Effect of cathode current on trap states density in In-Ga-Zn-O thin films

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Amorphous In-Ga-Zn-O (a-IGZO) is one of the most promising materials for development of Schottky diodes and metal–semiconductor field-effect transistors (MESFET) for fast and low power consumption integrated circuits, optical and chemical sensing devices, and active-matrix displays manufactured on both rigid and flexible substrates. Amorphous microstructure of a-IGZO results in intrinsically high concentration of subgap states, which could create shallow-levels in the depletion region of Schottky contact. This in turn increases probability of charge tunneling through the potential barrier. This could result in such negative impacts on MESFET performance as: increase of the subthreshold swing value, positive shift of the threshold voltage, and reduction of the channel mobility. It is acknowledged that deposition conditions strongly affect a-IGZO properties, therefore in the following study we examined the effect of one of the main parameters of sputtering, namely magnetron cathode current (I_c) on charge density in the depletion region of Ru-Si-O/In-Ga-Zn-O Schottky barriers and electrical properties of MESFET transistors.

The trap states density in the depletion region of Ru-Si-O/In-Ga-Zn-O Schottky barriers were studied based on I-V and C-V characteristics. We applied atom probe tomography, to evaluate chemical composition and atom pairs distances of a-IGZO thin films. The density of a-IGZO was evaluated by X-ray reflectivity. Carrier concentration and mobility were determined by Hall-effect measurements in van der Pauw configuration.

Results of our experiments show that increasing cathode current from 90 to 150 mA caused densification of a-IGZO thin films from 5.95 to 6.05 g/cm^3, while free carrier concentration (n) and mobility (μ_{Hall}) increased from $n = 6.2 \times 10^{16}$ cm^{-3} and $\mu_{Hall} = 7.8$ cm^2/V·s to $n = 3.7 \times 10^{17}$ cm^{-3} and $\mu_{Hall} = 9.1$ cm^2/V·s, respectively. Observed variations in electrical transport parameters are in good agreement with first-principles calculations reported by Kamiya et al. [1]. They show that a low-density structure forms numerous free spaces acting as electron traps. Therefore, we attribute the improvement of a-IGZO transport properties to the reduction of structural defect density of thin films sputtered at higher I_c. As I_c increases the In-In distances become smaller, leading to higher In 5s orbirals overlapping which in turn causes increase of free carriers mobility. Simultaneously, as I_c increases the Schottky barrier height increases from 0.79 to 0.90 eV and ideality factor decreases from 2.32 to 1.79. n_{depl} values, represented by subgap trap density and the ionized atoms that contribute to a-IGZO doping, evaluated from $1/C^2$-V decreases from 2.2×10^{18} to 4.1×10^{17} cm^{-3} for Schottky barriers with higher a-IGZO film density. One can also observe that as I_c increased from 90 to 150 mA MESFET channel mobility (μ_{ch}) and subthreshold swing (S) improved from $\mu_{ch} = 7.5$ cm^2/V·s and S = 580 V/dec to $\mu_{ch} = 8.8$ cm^2/V·s and S = 420 V/dec, respectively. Since that parameters are indicators of the subgap trap density of the semiconductor, the enhancement of MESFET performance at higher I_c indicates that the trap density in depletion region of Schottky gate contact can be reduced by the densification of a-IGZO thin films.

[1] T. Kamiya, et al., *Phys. Status Solidi A*, vol. 206, no. 5, pp. 860-867, Apr. 2009