SUBLIMATION GROWTH OF WIDE BAND GAP MATERIALS

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Bulk crystals as well as single-crystalline thin films can be easily grown by transporting gaseous species through an otherwise empty 'growth room'. A reservoir of growth-mediating species (source material) is kept on the one side of the growth room at a temperature T_1, which is typically highest in the growth room. The species evaporate due to the partial pressures forming in the space above the reservoir. On the other side of the growth room which we call the nucleation area, the temperature is kept at T_2 which is typically lower than T_1 and the lowest in the growth room. The equilibrium partial pressures of the species are also lowest in this area. Thus, the thermal gradient between source and nucleation area provides a concentration gradient (net flow) of the species, and the species preferably condensate in the nucleation area, eventually forming a crystal. Single crystals can be obtained by grain selection or (preferred) by employing a proper seed. If the source material is in the solid state, this growth method is called the sublimation method; for a liquid source, it would be called evaporation method. Note that even in its most basic forms, sublimation or evaporation methods greatly benefit from additional gases which are present in the growth room. If the gaseous species contain only elements that constitute the growing crystal and the additional gases do not react with the gaseous species, the process is called 'physical vapour transport' (PVT). We will briefly compare this method to other techniques of vapour growth (e.g., including chemical reactions during evaporation and/or condensation) and elucidate the role of additional gases.

Compared to growth from the melt, the concentration of species in the transporting phase is low and kinetics at the interface is governed by the 'low' temperature T_2 well below the melting temperature of the material. Diffusion of ad-atoms on the growing surface is slow, so the species 'stick' at their places leading to relatively high concentrations of defects; on the plus side, movement of defects such as dislocations and impurities is also hindered. Still, achievable growth rates are much lower (only a few hundred microns per hour) and structural defect densities much higher than in melt growth. Nevertheless, growth from vapour can be a fruitful alternative if melt growth cannot be performed, e.g. due to decomposition of the material prior to melting, or extremely high melting/decomposition points.

Interestingly, two important wide band-gap semiconductor materials fit in this scenario and made sublimation growth of bulk crystals a industrially applied technique. The first, silicon carbide (SiC), is used for high-power electronics, the second, aluminium nitride (AlN), will be used for novel UV optoelectronics. Both crystallize in the hexagonal wurtzite structure. They are thermally and chemically very stable and decompose before they melt at temperatures of 2500–2800°C. Yet, their vapour pressure over the solid material at 2200–2300°C is in the mbar range and thus sufficient for sublimation growth. The lecture will focus on growth and characterization of these two materials, especially on the crystal properties that are typical for high-temperature sublimation growth.

The following details are addressed in the lecture:
– growth set-ups including necessary equipment
– possibilities and limitations of process control
– materials compatibility issues
– the role of additional inert gases
– congruent/incongruent evaporation and re-condensation
– important structural defects: polytypes/inversion domains, micropipes/dislocations, and small angle grain boundaries
– impurities with their influence on growth and properties
– crystal habit, faceting and zonar structure
– seeding and crystal enlargement
– similarities and differences between AlN and SiC
– status, alternatives, and outlook regarding the sublimation growth technique