Current topics in sublimation growth of bulk AlN

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Single-crystalline aluminum nitride (AlN) is the most promising substrate material for deep-UV optoelectronics based on AlGaN epitaxial layers with high Al content. Other potential applications for high-power electronics, high-temperature piezoelectrics, and piezoacoustics also rely on the availability of bulk AlN. In recent years, AlN bulk growth by sublimation-recondensation (PVT method) at temperatures exceeding 2000°C greatly advanced to yield AlN single crystals and substrates of sufficient structural quality and size, which have already been employed in first device demonstrators. Bulk growth is now typically performed on AlN substrates, enabling perpetuation in quality and steady improvement in diameter by subsequent seeding on substrates cut from these boules. However, sublimation growth of bulk AlN still faces important challenges on its way to a technology feasible for production, and these are discussed in the presentation.

First, the technological route employed in AlN starting seed preparation is critically influencing structural quality of subsequently grown boules. We show that the excellent structural quality of spontaneously nucleated free-standing crystals can be perpetuated in terms of low dislocation density and low stress. The main task in homoepitaxial seeding remains crack prevention caused by seed fixation issues and improper thermal field during growth. In contrast, AlN material which stems from AlN-on-SiC template seeds suffers from low-angle grain boundaries. Here, significant quality improvement remains a veritable challenge.

Second, diameter enlargement is hindered by faceting, and only growth on N-polar basal plane facets yields reasonable growth conditions for single-crystalline enlargement. Also, parasitic nucleation in vicinity to the seed has to be avoided. Growth polarity strongly depends on impurity concentrations in the set-up, especially in regard to crucible materials and AlN feedstock. On the Al-polar facet, formation of pyramids leads to effective decrease of single-crystalline diameter, structural defects, and inhomogeneous properties due to segregation effects. Structural quality of boules grown on non-polar (prismatic) and semi-polar (rhombohedral) facets suffers from rivaling growth mechanisms in different directions.

Unfortunately, growth conditions and materials which promote N-polar growth lead to carbon contamination of the growing crystal. Carbon causes strong deep-UV absorption, which hinders substrate use in deep-UV applications. At the same time, low oxygen concentrations also seem to promote deep-UV absorption. Finally, electrical properties can be shifted from semi-insulating to weakly conductive by changing the silicon content. A precise control of impurity contamination is desirable, but doping concepts that work reliably under these harsh growth conditions are just under development.

COMMENTS: This talk is considered to be a review of the current status of bulk AlN growth and substrates, interesting both to bulk crystal growers and to III-nitrides epitaxy people. It is based on own long-term experience while including also findings of other research teams. But also new results are included which contribute a lot to understanding growth as well as materials issues (e.g. data on perpetuation of structural quality, techniques for seed fixation, data on oxygen influencing deep-UV absorption).