Fundamentals and Technology of Multifunctional Materials and Devices
Room Sunrise - Session C2-3

Novel Oxide Films for Active Devices

Moderators: Marko Tadjer, Naval Research Laboratory, USA, Vanya Darakchieva, Linkoping University, Sweden

8:00am **C2-3-1 Improved the PI Transmittance and ITO Conductivity by Supercritical CO_2 Fluid Treatment**, *G Chen, **ChienYu Lin**, T Chang,* National Sun Yat-Sen University, Taiwan*; S Lin, M Yu, Y Chuang,* HannStar Display Corp, Taiwan

In the flexible display, PI is often selected as the substrate, to achieve the requirement of foldable devices. The electrode of the display must be made of transparent metal. In this paper, the PI transmittance and ITO conductivity was improved the by supercritical CO_2 ($SCCO_2$) fluid technology. The advantages of supercritical fluid treatments are high penetration and high solubility can easily take away impurities and doped the film at room temperature. Supercritical fluid technology can bring out the monomer molecules and eliminate defects in PI substrate, inducing to higher transmittance. Hydrogenation $SCCO_2$ increase the conductivity of ITO to improve device performance.

8:20am **C2-3-2 Improving Performance by Inserting an In_2O_3 Layer into HfO_2-Based Resistive Random Access Memory**, ***Cheng-Hsien Wu,*** National Sun Yat-Sen University, Taiwan*; S Lin,* National Tsing Hua University, Taiwan*; T Chang, T Tsai, Y Lin, Y Tseng,* National Sun Yat-Sen University, Taiwan

This letter investigates the characteristics of inserting an indium-oxide (In_2O_3) layer in HfO_2-based resistive random access memory (RRAM). Inserting In_2O_3 layer in the Pt/HfO_2/TiN structure not only reduces the forming voltage and the operating current, but also enlarges the memory window. The fitting result of the current-voltage (I-V) curves shows that the conduction mechanisms in high resistance state (HRS) are dominated by Schottky emission conduction for both structures. However, in low resistance state (LRS), the conduction mechanism is Ohmic conduction in Pt/HfO_2/TiN, but Poole-Frenkel emission mechanism in Pt/HfO_2/In_2O_3/TiN. Based on the material analysis and the current fitting result, a physical model is proposed to explain this phenomenon.

8:40am **C2-3-3 Halide Vapor Phase Epitaxy of Ga_2O_3**, ***Ken Goto,*** *Q Thieu, D Wakimoto, K Sasaki,* Novel Crystal Technology, Inc., Japan*; K Konishi, H Murakami, Y Kumagai,* Tokyo University of Agriculture and Technology, Japan*; A Kuramata,* Novel Crystal Technology, Inc., Japan*; S Yamakoshi,* Tamura Corporation, Inc., Japan **INVITED**

Gallium oxide (Ga_2O_3) has been actively researched and developed as one of the wide-bandgap semiconductors for next-generation power devices in recent years, and literatures on high-voltage operation of SBDs and FETs were reported. However, in order to introduce Ga_2O_3-based power devices to the market, it is inevitable to establish mass production technologies, especially manufacturing technology for large-diameter wafers with thick and conductivity-controlled epitaxial films on them. Epitaxial growth of single crystal Ga_2O_3 films is reported, which is achieved by using several growth methods such as MBE, PLD, CVD (including MOCVD and mist-CVD) and halide vapor phase epitaxy (HVPE). Among them, HVPE method has demonstrated high-speed growth and doping control over a wide range, and it is suitable for a commercial use because it has a simple hardware structure without using a vacuum system, for instance.

It was thermodynamically analyzed that HVPE growth of β-Ga_2O_3 is possible by using gallium mono-chloride (GaCl) and oxygen (O_2) as precursors, and a high-purity single crystal homoepitaxial film can be grown at a high temperature of 1000 °C in a hot-wall reactor. The growth rate increased in proportion to the input partial pressure of GaCl gas, achieving 20 µm/h or more. Si doping into the epitaxial film was carried out by simultaneous supply of $SiCl_4$ gas into the reactor during the growth, and Si concentration in the range of 3E+15 to 1E+18 cm^{-3} can be controlled. It was confirmed that the Si-doped films show n-type conductivity and their carrier concentration (measured by Van der Pauw method) equal to Si concentration in the epitaxial films (measured by SIMS analysis). The mobility at room temperature was nearly 150 cm^2/Vs when carrier concentration was 1E+16 cm^{-3}.

By applying those findings, we demonstrated homoepitaxial growth by HVPE on a 2-inch-diameter substrate for the first time. Single crystal film was grown on the entire surface of the substrate: mean value (uniformity) of the film thickness and the carrier concentration in the 2-inch-diameter wafer were 10.9 µm (± 16.5 %) and 2.7E+16 cm^{-3} (± 19.7 %), respectively. It was demonstrated that any SBDs fabricated on this wafer worked normally and fluctuation of on-resistances was 3.8-7.7 $m\Omega cm^2$. Relatively good uniformity was obtained in an early stage of film growth development on the 2-inch-diameter wafer. By optimizing the gas flow, the film thickness uniformity improved to 8.0 %. Currently, we devote much effort on improving uniformity.

9:20am **C2-3-5 Severe Positive Bias Temperature Instability in N-type MOS Device with Dipole Doped HfO_2 Dielectric Layer**, ***FuYuan Jin,*** *T Chang, H Liu, C Lin,* National Sun Yat-Sen University, Taiwan*; J Liao,* National Tsing Hua University, Taiwan*; F Ciou, W Hung,* National Sun Yat-Sen University, Taiwan

In this work, we found severer positive bias temperature instability (PBTI) in N-type MOS device with dipole doped HfO_2 dielectric layer than N-type MOS device with pure HfO_2 dielectric layer. In addition, both electron trapping and defect generation are also more severer in dipole doping device. This phenomenon can be due to the lowering of the conduction band in HfO_2 with higher electric field which is induced by dipole at interface.

9:40am **C2-3-6 Physical Mechanisms of Negative Bias Illumination Stress in InGaZnO Thin Film Transistors with Different Metal Gate Structure**, ***Chung-I Yang,*** National Chiao Tung University, Taiwan*; T Chang,* National Sun Yat-Sen University, Taiwan*; W Chou,* National Chiao Tung University, Taiwan

In this study, the electrical analyses and physical mechanisms of structure-depended reliability tests in InGaZnO thin film transistors are investigated. First, the difference of shielded area between IGZO layer and metal gate is discussed. Under the different metal gate length devices, an abnormal rise in capacitance at the off-state in capacitance-voltage characteristics curves can be observed. It is attributed to edge effect-induced high electrical field when the metal gate length is shorter than IGZO layer length. Under light illumination measurement, the behaviors of subthreshold-leakage current can be observed whether the lengths of metal gate are larger than IGZO layer or not. After the negative gate bias illumination stress (NBIS), it is found that the devices which have edge effect caused the more severe hole injection into the gate insulator.

10:00am **C2-3-7 Fabrication of MSM UV Photodetector Based on ZnO/TFMG/UNCD Nanostructures**, ***Markos M. Yenesew,*** *B Huang,* National Taiwan University of Science and Technology, Taiwan*; J Chu,* National Taiwan University of Science and Technology (NTUST), Taiwan

In this study, we demonstrate the fabrication of a high performance photodetectors using a multilayer of ZnO nanotubes (NTs), thin film metallic glass(TFMG), and ultra-nano crystalline diamond (UNCD). The device is fabricated by depositing UNCD and TFMG on a glass substrate in microwave plasma enhanced-CVD and RF magnetron sputtering systems respectively. Finally, ZnO NTs are grown by two-step hydrothermal technique. Systematic device performance investigations have shown a high on/off ratio and a fast response speed at 5 V external bias. The developed fabrication design opens up possibility for gas sensor applications.

10:20am **C2-3-8 Effect of Cadmium Chloride Treatment on Poly-crystalline Thin Films of CdTe/Cd-Zn-Te/CdTe Structures**, ***Tushar Shimpi***, *C Reich, K Barth, W Sampath,* Colorado State University, USA

By varying the composition of zinc in the ternary alloy of $Cd_{(1-x)}Zn_xTe$ (Cd-Zn-Te), the band gap can be adjusted. This enables optimizing the Cd-Zn-Te top cell depending upon the number of junctions in the multi-junction solar cell.

In this study, sublimated poly-crystalline thin films of Cd-Zn-Te with a band gap of 1.70 eV was sandwiched in between two 100 nm CdTe films. The overall superstrate structure was glass/tin oxide doped with fluorine/Mg-Zn-O/CdTe seed layer/Cd-Zn-Te/CdTe cap. In the previous studies of 1-micron Cd-Zn-Te films and devices, the well-known $CdCl_2$ defect passivation treatment caused zinc loss in the film through the formation of volatile $ZnCl_2$. The loss of zinc reduced the high band gap thin film of Cd-Zn-Te to a lower band gap CdTe (1.48 eV). The objective of this study was to prevent this stoichiometry change by providing a zinc barrier in the form of CdTe cap prior to treatment. The CdTe seed layer was used to prevent delamination of the Cd-Zn-Te films after the $CdCl_2$ treatment and have a better band alignment at the front interface. After the passivation treatment, electrodes were deposited, and devices fabricated.

From the external quantum efficiency graph, the current generated was more than 60% including the optical losses in the wavelength range of 350 nm to 700nm. The band edge did not shift towards the longer wavelength region indicating that the band gap did not significantly change, and zinc loss was prevented from the Cd-Zn-Te thin film. The devices exhibited a rectifying curve in the current density and voltage graph. The line scans and the elemental maps collected from the cross-section viewed under a transmission electron microscope further confirmed that most of zinc was retained in the bulk of Cd-Zn-Te. Some diffusion of zinc was seen in the CdTe seed and capping layer. The chlorine decorating the grain boundaries of Cd-Zn-Te and accumulation at the front interface of Mg-Zn-O/CdTe seed layer, seen in effective $CdCl_2$ treatment of CdTe films was also observed.

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