Analysis of different vanadium charge states in vanadium-doped 6H-SiC by low temperature optical absorption and electron paramagnetic resonance

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Semi-insulating SiC can be prepared by vanadium doping, as vanadium forms a V^{4+}/V^{5+} mid-gap donor level and a V^{3+}/V^{4+} acceptor level in the upper band half depending on the compensation regime. Our study correlates concentrations of the different vanadium charge states directly by optical absorption and paramagnetic resonance measurements. Several samples were prepared from a vanadium doped and a vanadium/boron co-doped 6H-SiC bulk crystal. V^{3+} and V^{4+} fingerprints were detected by optical absorption at 15 K in the near-IR range and by electron paramagnetic resonance (EPR) spectra at different temperatures. The results are compared to chemical analysis and temperature dependent Hall effect measurements. We will present calibration curves relating V^{4+} to V^{3+} peak heights from both optical absorption and EPR measurements based on chemical and electrical analysis. We will also discuss features in the EPR and optical absorption spectra and provide data on temperature-dependent optical absorption on V^{3+} and V^{4+} intra 3d-shell transitions. This information can be used to determine the local compensation ratio and compensation mechanism in vanadium doped SiC samples.

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The use of semi-insulating SiC substrates is considered as a prerequisite for high-power and high-frequency SiC-based devices [1]. In semi-insulating SiC, shallow levels formed by residual impurities are overcompensated by deep levels, so that the fermi level is „pinned" to the deep level. Vanadium forms a V^{4+}/V^{5+} mid-gap donor level and a V^{3+}/V^{4+} acceptor level in the upper band half depending on the compensation mechanism [2,3]. In PVT growth of SiC, semi-insulating SiC with high yield can be obtained by tailoring a vanadium doping profile taking into account the incorporation of both residual impurities (mainly nitrogen and boron) and vanadium during growth [4]. As this information is very difficult to obtain, an approach is shown to determine the presence of different vanadium charge states and to estimate their respective concentrations by optical absorption and electron paramagnetic resonance (EPR) measurements. This information can be used to determine the local compensation ratio and compensation mechanism in vanadium doped SiC samples.

Several samples were prepared from a vanadium doped and a vanadium/boron co-doped 6H-SiC bulk crystal. As growth proceeds, the content of both vanadium and nitrogen (as a major impurity) decrease [4]. V^{3+} and V^{4+} intra 3d-shell transitions were detected by optical absorption at 15 K in the near-IR range at 2000...2060 nm [5] and 1400...1500 nm [6], respectively (see Fig. 1). Additionally, the V^{3+} and V^{4+} electron paramagnetic resonance (EPR) spectra [6,7] were recorded at 70 K or room temperature and at 4 K, respectively (see Fig. 2). The results are compared to chemical analysis and temperature dependent Hall effect measurements, from which the total amount of vanadium and compensating impurities in the samples can be obtained [4].

For the vanadium doped crystal, both V^{3+} and V^{4+} concentrations decrease with growth time in accordance to chemical and electrical analysis. Illuminating the sample with UV light ($h\nu > E_g$) in EPR measurements leads to a significant increase in V^{3+} concentration. In optical absorption, a calibration curve is established to relate peak heights of the V^{3+} and V^{4+} intra 3d-shell transitions. In samples cut from the co-doped SiC crystal, only very small traces of V^{3+} are found in optical absorption, while the decrease in V^{4+} concentration is again in accordance to chemical and electrical analysis. We will also discuss features in the EPR and optical absorption spectra and provide data on temperature-dependent optical absorption on V^{3+} and V^{4+} intra 3d-shell transitions.

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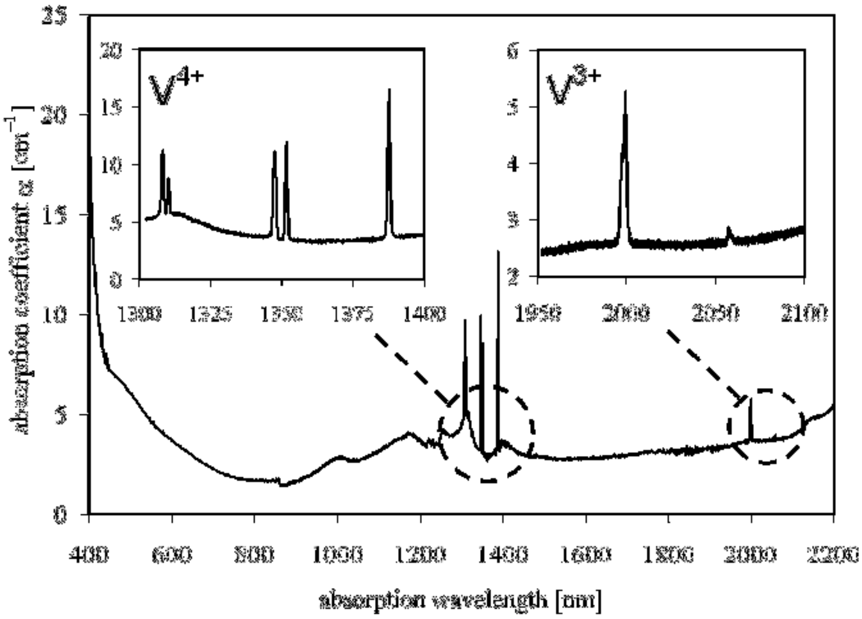

Fig. 1: Optical absorption spectrum of a vanadium doped 6H-SiC sample at 12 K showing both V^{3+} and V^{4+} intra 3d-shell transitions.

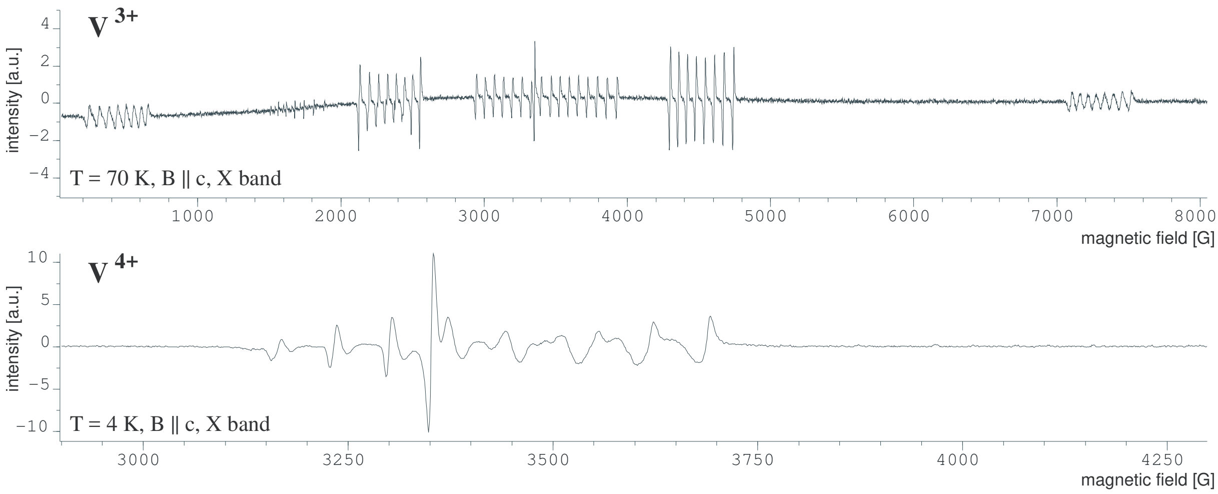

Fig. 2. Vanadium features in electron paramagnetic resonance of a 6H-SiC wafer.