METHODOLOGY FOR CALCULATION OF A MICROWAVE SWITCHING DIODE WITH PIN STRUCTURE

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This paper describes the most important properties of the PIN diode and illustrates methodology for it calculation. A PIN diode is a semiconductor device that operates as a variable resistor at RF and microwave frequencies. The resistance value of the PIN diode is determined only by the forward biased dc current. In switch and attenuator applications, the PIN diode should ideally control the RF signal level without introducing distortion which might change the shape of the RF signal. An important additional feature of the PIN diode is its ability to control large RF signals while using much smaller levels of dc excitation.

In addition, the PIN's small size, weight, high switching speed, and minimized parasitic elements make it ideally suited for use in miniature, broadband RF signal control components.

Keywords: microwave switching diode, PIN structure, electrical properties, technological factors.

1. INTRODUCTION

The ultrahigh frequency range (UHF) covers the frequencies from 0,3 to 300 GHz. The electromagnetic oscillations in it possess a number of physical features that make them close in character of propagation to the light waves, i.e. they possess quasi-optical properties [1]. Considering diodes used in this range, there is a great variety in respect of the principle of action, functionality, technology, etc. Common for all diodes operating in the UHF range is their design which achieves minimization of stray inductances and parasitic capacitances and provides possibility that they are included in other components of UHF systems – wave guides, coaxial lines, sensing heads, etc. They are produced in two forms – encapsulated and chip diodes. The encapsulation of the UHF diodes could be divided into several groups [2]:

- Cartridge type. This type of encapsulation provides hermeticity and easiness for replacement of the diodes in the apparatus;

- Coaxial type. It is used for operation in coaxial feeder lines;

- Small size glass encapsulation. The disadvantage is that it is difficult for combination with the wave guide lines;

- In the form of mini tablets and wave guide type encapsulation. UHF diodes with such encapsulation are used for operation in the millimeter range.

Chip diodes are used in hybrid integral microwave circuits. The chip is hermetically sealed by means of various compounds. The so prepared structure is stuck directly on the contact sites or the base plate.

The modern UHF diodes are produced mainly with Schottky junction.

Technologically it could be made in one of the following ways [2].

- Point contact. It is obtained by mechanical contact of tungsten or molybdenum metal needle on the semiconductor plate. The contact is regulated during the adjustment process by special spring. It is of 10-20 μm diameter.

- Micro alloy contact. It is obtained by mechanical contact of gold - gallium alloy needle on the semiconductor base. The alloying of the tip of the metal nib to the semiconductor is performed by flashing. The contact diameter is 5-10 μm.

- Flat contact. It is obtained by cathode sputtering of metal on semiconductor GaAs plate.

Depending on their function the UHF diodes are rectifying, switching and converting.

The function of the rectifying UHF diodes is to transform the UHF signals in constant current signals or constant current impulses. They are used in the receivers of UHF signals direct intensification and as measuring diodes. For current-voltage diagram of the measuring diodes there are requirements for a shape close to the quadratic dependence. This allows application of these diodes for measurement of the wave guide electric field intensity [2].

The switching diodes are intended to control the UHF signals amplitude and phase along the line of their transmission. This function is fulfilled as a result of the variation of their impedance under the action of constant direct or inverse voltage.

The converting UHF diodes are used as blenders, multipliers and modulators in the UHF area.

The diode fulfills these functions due to the non-linearity of the current-voltage diagram in the initial domain. The qualities of a converting diode are determined by the properties of the semiconductor of which it is made. Generally highly alloyed materials of low dielectric constant and great mobility of the charge carriers are used [2,3].

In order to improve the rectifying properties of the powerful high-voltage diodes PIN-structures are used which during operation in the UHF range show new properties. PIN diodes are used for regulation of high-frequency or UHF power, for amplitude modulation of various depths, for UHF signals commutation, etc. [2,4]

The design of semiconductor devices, including diodes of various types, is a sophisticated engineering problem which requires fundamental knowledge in the fields of: physics of semiconductors and semiconductor devices, mathematics, physics and chemistry of solids, semiconductor and information technologies, electronics and electrical engineering, computer engineering, etc. [3].

The present paper is closely related with the term design of discrete semiconductor devices.

The aim of the present paper is to provide a generalized method for calculation of UHF switching diode of PIN-structure, on the basis of which an algorithm and program for personal computer can be developed that would find application both in the education of the students in the subjects "Semiconductor technologies", "Electronics and electrical engineering", "Automation", "Information technologies", "Computer systems", etc., and among the research and production teams with direct relation to electro- and radio electronics, electrical engineering and microelectronics, automation and information technologies, etc.

Initial data:

The initial data for calculation of UHF switching diode of PIN-structure are as follows (the initial data for illustration of the suggested algorithm are given in brackets): 1. Semiconductor material - Si; 2. Inverse voltage U_R (U_R = 50 V); 3. Barrier layer capacitance C_b (C_b = 1 pF); Resistance of i-zone R_i (R_i = 100 Ω).

To define (or chose):

On the basis of the preset initial data define: 1. Grade of Si for i-zone; 2. Thickness of i-zone W; 3. The area of the PIN-structure; 4. The permissible direct current $I_{F.max}$; 5. Saturation current I_s and generation current $I_{\overline{RG}}$ (C_b and I_{RG} are calculated at U_R = 50 V).

2. Calculation Part

2.1 Choice of silicon for i-zone.

It is known that production of silicon of intrinsic conduction is not possible because of technological difficulties. Therefore, high resistance silicon is used. The choice of its resistivity is determined by many and contradictory factors. In particular, at decrease of ρ the resistance of i-zone also decreases but the barrier layer capacitance increases. For optimization of the values of C_b and we shall perform the following mathematical transformations [3,5,6].

$$C_b = \varepsilon_o \varepsilon . A/W \tag{1}$$

and $$A/W = C_b/ \varepsilon_o , \varepsilon \tag{1a}$$

but $$R_i = \rho . W/A, \tag{2}$$

so $$\rho = A.R_i/W. \tag{2a}$$

We replace equation (1a) in equation (2a):

$$\rho = C_b.R_i/\varepsilon_o\varepsilon \tag{3}$$

$$\rho = (1.10^{-12}).100/[12.(8,86.10^{-14})] = 94\ \Omega.\text{cm} \tag{3a}$$

As a result of the much higher processability and with the aim to avoid channeling it is preferable to use Si of N-type electric conductivity. At this resistivity the mobility of the electrons is maximal, i.e.: μ_n = 1500 $cm^2/(V.s)$. The concentration of the donor alloys is calculated by the classical equation:

$$N_D = \frac{1}{q.\rho_N.\mu_n} = \frac{1}{(1,6.10^{-19}).94.1500} = 4,4.10^{13}\ cm^{-3}. \tag{4}$$

We chose Si grade КЭ2Г, for which the diffusion length is L_p = 0,02 cm, and the life time is:

$$\tau_o = \frac{L_p^2}{D_p} = \frac{(0{,}02)^2}{12{,}5} = 3{,}2.10^{-5}\,\text{s} = 32\ \mu\text{s} \tag{5}$$

2.2. Thickness of i-zone W.

It is defined by the preset value of U_R that should have for instance double reserve in respect of the disruptive pressure:

$$U_{BR} = 2.U_R = 2.50 = 100\ \text{V} \tag{6}$$

In the ideal PIN-structure the whole field is concentrated in the i-zone due to which the disruptive pressure is defined as product of the electric field pressure at rupture ($E_{max} = 2.10^{-5}$ V/cm за Si) along the thickness of i-zone W [3,6,7].

$$W = \frac{U_{BR}}{E_{max}} = \frac{100}{2.10^5} = 5.10^{-4}\ \text{cm} = 5\ \mu\text{m} \tag{7}$$

The real structure has N-zone instead of i-zone that is why the value W=5 μm should be specified. In order to achieve low values of the resistance connected in series with the diode (in case of inverse connection of the diode) mode of piercing the base is used with which the width of the space charge region (SCR) is equal to the width of i-area. The width of the SCR of rapid P^+N-transition [3] is:

$$\delta = \sqrt{\frac{2\varepsilon\varepsilon_0 U_R}{qN_D}} = \sqrt{\frac{2.12.(8{,}86.10^{-14}).50}{1{,}6.10^{-19}.4{,}4.10^{13}}} = 3{,}9.10^{-3}\ \text{cm} \tag{8}$$

In that way for δ = 5 μm the mode of piercing will be sustained. We assume W = δ = 5 μm.

2.3. Area of PIN-structure A [2,3].

It is defined by means of equation (1):

$$A = \frac{C_b.W}{\varepsilon\varepsilon_0} = \frac{1.10^{-12}.(5.10^{-4})}{12.(8{,}86.10^{-14})} = 4{,}7.10^{-4}\ \text{cm}^{-2} \tag{9}$$

2.4. Direct permissible current $I_{F,max}$

$$I_{F,max} = J_{F,max}.A = 10^2.4{,}7.10^{-4} = 0{,}047\text{A} = 47\ \text{mA} \tag{10}$$

2.5. Saturation current I_s and generation current $I_{\overline{RG}}$.

The saturation current will be mainly porous/perforated. As L_p>W so in the design formula instead of L_p we shall place W:

$$I_s = j.A = qn_i^2\frac{D_p}{W.N_D}\cdot A \tag{11}$$

$$I_s = 1{,}6.10^{-19}.(1{,}6.10^{10})^2.\frac{12{,}5}{5.10^{-4}(4{,}4.10^{13})}\cdot(4{,}7.10^{-4}) = 1{,}1.10^{13}\ \text{A} \tag{11a}$$

The generation current in SCR at U_R=50 V is [3,8,9]:

$$I_{\overline{RG}} = q\frac{n_i}{\tau_0} \cdot W \cdot A \tag{12}$$

$$I_{\overline{RG}} = 1{,}6.10^{-19}\,\frac{(1{,}6.10^{10})}{3{,}2.10^{5}} \cdot (5.10^{-4}).(4{,}7.10^{-4}) = 1{,}9.10^{-11}\,\text{A} = 19\ \text{nA} \tag{12a}$$

It should be noted that at U_R=50 V $I_{\overline{RG}}$ remains practically constant because the width of SCR remains equal to the width of i-zone.

3. CONCLUSIONS

As a result of analyzing, systemizing and processing of the information related to the physics of the PN-transition in PIN-structure of the UHF switching diode the following conclusions could be made:

a) there is developed a method and algorithm for calculation of UHF switching diode of PIN structure;

b) the method is checked by a set of real initial data by means of which the main parameters of UHF switching diode of PIN structure are calculated;

c) on the basis of the developed method and algorithm a program for personal computer can be worked out that would find application in the activities of students, researchers and production personnel.

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