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S. ZAINABIDINOV,[1] O.O. MAMATKARIMOV,[2] O. KHIMMATKULOV,[3]
I.G. TURSUNOV[4]

[1] Andijan State University
(170100 Andijan, Uzbekistan)
[2] Namangan Engineering and Technology Institute
(716030 Namangan, Uzbekistan)
[3] Tashkent State Technical University
(100174 Tashkent, Uzbekistan)
[4] National University of Uzbekistan
(100174 Tashkent, Uzbekistan; e-mail: ikromjon0804@gmail.com)

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INFLUENCE OF DEEP-LEVEL IMPURITIES ON THE STRAIN ELECTRIC PROPERTIES OF MONOCRYSTALLINE SILICON

The piezoresistance effect has been investigated in compensated and thermally treated samples of Si : Zn and Si : Zn, Mn under a uniaxial elastic compression. This effect is shown to be caused by changes in the concentration and mobility of current carriers. The anomalous change in the carrier mobility under the compression along crystallographic axis [111] is connected with a change in their scattering on large-scale defect formations.

K e y w o r d s: deformation, impurities, strain resistance, elastic compression.

1. Introduction

It is known [1] that, under a uniaxial elastic deformation as opposed to a full hydrostatic isotropic compression, the band structure of a semiconductor undergoes a substantial change, which depends on the orientation of a deformation and is associated with the splitting and displacement of the allowed energy bands. Consequently, the interminimum redistribution of current carriers leads, in turn, to a change in the electrophysical properties of semiconductor crystals. The deep levels of an impurity, which are located in the forbidden zone of a semiconductors, also shift under the action of a directed compression, following the edges of the allowed zones. As a result, the degree of their filling and the electric parameters of these materials vary.

The investigation of the influence of an external pressure on the electrophysical properties of doped silicon provides the valuable information on the inhomogeneities formed in the bulk of silicon during the technological process of its doping and allows finding the new ways to create highly sensitive strain gages based on doped semiconductors.

In this paper, we present the results of studies of the strain-electric effect in compensated heat-treated silicon samples of n- and p-types of conductivity with impurities of zinc and manganese under a uniaxial elastic deformation (UED).

2. Experimental Procedure

The alloyed samples with the crystallographic axes [100] and [111] along the large rib and with various dimensions, resistivities, and conductivity types were obtained by the high-temperature diffusion of zinc

Technological conditions of diffusion and electric parameters of the samples

Sample	Initial silicon					
	SDP-15		SDP-3000			
	1120	1100	p-Si⟨B⟩	n-Si⟨B, TD⟩	p-Si⟨B, Zn⟩	p-Si⟨B, Mn, Zn⟩
$T_{\rm dif}$, ^0S	8	8	–	1100	1100	1100
t, h	n-Si⟨P, Zn⟩		–	2	2	4
ρ, $\Omega \cdot$ sm	1.17×10^3	7.47×10^2	3.21×10^3	3.41×10^2	2.75×10^2	67
μ, sm^2/V $\cdot$ s	1288	1361	365	1200	100	274
n, sm^{-3}	5.41×10^{12}	6.15×10^{12}	5.28×10^{12}	1.53×10^{13}	2.27×10^{14}	8.38×10^{14}

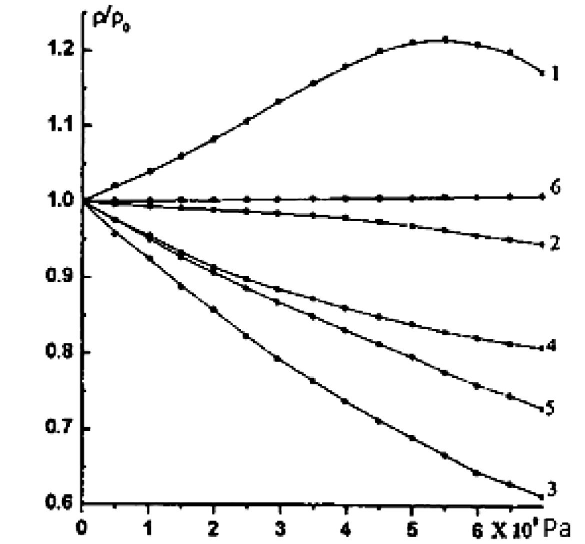

Fig. 1. Specific resistance of compensated silicon as a function of the uniaxial compression: $I||X||[100]$: *1* – n-Si⟨P, Zn⟩; $I||X||[111]$: *2* – n-Si⟨P, Zn⟩, *3* – p-Si⟨B⟩, *4* – n-Si⟨B, TD⟩, *5* – p-Si⟨B, Zn⟩, *6* – p-Si⟨B, Mn, Zn⟩

and manganese into the initial single crystals of silicon of the brand SDP-15 (Silicon Doped with Phosphorus) and SDP-3000 (Silicon Doped with Boron) (Table). Under the same conditions, the control samples were annealed.

The uniaxial compression was carried out with the help of a special UED unit with a preamplifier, which allows one to simultaneously study the strain resistance and Hall effect under different compression conditions.

The investigations were carried out in a wide pressure range and at room temperature. The surface layers with silicides enriched with impurities from all sides were removed after the diffusion by a mechanical grinding and subsequent etching.

3. Experimental Results and Their Discussion

Experimental studies of the dependence of the resistivity of the samples under the uniaxial compression X (Fig. 1) showed that, as the compression X along the crystallographic axis [100] increases, the resistivity of the compensated samples (curve *1*) first increases. Then the growth retardation is observed, and the resistivity of the samples decreases with increasing X.

The resistivity of the sample under compression (Fig. 1, curve *2*) decreases slightly with increasing H. We note that the similar results were obtained with previously compensated samples under the uniaxial compression in [2].

We have also studied the strain effect under a compression in samples obtained on the basis of SDP-3000 silicon.

From Table, it is seen that the thermal annealing of the initial samples leads to the conversion of a conductivity type. At the same time, the diffusion of zinc for two hours has restored the original p-type conductivity.

From Fig. 1, it is seen that the initial resistivity (curve *3*) and thoae of control (curve *4* – TD thermal donors) and doped (curve *5*) samples decrease with increasing X in the compression direction of crystallographic axis [111]. The resistivity of the samples (curve *6*) doped firstly consistently with zinc and then with manganese almost does not change with an increase in the compression value of X.

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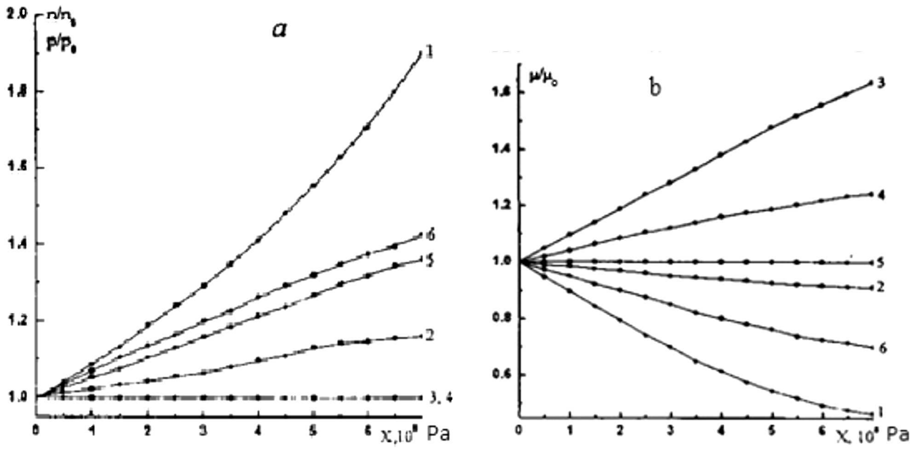

Fig. 2. Dependences of the concentration (*a*) and mobility (*b*) of electrons and holes on the uniaxial compression: $I||X||[100]$: *1* – *n*-Si⟨P, Zn⟩; $I||X||[111]$: *2* – *n*-Si⟨P, Zn⟩, *3* – *p*-Si⟨B⟩, *4* – *n*-Si⟨B, TD⟩, *5* – *p*-Si⟨B, Zn⟩, *6* – *p*-Si⟨B, Mn, Zn⟩

To identify the mechanism of the strain effect in the samples under the same compression conditions, we have studied the tensor Hall-effect – the concentration (Fig. 2, *a*) and the mobility (Fig. 2, *b*) of majority carriers under the uniaxial compression *X*.

From Figure 2, *a, b*, it is seen that the strain effect in the studied and control samples is caused only by changing the mobility of carriers, which agrees with the theoretical strain effect [1] in doped samples, – the concentration and mobility of charge carriers.

The increase in the concentration of electrons and holes under the action of a uniaxial compression can be explained by a change in the degree of filling of the deep levels of Zn and Mn due to a decrease in the energy gap between the impurity levels and the edges of the dilated silicon bands.

The decrease in the electron mobility in the samples during the compression in accordance with [1, 3] is due to the redistribution of electrons in the split valleys.

Under the conditions of a symmetric arrangement of the deformation axis with respect to all isoenergetic ellipsoids, there is no splitting of the equivalent valleys of the conduction band, and there is no redistribution of electrons between equivalent valleys.

The decrease in the mobility of electrons with increasing X in the samples is due to the increase in the transverse effective mass of electrons due to the presence of shear deformations [3].

The observed anomalous effects of an increase in the electron mobility in the converted samples (Fig. 2, *b*, curve *4*), as well as the constancy and decrease of the hole mobility in the samples (curve *5*) and (curve *6*), respectively, with increasing X under the compression cannot be explained by the existing concepts of the theory of the strain effect. This suggests the possibility of other mechanisms for changing the mobility of current carriers.

It is known that, under the doping and heat-quenching at high speeds of single-crystal silicon, nanoscale and microdimensional defects can be formed in the bulk of the semiconductor due to the accumulation of atoms of introduced and uncontrolled impurities. The presence of inhomogeneities associated with the formation of the above-mentioned defects leads, in turn, to the appearance of a potential relief in the volume of the semiconductor [4].

The uniaxial compression along crystallographic axis [111] leads, apparently, to a change in the potential relief due to a deformation of defective formations. Therefore, it can be assumed that an increase in the mobility of electrons in samples with increasing X is due to a decrease in their scattering by inhomogeneities due to a change in the potential relief.

In the initial samples, the mobility of holes increases with *X*, which can be explained by the redistribution of current carriers from the zone of heavy holes into the long zones [1, 2].

The anomalous decrease and constancy of the mobility of holes in the samples under the increasing compression X along crystallographic axis [111] is apparently due to an increase in the scattering of holes by inhomogeneities associated with impurity centers Zn and Mn.

4. Conclusion

Thus, the conducted studies have shown that the strain effect in doped silicon samples is due to changes in the concentration and mobility of the current carriers. The anomalous changes in the mobility of the current carriers with increasing the uniaxial compression are apparently explained by possible changes in the scattering of current carriers by deformed inhomogeneities of various impurity clusters in the bulk of silicon.

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С. Зайнабідінов, О.О. Маматкарімов, О. Хімматкулов, І.Г. Турсунов

ВПЛИВ ДОМІШОК
З ГЛИБОКИМИ РІВНЯМИ
НА ТЕНЗОЕЛЕКТРИЧНІ ВЛАСТИВОСТІ
МОНОКРИСТАЛІЧНОГО КРЕМНІЮ

Р е з ю м е

Ефект п'єзорезистентності досліджено в компенсованих та термічно оброблених зразках Si : Zn і Si : Zn, Mn при одновісному пружному стискуванні. Показано, що цей ефект зумовлений змінами концентрації та рухливості носіїв струму. Аномальні зміни рухливості носіїв при стиску навколо кристалографічної осі [111] пов'язані зі зміною їх розсіювання на великомасштабних утвореннях дефектів.