

Piezocapacitance spectroscopy of a radiation defect in silicon

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Abstract. In this article, using non-stationary capacitive deep-level spectroscopy (DLTS), the dependence of the parameters of the radiation defect with the ionization energy $E_i = E_c - (0.33 \pm 0.02)eB$ arising after irradiation with $n-Si \cdot \gamma$ - quanta of the ^{60}Co isotope and annealing the samples at 250 °C on uniaxial compression was studied. It is shown that, under the action of pressure, $E_i \Delta E_i$ changes depending on the crystallographic direction and reaches values of $0.06 - 0.12eB$. A comparison is made with a similar effect for the level of the A-centre $E_c - 0.17eB$.

1 Introduction

Uniaxial elastic deformation of cubic crystals can, under certain conditions, lead to a shift and splitting of the energy levels of anisotropic centres [1]. The study of the dependence of the properties of the centres on the direction and magnitude of the pressure P provides significant additional information about the symmetry of these centres. Uniaxial deformation is widely used in the study of luminescence spectra, optical absorption, and electron paramagnetic resonance (EPR) of local centres. Capacitance spectroscopy methods [2, 3] are used much less frequently to detect the effect of uniaxial pressure on the parameters of centres with deep levels (DL), although they are highly sensitive, allow one to determine the parameters of centres at their low concentration, and can be used to study centres of nonradiative recombination and non-paramagnetic centres. $E_i = E_c - (0.33 \pm 0.02)eB$; A-centre and E-centre from P using non-stationary capacitance spectroscopy DL (DLTS).

2 Samples and measurement methods

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Samples for measurements were made from $n-Si$ brand KEF-5 (specific resistance $5\text{ }Om.cm$) and had the shape of a parallelepiped with dimensions $6 \times 1.5 \times 1.5$ or $6 \times 1 \times 1\text{ }mm^3$. The long sides of the samples coincided with the $[111]$, $[110]$, and $[100]$ axes, and external pressure was applied along these directions. On the side faces, Schottky barriers were created by sputtering with gold and ohmic contacts.

The DL parameters were determined using DLTS in the constant capacity mode by measuring the dependence of the level recharge time constant θ on temperature T at different gating windows. The voltage across the diode was measured at times $t_1, t_2 = 3t_1$ from the beginning of the rectangular back mix pulse.

2.1 Piezocapacitance RD spectroscopy, A-centre and E-centre

Oriented deformation in combination with DLTS was used for the first time in [3]. Options A-centre, we determined using DLTS in constant capacity mode. To determine the ionization energy A-centre (without deformation and with deformation after splitting) t_1 changed within $0.5 \div 500\text{ }ms$.

DLTS measurements were made immediately after irradiation. Irradiation was carried out at $300\text{ }K$ γ -isotope quanta ^{60}Co with intensity $3.4 \cdot 10^{12}$ quantum/ cm^2 up to a dose of the order $1 \cdot 10^{18}$ quantum/ cm^2 . Large doses lead to diode base compensation and DLTS measurements become impossible. Immediately after irradiation, several peaks were observed in the spectrum (Fig. 1, curve 2) due to the charge exchange of DL with ionization energies of 0.17 (A-centre), 0.23 (B), 0.3 (C), 0.37 (D), 0.44 (E-centre) and 0.53 (K) from the bottom of the conduction band. A-centers had the maximum concentration $(1.5 \cdot 10^{14}\text{ }cm^{-3})$.

Uniaxial deformation causes a noticeable splitting of the DLTS peak (Fig. 2). As can be seen from the figure, with increasing strain, the DLTS spectrum associated with the A centre begins to expand and the peak shifts towards lower temperatures. Starting from some deformation values for example, in the direction $[100]$ $P=0.394$, and $P=0.65\text{ }GPa$ for $[111]$, a splitting of the DLTS peak is observed. Table 1 shows the results of changes in the activation energy ΔE_i level of the A-centre under uniaxial deformation by pressure P (in units meB / GPa) and compared with the results of [3].)

In this work, we also studied the effect of uniaxial deformation in the $[100]$, $[110]$, and $[111]$ directions in samples $n-Si$ on the properties of the E-centre $[E_c - 0.44\text{ }eB]$ after γ -exposure to dose $\Phi = 5 \cdot 10^{18}\text{ }cm^{-2}$. The measurements showed that, under the action of deformation, the position of the peak associated with E-centre, shifts towards lower T , but the sensitivity to strain in all cases studied was very low (Table 1). After annealing at $250^\circ C$ for 20 minutes, the sensitivity of the peak (corresponding E-centre) to deformation increases significantly.

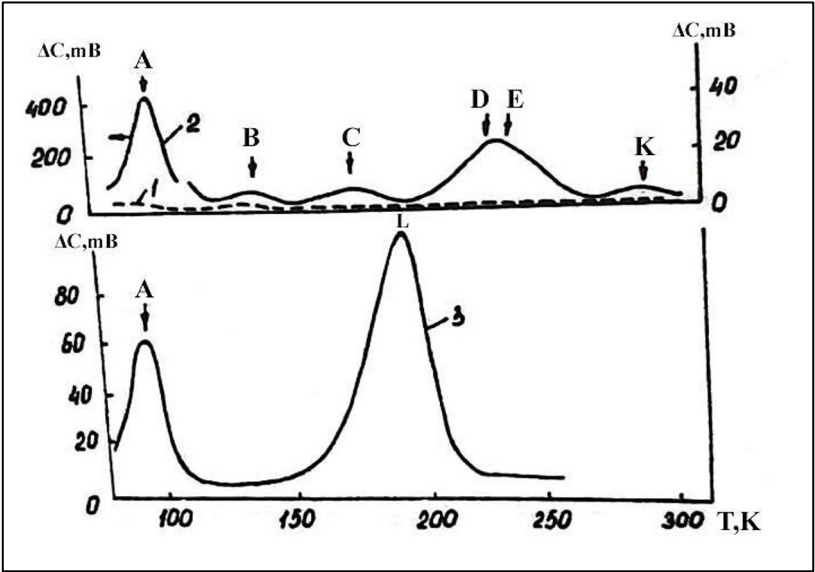


Fig. 1. Typical dependences of DLTS in diodes before irradiation (1), after irradiation (2) and after annealing (3)

As can be seen from Table 1, our results agree satisfactorily with the data of [3].

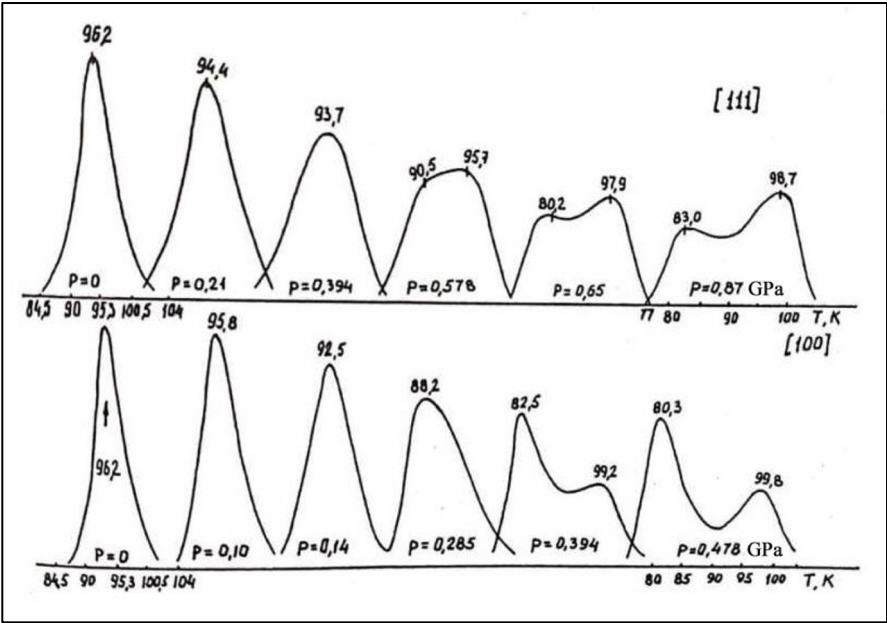


Fig. 2. DLTS spectra of the A-center for different directions of uniaxial compression.

Table 1. Results of activation energy change ΔE_i

Crystallograph	A-centre	E-centre
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ic direction	R, GPa	E _i eB P=0	meB/GPa	[3] β meB/GPa	before maintena nce β meB/GPa	after maintena nce β meB/GPa
[100]	0.48	0.17	58	69	⁻ (7.2±0.8)	⁻ (22.4±1.2)
[110]	0.65	0.17	41	53	⁻ (5.7±0.7)	⁻ (19.2±1.5)
[111]	0.87	0.17	33	28	⁻ (5.2±0.78)	⁻ (15.3±1.4)

2.2 Piezocapacitance spectroscopy of a radiation defect in *n* – Si

In this paper, we present the results of measuring the dependence of the RD parameters on the ionization energy $E_i = E_c - (0.33 \pm 0.02) eB$ from P using DLTS in constant capacity mode.

Before irradiation, the concentration of HC in silicon did not exceed $10^{11} cm^{-3}$ (Fig. 1, curve 1). Irradiation was carried out at 300 K γ -isotope quanta ^{60}Co with intensity $3.4 \cdot 10^{12}$ quantum/cm² from to dose $F = 1 \cdot 10^{18} cm^{-2}$. immediately after irradiation, several peaks were observed in the spectrum (Fig. 1, curve 2) due to the charge exchange of DL. After measuring DLTS, the sample was annealed at 250 °C for 20 minutes. As a result of annealing, the concentrations of all RDs decrease (A centre from about $1.5 \cdot 10^{14}$ before $1 \cdot 10^{13} cm^{-3}$) and a new RD arises (level *L* in Fig. 1, curve 3) with a concentration of the order $3 \cdot 10^{13} cm^{-3}$. For this RD dependency $lg(\theta T^2) = f(1/T)$ linear (Fig. 3, curve 1), i.e. it has a fixed ionization energy $E_i(L) = E_c - (0.33 \pm 0.02) eB$ and electron capture cross section $\sigma_n \approx 4.6 \cdot 10^{-16} cm^2$. The nature of this centre is debatable; it may be an oxygen-divacancy complex [4]. The splitting of the energy level of just this centre under the action of uniaxial compression was investigated.

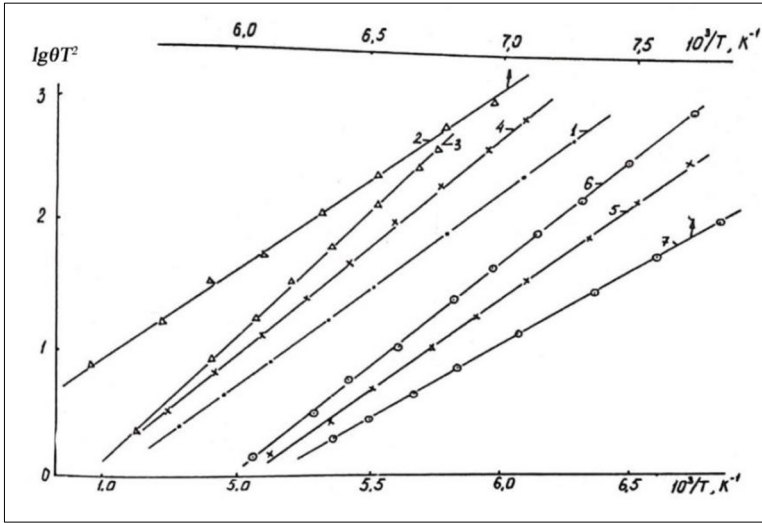


Fig. 3. Dependencies $\lg(\theta T^2) = f(1/T)$ for the level L at pressures P, Pa : 1-0; 2, 3-0.87, directions [111]; 4,5-0.81, directions 110; 6,7-0.56, direction [100]. The upper scale refers to lines 2 and 7

Before proceeding to the measurement of uniaxial compression, we studied the annealing kinetics of the levels L . The diodes were subjected to isothermal annealing at 250 °C. The heat treatment process can be divided into two stages (Fig. 4). First stage annealing for 1 h. Level concentration L drops by about an order of magnitude. Upon further annealing (II stage) in the time interval $3.6 \cdot 10^3 - 5.4 \cdot 10^3$ c DL concentration changes slowly. In two samples, the level concentration L during the entire annealing decreased synchronously (Fig. 4, curves 1, 2)

Fig. 5a and 5b show the DLTS peaks due to level recharging L , at $P=0$ and under uniaxial compression along the [110], [111], and [110] axes. It can be seen from the figure that deformation leads to a significant change in the PD property and level splitting; the level is related to the anisotropic centre. The parameters of the split states were determined, as was related above, from the temperature dependence of the position of the peak maximum with varying strobing windows.

The amplitude of the peaks practically did not depend on T . The measurement results are shown in Fig. 3. As can be seen from the figure, the experimental values $\theta(T)$ lie well on the Arrhenius lines, i.e.

$$\theta = \theta_0 \exp(E_i / \kappa T)$$

and the split levels have a fixed ionization energy. The values are determined from the Arrhenius lines E_i and θ_0 . for all three directions of deformation (Table 2).

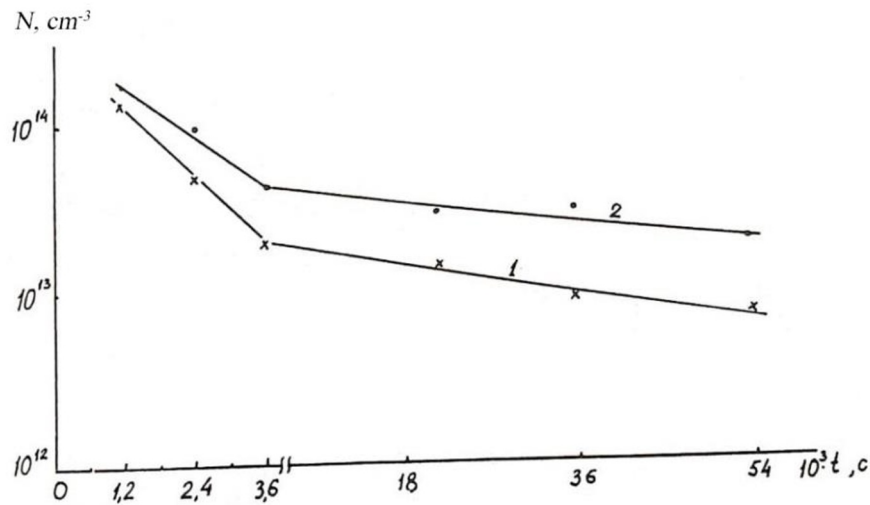


Fig. 4. Kinetics of changes in level concentrations L in two samples under isothermal annealing at 250 °C

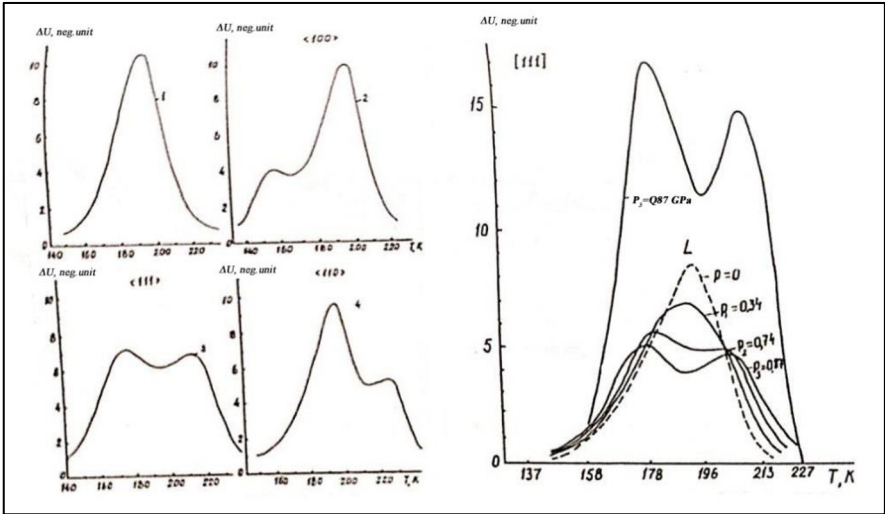


Fig. 5. Spectra of the DLTS level L with equal directions of uniaxial compression. Pressure R , Pa 1-0; 2-0.56; 3-0.87; 4-0.81. b) Shows in more detail the change in the pattern of level splitting L under different P directions [111]

Table 2. Values determined E_i and θ_0 for all three directions of deformation

Crystallographic direction	R, GPa	E_i eB	θ 1013	Amplitude ratio	β L	GPa-I for RD levels		
						A-centre		
						cm 5.4	/3/	/6/
[100]	0.65	0.25	210	1:3	0.54	0.3	0.41	0.3
		0.35	17			4		
[110]	0.65	0.303	69	5:3	0.45	0.2	0.31	0.08

		0.401	33			4		
		0.283	78					
[111]	0.65	0.352	1.27	1.1:1	0.30	$\frac{0.1}{9}$	0.16	0

Values E_i defined with accuracy $\pm 0.2eB$ for all levels. Under uniaxial deformation, the effective density of states in the band also changes, and the determination of the electron capture cross sections in the usual way becomes incorrect. Therefore, the table shows only the values of the pre-exponential factor θ_0 , equal to $P = 0.65 \cdot 10^{-12} \text{ GPa}$. As follows from the table, uniaxial elastic deformation leads to a significant shift and splitting of the level L , as well as to change θ_0 . The average relative level split $\beta = \Delta E_i / (E_i \cdot P)$ depends on the crystallographic direction and $0.30 - 0.54 \text{ (GPa)}^{-1}$. It is interesting to compare this value with other known centres. From the results of [3], we can calculate ΔE ; for the A-centre under the assumption that $\theta_0 \neq f(P)$. The values thus calculated β for the A-centre and level L close to each other (Table 2), however, the symmetry of these two centres, apparently, is different.

3 Results and discussion

In article [5] from the dependence of resistivity, $n-Si$ compensated A-centers, the average displacement of the level is determined from the deformation $E_c - 0.17 \text{ eB}$ relative to the day of the conduction zone. According to [5].

The deformation coefficient β for the A-centre is small, especially in the direction [110] and $\beta=0$ in [111]. Mapping to values β for impurity levels shows that for impurity centres β much less [6,7].

Piezocapacitance RD (A-centre) spectroscopy study showed that uniaxial deformation causes noticeable splitting of the DLTS peak A-centre.

The effect of uniaxial strain on the DLTS of the E centre in $n-Si$. It is shown that the peak corresponding to the E-centre retains its shape during deformation and shifts relatively weakly towards low energies. After annealing at 250 °C for 20 minutes, the sensitivity of the peak corresponding to the E centre to deformation increases significantly.

For the first time, using DLTS, the effect of uniaxial compression on the level parameters was studied. $E_i(L) = E_c - (0.33 \pm 0.02) eB$ RD occurring after irradiation $n-Si \cdot \gamma$ Quantum and annealing samples at 250 °C for 20 minutes.

It was found that under the action of deformation the splitting of the level L . ΔE_i depends on the crystallographic direction and reaches the values $0.06-0.12eB$.

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