Amorphous Thin Film for Thermoelectric Application

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Abstract. Amorphous-InGaZnO is n-type semiconductor material and has enormous potential such as transparency, flexible application owing to a low temperature fabrication process. In this study, Effects of annealing on the thermoelectric properties of a-IGZO thin film are evaluated for a low temperature process. We also demonstrated flexible TEG using a-InGaZnO and PEN substrate.

1. Introduction

Transparent Amorphous Oxide Semiconductor (TAOS) have been well-studied as channel layers for thin film transistors (TFTs), owing to their good transparency, flexibility and room temperature process. Among them, amorphous-InGaZnO (a-IGZO) thin films have been studied for applications other than TFT, which has been reported for a wide range of research results [1]. Our research group had previously reported on the thermoelectric performance of annealed a-IGZO [2, 3].

In this study, the thermoelectric properties of as-deposited and annealing a-IGZO were investigated. Additionally, a flexible a-IGZO thermoelectric generator (TEG) using polyethylene naphthalate (PEN) was fabricated. PEN is commonly used as a flexible substrate and offers good stability up to around 150 °C. Therefore a low temperature processes are needed.

2. Effect of annealing temperature

At first, annealing effects were evaluated. The a-IGZO thin film (200 nm) was deposited on quartz substrates using RF magnetron sputtering using sintered targets (In:Ga:Zn_2:2:1, at %) with an input power of 100 W. The thin film deposition was performed at a pressure of 0.6 Pa under O_2 and Ar atmosphere. In this process, oxygen partial pressure was set at 0%, 1% and 4.5%. Then, Au/Mo electrodes were deposited by electron beam evaporation. Finally, samples were annealed. The Seebeck coefficient and electrical conductivity were obtained at the room temperature.

As a results, annealing process is needed to increase the thermoelectric property (power factor: PF) in the samples with fabricated 1% and 4.5% oxygen partial pressure. On the other hand, the post annealing process is not necessary in the samples with fabricated 0% partial pressure.
3. Demonstration of flexible InGaZnO-TEG

Then flexible device was demonstrated as follows, the a-IGZO thin film (200 nm) was deposited on PEN substrate (2 cm × 4 cm) with same process (with 0% partial pressure). Au/Mo electrodes (20nm/100nm) were deposited by electron beam evaporation. No heat treatments were performed since a polymer substrate is used (Fig. 2).

Output voltage 6.7 mV and output power 0.12 nW was obtained at temperature difference of 53 K (Fig. 3). The thermoelectric performances are stable against bending. From the shape of the fabricated device, it can be seen that the thermoelectric module can generate 0.1nW with only two IGZO parts.

**Figure 1.** Thermoelectric properties and annealing effect of InGaZnO films on glass substrate formed with different oxygen partial pressure (0%, 1% and 4.5%).

**Figure 2.** Demonstrated flexibleπ-type device with two-IGZO area and one-electrode area on PEN substrate.
4. Demonstration of flexible InGaZnO-TEG with heat guide

Flexible thermoelectric generator with heat guide was demonstrated using a-InGaZnO and Mo electrode uni-leg structure with heat guide (Fig.4). The sample TEG was fabricated using PEN substrate with metal masks and photolithography process. The heat guides were formed using KMPR photoresist (thickness: 100µm). The 625 pairs of a-InGaZnO and Mo areas was designed. As shown in Fig.5, the demonstrated TEG was fully flexible. Output power of the demonstrated device was still small. However, the output power will be improved by optimizing the atomic composition of InGaZnO and the device structure.

Figure 3. I-V characteristics and output characteristics at ΔT=50°C. And output voltage at room temperature. Output power at room temperature.

Figure 4. Demonstrated thermoelectric device using hear guide. (a) Schematic image of TEG device. (b) Optical microscope image of TEG device before heat guide formation. (c) Optical microscope image of TEG device after heat guide formation.
5. Conclusion

The effects of annealing on thermoelectric properties of amorphous InGaZnO thin film were shown. And we also demonstrated flexible TEG using Mo and a-InGaZnO uni-leg structures on PEN substrate. If the Mo electrode were changed to the transparent conductive materials such as ITO, transparent and flexible TEG is possible with this structures. Additionally, semiconductor fabrication processes of IGZO are already well established. Therefore, it is easy to integrate the hundreds or thousands of pi-structures and it will generates $\mu$W scale output power.

References
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