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CHARGE-ACCUMULATION EFFECT IN EPITAXIAL

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Abstract

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PHYSICS

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CHARGE-ACCUMULATION EFFECT IN EPITAXIAL

p–n STRUCTURES OF GALLIUM ARSENIDE

(Presented by Academician A. P. Aleksandrov, 31 VII 1968)

The properties of emitting-diode GaAs p–n structures obtained by liquid-phase epitaxy in an open system by the Nelson method ([1]) were investigated. The main impurity in the p- and n-regions of the junction was silicon, which, as is known ([2], [3]), is capable of creating both donor and acceptor levels. The area of the p–n junction was 1-1.5 mm^2. The radiation was brought out through a flat n-region about 0.1 mm thick. No antireflection coatings were deposited on the surface of the p–n structures.

Power for the p–n structures was supplied by rectangular current pulses from a G5-15 generator. The current and voltage pulses across the p–n structure and the pulses of the radiation generated by it were recorded. An FEU-62 was used as the radiation detector; its load was the wave impedance of a matched cable, 75 ohms. To record the current pulse, a 50-ohm resistor was connected in series with the diode. The current, voltage, and radiation pulses were observed on a dual-beam oscilloscope with a bandwidth of 10 MHz. All measurements were carried out at room temperature.

Microscopic examination of the luminescent region established that its width is 20–40 μ and that radiative recombination occurs in the p-region of the p–n structure.

The radiation spectrum had one band, with a maximum energy of 1.28–1.30 eV. The position of the maximum did not depend on the current through the p–n junction in the current-density range 10^{-1}–10^2 A/cm^2, while the radiation intensity increased practically linearly with current.

The radiation power of the p–n structures investigated was 2–4 mW at a forward current of 100 mA, which corresponds to an external quantum yield of 1.5–3.0%.

Fig. 1. Oscillogram of pulses.
a, v –at top, current pulse $i_{\text{pr}} = 15$ mA; at bottom, radiation pulse;

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Fig. 1. Oscillogram of pulses.

Figure 1: Fig. 1. Oscillogram of pulses.

Fig. 2

Figure 2: Fig. 2

b –at top, voltage pulse $U_{\text{pr}} \simeq 1.1$ V; at bottom, radiation pulse. Time scale 3 μsec/cm.

A peculiarity of the p-n structures under consideration is the appearance of a reverse-current pulse after the end of the forward-current pulse when disconnected from–

in the absence of an external negative voltage on the diode (Fig. 1a). The reverse-current pulse has two clearly pronounced phases: the first, when the magnitude of the reverse current i_0 is close to constant, and the second, when the reverse current decreases from i_0 to zero. The duration of the first phase is approximately 10 times greater than the duration (at the 0.1-0.9 level) of the second phase. It has been established that the dependences of the amplitude and duration of the first phase of the reverse-current pulse on the parameters of the forward-current pulse and on the magnitude of the load resistance are analogous to the same dependences for germanium and silicon diodes with charge storage.

It is known ([4,5]) that the appearance of a reverse-current pulse in the external circuit of such diodes is associated with a retarding "built-in" field caused by the impurity-concentration gradient in the base of the p-n structure. This field changes the spatial distribution of injected carriers in the p-region, drawing them toward the p-n junction.

After the end of the forward current pulse, some of the carriers that have not had time to recombine are drawn in by the field of the space-charge layer, creating a surge of reverse current in the external circuit.

The degree of influence of the "built-in" field on the spatial distribution of electrons in the p-region is determined by its normalized field strength

$$E_n = \frac{qL_n}{2kT} E,$$

Fig. 2. Dependence of the electron lifetime in the p-region on the injection level. a–from current oscillograms, b–from radiation oscillograms

where L_n is the diffusion length of electrons, and E is the field strength of the "built-in" field.

The field is usually considered weak if $|E_n| < 1$, and strong if $|E_n| > 1$. In the first case, the influence of the field on the spatial distribution of minority

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carriers may be neglected.

The value of E_n can be determined from the current oscillogram by the relation

$$|E_n| = \left| \frac{1}{2} \sqrt{\frac{Q_1}{Q_2} \frac{1}{\ln(1+B)/B}} \right|,$$

where Q_1 is the charge of the first phase of the reverse-current pulse; Q_2 is the charge of the second phase of the reverse-current pulse; $B = i_0/i_{\text{pr}}$ is the ratio of the current of the first phase to the forward current. For our case, the value of $|E_n|$ at a current density of 1 A/cm^2 is close to 2.

In the p–n structures under consideration, the rise and decay times of the radiation pulse proved to be 20–50 times greater than in p–n structures in which only the p-region was doped with silicon ([3]).

The carrier-dissipation time in the p-region depends on the parameters of the forward-current pulse and on the switching mode of the p–n structure. Accordingly, the shape of the radiation pulse also depends on the same factors.

With a small load resistance, the field of the p–n junction pulls a significant fraction of the injected carriers into the n-region, while the remaining fraction recombines radiatively in the p-region. In this case, the beginning and end of the light pulses, reverse current, and post-injection voltage coincide (Fig. 1, a, b).

When a fast-acting germanium diode (D-311) was connected in series with the emitting p–n structure, extraction of the accumulated charge into the n-region was precluded, and all injected carriers recombined in the p-region. This led to a prolongation of the decay time of the light pulse (Fig. 1c).

From oscillograms similar to those shown in Figs. 1a and 1b, the lifetimes of electrons in the p-region were calculated independently of one another.

To calculate the lifetime from the current oscillograms, the equation from (5) was used:

$$\tau_n = t_1 \left[\ln \left(1 + \frac{i_{\text{pr}}}{i_0} \right) \right]^{-1},$$

where t_1 is the duration of the first phase of the reverse current (the equation is valid under the condition $Q_1 \gg Q_2$).

From the oscillograms of the emission pulse, τ_n was calculated as the time constant of the exponential decay.

The lifetime of electrons in the p-region decreases with increasing injection level (Fig. 2). The electron lifetimes calculated from both types of oscillograms agree well with one another.

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The slow rise of the emission pulse is also apparently explained by the charge-storage effect.

Thus: 1) the presence of an internal field has been established in epitaxial GaAs p–n structures doped with silicon; 2) the lifetime of electrons in such p-n structures is 1-3 μs, depending on the injection level.

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Note: Figure translations are in progress. See original paper for figures.

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