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Inductively Coupled Plasma Sputtering System for Oxide Semiconductors for a Large Area Deposition

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ABSTRACT

In this study, we have developed a Gen.4.5 size (730 × 920 mm) inductively coupled plasma (ICP) sputtering and evaluated the film density and thickness uniformity of the InGaZnO (IGZO) film. The film density was close to the theoretical value and the in-plane uniformity was ± 1% or less. The thickness uniformity was ± 2.2%. By using the ICP sputtering system, both high film density and thickness uniformity could be achieved.

1. INTRODUCTION

Recently, our life style have been influenced by the rapid development and widespread use of advanced display products such as tablet devices, and further development of those devices is being in progress. Therefore, high performance of thin film transistors (TFTs) for displays is required. Although some kinds of semiconductor materials for TFT have been investigated, those actually used for display are only amorphous silicon (a-Si), metal oxide semiconductor such as InGaZnO (IGZO), and low temperature polycrystalline silicon (LTPS). The LTPS has high electron mobility, however, the cost-effective production of LTPS is hard since the process cost is high due to having many fabrication steps. The a-Si is the standard TFT material in large area LCD panel. Because it's fabrication process has fewer steps ~~is simple~~ and is available for large substrate. However, the electron mobility of a-Si shows a low value and the switching speed and the drain current of TFT are resulted in low values. The IGZO is an excellent material because of high electron mobility and can apply to the large size substrate[1],[2]. Therefore, IGZO can be used for the large and high-definition screens, and organic EL displays with ~~at~~ low fabrication cost. But IGZO TFT has some issues in practical applications. One of them is that IGZO TFTs are not reliable enough for light and electrical stress [3], [4]; however, we have reported that high-reliability TFTs can be achieved by using a high-density IGZO film deposited by an Inductively coupled plasma (ICP) sputtering system (Gen. 1 size: 320 x 400 mm) [5], [6]. From the view point of the manufacturing processes for flat panel displays, a sputtering system that can deposit large-area substrates with good uniformity is required. In this study, we introduce the Gen. 4.5 size (730 x 920 mm) ICP sputtering system which have developed for the large-area film deposition.

2. ICP sputtering system

Figure 1 shows the schematic of the ICP-sputtering system. In this system, novel ICP antennas which has quite low inductance are installed in the vacuum chamber, and radio frequency （RF） generator of 13.56MHz is connected to the antennas. The high density of inductively coupled plasma is generated uniformly in the chamber space by modifying RF current phase. In this system, any magnetic fields are not arranged around the target, however, high density and uniform ICP plasma could assist target sputtering process. In order to get target material sputtering, a negative pulsed bias voltage is applied. We have reported that a high film density IGZO film can be obtained by independently controlling the ICP plasma generation and target bias voltage by the Gen.1 size ICP sputtering [6]. In case of a large-size substrate, we have developed highly uniform sputtering system thanks to placing low inductance ICP antennas in the optimal locations in vacuum chamber without any standing wave.

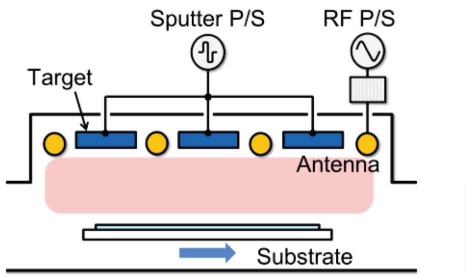

Fig. 1 ICP sputtering system constitution.

3. Experimental methods

The Gen. 4.5 size (730×920 mm) ICP sputtering equipment consisted of six antennas connected to the RF power supply and five IGZO (In:Ga:Zn = 1:1:1) targets connected to the DC pulse power supply. The IGZO films were deposited on a SiO_2 glass substrate with a film thickness of 50 nm by Gen. 4.5 size ICP sputtering system at room temperature. Film depositions were carried out by changing the O_2 / (O_2+Ar) gas ratio. The deposition pressure was 0.5 and 0.9 Pa, the input RF power was 20 kW, and target bias voltage was -400 V, respectively. For comparison, other samples were deposited by Gen. 1 size ICP sputtering at room temperature. The deposition pressure was 0.9 Pa, the input RF power was 7000 W, and target voltage was -200 V, respectively. The density of the IGZO films deposited by changing the oxygen ratio was obtained using X-ray reflectivity (XRR; Bruker D8 DISCOVER). The thickness of the IGZO films was obtained using spectroscopic ellipsometry.

4. Results

Figure 2 shows the relationship between oxygen ratio and IGZO film density by Gen. 4.5 and Gen. 1 sputtering system. The film density of the Gen. 4.5 size increased as the oxygen ratio increased up to around 6.3g/cm^3 which close to theoretical IGZO film density. Moreover, in the range where the oxygen ratio was 10% or more, the film density was higher than that of Gen. 1 size. Figure 3 shows the film density uniformity at the substrate area of 600x800mm^2. The film density shows between 6.15 and 6.24 g / cm^3, and its uniformity was less than ± 1% at the oxygen ratio of 2.5%. Figure 4 shows the film thickness uniformity of the IGZO film deposited by the Gen. 4.5 size sputtering system. The thickness uniformity was ± 2.2% at the substrate area of 700x900mm^2.

5. Discussion

The reason why the high film density could be obtained in spite of the large area substrate should be discussed. We have developed novel low impedance ICP antenna for large area substrate which can generate high density O_2 and Ar plasma above the IGZO target. These high density plasmas can assist IGZO sputtering deposition without applying higher bias voltage into the IGZO target. Therefore, sputtered IGZO particles will have an equivalent composite density to the IGZO target because the decomposition during sputtering reaction was suppressed thanks to low energy Ar ion irradiation. Furthermore, large amount of oxygen ions or radicals in the ICP assist plasma could oxidize sputtered IGZO particles during deposition.

The uniformity of the film density and deposition rate were resulted in high performance in large area of substrate. These results were obtained because low impedance antennas were used and the RF current of each antenna was uniformed by controlling RF circuit. We have previously reported that a low impedance antenna was used in a Gen. 6 size ICP-CVD to uniform the current of each antenna, resulting in good uniformity of deposition rate [7]. In the ICP sputtering system, excellent uniformity was obtained by using the same method. Figure 5 shows the relationship between the uniformity of each antenna current and the uniformity of the film deposition rate. The uniformity of film deposition rate becomes better with antenna current uniformity. We could control antenna current uniformity by adjusting variable capacitances which are inserted into RF circuit. It could be said film thickness uniformity is able to control by ICP antenna current adjustment which is our key feature. The film quality, the deposition uniformity and its controlling method using an ICP sputtering will be introduced at the conference.

6. Conclusion

We have developed a Gen. 4.5 size ICP sputtering system, and were able to obtain good film density and thickness uniformity. The low inductance ICP antenna technology could scale up to 3m in size without any standing wave effect. These results could increase the possibility of oxide semiconductor sputtering deposition for a large sized substrate up to Gen.10.

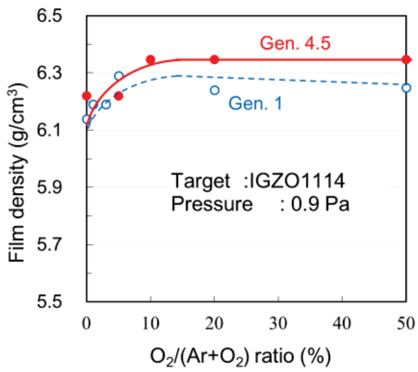

Fig. 2 Relationship between film density and oxygen partial pressure

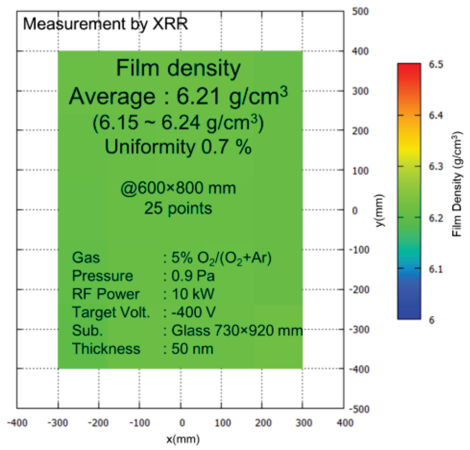

Fig. 3 Uniformity of film density by Gen. 4.5 ICP sputtering

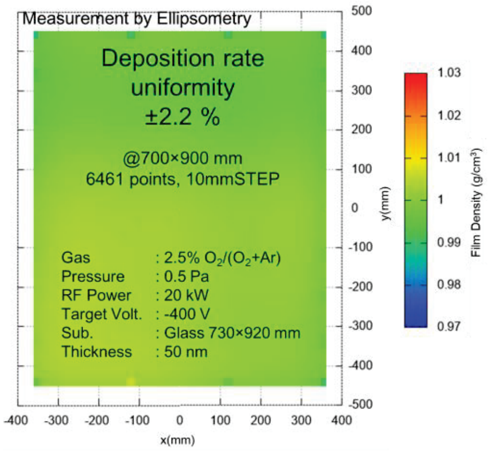

Fig. 4 Uniformity of deposition rate by Gen. 4.5 ICP sputtering

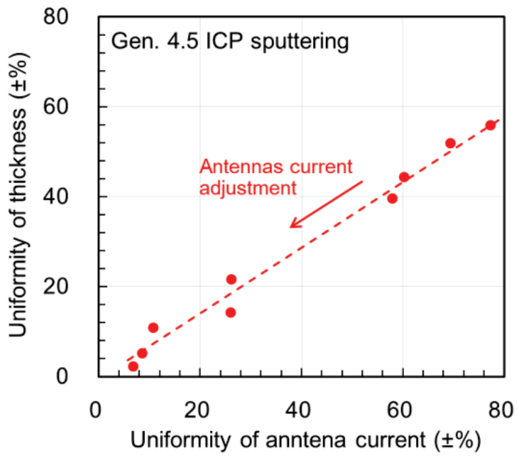

Fig. 5 Relationship between the uniformity of each antenna current and the uniformity of the film deposition rate by Gen. 4.5 ICP sputtering.

REFERENCES

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, "Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors" Nature, 432, pp. 488-492, (2004).

[2] T. Kamiya, K. Nomura, and H. Hosono, "Origins of high mobility and low operation voltage of amorphous oxide TFTs: electronic structure, electron transport, defects and doping" J. Display Technol., 5, pp. 273-288, (2009).

[3] A. Suresh, and J. F. Muth "Bias stress stability of indium gallium zinc oxide channel based transparent thin film transistors" Appl. Phys. Lett. 92, pp. 033502-1-033502-3 (2008)

[4] J.-M. Lee, I.-T. Cho, J.-H. Lee, and H.-I. Kwon, "Bias-stress-induced stretched-exponential time dependence of threshold voltage" Appl. Phys. Lett. 93, pp. 093504-1-093504-3 (2008).

[5] D. Matsuo, S. Kishida, Y. Setoguchi, Y. Andoh, R. Miyanaga, M. N. Fujii, and Y. Uraoka "High reliability a-InGaZnO TFT by inductively coupled plasma sputtering system" Proc. AM-FPD'17, P-L2, pp.197-198, (2017)

[6] D. Matsuo, R. Miyanaga, S. Kishida, Y. Setoguchi, Y. Andoh, M. Fujii, and Y. Uraoka "Fabrication of low temperature process TFT using high density a-InGaZnO film deposited by inductively coupled plasma sputtering system" Proc. The 24st Int. Display Workshops, pp.441-443 (2017)

[7] T. Sakai, M. Fujiwara, D. Azuma, S. Nakata, Y. Setoguchi, Y. Andoh "Deposition of Insulator Film by Inductively Coupled Plasma CVD System with Low Impedance Antennas" Proc. The 25st Int. Display Workshops, pp. 557-559, (2018)