Crystals and Substrates for Semiconducting and Multiferroic Oxide Applications

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Since the advent of semiconductors in the 1950ies, bulk single crystals are cut into wafers, polished and used as substrates for epitaxy in order to prepare thin film devices. Today, this approach is used for a variety of materials and applications, including oxide semiconductors and piezo-/ferroelectric thin films. Complex structures and novel concepts do not fit anymore into the established categories of homo- and heteroepitaxy. For best structural quality and to tailor functionality, the key aspect is to provide a controlled lattice match to the epilayers; chemical/thermal stability and compatibility as well as electrical and optical properties of the substrate might offer additional value.

In this presentation, I will focus on the work at IKZ to prepare oxide single crystals for substrate use by the Czochralski method, in which the crystal is pulled out of the melt. After briefly introducing the IKZ and its fields of research, facilities and activities, I will present two examples in greater detail.

The first example is the preparation of beta gallium oxide (β-Ga_2O_3), a semiconducting oxide currently receiving worldwide interest as it might be employed in future power electronics. We have developed a Czochralski growth technique to produce β-Ga_2O_3 boules with 2-inch in diameter and up to 80 mm in length. However, growth stability decreases with increasing diameter and high n-type doping remains an issue. Nevertheless, results of β-Ga_2O_3 epitaxy and devices are encouraging. Recent work at IKZ was done to incorporate a variety of dopants and to prepare gallate single crystals that open up new directions.

As the second example, the preparation of (inorganic) perovskite-type substrates is discussed. These materials serve the physics communities for more than two decades now. What started to provide substrates for high-temperature superconducting thin films is now demanded for tailoring the properties of piezo- and ferroelectric thin films by controlled lattice mismatch (the “strain game”). Recently, the need of proper substrates propelled as they became a key driver for the exploration of novel physical phenomena in thin films, e.g. multiferroic effects or oxides with record high charge carrier mobility, and their interfaces, e.g. topological insulators. As of today, the IKZ can provide bulk single crystals with tailored (pseudo-cubic) lattice constants in the 3.70–4.20 Å range. But issues such as self-absorption of heat and cracking due to thermal stress had to be mastered to enable a reasonable yield. For this work, the former group leader Reinhard Uecker received the Frank Prize, the highest award of the International Organization for Crystal Growth, in the summer of 2019.