THE CALCULATION OF THE GETTERING EFFICIENCY OF THE CHARGE-COUPLED DEVICES

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The calculation of the gettering efficiency of silicon CCD-structure (charge-coupled devices) has been carried out by means of the microscopic model of the gettering layer capacity, taking into account processes of the capture and the ejection of impurity atoms to runoffs. It has been shown, that the temperature of the process, parameters of the gettering layer and also the initial impurity concentration have the essential influence on the gettering efficiency.

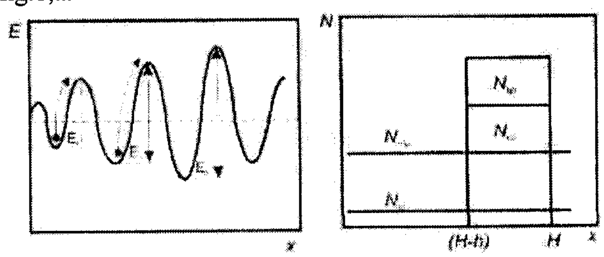
In spite of variety of devices with the charge transfer, where capacities of both the p-n junction and the Shottki barrier are used [1-3], base of their majority is the MOS-condenser. Therefore the great attention is paid to research of electrophysical properties of Si-SiO_2 structure and the growth of their stability [4]. Problems of the growth of the charge transfer efficiency in CCD-structures and their quick-action essentially depend on the quality of the surface of the monocrystal silicon film, which is determined essentially by the gettering operation [5]. The specific charge capacity of the volumetric channel of the CCD-structure is reduced in comparison with the surface channel and demands the decrease of the density of the generation-recombination centers, the suppression of different types of heterogeneities in the silicon and on the boundary surface. On this reason the gettering has to be intensified, satisfying the technology of CCD-structures with the surface channel and the internal getter has to be created in the initial plates of the silicon [6].

Existing methods of the gettering have essential defects [7], concluding, firstly, in the large duration and the high temperature of the treatment, the instability of gettering centers, usually introduced in the plane at the first stage of the microscheme preparation and capable to the decay in the process of the prolonged high-temperature operations. Therefore it is necessary to create new efficient methods of the formation of the gettering centers.

By means of C-V-characteristics measurement of MOS-structures, formed on the base of silicon plates, the gettering efficiency of their volume at the introduction of gettering centers by means of the rapid thermal treatment (RTT) has been shown in [8]. The RTT operation has been produced on the ITT-18M device by samples irradiation by the incoherent IR radiation [9]. The gettering efficiency is determined by the value of the product of part of the substrate volume, occupied by the gettering layer, on the segregation coefficient of quick-diffused impurities (QDI) on the boundary surface of the gettering layer-substrate. Such approach allows to explain experimental results of the impurity redistribution in the substrate-gettering layer system at known empirical values of the segregation coefficient of the QDI for concrete conditions of gettering operations. However, the experimental determination of the segregation coefficient for different gettering conditions and levels of the substrate soiling is the sufficiently laborious task. The microscopic model of the gettering layer capacity, taking into account processes of the capture on runoffs and ejection of impurity atoms in the gettering layer [10], allows to avoid these difficulties.

Structural defects of gettering layers provide the reduction of the free energy of atoms of QDI in the gettering layer in comparison with the substrate. In the gettering process atoms of QDI diffuse on the interstices of the crystal lattice of the substrate, reach the gettering layer; are captured by structural defects in it and become low-mobile.

Any structural defects of the gettering layer may be presented in the form of one or several centers of the impurity capture. The dependence of the energy E of the impurity atom on the x coordinate near the capture center is shown on fig.1,a.



a b

Fig.1. The energy diagram of the capture center of impurity atom (a) and the scheme of the distribution of gettering impurities in the substrate with the gettering layer (b).

The given energy diagram includes energetic barriers for interstitial diffusion of quick-diffusing impurities E_i, for the atom transfer of these impurities from the interstice to the center of capture E_1 and for the reverse transition E_2.

Let us assume, that the monocrystal substrate of the H thickness, homogeneously alloyed by the monotype QDI with the concentration $N=N_{sio}$, exists in the initial state. The concentration of structural defects is low in substrates and therefore atoms of quick-diffusing impurities are placed mainly in interstices [11]. The gettering layer of the H thickness is created on the reverse side of the substrate, containing monotypical capture centers with the concentration N_{CO}. The gettering layer may be characterized by the surface density of capture centers because of its small thickness with respect to the substrate. Later the substrate is exposed to the thermal treatment for the redistribution of QDI from the substrate to the gettering layer. The new equilibrium concentrations of quick-diffusing impurities (N_{cnf}, N_{cf}) are established in the substrate and in the gettering layer. The concentration of structural defects is high in the gettering layer and only the part of centers is filled by atoms of quick-diffusing impurities:

$$N_{CO} = N_{cnf} + N_{cf} \qquad (1)$$

where N_{cnf} and N_{cf} are concentrations of free and filled by impurity atoms of capture centers respectively. The following expression was obtained in [10] for the segregation coefficient:

$$k_C = 1 + \frac{H}{2h}\left\{\left[1 + 2(k_{max} - 1)(N_{SiO}/N_{CO} - h/H) + (k_{max} - 1)^2 (N_{SiO}/N_{CO} - h/H)^2\right]^{\frac{1}{2}} - (k_{max} - 1)(N_{SiO}/N_{CO} - h/H) - 1\right\} \qquad (2)$$

$$k_{max} = 1 - \frac{N_{SiO}}{N_{1Si}} \exp[(E_2 - E_1)/kT] \qquad (3)$$

where k_{max} is the limiting value of the segregation coefficient, obtained at low concentrations of quick-diffusing impurities in initial substrates, N_{1Si} is the limiting solubility of interstitial atoms of QDI.

The conception of the cleaning degree is used for the estimation of the gettering efficiency, $\delta_N = N_{SiO}/N_{Si}$ is the value, showing in how many times the concentration of QDI has reduced near the working surface of the substrate in consequence of the gettering, N_{Si} is the concentration of interstitial atoms of QDI in the substrate and in the gettering layer after the gettering completion,. It is easy to obtain the expression for the cleaning degree from the equation of the impurities balance [12]:

$$\delta_N = 1 + (k_C - 1)\ h/H \qquad (4)$$

It follows from relationships (2)-(4), that the cleaning degree is determined by the concentration N_{Cd} and by the nature of capture centers ($\Delta E = E_2 - E_1$), by the temperature of the gettering process, by the part of the substrate volume, occupied by the gettering layer h/H and by the type of the QDI (N_{1Si}). Results of calculations of the cleaning degree, according to formulas (2)-(4), are shown on fig. 2 for the basic set of gettering conditions and parameters of the structure: T=1273K; ΔE=0.5eV; $N_{Co}=10^{23}\mathrm{m}^{-3}$, $N_{SiO}=10^{19}\mathrm{m}^{-3}$; $h=10^{-5}$m; $H=4\cdot10^{-4}$m. The known quantitative characteristics [12] of temperature dependences of the limiting solubility of atoms of copper, gold and iron in the silicon have been used at calculations. The following conclusions may be done in the result of the carried out calculations.

The gettering efficiency reduces with the growth of the temperature (fig.2,a). The gettering layer capacity grows according to the exponential law at the temperature reduction. It is necessary to remember, that calculated values of the cleaning degree are limiting for the given temperature. The gettering efficiency will be determined also by the gettering coefficient at low temperatures and the limited time of the process.

The gettering effect becomes essential only at the presence of the sufficient number of capture centers in the gettering layer (fig.2,b). The minimum necessary concentration of capture centers, determined by the level δ_N=10, essentially depends on the type of the gettering impurity.

Since practically all QDI are contained in real silicon plates, then, according to the fig. 2,b, the density of capture centers should exceed 10 cm² in the gettering layer.

Such situation is realized, if the gettering layer is saturated by vacancies, is in the stressed compression state and is alloyed by the slowly diffusing impurity on interstices. One and the same gettering layer possesses by the different gettering capacity with respect to different QDI exactly in connection with the different limiting solubility of impurities.

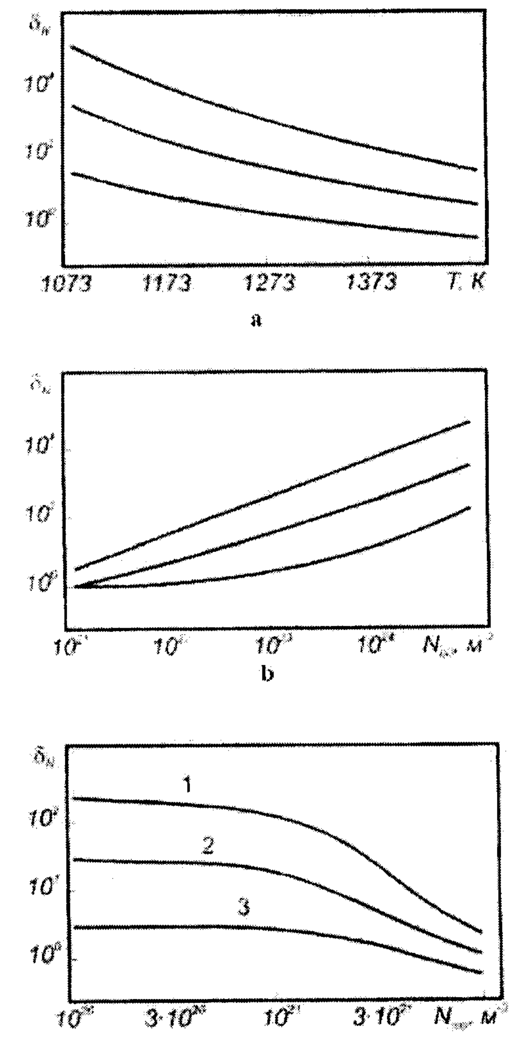


Fig.2. The dependence of the limiting cleaning degree of the working surface of siliceous plates on the temperature of the gettering process (a), on the concentration of capture centers in the gettering layer (b), concentrations of atoms of iron (1), gold (2), copper (3) – in the initial substrates (c).

The most high values of the cleaning degree occur for atoms of iron, possessing by the low limiting solubility in the silicon (fig.2). The figure 2 illustrates the essential dependence of the gettering efficiency on the initial impurity concentration in the plate. The sharp fall of the geterring efficiency at high levels of the pollution of initial plates is caused by the fact, that the impurity concentration in the gettering layer grows quickly in the gettering process and reaches summary limiting solubility: ($N_{1Si}+N_{CO}$). Then capture centers in the gettering layer are practically completely filled and this layer loses the gettering capacity with respect to the rest in the QDI substrate. The loss of the gettering capacity of the gettering layer begins on the identical levels of the pollution of initial substrates independently of the impurity type. The use of more effective capture centers with the higher value of the energy barrier $\Delta E=E_2-E_1$ does not allow to increase the cleaning degree of the substrate. In given case the cleaning degree may be increased only by means of the growth of the number of capture centers in the gettering layer.

Therefore, it has been established, that the initial concentration of QDI has essential influence on the gettering layers efficiency side by side with the temperature of the gettering process and parameters of the gettering layer.

The given model of the gettering efficiency takes into account both parameters of initial substrates and characteristics of gettering layers, and may be used at the choice of methods and conditions of the gettering layer creation on defined substrates.

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YÜK ƏLAQƏLİ CİHAZ STRUKTURLARIN HETTERİRLƏMƏ EFFEKTİVLİYİNİN HESABATI

Müxtəlif metallar üçün aşqar atomlarının axına zəbt etmə və tullanma proseslərini nəzərə alan hetterirləmə təbəqəsinin tutumunun mikroskopik modelinin köməyi ilə silisium YƏC-strukturların (yük əlaqəli cihaz–struktur) hetterirləmə effektliliyinin hesabatı aparılmışdır. Göstərilmişdir ki, hetterirləmə effektliliyinə prosesin temperaturu, hetterirləmə parametrləri, həmçinin aşqarların ilkin konsentrasiyası kifayət qədər təsir göstərir.

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РАСЧЕТ ЭФФЕКТИВНОСТИ ГЕТТЕРИРОВАНИЯ ПЗС-СТРУКТУР

Проведен расчет эффективности геттерирования кремниевых ПЗС-структур при помощи микроскопической модели емкости геттеростоя, учитывающей процессы захвата и выброса примесных атомов на стоки. Показано, что на эффективность геттерирования оказывает существенное влияние температура процесса, параметры геттерослоя, а также исходная концентрация примесей.

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