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RELATIONSHIP BETWEEN COMPLEX RESISTANCE OF THE DEPLETION LAYER AND MICROPLASMA DIAMETER FOR VARIOUS FREQUENCIES AND CURRENT DENSITIES

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ANNOTATION

The work develops an analytical method for determining the parameters of microplasmas. This phenomenon of localized avalanche breakdown plays an important role in avalanche-transit diodes and other semiconductor devices operating in an avalanche mode, while the switch-on voltage and differential resistance are the two main electrophysical parameters of the microplasma. The latter is determined by the sum of series resistances - the current cord itself and the spreading resistance. The paper proposes a variant of using the diode impedance measurement in the breakdown mode and its analytical interpretation.

KEYWORDS: ***d value, electric field, microplasma, charge, drift velocity, frequency, series, sum.***

The phenomenon of microplasma breakdown, leading to the appearance of local regions of avalanche multiplication in the space charge region, is inherent in almost all reverse biased p – n junctions and Schottky diodes operating in the avalanche breakdown mode [1-3].

Despite numerous works, the very mechanism of the emergence of micro plasmas [MP] remains controversial, however, most authors [4-7] believe that the local breakdown of p - n junctions is due to various kinds of inhomogeneities. Taking into account the important role of the spatial inhomogeneity of breakdown for the functioning of avalanche diodes, the theoretical determination of the dependence of the value of RS on the diameter of the MF dmp is relevant both in the fundamental and applied aspects.

As is known [4], in the general case, the magnitude of the differential resistance of the MF RS can be written as the sum

$$R_S = R_0 + R_c + R_t \quad (1)$$

where R_0 - spreading resistance,
R_c - resistance (SCR) area of space charge,
R_t- thermal component of the resistance of the MF.

In contrast to the classical McInteyr approach [8-11], we obtained a significantly more accurate dependence for RS (d mm) taking into account the following circumstances:

1. Three-dimensionality of the distribution of the electric field of mobile carriers in the channel of the MF, which makes it possible to find the value of RS (dmp) at arbitrary ratios between the MF diameter and its length.
2. Inhomogeneity of heat release in the MF channel, associated with the variability of the electric field in the p - n junction, the nonlinear dependence of the semiconductor thermal conductivity on temperature, as well as the presence of a heat sink.

In this work, we investigate Rc - resistance (SCR) space charge region.

We have shown that the expression for the SCR resistance Rc, taking into account the three-dimensionality of the distribution of the electric field of mobile charge carriers, can be written in the form:

$$R_c = \frac{2}{\pi \cdot \varepsilon \cdot \varepsilon_0 \cdot \nu} \left(\frac{L - L_y}{d_{мп}} \right)^2 f(z,y) = R_{co} f(z,y) \qquad (2)$$

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where – ε – semiconductor dielectric constant, ε_0 - dielectric constant, ν - saturation drift rate, L – length of the OPZ,L_y- the length of the multiplication area.
In the same time f (z, y) – function that determines the decrease in magnitude R_c compared with R_{co}, когда $d_{мп}$>> L.
at d~2L, R_c less than Rco by almost two times, and with a further decrease in the d / L ratio, the value of Rc can be neglected.
На формуле (2) где

$$R_{co} = \frac{\omega_0^2}{2\varepsilon\varepsilon_0 \nu_n S_{мп}} = \frac{(L-L_y)^2}{2\cdot\varepsilon\cdot\varepsilon_0\cdot\nu_n\cdot\frac{\pi\cdot d_{мп}^2}{4}} = \frac{2}{\pi\cdot\varepsilon\cdot\varepsilon_0\cdot\nu_n\cdot}\cdot\left(\frac{L-L_y}{d_{мп}}\right)^2$$

Microplasma wire crossing will be a circular area

intersection equals $S_{мп} = \frac{\pi\cdot d_{мп}^2}{4}$

Resistance Rc - resistance (SCR) area of space charge p-n junction

$$R_c = \frac{1}{\omega\cdot C} = \frac{1}{2\cdot\pi\cdot f\cdot C} = \frac{T}{2\cdot\pi\cdot\cdot\frac{\varepsilon\cdot\varepsilon_0\cdot S_{мп}}{\omega_0}} = \frac{\frac{\omega_0}{\nu_n}}{2\cdot\pi\cdot\frac{\varepsilon\cdot\varepsilon_0\cdot S_{мп}}{\omega_0}} = \frac{\omega_0^2}{2\varepsilon\varepsilon_0\nu_n S_{мп}}\cdot f(Z,Y) = R_{co}\cdot f(Z.Y)$$

Dependences of the resistance (SCR) of the space charge region on the real part of the admittance YI (differential conductivity) and the minimum part of the impedance ZII (normalization to the maximum value of ZIIm) on the frequency f of the alternating current through the diode.

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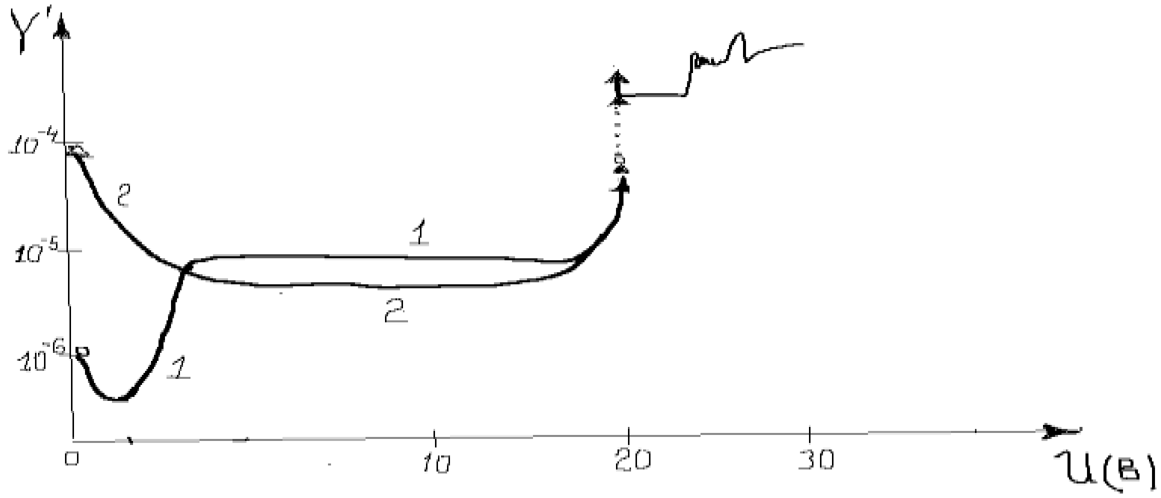
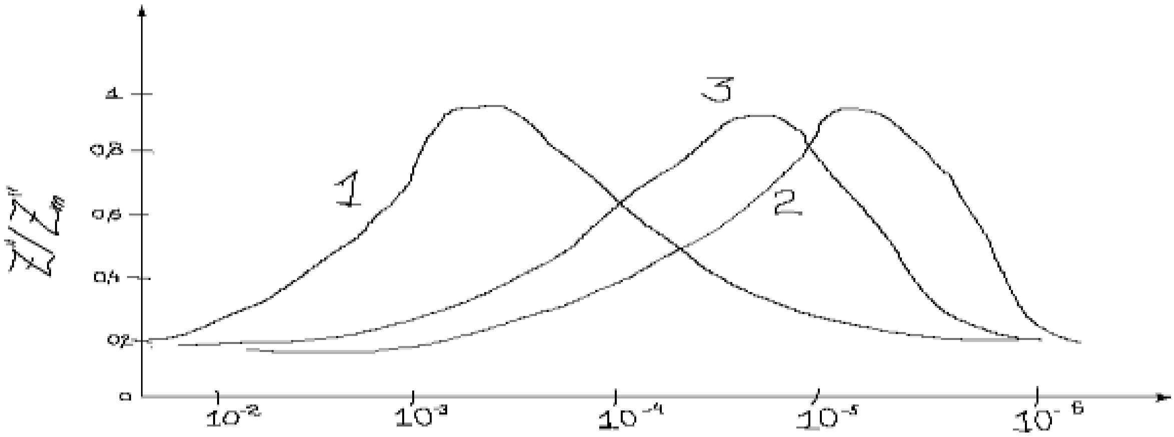


Fig-1. Figure 1 shows the dependences of the real part of the admittance YI (differential conductance) versus voltage and back mixing, obtained by measurements at frequencies of 1 kHz (curve 1) and 1 MHz (curve 2).

At voltages, measurements at an alternating current with a frequency of 1 kHz gives results that are consistent with the data obtained by differentiating the I – V characteristic using modulation characterization. Such dependences are free from the characteristic noise of numerical differentiation. High-frequency (1 MHz) measurements give slightly underestimated values of differential conductivity, which is possibly associated with the shunting effect of the barrier capacitance [12].



f (Гц)

Fig 2 Dependences of the minimum part of the impedance of diodes on the frequency of alternating current voltage mixing U1 = -18V U2 = -19.9V U3 = -20V

Figure 2 shows the dependences of the imaginary part of the impedance (normalization to the maximum value) on the frequency f of the alternating current through the diode.

From the data shown in Fig. 2, it follows that the inclusion of microplasma leads to significant changes $Z^{''}(f)/Z_m^{'''}$. It is known that the position of the maximum on the frequency dependences of the imaginary part of the impedance obeys the condition $\omega \cdot r = 1$, where $r = R \cdot C$ time constant, a $\omega = 2 \cdot \pi \cdot f_m$ angular frequency.

Thus, a change in the position of the maximum by can be caused either by a change in the value of the barrier capacitance C or the resistance R. The space charge resistance Rc can be calculated from the results of approximations of the frequency dependence of the impedance. A number of studies have established that microplasma breakdown practically does not affect the reactive component of the Z diode impedance [12].

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Rc - resistance (SCR) of the space charge region depends on the current density in the following way:

$$R_c = R_{co}\left[\frac{(1+\gamma)\,j + j_1}{\lambda \cdot j + j_1}\right]^2$$ where

$$R_{co} = \frac{\omega_0^2}{2\varepsilon\varepsilon_0 v_n S_{мп}}$$

$$j_1 = q \cdot v_{n\cdot} \cdot n_1$$

j – current density $v_{n\cdot}$ - electron drift velocity $$n_1 = \frac{a_n}{b_n} = N_e \cdot \exp(-\frac{E_i}{k \cdot T})$$

N_e – effective state density E_i – ionization energy

$$\lambda = (1+\gamma-\frac{N_t}{N}) \qquad \gamma = \frac{C_{nn}}{b_n}$$ where ai and bi are the coefficients emission and capture C_{ij} – impact ionization probability (i=n,p)

Consider a sharply asymmetric p + –n junction or Schottky barrier. n - a layer of which is uniformly doped with shallow donors with Nd concentrations, Na acceptors, and singly charged deep Nt centers. Under the assumption of an equilibrium charge state, if HY are acceptors, then N = Nt -Na, if HY are donors, then N = Nd-Na + Nt [13].

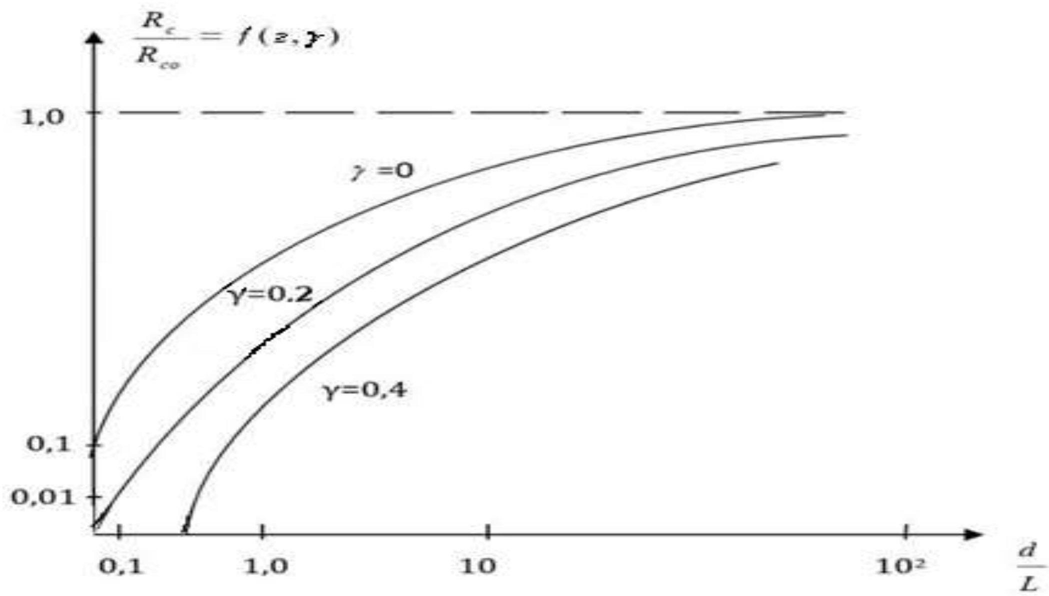

Fig - 3. Decrease in the value of the SCR resistance Rc and in relation to Rco, depending on the MF diameter normalized to the SCR thickness.

If the width of the p + -n junction increases, then the field strength in this part of the junction decreases, which leads to an increase in the microplasma breakdown voltage. With a changing drift velocity Vpr, the space charge resistance is expressed by the dependence

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$$R_c = \frac{\eta_n \cdot W_n^2}{2 \cdot \varepsilon \cdot \nu \cdot S_m} = \frac{\tau_n \cdot V_{np}}{e \cdot N_D \cdot \nu \cdot S_m}$$

where $\eta_n = (1 - \frac{\delta_n}{W_n})^2 = \frac{l_n^2}{W_n^2}$ coefficient depending on the structure of the pn junction, field dependence of the ionization coefficients of electrons and holes and the relationship between drift velocities, is the equivalent multiplication layer, ln is the carrier drift region, Wn is the width of the p + - n transition in the n-region, is the dielectric constant, ND is the concentration of the dopant; is the drift velocity of electrons; S is the area of the microplasma.

As follows from $R_c = \frac{\eta_n \cdot W_n^2}{2 \cdot \varepsilon \cdot \nu \cdot S_m} = \frac{\tau_n \cdot V_{np}}{e \cdot N_D \cdot \nu \cdot S_m}$, an increase in the space charge width Wn with time should lead to an increase in Rc, while a decrease in Rc was obtained experimentally. This behavior can be explained by a more significant increase in Wn2 and Vpr [14].

$$R_c = \frac{\eta_n \cdot W_n^2}{2 \cdot \varepsilon \cdot \nu \cdot S_m} = \frac{\tau_n \cdot V_{np}}{e \cdot N_D \cdot \nu \cdot S_m}$$

Consequently, the resistance of the space-charge region in the case of a non-stationary bias voltage is determined by several physical quantities; The main part of Rco depends on the geometrical dimensions of the microplasma: the diameter of the microplasma, L is the SCR length, Ly is the length of the multiplication region, the width of the space charge Wn and the dielectric constant of the semiconductor, is the dielectric constant, is the saturation drift velocity, j is the current density. Ne - effective density of states, Ei - ionization energies where ai and bi - coefficient of emission and capture of carriers by centers, Cij - probability of impact ionization (i = n, p), [13], - thickness of equivalent multiplication layer, ln are the lengths of the carrier drift region [14].

The study of the dependence of the resistance of the space-charge region (SCR) with its decomposition into the real part of the admittance YI (differential conductivity) and the imaginary part of the impedance ZII (normalization to the maximum value of ZIIm) on the frequency f of the alternating current through the diode confirms the decrease in the SCR resistance.

At the same time, the detected impedance anomalies suggest that there is an additional mechanism for the appearance of MF in p-n junctions based on GaAs, apparently directly related to the existence of large inhomogeneities comparable to the SCR thickness, which determine the size of the MF localization region.

Thus, it has been shown that the study of the impedance of a diode in a state of microplasma breakdown gives an important and clearly interpreted picture of carrier transport in the space charge region, which can be used as a tool for non-destructive diagnostics of semiconductor devices.

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