MOCVD grown Zinc Oxide Thin-Film Transistor

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Abstract

Zinc oxide (ZnO) is typically highly doped n-type semiconductor. To be used for thin-film transistor (TFT) devices, carrier concentration must be controlled precisely. We studied characteristics of ZnO grown by MOCVD at temperatures between 200℃ and 400℃. We found that hydrogen incorporated during growth plays important role in determining carrier density.

1. Introduction

Recently, ZnO attracted considerable attention as a promising wide-gap semiconductor for utilization in display devices and optoelectronic devices. ZnO has wurtzite structure with 3.4 eV band-gap energy. Among the many applications of ZnO, TFT is an important application due to high mobility and optical transparency. In 2004, Hosono group fabricated InGaZnO TFT by laser-deposition at room temperature [1]. In ref.1, their TFT has remarkable mobility, around 10 cm^2/Vsec. Today's trends show that next generation light emitting device in display system will be made of organic light emitting diodes (OLED). If OLED is employed, the driver circuit needs more current than conventional TFT-LCD, and ZnO can be a good candidate for this. But it still has some problems. ZnO can be degenerately doped n-type and electron concentrations in excess of 10^{21} cm^{-3} are achievable. But the high electron concentration of ZnO makes it difficult for transistor application. To be optimized for ZnO TFT, it is essential to control doping. The origin of n-type behavior is not completely understood yet. In 2000, Van de Walle suggested that hydrogen is responsible for donor-like defect in ZnO [2].

The purpose of this study is to realize ZnO-TFT for display devices. We investigated unintentionally doped hydrogen, caused by metal organic precursor, diethylzinc (DEZn). There are many methods to grow ZnO thin films. We chose metal organic chemical vapor deposition (MOCVD), because our goal is to develop technologies for large-area application, such as wide screen television. MOCVD has more advantage for large-area growth and mass production, compared to sputtering method. We grew ZnO films at low-temperatures, to make this method applicable for glass substrates.

2. Results

ZnO thin films were grown on silicon oxide substrate by MOCVD in horizontal reactor at atmospheric pressure. DEZn and oxygen (O_2) were used as precursors for Zn and O, respectively, and nitrogen (N_2) was employed as a carrier gas. The growth temperature was varied from 200℃ to 400℃. ZnO was also grown on high temperature-ZnO buffer layers. ZnO on high temperature buffer layer has better structural property and lower interface problem.

Fig. 1 is images of SEM (Scanning Electron Microscopy). It shows that smaller-grain structure at 200℃ (a), and the grain size becomes larger at 400℃ (b). In Fig. 2, (002) peak of wurtzite structure is observed from XRD measurement. The (002) peak is getting stronger as growth temperature is increased from 200℃ to 400℃. As expected, an increase in crystallinity is observed with increasing temperature.

Photoluminescence (PL) spectra measured at room temperature are shown in Fig. 3. It shows strong UV emission (around 389 nm), which is common characteristic of ZnO. Room temperature PL has been used to study electronic states and defects in greater detail. The little peak in Fig. 3 around 550 nm is possibly due to defects.

We fabricated ZnO TFTs on heavily doped n-type Si substrates (10^{19} cm^{-3}) with a thermal oxide layer of 1100 Å (Fig. 4 inset). Source and drain electrodes were deposited by Al evaporation using shadow mask (channel length=15 μm, width=500 μm).

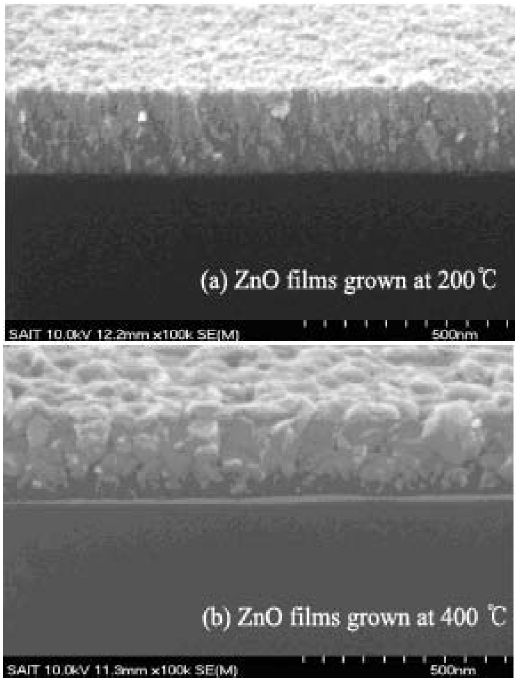

Fig. 1. SEM images of the ZnO films grown at different temperatures.

Fig. 4 is current-voltage characteristics of TFT grown at 300℃. It shows 15 cm^2/Vsec mobility measured at room-temperature. TFT grown at 400℃ showed lower mobility of 5 cm^2/Vsec. This is different from general case where higher growth temperature improves mobility. From Fig. 2, we can expect that 400℃ sample has better crystal quality than that grown at 300℃. This point tells us that crystal quality is not main factor in determining TFT characteristics.

Fig. 5 shows gate voltage dependence measured in the same device. It shows that turn-off is not complete, possibly due to defects in the channel. Fig.3 shows that the threshold voltage is about −30 V, which is too high for practical application. Our TFT also showed poor on/off ratio, and we think that it is due to the defects in the channel. More work is in progress to control the threshold voltage and leakage current.

We investigated the origin of mobility change. Fig. 6 is results of SIMS (Secondary Ion Mass Spectroscopy). It shows that our ZnO films have significant hydrogen and carbon concentrations, which depends on growth temperature. 400℃ grown sample shows lower hydrogen concentration than that of 250℃ sample. The origin of hydrogen and carbon is DEZn, because it is the only material containing them among our MOCVD source. Hydrogen and carbon are generated during growth when DEZn is decomposed by oxygen. Fig. 6 shows that more hydrogen is incorporated into the film when growth temperature is lower. Due to higher burning rate of H at high temperature, we can expect lower concentration of H at the substrate. SIMS profile also showed that more carbon is incorporated into the film at lower growth temperature. We think that the higher mobility in Fig. 4 is due to higher hydrogen concentration.

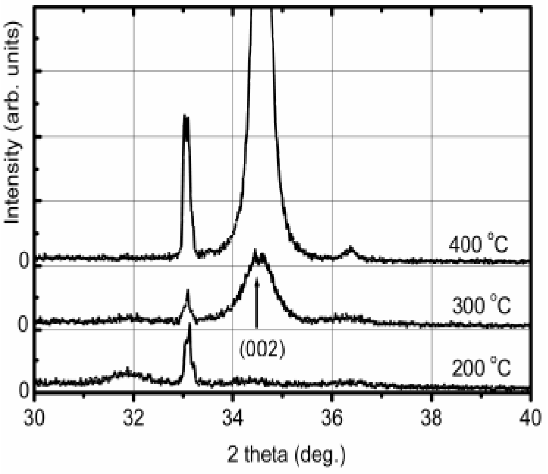

Fig. 2. X-ray diffraction from ZnO grown at different temperatures. The arrow indicates wurtzite (002) peak position, 34.422°.

Many experimental indications for hydrogen's behavior as a donor in ZnO were reported since 1950's. In ref. 3, Mollow observed that conductivity increase in ZnO by hydrogen exposure. Kohiki *et al* introduced hydrogen by proton implantation followed by annealing [4]. Those results show that hydrogen is a donor, similar to our results. It indicates that the hydrogen in ZnO does not reduce the conductivity, in contrast with hydrogen's behavior in other semiconductor.

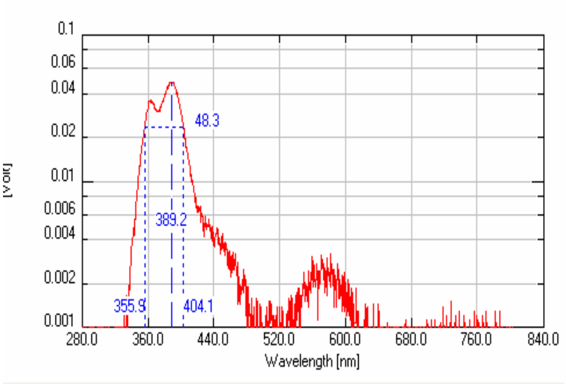

Fig. 3. PL spectra of ZnO grown at 400℃

SIMS profile also shows thickness of ZnO thin-film. The time axis represents thickness in Fig. 6. It can be seen that (a) 400℃ sample is thinner than (b) 200℃ one. It can be explained that Zn and O react quickly in reactor at the high temperature condition, between gas outlet and substrate. As a result, smaller amount of source material arrives on the surface of substrate at high temperature. This is the reason of the thickness difference of ZnO films at the same partial pressure of the source. And the carbon profile in ZnO film shows the defects of interface. The carbon peak of SIMS profile shows that more defects at the surface and interface of the film. It may cause leakage current or poor turn-off characteristic, which were mentioned above.

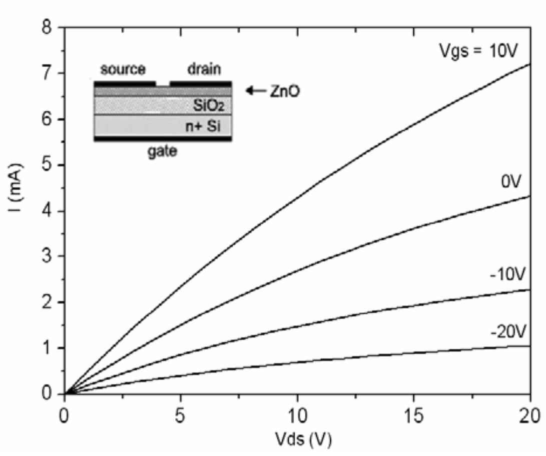

Fig. 4. Current-voltage characteristic of ZnO TFT, grown at 300℃.

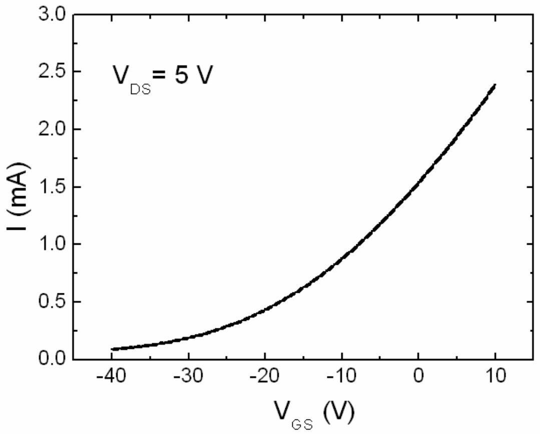

Fig. 5. Current change by gate voltage. The device is the same one used in Fig.4.

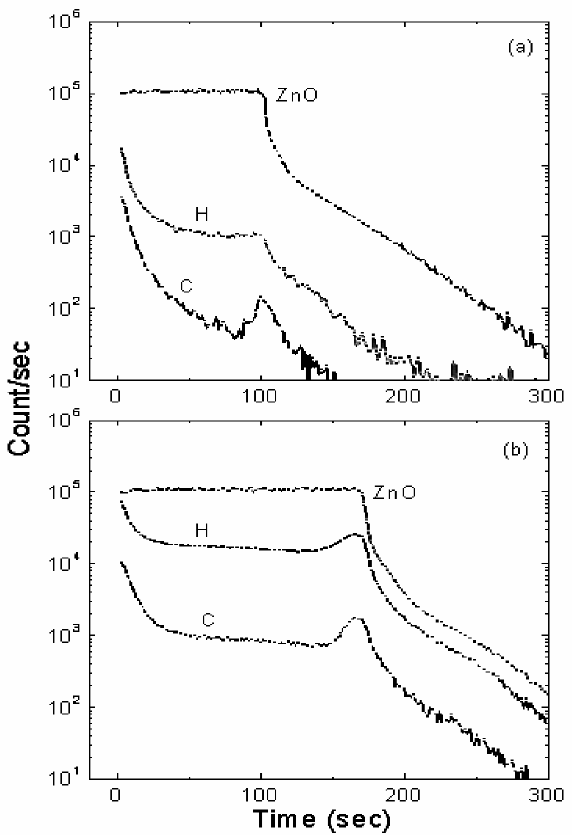

Fig. 6. SIMS profiles of hydrogen and carbon in ZnO. (a) grown at 400℃. (b) grown at 250℃.

The C and H peak at the surface show higher gas concentration at fresh surface. As growth continues, part of gas escapes from the film due to annealing. The peak at the interface is considered a result of defects. When ZnO growth starts at silicon dioxide surface, more defects will be generated, which are good collection sites for C and H. It is necessary to reduce these peaks in order to achieve good turn-off characteristics.

3. Conclusion

We demonstrate that high mobility ZnO films can be grown by low temperature MOCVD. Our SEM and XRD results show that good crystallinity can be achieved at growth temperatures below 400℃. The characterizations of defects in ZnO have important technological implications. In this work, SIMS measurement showed that hydrogen incorporated during MOCVD growth is responsible for the n-type behavior and hydrogen concentration depends on growth temperature. This is encouraging, because we can control doping by varying growth temperature. Remaining problems with this method are relatively poor turn-off characteristics and threshold voltage. It should be improved. We hope that optimum TFT performance can be obtained by adjusting growth condition and controlling H and other defects during growth.

4. Acknowledgements

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5. References

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