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Two-Barrier model for Description of Charge Carriers Transport Processes in Structures with Porous Silicon

S.P. Zimin[a], V.S. Kuznetsov[a], A.V. Prokaznikov[b]

[a]Yaroslavl State University,
Sovetskaya,14, 150000 Yaroslavl, Russia
Tel.(0852) 25-55-53, Fax(0852) 22-52-32
E-mail: phystheo@univ.uniyar.ac.ru
[b]Institute of Microelectronics RAS,
Universitetskaya,21,150007, Yaroslavl,Russia
Tel.(0852) 11-22-71, E-mail: imras@iman.yaroslavl.su

Abstract

In this work the simulation of charge carrier transport processes was carried out in the structure consisted of metal - porous silicon - mono-silicon - metal for p-type silicon on the base of hypothesis of two rectifying transitions. Approbation of this model was done and it was demonstrated a good agreement between theoretical and experimental results. The specific resistivity value was estimated for different formation regimes.

1. Introduction

Porous silicon(PS) is a new perspective material for creation different semiconductor devices, sensors, VLSI's functional elements and so on. In the present time (see [1, 2, 3] and so on) the processes of carrier drift in PS and in structures on its base are studied not complete by enough and further experimental as well as theoretical investigations are needed. The investigation of charge carrier transport in the structure metal - porous silicon - monosilicon - metal (Me-PS-MS-Me) excites special interest because the study of physical processes in this structure make it possible, on one hand, better understand PS properties and, on the other hand, to help in creation of effective electroluminescent cells in the visible region and another semiconductor devices on the base of PS. In the present work investigation of electron and hole transport was carried out in the Me-PS-MS-Me structure, which was formed on the base of p-type silicon and includes porous layer with porosity more than 50%.

2. Two-barrier model

The authors [1] have used the model, that contains one rectifying transition on the Me-PS boundary, while studying electrical properties of Me-PS-MS-Me structure in order to interpret the experimental results. The investigations during last years have showed that some experimental results can not be explained within the frameworks of this model especially for p-type silicon of high porosity. In this case two-barrier model was suggested [4], that takes into account the work of two rectifying transitions on Me-PS and PS-MS boundaries. ¿From the physical point of view the presence of these transitions is connected with dopand depletion processes in monocrystalline PS matrix at high porosity and with increasiny of forbidden band width of PS comparing to mono-silicon.

On the base of analysis of band energy diagram in the case of p-type silicon an equivalent electrical scheme was suggested. It consists of two oncoming diodes and resistor, that corresponds to a resistance of PS layer. For forward bias of voltage-current characteristic (VCC) of the structure (corresponding to the mono-Si being positive) a mathematical model was presented that described a transport of forward current through the heterojunction of PS-MS and reverse current through Schottky barrier of Me-PS. For forward biasing branch of VCC for heterojunction the expression was used that looks like this [5]:

$$I = J_s S exp(qU_1/nkT), \tag{1}$$

for reverse biasing branch of VCC for Schottky barrier an assumption concerning generation-recombination mechanism of current transport was used [6]

$$I = S\beta^{-1/2}\sqrt{\phi_0 + U_2}, \tag{2}$$

where I is the current through the structure, S is the contact area, J_s is saturation current density, q is the charge of an electron, n is the current transition coefficient in heterojunction, U_1 is the potential of heterojunction, U_2 is the potential of Schottky barrier, ϕ_0 is potential value of a barrier on Me-PS boundary, β is some coefficient, which depends on dopand atoms concentration, PS dielectric constant, life time of charge carriers which is considered in this work as some variation parameter. It was presupposed that PS behavior is ohmic within not large potential limits. The MS-Me was considered as ohmic one. The program "POR" was elaborated within the frameworks of these conditions taking into account charge carriers of both signs, which makes it possible to compare experimental and theoretical VCC and to calculate two very important parameters: the value of specific resistivity of PS layer and current transport coefficient for heterojunction of PS-MS.

3. An approbation of the model

An approbation of presented model was carried out for Al-PS-MS-Al and In-PS-MS-Al structures that were performed on the base of boron doped, 0.03 $Ohm \cdot cm$ silicon, boron doped, 1 $Ohm \cdot cm$ silicon an boron doped, 10 $Ohm \cdot cm$ silicon. PS was obtained by electrochemical anodization in electrolytes on the base of HF at current densities within the limits 10-60 mA/cm^2 and anodization duration time equals 5-60 min. PS layers had thickness of the order of 6-70 μm and weight porosity more than 50%. The investigations, that were carried out according to Cox-Strack method, showed that Al-PS and In-PS contacts had pronounced non-ohmic character but MS-Al transition was ohmic one. Rectifying coefficients of Me-PS-MS-Me structures within the temperature interval 120-300K were either more or less than 1. Comparison of theoretical and experimental VCC showed, that they are in good correspondence with each other and maximum differences are not exceeded 4-7%. The PS specific resistivity value, that was formed by different technological conditions, was within a large limit of values $10^4 - 10^7 Ohm \cdot cm$. It was stated that appearance of surface porous dielectric film takes place, which has specific resistivity of the order up to $10^{10} Ohm \cdot cm$ and formes by any anodization regimes.

Alongside with good conformity of theoretical and experimental characteristics, other proof of two-barrier model serviceability can serve of the experimental results, when on the same PS surface the metal was deposited in various conditions. It resulted in that, that the characteristics of Schottky barrier on various platforms were various, rectifying coefficient of Me-PS-MS-Me structures and kind of VCC is sharp changed. However use of program "POR" resulted in that, that the size determined from model of PS specific resistance under each contact was in enough narrow interval of significances, explainable by natural spread of PS specific resistance on area of film.

The usage of two-barrier model to Me-PS-MS-Me structure has allowed to describe the processes of injection hole from silicon substrate to PS, to find out the phenomenon of modulation of electrical resistance of PS layer at submission on structure of large potential and to put on record the availability of currents of outflow on perimeter of contacts. These experimental results were described by us in [4, 7]. The presence of two rectifying transitions in Me-PS-MS-Me structure manifest itself also by analysis of voltage - capacitance characteristics which will be reported in the future.

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