Effect of a wideband heteroepitaxial emitter on dynamics of turn-off switching of high-voltage power GaAs p-i-n diodes

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Abstract. The possibility of improving the dynamic characteristics of turn-off switching of high-voltage power GaAs p-i-n diode by applying a heteroepitaxial AlGaAs emitter is investigated in this work. Using a wideband AlGaAs n+ emitter in manufacturing of power GaAs p-i-n diodes allows to vary the coefficient $K$ value which characterizes the recovery softness of diode blocking properties when switching off in the range of 0.1 to 2 or more. The diodes with blocking voltage of up to 700 V, the reverse recovery time of about 40 ns and $K > 1$ were manufactured.

1. Introduction

Application of heterostructures in manufacturing of high voltage power devices on the base of GaAs allows improving the set of their main static and dynamic characteristics [1-4]. Using wideband heterostructure emitters can significantly extend the dynamic range of current densities within which the emitter injection efficiency remains close to unity. This has implications for improving the conductivity modulation of the diode base layers at high current densities and reducing the static energy losses in the device in a conducting state. Besides static characteristics, using of heterostructure emitters also allows changing the diode switching-off process dynamics, which is especially important for fabricating diodes with a soft and sharp recovery character.

One of the most important dynamic characteristics of high-power pulse bipolar diodes is the reverse recovery time $t_{rr}$ (the time in which the blocking properties of a p-n junction are restored after the diode was switched from the conducting to blocking state). During this time the charge accumulated in the base layers dissipates resulting in reverse diode current. When a diode is switched off the two phases of reverse resistance recovery can be distinguished: (i) the stage of a high reverse conductivity $t_s$ in which the p-n junction remains forward-biased despite the change of the polarity of the applied external voltage (at this stage the diode reverse current grows from zero to its maximum value $I_{max}$) and (ii) the stage of recovery of the high reverse resistance $t_f$, in which a space-charge region is formed near the p-n junction and, while extending, this region blocks the voltage applied to the diode ($t_f$ is the time during which the reverse diode current drops from $I_{max}$ to $0.2 \cdot I_{max}$). The ratio of durations of these stages, $K$ (the softness coefficient, $K = t_f/t_s$) mainly characterizes the degree of softness or sharpness of the blocking properties recovery for a diode when switching-off.

Devices with a soft character of the blocking properties of recovery at switching-off are the most desirable for applying in electric power converters, since they contribute significantly less...
electromagnetic interference in the operation of other parts and devices of power electronic systems. Besides, the soft character of recovery of the diode blocking capability prevents the appearance of sharp splashes of voltage on a parasitic inductivity of the power circuit of electronic power converters [5].

2. **Sample fabrication**

Fabrication of p-i-n GaAs diode structures was carried out in two stages with using the liquid phase epitaxy (LPE). The epitaxial growth of high-voltage lightly doped gradual GaAs p0-i-n0 junction layers was carried out from a confined Ga-As melt in the hydrogen atmosphere in quartz boats from 900 °C to room temperature. This procedure for GaAs p0-i-n0 structure growth is presented in detail in [2,4]. In this mode of LPE growth of p0-i-n0 structures, it is possible to obtain thick i-type layers of lightly doped GaAs with a free carrier concentration of \( \sim 10^{13} \text{ cm}^{-3} \), which makes it possible to reach blocking voltages \( U_b \) of up to 2000 V [3]. The heavily doped (with Te) GaAs or AlGaAs n+-emitter layers of diode structures were grown in graphite piston cassette. The typical free carrier distribution across the thickness of diode structures is shown in figure 1.

![Figure 1. Typical free carrier distribution across the thickness of GaAs high voltage p0-i-n0 layers grown on p+-GaAs substrates with a later-grown GaAs or AlGaAs n+-emitter.](image)

To study the effect of presence of a potential barrier on a heterointerface between a lightly doped base layer and a heavily doped heteroepitaxial n+-emitter on the diode switching-off behaviour, we have fabricated test GaAs p-i-n diodes with same structures of the p+-emitter (substrate) and lightly doped p0-i-n0 base layers but with different n-type emitters (see figure 1). The fabricated devices of the first group were fully homo-epitaxial and had a GaAs n+-emitter. Devices of the second group had a hetero-epitaxial AlGaAs n+-emitter with the AlAs content of up to 15% ensuring the presence on its boundary a potential barrier for carriers \( \Delta E_g \sim 0.19 \text{ eV} \). The devices had the same base thicknesses of 55µm, the emitter area of 1mm² and the breakdown voltage \( U_b = 700 \text{ V} \).

3. **Turn-off switching of high voltage power GaAs p-i-n diodes with different n+-emitters**

Figure 2 shows oscillograms of turn-off switching for the diodes of the first and second groups from the conducting state with the current \( I_f = 1.5 \text{ A} \) into the blocking one by applying the reverse voltage \( U_r = 300 \text{ V} \) at a rate of current change \( dI/dt \) of about 150 A/\( \mu \text{s} \).
Figure 2. Waveforms of turn-off switching for GaAs p-i-n diodes with the same high voltage base layers and different n+-emitters: a homostructure GaAs n+-emitter (a) and a heterostructure AlGaAs one (b). Vertical scanning is 0.5 A/div and horizontal one is 20 ns/div; \(dI/dt\) is about 150 A/µs.

It is clear from figure 2 that application of the wideband heterostructure AlGaAs n+-emitter allows changing the character of the process of GaAs p-i-n diode blocking properties recovery from a sharp switching-off mode (the softness coefficient \(K\) is about 0.15) to a soft one (the softness coefficient \(K\) is about 2). The reverse recovery of full charge for diodes of the first and second groups had similar values. The difference between \(K\) values for the first and second groups of diodes can be explained by the presence of a wideband AlGaAs n+-emitter in the second group of diodes. On the one hand, the formation of a hetero-junction results in a higher concentration of injected carriers plasma near the diode AlGaAs n+-emitter in the conducting state, but, on the other hand, it prevents its rapid resorption by the reverse current at switching the diode off owing to the presence of a potential barrier on the hetero-junction. In such a device, the phase of charge resorption in the n+-base away from the p-n junction lasts much longer, since the process of space-charge layer widening in the p-n junction is hampered by the presence of residual electron-hole plasma in the region near the AlGaAs n+-emitter, and the recovery character becomes softer.

4. Summary
Application of wideband AlGaAs n+-emitters in the design of high voltage power GaAs p-i-n diodes allows controlling the degree of softness of the switching-off process and optimizing the dynamic characteristics of devices for operating in different modes. The carried out investigations have allowed fabricating diodes with blocking voltage of up to 700 V with a soft character of turn-off switching (with the softness coefficient \(K\) value of about 2).

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5. References
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