GaAs pin diodes – highly efficient and simple power devices

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Over the past decades, gallium arsenide (GaAs) has become an established material in high-frequency and optoelectronic applications and is, after silicon, the second most widely used material in the semiconductor industry [1]. Owing to its widespread availability, GaAs provides the foundation for the development of cost-effective, highly efficient pin diodes presented in this work, which represent an excellent alternative to SiC- and GaN-based power devices. The semi-wide bandgap material GaAs have not been taken into the consideration to design bipolar power devices like diodes and IGBTs for high voltage classes so far. Formerly, the potential of the GaAs based pin diodes were demonstrated in many literatures [2]–[6] for voltage classes of up to 600 V. GaAs material possesses many useful properties like high electron mobility in comparison to Si and SiC, twice the critical field strength as for Si, low intrinsic carrier density and low inherent minority carrier lifetime [7]

The presented work will summarise the latest developments in regard to utilize the inherent and beneficial material properties of GaAs combined with advanced manufacturing processes of an up to 100 µm thick epi-layer stack. The fabrication of vertical GaAs pin-diodes was done by metal-organic chemical vapor deposition (MOCVD) growing n^{++} and p^{-} epi-layer on 4” p^{+} substrate with an overall epi thickness of up to 100 µm. The lateral junction termination is done by wet chemical etching down to the substrate and combined with new vertical surface passivation is introduced. The reliability data for those improved devices are presented for the first time.

The devices blocking voltages exceeding 1200 V and operate over a wide temperature range of up to 175 °C, while maintaining a low forward voltage drop for rated currents from 10 A to 60 A, as example see Fig. 1. Furthermore, ion irradiation offers the possibility to tailor the switching behavior according to specific application requirements. The reduction of the charge carrier lifetime through the introduction of deliberately engineered defects results in a substantial decrease in reverse recovery charge during switching events, thereby enabling significantly lower switching losses. The device development is supported by simulations using SILVACO TCAD [8], showing the that the reverse recovery charge was reduced from 1880 nC to 380 nC for the simulated, as well as for the fabricated diodes, with tailored lifetime. The GaAs diode with lifetime killing shows nearly 5 times reduction in Q_{rr} than the diode without lifetime reduction. The reverse recovery maximum current (I_{rrm}) got reduced from 38 A to 17.5 A for such improved diodes, see Fig. 2.

A typical application of such diodes is the phase-shifted full-bridge (PSFB) topology. In the 10 kW power class, performance comparable to SiC-based solutions was demonstrated [9], see Fig. 3 (a). In addition, when applied in a boost converter, a significant efficiency improvement was achieved, particularly under partial-load conditions, see Fig. 3 (b). Overall the GaAs diodes are ideal for soft switching topologies (LLC, PFSB etc) and secondary side rectification applications like industrial battery charging, welding, induction heating and much more.

In combination with mass production costs are significant lower as SiC, GaAs pin diodes could be proven as suitable candidate for high efficient application replacing Si, SiC and GaN power devices.

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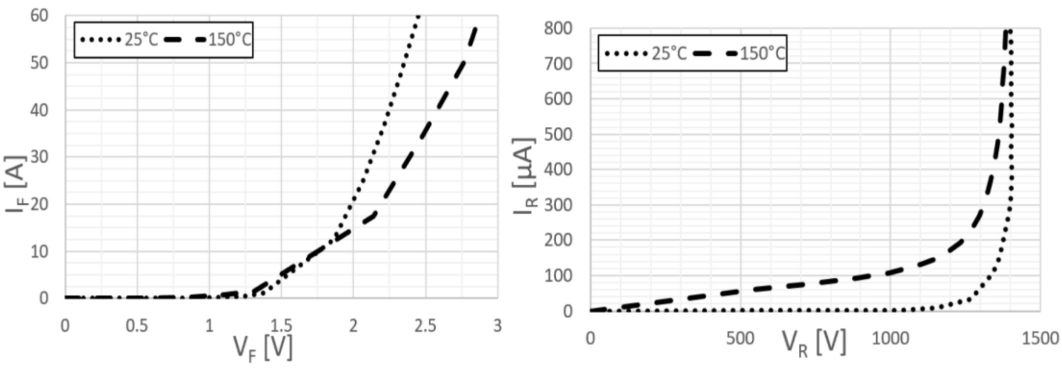


a) *b)*

Fig. 1: Exemplaric forward (a) and reverse (b) characteristic of a soft switching 60 A, 1200 V GaAs pin diode at 25 °C and 150 °C.

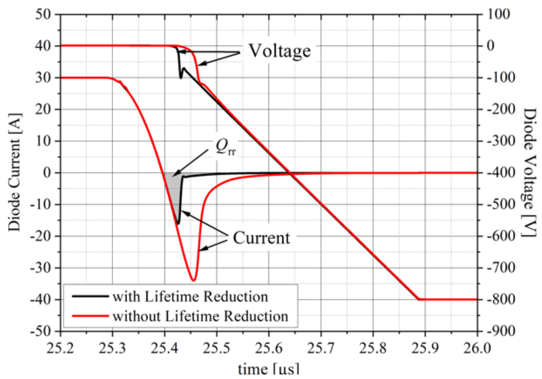
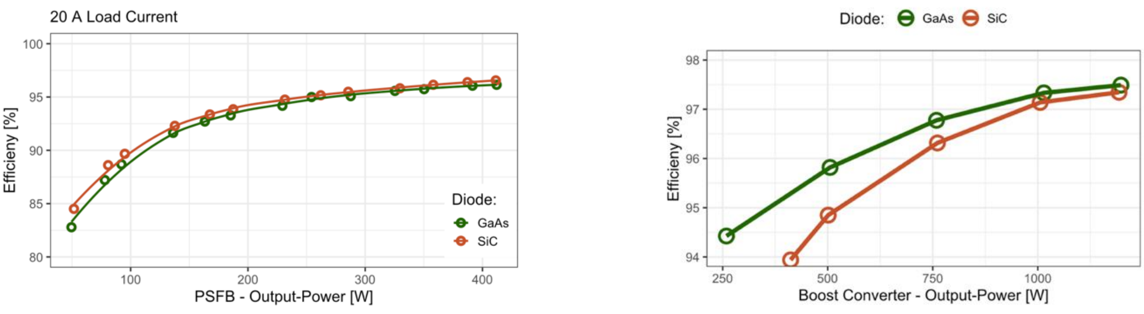


Fig. 2 Simulation of the dynamic behavior for GaAs pin diode with and without lifetime reduction at 300 K, 30 A, 500 A/µs, and 800 V DC-link voltage.



a) *b)*

Fig. 3: Efficiency comparison between GaAs and SiC devices in a soft-switching converter at a load current of (a) 20 A and a maximum output power of 8.2 kW at 100 kHz, adapted from [1]. Silicon hyperfast diodes experienced thermal failure at load currents exceeding 10 A and are therefore not included. In (b), a comparison of the efficiency of a SiC Schottky diode and a GaAs pin diode from 3-5 Power Electronics GmbH in a boost converter (PFC) operating at a switching frequency of 100 kHz.