PCSI
Room Redondo - Session PCSI-WeM2
Oxide Semiconductors nd Memristor Materials

Moderator: Holger Eisele, Otto-von-Guericke-Universität

10:35am **PCSI-WeM2-26 Advancement and Prospects of Ultra-Wide-Bandgap Oxide Semiconductors*, Shizuo Fujita,*** Kyoto University, Japan*; K. Kaneko,* Ritsumeikan University, Japan*; K. Tanaka,* Kyoto University, Japan **INVITED**

It is a general trend of semiconductors that the wider bandgap materials show the higher characteristic breakdown field E_c, exhibiting high Baliga's figure of merit, which is proportional to E_c^3. The bandgap of gallium oxide (Ga_2O_3), 4.5-5.7 eV dependent on its crystal phase, is wider than those of SiC and GaN, and therefore Ga_2O_3 is attracting high attention as a material for future power devices. In addition, Ga_2O_3 bulk substrates are grown by the conventional solution-based methods, and the device-oriented research is done based on the homoepitaxial growth, similarly to the traditional III-V semiconductor research like GaAs and InP. Since the first demonstration of MESFETs and MOSFETs in 2012 and 2013, respectively by NICT, Japan, rapid progress of the devices, including 1.4 kV SBD, normally-off MOSFETs, 2.66 kV vertical FINFETs, high frequency MOSFETs (f_{max}=27 GHz), high-frequency HFETs (f_{max}=37 GHz), and 4.4 kV MESFETs, are going on.

Ga_2O_3 takes at least five polymorphs, and β-phase is the most stable phase. The Ga_2O_3 substrates are the β-phase, and the most advanced device research shown above is based on the β-phase. Other phases are semi-stable, but interesting characteristics which are not realized by the β-phase are expected. For example, the crystal structure of α-phase (corundum) is the same as that of sapphire, allowing complete bandgap engineering from that of Ga_2O_3 to Al_2O_3. Our group has been contributing to the research on α-Ga_2O_3, which was grown on sapphire substrates by the mist CVD method. FLOSFIA Inc. has developed SBDs of α-Ga_2O_3, and they may be supplied at a low cost because of the use of low-cost sapphire substrates. P-type conductivity of Ga_2O_3 is a difficult problem, but there is a p-type corundum-structured α-$(Ir,Ga)_2O_3$ closely lattice matched to α-Ga_2O_3, allowing the pn junction of ultra-wide-bandgap semiconductors. For α-Ga_2O_3, heteroepitaxial growth on sapphire results in dislocation defects, and how to overcome this problem is now one of the most important subjects of our research. The orthorhombic ε (or named as κ) phase is expected to cause strain-induced in-axis polarization, preferrable to heterojunction FETs like AlGaN/GaN.

At the conference, we plan to show the up-to-date research achievements on ultra-wide-bandgap oxide semiconductors and their devices. The focus is given to Ga_2O_3 semiconductors, but may not be limited to Ga_2O_3. The efforts on developing other promising ultra-wide-bandgap oxide semiconductors will also introduced.

A part of our research works was conducted under the support by JSPS KAKENHI (20H00246) and MIC research and development (JPMI00316).

11:15am **PCSI-WeM2-34 Adsorpion of Gases on β-Ga2O3 Surfaces*, Jonathan Karl Hofmann,*** Forschungszentrum Juelich GmbH, Germany*; C. Schulze, D. Rosenzweig,* Technical University of Berlin, Germany*; Z. Galazka,* Leibnitz-Institut für Kristallzüchtung, Germany*; M. Dähne,* Technical University of Berlin, Germany*; H. Eisele,* Otto-von-Guericke-Universität, Magdeburg, Germany

β-Ga2O3 is a transparent conductive oxide with a fundamental bad gap of E_G=4.9 eV [1]. Its typical n-type conductivity is controllable via the growth conditions, intentional doping or post-growth heat treatment [2]. Due to its large band gap, β-Ga2O3 is a promising candidate for applications in high power electronics e. g. in field effect transistors with high breakdown voltages [3]. Additionally, since its conductivity is dependent on the ambient conditions, β-Ga2O3 can be used in oxygen sensors [4]. In this contribution, we address the question how its surface properties develop under typical ambient conditions, i. e. under H2O and O exposure, but in a controlled way. Therefore, we used a gas-inlet for H2O vapor and an atomic O source. The β-Ga2O3 single crystals were grown with the Czochralski method [5] and cleaved under UHV-conditions in order to achieve intrinsic surface conditions before gas adsorption. Using Auger electron spectroscopy (AES), low energy electron diffraction (LEED), and scanning tunneling microscopy/spectroscopy (STM/STS), we show how the different adsorbed atoms/molecules change the structure and electronics properties of β-Ga2O3(100) and (001) surfaces in comparison to the freshly cleaved surfaces. On the (100) surface, large clusters of H2O with an undisturbed surface in between were observed. However, STS showed no change in the electronic states. All spectra exhibit a large apparent band gap due to upwards band bending. Negative tunneling voltages gave rise to an accumulation current. Also, an additional exposure to atomic O did not lead to a change in the electronic states, although it lead to a higher surface coverage. On the (001) surface, oxygen covered almost the complete surface. STS showed that O lifts the band bending inherent in clean β-Ga2O3 surfaces.

The project was supported by the Leibnitz association, Leibnitz Science Campus GraFOX, project C2-3.

[1] M. Mohammed et al., Journal of Physics: Conference Series 286, 012027 (2011)
[2] Z. Galazka et al., Journal of Crystal Growth 404, 184 (2014)
[3] K. Tetzner et al., IEEE Eletrcon Device Letters 40, 1503-1506 (2019)
[4] M. Bartic, physica status solidi (a) 213, 457-462 (2015)
[5] Z. Galazka, J. Appl. Phys. 131,031103 (2022)

11:20am **PCSI-WeM2-35 Design of Rare-Earth Nickelate Memristors*, Olivia Schneble,*** Colorado School of Mines*; B. Tellekamp,* National Renewable Energy Laboratory*; J. Zimmerman,* Colorado School of Mines

Rare-earth nickelates ($RNiO_3$) are distorted perovskite oxides that exhibit a charge-transfer insulator-metal transition (IMT) at temperatures dependent on the rare-earth cation size. $LaNiO_3$ is the exception, remaining metallic at all temperatures. Materials with this thermally driven transition lend themselves memristor applications because they can be switched from high-resistance to low-resistance states via Joule heating. Rare-earth nickelates (RNOs) also span the ideal transition temperature range (400-500 K) and the IMT can be modified by alloying as well as strain state [1]. Previous research in other material systems has found that higher transition temperatures require more energy per operation, but transitions too close to room temperature would require active cooling[2]. This work focuses on the control of RNO material properties for biomimetic neuronal devices.

Our proposed vertical device consists of an $LaNiO_3$ layer that acts as both a bottom electrode and an epitaxial buffer, an epitaxial RNO switching layer, and metallic top contacts. This structure can be translated to dense crossbar arrays and can be grown on numerous crystalline substrates. However, the different bulk structure of $LaNiO_3$ (rhombohedral) from the other RNOs and the relevant substrates (orthorhombic) complicates the heteroepitaxial picture. Factors such as biaxial strain alter the NiO_6 octahedral distortions that govern electronic structure, so understanding the substrate/$LaNiO_3$ and $LaNiO_3$/RNO interfaces is critical.We have employed both pulsed laser deposition and RF sputtering to grow epitaxial layers and heterostructures. Preliminary studies focus on $NdNiO_3$, which is more widely studied and easier to stabilize. Both deposition techniques can produce fully-strained, highly-crystalline $NdNiO_3$ on $LaNiO_3$ buffer layers. However, crystallinity does not predict electrical behavior, which we find to be highly dependent on deposition conditions even with nominally constant composition and strain state. These effects are not fully explained by thickness variation, and we will discuss additional mechanisms underlying this variability. We also use measured material properties to model RNO memristors in LT-SPICE, which provides insight into the necessary electrical behavior as we optimize our thin films.

11:25am **PCSI-WeM2-36 Image Recognition Process of IGZO/$CsPbBr_3$ Photo-synaptic Transistors Imitating Human Learning Processes*, Goeun Choi,*** *Y. Rim,* Department of Intelligent Mechatronics Engineering, and Convergence Engineering for Intelligent Drone, Sejong University, Republic of Korea

Neuromorphic devices are consisted of mimic structures of neurons and synapses in the human brain, which can simultaneously process computation and memory roles for the high- speed computations and high-power efficiencies. Recently, light-applied optical synapses with light applied among neuromorphic semiconductors systems have received attentions due to low crosstalk, wide bandwidth, fast computation, and lower energy consumption [1].

In this study, perovskite CsPbBr3 photo absorber embedded IGZO semiconductor-based photo-synaptic transistors were proposed. Oxide semiconductor (IGZO) is being actively studied because it can realize high mobility and high transparency with low process temperature and low manufacturing cost [2]. However, since the bandgap is wide, there is a limitation in not recognizing light in the visible ray region. CsPbBr3 has a low bandgap (~2.3 eV) and can be formed easily onto the IGZO surface using a solution process. In the optical synaptic arrangement, as the number of pulses increased and the intensity of light increased, the image tended to be clearly recognized [3]. It is consistent with the fact that the more often humans meet, the more facial features they remember [4]. We prove that the image recognition process of the produced photo-synaptic array is similar to that of human learning.

11:30am **PCSI-WeM2-37 IGZO Synaptic Transistors Using Ionic Gel-Based Electric Double Layer Operation for Low Voltage Driving**, ***Kyongjae Kim**, Y. Rim,* Sejong University, Republic of Korea

Neuromorphic computing, which mimics the behavior of biological neurons and synapses is a method that dramatically solves the problem of the traditional von Neumann structure by performing information processing and data storage simultaneously. Transportation of neurotransmitter from pre-synaptic neurons to post-synaptic neurons induce excited post-synaptic potential, and this process of excitatory post-synaptic potential is the key factor in conducting memory function and data processing simultaneously. Here we propose a coplanar structure having an ionic gated electric double layer transistor (EDLT) with indium gallium zinc oxide (IGZO) for low voltage driving and its synaptic behavior based on modulated channel conductivity induced by an electric double layer (EDL) [1]. The EDL is formed at the interface between IGZO and ionic gel dielectric, and we confirmed that the operation voltage was below 1 V due to the formation of large capacitance (~2µF) [2]. We studied the physical phenomenon at the interface between the IGZO channel and the ionic gel where EDL was formed by the oxygen vacancy of the channel and the ion contents of the ionic gel. This interface is a crucial point for the synaptic behavior owing to the variations of conductance of the interface with the ion movements. The ionic gated EDLT achieves subthreshold swing of 0.1/dec, on/off ratio of 105, and 103 range of excitatory post-synaptic current (EPSC). We successfully demonstrated that the gate bias applied in the form of a pulse and source/drain bias linearly controls the conductance of the channel and shows potentiation, depression, and memory characteristics, revealing its potential to be industrialized in next-generation neuromorphic computing.

11:35am **PCSI-WeM2-38 UPGRADED: Electrostatic *S*haping of Magnetic Transition Regions in $La_{0.7}Sr_{0.3}MnO_3$**, *Q. Lan,* Forschungszentrum Jülich GmbH, Germany; *C. Wang,* Tsinghua University, China; *L. Jin, M. Schnedler, L. Freter,* Forschungszentrum Jülich GmbH, Germany; *K. Fischer,* National Institute of Technology, Japan; ***Philipp Ebert**, R. Dunin-Borkowski,* Forschungszentrum Jülich GmbH, Germany

We report a magnetic transition region in $La_{0.7}Sr_{0.3}MnO_3$ with gradually changing magnitude of magnetization, but no rotation, stable at all temperatures below T_C. Spatially-resolved magnetization, composition and Mn valence data reveal that the magnetic transition region is induced by a subtle Mn composition change, leading to a charge transfer at the interface due to carrier diffusion and drift. The electrostatic shaping of the magnetic transition region is mediated by the Mn valence which affects both, magnetization by Mn^{3+}-Mn^{4+} double exchange interaction and free carrier concentration.[1]

[1] Q. Lan *et al.*, Phys. Rev. Lett. **129,** 057201(2022)

Author Index

Bold page numbers indicate presenter