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Conception and high temperature characterization of 10 kV 50 A 4H-SiC PiN diodes

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This preliminary paper presents the early results obtained from the characterization of high voltage SiC PiN diodes. We first present the context of this work in Supergrid Institute. We then show the structure of these devices for which the conception was made by the Supergrid Institute and Caly Technologies. The fabrication was led with Caly Technologies and Ion Beam Services. The devices from the first run showed withstand voltages up to 5 kV and the devices have been characterized at temperatures as high as 200 °C. In forward mode, the 59 mm² diodes were characterized up to 50 A. The full paper will present results from the second run for which preliminary characterization has shown breakdown voltages up to 9 kV, and typical voltage drops lower than 4 V at 20 A in forward mode. The goal for the near future will be more reliable process and devices in the long run.

The market of SiC devices has grown during the past decade and transistors and diodes are now available at affordable cost. Although some high voltage devices have been made [1], the ones industrially available mostly are MOSFET and JBS diodes, up to 1700 V [2]. Although reliability studies remain to be done, unipolar devices seem to be suitable for this range of voltages and show good characteristics during conduction and upon switching.

For the Supergrid applications and high power converters, it will be interesting to work with devices which show higher breakdown voltages, up to 10 kV [3]. At these voltages, a large part of the devices resistivity is due to their drift, which is the thick and lightly-doped region that permit to withstand the high electrical field caused by the high voltage. Plus, increasing the nominal temperature reduces the charge carrier mobility which is even more detrimental to the resistivity of unipolar devices that rely on field effect conduction. This led Supergrid to work on the conception and fabrication of SiC 10 kV PiN diodes with the Ampère lab and Caly Technologies. The main interest of bipolar devices compared to unipolar devices is the modulation of drift conductivity thanks to the injection of minority carrier [4]. If the carrier lifetime is high enough, the resistivity can be greatly reduced in high-injection mode of operation. If the lifetime is too low, dynamic characteristics could be similar to those observed in unipolar devices. The mechanism of field assisted current conduction is enhanced by the diffusion mechanism which is less sensitive to temperature and lead to lower increase of the resistivity with temperature in bipolar devices.

The structure of the devices fabricated is presented in fig. 1. An N-type buffer is grown on the highly doped 4h-SiC substrate. A 110 μm thick and 7×10^{14} cm⁻³ N-doped drift is then grown to complete the N-type cathode. The P-type anode is then made with two layers. The first anode layer grown on the drift is 1 μm thick and doped at 6×10^{17} cm⁻³ while the second layer is 0.5 μm thick and highly doped at 5×10^{19} cm⁻³ to guarantee a good quality P-type contact. Finite elements simulation showed that the maximum breakdown voltage with these parameters is around 13 kV. For the peripheral protection, we used a mesa etching coupled with a 400 μm JTE and 6 JTE rings realized with the same P-type implantations.

Two sizes of diodes were made. The active area is 59 mm² for the large diodes and 9 mm² for the smaller ones. Some devices have been put in package by Deep Concept for high temperature characterization. The fig. 2 shows the typical results obtained in static characterization in reverse mode on small diodes. The characterization was done in the Ampère laboratory. The packaged devices were placed on a hot plate and the temperature specified is the case temperature. To avoid self-heating or further variation in temperature, characterization was performed in pulsed mode with 50 μs measurement.

As can be seen on fig. 2a, the typical breakdown voltage is as low as 5 kV. We realized later that a shift in the ion beam implanter measured current caused the JTE effective dose to be a lot lower than the targeted value. A second run of devices was performed and adjustments in the targeted dose permitted to observe higher breakdown voltages, up to 9 kV. We highlighted the fact that interface charges with the polyimide passivation tends to lower the effective JTE dose. We can see here that for the first run, temperature increases the leakage temperature and increases the withstand voltage. The lowering in current with voltage is due to capacitive effect of the voltage source and caliber variations of the current probe. The full article will present the full set up used for characterization. A third run will be performed during 2018 and we should henceforth surpass the 10 kV threshold.

As can be seen on fig. 2b, forward characterization showed limitation of the current variation with temperature at higher voltages. This might be due to a high contact resistivity. For large devices, at room temperature and at 10 A, we measure a typical $V_F = 4.9$ V and a dynamic resistance of $R_{dyn} = 150$ m Ω which corresponds to a dynamic resistivity of 90 m Ω .cm². The preliminary measurements on devices from the second run show, at 10 A, a typical $V_F = 3.5$ V and dynamic resistance lower than 25 m Ω .cm², thanks to an enhancement of the metallization process. The full paper will present results obtained from high temperature static and dynamic characterization of PiN diodes from the first and maybe the second run as well.

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Fig. 1. Schematic cross-view and doping and thickness parameters of the different 4H-SiC layers used for the fabrication of a 10 kV PiN diode.

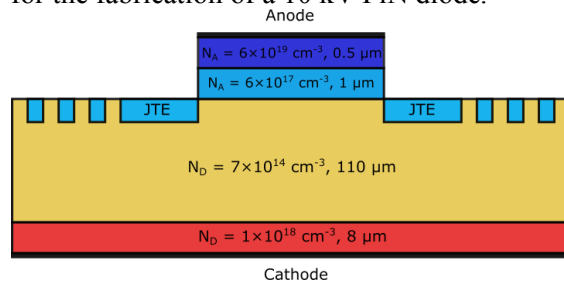


Fig. 2. Typical IV curves obtained from (a) reverse characterization of a 9 mm² PiN diode and (b) forward characterization of a 59 mm² diode at several temperatures.

