MICROPLASMA BREAKDOWN OF p-n JUNCTIONS

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It is shown that the charged point defect clusters (PDC) by perturbing the electrical field E of space charge layer of the p-n junctions create large-scale traps, which decrease a voltage of breakdown. It is found that at the magnitude of E less than its critical value E_c PDC behave themselves as the generation centers and increase the leakage current of the p-n junctions, but at the magnitude of the field $E \gtrsim E_c$ they behave themselves as the recombination centers on which microplasma arises and the breakdown of the p-n junction starts. The formula of dependence of E_c on the PDC parameters is obtained.

INTRODUCTION

It is known that in processes of fabrication of the semiconductor devices various defects, which change their electrophysical parameters appear. An influence of defects on the electron processes in active elements of integrated circuits becomes especially actual in connection with miniaturization of production of the semiconductor microelectronics.

Thus, for instance, as a result of thermotreatment of devices with space charge layer (SCL) unequilibrium own point defects which can be locally clustered under various factors appear and they may have an essential influence on the electron processes in it [1-9]. It is clear that the degree of this point defect cluster (PDC) influence on electron processes will depend on both of their size and the charge state. However, in spite of revealing of this dependence the investigation devoted to this problem is absent in a known literature.

The present paper is devoted to an investigation of the PDC influence on microplasma breakdown of p-n junction.

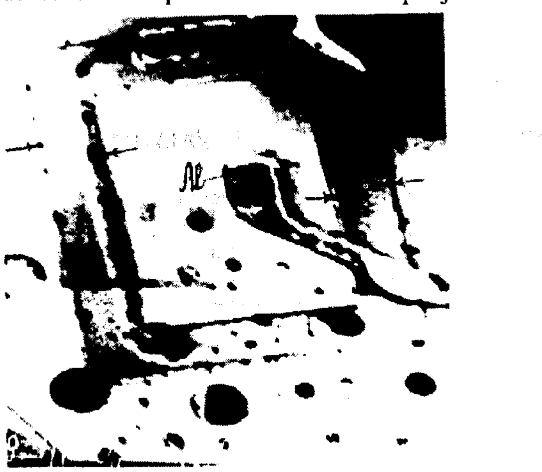

Fig.1 Microphotography of n^+-p junction. obtained in the regime of second electrons of SEM.×1400. The cluster of impurity in space charge layer on the interface of collector-base and collector-matrix are shown by pointers. Al is the aluminum contact.

The investigation was carried out on n^+-p junction of integrated circuits in which 2.1-μm - thick B-doped (111) Si epitaxial film with p~5×10^{16}cm^{-3}served as a base layer, and the collector comprised a buried n^+ (~10^{20}cm^{-3}) layer, prepared by diffusion of As into the p-type substrate, and an adjacent n^+ vertical contact layer reaching the surface.

By the methods of scanning electron microscope in the interface of base-collector and collector-matrix of space charge layer of p-n junction of the integrated circuits with increased leakage currents globe-shaped clusters which were responsible for leakage currents were discovered (fig.1). Localization of these clusters at negative poles of SCL testifies that they are positively charged and clear-cut boundaries of PDC show that defects in them are distributed by the Poisson law . The charge Q on PDC is considered as one which uniformly distributed on the surface of a good conducting sphere of a radius R.

It was shown in [4,5] that impurity clusters in SCL of p-n junction play the role of generation centers at the magnitude of electric field less than $1,91\cdot10^5$ V/cm through which the generation of unequilibrium carriers due to increased leakage current take place.

At field E_0 of the magnitude greater than $1,91\cdot10^5$ V/cm as a result of collision ionization an avalanche breakdown of p-n junction take place and on SCL microplasmas appear. They appear also as a result of recombination of "hot" carriers on them. So under the strong electric field condition and growing of concentration of the carriers in PDC they transform from generation centers into recombination ones.

DISCUSSION OF THE RESULTS

As fig.1 shows the PDC has a spherical form. Therefore it can be viewed as a charged sphere put into uniform electric field of the SCL of the p-n junction. Under the action of electric field of the SCL free carriers leave the region of space charge of the p-n junction. At the strong electric field of SCL of p-n junction when the screening of PDC charge by the free carriers are impossible, the characteristic picture of a distribution of force line arises, as it shown in fig.2. As a result of a such distribution of force lines, the potential barrier appears which is a large-scale trap for carriers. Generation and recombination properties of PDC are determined by the height of the potential barrier and a capture cross section, which vary under the action of electric field. The potential of the charged globe in the uniform electric field is described by the following expression [6]:

$$\varphi(r.\theta) = -rE_0\cos\theta + E_0\frac{R^3}{r^2}\cos\theta + \frac{Q}{4\pi\varepsilon\varepsilon_0\cdot r} \qquad (1)$$

where first term is the contribution of the field E_0, the second is the contribution of polarization of the neutral part, and the third one is the contribution of the charge Q. The angle θ is counted on the direction of the field E_0.

As a consequence of screening of the field, directly after a trap there is a saddle point of the potential relief in $r=R_c$. It is necessary to note that between the saddle point and charged surface of the globe there is a potential barrier which regulates the flow of carriers from the trap.

The height of this barrier is

$$\delta\varphi = \varphi(R_c) - \varphi(R) \qquad (2)$$

where $\varphi(R_c)$ and $\varphi(R)$ are the potential magnitudes at the points R_c and R, respectively.

Putting in Eq. (2) instead of $\varphi(R_c)$ and $\varphi(R)$ their values determined by the formula (1) and making some transformations, we obtain:

$$\delta\varphi = E_0 R\left(\frac{R^2}{R_c^2} - 1\right) - \frac{R^2 N_t e}{3\varepsilon\varepsilon_0}\left(\frac{R}{R_c} - 1\right), \qquad (3)$$

where N_t is the density of ionized impurity in PDC, e is an electron charge.

Keeping in mind that for every PDC its characteristic parameters such as R_1, R_2 and N_t are constant in the stationary condition, we can rewrite the expression (3) as follows:

$$\delta\varphi = C - \alpha E_0 \qquad (3a)$$

where C and α are the positive magnitudes, which are determined by the parameters of PDC indicated above, so that they are constant under the stationary conditions.

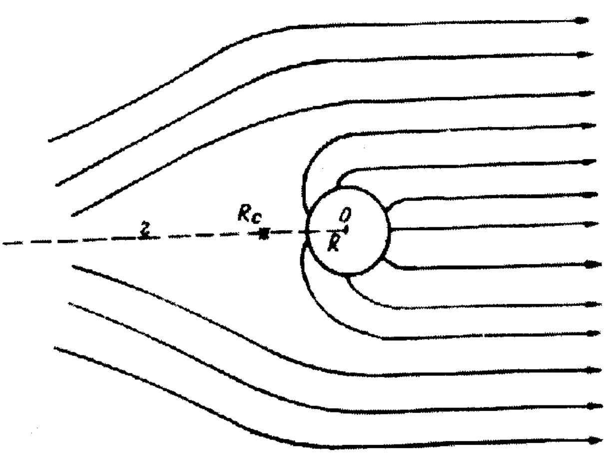

Fig.2. The perturbation of uniform electrical field of charged point defect cluster (PDC). R is the radius of (PDC), R_c is the coordinate of a saddle point, r is the current coordinate.

As it is seen from the Eq. (3a) at the small value of the field, when $\alpha E_0<C$, the height of voltage barrier will be diminished by the increasing of the field that will lead to the increase of the probability of emission of the carries from trap i.e. to the generation of free carries. At the critical value of the field E_0, when $\alpha E_0<C$, the height of potential barrier disappears ($\delta\varphi$=0) that corresponds to the equality $R=R_c$ i.e. the saddle point touches surface of PDC. This condition is implemented when the intensity of the electric field, created by the surface charges of PDC is equal to E_0. Under these conditions minority carries accelerated by the field will be reaching the surface of PDC that will lead to the recombination of "hot" carriers and appearing of microplasmas on the PDC and the local breakdown of p-n junction are takes place. At a certain value of E_0, when the energy of "hot" carriers is enough for collision ionization, there have been appeared a microplasma on the PDC surface and the local breakdown have taken place. The last one is in agreement with experimental results of [4, 5, 7].

Thus the change of $\delta\varphi$ leads to the change of carriers concentration in the trap and the capture cross-section σ. The dependence $\sigma(E_0)$ can be found from the equation for the principle of detailed balance of the rate of capture and emission of carriers from the trap:

$$G\sigma = \frac{S\Delta n}{\tau} exp\left(-\frac{e\delta\varphi}{kT}\right) \qquad (4)$$

where S is the square of that part of sphere from which emission of carriers generated by "hot" carriers, G is a rate of generation of unequilibrium carriers, Δn is concentration of unequilibrium carriers, τ is a life time of carriers.

We obtain from (3a) and (4):

$$\sigma = \frac{S\Delta n}{G\tau} exp\left[\frac{(\alpha E_0 - C)}{kT} e\right] \qquad (5)$$

According to Eq. 5) when E_0 reaches the value E_c at which the condition is fulfilled

$$\alpha E_c = C \qquad (6)$$

the height of voltage barrier $\delta\alpha$=0 and the capture cross-section does not depend on the field. It dictates, that radiation intensity of microplasma is independent of field.

Actually, it has been experimentally determined in [7,8], that the number of microplasmas increased with the increasing of field, but intensity of radiation of some microplasma have not changed till the ceasing of forming of new microplasma.

Thus, the fulfillment of the $\alpha E_0=C$ condition, the recombination of "hot" carriers on the surface of PDC and the independence of the capture cross-section on field correspond to the initial condition of arising of the microlpasma and avalanche breakdown of p-n junction.

The magnitudes of critical field E_c on which microplasma arise, as it follows from Eq. (6), depend on the PDC parameter. When fulfillment of condition Eq. (6) from Eq. (3) we obtain

$$E_c = \frac{eN_t R}{6\varepsilon\varepsilon_0} \qquad (7)$$

i.e. E_c is proportional to the radius of PDC and the density of ionized impurity in PDC.

According to Eq. (7), with the increase of the number of microplasmas with the increase of the field the electric field first reaches critical value on PDC of small size, then on large ones. The last one is agreement with experimental results of [7,8], that testifies the certainty of Eq. (7).

The certainty of obtained dependence is proved by the fact that it accurately coincides with the dependence for intensity of electrical field on surface of charged globe, which, according to the condition of the problem, is related to PDC. We must note that the obtained dependence can be used in any material, where the screening of charge PDC by free carriers is absent.

Given model completely describes the experimental results in [4,5,7,8].

The sizes of PDC which are within $(0,3\pm0,5)\cdot10^{-4}$cm, in SCL of investigated p-n junction are determined by the means of SEM (fig.1), and a magnitude of critical field at which microplasmas arise, that corresponds to the condition (6) and changes within $(1,8\pm2)\cdot10^{5}$V/cm. depending on the size of the PDC.

By using of experimental data and proceeding from the condition (6) such parameters of PDC are determined: the capture cross section ($3\cdot10^{-8}$cm^2), its charge ($2,2\cdot10^{-14}$C) density of ionized impurity ($1,7\cdot10^{16}$cm^{-3}), lifetime of unequilibrium carriers in the region of microplasma (<10^{-15}s).

CONCLUSIONS

It is shown that charged point defects clusters create large-scale traps, by perturbing electric field of space charge layer of p-n junction.

The dependence of the height of the potential barrier and the capture cross-section of traps are determined both from parameters of PDC and the magnitude of external electric field. We found that there is a critical value of an external electric field E_c on which microplasma on PDC arises and avalanche breakdown of p-n junction takes place.

It is found that at the magnitude of the field less than E_c PDC behave themselves as generation centers and increase the leakage current of p-n junction, but at the magnitude of field $E\geq E_c$ they behave themselves as recombination centers on which microplasmas arise and starts to breakdown of p-n junction.

The necessary conditions and mechanism of microplasma formation on PDC are presented. The dependence of E_c on the parameters of PDC is obtained. It is shown that capture cross-section of traps, depends exponentially on the electric field due to impurity cluster.

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p-n KEÇİDLƏRİN MİKROPLAZMİK DEŞİLMƏSİ

Göstərilmişdir ki, yüklənmiş nöqtəvi defektlər topaları (HDT) p-n keçidlərin fəza yük qatının sahəsini E həyəcanlandıraraq böyük ölçülü tələlər yaradır. Onlar p-n keçidin deşilmə gərginliyini azaldır. Müəyyən edilmişdir ki, elektrik sahəsinin kritik qiymətinə E_c qədər onlar qenerasiya rolunu oynayır. $E\geq E_c$ olduqda onlar rekombinasiya mərkəzlərinə çevrilirlər və onların üzərində mikroplazma yaranır, bununla adi p-n keçidin deşilməsi başlayır. E_c-nin HDT parametrlərindən asılılığının düsturu alınmışdır.

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МИКРОПЛАЗМЕННЫЙ ПРОБОЙ p-n ПЕРЕХОДОВ

Показано, что заряженные скопления точечных дефектов (СТД), возмущая электрическое поле E слоя объемного заряда p-n переходов, создают крупно-масштабные ловушки, которые уменьшают напряжение пробоя. Установлено, что при значениях электрического поля меньше его критической величины E_c, СТД ведут себя как генерационные центры и увеличивают токи утечки p-n переходов, а при $E\geq E_c$ они ведут себя как центры рекомбинации, на которых зарождаются микроплазмы и начинается пробой p-n перехода. Получена формула зависимости E_c от параметров СТД.

Received: 29.06.01