GaN detector development for particle and X-ray detection

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Summary. We report on preliminary alpha particle and X-ray measurements on a number of prototype GaN PIN diodes. The devices have a planar structure consisting of a 2 µm epitaxial SI layer grown by MOCVD on a p–type 4H–SiC substrate. A highly doped n–type $Al_xGa_{1-x}N$ film is used as a nucleation layer to compensate for the lattice mismatch between the SI-GaN and the substrate. A number of different sized devices were tested with contact diameters ranging from 0.4 mm to 0.7 mm. All devices showed good diode behaviour with reverse leakage currents in the tens of micro-amp range. C–V measurements showed that the GaN layers were fully depleted for biases > 20V. When exposed to a 5.5 MeV alpha particles, the devices showed a spectroscopic response with energy resolutions of ~25% FWHM at RT and 10V bias and 20% FWHM at -50°C. No response to 60 keV photons could be measured.

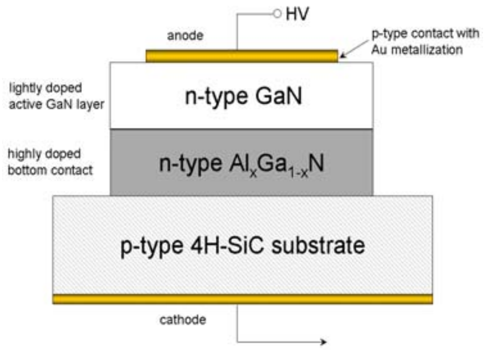

Fig. 1. A schematic cross-section of a pn device used in the present investigations. It consists of a 2 µm epitaxial GaN layer grown on a on an n–type $Al_xGa_{1-x}N$ nucleation layer, on a p–type 4H–SiC substrate.

Historically, GaN has attracted considerable attention for optoelectronic [1] and high temperature/high power electronic component applications [2]. Its direct band gap of 3.4 eV means that it is an efficient emitter of blue light, which along with red and green opto-materials, such as AlGaAs and AlGaP makes the solid state generation of white light possible, while its material properties such as large displacement energy (~ 20 eV), high breakdown field (5×10^6 V cm^{-1}) and thermal stability, offer an order of magnitude improvement in power amplifier performance over say GaAs or Si, particularly at microwave frequencies. The wide band gap and large density (6.2 g cm^{-3}), also make GaN an ideal candidate as a high temperature, radiation hard particle and X–ray detection media, particularly for solar blind applications [3].

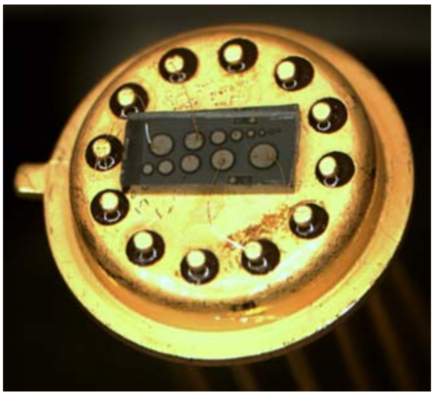

Fig. 2. Photomicrograph, showing a diced piece of the processed wafer, on which a number of diodes have been patterned. Four have been wire bonded for testing.

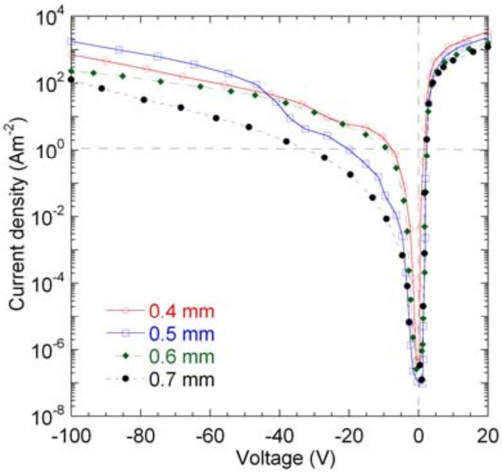

Fig. 3. I-V characteristic for the four devices.

The devices are shown schematically in Fig. 1. They consist of a 2 µm GaN epitaxial layers grown on a on an n–type $Al_xGa_{1-x}N$ nucleation layer deposited on a p–type 4H–SiC substrate. Au ohmic contacts were applied to both the the top off the GaN layer and the bottom of the SiC substrate and consequently act as the anode and cathode electrodes, respectively. Four devices of radii 0.4mm, 0.5mm, 0.6mm and 0.7mm dia were diced from the wafer, mounted on a TO39 header and wired bonded (see Fig. 2). All four devices showed good diode behavior with reverse leakage currents in the tens of µA range. Fig. 3 shows the data plotted in current density form, from which we see there is no systematic variation between contact sizes. The reverse bias break-down voltage is ~100V, which implies extremely high field strengths (E~500 $kVcm^{-1}$) if the full bias is dropped across the ~2 µm GaN layer. C-V measurements indicate that the SI-layer is fully depleted for nominal biases between 10V for the 0.4 mm device to 60V for the 0.7 mm device (see Fig. 4).

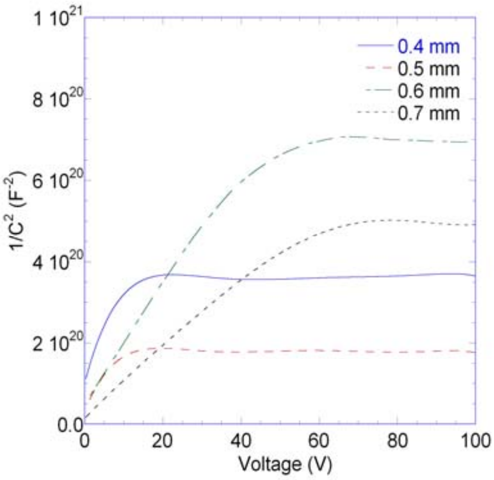

Fig. 4. C-V characteristic for the four devices.

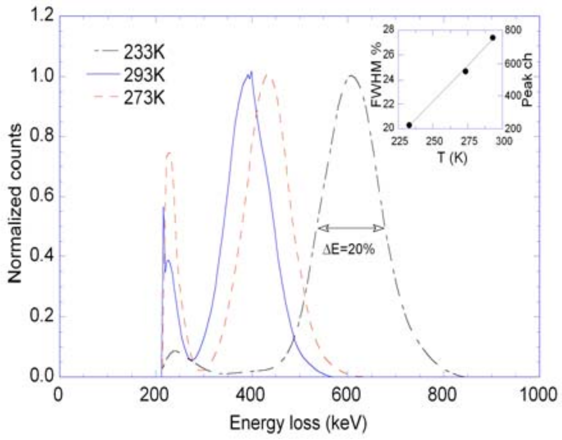

Fig.5. The response of the 0.6 mm dia device to 5.5 MeV alpha particles.

The devices also showed spectroscopic responses to 5.5 MeV alpha particles from ^{241}Am. At a bias of 10 V, the typical energy resolutions were ~25% FWHM at RT and 20% at -50°C. Pulse height spectra are shown in fig. 5 for the 0.6 mm dia device for three temperatures, -50°C, 0°C and 20°C at 10V bias. Note: the abscissa shows the energy deposited in the device and was calibrated using pulses of known amplitude into a 1.87 pF capacitance connected to the pre-amplifier input. The assumed ehp creation energy in GaN was 8.9 eV per electron–hole pair.

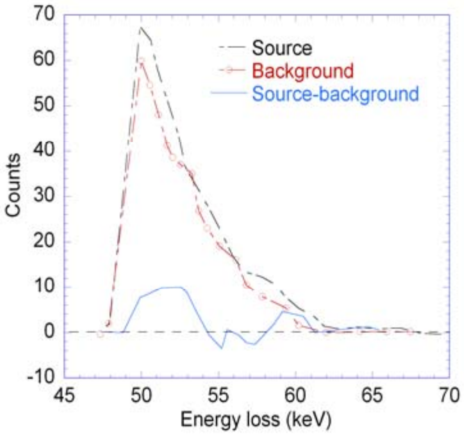

Fig.6. Response of 0.6 mm dia device to 60 keV photons.

The peak centroid position was also found to increase linearly with increasing bias which is expected from the CV data due to the increasing depth of the depletion region and/or increasing charge transport due to the higher field strength. As seen in Fig. 6 there is no response to 60 keV photons. Unfortunately cooling did little to reduce leakage currents and so it was not possible to reduce the noise floor sufficiently to resolve a photon peak.

References

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