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Effects of Annealing on In-Ga-Zn-Oxide Films

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Abstract

A crucial factor in determining the characteristics of semiconductor devices utilizing In-Ga-Zn-O (IGZO) films is the initial quality of the films. We formed IGZO films under various deposition conditions and evaluated the film quality to find that a low-density film formed under high deposition pressure contains much moisture and is extremely unstable. At the same time, such a film was shown to have higher quality, higher density, and higher stability by being subjected to annealing. Annealing also improved the quality of an initially dense film. This revealed that annealing has an effect of reducing a variation in characteristics of field-effect transistors.

1. Introduction

Recently, electronic devices using oxide semiconductors have attracted attention and have been researched and developed actively. Field-effect transistors (FETs) utilizing In-Ga-Zn-O (IGZO) have relatively high mobility and IGZO is replacing a-Si in commercialized liquid crystal and organic light-emitting diode displays having high resolution and low power consumption. In previous studies of IGZO films, IGZO including nano-crystals (what we name “nc”), which are an aggregation of nanoscale crystals, and c-axis-aligned-crystal (CAAC) IGZO [1−2] where crystal orientation is aligned in the c-axis direction and disordered in the a-axis and b-axis directions have been reported. This indicates the existence of a variety of crystal structures different from a so-called amorphous or single crystal structure. FETs utilizing CAAC-IGZO can have particularly high reliability, and use of the FETs in not only low-power-consumption displays but also nonvolatile memories and LSIs has been proposed [3].

Among various deposition methods of IGZO, which have been under study, sputtering is often employed in fabrication of displays. The film quality of IGZO is greatly dependent on deposition conditions of sputtering, and some sputter deposited films are so unstable as to be crystallized by electron-beam irradiation in transmission electron microscope (TEM) observation [4], which suggests the need to select deposition conditions carefully. Meanwhile, annealing is thought to be effective in reducing a variation in FET characteristics, and it has been reported that a variation in crystallinity of IGZO films was reduced by annealing [5]. The present study reports film qualities of IGZO depending on deposition condition and the effect of annealing.

2. Experiment

An IGZO thin film was deposited on a cleaned quartz substrate by RF or DC magnetron sputtering. As the target, a polycrystal substance containing In, Ga, and Zn at an atomic ratio of 1 : 1 : 1 was used. The relative density and purity of the target were 97.5 % or higher and 99.95 % or higher, respectively. Deposition power was 100 W and deposition pressure was 0.4 or 1.0 Pa. Ar and O_2 gas flow rates were set such that the gas flow ratio, O_2 / (Ar + O_2), was 0.02−0.33. Some of the fabricated samples were subjected to annealing at 450 °C.

Densities and impurity concentrations of the obtained films were measured by X-ray reflectivity analysis and by secondary ion mass spectrometry analysis, respectively. In addition, thermal desorption spectroscopy (TDS) analysis for estimation of the amount of gas released from the films was performed. The IGZO thin films were observed with a TEM to evaluate structures and crystallinity. To determine whether the crystal states of the films were changed by the electron-beam irradiation, the same regions were observed with a high-resolution TEM and examined for their crystal sizes. The current densities at the observation regions were measured to quantify the effect of the electron-beam irradiation, and the cumulative irradiation dose was calculated.

3. Result and Discussion

Table I presents density measurement results of the IGZO films formed under various deposition conditions, with or without the 450 °C annealing. The sample A formed under high deposition pressure exhibited a low film density, and it was found that lower deposition pressures lead to higher film densities. The density of the low-density film was not changed greatly by the 450 °C annealing.

Table I Film density under various deposition conditions, with or without annealing

	RF power [W]	Deposition pressure [Pa]	O_2 gas ratio [%]	Deposition temperature [°C]	Film density [g/cm^3]	450 °C annealing
sample A	100	1.0	2	RT	5.78	
sample B	100	1.0	2	RT	5.79	✓
sample C	100	0.4	2	RT	6.06	
sample D	100	0.4	2	RT	6.06	✓

Figure 1 shows TDS analysis results of the IGZO films deposited under the above conditions with or without the annealing. TDS analysis reveals release of gases with various mass numbers, from among which the amount of a gas at m/z = 18 derived from H_2O is shown in Fig. 1. As shown in the graph, from the sample A with a low film density, an extremely large amount of gas was released at approximately 100 °C in the TDS analysis; in contrast, the amount of released gas of the sample B subjected to the 450 °C annealing significantly decreased. It is presumable that the annealing changed the film quality and resulted in a reduction in the release at approximately 100 °C, which can be regarded as due to surface adsorbed water. In the samples formed under low deposition pressure, regardless of whether they were subjected to the annealing, the amounts of released gas in the TDS analysis were small, indicating that the moisture content of these films is initially low.

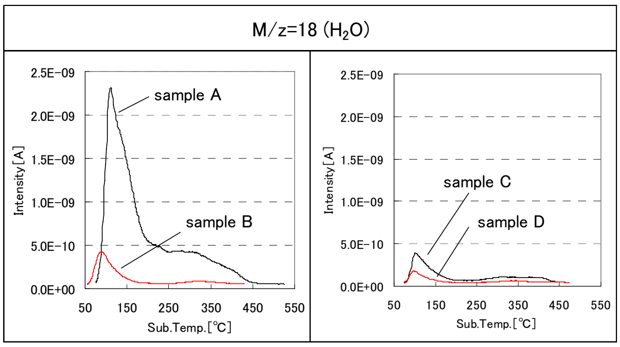

Fig. 1 TDS analysis results of the samples (m/z = 18).

Cross sections of the samples A to D were observed with a TEM. Voids were found in the films of the samples A and B but not in the films of the samples C and D, showing that the films of the samples C and D are uniform. To examine the stability of the films, we performed electron-beam irradiation with a TEM and checked film crystallization and crystal size. The results are shown in Fig. 2. As can be seen in the graph, in the sample A, the crystal size increased with an increase in cumulative irradiation dose; in contrast, in the sample B, a change due to the electron-beam irradiation was inhibited by the annealing and stability was achieved. In the sample C formed under low deposition pressure, a crystal size change due to the electron-beam irradiation was not seen without performance of the annealing. These results suggest that the initial film quality is of great importance and that annealing can improve film quality. On the day of the conference, we will give a more detailed description of the effect of annealing and will report FET characteristics.

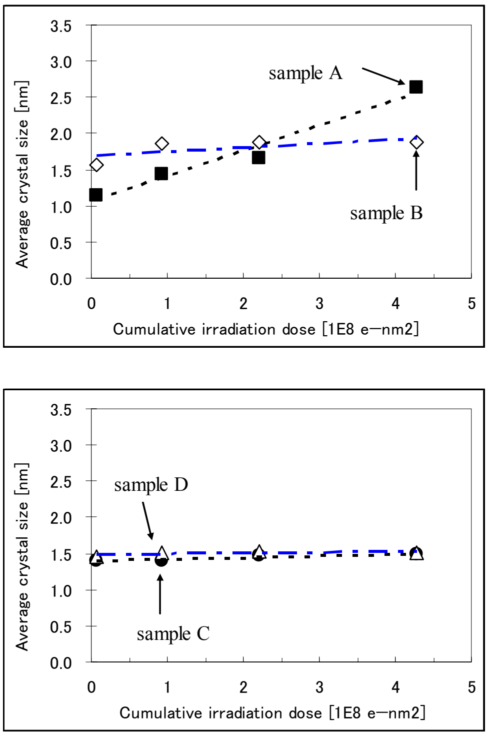

Fig. 2 Effects of electron-beam irradiation on the crystal size of the samples.

4. Conclusion

We conclude that a crucial factor in determining the characteristics of semiconductor devices utilizing IGZO films is the initial film quality. A low-density film formed under high deposition pressure contains much moisture and is extremely unstable. At the same time, such a film was shown to have high quality by being subjected to annealing. Annealing also improved the quality of an initially dense film. This revealed that annealing has an effect of reducing a variation in characteristics of FETs.

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