# Formation of Ga-based amorphous oxide thin film transistors using plasma-assisted reactive processes

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**Abstract:** Fabrication of thin film transistors (TFTs) using amorphous oxide semiconductors (AOSs) was demonstrated via plasma-assisted reactive process. AOSs including a-InGaZnO$_x$ and a-Ga$_2$O$_x$ was formed by plasma-assisted reactive sputtering. The feasibility in control of amount of oxygen vacancy in AOS thin films was demonstrated due to independent control of the sputtering flux and reactivity via adjustments to the control target voltage and plasma density.

**Keywords:** AOS, a-IGZO, a-Ga$_2$O$_x$, TFT

## 1. Introduction

Amorphous oxide semiconductors (AOSs) with wide band gap have been attracting attention since their unique material properties including an extremely large bandgap, a high critical electric field, and acceptable electrical conductivity.[1] In application of AOSs, high-performance thin film transistors (TFTs) incorporating amorphous oxide semiconductors have attracted considerable attention as potential driving elements in next-generation flat panel displays. Among various oxide semiconductors, Fabrication of AOS TFT was demonstrated focusing on a-InGaZnO$_x$ (a-IGZO) and a-Ga$_2$O$_x$, which exhibits exceptional field-effect mobility values on the order of 10 cm$^2$ V$^{-1}$ s$^{-1}$. [1] It is also known that the electrical properties of a-IGZO films and a-Ga$_2$O$_x$ films can be greatly affected by minute amounts of oxygen introduced during the fabrication process. [2]

In this study, a-IGZO and a-Ga$_2$O$_x$ thin films was deposited using a plasma-assisted magnetron sputter deposition system and fabrication of AOS TFT using deposited films was demonstrated.

## 2. Experimental

Figure 1 shows plasma-assisted reactive magnetron sputtering deposition system incorporating internal LIAs, used to deposit AOS thin films. In this apparatus, four internal-type LIA modules were installed around a circular magnetron target inside the top flange of a cylindrical chamber made of aluminium with an inner diameter of 300 mm and a height of 70 mm. As post-deposition treatment, plasma irradiation and thermal annealing treatments were performed on the thin films deposited by this system. These four internal LIA modules are coupled to an RF power generator driven at 13.56 MHz via a matching network. The target to substrate distance was fixed at 50 mm, and an RF power of 500 W were applied for LIA modules and a target voltage of -400 V for a-IGZO deposition and RF power of 100 W for a-Ga$_2$O$_x$ deposition were applied to the targets. The electrical properties of the TFTs fabricated using these films were assessed with a semiconductor characterization system (Keithley 4200-SCS).

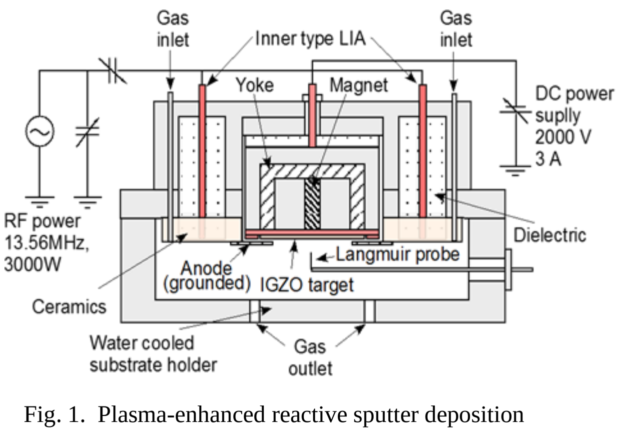


Fig. 1. Plasma-enhanced reactive sputter deposition system with inner-type LIAs.

## 3. Results

### 3.1 Fabrication of IGZO TFT using plasma assisted reactive processes

Figure 2 shows the typical transfer characteristics of TFTs fabricated using a-IGZO films treated with an Ar-H$_2$-O$_2$ plasma. The specimens fabricated using a-IGZO films treated with the Ar-H$_2$-O$_2$ plasmas exhibited the expected TFT transfer characteristics. A TFT fabricated using an a-IGZO film exposed to an Ar-H$_2$-O$_2$ plasma at substrate temperatures as low as 300 °C exhibited the best performance, with a field effect mobility as high as 42.2 cm$^2$V$^{-1}$s$^{-1}$, a subthreshold gate voltage swing of 1.2 V decade$^{-1}$ and a threshold voltage of 2.8 V. These results indicate that the species responsible for oxidation in the Ar-H$_2$-O$_2$ plasmas were able to oxidize the a-IGZO layers sufficiently and thus reduce the number of oxygen-deficiency-related defects. [3]

### 3.2 a-Ga$_2$O$_x$ deposition by plasma assisted reactive sputtering

Insulator-to-semiconductor conversion of a-Ga$_2$O$_x$ films by metal/oxide ion off-stoichiometry such as oxygen vacancy formation and hydrogen doping have been achieved by plasma-assisted reactive sputter deposition system. The change in conductivity of a-Ga$_2$O$_x$ thin films deposited by hydrogen-doped plasma-assisted reactive sputtering was then investigated by changing the H$_2$ partial pressure. The electrical resistivity of a-Ga$_2$O$_x$ thin films can be controlled from 10$^2$ Ωcm to 10$^5$ Ωcm by appropriately controlling the amount of hydrogen

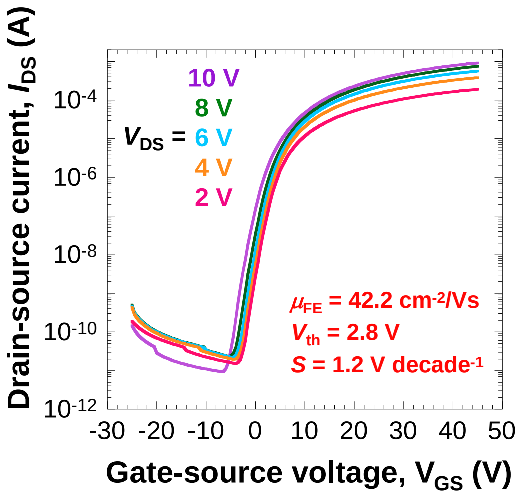


Fig. 2. Field effect mobility values for IGZO TFTs fabricated using a-IGZO thin films treated with Ar-$H_2$-$O_2$ plasma. (Reproduced from Ref. 3 with the permission of AIP Publishing.)

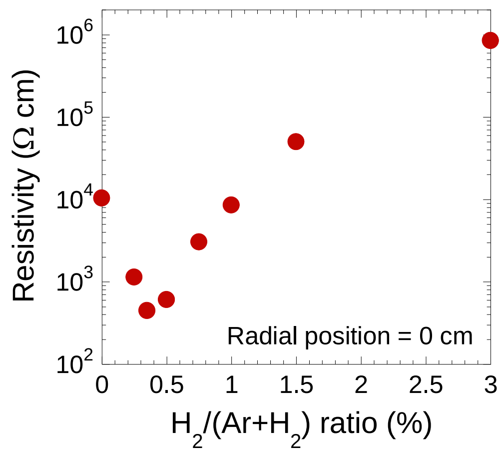


Fig. 3. Variation in resistivity of a-$Ga_2O_x$ thin film deposited by changing the $H_2$ partial pressure.

introduced from the plasma as shown in Fig. 3. The results indicate that the hydrogen acts as a shallow donor which increased the carrier concentration can be efficiently introduced by using the plasma-assisted reactive sputtering system with addition to $H_2$.

## 4. Summary

Fabrication of thin film transistors (TFTs) using amorphous oxide semiconductors (AOSs) was demonstrated via plasma-assisted reactive process. AOSs including a-InGaZn$O_x$ and a-$Ga_2O_x$ was formed by plasma-assisted reactive sputtering. In the formation of IGZO as the channel layer of a TFT, the fabrication of high mobility IGZO TFT demonstrated used by plasma-assisted reactive process. In the deposition of a-$Ga_2O_x$ thin films, the electrical resistivity of a-$Ga_2O_x$ thin films can be controlled from $10^2$ Ωcm to $10^5$ Ωcm by appropriately controlling the amount of hydrogen introduced from the plasma. The feasibility in control of amount of oxygen vacancy in AOS thin films was demonstrated due to independent control of the sputtering flux and reactivity via adjustments to the control target voltage and plasma density.


## 5. Acknowledgments

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