SOLUTION PROCESSED ULTRAWIDE BANDGAP INSULATOR TO SEMICONDUCTOR CONVERSION OF AMORPHOUS GALLIUM OXIDE VIA FERMI LEVEL CONTROL

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Silicon and more recently wide bandgap (WBG) semiconductor materials have dominated the integrated circuit (IC) and thin-film transistor (TFT) space, respectively. For instance, Si technology is widely used in complementary metal oxide semiconductor (CMOS) architectures and as conventional channel material in TFTs in its amorphous and polycrystalline phases. On the other hand, WBG semiconductors such as amorphous InGaZnO have been recently poised to replace a-Si as the dominant TFT channel material especially in modern displays for their superior mobility, transparency, and low temperature processability. Nevertheless, a shift towards ultrawide bandgap (UWBG) semiconductors which have bandgaps (E_g) larger than 4.0 eV unlocks additional properties such as higher breakdown voltage, excellent transparency at wider wavelength range, and harsh environment resilience [1]. These UWBG materials, such as Gallium oxide (Ga_2O_3), will have applications in power electronics, solar blind photodetectors, deep-UV optoelectronics, and harsh environment electronics. However, research on UWBG materials have been largely focused on their crystalline phase and vacuum deposition [2]. For achieving cost-effective and large area scalable devices, amorphous UWBG materials deposited using solution process need to be studied and developed. A large roadblock is that amorphous UWBG materials, especially when solution processed, tend to be insulating because the combination of large E_g (>4.0 eV) and amorphous phase makes it difficult to attain electronic conduction which is further exacerbated by having low carrier concentration and precursor-related defects. Here, we demonstrate how insulator to semiconductor conversion of an UWBG material, amorphous gallium oxide (a-Ga_2O_x), was achieved through Fermi level (E_F) control. By subjecting a-Ga_2O_x to hydrogen annealing, its carrier concentration is increased due to hydrogen acting as a shallow donor which shifted E_F closer to the conduction band. As a result, TFT switching characteristics was obtained as shown by the comparison between as-deposited and H_2 annealed a-Ga_2O_x TFT in Figure 1. In addition, because of the huge number of experimental parameters such as film thickness, annealing temperature, H_2 gas concentration, and their complex interaction among each other and with E_F, we utilized supervised machine learning to predict the E_F of solution processed UWBG a-Ga_2O_x film as shown in Figure 2. With the E_F prediction method and knowledge of how hydrogen affects E_F, we are able to achieve semiconducting behavior even in as-deposited solution processed a-Ga_2O_x TFTs by controlling the relative humidity during the film deposition and baking processes.

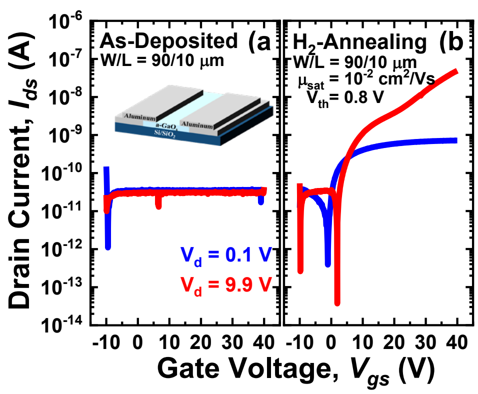

Figure 1 – Transfer characteristics of a-Ga_2O_x TFT (a) as-deposited and (b) after H_2 annealing [3]

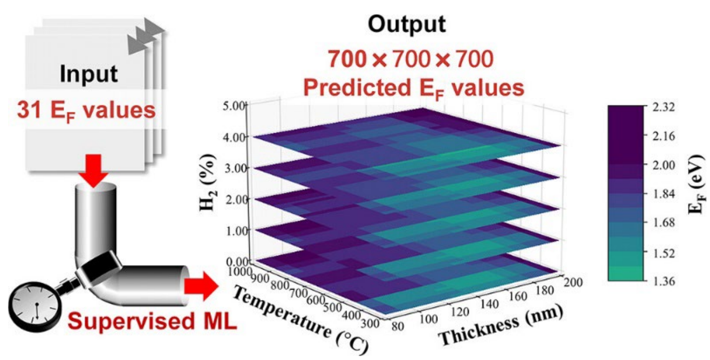

Figure 2 – Fermi level prediction of a-Ga_2O_x through machine learning regression models [4]

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