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THE POTENTIAL RELIEF CLOSE TO THE ISOLATED DISLOCATION IN Si

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By the investigation of the Frenkel-Pull effect in the silicon, containing the one electrically active edge dislocation, it has been established that it creates the deep centers of Coulomb type. The relief of the potential energy of an isolated charge dislocation interaction with the charge carriers has been determined.

INTRODUCTION

The actual task of semiconductors physics is to reveal the mechanism and peculiarities of the defects influence on the electron process in semiconductor devices. This issue acquires the special actuality in microelectronics, as the small sizes of the active elements of the integrated circuits lead to the fact, that the defects occupy the considerable part of their working volume, in consequence of what the degree of the defects influence on their parameters increases.

Among the known defects edge dislocations are worthy of the special observation, due to their considerable influence on the electron processes in semiconductors.

As the analysis of numerous papers [1-6], devoted to the research of the dislocation electron activity shows that it was carried out in samples, containing the uncontrollable number of the dislocations. The complexity of their interaction picture both between each other and with the charge carriers and with the point defects makes the analysis of the obtained results more difficult. In consequence of these measured values have the high statistical spread, and the results are speculative and sometimes contradictory.

Therefore the study of the electric properties of an isolated dislocation has a considerable scientific and practical interest. The valuable information on the electric properties of an isolated dislocation may be obtained by research of the dependence of the height change of the potential barrier's bulk charge (BC) about the dislocation and dislocation conductivity on the electric field. These properties of the dislocation versus the direction and the electric field strength become apparent in a variable extent. In [7] we investigated in details conductivity along dislocation. However the unambiguous information on the relief and properties of the potential barriers, created by an isolated dislocation, which plays the determining role in the generation-recombination properties of the dislocation, is absent in the literature. Such factors as the dislocation interaction with the charge carriers and the impurity atoms, and also the electric and elastic disturbance of the adjacent regions of the lattice have the influence on the potential relief of BC. The simultaneous account of these factors and the construction of the theoretical model of the potential relief about the dislocation are very complicated. Therefore the experimental determination of such relief may give the valuable information on the real behavior of the BC potential barrier and the electric activity of the dislocation.

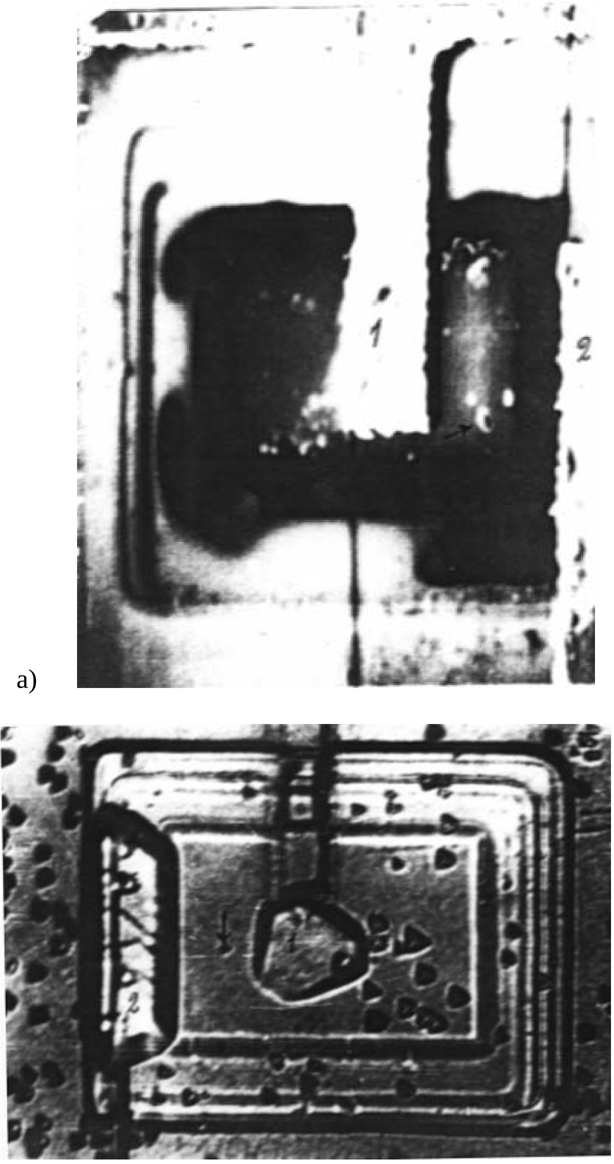
The present paper is devoted to the research of the height change of the BC potential barrier close to an isolated edge charge dislocation under the influence of the perpendicular external electric field with the purpose of the determination of the potential energy relief. The relief of the potential energy of the carrier's interaction (the shape of the potential barrier) with the dislocation has been determined from the research of the Frenkel-Pull effect (FPE) [8].

METHODS AND THE EXPERIMENT

The method of the thermostimulated currents (TSC), whose peculiarities are applicable to the investigated samples, represented in [7], is direct and experimentally convenient for the determination of the dependence of the potential barrier change on the electric field.

The research was carried out on the silicon epitaxy-planar n^+-p junctions of the integrated circuits. The basic region of the junction consists of the boron alloyed ($\approx 5\cdot10^{16}$cm^{-3}) part of the epitaxy film of 111-surface with ~2.1μm thickness. The collector region consists of the n^+- buried layer, formed in p-substrate by the As diffusion ($\approx 10^{20}$cm^{-3}) and adjacent to it the vertical layer, created in the epitaxy film of the phosphorus diffusion ($\approx 5\cdot10^{18}$cm^{-3}), which comes out on the film surface. The small area of the structure ($\sim 10^{-6}$cm^2) allows selecting samples, containing in the p-basic region an electrically active dislocation.

The complex of the independent methods [9-13]: the analysis of the J-V and C-V characteristics, the analysis of the thermostimulated currents (TSC), DLTS methods of the transmission and scanning electron microscopy (SEM), regime of the secondary electrons and the induced current, and methods of chemically selective and by-layered etching have been applied to reveal and study the electrically active dislocation (EAD). The type of the deep centers and their dislocation place in the p-n junction are determined by these methods, the region of the cylindrical bulk charge and the EAD core are revealed. The selected method makes possible to reveal and carry out the research of the electric activity of an individual dislocation at the absence of the electrically active defects. The statistic spread of the measured values is excluded, and the experiment is carried out in the controllable conditions. The microphotography of the investigated p-n structures, obtained by SEM in the combined regime of the secondary electrons and the induced current, is represented on fig.1a. Only one generation-recombination region, localized between basic and collector contacts in the form of the hollow light cylinder, (the region on the photo has elliptic shape because of the fact, that the electron beam of SEM falls on the sample surface under the oblique angle) has been revealed on the microphotography, i.e. only one electrically active defects has been revealed. The white spots over the basic region represent the contamination in the isolated SiO_2-layer, which disappears after the etching of this layer. The dark core of the defects (the cavity of cylinder) testifies the fact, that it is charged positive and intensive absorbs electrons, in consequence of what it looks dark and the light region, surrounding the core, is charged negative, in consequence of what the intensity of the reflected from this region electrons is high, therefore it looks light on the microphotography.


a)

b)

Fig.1. The microphotography of the p-n junction with the one electrically active defect (it is shown by the pointer):
a) in the combined regime of the secondary electrons and induced current of SEM. E=20 kV, ^{x}1400. 1 and 2 are the metallic contacts, respectively to the base and collector. The dark region corresponds to SCL.
b) after the selective chemical etching-1 and 2 are windows under the basic and collector contacts.

The method of the chemical selective etching is applied for the determination of the defect nature. The microphotography of the investigated *p-n* structure after the etching, on which the dislocation etching pits are seen, is represented on fig.1b. The symmetry shape of the dislocation etching pits testifies the fact that the asymmetry etching pits [14, 15] correspond to 30 and 60˚ dislocations. As it is seen from the microphotography comparison (a and b), the secondary (without the impurity atmosphere) dislocation is revealed between the basic and collector contacts under the electrically active defect, the low value of the etching pit in comparison with another etching pit testifies this fact

Such difference in the size of the etching pits is explained by the dislocation genesis. Large etching pits correspond to the grown dislocations, which are germinated from the substrate in the film and are acquire in the process of the film growing by the impurity atmosphere. It is quickly dissolved by the selective etching [16], what causes the extra sizes of the etching pits. The secondary dislocations, occurring at the final stage of the technological process of the device production, have not time for acquisition the impurity atmosphere, therefore the etching pits, corresponding to them have the small sizes.

Thus, it is seen from the microphotography comparison (a and b- fig.1), that the electric activity show only the secondary dislocation (without the impurity atmosphere), its nuclear is charged positive. The latter testifies the donor type of the deep centers, created by the dislocation nuclear.

RESULTS AND THEIR DISCUSSION

Curves of the thermostimulated currents (TSC), obtained at the p-n junction only from the one electrically active edge dislocation in the basic region, at the various values of the reverse bias are represented on fig.2. As it was shown above, the absence in the basic region of the investigated p-n junction of another electrically active defects has been established by means of SEM.

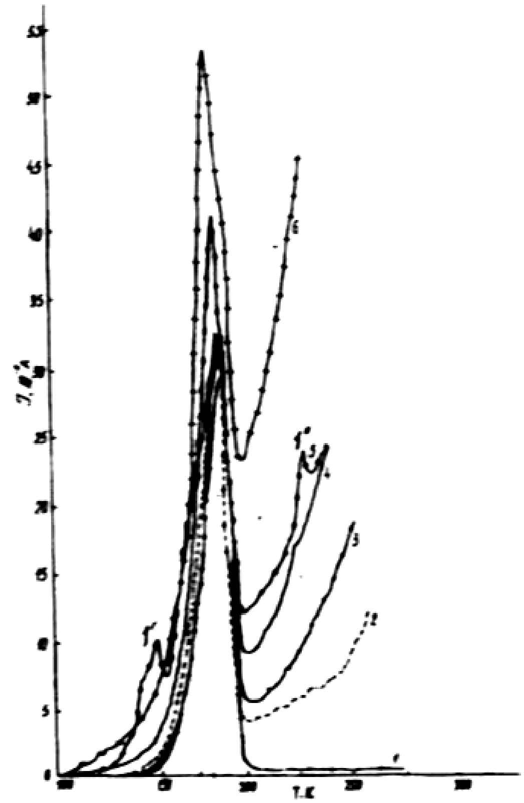


Fig.2. The thermostimulated currents at the various values of the reverse bias U_R on the *p-n* junction: U_R=(0, 2, 3, 4, 5, 6) B is for curves 1-6. The corresponding values of the electric field close to the dislocation are (0,6; 1; 1,24; 1,35; 1,5; 1,6)·10^5V·/cm. The velocity of the sample heating is b=0,35 K·s^{-1}.

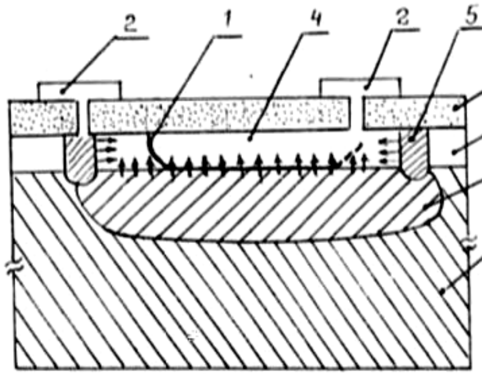


Fig.2a. The *p-n* junction cross-section with the one electrically active dislocation: 1 is the dislocation, 2 is the Al, 3 is SiO_2, 4 is the base, 5 is the collector, 6 is p-Si (the epitaxy layer), 7 is n^+-buried layer, 8 is p-Si- the substrate, 9 is the space charge layer and the field direction is shown by pointers.

These dislocations generate from the surface sources (the scratches, cut, microcracks) in the form of the half-loop and all of them (as a result of the low thickness of the film ~2 microns) approach the space charge layer (SCL) at the result of the slipping from the source under the influence of the voltage, occurring in films because of their nonuniform cooling. As it is shown in [17], in the heavy doped n^+-region the activation energy of the dislocation motion is more on 0,4eV, than in p-region. Therefore the n^+-region will prevent the dislocation motion, as a result the dislocation half-loop, approaching the n^+-heavy layer, i.e. the metallurgic interface of the p-n junction, will “spread” on the plane of the p-n junction, at the result the main part of the secondary dislocation will be localized in the space charge layer. It is confirmed by the by-layered etching of the film. As the field of the space charge layer is directed perpendicular to the plane of the p-n junction, and then it will be also directed perpendicular to the dislocation, placed in this plane. The section scheme of the investigated p-n junction and the place of the electrically active (secondary) dislocation localization (1) in the space charge layer are represented on fig.2a. It should be noticed, that in consequence of the fact, that the donor impurity concentration in the collector is two orders more, than that of the acceptor impurity in the base, SCL of the p-n junction will be wholly concentrated in p-base [11, 12]. The external reverse bias, applied to the p-n junction, increases the field of the space charge layer and increases its width. Because of the free carriers absence in SCL, the dislocation will cause all kinetic phenomena. As rising to the surface the dislocation hall-loop part, which takes its negligible part, is localized between basic and collector contacts (2), then the external field, applied to these contacts, will also be directed perpendicular to the dislocation part. Another rising to the surface dislocation half-loop part penetrates possibly the region of the SCL vertical part of the collector-base junction and therefore it is not presented on fig.1. Therefore, the external field, applied to the basic region, will be directed perpendicular to the dislocation. As it was established before [9, 11, 12], the peaks on the curves of TSC are caused by the thermal emission of the carriers, captured at levels, created by the dislocation. As it is seen from fig.2, by the field increase the TSC peak shifts at the temperature scale to the low value part and its height increases. As the peak on the curve of the thermostimulated current is directly caused by the emission of carriers, captured at the dislocation deep centers, then its shift at the temperature scale with the change of the external electric field at the given velocity of the sample heating indicates to the change of the height of the potential barrier, which carriers get over at the emission, i.e. .the Frenkel-Pull effect is observed (FPE). The value of the potential barrier decay $\Delta\varphi$ has been determined as the difference of the activation energy values, calculated by the peaks position at the temperature scale at various values of the electric field (fig.3)

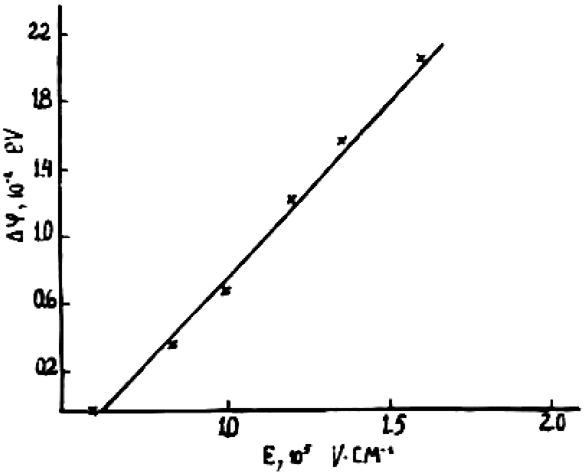


Fig.3. The dependence of the decay of the potential barrier height on the electric field.

It has been established by methods, represented in [9-11, 14], that the deep centers, created by the dislocation, are donor. By processing the experimental curves of TSC by means of the formula [10] the main parameters of the deep centers are determined:

$$ln\left(\frac{T_m^4}{b}\right)=ln\frac{\varphi}{kB}+\frac{\varphi}{kT_m} \tag{1}$$

where T_m is the temperature corresponding to the maximum of TSC, b is the velocity of the sample heating, k is Boltzmann constant, φ is the activation energy (the height of the potential barrier), B is the emission coefficient. The activation energy determined of $ln\left(T_m^4/b\right)$ on $1/T_m$ dependence makes φ=0.38eV and the emission coefficient, calculated by the cross point of the same straight line with the ordinate axis is $B=5.33\cdot10^3c^{-1}\cdot K^{-2}$. Moreover, on the TSC line (fig.2) beside the main peak 1, on right and left, at the reverse bias on the *p-n* junction $V_R=5B$, two peaks$1'$ and $1''$, which coincide with the dislocation levels DH_1 and DH_3, obtained in [18] and also with the peaks A,B,C on the *DLTS* line, represented in [6]. These data testifies the authentic of the obtained results.

As it is seen from fig.3, the dependence $\varphi(E)$ is linear. By the extrapolation of the dependence to the zero value of the field, we will obtain for φ_0 the value 0,39eV, which coincides with the dislocation energy DH_2 in *p*-Si, obtained in [18].

The experimentally obtained dependence $\Delta\varphi(E)$ allows carrying out the identification of the deep centers type and the form of their screening. According to the criterion, represented in [19.20], the line dependence $\Delta\varphi(E)$ testifies the Coulomb type of the dislocation centers and statistic nature of their screening, just as the dependence $\Delta\varphi\approx E^{1/3}$ occurs in the case of the dynamic screening. Thus, it follows from fig.3, that the dislocations in Si create the deep centers of the Coulomb type.

From experimentally determined dependence $\Delta\varphi(E)$, it is possible to construct the dependence of the potential barrier height on the distance to the dislocation nuclear $\Delta\varphi(X)$, i.e. to determine the form of the potential barrier irrespective of the type of the capture centers.

The dependence, represented in [21], has been applied for the determination of the potential barrier form (the relief of the potential energy).

$$\Delta\varphi(X)= E\varphi'(E)+ \Delta\varphi(E) \qquad (2)$$

where $\Delta\varphi'(E)$ is the derivative of the $\Delta\varphi(E)$ function, which is determined by the graphic differentiation of the experimental dependence $\Delta\varphi(E)$ from fig.3.

The curve of the potential energy of the carrier's interaction with the one isolated edge dislocation (the form of the potential barrier) is represented on fig.4. Having φ(E), it is possible to determine the distance to the maximum of the potential barrier: $X_m=\Delta\varphi(E)/q$ (where q is the electron charge).

CONCLUSION

1. It is shown, that the charge edge dislocation in the silicon creates the deep centers of the Coulomb type.
2. The dependence of the change of the potential barrier height close to the charge edge dislocation in the silicon on the external perpendicular field has been determined and it is shown, that this dependence is linear by its nature.
3. The potential relief of the interaction energy of an isolated charge dislocation with the charge carriers has been determined.

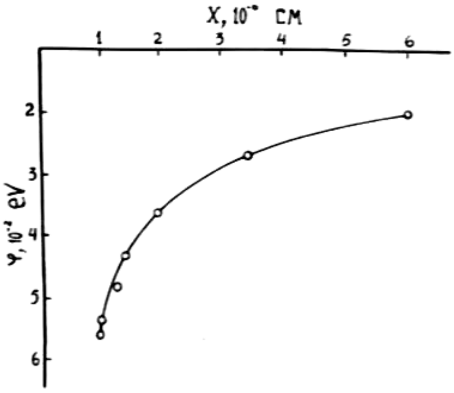


Fig.4. The relief of the potential energy close to the dislocation in the silicon. *X is* the distance from the dislocation core.

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SİLİSİUMDA TƏKLƏNMİŞ DİSLOKASİYANIN ƏTRAFINDAKI POTENSİAL RELYEF

Tərkibində bir elektrik aktiv qıraq dislokasiya olan silisium kristalında Frenkel-Pul effektinin tədqiqatı nəticəsində müəyyən edilmişdir ki, onun aktivliyinin səbəbi özəyində olan atomların doymamış rabitələridir. Göstərilmişdir ki, dislokasiya kulon tipli dərin mərkəzlər törədir. Təklənmiş yüklü dislokasiyanın yükdaşıyıcılarla qarşılıqlı təsirinin potensial enerjisinin relyefi müəyyənləşdirilmişdir.

С.Г. Рзаев, З.М. Захрабекова

ПОТЕНЦИАЛЬНЫЙ РЕЛЬЕФ ВБЛИЗИ ИЗОЛИРОВАННОЙ ДИСЛОКАЦИИ В Si

Исследуя эффект Френкеля-Пула в кремнии, содержащем одну электрически активную краевую дислокацию, установлено, что она создает глубокие центры кулоновского типа. Определен потенциальный рельеф энергии взаимодействия одной изолированной заряженной дислокации с носителями заряда.

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