Gallium Oxide Bulk Crystals Prepared by the Czochralski Method, (100) Substrates, and Homoepitaxy Results

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Gallium oxide (β-Ga_2O_3) is an emerging ultra-wide bandgap semiconductor. Due to its bandgap of 4.8 eV, the calculated values for Baliga's figure of merit and breakdown voltage are outstanding. On the other hand, high n-type doping is possible, while semi-insulating crystals are also available. Thus, β-Ga_2O_3 is considered for use in future power electronics, and first devices with very promising properties have been demonstrated [1]. Additionally, the preparation of bulk crystals from the melt is considered a strong advantage, as this should enable large-diameter, high-quality substrates for homoepitaxy at potentially low cost. Despite serious challenges in stabilizing bulk growth and improving crystalline quality, the technology advances, and wafers are commercially available. However, wafer preparation and homoepitaxy still need a lot of development. The best approach for commercial application will critically depend on materials availability, properties, and device design.

At the IKZ, we have been preparing β-Ga_2O_3 bulk crystals by the Czochralski growth method for over a decade. I will present our status in the growth of 2-inch bulk crystals doped with magnesium (semi-insulating) and silicon (n-type conductive), and I will discuss the different challenges involved, such as growth stability, melt stoichiometry, dopant segregation, and iridium loss [2]. While the crystals have to be grown in directions perpendicular to the <010> direction to mitigate cleavage during growth, other orientations seem to be clearly advantageous for epitaxy and device fabrication, and thus the length of the bulk crystals is important for providing large-area substrates [3]. At the same time, we have substantially improved the metalorganic vapor phase epitaxy (MOVPE) process by maintaining a high effective diffusion rate of the species on the surface. The resulting growth stability enabled a 15-fold increase of the growth rate under step-flow conditions. Using substrates cut 4° off-oriented from (100) from our crystals, we were able to demonstrate state-of-the art properties of 4 µm thick homoepitaxial films with carrier mobilities of 160 $cm^2V^{-1}s^{-1}$ at carrier concentrations of 5.7×10^{16} cm^{-3} [4]. Such thick, homogeneous drift layers are the prerequisite for vertical devices employed in power electronics operating at high voltages. I will also briefly discuss the limitations in doping and remaining challenges of β-Ga_2O_3 bulk growth and epitaxy.

References

[1] Andrew J. Green, James Speck, Grace Xing et al., "β-Gallium oxide power electronics", APL Materials **10** (2022) 029201 (2022)
[2] Zbigniew Galazka, "Growth of bulk β-Ga_2O_3 single crystals by the Czochralski method", J. Appl. Phys. **131** (2022) 031103
[3] Zbigniew Galazka, Steffen Ganschow, Klaus Irmscher et al., "2 Inch Diameter, Highly Conducting Bulk β-Ga_2O_3 Single Crystals Grown by the Czochralski Method for High Power Switching Devices", Appl. Phys. Lett. **120** (2022) 152101
[4] Ta-Shun Chou, Palvan Seyidov, Saud Bin Anooz et al., "High-mobility 4 µm MOVPE-grown (100) β-Ga_2O_3 film by parasitic particles suppression", Jpn. J. Appl. Phys. **62** (2023) SF1004