Hot Implantation Method for Oxide Semiconductor Resistance Control Technique

Yuya Yamane, Keisuke Yasuta, Toshimasa Ui and Junichi Tatemichi

E-mail: ui_toshimasa@nissin.co.jp
NISSIN ION EQUIPMENT CO., LTD.
29, Hinokigaoka, Minakuchi-cho, Koka, Shiga, 528-0068, Japan

Keywords: Hot implantation, IGZO, Resistance

ABSTRACT
As a next-generation device process, Hot implantation method for oxide semiconductor resistance control technique were investigated. We carried out investigation of hot implantation in a-IGZO film on glass structure. As a result, we find a-IGZO sheet resistance drastically decrease and implantation process window enhancement.

1 Introduction
Amorphous oxide semiconductors (AOS) are much widely used in flat-panel display industry due to the large bandgap, low-temperature processability, and low-cost fabrication ability in film deposition. Actually, thin-film transistors (TFTs) using the a-IGZO films show superior behavior compared with amorphous Si-based TFTs [1, 2]. In a-IGZO TFT processing, ion implantation technology as the a-IGZO sheet resistance reduction in the source and drain regions are widely used in industry, which has advantages in terms of implantation depth controllability, microfabrication processability, and mass productivity. In our previous work, we carried out conventional ion of boron (B+) or neon (Ne+) implantations in a-IGZO thin films and analyzed the implanted a-IGZO via Hall measurement with wet etching method [3, 4]. As a result, we find that a-IGZO sheet resistance $R_s$ reduction can be attributed to boron atom itself and oxygen vacancy (Vo) generated by ion implantations. We exhibited also that B+ or Ne+ implantations in a-IGZO films are useful as a resistance control technique. However, we find that there are cases of $R_s$ fluctuate greatly after annealing processes depending on implantation conditions, such as a-IGZO $R_s$ depending on B+ or Ne+ concentration variation in a-IGZO film owing to thickness fluctuations. Therefore, $R_s$ decrease and implantation process window enhancement are very important to improve device performances from the current for the future. In this work, we investigated implantation with sample heating (Hot implantation) method in terms of AOS $R_s$ decrease and implantation process window enhancement. Electron transport properties of B+ implanted one of conventional AOS a-IGZO films were investigated. On the other hand, bonding analyses by X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), and X-ray reflectivity (XRR) were carried out. As a result, we confirmed hot implantation method validity compared with the conventional process.

2 Experiments and Results
We prepared a-IGZO films with a film thickness 50 nm and sheet resistance ~ $10^{13}$ $\Omega/$sq. deposited by sputtering on glass (0.5-mm-thick Eagle-XG) [5]. In order to decrease the a-IGZO $R_s$, implantation at room-temperature (RT IMP) with or without post annealing, and the hot implantation were performed using iG series as shown in Figure 1 [6].

![Figure 1](image)

Fig. 1 (a) Schematic images of implantation in a-IGZO/glass structure at room-temperature (RT IMP), (b) RT IMP with post annealing, and (c) the hot implantation.

![Image](chart)

Fig. 2 50-nm-thick a-IGZO sheet resistance $R_s$ without implantation (No IMP) or with RT IMP, RT IMP with post annealing (RT IMP + ANL), hot implantation (Hot IMP) for all ion species, where dose $1 \times 10^{15}$ ions/cm$^2$ and mean projected range $R_p \sim 15$ nm. The inset shows implantation scheme on a-IGZO/glass structure.
Fig. 2 shows a-IGZO $R_s$ without implantation (No IMP) and with RT IMP or hot implantation at 300 °C (Hot IMP), where the implantation dose $1 \times 10^{15}$ ions/cm$^2$ and mean projected range $R_p \sim 15$ nm for all ion species. In addition, post ANL with 300 °C 1 hour in N$_2$ ambient after RT IMP (RT IMP + ANL) cases for each ion species were also plotted. Although a-IGZO $R_s$ decreases in the case of RT IMP + ANL compared with RT IMP case, a-IGZO $R_s$ further decreases after Hot IMP. We find that B$^+$, Ne$^+$, PH$_x^+$, and Ar$^+$ implanted a-IGZO $R_s$ are small value in these ion species. From these ions, we investigated the B$^+$ implanted a-IGZO films in terms of device processing, such as large penetration ability from insulators to a-IGZO channel layer. Figure 3 shows 50-nm-thick a-IGZO $R_s$ as a function of B$^+$ ion energy $E_{ion}$ with RT IMP, RT IMP + ANL, and Hot IMP at 300 °C, respectively, where dose $1 \times 10^{15}$ ions/cm$^2$. The inset shows implantation scheme on a-IGZO/glass structure.

Fig. 4 (a) B atom concentrations as a function of depth in the cases of RT IMP, Hot IMP, and a calculation using Transport of Ions in Matter (TRIM), where $E_{ion} = 40$ keV, dose $1 \times 10^{15}$ ions/cm$^2$, the depth = 0 nm is a-IGZO surface and depth = 200 nm is a-IGZO/glass interface position, respectively. (b) Electronic and nuclear stopping powers in a-IGZO estimated by TRIM.

Figure 2 shows a-IGZO $R_s$ without implantation (No IMP) and with RT IMP or hot implantation at 300 °C (Hot IMP), where the implantation dose $1 \times 10^{15}$ ions/cm$^2$ and mean projected range $R_p \sim 15$ nm for all ion species. In addition, post ANL with 300 °C 1 hour in N$_2$ ambient after RT IMP (RT IMP + ANL) cases for each ion species were also plotted. Although a-IGZO $R_s$ decreases in the case of RT IMP + ANL compared with RT IMP case, a-IGZO $R_s$ further decreases after Hot IMP. We find that B$^+$, Ne$^+$, PH$_x^+$, and Ar$^+$ implanted a-IGZO $R_s$ are small value in these ion species. From these ions, we investigated the B$^+$ implanted a-IGZO films in terms of device processing, such as large penetration ability from insulators to a-IGZO channel layer. Figure 3 shows 50-nm-thick a-IGZO $R_s$ after RT IMP, RT IMP + ANL, and Hot IMP at 300 °C as a function of B$^+$ ion energy $E_{ion}$, where the $E_{ion}$ range is 10-80 keV and dose $1 \times 10^{15}$ ions/cm$^2$ for all the samples. In the case of RT IMP, a-IGZO $R_s$ reduction can be attributed to electrons generated by Vo. Although Vo densities are decreased by the RT IMP + ANL, a-IGZO $R_s$ decrease in $E_{ion} < 20$ keV, which is attributed to electrons generated by boron-oxygen bonding owing to many boron atoms staying at 50-nm-thick a-IGZO film. On the other hand, in Hot IMP case, a-IGZO $R_s$ < a few 10$^3$ $\Omega$/sq. in $E_{ion} = 10-80$ keV. In addition, Hot IMP a-IGZO $R_s$ is smaller than that of RT IMP + ANL a-IGZO in $E_{ion} \sim 20$ keV. Therefore, a-IGZO $R_s$ decrease and implantation process window enhancement are
expected by Hot IMP, compared with RT IMP and RT IMP + ANL a-IGZO films. In order to elucidate the difference between the a-IGZO Rs results via RT IMP or Hot IMP, secondary ion mass spectrometry (SIMS) was performed for the sake of boron atom (B) profile evaluations in the 200-nm-thick a-IGZO films. Figure 4 (a) shows B atom concentrations as a function of depth in the cases of RT IMP, Hot IMP, and a calculation using Transport of Ions in Matter (TRIM), where Eion = 40 keV, dose 1x10^15 ions/cm^2, the depth = 0 nm is a-IGZO surface and depth = 200 nm is a-IGZO/glass interface position, respectively [7]. The all profiles are consistent, which exhibit that B atom diffusion can hardly be occurred in Hot IMP processes. Hence, Rs reduction by Hot IMP is independent of B profile. On the other hand, Figure 4 (b) shows electronic and nuclear stopping powers in a-IGZO estimated by TRIM. From the stopping powers, we obtain B⁺ Hot IMP depth control technique in a-IGZO films. We carried out room-temperature Hall measurements 50-nm-thick a-IGZO films after RT IMP or RT IMP + ANL or Hot IMP to separate from carrier concentration n and Hall mobility μ. From the measurements, we obtained n and μ as a function of Eion as shown in Figure 5 (a) and (b), respectively, where the doses are 1x10^15 ions/cm^2 for all the samples. In the case of Hot IMP, n and μ in the range of Eion > 20 keV are higher than that of RT IMP and post ANL a-IGZO films. In terms of higher n analysis, we performed XPS analyses of a-IGZO so as to analyze Vo concentration. Figure 6 shows XPS oxygen 1s (O1s) spectra on No IMP a-IGZO and a-IGZO with RT IMP or RT IMP + ANL or Hot IMP, where the implantation conditions are Eion = 15-20 keV, dose 1x10^15 ions/cm². The fitting lines consist of three peaks with the peak center of In, Ga, and Zn metal-oxygen (M-O) at 530 eV, M-O related to Vo (M-O vac.) at 531 eV, metal-hydroxyl groups (M-OH) at 532 eV.
or without the post ANL. In addition, M-O vac. peak decreases after the RT IMP + ANL compared with RT IMP, which exhibits Vo density decreases by the post ANL. On the other hand, M-O vac. peak after Hot IMP is comparable with RT IMP case, which exhibits the Vo concentration decrease is suppressed by Hot IMP. Therefore, $a$-IGZO $R_s < a$ few $10^3$ $\Omega$/sq. in $E_{ion} = 10-80$ keV are realized by Hot IMP, as shown in implantation process window enhancement in Figure 3. In terms of higher $\mu$ analysis, we performed X-ray diffraction (XRD) measurements of 50-nm-thick a-IGZO film on glass to analyze amorphousness. Figure 7 shows XRD profiles of glass substrate and a-IGZO/glass structures without implantation and with Hot IMP, where the implantation conditions are $E_{ion} = 20$ keV, dose $1x10^{15}$ ions/cm$^2$. The all profiles except the glass are consistent halo peaks without crystal nature, regardless of whether with or without implantation, which exhibit that amorphous nature of a-IGZO keeps after the implantations.

We carried out XRR analyses of a-IGZO/glass structures through 5 parallel processes, a-IGZO/glass (1) No IMP, (2) No IMP + ANL, (3) RT IMP, (4) RT IMP + ANL and (5) Hot IMP shown in Figure 8. From XRR analyses, we obtained a-IGZO densities shown in Figure 8. From (1) and (3) in Figure 8, a-IGZO film density decreases after the RT IMP due to breaking bonds between atoms. In addition, a-IGZO film density increases after RT IMP + ANL compared with RT IMP case from (3) and (4). Furthermore, a-IGZO film density increases after Hot IMP compared with RT IMP + ANL case from (4) and (5). Hence, we find a possibility of breaking bonds with recombination between atoms in a-IGZO by Hot IMP. From the recombination, higher $\mu$ behaviors are generated by carrier scattering probability reduction, which induces further $R_s$ reduction.

3 Summary

We carried out $B^+$ Hot IMP method in order to a-IGZO $R_s$ decrease and implantation process window enhancement. From electron transport properties, a-IGZO $R_s$ decrease and process window enhancement are expected by Hot IMP, compared with RT IMP and RT IMP + ANL. On the other hand, from bonding analyses, we find $n$ increase due to Vo density decrease suppression by Hot IMP. In addition, we find also a possibility that $\mu$ increases due to the recombination between atoms in a-IGZO film by Hot IMP. We expect that Hot IMP method are useful as a resistance control technique for oxide semiconductor device processing.

References


