ABOUT THE SILICON SENSITIVITY OF THE DEEP LEVEL WITH ALTERNATING PRESSURE

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ABSTRACT: This paper discusses the strain sensitivity of silicon with deep levels under variable pressure. It is shown that in the pressure swing in silicon with deep levels, there is a redistribution of the primary spatial inhomogeneities in the distribution of impurities so that the electron-hole relaxation after stress relief will occur in the new potential relief.

ABSTRAK: Kajian ini membincangkan tentang sensitiviti kepekaan strain silikon pada pelbagai tahap dalam tekanan. Keputusan menunjukkan terdapat ketidakharmonian agihan pada spasial utama dalam agihan kotoran dengan ayunan tekanan dalam silikon pada tahap dalam, supaya relaksasi lubang-elektron setelah pelepasan tekanan akan berlaku dalam pelepasan potensi baru.

KEYWORDS: *semiconductors; properties; dynamic and deep levels*

1. INTRODUCTION

It is known [1-4] that semiconductors with deep levels are more sensitive to external influences. These properties of semiconductors are explained by the notion that the deep levels in semiconductors may be in a partially ionized state, even at room temperature. In addition, only in semiconductors with deep levels is there a dynamic tenzoprovodimost. Until now, the dynamic strain conductivity was explained by a change in temperature at the pulse pressure. That is, it was assumed that the dynamic strain effect in semiconductors with deep levels was only seen by stimulated pulse pressure temperature. But, according to our experimental results, the dynamic strain effect is manifested not only by temperature but also by relaxation effects. Strain sensitivity means in such samples may be due to the different components. In this regard, we studied the dynamic Strain sensitivity in silicon samples with deep levels. We believe that when the pulse pressure is a common dynamic, strain sensitivity is determined by multiple components: the static, thermal, and dynamic.

2. EXPERIMENTAL PROCEDURE

To investigate the effects of contact strain sensitivity, Si samples were prepared with varying degrees of compensation and conductivity type. Samples of (Si:Au) compensated with gold have been obtained on the basis of single-crystal silicon brand SDP (silicon doped

with phosphorus) and SDP (silicon doped with boron) with resistivity ρ ~ 20-80 Om·sm, These were grown by Zhohralski method and the floating zone melting. For this study, crystals were made with a size of $6 \times 3 \times 3 \ mm^3$, with the directions of the crystallographic axes [100], [110], [111] along the edges of the large, crystallographic directions, determined by X–ray analysis.

After Si single crystal cutting, the samples were ground with diamond micro powders M–14 and M–4 by providing specific flatness lapping opposite edges up to (2-3) microns. In order to remove the crystals, the surface layer is impaired and degreased, and the samples were chemically etched in a solution of HF:HNO₃ = 3:5.

The process of gold doping of silicon single crystals requires a diffusing layer deposited on a silicon surface by vacuum deposition on the installation VUP-5. The diffusion furnace was used in a horizontal-type SOUL-4 in the temperature range of T=900÷1200 °C for two hours. The temperature in the furnace was controlled by thermocouple Platinum –Platinum– Radii and maintained to within ±3 °C. The diffusion resulted in a high purity of Au (99.999%). After diffusion annealing, removal of the surface layer on each side of the samples ground off layers 50–60 microns was performed using lapping, under conditions to preserve flatness of opposite faces, and then samples were subjected to chemical treatment.

The electrical parameters of the samples (conductivity, concentration and mobility of charge carriers) were determined on the installation measurements of the Hall Effect.

The samples were placed between the poles of a permanent magnet with a magnetic field of H = 3000, the magnetic field direction was changed by turning the magnet 180°.

Resistivity measurement sample was calculated according to the formula:

$$\rho = \frac{u}{I} \frac{d \cdot b}{l}$$

where I – current through the sample, u –voltage between the potential contacts, b – width, d – thickness, l – length of the sample.

The Hall coefficient is calculated as follows:

$$R_x = \frac{U \cdot d}{J \cdot B} 10^8 \left[\frac{sm^3}{Kl} \right]$$

where the U - Hall Electrical driving forces, B - magnetic induction.

The Hall mobility was calculated by the formula:

$$\mu = \frac{R_x}{\rho} \left[\frac{sm^2}{V \cdot s} \right].$$

Electric parameters of investigated samples are presented in Table 1.

To control the temperature in the measurement, samples were attached to an alloyed copper thermocouple. To protect the electrical contacts of the samples were coated with epoxy resin. Prepared in this way the samples were mounted on the holder and placed in a chamber in which a high hydrostatic pressure created. Also, a heater has been installed on the holder for changing the temperature of the sample.

Table 1: Electric parameters of investigated samples

№	Samples	Type Conductivity	Specific resistance ρ, Om·sm	Concentration of charge carriers sm^{-3}	Charge carrier mobility sm^2/V.s
1	Si :Au	n	$1.5 \cdot 10^2$	$3.96 \cdot 10^{13}$	1219
2	Si :Au	p	$2.1 \cdot 10^2$	$3.15 \cdot 10^{14}$	500
3	Si :Au	n	$2.88 \cdot 10^5$	$1.78 \cdot 10^{10}$	1214
4	Si :Au	n	$4.7 \cdot 10^4$	$1.15 \cdot 10^{10}$	1205
5	Si :Au	n	$2.98 \cdot 10^5$	$1.96 \cdot 10^{10}$	1091
6	Si :Au	p	$5.8 \cdot 10^4$	$4.39 \cdot 10^{11}$	254
7	Si :Au	p	$1.2 \cdot 10^5$	$1.82 \cdot 10^{11}$	343
8	Si :Au	n	$3.2 \cdot 10^5$	$1.67 \cdot 10^{10}$	1208
9	Si :Au	n	$1.95 \cdot 10^5$	$2.7 \cdot 10^{10}$	1220
10	Si :Au	n	$2.2 \cdot 10^3$	$2.66 \cdot 10^{12}$	1073

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To investigate strain properties of compensated samples under uniform hydrostatic compression, installation hydrostatic pressure is used as described in [5].

3. THE SILICON SENSITIVITY WITH DEEP-LEVEL PRESSURE SWING

The total strain sensitivity can be represented as follows:

$$S = S_{cm} + S_{\partial} \tag{1}$$

where, S_{cm} is the static part of the strain sensitivity, and S_{∂} is the dynamic part of strain sensitivity.

The dynamic part of the strain sensitivity is also divided into two components.

$$S_d = S_T + S_{rel} \tag{2}$$

where, S_T and S_{rel} are the temperature and relaxation of the strain sensitivity.

In its general form, strain sensitivity components can be determined according to known relationships, in dimensionless form [6].

$$S = \frac{\Delta I}{I} \frac{E^{yo}}{P} \tag{3}$$

where, $\Delta I -$ is the current change at variable pressure, $I -$ is the starting current, $E^{yo} -$ the Young's modulus of the semiconductor crystal, and $P -$ is the pressure pulse amplitude.

The kinetic dependence of the relative current change is shown in Fig. 1. Figure 2 illustrates the dependence of dynamic and thermal parts separately. From these figures, the individual components of the strain sensitivity can be identified.
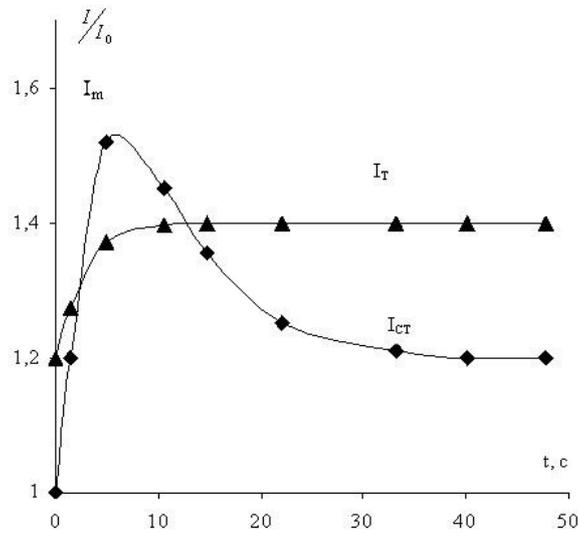
Fig. 1: The relative change in current in pulsed hydrostatic pressure and increasing the temperature by an electric heater in the $Si\langle Ni\rangle$, $\rho=10^3\ Om\cdot sm$.
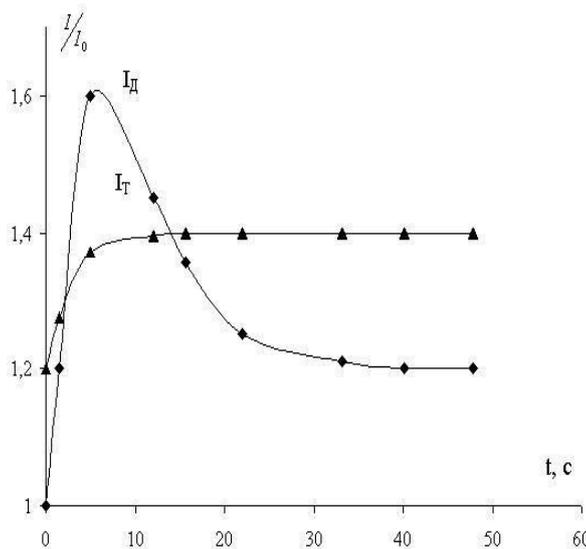
Fig. 2: The dynamic part of the relative change in the current passing through the sample $Si\langle Ni\rangle$, $\rho=10^5\ Om\cdot sm$.

Using the general strain sensitivity (3) and Fig. 1, we find $\dfrac{\Delta I}{I}$ for each component:

Relative to the total current change pressure $\dfrac{\Delta I}{I}=\dfrac{I_M-I_0}{I_0}=\dfrac{I_M}{I_0}-1$ swings and therefore, in this case, strain sensitivity becomes

$$S_M = \left(\frac{I_M}{I_0} - 1 \right) \frac{E^{yo}}{P} \tag{4}$$

where the values of $\dfrac{I_M}{I_0}$ is taken from Fig. 1.

For the current temperature changes

$$\frac{\Delta I_T}{I_{cm}} = \frac{I_T - I_{cm}}{I_{cm}} = \left(\frac{I_T}{I_{cm}} - 1 \right) \cdot \frac{E^{IO}}{P}$$

and strain sensitivity

$$S_T = \left(\frac{I_T}{I_{cm}} - 1 \right) \cdot \frac{E^{yo}}{P} \tag{5}$$

The change in the current for the dynamic part is

$$\frac{\Delta I_\partial}{I_{cm}} = \frac{I_\partial}{I_{cm}} - 1 \text{ and } S_\partial = \left(\frac{I_\partial}{I_{cm}} - 1 \right) \cdot \frac{E^{yo}}{P} \tag{6}$$

Using formulas (2), (5), and (6) it is possible to find a general expression for the relaxation of the strain sensitivity

$$S = S_\partial - S_T = \left(\frac{I_\partial}{I_{cm}} - 1 \right) \frac{E^{yo}}{P} - \left(\frac{I_T}{I_{cm}} - 1 \right) \cdot \frac{E^{yo}}{P} = \left(\frac{I_\partial - I_T}{I_{cm}} \right) \cdot \frac{E^{yo}}{P} \tag{7}$$

With the help of formula (7) it is possible to calculate the contribution to the overall relaxation effects tensosensitivity compensated samples.

So, using the above mentioned expression, it is possible to calculate all the components of the strain sensitivity.

Figure 3a shows the general tensosensitivity of the silicon with the impurities $Si\langle Ni\rangle$, $Si\langle Mn\rangle$, $Si\langle Au\rangle$ represented by three curves, under static (1, 2, 3) and dynamic (1', 2', 3') pressure, respectively. It can be seen that the static pressure is the biggest strain sensitivity in samples $Si\langle Ni\rangle$. In the $Si\langle Mn\rangle$ samples, static strain sensitivity is lower. The silicon samples with gold impurities have little sensitivity to static pressure.

In all the samples of silicon with deep levels, when resistivity increases, strain sensitivity increases. After overcompensation, with a further increase in the concentration of impurities, the resistivity starts to decrease and strain sensitivity reduced accordingly. From Fig. 3, also shows the dynamic strain sensitivity of the samples in reverse order, since silicon samples doped with gold have the largest dynamic strain sensitivity and samples of $Si\langle Ni\rangle$ have smaller dynamic strain sensitivity. Furthermore, in all the samples with deep impurity levels having a conductivity type p, the strain sensitivity is less than that of silicon samples with deep levels having n type conductivity. We calculated the individual components of the strain sensitivity for the above described samples.
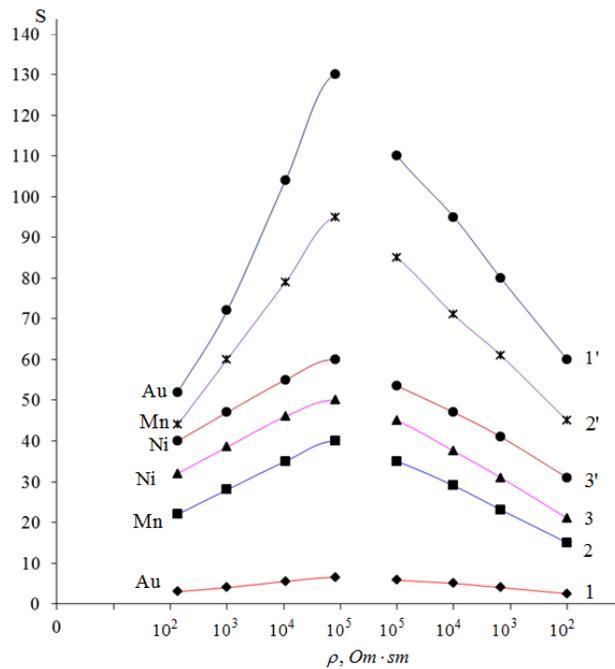
Fig. 3a: General strain sensitivity of the silicon with the impurities Ni, Mn, Au
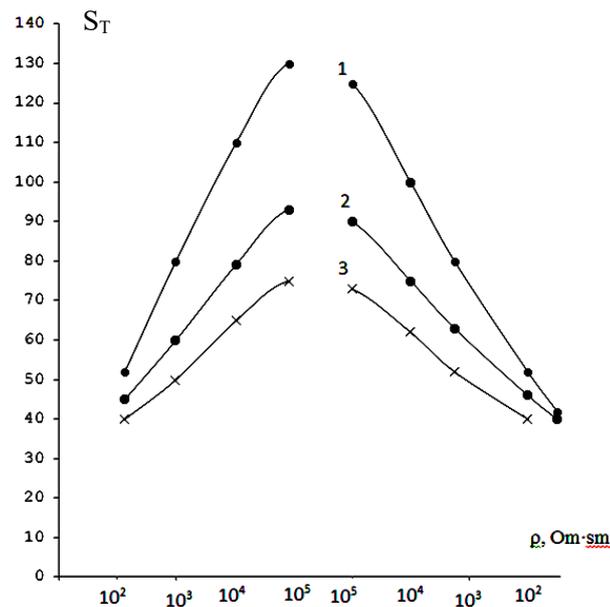where curves 1, 2, 3 are under static and dynamic (1', 2', 3') pressure, respectively.

Fig. 3b: The temperature of the strain sensitivity of silicon samples with Ni
impurities (curve 3), Mn (curve 2), Au (curve 1).

Figure 3b shows the temperature gage component samples of $Si\langle Ni\rangle$, $Si\langle Mn\rangle$, $Si\langle Au\rangle$ (curves 1, 2, 3, respectively). The figure shows that an increase in the degree of compensation, increasing the temperature and strain sensitivity component in the samples having a maximum degree of compensation (with a special resistance 10^5 $Om \cdot sm$), the maximum temperature gage of the component is reached. Further, with increasing concentration, the type of conductivity of the sample and the temperature gage component decrease.
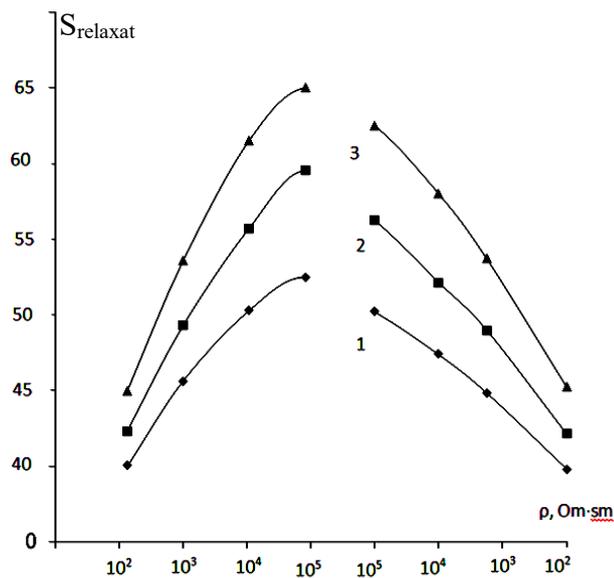
Fig. 3c: Relaxation part of the strain sensitivity of silicon samples with impurities of the Ni, Mn, Au (curve, 1, 2, 3, respectively).

Silicon samples with amphoteric impurities have almost no static and relaxation strain sensitivity components pressure swing. In these samples, only strain sensitivity associated with temperature effects were perceived. In the samples of $Si\langle Au \rangle$ Si under the pulse pressure, there is a redistribution of the primary spatial homogeneities impurity distribution so that the electron-hole relaxation after removal of the stress will occur in the new potential relief.

4. CONCLUSION

Silicon samples with acceptor impurities have large static and dynamic tensosensitivity that is smaller than silicon samples with donor and amphoteric impurities.

Silicon samples with amphoteric impurities have almost no static and relaxation components tensosensitivity pressure swing. In these samples, only tensosensitivity associated with temperature effects is observed. When the samples of *Si:Au* are under pulse pressure, there is a redistribution of the primary spatial in homogeneities impurity distribution so that the electron-hole relaxation, after removal of the stress, will occur in the new potential relief.

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