ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 8| Issue: 12| December 2022|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2022: 8.205 || ISI Value: 1.188

UDK 621.382.2

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF AVALANCHE BREAKDOWN VOLTAGE OF DIODES WITH AN ARBITRARY BASE DOPING PROFILE

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ANNOTATION

With the improvement of the elements of the base of modern microelectronics and microwave electronics, the capabilities of devices based on homogeneous semiconductor materials in some cases are no longer satisfactory. At present, these devices are manufactured on the basis of semiconductor eliteaxial structures with a complex doping profile and with parameters corresponding to the calculated ones. Such structures have one more advantage: they do not contain microplasmas [1]. The mechanism leading to the absence of microplasmas is not yet clear. However, in order to predict the characteristics of such systems in the process of their design and manufacture, it becomes necessary to theoretically calculate such an important parameter as the avalanche breakdown voltage $V_{\text{в}}$.

KEY WORDS: ***shape, Schottky, concentration, electric field, level, magnitude***

In this paper, we will propose a method for calculating the value of V_b for a p-n junction or a Schottky barrier with a variable doping level N, and its profile can be specified both in tabular form and in the form of the N(x) dependence. In this case, when the working part of the diode consists of two regions (lo-hi and hi-lo) with a constant impurity concentration in each of the convenient technique. It is based on the knowledge of the analytical dependence of the potential value V_b and the electric field strength E on the doping levels of the hi and lo regions, which was studied in [2].

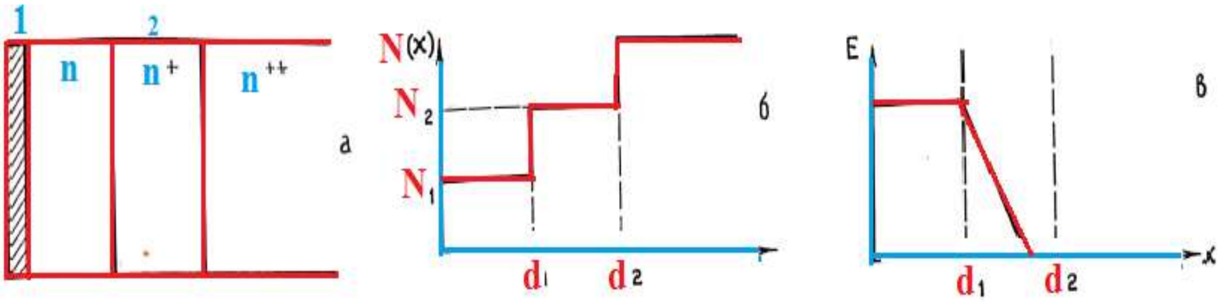

Fig-1. Schematic drawing of a diode (to define the metal-semiconductor contact) with l0-hi doping profile (a). Doping profile of the base region with an arbitrary ratio between N_1 and N_2 possible ($N_1 >= N_2$, $N_1 < N_2$) (b). (1)-metal, (2)-semiconductor, $n^{++}>>n^{+}$. Distribution of the electric field in the base area of the device(s).

Theoretical curves are compared with the experimental values of the breakdown voltage V_b in silicon Schottky diodes with a lo-hi structure obtained by membrane technology [3]. The magnitude of the avalanche breakdown voltage V_b was determined using the integral criterion [4].

$$J = \int_{0}^{D} \alpha(x)dx = \int_{0}^{D} A \cdot e^{-\left[\frac{B}{E(x)}\right]^{m}} dx = 1 \quad (1)$$

where α(E) is the coefficient of avalanche multiplication of electron-hole pairs, A and B are constants known for the semiconductors used, depending on their type m=1 or m=2. The application of the criterion that uses the double integral instead of (1) in this case [4] seems inappropriate, since the errors in the experimental determination of the alloying profile make the main contribution to the error value. At the same time, the calculation method proposed below is fully compatible with a more accurate criterion, since numerical integration is necessary in any case. In turn, such use of the criterion [1] requires knowledge of the dependence E(x), which will be determined below.

Let us consider a planarly homogeneous system, the doping level N, in which is only a function of the coordinate deep into the semiconductor (see Fig. 1). The electric field E(x) in this case is determined by the equation:

$$\frac{dE}{dx} = -\frac{e \cdot N(x)}{\varepsilon \cdot \varepsilon_0} \quad (2)$$

where and is the charge of the electron, -dielectric is at the point d_0 , then the value of E(x) at x<x0 is found by the formula:

$$E(x) = -\frac{e}{\varepsilon \cdot \varepsilon_0} \int_{d_0}^{x} N(x)dx \quad (3)$$

When x=0, E(x)=Es is a superficial knowledge of the electric field. From the known knowledge of E(x), for the potential φ applied to the semiconductor, we have:

$$\varphi(x) = \int_{d_0}^{x} E(x)dx \quad (4)$$

Using (3), (1), and then (4) with the help of a program developed for computer technology, we obtain numerical values for such parameters as Vb, E_s , d_0 .

As already noted, the approach described above is valid for an arbitrary doping profile of the base part of the diode. At the same time, admixture technologies exist. If this profile corresponds to the case shown in Figure 1, then the problem of determining the value of V_b can be solved even taking into account the capabilities of programmable computing technology.

Indeed, in this case, for the fields in areas I and II we can write

$$E(x) = \left\{ \frac{E_1 = E_s - \alpha_2 x; \ldots x \le d_1}{E_2 = (E_s - \alpha_1 x_1) - \alpha_2 (x - d); \ldots d_1 < x \le d_2} \right. \quad (5)$$

$$\alpha_1 = \frac{e \cdot N_1}{\varepsilon \cdot \varepsilon_0};$$

$\alpha_2 = \dfrac{e \cdot N_2}{\varepsilon \cdot \varepsilon_0}$, moreover, it is assumed that only domains II of the modification of formulas (5) are "pierced". These expressions are obtained by 23 simple geometric considerations of valid constant values of N within a given region.

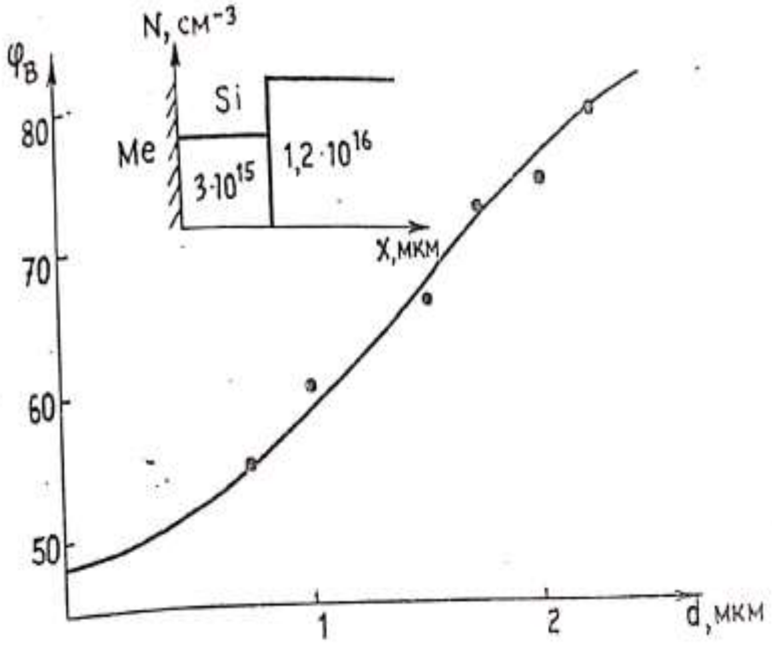

Figure 2. Dependence of the avalanche breakdown voltage of silicon Schottky diodes on the structure parameters from the table 1.N_1=3 10^{15}cm^{15}cm^{3}, N_2=1.2 10^{16}cm-^{3}.

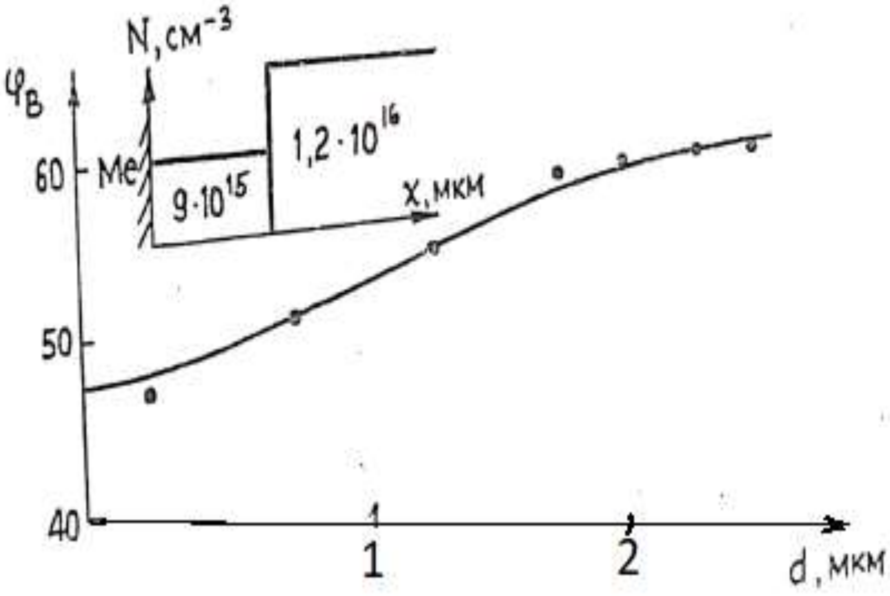

Рис 3. Зависимость напряжения лавинного пробоя кремневых диодов Шоттки от параметров структуры из таблицы1.N_1=9 10^{15}см^{15}см$^{-3}$,N_2=1,2 10^{16}см$^{-3}$.

Table 1
Parameters of epitaxial silicon layers

№	N_1 ,(sm^{-3})	d_1 (mkm)	N_2 ,(sм$^{-3}$)	d_1 (mkm)	N_3 ,(sм$^{-3}$)	d_3 (mkm)
1	0,3 10^{16}	0,3				
2	0,6 10^{16}					
3	0,9 10^{16}					
4	1,2 10^{16}	0,6	1,2 10^{16}	2,5	25 10^{16}	300
5	0,3 10^{16}					
6	0,6 10^{16}					
7	0,9 10^{16}					
8	0,3 10^{16}	0,9				
9	0,6 10^{16}					
10	0,9 10^{16}					

In contrast to a more complex doping profile, in the case described by formulas (5) for any chosen value of the electric field E(x) and the voltage applied to the diode, according to the formulas:

$$E_s = \alpha_2 \cdot (t - d_1) + \alpha_1 \cdot d_1 \quad (6)$$

$$\varphi = \alpha_2 \cdot (t - d_1) \cdot d_1 + \frac{\alpha_1 \cdot d_1^2}{2} \quad (7)$$

Taking into account formulas (5) - (7), the avalanche breakdown voltage was calculated for Schottky diodes obtained using the membrane technology described in [4]. The avalanche breakdown voltage was determined using double differentiation of the current-voltage characteristic according to the method [5] .

Figure 2 shows the theoretical dependences of the avalanche breakdown voltage obtained by us for several types of diodes (the values of the doping levels in the hi and lo layers are indicated in the figures at 1. The experimental values are also shown there. The figures show good agreement between the experimental data on V_b and theoretical values, which indicates the applicability of the developed approach [6-10].

It has been experimentally established that, regardless of the method of manufacturing silicon avalanche transit diodes, the microplasma parameters in them are identical, which indicates the common nature of their occurrence, associated with the inhomogeneities of heavily doped silicon substrates and n-n $^+$ structures.

Using theoretical and experimental analysis, that the diameters of microplasmas in silicon avalanche transit diodes are: 0.2-0.4 μm, and in silicon zener diodes - 0.6-10 μm, the overheating of microplasma channels, respectively, is equal to 70-120K in avalanche transit diodes, and in zener diodes they exceed 100K.

Thus, the proposed method for determining the diameter of microplasmas makes it possible to reliably determine this key parameter according to differential characterography data (breakdown voltage and differential resistance of microplasma) and, accordingly, the parameters of current filaments, which plays an important role in diagnosing the reliability of semiconductor diodes operating in the avalanche breakdown mode.

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