УДК 531

МОДЕЛЬ ПОДВИЖНОСТИ НЕОСНОВНЫХ НОСИТЕЛЕЙ В ПОЛИКРЕМНИЕВЫХ ЭМИТТЕРАХ

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Разработана модель подвижности неосновных носителей в поликремниевых эмиттерных контактах. Она основана на эффекте сегрегации электрически активных примесей на границах зёрен поликремния, а также термионно-эмиссионной и диффузионной теории дырочного тока. Выведено аналитические уравнение, которое позволяет рассчитывать подвижность дырок в поликремниевых эмиттерных контактах и её зависимость от концентрации примесей и размера зёрен поликремния

Ключевые слова: МАТЕМАТИЧЕСКАЯ МОДЕЛЬ, НЕОСНОВНЫЕ НОСИТЕЛЕИ, ПОДВИЖНОСТЬ, ПОЛИКРЕМНИЙ, ЭМИТТЕР, БИПОЛЯРНЫЙ ТРАНЗИСТОР

UDC 531

A MODEL FOR MINORITY CARRIER MOBILITY IN POLYSILICON EMITTERS

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A model for minority carrier mobility in polysilicon emitter contacts is developed. It is based on the effect of the segregation of electrically active dopants to polysilicon grain boundaries and the thermionic emission - diffusion theory of the hole current. An analytical equation is derived which allows to calculate hole mobility in polysilicon emitter contacts and its dependence on dopant concentration and polysilicon grain size

Keywords: MATHEMATICAL MODEL, MINORITY CARRIERS, MOBILITY, POLYSILICON, EMITTER, BIPOLAR TRANSISTOR

1. INTRODUCTION

Bipolar transistors with polysilicon emitter contacts are the main active elements of contemporary bipolar and BiCMOS IC. One of the differences of these transistors from the transistors with metal contacts is a higher current gain. According to the transport theory, high values of the gain are associated with low mobility of holes in polysilicon emitter contacts [1-6]. A significant feature of polysilicon is dopant segregation to its grain boundaries. The segregation of electrically-active dopants produces a potential barrier for holes, which reduces their mobility [7,8].

In this paper, a model for minority carrier mobility in polysilicon emitters is developed. It is based on the effect of dopant segregation to the polysilicon grain boundaries. The model is capable of predicting the low values of the mobility.

2. RESULTS AND DISCUSSION

The segregation of the electrically active and ionized donor dopants to the grain boundary charges the boundary positively and creates a negative space charge region next to the grain boundary. A one-dimensional Poisson equation was solved under the assumption of uniform charge distribution in both regions. The solution is

$$j = j_B - \frac{qN_a x^2}{2e_s} \qquad (1)$$

within the grain boundary and

$$j = \frac{qN_a b}{2e_s (w-b)} \left(|x| - \frac{w}{2} \right)^2 \qquad (2)$$

within the negative space charge region, where N_a is the concentration of the electrically active dopant in the grain boundary, b is the grain boundary width, w is the space charge region width, and φ_B is the potential barrier height for holes given by

$$j_B = \frac{qN_a bw}{8e_s} \qquad (3)$$

The charge and potential distributions are shown in Fig.1.

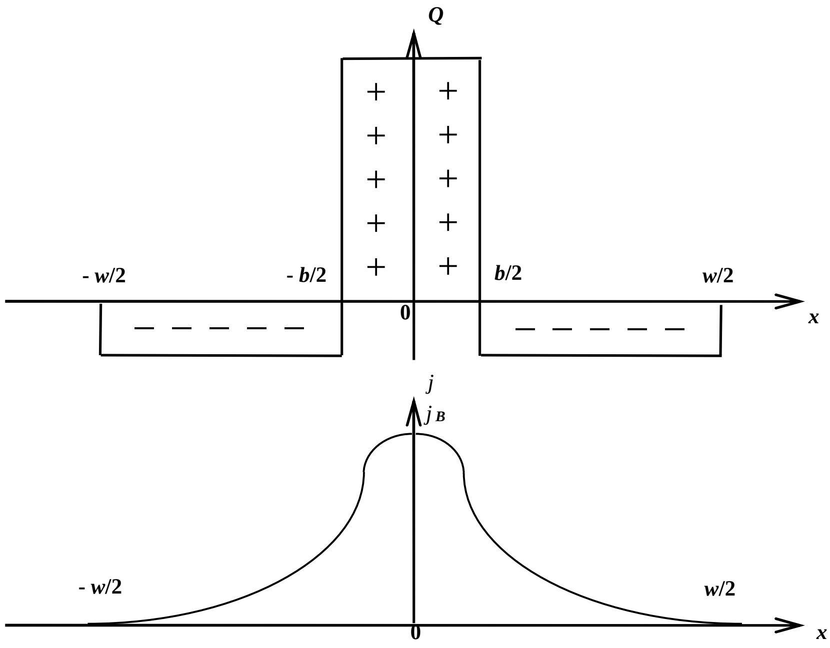

Fig. 1. The charge and potential distribution within the grain boundary and the negative space charge region. j_B is the potential barrier height for holes.

The model of the hole current is based on the thermionic emission - diffusion theory [9] under the assumption that the current flow does not change the condition of thermodynamic equilibrium in the space charge region. Based on this model, the effective mobility of holes in the polysilicon contact can be expressed as

$$m_{pc} = \frac{q}{kT} w \exp\left(-\frac{qj_B}{kT}\right) v_{eff} \tag{4}$$

where the effective velocity v_{eff} is defined as

$$v_{eff} = \left(\frac{1}{v_{th}} + \frac{1}{v_d}\right)^{-1} \tag{5}$$

with the hole thermal velocity v_{th} and the effective diffusion velocity v_d given by

$$v_{th} = \sqrt{\frac{kT}{2pm_p^*}} \tag{6}$$

$$v_d = \frac{D_p}{2L_p \sinh\left(\frac{w}{2L_p}\right)} \tag{7}$$

where m_p^* is the effective hole mass, D_p and L_p are the hole diffusion coefficient and diffusion length in silicon.

Assuming that the concentration of the electrically active dopant is proportional to the average grain boundary dopant concentration, N_a can be expressed as

$$N_a = a(1 - c)N \tag{8}$$

where N is the total dopant concentration in the polysilicon, c is the segregation coefficient (the ratio of the average dopant concentration in the grain to the total concentration), a is the proportionality coefficient.

If the process of the redistribution of the dopant between the grain and grain boundary has finished, the equilibrium segregation coefficient is given by [10]

$$c_{eq} = \left[\frac{AQ_s}{LN_{Si}}\exp\left(\frac{E_a}{kT}\right) + 1\right]^{-1} \tag{9}$$

where N_{si} is the atomic density of silicon, Q_s is the surface state density at the grain boundary, L is the grain size, E_a is the activation energy, T is the anneal temperature, and A is the proportionality coefficient.

If the redistribution has not finished yet, the segregation coefficient is given by [11]

$$c = c_{eq} - (c_{eq} - c_0)\exp\left(-\frac{t}{t}\right) \qquad (10)$$

where c_0 is the initial segregation coefficient (before annealing), t is the annealing time, and t is the relaxation time.

The hole mobility was calculated by the equation (4) for two extreme values of w: w=b and w=L. The results are shown in Fig. 2 and 3. The segregation coefficient was considered to be equal to the equilibrium one. c=0.5 was used for L=1000 Å. For the other L, the segregation coefficient was calculated by the equation (9). For both w, the mobility decreases with increasing the total dopant concentration (Fig. 2). For w=b, the mobility increases with the increase in the grain size (Fig. 3a). For w=L, the mobility decreases or has a maximum (Fig. 3b). Since the experimental data show that the hole mobility in polysilicon emitter contacts decreases when the grain size becomes smaller [12], the approximation w= b may be considered as more accurate.

In Fig. 2a the calculated hole mobility is compared with the experimental results obtained from [3,13] and the mobility values, derived from the effective

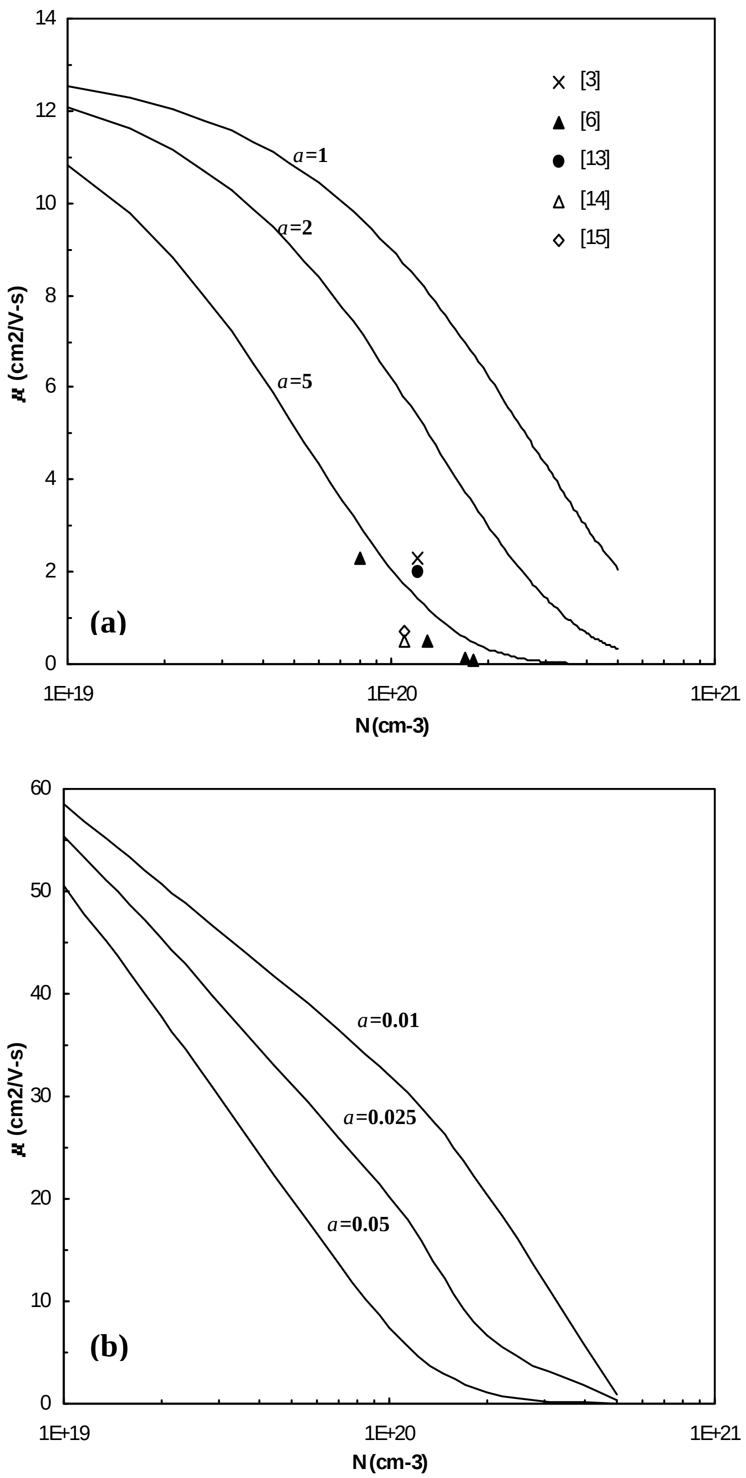

Fig. 2. Calculated dependence of the hole mobility in the polysilicon emitter contact on the total dopant concentration in the polysilicon. b=10 Å, L=1000 Å, c=0.5. (a) $w = b$, previously reported values of the mobility are plotted. (b) $w = L$.

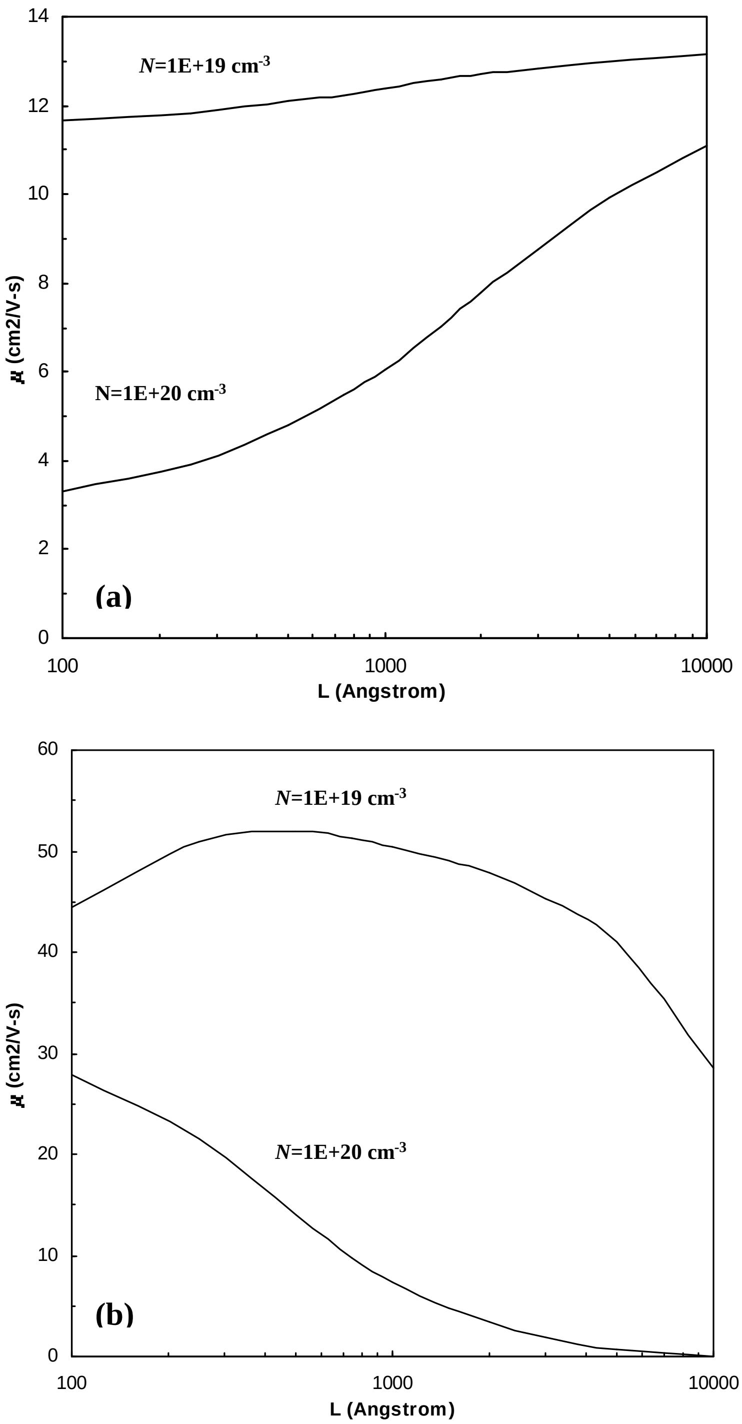

Fig. 3. Hole mobility versus grain size for two values of the total dopant concentration. b=10 Å. (a) $w=b$, a=2. (b) $w=L$, a=0.05.

recombination velocity at the emitter/contact interface, reported in [6,14,15]. The effective recombination velocity is given by [6]

$$S_p = \frac{D_{pc}}{L_{pc}} \coth \frac{W_c}{L_{pc}} \tag{11}$$

where W_c is the contact width, D_{pc} and L_{pc} are the hole diffusion coefficient and diffusion length in the contact. The closest agreement with the reference data can be reached with $w=b$ and a =5.

3. CONCLUSIONS

The model for the minority carrier mobility in polysilicon emitter contacts is created. The model is based on the effect of the dopant segregation to the polysilicon grain boundaries, which reduces the mobility of holes. The analytical equation for the mobility is derived by using the thermionic emission - diffusion theory. The comparison with the previously published data shows that the model allows to calculate the hole mobility in polysilicon emitter contacts and its dependence on the dopant concentration and the polysilicon grain size quite accurately.

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