Thermally Stimulated Luminescence in Aluminum Nitride Crystals

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Single-crystalline AlN substrates are beneficial e.g. for fabrication of efficient UV optoelectronic devices [1]. On the other hand, optical absorption and luminescence spectra of such AlN crystals point to the presence of deep electronic levels. Thermally stimulated luminescence (TSL) measurements offer new insights into the nature of the defects involved, as thermal activation energies of defect levels can be determined even in cases where other optical techniques fail (e.g., DX centers).

We report on the results of TSL measurements of AlN crystals grown by physical vapor transport (PVT) in tungsten crucibles [2] using AlN source material of different purity levels. Main contaminants are oxygen, silicon, and carbon, all at ppm wt levels. Additionally, two AlN-SiC mixed crystals [3] which contain up to 5% at of silicon and carbon are examined. Deep electronic levels (traps) are populated through X-ray excitation at 20 K, and the recombination luminescence of thermally activated carriers is recorded while heating up to 600 K at constant heating rates of 10, 15, and 20 K/min. Thermal activation energies are obtained by evaluating the slope in a plot of $\ln(T_{mi}^2/\beta_i)$ vs. T_{mi}^{-1} with T_{mi} as peak temperature at heating rate β_i (Hoogenstraten method [4]). This yielded most reasonable results as compared to other methods. The major wavelength range of the recombination luminescence is studied by inserting optical filters. The results are discussed in terms of impurity content as well as existing data about deep level transitions and DX center formation energies.

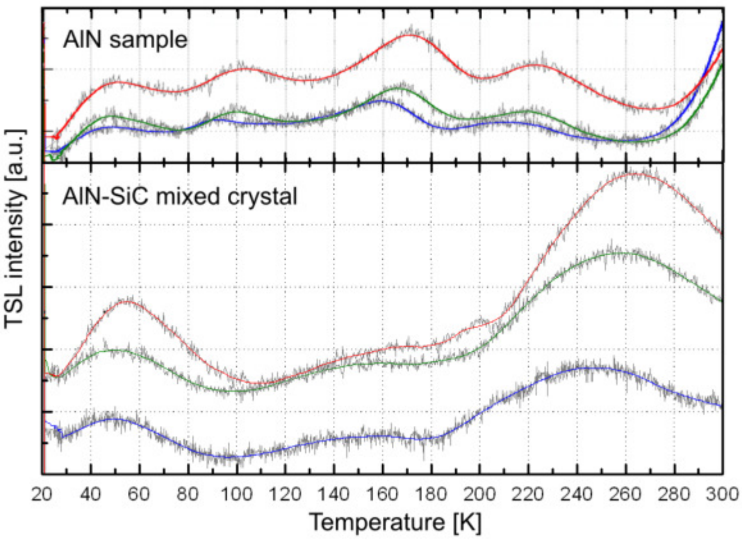

Fig. 1: TSL spectra measured at heating rates of 20 K/min (upper curve), 15 K/min (middle curve) and 10 K/min (lower curve) of a) an AlN sample with silicon and oxygen around $1*10^{18}$ cm^{-3} and b) and AlN-SiC mixed crystal.

In the TSL spectra, broad peaks are detected around 40–70 K, 100 K, 170 K, 220 K, and 390 K. The corresponding activation energies were calculated to 8–35 meV, 40 meV, 150–215 meV, 130–180 meV, and 590–770 meV, respectively, substantially lower than reported previously in literature [5]. Obviously, the population of deep levels after X-ray excitation is strongly influenced by the concentrations of various defects in the samples. The 390 K peak is strongest in samples in which the oxygen content is much higher than the silicon content. On the other hand, in AlN-SiC mixed crystals this band is only very weak, while a band at 260 K with activation energy of ~170 meV arises and dominates the spectra. Finally, the 170 K peak is of highest intensity in crystals with concentrations of silicon and oxygen around $1*10^{18}$ cm^{-3}. The observations can be explained taking into account thermal activation of dislocations as well as DX centers of silicon and oxygen.

[1] M. Kneissl et al., J. Appl. Phys. 101 (2007) 123103.
[2] M. Bickermann et al., phys. stat. sol. (b) 246 (2009) 1181–1183.
[3] M. Bickermann et al., phys. stat. sol. (c) (2010) in press, DOI: 10.1002/pssc.200983423.
[4] W. Hoogenstraaten, Philips Research Reports 13 (1958) 515–593.
[5] K. Irmscher et al., Physica B 401–402 (2007) 323–326.