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Thermal Conductivity Temperature Dependence of Indium-Gallium-Zinc-Oxide Thin Films with Three-Omega Method and Characterizing Microstructure Analysis

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Abstract: *The thermal conductivity of Indium-Gallium-Zinc-Oxide (IGZO) thin films is investigated by the differential three-omega method at some temperatures (273K to 373K). The IGZO thin films are deposited on Al_2O_3 substrate by DC magnetron sputtering at different oxygen partial pressure (P_{O2}=0%, 10%, and 65%) and their thermal conductivities are found to be 1.64, 1.75 and 2.58 $Wm^{-1}K^{-1}$, respectively, at room temperature. The thermal conductivities are decreasing with increasing temperature due to the short mean free path of phonons. The mean free path is inversely proportional to the temperature, which indicates the crystallinity inside the IGZO. We found the nanocrystalline structure with multiphase by high resolution Transmission Electron Microscopy (HRTEM). The grain size of lattice fringes is estimated to be about 5 nm. The nano-size crystallites are oriented with the amorphous phase, but the crystalline structure is dominant.*

Keywords: Three Omega (3ω) Method, Thermal Conductivity, HR-TEM, Mean-Free Path

1. INTRODUCTION

The Indium Gallium Zinc Oxide thin film transistors have attracted numerous attention in the area of thin film transistor technology due to its high electron carrier mobility, controllability with respect to electrical conductivity, low intrinsic carrier concentration and promising optical transparency.[1] Most of the studies have been focused on the characterizing electrical, and optical properties of IGZO thin films but a careful study of the thermal properties and microstructure analysis have been lacking.[2] This study will examine the temperature dependency thermal conductivity measurement by using differential three omega (3ω) method of IGZO thin films at high temperature to make a clear conclusion about structural analysis. We estimated mean free path of IGZO thin films to clarify the phonon heat conduction. TEM (Transmission Electron Microscopy), HR-TEM (High Resolution Transmission Electron Microscopy) and FFT (Fast Fourier Transmission) pattern was obtained to characterize microstructure analysis.

2. METHODS

2.1 Thin Films Sample Preparation

IGZO thin films were deposited on a-Al2O3 substrate (Anode) having a thickness 500 nm by using DC magnetron sputtering method. As the target, a ceramic substance containing In, Ga, Zn (1:1:1) was used which is cathode. The deposition conditions of DC magnetron sputtering were as follows: the deposition power was 1000 W, the power density 1.43 W/cm^2, and the deposition pressure 0.7 Pa. The distance between the target and the substrate was 80 mm. The mixture of Ar and O_2 gases were used as a sputtering gas and flow rate of O_2 was varied at 0%, 10%, 65%. Fig.1 shows the Schematic diagram of dimension of shadow mask, metallic wire and IGZO thin film on a-Al_2O_3 substrate.

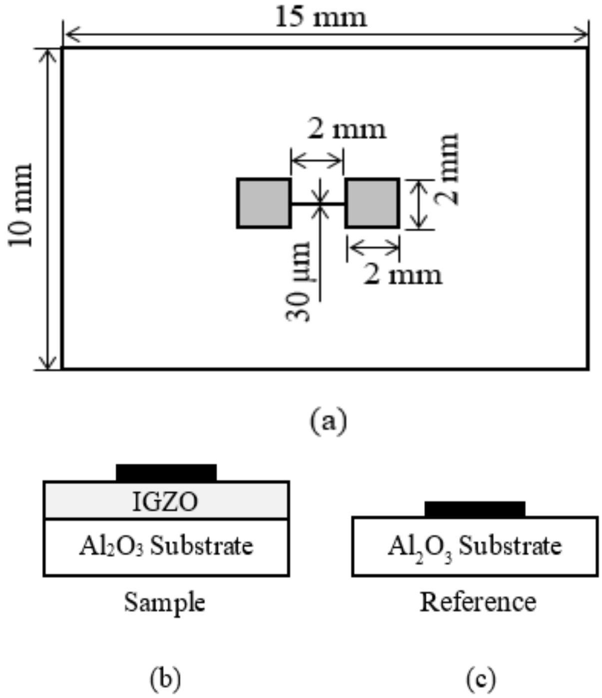

Fig. 1. Plain view (a) and sectional views for a sample (b) and for a reference (c).

2.2. Overview of Three Omega Method

3ω method employs very Cost effective and simple thermal conductivity measurement technique. Table 1 shows the values of thermal conductivity and Fig. 1 shows the temperature dependency thermal conductivity curve.

2.3. Overview of Focus Ion Beam (FIB) milling and TEM analysis

For TEM analysis, micro and nanoscale sample fabrication is very important. Focus Ion beam (FIB)milling is very popular technique for nanoscale fabrication. The FIB milling sample should be >100nm for nanocrystal analysis. FIB milling with very low beam current, we found surface defects top on the sample. It is very important to do Ar milling for removing the surface defects.

Table 1. Thermal conductivity measurement by 3ω method and fitted value of different sample at different temperature

Sample	Temperature	Thermal Conductivity ($Wm^{-1}k^{-1}$)
O_2 flow ratio 0%	RT	1.69
	50^0C (323 K)	0.79
	100^0C (373 K)	0.71
O_2 flow ratio 10%	RT	1.75
	50^0C (323 K)	1.08
	100^0C (373 K)	0.7
O_2 flow ratio 65%	RT	2.58
	50^0C (323 K)	1.23
	100^0C (373 K)	1.05

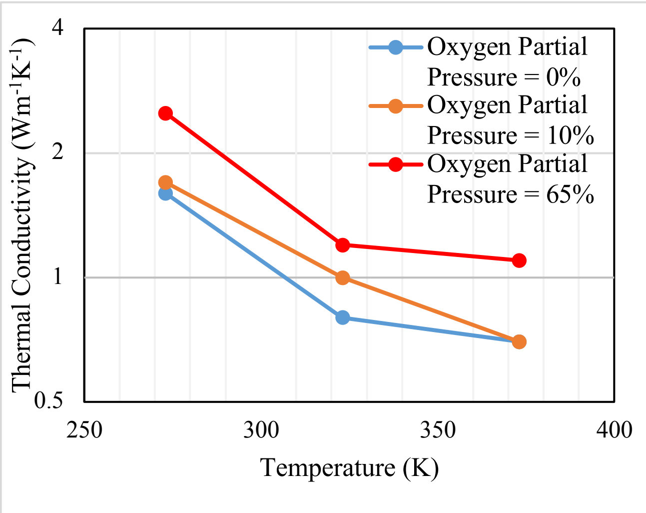

Fig. 2. the temperature dependency thermal conductivity of IGZO thin film.

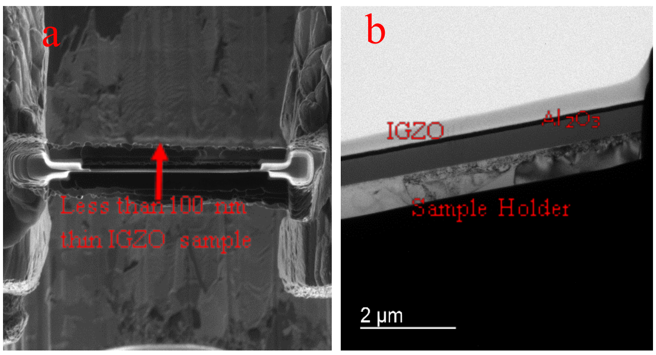

Fig. 3. (a) FIB milling >100 nm thinner sample of O_2 slow ratio of 10%, (b) surface defects before Ar milling

3. RESULT & DISCUSSION

The temperature dependency thermal conductivity has been measured at room temperature, 273 K (50 °C) and 373K (100 °C) for O_2 flow ratio 0%, 10% and 65%. As a result, we measured the cross – plane thermal

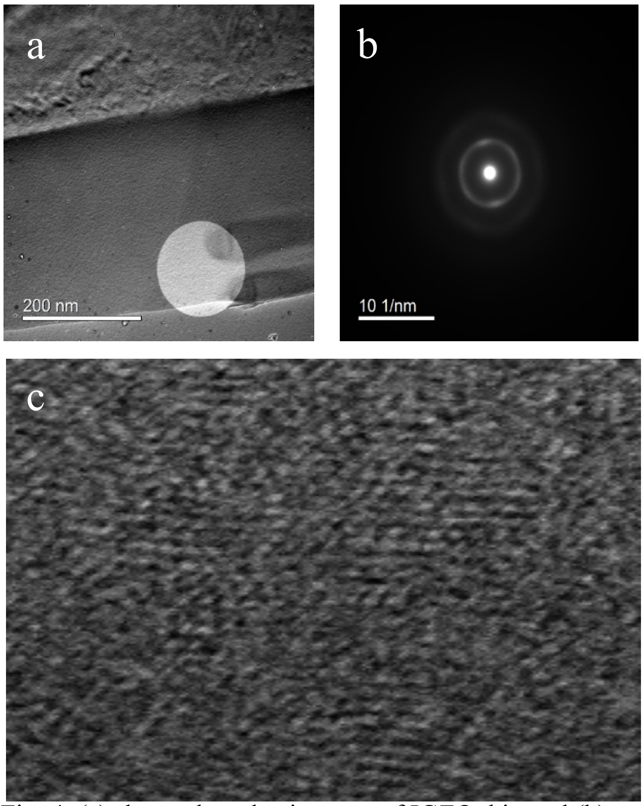

Fig. 4. (a) shows the selective area of IGZO thin and (b) is the image of SADF (Selective area diffraction pattern) (c) High resolution transmission electron microscopy (HRTEM) image.

conductivity of O_2 flow ratio 10% IGZO thin film sample is determined to be 1.75 $Wm^{-1}K^{-1}$ at room temperature. Table 1 shows the thermal conductivity of different O_2 flow ratio sample at different temperature. Fig.2. shows the temperature dependency thermal conductivity. The calculated mean free path is about 0.6 nm. Fig. 4 (b) & (c) represents the SADF pattern. From Fig. 4 (c), we have observed many lattice fringes which interpreted the nano-crystallinity orientation of IGZO thin film.

4. CONCLUSION

We successfully measure the thermal conductivity for the 0%, 10% and 65% O_2 flow ratio 500 nm IGZO thin film at high temperature which shows the nano-crystalline tendency. For microstructure analysis, we accomplished the TEM, HETEM, FFT analysis and we found the nano-crystallinity inside the amorphous IGZO. For qualitative analysis, we fitted the value of thermal conductivity in temperature dependency thermal conductivity curve to compare with the measurement parameter. Heat is conducted in IGZO thin film by lattice vibration. So that we estimated the mean free path of IGZO.

5. REFERENCES

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