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Contribution of f- and g- transitions to electron intervalley scattering of n-S at temperatures 300 to 450 K

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Abstract. The change in mobility with increasing the temperature which may be due to the inclusion of gLO-phonon energy of 720K, is presented. In orientation of the uniaxial pressure **X**//[110]//**J,** g-transitions are attached in the directions [100] and [010]. The f-transitions are not completely removed from valleys located in the plane (100). In this case, there is no change in the slope of the dependence $\log\rho$ vs. $\log T$ for the temperature range 300 to 450 K. So, no contribution of g-transitions to intervalley scattering occurs, while the observed is tha decisive role of f–transitions to this scattering.

Keywords: silicon, electron mobility, uniaxial strain, g-transitions, f-transitions, tenso-resistive effect.

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1. Introduction

As known, «Intel Corporation» introduced n-MOS transistors with silicon uniaxially deformed in the direction [001] channels, thus improving the mobility of electrons around twice at T = 300K [1, 2]. This increase is due to removal of intervalley scattering related with f-transitions, thereby increasing the steepness of the current-voltage characteristics (CVC) and cutoff frequency of switching.

Previously [3], the crucial role of f-transitions in intervalley scattering of electrons in n-Si with strong uniaxial pressures **X**//[001] and temperatures to 300 K was first demonstrated. In the same work, small contribution of g-transitions to this type of scattering was shown. It is unknown, however, wether the electron mobility wile change at $T > 300$ K, if there is the possibility of g-transitions, which, moreover, are not completely eliminated under strong uniaxial pressure **X** // [001].

The analysis of experimental data of many works on the study of f- and g-transitions in n-Si indicates that the discussion of their role in intervalley scattering is not finished until now. This is due to the fact that silicon possesses a sufficiently wide set of phonons, which can make sufficiently comparable contribution of electrons to the intervalley scattering .

The change in mobility with increasing temperature may be due to inclusion of intervalley scattering related with g-transitions. Their contribution can increase with increasing temperature as a result of gLO-phonon energy of 720K, deformation potential constant of which is $\approx 7{,}5\cdot 10^8$ eV/cm. We used the direction of uniaxial pressure **X**//[110]//**J** to change at T > 300K g-value and f-transitions in intervalley scattering. In this orientation of the uniaxial pressure, g-transitions are attached in the directions [100] and [010]. Furthermore, with strong intervalley scattering in uniaxial pressures, f-transitions between valleys [001] and [100] and $[\bar{1}00]$; $[00\bar{1}]$ and [100] and $[\bar{1}00]$; [001] and $[0\bar{1}0]$ and [010]; and $[00\bar{1}]$ and $[0\bar{1}0]$ and [010] (Fig. 3) are excluded, and thus their intensity as compared to that in unstrained crystals decreases. This type of experiment gives us confidence that if there is contribution of gLO-conversion to the intervalley scattering of electrons in silicon at T = 300-450K, too.

2. Results and their discussion.

In this work we, used the tensoresistivity (TR) effect at different directions and uniaxial pressure and temperature dependence of resistivity $\rho=\rho(T)$ in uniaxially deformed and undistorted crystal n-Si ($n_e = 4\cdot10^{13}$ cm^{-3}) for tha temperature range T = 300…450K. This temperature range covers the region of its conductivity of silicon crystals, so all conclusions about the impact of f - and g - transitions are limited to the temperature at which the intrinsic conductivity sets in.

Fig. 1 presents the results of measuring the tensoresistive effect for n-Si crystals under **X**//[001]//**J** at different temperaturest. Tha view of data dependencies shows that under uniaxial pressure X = 12 000 kg/cm^2 at temperatures T = 77-350 K, redistribution of carriers between valleys is completely finished, and the dependence of ρ_X/ρ_0=f(X) goes to saturation (curves 1–4). Clearly, the saturation function of $\rho(X)$ is characterized by lack absence of manifestations of f-transitions, and the possible presence of high gLO-temperature transitions in intervalley scattering. In the case of uniaxial pressure in the direction **X**//[001] as previously in TR measurements at

T < 300 K, the slope $\log\rho$ vs. $\log T$ is observed , which in the absence of pressure corresponds to the exponential law of changes in mobility $\mu \sim T^{2,3}$ (Fig. 2 curve 1) and with strong uniaxial pressure X = 12000 kg/cm^2 – $\mu \sim T^{1,6}$ (Fig. 2 curve 2). It is under this pressure thot f – transition of intervalley scattering is completely removed, indicating their crucial contribution to the intervalley scattering at X = 0.

For greater confidence in the decisive contribution of f - transition in intervalley scattering, we used the uniaxial pressure direction **X**//[110], in which the g - transitions in the directions [100] and [010] are added. Also, f – transitions are not completely removed, and f - transitions between valleys located in the plane (100) remain (Fig. 3).

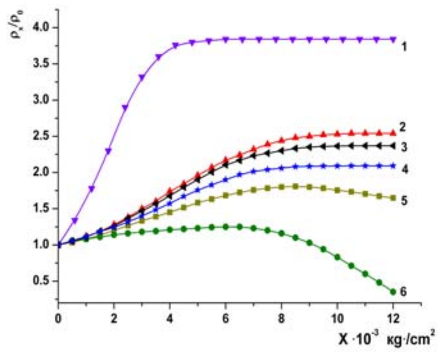

Fig. 1. Dependence of $\rho_X/\rho_0 = f(X)$ n-Si ($n_e = 4\cdot10^{13}$ cm^{-3}) in **X**//[001]//**J** at different temperatures: 1 – 77; 2 – 300, 3 – 320, 4 – 350, 5 – 400, 6 – 450 K.

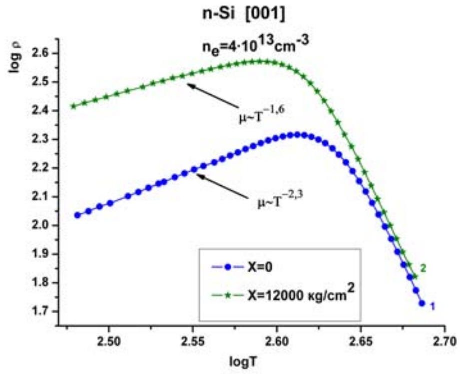

Fig. 2. The dependence of $\rho=\rho(T)$ in double logarithmic scale for n-Si (n_e = $4\cdot10^{13}$ cm^{-3}) at **X**//[001]//**J**: 1 – X = 0; 2 – X = 12 000 kg/cm^2 .

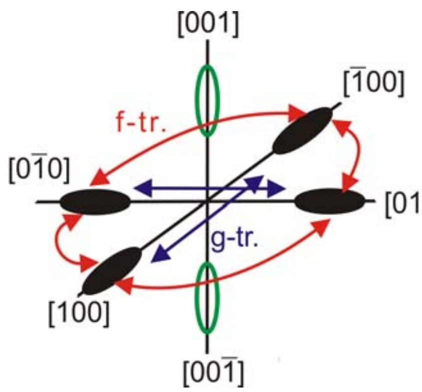

Fig. 3. Scattering of electrons in n-Si in **X**//[110] at X = 12000 kg/cm^2.

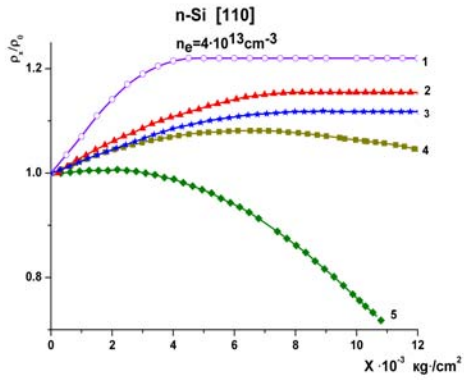

Fig. 4. Dependence of $\rho_X/\rho_0 = f(X)$ n-Si ($n_e = 4\cdot10^{13}$ cm^{-3}) in **X**//[110]//**J** at temperatures: 1 – 77; 2 – 300, 3 – 350, 4 – 400, 5 – 450 K.

Fig. 4 represents the results of measurements of the TR effect for n-Si crystals under **X** // 110 // **J** at different temperatures T, K.

In this case, there is no change in the slope of $\log\rho$ vs. $\log T$ depending on the transition from the unstrained crystal n-Si to uniaxially-deformed, and the value of this slope corresponds to the exponential law of changes in mobility $\mu \sim T^{-2,3}$ (Fig. 5), indicating the absence of any contribution of g-transitions in intervalley scattering of electrons and the presence of a decisive contribution to *f* – conversion of intervalley scattering in this temperature range.

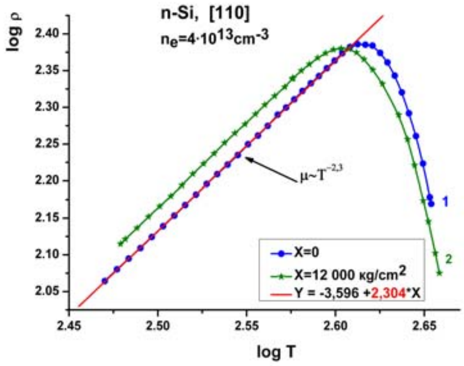

Fig. 5. Dependence of ρ=ρ(T) in double logarithmic scale for n-Si (n_e=4·10^{13} cm^{-3}) in **X**//[110]//**J**: 1 - X = 0, 2 - X = 12 000 kg/cm^2.

3. Conclusions

Thus a significant change in the slope depending on μ vs. *T* at temperatures *T* = 300-450K in the pass from unstrained silicon $\mu \sim T^{-2,3}$ to uniaxialy strained crystals $\mu \sim T^{-1,6}$ for **X**//[001] indicate a decisive contribution of f-transitions to intervalley scattering. Absence of changes in the slope of this relationship in the **X**//[110] indicates the absence of any contribution of g-transitions in intervalley scattering of electrons in this temperature range, too, and the presence of decisive contribution of *f* – transitions to the intervalley scattering. With in the temperature range *T* = 300-450K at high temperature band for the temperature dependencies logρ=logT, the silicon intrinsic conductivity begins. Therefore, to determine the slope of logρ = log*T* dependence, we use there a comparatively narrow temperature range.

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