Incorporation of Boron and the Role of Nitrogen as a Compensation Source in SiC Bulk Crystal Growth

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P-type doping during PVT growth of bulk SiC is a difficult task because of the lack of a suitable gaseous doping source. Despite recent efforts to solve this problem by applying an additional gas flow where the dopant can be introduced directly into the growth chamber [1], still the most favorable technique implies adding solid sources to the starting material. For example, adding boron carbide to the SiC powder source leads to p-type material with charge carrier concentrations p up to 10^{16} cm^{-3} [2]. This may be used for compensation with a deep donor level like vanadium to obtain semi-insulating behavior [3]. Therefore dopant incorporation homogeneity is crucial, i.e. the concentration N_A–N_D should not vary throughout the crystal.

From previous experiments it is known that nominally undoped crystals exhibit n-type behavior originating from nitrogen as residual impurity. The nitrogen content in the crystal was measured to be $N_D = 2 \times 10^{18}$ cm^{-3} at the beginning and below $N_D = 1 \times 10^{17}$ cm^{-3} at the end of growth, leading to charge carrier concentrations at 293 K as low as $n = 8 \times 10^{15}$ cm^{-3}.

Several SiC crystals were grown with different boron concentrations in the source and with different polarity of the seed. Boron is incorporated with a transfer coefficient (ratio of B content in the top of the crystal to initial B content in the source) of about 0.22 for growth on the silicon face and about 0.1 for growth on the carbon face. Chemical analysis shows that during growth the B content in the source slowly depletes, while the B content in the crystal roughly remains constant. At the end of growth, the B concentration in the source is virtually the same as in the crystal. As a result, boron incorporation is segregation-related.

The concentrations of boron acceptors and compensating donors were investigated using Hall effect measurements at 120…700 K. Solving the charge carrier neutrality equation, N_A and N_D were determined in dependence of the growth time for SiC crystals doped with B of various amounts. N_A remains constant during growth, while N_D strongly decreases. Detailed analysis shows that, especially for low compensation ($N_A/N_D \geq 10$), the onset of the freeze-out range strongly depends on N_D, which in turn leads to an almost exponential rise of the hole concentration with growth time, even though N_A–N_D remains constant.

As a conclusion, boron is incorporated homogeneously into SiC when added as a solid source, but nitrogen contamination strongly influences the charge carrier concentration below 300 K. To achieve high homogeneity of N_A–N_D, impurity control is decisive especially for low-doped growth. Finally, a decrease in the hole concentration around faceted areas, which is observed in p-type SiC growth, is found to be related to the step height on the growth surface. A model for the dopant incorporation on different step heights is proposed.

[1] T.L.Straubinger, P.J.Wellmann et al., oral presentation #72 at the conference
[2] M.Bickermann et al., Journal of Crystal Growth 233 (2001) 211
[3] M.Bickermann et al., oral presentation # 79 at the conference

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