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

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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 specialised LPE technology are presented.

1. Potential of GaAs

GaAs Schottky diodes have been presented some time ago [1]. 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 basewith w_B. shows a 450 V higher breakdown voltage of the GaAs device due to the lower intrinsic carrier density and thus higher critical field strength E_C, 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 Eq.1

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

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 Cost of Ownerchip. Quality and Reliability making GaAs an attractive alternative to SiC or GaN.

2. 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. The analysis of interactions between the quartz reactor, vaporized oxygen, and molten gallium showed that the homogenization process of the melt gallium before epitaxial growth takes place only then, when this environment is doped additionally with silicon atoms by adding vaporized oxygen into the gas environment [3]. The decrease of 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 Fig 1

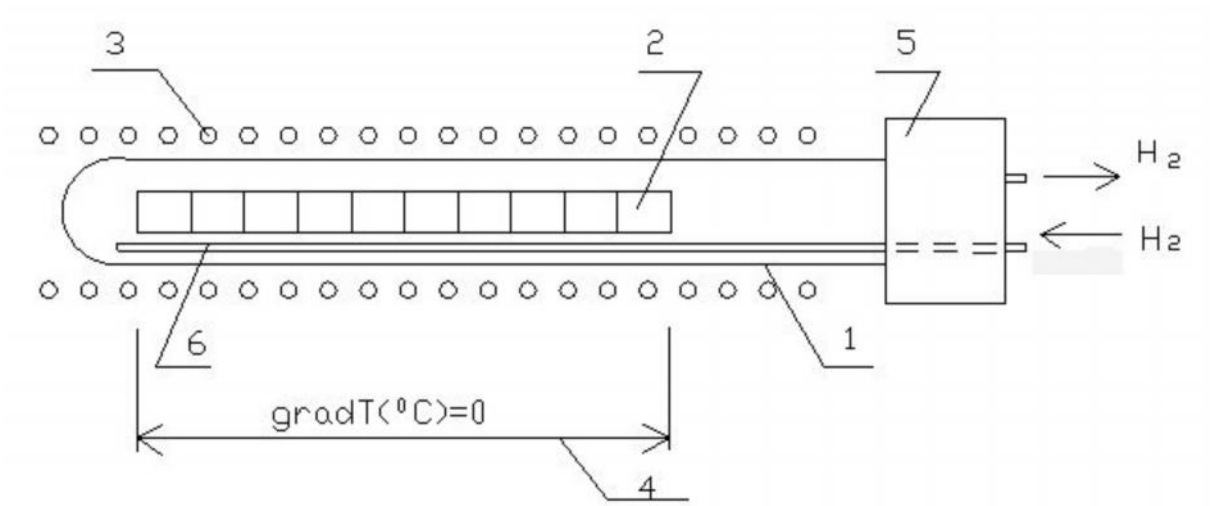

Fig. 1. Schematic cross-section of the LPE equipment
(1-reactor, 2-cassette, 3-heater; 4-actice zone, 5-locking/rotating part of the equipment, 6-paddle).

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.

3. Experimental results for 600V GaAs pin diodes

3.1. Forward characteristics

The forward characteristics is shown in Fig.2 in linear (left) and logarithmic current scale (right). The junction voltage at 300K can be taken as 1.1 V, at 450 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.

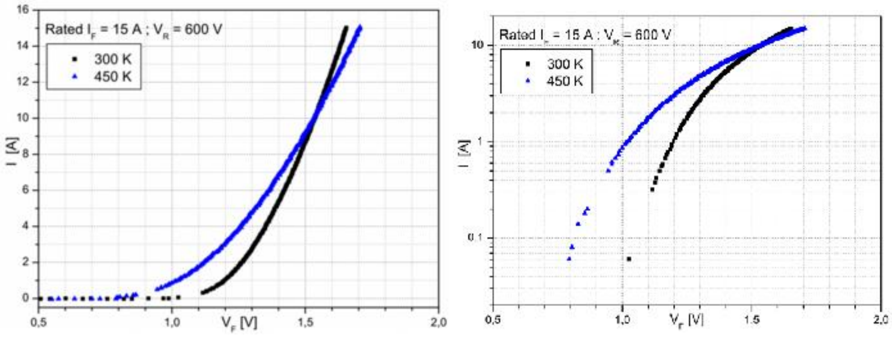

Fig. 2. Forward Characteristics of 3.1 x 3.1 mm^2 GaAs pin diodes, rated 600 V

In the blocking mode, the diodes show typically a very low leakage current. At 150° C, 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.

3.2. Switching behavior

Measurement results of the switching behaviour are shown in Fig.3 and Fig.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 and a 600 V – 15 A GaAs pin diode.

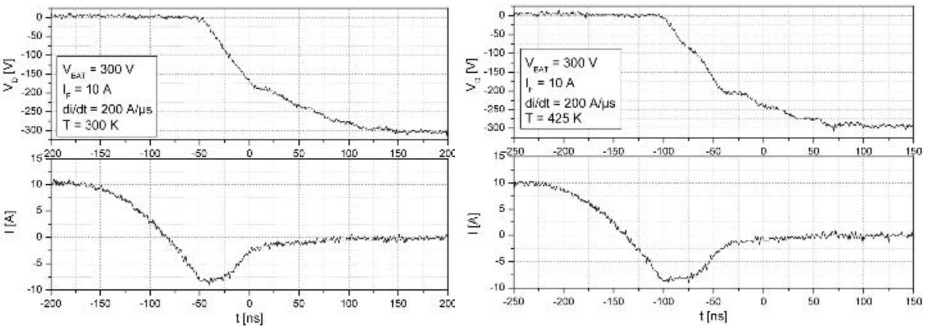

Fig. 3. Reverse Recovery behaviour at usual test parameters for 15 A 600 V diodes

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

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

A measurement showing the switching behaviour with low current is shown in Fig 4.

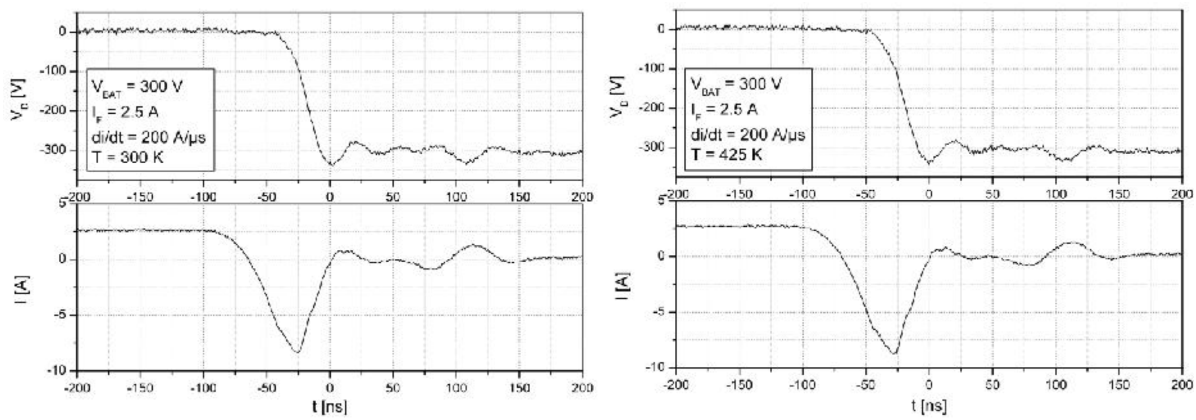

Fig. 4. Reverse Recovery behaviour for low current

T [K]	I_{rrm} [A]	Q_{rr} [nC]	W_{rr} [µWs]
300	-8,3	281,2	23,5
425	-8,7	314,2	27,5

Table 2. Calculated values of Reverse Recovery behaviour 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 been seen, that the temperature stability of these devices has been proofed. Increasing the temperature leads to hardy noticeable increase of the stored charge up to 150° C (450 K), see Fig. 5 and 6. In contrast to fast Si pin-diodes, GaAs diodes show also low Q_{rr} and I_{rrm} at evaluated temperature. Shown in a HTRB test these diodes also have a very low leakage current.

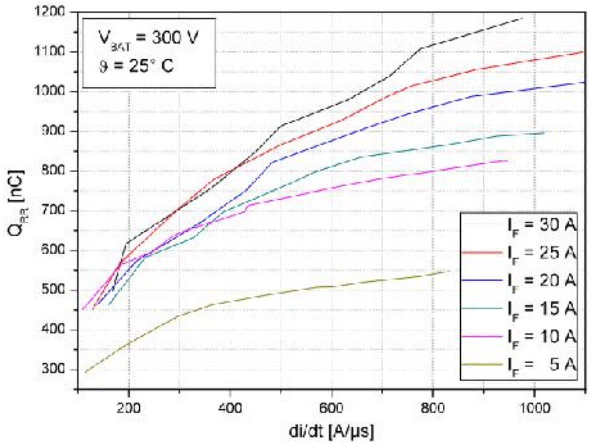

Fig. 5: reverse recovery charge at T = 300 K

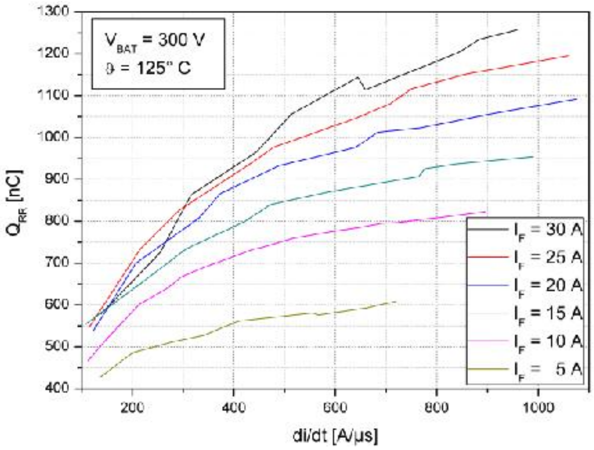

Fig. 6: reverse recovery charge at T = 425 K

4. Intended applications

A fast 3.1 x 3.1 mm^2 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 of most of the stored charge during the tail phase is important. With the same V_F and reduced Qrr the losses can be significantly decreased. This makes a GaAs Diode to a suited low cost candidate for motor drive applications

5. Literature

[1] A. Lindemann, S. Steinhoff, A New Generation of Gallium Arsenide Diodes Optimised for Low Forward Voltage Drop, Nürnberg: PCIM Conference, 2004.

[2] Jens Kowalsky, Thomas Basler, Riteshkumar Bhojani, Josef Lutz, Volker Dudek, Dmitri Opalnikov, Viktor Voitovich, GaAs pin Diodes as Possible Freewheeling Diodes, Nürnberg: PCIM Conference, 2013

[3] Voitovich, V., Development of LPE technology for GaAs high-voltage structures. Doctoral theses, TTU Press, 2006.