Methods for Industrial Scale Production of Free-Standing GaN Substrates

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Introduction & Motivation

- The growth of nitride-based devices requires elaborate buffers due to the lack of a native substrate.
- GaN bulk crystals are difficult to synthesize from melt due to the high pressures involved.
- Hydride Vapor Phase Epitaxy (HVPE) is a promising alternative production technology because of its high growth rates.

HVPE for the Growth of Free-Standing Substrates and Boules

Two Strategies for the Mass Production of GaN Substrates

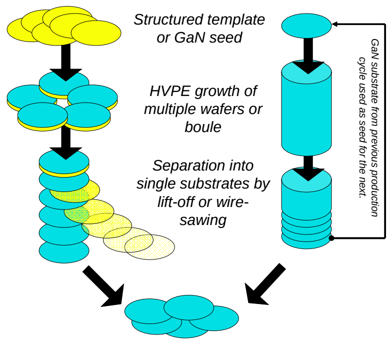

Fig. 1: Two different strategies for the mass production of free standing GaN substrates by HVPE: Multi-wafer or single boule approach.

Multi-Wafer Reactor Concept for the Growth of Free-Standing Substrates

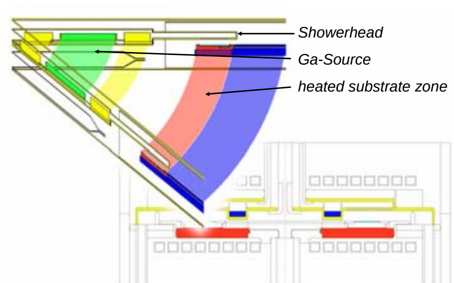

Fig. 2: The multi-wafer HVPE concept combines the conventional single-wafer HVPE design and the well proven Planetary Reactor® design known from MOCVD by rotating the horizontal tube reactor around its inlet. The individual wafers are rotated by Gas Foil Rotation (GFR®).

Vertical HVPE System (VHVPE) for the Growth of Boules

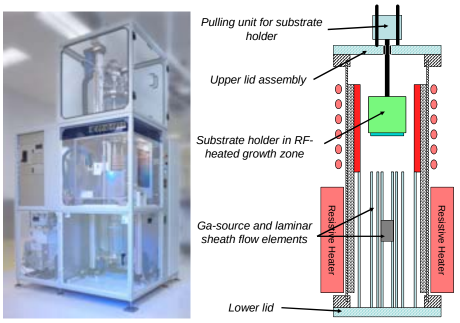

Fig. 3: VHVPE tool for the growth of GaN boules of up to 7 cm length. A pulling unit keeps the optimum distance between inlet and growing surface by retracting the boule at the speed of growth. GaCl and NH_3 flows are separated by laminar sheath flows to prevent pre-reactions until they reach the growth surface.

VHVPE – Source and Growth Area

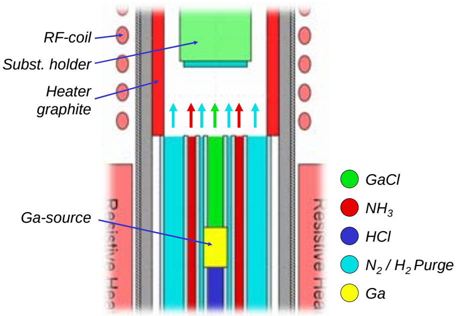

Fig. 4: The GaCl source flow is separated from the NH_3 flow by a circular laminar separation sheath flow to prevent the species from reacting before the substrate. An additional sheath flow prevents deposition along the reactor walls.

VHVPE – Function Principle of Pulling Unit

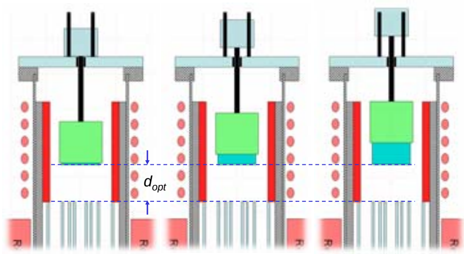

Fig. 5: The optimum distance d_{opt} between injector and growth front can be changed in-situ and kept constant during growth by retracting the boule at the speed of growth.

Numerical Modelling of the VHVPE System and its Processes

Numerical Simulation of RF Heating

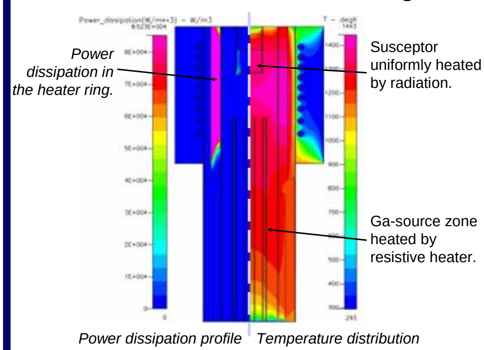

Fig. 6: Numerical modelling of the RF-power dissipation (left) and the resultant temperature distribution profile (right) in the reactor chamber. The resistive heater in the lower part of the reactor is switched to 850°C. As can be seen RF-power is only dissipated at the graphite heater ring surrounding the growth zone and the susceptor is uniformly heated.

Temperature Profile Along the Reactor Axis

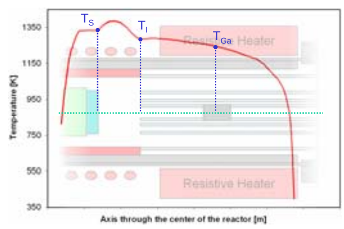

Fig. 7: Temperature profile (from numerical modelling) along the reactor axis (dotted green line). As can be seen a monotonous increase from Ga-source temperature T_{Ga} to the growth zone temperature T_S is achieved.

Computational Fluid Dynamics (CFD) Modelling of the Flow Development at the Gas Injector

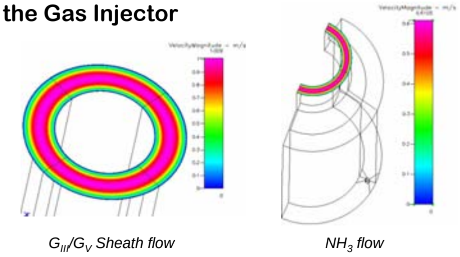

Fig. 8: CFD modelling results for the sheath flow between the GaCl and NH_3 inlet (left) and the group-V NH_3 inlet (right) at the outlet of the injector head. As can be seen, all flows are fully developed around the inlet circumference indicating turbulence free laminar flow.

VHVPE – Experimental Results

Growth Rate Distribution for GaN Layers

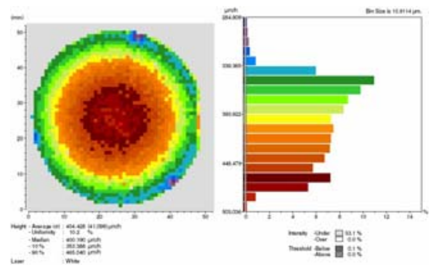

Fig. 9: White Light Interference (WLI) mapping of the growth rate of a GaN layer grown on a template with seed layer and SiN_x hole mask. The growth rate uniformity across the layer was 10.2% at an average growth rate of 400 µm/h. The concentration of H_2 at the growth surface was estimated to be ~50%. Under these conditions layers with a total thickness of 1.4 mm could be grown.

Micrographic Investigation of the Grown GaN Layers

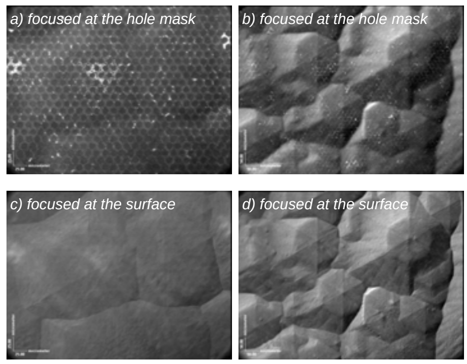

Fig. 10: Micrographs of a 40 µm thick layer focused at the interface from hole mask to GaN layer (a and b) and at the surface of the layer (c and d).

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Conclusion

- HVPE was investigated as a method for the mass production of GaN substrates.
- A VHVPE system for the growth of boules was developed and optimized.
- Initial growth results yield high growth rate and good uniformity.