ELECTRICAL CHARACTERIZATION OF ION IMPLANTATION INDUCED DEFECT STATES IN GALLIUMNITRIDE

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In the last few years, gallium nitride has been established as a basic material for novel device concepts, e.g. in optoelectronics. As a result of the tremendous efforts, several applications such as blue light emitting devices, visible blind photo detectors, and high temperature bipolar transistors have been developed. However, for the function of most of these devices a space charge region formed by a p-n-contact is necessary. Unfortunately, at present such a p-n-contact can be only realized by growing n- and p-type layers on top of each other. An alternative way is given by implanting selective areas of a n-type wafer with distinct ion species to create a p-type region within a n-type matrix. On the other hand, ion implantation generates deep defects in addition to the intentional acceptors. These deep levels may provide non-radiative recombination centers in optical devices and act as compensating states in low doped GaN materials.

In this paper we investigate implantation induced defect generation in GaN combining various complementary electrical spectroscopy techniques to characterize defect states over a wide range of energy.

GaN layers grown by molecular beam epitaxy on c-axis oriented sapphire substrates were implanted with different ion species, i.e. carbon, calcium, oxygen, magnesium, and helium, respectively. The energy of the ions was varied between 20 keV and 180 keV. The ion dose was kept constant at approximately 1E14 /cm^2. The samples were not thermally annealed. N-type conductivity was preserved due to deep defects, which were systematically generated during the implantation process. The resulting deep level spectra were characterized by temperature dependent conductivity measurements (TDC) as well as by thermal and optical admittance spectroscopy investigations (TAS, OAS) at temperatures between 15 K and 520 K and photon energies ranging from 0.4 eV to 4 eV.

Thermal admittance measurements revealed two dominant electron traps with activation energies of about 700 meV and 800 meV, reaching their emission maxima at about 370 K and 500 K, respectively. The same deep defect states were also observed in TDC spectra.

An additional new electron trap caused by the implantation process was found with TDC in the temperature range between 200 and 300 K, having a thermal activation energy of 360 meV. This characteristic implantation trap does not appear in the non-implanted reference sample.

An implantation induced increase of defect-to-band-transitions is observed in optical admittance spectra in the near band gap region around 3.45 eV where transitions between shallow states (acceptors and donors) and the opposite band were monitored as well as at photon energies between 3.1 eV and 1.8 eV. Again, an additional new transition at 2.0 eV was found not observable in the reference material, which could be unambiguously correlated to the implantation process.

The fact, that after implantation with different ion species the resulting deep level spectra are very similar strongly suggests the intrinsic nature of the observed implantation induced defect states.

No indications of any correlation between the ion species for implantation and the appearance of distinct individual deep defects were found.

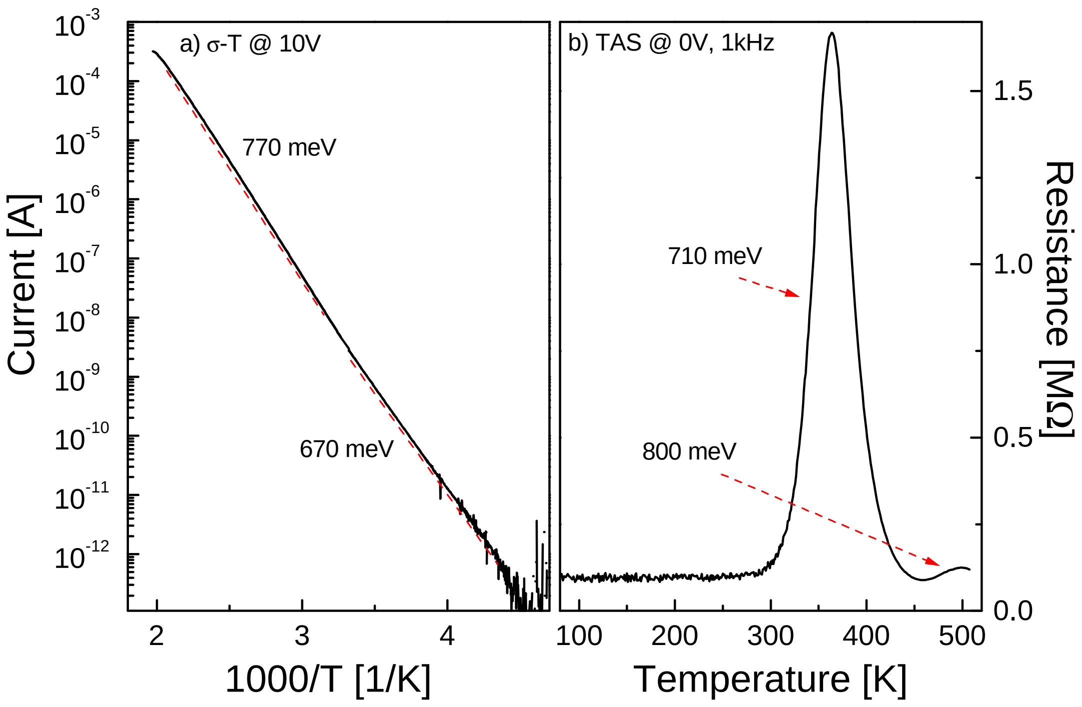

Figure 1: Comparison of temperature dependent conductivity (a) and thermal admittance measurements (b) of a GaN sample which was implanted with He ions of 20, 90, 180 keV and ion doses of 1.8,2.9,3.4*10^{14} /cm^2, respectively.
Both spectroscopic methods reveal two defect states with thermal activation energies at about 700 meV and 800 meV, respectively. The same defects were also observed in samples, which were implanted with other species of ions giving strong evidence for their intrinsic nature.

Figure 2:
Optical admittance spectra of GaN samples implanted with 80 keV oxygen and 60 keV carbon ions as well as the non-implanted reference material. Independent of the ion species, the defect-to-band-transitions within the blue band BB around 400 nm (3.1 eV) and in the spectral range between 500 nm and 700 nm (2.5-1.8 eV) are enhanced by the implantation process. A new transition I1 at 2.0 eV was exclusively observed in implanted samples.