

GaAs pin Diode Devices and Technology for High Power applications at 600V and above

Volker Dudek¹, Jens Kowalsky², Josef Lutz²

¹Clifton GmbH, Weipertstraße 8-10, 74076 Heilbronn, Germany

²Chemnitz University of Technology, Chair of Power Electronics and Electromagnetic Compatibility, Reichenhainer Straße 70, 09126 Chemnitz, Germany
e-mail: volker.dudek@cliftonsemi.com, +49 151 611 387 82

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Abstract

GaAs is a direct semiconductor with a bandgap of 1.42 eV. The direct bandgap has the consequence of a low lifetime. Additionally, GaAs has high electron mobility, so for a bipolar device low switching losses combined with low conduction losses can be expected. On the technology side, up to now no low cost high voltage GaAs technology with GaAs epi layers thicker 100µm are available. In this article low cost, high voltage, high power GaAs pin-diodes manufactured using a specialized LPE technology are presented. [1].

POTENTIAL OF GAAS

GaAs Schottky diodes have been presented some time ago [2]. However, the main advantage of GaAs is the high electron mobility and the higher, direct Bandgap. A diode simulation of the blocking capability with “Sentaurus Device” where GaAs is compared with Si for the same doping profile and basewidth w_B . shows a 450V higher breakdown voltage of the GaAs device due to the wider bandgap and thus lower intrinsic carrier density n_i and higher critical field strength E_C and increased maximum junction temperature $T_{j(max)}$, of GaAs.

In consequence, for the same blocking voltage, GaAs devices can be designed with a thinner base. This has consequences for the stored charge in a bipolar diode. For the stored charge Q_F , causing the switching losses and considering the base width one gets Equation 1

$$\frac{Q_F(GaAs)}{Q_F(Si)} = \frac{(\mu_n + \mu_p)_{Si}}{(\mu_n + \mu_p)_{GaAs}} \cdot \frac{w_{B,GaAs}^2}{w_{B,Si}^2} = 0.1478 \quad (1)$$

From the simulation results, it is reasonable to allege that with the GaAs diode one can achieve the same blocking voltage as silicon diode with reduced base region width. From the above expression, the stored charge of the GaAs diode is about 14.78 % of stored charge of the Si diode. This

results in significantly lower switching losses. Precondition to achieve this huge advantage is that GaAs technology becomes as mature as Si technology in terms of Total Cost of Ownership. A Young’s Modulus of only 85.5 GPa increases the reliability in respect of various contact- and packaging-technologies. Quality and reliability make GaAs an alternative to SiC or GaN.

TECHNOLOGY OF GAAS PIN DIODES

The technology developed in Clifton Ltd. uses quartz and graphite cassettes for growth process of LPE GaAs epi-layers. High quality quartz reactors have been chosen for the LPE process. Investigations about the interactions between the quartz reactor, vaporized oxygen, and molten gallium proved that the homogenization process of the liquefied gallium takes only place before epitaxial growth, if the environment is additionally doped with silicon atoms by adding vaporized oxygen into the gas environment [3]. Varying the amount of vaporized oxygen strongly influences the contamination of molten gallium with silicon. Therefore during the thermal treatment it is obligatory to follow two contradictory processes – contamination and cleaning of the alloy simultaneously. The equipment for the growth of the GaAs epitaxial layers is shown in Figure 1

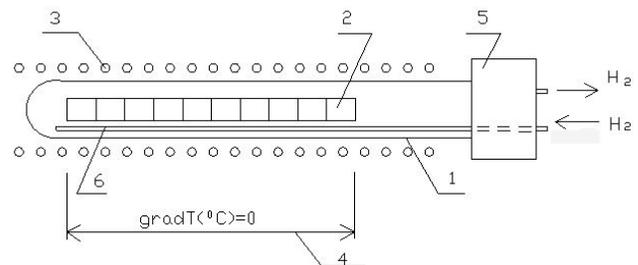


Figure 1 Schematic cross-section of the LPE equipment (1-reactor, 2-cassette; 3-heater;4-active zone, 5-locking/ rotating part of the equipment, 6-paddle)

Czochralski or VGF substrates with 2- and 3-inch GaAs wafers are used for the epitaxy. The pin epitaxial layers are grown, followed by an edge contouring and polishing procedure. After deposition of an n⁺-doping layer and lapping/cleaning, the AuGe/Ni/Ag metallization is deposited and structured using a lift-off technique. For isolation, a multi-step mesa etch technology is used followed by a polyimide passivation and a backside p⁺-contact metallization of the anode.

EXPERIMENTAL RESULTS FOR 600V GAAS PIN DIODES

Forward characteristics

The forward characteristic is shown in Figure 2 in linear (Fig 2a) and logarithmic current scale (Fig 2b). The junction voltage at 300 K can be taken as 1.1 V, at 425 K the junction voltage decreases down to < 0.8 V. This is even in the same range as for GaAs Schottky diodes reported in [1] and gives the possibility to obtain low conduction losses. At rated current, the temperature coefficient of V_F is positive.

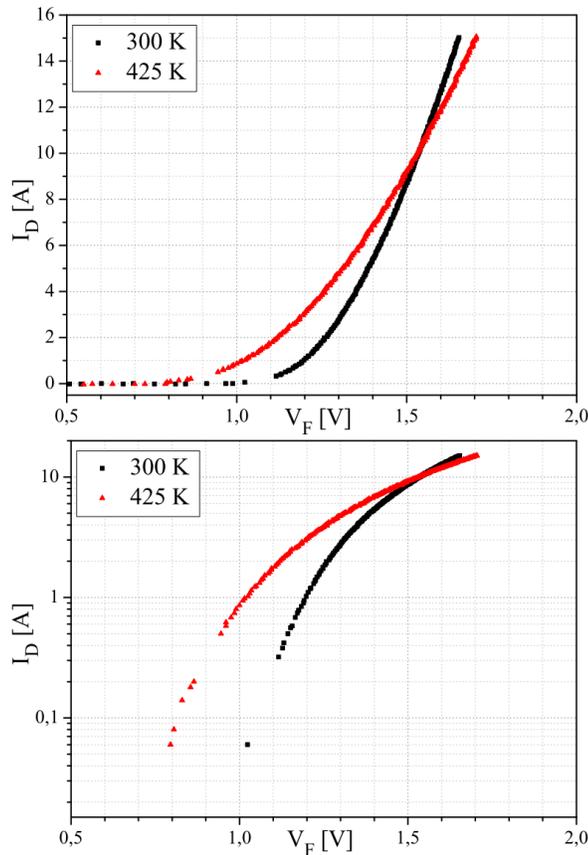


Figure 2 Forward Characteristics of 3.1 x 3.1 mm² GaAs pin diodes, rated 600 V

In the blocking mode, the diodes show typically a very low leakage current. At 425 K, a leakage current of typical

10...20 μA (measured at 700 V) was found. The increase of the leakage current with temperature is very small.

Switching behavior

The switching behavior is shown in Figure 3 and Figure 4. This measurements had been executed in a low inductive setup (60 nH) using an application conform double pulse circuit (buck converter topology) with a 1.2 kV - 140 A - NPT - IGBT as switch for test of 600 V – 15 A GaAs pin diodes at different parameters.

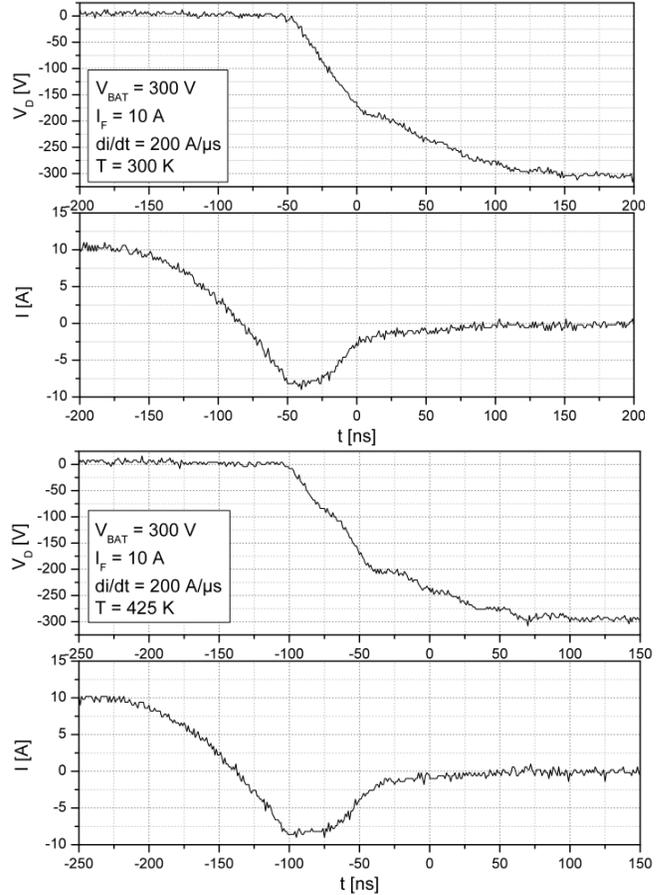


Figure 3 Reverse Recovery behavior at usual test parameters for 15 A 600 V diodes

Table 1
Calculated values for Reverse Recovery behavior at usual test parameters for 15 A 600 V diodes

T [K]	I _{rrm} [A]	Q _{rr} [nC]	W _{rr} [μWs]
300	-8,4	487,6	29,1
425	-8,6	571,8	36,3

A measurement showing the switching behavior with low current is shown in Figure 4.

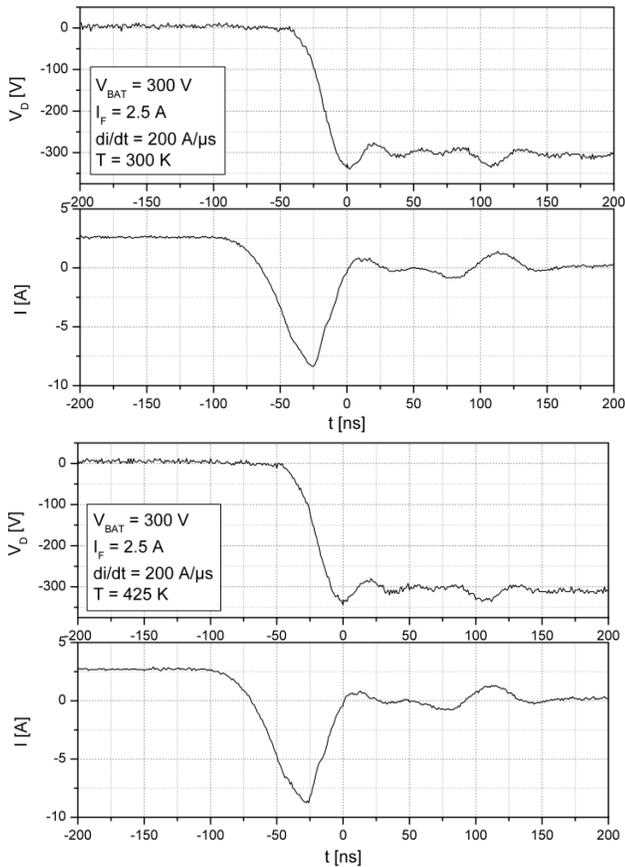


Figure 4 Reverse Recovery behavior for low current

These diodes could be suitable for use as freewheeling diodes, since losses are already smaller than for comparable Si diodes. It can also be seen, that the temperature stability of these devices has been proofed. Increasing the temperature leads to hardly noticeable increase of the stored charge up to 150° C (425 K), see Figure 5 and 6. In contrast to fast Si pin-diodes, GaAs diodes show low Q_{rr} and I_{rrm} even at evaluated temperatures. Shown in a HTRB test these diodes retain a very low and stable leakage current during long-term stress.

SURGE CURRENT CAPABILITY

Due to the low intrinsic carrier density and direct bandgap a lot of parameters change which influence the device behavior at high current densities. The lower intrinsic carrier density leads on the one hand to a higher forward voltage drop and more dissipated energy. On the other hand it is known, that at high temperatures an increased n_i is expected to trigger a negative differential resistance and destruction of electrical devices. [4,5]

A 10 ms sinewave was generated using a series resonant circuit, triggered by a thyristor. A DUT1506 (600°V/15°A) diode in TO-247 case was at 300 K exposed to a surge current pulse. Time dependent waveforms are shown in Fig. 7. The associated IV-graphs are pictured in Fig. 8. Current and voltage maximum are synchronously for small current. As the surge-current maximum is increased, the maximum of the voltage drop is shifted in time. This points to a considerable heating of the device during the pulse causing a reduction of the mobility. At even higher current densities the voltage waveform changes. The hysteresis in the IV-graphs becomes bigger, but no negative differential resistance is revealed.

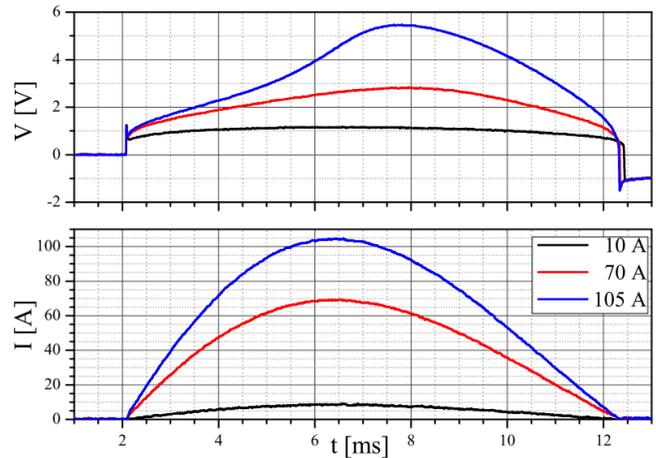


Figure 5 Surge Current pulses at $T_a = 300$ K

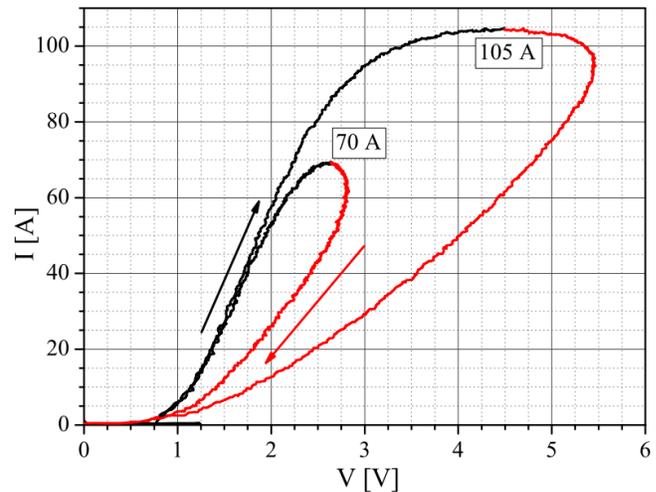


Figure 6 Surge current IV-characteristics at $T_a = 300$ K

INTENDED APPLICATIONS

A fast 3.1 x 3.1 mm² 15 A 600 V diode is suited as boost diode for power factor correction (PFC) applications. In these applications, compact wiring with low parasitic

inductance is typical. The GaAs diode will compete with Silicon Tandem diodes and with SiC Schottky diodes.

In motor drive applications, the main part of the IGBT turn-on losses are often caused by the diodes turn-off behaviour, even for an optimised Si diode. Precondition for application in such a circuit is low Q_{rr} and V_F . Especially a low reverse recovery peak I_{rrm} and extraction to a large part of the stored charge during the tail phase is important. With the same V_F and reduced Q_{rr} the total losses can be significantly decreased. This makes a GaAs Diode to a suited low cost candidate for motor drive applications.

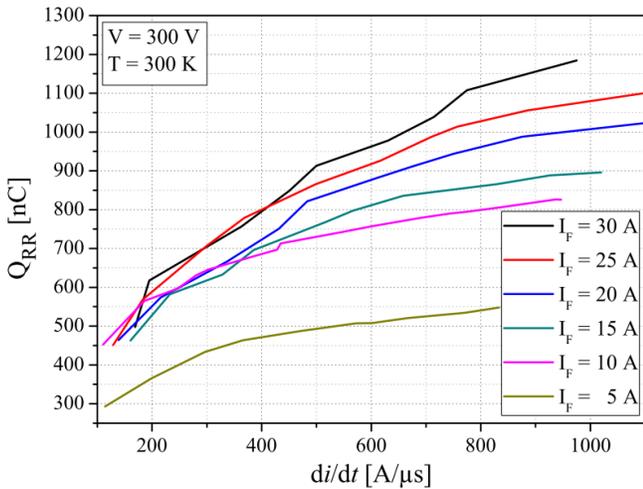


Figure 7 Reverse recovery charge at T = 300 K

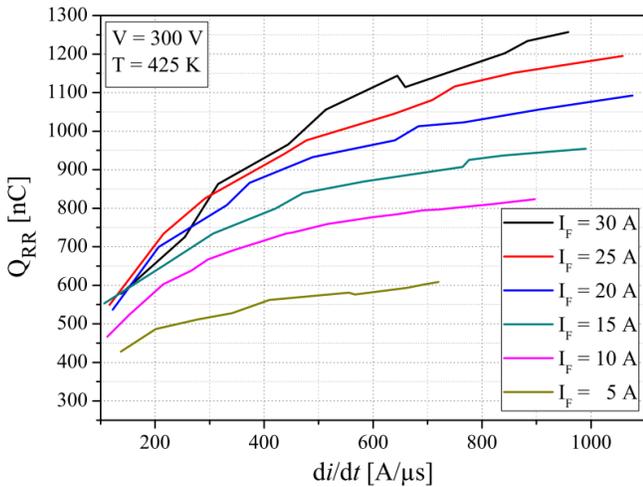


Figure 8 Reverse recovery charge at T = 425 K

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