Preparation of semi-insulating and weak n-type conducting AlN substrates

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Single-crystalline aluminum nitride (AlN) is a promising substrate material not only for AlGaN epilayers with high Al content, e.g. for solid-state deep-UV optoelectronics, but also for high-temperature electronics and piezoelectric sensors. Apart from structural quality, these applications require properties of the substrates such as high-temperature semi-insulating or n-type conducting behavior that are not met by the current AlN bulk crystals [1].

AlN bulk single crystals are grown by the physical vapor transport (PVT) method at temperatures well above 2000°C. At these conditions, the unintentional incorporation of impurities (O, C, Si) into the growing crystals during growth is inevitable. Adjusting the electrical properties of the growing crystal is possible at least partially by providing proper growth conditions, pure starting materials, or by employing doping.

In our growth technology, we employ tungsten parts in TaC crucibles and pre-purified AlN starting materials, adjust the growth temperature, and use orientation-dependent segregation to control the incorporation of carbon and oxygen in the AlN crystals. We will show that bulk AlN that is electrically semi-insulating even at temperatures beyond 1000°C can be prepared by reducing the oxygen content in the growth atmosphere, and present appropriate optical and electrical measurements, e.g., based on the decrease in temperature-dependent near IR transmission proportional to the charge carrier concentration (Fig. 1). On the other hand, we have developed a suitable Si doping technique in PVT growth which leads to bulk AlN with weak n-type conductivity even at room temperature ([Si] ≈ 1.6×10^{19} cm^{-3}, $n = 1.2 \times 10^{15}$ cm^{-3}, $\mu = 36.5$ cm^2/Vs). These crystals show trap levels at 250 meV and 620 meV below the conduction band associated with silicon and oxygen, see Fig. 2. Finally we will also discuss implications of the doping technology on the structural quality of the AlN bulk crystals, and perspectives for using these materials in novel applications.

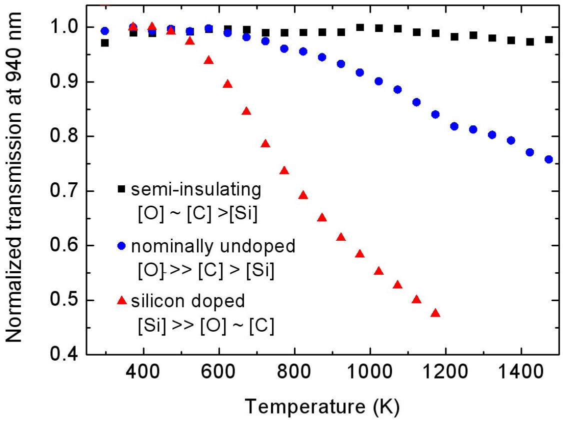

Fig. 1: AlN bulk crystals with different decrease in near-IR transmission due to free carrier absorption at elevated temperatures. The difference is caused by different concentrations of impurities in the crystals.

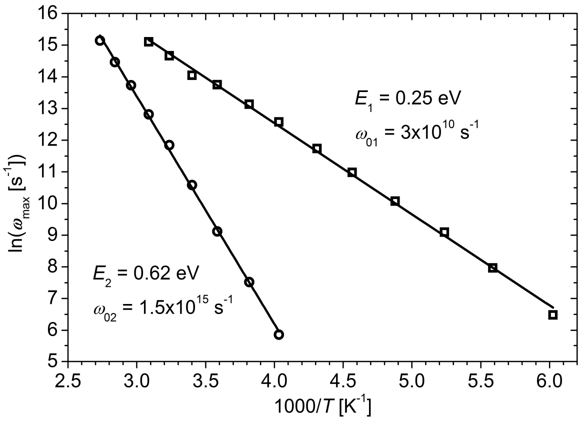

Fig. 2: Activation energy of electron traps in Si-doped AlN as measured by temperature-dependent admittance spectroscopy.

[1] C. Hartmann, A. Dittmar, J. Wollweber, M. Bickermann, "Bulk AlN growth by physical vapour transport", Semicond. Sci. Technol. 29 (2014) 084002.