed on sapphire (0001) substrates. A low-temperature process (non-equilibrium process) such as a PLD is effective to introduce a much larger amount of exotic ions (magnetic ions) into the ZnO films, comparing with a conventional synthesize process for constructing bulk materials. Therefore, low temperature formation enables us to expand the solubility limit. Co and V are used as substituting TM elements up to 15%.

The crystal structure was evaluated by X-ray diffraction (XRD). The resistivity, carrier concentration, and Hall mobility, μ_{Hall}, of the films were measured by the Van der Pauw method using a four point probe. The surface morphology of the films was observed using an atomic force microscope (AFM). Magnetic measurements were performed using a superconducting quantum interference device (SQUID) magnetometer with the magnetic field applied parallel to the film plane. The magnetic circular dichroism (MCD) and Vis-UV spectra were measured under the magnetic field of –1.5T~+1.5T. XMCD, XAS and PES measurements were also performed under the collaboration of Dr.Fujimori's group.

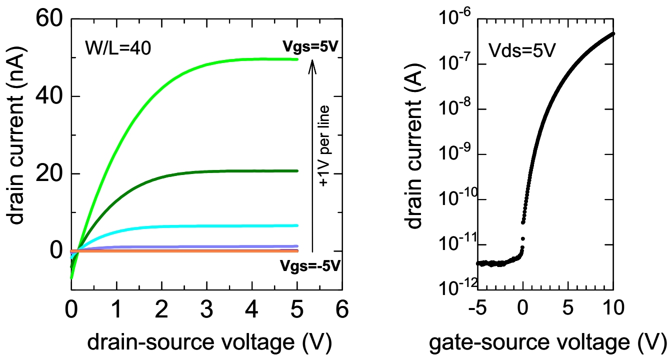

Fig.2 Id-Vds and Id-Vgs curves of ZnO-TFT[7]

III. RESULTS AND DISCUSSION

The 250nm thick SiO_2 layer had good insulation performance with a leakage current of approximately 10^{-10}A/cm^2 at an applied voltage of ±5V. However, upon depositing ZnO on the SiO_2 layer, the leakage current of the ZnO/SiO_2 double layer increased to 10^{-4}A/cm^2, and the insulating properties of the SiO_2 layer were degraded. Even in case of very thick SiO_2 insulating layer of 1.2 μm, it is not enough to protect the leakage current up to 1.0x10^{-9}A/cm^2. The double layer gate insulator comprised of SiO_2 and SiN_x is quite effective to realize the low leakage current below 1.0x10^{-11}A/cm^2.

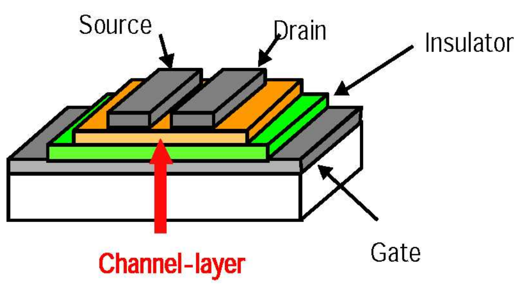

Fig. 1 Schematic model of ZnO-TFT

Using the SiO_2 and SiN_x double gate insulator suppressed the gate-source/drain leakage current and enabled the ZnO-TFT to operate successfully.(Fig.1) Figure 2 shows the electrical characteristics of a ZnO-TFT with a double gate insulator. It shows a typical feature of an enhancement-mode device as there was low drain current below 10^{-11}A/cm^2 at a gate voltage of 0V. And it shows good transistor character. The ratio of I_{on}/I_{off} was more than 10^5 whose value is similar with that of a-Si TFT using in practical device applications [7].

Theoretical calculations predict the ferromagnetic semiconducting properties should be observed in the transition metal doped ZnO [8]-[10].

Substituted Co and V for Zn have di-valent cationic state in the ZnO thin films formed epitaxially on the sapphire substrates [11]-[12]. XRD pattern and Raman measurements guarantee the wurtzite crystal structure can be maintained up to 15 % and 5% for Co and V substitution, respectively. The results of photo emission spectra also suggest that Co does not have metal state but 2+ states. Magnetic circular dichroism(MCD), X-ray MCD and SQUID measurements of (Zn,Co)O films indicate ferromagnetic properties with magnetization of 0.1-0.3 μ_B/Co. From these results, we can neglect the ferromagnetic properties coming form metal-Co. M-H hysteresis curves are observed by SQUID measurements (Fig.3). But it is not enough value when we think about the origin of double exchange type ferromagnetics. Additional experiments are required to discuss details before elucidating the mechanism of ferromagnetic properties of (Zn, Co)O films.

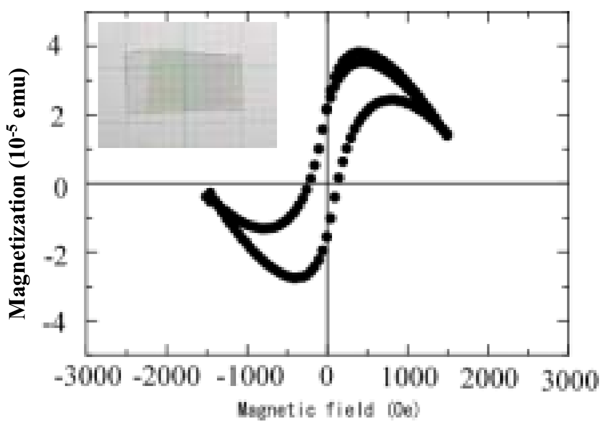

Fig. 3 M-H curve of (Zn,Co)O films. Inset shows photograph of transparent magnetic film

IV. CONCLUSION

We have demonstrated the bottom-gate-type TFTs using ZnO as the active channel layer and a two-layer gate insulator. And also ferromagnetic semiconductors are fabricated transition metal doped ZnO films. ZnO is one of the promising wide gap semiconductors having the various kinds of functions.

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