Fundamentals and Technology of Multifunctional Materials and Devices
Room Royal Palm 4-6 - Session C2-1
Thin Films for Active Devices

Moderators: Vanya DarakchievaMarco Cremona, Pontificia Universidade Católica do Rio de Janeiro, Junichi Nomoto, Kochi University of Technology, Japan,

10:00am **C2-1-1 Application of Gallium Oxide for High-Power Electronics**, ***Masataka Higashiwaki**, M Wong, K Konishi,* National Institute of Information and Communications Technology, Japan*; K Sasaki, K Goto,* Tamura Corporation, Japan*; H Murakami, Y Kumagai,* Tokyo University of Agriculture and Technology, Japan*; A Kuramata, S Yamakoshi,* Tamura Corporation, Japan **INVITED**

Wide bandgap semiconductor material - gallium oxide (Ga_2O_3) - has emerged as a new competitor to SiC and GaN in the race toward next-generation power devices by virtue of the excellent material properties and the relative ease of mass wafer production. In this talk, following a short introduction of material properties and features of Ga_2O_3, an overview of our recent development progress in device processing and characterization of Ga_2O_3 field-effect transistors (FETs) and Schottky barrier diodes (FP-SBDs) will be reported.

State-of-the-art Ga_2O_3 metal-oxide-semiconductor FETs (MOSFETs) were fabricated with unintentionally-doped (UID) β-Ga_2O_3 (010) epitaxial layers grown on semi-insulating Fe-doped substrates by ozone molecular beam epitaxy [1]. Selective-area Si-ion implantation doping of the UID Ga_2O_3 epilayer formed the device channel and ohmic contacts, while the high resistivity of UID Ga_2O_3 was harnessed for planar device isolation without mesa etching. SiO_2-passivated depletion-mode MOSFETs with a gate-connected field plate (FP) demonstrated a high off-state breakdown voltage (V_{br}) of 755 V, a large drain current on/off ratio of over nine orders of magnitude, DC-RF dispersion-free output characteristics, and stable high temperature operation against thermal stress at 300°C.

We also fabricated and characterized Pt/Ga_2O_3 FP-SBDs on n^--Ga_2O_3 drift layers grown on n^+-Ga_2O_3 (001) substrates [2], owing to the success of halide vapor phase epitaxy (HVPE) for high-speed growth of high-quality Ga_2O_3 thin films [3, 4]. The illustrative device with a net donor concentration of 1.8×10^{16} cm^{-3} exhibited a specific on-resistance of 5.1 mΩ·cm^2 and an ideality factor of 1.05 at room temperature. Successful FP engineering resulted in a high V_{br} of 1076 V. Note that this was the first demonstration of V_{br} of over 1 kV in any Ga_2O_3 power device.

In summary, we succeeded in fabricating depletion-mode Ga_2O_3 FP-MOSFETs and vertical Ga_2O_3 FP-SBDs on single-crystal β-Ga_2O_3 substrates. Despite the simple structures, both the FP-MOSFETs and FP-SBDs revealed excellent device characteristics and demonstrated great potential of Ga_2O_3 electron devices for power electronics applications.

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[1] M. H. Wong *et al.*, IEEE Electron Device Lett **37**, 212 (2016), [2] K. Konishi *et al., 74th Device Research Conference IV-A.5, 2016*, [3] K. Nomura *et al.*, J. Cryst. Growth **405**, 19 (2014), [4] H. Murakami *et al.*, Appl. Phys. Express **8**, 015503 (2015).

10:40am **C2-1-3 Phenomenon of Oxygen Ion Migration in In_2O_3-Based Resistive Random Access Memory**, ***Cheng-Hsien Wu**,* National Sun Yat-sen University, Taiwan*; T Chang, T Tsai,* National Sun Yat-Sen University, Taiwan

In this study, we demonstrate how using a positive bias or negative bias in the forming process can control whether the switching layer of a Pt/In_2O_3/TiN device is near the Pt electrode or the TiN electrode. This means that In_2O_3-based resistive random access memory (RRAM) not only can be switched at either the active or inert electrode, with resistive switching I–V curves for both electrodes exhibiting stable memory windows. Therefore, it is a bilaterally operating RRAM device. Since RRAM usually switches at the active electrode, we investigate the mechanism during operation at the inert electrode. After curve fitting, we found multi-set and multi-reset stages, both dominated by Schottky emission, as well as gradual changes in the value of the slope and the intercept. Finally, we use this result to propose a model with oxygen ions.

11:00am **C2-1-4 Vapor-Liquid-Solid Growth of SnO_2 Nanowires Utilizing Alternate Source Supply and Their Photoluminescence Properties**, ***Tomoaki Terasako**, K Kohno,* Ehime University, Japan*; M Yagi,* National Institute of Technology, Kagawa College, Japan

An important *n*-type wide band gap semiconductor, tin dioxide (SnO_2), has various high functionalities. Especially, we pay attention to the applications of SnO_2 to the gas-sensing devices. It is expected that the use of the nanowires (NWs), nanorods and nanobelts is effective for achieving the high gas-sensing performance. Among the various techniques, vapor-liquid-solid (VLS) growth based techniques are most widely studied because of their high forming position and diameter controllability. In general, the diameters of the NWs grown through the VLS growth can be controlled by the diameters of the catalyst particles or the thickness of the catalyst film. However, the film growth on the NW's side walls by vapor-solid (VS) growth contributes to the increase in average diameter and obstructs the growth of the NWs with the well-controlled diameters [1,2]. In this paper, we will examine the possibility of suppressing the influence of the VS growth on the shapes of the NWs utilizing alternate source supply (ASS). During the VLS growth process, the catalyst particle acts not only as a crystal growth front, but also as a "storage box" of the metal atoms by forming the alloy droplet. The ASS technique utilizes the latter.

The SnO_2 NWs were grown on the Au/α-Al_2O_3(001) substrates by atmospheric-pressure CVD using Sn powder and H_2O as source materials. Both the substrate and Sn powder were heated by the horizontal furnace, whereas H_2O was vaporized in its own vaporizer. Both the vapors of Sn and H_2O were timely separated and transported onto the substrate by nitrogen carrier gaseous.

X-ray diffraction measurements and SEM observations revealed the successful growths of the SnO_2 NWs by the ASS conditions. The average diameter of the SnO_2 NWs grown under the simultaneous source supply (SSS) condition increased exponentially with increasing growth temperature (T_g), reflecting the enhancement of the contribution of the VS growth. In contrast to this, the average diameter of the NWs grown under the ASS condition was almost independent of T_g, indicating that the contribution of the VS growth is effectively suppressed using the ASS condition. PL spectra showed the increase in the intensity of the orange band emission with increasing Tg, suggesting that the increase in the O vacancies and/or Sn interstitial atoms [3]. Moreover, the NWs average diameter was found to be independent of cycle number in the cycle number range of 300-700.

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[1] T. Terasako *et al*., Thin Solid Films 528 (2013) 237.

[2] T. Terasako *et al*., Thin Solid Films (to be published).

[3] D. Calestani *et al*., Mater. Sci. Eng. C 25 (2005) 625.

11:20am **C2-1-5 Endurance Improvement and Resistance Stabilization of Transparent Multilayer ReRAM with Oxygen Deficient WO_x Layer and Heat Dissipating AlN Buffer Layer**, ***Yu-Hsuan Lin**,* National Chiao Tung University, Taiwan*; D Huang,* Peking University, China*; T Tseng,* National Chiao Tung University, Taiwan

This paper discusses the transparent resistive random access memory (ReRAM) from ITO/WO_3/ZnO/ITO structure to multilayer ITO/WO_x(x<3)/WO_3/ZnO/AlN/ITO structure with oxygen concentration distribution and heat dissipating layer. The X-ray photoelectron spectroscopy (XPS) is used to confirm the existence of WO_x/WO_3 double layers. The transmission electron microscopy (TEM) images show the AlN layer has limited effect on the grain structure and the interface roughness of ZnO. Moreover, the transmittance of the multilayer ReRAM achieves 85.49% that is suitable for optoelectronic applications.

The bipolar ReRAM mechanism is based on filament model with the movement of oxygen vacancies. Because the oxygen ions may recombine with the vacancies and break the conductive path near the top electrode during the SET operation, the WO_x between electrode and WO_3 provides sufficient vacancies for efficient resistive changes. In the meanwhile, the WO_3 can limit the rupture and formation region of filaments. This gradient tungsten oxide stabilizes the low resistance states, decreases the operating voltages, and increases the endurance from < 10^3 cycles to 10^4 cycles. Since the electrical field and heat drive the movements of ions and vacancies, the inserted AlN with high thermal conductivity can dissipate the uncontrollable heat and remain the directional electrical field. This AlN layer prevents the ReRAM from the heat-activated ion movement and further masters the high resistance state, so the resistance levels of the multilayer ReRAM are tight and stable. Conclusively, in the

ITO/WO_x/WO_3/ZnO/AlN/ITO ReRAM, the operating voltages of SET and RESET operations are 1.9V and -1.1V, respectively, the retention stay more than 10^4s at 150°C, the endurance is 10^4 cycles with resistance ratio over 20x, and both of the low and high resistance states are extremely stable during cycling.

11:40am **C2-1-6 Mechanism of Selectivity Increased during Operation on Vanadium Oxide Based Selector***, C Lin,* National Sun Yat-sen University, Taiwan*; T Chang, K Chang,* National Sun Yat-Sen University, Taiwan*; T Tsai, C Pan,* National Sun Yat-sen University, Taiwan*; **Jih-Chien Liao,*** National Tsing Hua University, Taiwan*; P Chen,* National Sun Yat-sen University, Taiwan*; C Chen,* National Sun Yat-Sen University, Taiwan*; S Sze,* National Chiao Tung University, Taiwan

Technological development for memory, logic IC, on-display devices and batteries is indispensable for advanced portable electronic products. Among all these devices, a reliable, fast-working, and energy-saving non-volatile memory is extremely important. There are several next generation memory under developed, RRAM, PCRAM, MRAM, MTJ, FeRAM. All these devices must use array to storage, but the sneak path current is still the problem that we can’t integrate large amount of advanced RAM into a chip. One Selector connect to one Memory is one of the solution to sneak current, and it is the most efficient method to integrate memories into array chip.

Selector can be used in any resistance-changed memory. There are large amounts of selectors developed in recent year, one of they use transition metal oxide to achieve double side diode properties. Metal insulator transition (MIT) has been widely developed because of its volatile state switch. In this article, we use Vanadium Oxide to be our device to find two factors that influences the switch characteristic. Because MIT happens in the difference of temperature, we think the thermal and electric field will influences the devices meanwhile. By current fitting and Comsol simulation, we conclude the phenomena happens in transition layer.

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