EFFECT OF ELECTRON IRRADIATION ON THE PARAMETERS OF GALLIUM ARSENIDE PULSED DIODES

V. N. Brudnyi, A. A. Vilisov, A. P. Vyatkin, M. A. Krivov, and S. V. Malyanov

It is shown that the current-voltage characteristics of diodes produced by various methods vary in approximately the same manner. The behavior of the capacitance \( C(U) \) during irradiation can be explained on the basis of the theories developed for planar \( p-n \) junctions and Schottky barriers. The recovery time of diodes always increases during irradiation with large doses \( (\varphi \sim 10^{16} \text{ electrons/cm}^2) \). At smaller doses for diodes of the Schottky-barrier type (weakly formed), \( \tau_{\text{recoy}} \) always increases with irradiation, perhaps due to a decrease in the concentration \( n \); for strongly formed diodes (having parameters approximating those of diffused diodes), the \( \tau_{\text{recoy}} \) behavior is governed by the nature of the impurity distribution and by the ratio of the lifetime \( \tau \) of the minority carriers to the diode time constant \( RC \). With \( \tau > RC \), a decrease in \( \tau_{\text{recoy}} \) may be observed as a result of a decrease in \( \tau \).

For a study of the effect of electron irradiation on the current-voltage, current-capacitance, and pulsed characteristics of point-contact gallium arsenide pulsed diodes, diodes having the following parameters were produced from \( n \)-type gallium arsenide: a resistivity of 0.06 or 0.9 \( \Omega \cdot \text{cm} \), a charge-carrier concentration of \((3-5) \cdot 10^{18} \) or \((1-2) \cdot 10^{17} \text{ cm}^{-3} \), and a mobility of 4500 or 5500 \( \text{cm}^2/(\text{V} \cdot \text{sec}) \). Gallium arsenide plates \( d < 0.5 \text{ mm} \) in thickness were soldered with tin to a nickel substrate; electrical contacts were formed from beryllium bronze needles. After synthesis, the diodes underwent electrical forming by half-cycle forward current pulses. The peak currents ranged from 0.05 to 0.8 A, and the pulse length was \( \sim 0.5 \text{ sec} \). The diodes were irradiated by 1.5 MeV electrons at room temperature on an electrostatic generator. The \( p-n \) junctions were irradiated in metal-glass envelopes, so all the data refer to the incident doses \( (\varphi) \).

The current-voltage characteristics were measured with a direct current and a relative error of 5%. The differential resistivity was determined from the slope of the forward branch of the current-voltage characteristic at direct currents of 2 and 3 mA. The capacitance measurements were carried out at 30 MHz, within 10%. The recovery time \( \tau_{\text{recoy}} \) and the switching charge \( Q \) were determined from the transient switching characteristics of the diodes as the forward current was switched to a reverse current.


The forward branch of the current-voltage characteristics can be described by [1]

\[
I = I_0 \left\{ \exp \left( \frac{U_{pn} - IR_s}{R_s} \right) - 1 \right\},
\]

(1)

where \( I_0 = 10^{-15} - 10^{-10} \text{ A} \), \( U_{pn} \) is the voltage across the \( p-n \) junction, and \( R_s \) is the leakage resistance. For small \( I \) and for \( I/I_0 \gg 1 \), the forward branch can be written as

\[
\ln \left( \frac{I}{I_0} \right) \sim a U_{pn}.
\]

(2)

In the case of gallium arsenide point diodes this expression holds even with \( I > 10^{-6} \text{ A} \); for large values of \( I \) and \( R_s \), and taking account of the voltage drops in the diode base, we can rewrite Eq. (1) as [2]

\[
\ln \left( \frac{I}{I_0} \right) \sim a (U_{pn} - IR_s).
\]

(3)
On the basis of the forming currents and the electrical properties, we can classify these diodes into the following three groups:

a) **Unformed Contact:**

\[ \alpha = 15 - 20 \, \text{V}^{-1}, \quad \beta = 2 \quad \text{at} \quad 300^\circ \text{K}. \]

The dependence of the capacitance on the applied reverse voltage is described by

\[ C = A U^n, \]

where \( n \geq 3 \). As was shown in [3], the current-voltage characteristic of such a contact can be described on the basis of the theory developed for a planar p-n junction [4].

b) **Weakly Formed Contact:**

\[ \alpha = \frac{q}{\kappa T}, \quad \beta \approx 1. \]

The voltage dependence of the capacitance is approximately quadratic. This is the case of a contact with a Schottky barrier.

c) **Strongly Formed Contact:**

\[ U = 0.6 - 1.2 \, \text{V}, \quad \beta \ll 2, \quad C = A U^{\beta/3}. \]

A junction with a smooth impurity distribution results. The basic properties of the diodes in these three groups change in essentially the same manner during electron irradiation. Figure 1 shows the change in the forward current-voltage branch as a function of the irradiation dose. When gallium arsenide diodes are irradiated, both the n-type and p-type regions are compensated [5]. It follows from relation (2) that

\[ U_{pn} = \frac{\beta kT}{q} \ln j/j_0. \quad (4) \]

Using the data of [6], we can write a relation for the change in the carrier lifetime in the base during irradiation:

\[ \frac{1}{\tau} = \frac{1}{\tau_0} + \frac{\Phi}{m}. \quad (5) \]