HALL EFFECT AND CONDUCTIVITY IN POROUS SILICON WITH LOW POROSITY ON THE BASE OF Si<As>

H.A. HASANOV
H. Aliev Academy of Ministry of National Safety

The investigation results of temperature dependences of specific resistance and Hall coefficient of mesoporous silicon with low porosity, formed on the base of Si<As> are given in the present article. The formulas of double-layer Petritz model are used at calculations. The obtained results are analyzed in the in the framework of theory of effective medium, which allows us to consider the materials with foreign inclusions in matrix.

Introduction

Hall effect is the classic method for data accessing about concentration of charge carriers in the semiconductors [1] and that's why its use for investigation of porous silicon (PS) is reasonable. There are only two works, in which the measurement of Hall effect in porous silicon [2, 3] is mentioned, are known in World. The detail description of experimental data is absent in these two works and that's why it is hard to agree with some conclusions of authors. The main difficulties at Hall effect measurement in PS are connected with its high specific resistance and necessity to take into consideration the substrate short-circulating effect, especially that's why this method has not found such wide application for the investigation of porous structures. However, as our investigations show, Hall effect can be effectively used for the investigation of low-resistance layers of porous silicon. The aim of the given paper is the investigation of Hall effect and electrical conduction of mesoporous silicon with low porosity (5-30%) on the base of Si<As>.

Experimental part

The measurements of Hall effect and conductivity are carried out by potentiometer on double-layer PS/silicon substrate structures (fig. 1) on direct current with the use of commutation of electric and magnetic fields at the value of magnetic field 0.3÷0.5 *T* in temperature interval 290-380K. PS, formed on substrates KES-0.01 with electron concentration $n=10^{18}$ cm^{-3} of orientation (111) is used for investigations. The anodizing is carried out in 46% water solution HF at current density 10÷20 mA/cm^2.

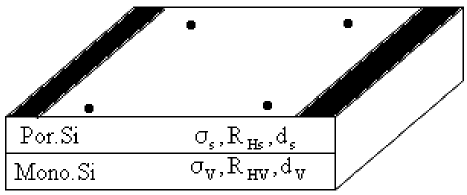

Fig. 1. The image of double-layer PS/silicon structure for measurement of Hall effect [3].

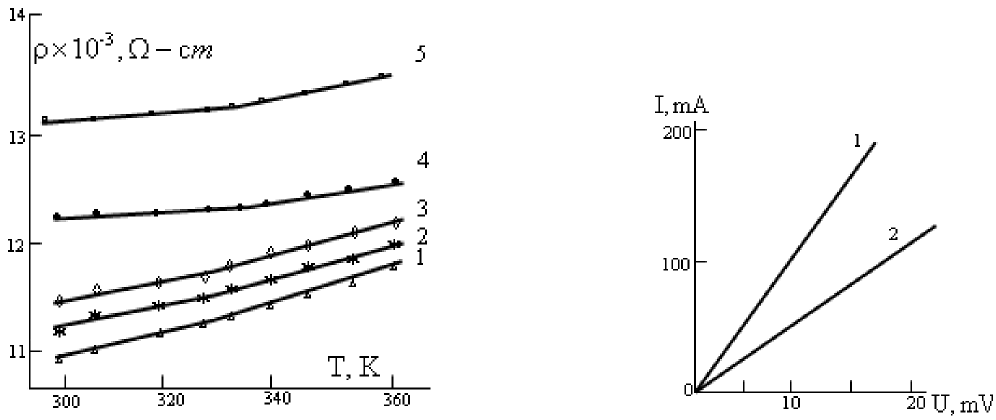

Fig. 2. a – temperature dependences of specific resistance for initial silicon (1) and double-layer structures (2-5), obtained at j=10mA/cm^2 for t_a : 2 - 20, 3- 30, 4 - 40, 5 – 60 min.; *b* – linear volt-ampere characteristics of contacts: 1- j=10mA/cm^2, t_a=10min., 2 - j=10mA/cm^2, t_a=50min.

The time of anodic treatment varies in the limits 20÷60 min. The practically linear dependencies of layer thickness of PS on treatment time and weight porosity on thickness of porous layer are observed under these conditions. PS layers have the thickness 10÷90 mcm and weight porosity 5-30%. The plasmachemical elimination of surface amorphized film is carried out for improvement of contact ohmicity and decrease of value of transient resistance. The indium test contacts for measurement of Hall effect and specific resistance are covered on PS surface by mask. The contact ohmicity is proved by Koh-Streck method, the values of transient resistances are 0.7÷2.1Ω-mm.

The typical dependencies of specific resistance ρ of double-layer structures in temperature interval 290-380K are given on the fig.2,a; the temperature dependence of specific resistance for initial silicon is also given here. As it is seen from this figure, the similar temperature variations $\rho(T)$ for investigated samples and monocrystalline silicon is observed and increase of specific resistance values of double-layer structure at increase of anodic treatment time takes place. The temperature change of Hall coefficient R_H for investigated structures is shown on the fig.3,a. Moreover, temperature dependences $R_H(T)$ for double-layer samples have similar change character in the comparison with monocrystalline silicon; the values of Hall coefficient for all samples are in narrow band of values (1.1÷1.7)·10-6m^3/C, shown on the fig.3,a. Any change regularity of Hall coefficient in the dependence of regimes of electrochemical working is absent inside this band. Moreover, the experimental values R_H also fill the given band of values for double-layer samples, obtained in similar technological conditions and for samples of monocrystalline silicon from different plates.

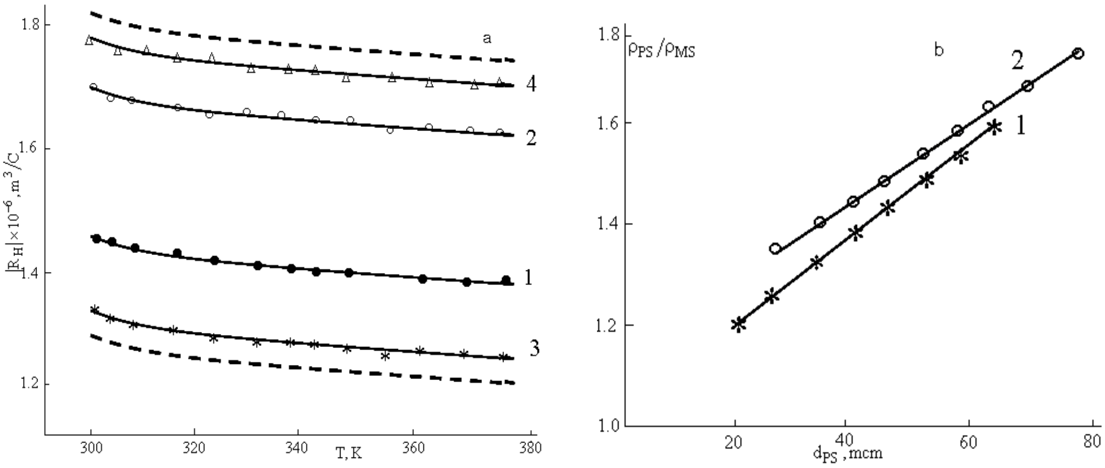

Fig. 3. a – typical temperature dependences of Hall coefficient for initial silicon (1) and double-layer structures (2-4), obtained at: 2- j=10mA/cm^2, t_a=40min.; 3- j=10mA/cm^2, t_a=30min.; 4- j=10mA/cm^2, t_a=60min.; *b* – dependence of ratio ρ_{PS}/ρ_{MS} on PS film thickness for different j: 1 - 10mA/cm^2, 2 - 20mA/cm^2.

Discussion of obtained results

The traditional calculation methods of layer electrophysical parameters, consisting in double-layer structure [1] are used for treatment of obtained results. The experiment cycle on layerwise elimination of substrate material simultaneously with Hall measurements is carried out in order to more reliably eliminate the influence of silicon substrate. It is established, that the changes of concentration and mobility of charge carriers in the comparison with initial silicon don't take place in the volume of substrate KES-0.01 itself at given treatment regimes. That's why the parameters of one layer (silicon substrate) in double-layer structure are taken as equal ones for initial silicon at following calculations. It is known, that porous silicon, obtained in close regimes on silicon, strongly doped by arsenic, has the columnar structure [4, 5] with pore diameter of 5nm order. That's why the two-phase model of porous silicon layer, consisting of monocrystalline matrix-frame (phase 1) and cylindrical empty places, perpendicular to surface (phase 2) is put in calculation formulas.

The formulas of double-layer Petritz model [1] are used at calculations:

$$\sigma = \frac{\sigma_s d_s + \sigma_v d_v}{d}, \tag{1}$$

$$R_H = \frac{\sigma_s^{\,2} d_s R_{Hs} + \sigma_v^{\,2} d_v R_{Hv}}{\left(\sigma_s d_s + \sigma_v d_v\right)^2}, \tag{2}$$

where R_{Hs} is Hall coefficient for upper layer (porous silicon), σ_s is electrical conduction of upper layer (PS), R_{Hv} is Hall coefficient for lower layer (silicon substrate), σ_v is electrical conduction of lower layer; d_s, d_v, d are thicknesses of upper, lower layers and whole structure, correspondingly. In formulas (1) and (2) R_H and σ are Hall coefficient and conductivity correspondingly for whole double-layer structure. The measurement results on silicon substrates, crude in electrolyte are used in the capacity of data for the layer of monocrystalline silicon.

The calculations show that PS specific resistance value is bigger in 1.1÷1.6 times than specific resistance of initial silicon substrates in measured double-layer structures. This is shown on the fig.3,b, where the ratios of specific resistances of PS and monocrystalline silicon (ρ_{PS}/ρ_{MS}) are given for two densities of anodizing current for investigated interval of PS thicknesses. As it is mentioned above, the porosity of investigated samples is almost proportional to PS thickness, so the ratio of specific resistances should increase with increase of porosity value by the law, which is close to linear one. The obtained results are analyzed in the framework of theory of effective medium, which allows us to consider the materials with foreign inclusions in matrix. If PS is considered as monocrystalline frame (with conductivity σ_{MS}, value of Hall coefficient R_{HMS} and mobility of carriers μ_{MS}), penetrated by cylindrical non-conducting empty places, then conductivity σ_{PSv}, Hall coefficient R_{HPS} and mobility μ_{PS} of such heterogeneous system depend on porosity value. We have the following relations:

$$\sigma_{PS} = \frac{\sigma_{MS}\left(1-P\right)}{1+P}, \tag{3}$$

$$R_{HPS} = R_{HMS}, \tag{4}$$

$$\mu_{PS} = \frac{\mu_{MS}\left(1-P\right)}{1+P}. \tag{5}$$

at cylindrical spaces of arbitrary cross-section, the axes of which are perpendicular to electric field and parallel to magnetic one in the framework of theory of effective medium [1].

The analysis of experimental results with the help of formula (3) shows, that experimentally observed law of the increase of PS specific resistance on the increase of porosity value enough well corresponds to theoretical statements of theory of effective medium. This is shown on the fig.4, where theoretical and experimental data in the porosity interval 5-30% are presented.

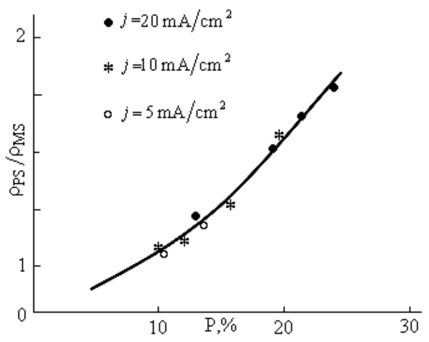

Fig. 4. The theoretical and experimental dependencies $\rho_{PS}/\rho_{MS}=f(P)$ for investigated samples. The points are experimental values; line is theoretical dependence in the framework of theory of effective medium.

Thus, analysis of experimental results on measurement of Hall effect and specific resistance of structures with porous layers shows that all changes of specific resistance of double-layer structures on the base of KES-0.01 can be explained by the formation of unconducting empty places in silicon without formation of depletion regions round pores and without concentration change of charge carriers in silicon frame. The calculations of Hall coefficient for double-layer structures (f.2) at the condition of concentration constancy of charge carriers in PS matrix at observable increase of resistance of porous layer in 1.1÷1.6 times prove about the fact that changes of Hall coefficient shouldn't exceed the value of measurement experimental error R_H, that explains the observable effects (fig.3) at carrying out of Hall measurements. Note, that absence of depletion in PS, obtained on strongly doped substrates of n-type, is also mentioned by Andersen [6] on the base of capacitance measurements at the use of substrates, doped by phosphorus (0.003÷0.005 Ω-cm).

Conclusion

1. The value of PS specific resistance in measured double-layer structures is bigger in 1.1-1.6 times, than the specific resistance of initial silicon substrates.
2. The ratio of specific resistances of porous structure and substrate increases with the increase of porosity value on the law, closed to linear one.
3. Hall coefficient value for all investigated samples are in small interval of values $(1.1 - 1.7)\cdot10^{-6}$ m^3/C.
4. Any regularity of the change of Hall coefficient is absent in the dependence on the regimes of electrochemical treatment.

[1] *E.V. Kuchis.* 1990 Galvanomagnitnie effekti i metodi ikh issledovaniya. (Moscow, Radio I svyaz) s. 264. (In Russian).

[2] *M.N. Preobrajenskiy, S.P. Zimin, D.S. Zimin.* 1998. Vozmojnosti metoda akusticheskoy mikroskopii pri izuchenii kristallicheskogo stroeniya tonkikh plyonok. Sb. "Visokii tekhnologii v promishlennosti Rossii".(Moscow ,MAI) s. 168 (in Russian).

[3] *S.P. Zimin, D.S. Zimin.* 2000. Variety of aluminium – porous silicon contacts electrical parameters. Materials for Advanced Metallization :Materials of European Workshop. (Streza, Italy) p.138.

[4] *H.Ə. Həsənov, R.Ş. Rəhimov*. Bakı. Bakı Universitetinin Xəbərləri, fizika-riyaziyyat elmlər seriyası, 2008, №1, səh. 134-140.

[5] *H.Ə. Həsənov.* Bakı, "Elm", "Fizika", XIII cild, 2007, №5, səh. 88-92.

[6] *R.C. Anderson, R.S. Muller, C.W. Tobias.* 1991 Investigations of the electrical properties of porous silicon J. Electrochem. Soc., V.138, P.3406-3411.

H.Ə. Həsənov

AZMƏSAMƏLİ Si <As> ƏSASINDA FORMALAŞDIRILMIŞ MEZOMƏSAMƏLİ SİLİSİUMDA HOLL EFFEKTİ VƏ ELEKTRİK KEÇİRİCİLİYİ

Təqdim olunmuş işdə azməsaməli Si <As> əsasında formalaşdırılmış mezoməsaməli silisiumda Holl effekti və elektrik keçiriciliyinin temperatur asılılıqlarının tədqiqinin nəticələri verilmişdir. Hesablamalar Petrits düsturlarının köməyilə aparılmışdır. Alınmış nəticələr materialı matrisdə yad qoşmalar olan materiallardakı prosesləri izah edə bilən effektiv mühitlər nəzəriyyəsi çərçivəsində təhlil edilmişdir.

Г.А. Гасанов

ЭФФЕКТ ХОЛЛА И ПРОВОДИМОСТЬ В МЕЗОПОРИСТОМ КРЕМНИИ С НИЗКОЙ ПОРИСТОСТЬЮ НА ОСНОВЕ Si<As>

В представленной работе приведены результаты исследований температурных зависимостей удельного сопротивления и коэффициента Холла мезопористого кремния с низкой пористостью, сформированного на основе Si<As>. Вычисления проведены на основе двухслойной модели Петрица. Полученные результаты проанализированы в рамках теории эффективной среды, которая позволяет нам рассматривать исследуемые объекты как материалы с инородными включениями в матрице.

Received:10.09.08