Advancement and Prospects of Ultra-Wide-Bandgap Oxide Semiconductors

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It is a general trend of semiconductors that the wider bandgap materials show the higher characteristic breakdown field E_c, exhibting 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 the 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.

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