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CONCENTRATION DEPENDENCES OF THE ANISOTROPY PARAMETER OF MOBILITY $K = \mu_\perp/\mu_\parallel$ AND THE ANISOTROPY PARAMETER OF ELECTRON-PHONON DRAG THERMOPOWER $M = \alpha_\parallel^{ph}/\alpha_\perp^{ph}$ IN *n-Ge* AND *n-Si*

In the range of $10^{12} \le n_e \le 2\cdot10^{15}$ cm^{-3} at $T = 83$ K the concentration dependences of the parameters of the mobility anisotropy $K = \mu_\perp / \mu_\parallel$ and the anisotropy of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ in n-Ge single crystals were investigated and the significant distinctions in changes of these dependencies from the ones observed (in similar conditions) in n-Si single crystals were found. It was found that the n-Ge crystals are characterized by significantly higher (absolute) values of anisotropy parameters M and K in comparing with the corresponding values of these parameters for n-Si. It was shown that the parameter M in n-Ge (as distinct from n-Si) is insensitive to the presence of impurities in the crystals, but the parameter K monotonically decreases both in n-Ge and in n-Si with increasing the carrier concentration n_e.

Key words: germanium, silicon, the anisotropy parameter of mobility, the anisotropy parameter of thermopower, charge carrier concentration.

Introduction

Theory of kinetics of electronic processes in many-valley semiconductors [1] and general literature in this field (including that dedicated to experiments) [2–6] make wide use of two particularly important parameters, namely the anisotropy parameter of mobility $K = \mu_\perp / \mu_\parallel$ (where $\mu_\parallel$, $\mu_\perp$ are charge carrier mobilities along and across the long axis of isoenergetic ellipsoid, respectively) and the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ (where $\alpha_\parallel^{ph}$, $\alpha_\perp^{ph}$ are phonon components of electron-phonon drag thermopower along and across the long axis of isoenergetic ellipsoid, respectively).

The temperature dependence of the anisotropy parameter $K(T)$ for *n-Ge* crystals was experimentally studied in [7] and described on the basis of concepts related to the anisotropic type of relaxation time τ [8, 9]. Under the assumption concerning the anisotropic character of relaxation time the anisotropy parameter of scattering K_τ (hence, K) is largely defined by the contribution of impurity scattering which (at given crystal temperature) is equivalent to dependence of K on the impurity concentration in the bulk of the crystal. Reduction of both M and K in *n-Si* single crystals with a rise in temperature from 77.4 K to 350 K was found in [10].

In [11], by measuring the saturation of longitudinal magnetoresistance $\rho_H^\parallel / \rho_0$ in *n-Ge* in strong ($\frac{\mu H}{c} >> 1$) magnetic fields (up to 250 кЕ) the concentration dependence of the anisotropy parameter of mobility *K* was studied in the range of $5 \cdot 10^{13} \le n_e \equiv N_{Sb} \le 1.38 \cdot 10^{17}$ cm^{-3}, and comparison of the experimental data to the results of theoretical calculations of dependence $K = f(n_e)$ performed within the anisotropic scattering theory yielded their quantitative fit.

The concentration dependence of the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph} = f(n_e)$ for *n-Si* single crystals was studied in [12]. Different authors with the aid of different methods found the value of *M* parameter for *n-Ge* as well, but only for conditions of preferably phonon scattering [13–15].

However, taking into account that instrument making utilizes silicon and germanium doped with impurities in a wide concentration range, in the calculation of various effects in such crystals (especially in the calculation of thermoelectric and thermomagnetic effects on the basis of anisotropic scattering theory generalized in [16] for the case of electron-phonon drag and elastic deformation) one must also know the values of parameters *K* and *M* in mixed scattering area.

The objective of this paper was to study changes in the anisotropy parameter of mobility $K = \mu_\perp / \mu_\parallel$ and the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ with increase in concentration $n_e \equiv N_d$ in *n-Ge* and *n-Si* in the range of charge carrier concentration $10^{12} \le n_e \equiv N_d \le 3 \cdot 10^{16}$ cm^{-3} at temperature $T = 83$ K.

Results and discussion

The value of parameter *K* is known to be experimentally obtained (see, e.g. [17]) from the data on tensoresistance using the relation

$$K = \frac{3}{2} \frac{\rho_\infty^{\langle ijk \rangle}}{\rho_0} - \frac{1}{2}, \tag{1}$$

where ρ_0, $\rho_\infty^{\langle ijk \rangle}$ is resistivity of undeformed $\rho(X = 0) \equiv \rho_0$ and uniaxially elastically deformed $\rho(X \to \infty) \equiv \rho_\infty$ (ρ_∞ corresponds to saturation region of function $\rho = \rho(X)$) crystal in crystallographic direction $\langle i\ j\ k \rangle$ (i.e. under conditions $\vec{X} \parallel \vec{J} \parallel \langle i\ j\ k \rangle$, where *X* is mechanical load, *J* is current; and $\langle i\ j\ k \rangle \to \begin{cases} \langle 111 \rangle & - \text{ for } n\text{-}Ge \\ \langle 100 \rangle & - \text{ for } n\text{-}Si \end{cases}$

As regards parameter *M*, similarly to *n-Ge* in [18], for *n-Si*, elastically deformed in the direction of [001] // ∇T // $\vec{X}$, on the basis of general expressions represented in [16], we shall write

$$\alpha - \alpha^e = \alpha_\perp^{ph} \frac{M + \gamma \frac{8K + M}{3}}{1 + \gamma \frac{8K + 1}{3}}, \tag{2}$$

where γ is the relation of charge carrier concentration in the ascending minima to charge carrier concentration in the descending minima, α is experimentally measured thermopower value in phonon

drag region, $\alpha^e = \frac{k}{e}\left[2 + \ln \frac{2\left(2\pi m^* k T\right)^{3/2}}{n_0 h^3}\right]$ is electron (diffusion) thermopower component which is calculated by the Pisarenko formula; n_0 is charge carrier concentration; e is electron charge; k is the Boltzmann constant; T is temperature; h is the Planck constant; $m^* = N^{3/2} \sqrt[3]{m_\parallel m_\perp^2}$ is density-of-state effective mass; N is the number of isoenergetic ellipsoids.

From expression (2) for boundary cases $X = 0$ (absence of deformation) and $X \to \infty$ (corresponding to X values assuring complete transition of carriers to the descended minima) we obtain a system of equations

$$\left.\begin{aligned} \alpha_0^{ph} \equiv \alpha_0 - \alpha^e = \alpha_\perp^{ph} \frac{M + 2K}{1 + 2K} \\ \alpha_\infty^{ph} \equiv \alpha_\infty - \alpha^e = \alpha_\perp^{ph} \cdot M \equiv \alpha_\parallel^{ph} \end{aligned}\right\}, \tag{3}$$

where α_0 and α_∞ are thermopower values in the undeformed and deformed samples, respectively; α_0^{ph} and α_∞^{ph} are phonon components of thermopower measured in the undeformed and elastically deformed crystal; $\alpha_{(0\ or\ \infty)} = \alpha_{(0\ or\ \infty)}^{ph} + \alpha_{(0\ or\ \infty)}^{e}$.

Excluding $\alpha_\perp^{ph}$ from the system of equations (3), we obtain for *n-Si* crystals (just as for *n-Ge*):

$$M = \frac{2K}{(2K+1)\dfrac{\alpha_0 - \alpha^e}{\alpha_\infty - \alpha^e} - 1} = \frac{2K}{(2K+1)\dfrac{\alpha_0^{ph}}{\alpha_\infty^{ph}} - 1}\ . \tag{4}$$

Table 1 gives characteristics of samples under study and the results of processing the experimental and calculated data to determine the anisotropy parameter of electron-phonon drag thermopower M in *n-Ge* at $9.8 \cdot 10^{11} \le n_e \le 1.7 \cdot 10^{15}$ cm^{-3}. The values of the anisotropy parameter K were obtained from the data on tensoresistance with the use of expression (1) for *n-Ge*.

Table 1

Characteristics of n-Ge samples under study at temperature T = 83 K under conditions of $\vec{X}$ // ∇T // [111] and X ≥ 0.6 GPa

Sample №	n_e, cm^{-3}	α^e, μV/K	$\alpha_\parallel^{ph}$, μV/K	$\alpha_\perp^{ph}$, μV/K
1	$9.8 \cdot 10^{11}$	1395	9205	751
2	$1.6 \cdot 10^{13}$	1159	7921	702
3	$1.6 \cdot 10^{13}$	1152	7348	617
4	$6.9 \cdot 10^{13}$	978	7282	632
5	$1.7 \cdot 10^{15}$	757	5668	505

It was shown that at $T = 83$ K the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$, measured by tensothermopower (i.e. in the absence of a magnetic field) is practically independent of concentration, as is evident from Fig. 1, though all components of the right-

hand side of formula (4) (namely : K, α_0^{ph}, α_∞^{ph} and even α^e that does not appear in (4) directly, but was used in the system of equations (3) when finding the phonon components of electron-phonon drag thermopower α_0^{ph} i α_∞^{ph}) are essentially dependent on $n_e \equiv N_d$.

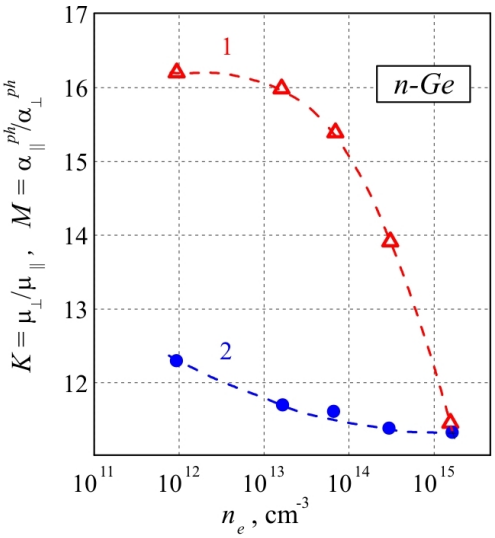

Fig. 1. Concentration dependences of the anisotropy parameter of mobility $K = f(n_e)$ *(1) and the anisotropy parameter of electron-phonon drag thermopower* $M = f(n_e)$ *(2) in n-Ge single crystals at T = 83 K.*

Thus, the anisotropy parameter of mobility K with increase in concentration from $9.8 \cdot 10^{11}$ to $1.7 \cdot 10^{15}$ cm^{-3} (i.e. approximately 2000 times) is constantly reduced from 16.2 to 11.4 (by a factor of 1.42), whereas the anisotropy parameter of electron-phonon drag thermopower M is reduced only by a factor of ~ 1.088 (actually, a change of M in *n-Ge* is as low as 9 %), as illustrated in Fig. 1.

It may be considered that within the accuracy of performed investigations parameter M practically remains invariable and uniform $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph} \cong 11.7 \pm 0.3$ at measurement temperature $T = 83$ K. Thus, unlike the anisotropy parameter of mobility K formed by combination of electron scattering mechanisms on crystal lattice vibrations and on impurity centres, the phonon part of thermopower (to be more precise, its anisotropy, that is, the ratio $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$) is practically independent of concentration $n_e \equiv N_d$ (in any case, under investigation limits $9.8 \cdot 10^{11} \div 1.7 \cdot 10^{15}$ cm^{-3}) and is fully defined by atomic vibrations in crystal lattice sites.

In weakly doped crystals, when scattering on crystal lattice vibrations is practically dominant, the ratio ρ_X / ρ_0, in any case within the concentration range $10^{12} \le n_e \equiv N_d \le 10^{14}$ cm^{-3}, is free from prominent impurity influence [10, 19], it would be interesting to compare the values of K obtained at crystal deformation in different crystallographic directions.

With this objective, to determine the anisotropy parameter of mobility $K = \mu_\perp / \mu_\parallel$, not only relation (1) was used with the values of $\langle i\ j\ k \rangle \to \langle 111 \rangle$, but also the relation

$$K = 3 \cdot \frac{\rho_\infty^{\langle 111 \rangle}}{\rho_\infty^{\langle 110 \rangle}} - 2, \qquad (5)$$

which is associated with the necessity of measuring resistivity ρ in two crystallographic directions of *n-Ge*

samples. Moreover, $\rho_\infty^{\langle 111\rangle} = \lim_{X\to\infty} \rho(X)$ and $\rho_\infty^{\langle 110\rangle} = \lim_{X\to\infty} \rho(X)$ are resistivity values at uniaxial elastic deformation X assuring complete migration of current carriers to energy minima located in the direction of deformation axis (<111> or <110>).

For experiment set up, two series of *n-Ge* samples were used (four samples in each) with charge carrier concentrations $1.5 \cdot 10^{13}$ and $9.5 \cdot 10^{13}$ cm^{-3}, respectively. Two samples of each series were cut in crystallographic direction [111], and the other two – in [110] direction. Changes in tensoresistance of *n-Ge* crystals were measured at temperature 77.4 K. The results of the experiments were summarized in Table 2.

Table 2

Results of processing the experimental data on tensoresistance obtained at T = 77.4 K on n-Ge samples of different doping level under conditions of $\vec{X}$ *//* $\vec{J}$ *//[111] and* $\vec{X}$ *//* $\vec{J}$ *//[110]*

Series №	n_e, cm^{-3}	$\rho_\infty^{[111]} / \rho_0$	$\rho_\infty^{[111]} / \rho_\infty^{[110]}$	$K = \mu_\perp / \mu_\parallel$, found by formula (1)	$K = \mu_\perp / \mu_\parallel$, found by formula (5)
1	$1.5 \cdot 10^{13}$	10.93	6.0	15.9	16.0
2	$9.5 \cdot 10^{13}$	10.26	5.66	14.98	15.0

It was established that the numerical values of the anisotropy parameter of mobility *K*, found by using the relation (1), as well as formula (5), coincide. This, in turn, means that at deformation of *n-Ge* in crystallographic directions [111] and [110] the isoenergetic ellipsoids are only displaced in the energy scale, remaining practically undeformed (as ellipsoids of revolution).

Besides, as is evident from the experiments performed, the identity of values of the anisotropy parameter of mobility *K* is retained not only with different production methods (i.e. with the use of various formulae), but this statement also remains valid in going from one to another (higher) charge carrier concentration (see Table 2).

On *n-Si* single crystals, experimental study of the anisotropy parameter of electron-phonon drag thermopower *M* and the anisotropy parameter of mobility *K* was performed at $T = 83$ K and $1.9 \cdot 10^{13} \le n_e \le 2.6 \cdot 10^{16}$ cm^{-3} (characteristics of samples are given in Table 3).

Table 3

Characteristics of n-Si samples investigated at temperature T = 83 K under conditions of $\vec{X}$ *//* ∇T *// [001] and X ≥ 0.6 GPa*

Sample №	n_e, см$^{-3}$	$\mu_{H_{77\,K}}$, cm^2/ V·s	ρ_{300K}, Ω·cm	α^e, μV/K	$\alpha_\parallel^{ph}$, μV/K	$\alpha_\perp^{ph}$, μV/K
1	$1.9 \cdot 10^{13}$	19250	230	1227	30770	4650
2	$1.29 \cdot 10^{14}$	18700	27.7	1063	27440	4530
3	$6.55 \cdot 10^{14}$	14550	4.16	923	20180	3500
4	$2 \cdot 10^{15}$	9290	0.9	827	17670	3350
5	$6.21 \cdot 10^{15}$	6370	0.245	729	15530	3530
6	$2.60 \cdot 10^{16}$	1790	0.054	606	7640	2350

Measuring tensoresistance $\rho_X = f(X)$ and tensothermopower $\alpha_X = \varphi(X)$ on *n-Si* crystals under conditions $\vec{X} \,//\, \vec{J} \,//\, [001]$ and $\vec{X} \,//\, \nabla T \,//\, [001]$ (typical appearance of this data is represented for one of investigated silicon samples in Fig. 2), as well as subtracting from α_0 and α_∞ the diffusion component α^e (which is practically independent of *X*) in expression (4), we find parameter *M* for each sample.

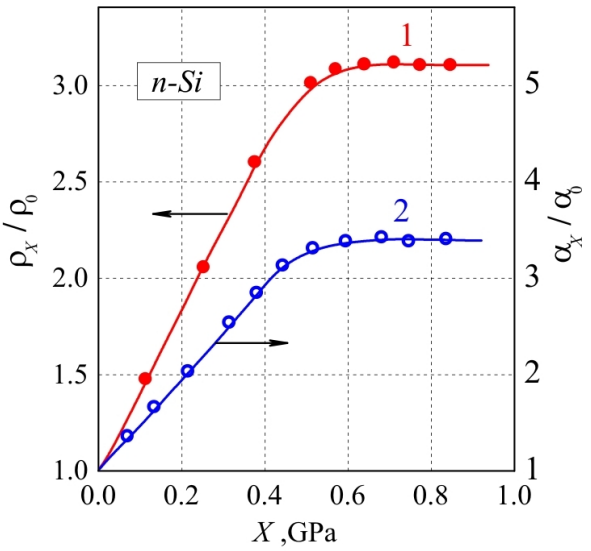

Fig. 2. Typical dependences of tensoresistance ρ_X / ρ_0 *(1) and tensothermopower* α_X / α_0 *(2) on mechanical load X for n-Si.*

The value of parameter *K* will be obtained from the experimental data on tensoresistance and expression (1) for *n-Si*.

The concentration dependences of the anisotropy parameter of mobility $K = \mu_\perp / \mu_\parallel$ and the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ for *n-Si* single crystals at $T = 83$ K are given in Fig. 3.

Note that as long as electron-phonon drag thermopower is proportional to the mean free path of long-wave phonons (l^{ph}) [20], the experimentally observed reduction of $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ (due to a more efficient reduction of $\alpha_\parallel^{ph}$ than $\alpha_\perp^{ph}$ with increasing $n_e \equiv N_d$) results from "cutting" of l^{ph} by growing efficiency of phonon scattering on impurity atoms.

Reduction of the anisotropy parameter of mobility $K = \dfrac{\mu_\perp}{\mu_\parallel} = \dfrac{K_m}{K_\tau} = \dfrac{m_\parallel}{m_\perp} \dfrac{\langle \tau_\perp \rangle}{\langle \tau_\parallel \rangle}$ in multi-valley semiconductors with growing contribution of impurity scattering is due to increase in scattering anisotropy, as long as impurity scattering in such semiconductors as silicon and germanium is fairly anisotropic. Exactly this results in the reduction of tensoresistivity $\rho_{X\to\infty}^{[001]}$ (in case of *n-Si* (Fig. 3)) and $\rho_{X\to\infty}^{[111]}$ values (in case of *n-Ge* (Fig. 1)) with increase in doping level of silicon and germanium crystals and in the monotonic decrease (in both cases) of parameter *K* with increasing concentration of charge carriers n_e. Note that scattering conditions in crystals are defined by several basic factors, namely the concentration of scatterers, their structure and arrangement in crystal lattice.

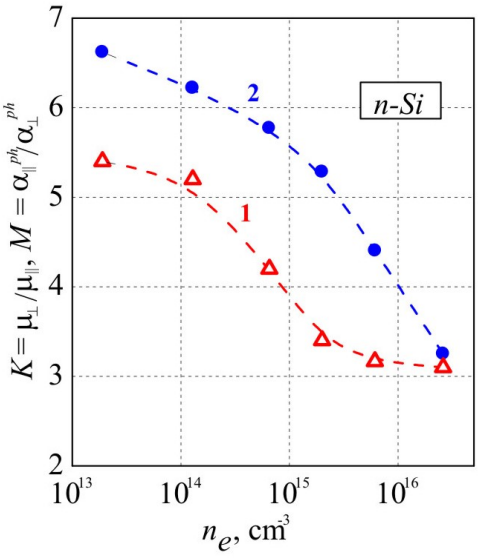

Fig. 3. Concentration dependences of the anisotropy parameter of mobility $K = f(n_e)$ *and the anisotropyparameter of electron-phonon drag thermopower* $M = f(n_e)$ *(2) in n-Si single crystals at T = 83 K.*

Comparison of data for *n-Ge* and *n-Si* samples represented in Fig. 1 and Fig. 3 points to considerably higher (absolute) values of *M* and *K* that characterize *n-Ge* single crystals as compared to corresponding values for *n-Si*. This is primarily related to higher anisotropy of charge carriers effective mass in *n-Ge* than in *n-Si* ($\frac{m_\parallel}{m_\perp} = \frac{1.58}{0.082} \cong 19.3$ – in *n-Ge* and $\frac{0.91}{0.191} \cong 4.75$ – in *n-Si*) which brings about the appearance of essentially different scattering conditions in *n-Ge* and *n-Si* crystals, as well as to significant difference in the arrangement of isoenergetic ellipsoids with respect to crystal axes in germanium and silicon.

Conclusions

1. Formulae (1), (4) and (5), convenient for processing the experimental data obtained when measuring changes in the resistivity and thermopower in directionally elastically deformed *n-Ge* and *n-Si* single crystals of known crystallographic orientation are given.
2. In a wide range of charge carrier concentrations n_e ($10^{12} \div 3 \cdot 10^{16}$ cm^{-3}) in *n-Ge* and *n-Si* single crystals the anisotropy parameter of mobility $K = \mu_\perp / \mu_\parallel$ and the anisotropy parameter of electron-phonon drag thermopower $M = \alpha_\parallel^{ph} / \alpha_\perp^{ph}$ was studied at temperature $T = 83$ K on samples of known crystallographic orientation. Changes in the investigated parameters *K* and *M* with increase in doping degree of germanium and silicon crystals by donor-type impurity were obtained. It was shown that parameter *M* in *n-Ge* (unlike *n-Si*) is low-sensitive to the presence of impurities in crystals, however, parameter *K* is monotonically decreased both in *n-Ge* and in *n-Si* with increase in charge carrier concentration n_e.
3. It was established that *n-Ge* single crystals are characterized by much higher (absolute) values of the anisotropy parameters *M* and *K*, as compared to the respective values for *n-Si*.

References

1. P.I.Baranskii, I.S.Buda, and I.V.Dakhovsky, *Theory of Thermoelectric and Thermomagnetic Effects in Anisotropic Semiconductors* (Kyiv, Naukova Dumka, 1987), 272 p.
2. P.I.Baranskii, O.E.Belyayev, G.P.Gaidar, V.P.Gaidar, V.P.Kladko, and A.V.Kuchuk, *Problems of Diagnostics of Real Semiconductor Crystals* (Kyiv: Naukova Dumka, 2014), 462 p.
3. G.P.Gaidar, P.I.Baranskii, Thermoelectric Properties of Transmutation Doped Silicon Crystals, *Physica B: Condensed Matter*. **441**, 80–88(2014).
4. P.I.Baranskii, G.P.Gaidar, Some Thermoelectric Features of Conventional and Transmutation Doped Silicon Crystals, *J.Thermoelectricity* **1**, 5–12 (2012).
5. P.I.Baranskii, A.V.Fedosov, and G.P.Gaidar, *Semiconductor Inhomogeneities and Critical Tasks of Defects Interaction in Radiation Physics and Nanotechnology* (Kyiv-Lutsk, Lutsk State Technical University, 2007), 316 p.
6. P.I. Baranskii, I.S. Buda, I.D. Dakhovsky, and V.V. Kolomoyets, *Electric and Galvanomagnetic Effects in Anisotropic Semiconductors* (Kyiv: Naukova Dumka, 1977), 270 p.
7. R.A.Laff, H.Y.Fan, Magnetoresistance in *n*-Type Germanium at Low Temperatures, *Phys. Rev.* **112**(2), 317–321 (1958).
8. C.Herring, E.Vogt, Transport and Deformation-Potential Theory for Many Valley Semiconductors with Anisotropic Scattering, *Phys. Rev*. **101**(3), 944–961 (1956).
9. I.V. Dakhovsky, Anisotropic Scattering of Electrons in Germanium and Silicon, *Physics of the Solid State* **5**(8), 2332 – 2338 (1963).
10. P.I.Baranskii, V.V.Savyak, and Yu.V.Simonenko, Temperature Dependence of Phonon Drag ThermoEMF Anisotropy in Uniaxially Deformed *n-Si, Semiconductors* **18**(6), 1059–1063 (1984).
11. V.M.Babych, P.I.Baranskii, Concentration Dependence of the Anisotropy Parameter *K* in *n*-Germanium, *Semiconductors*. **1**(7), 1029–1032 (1967).
12. P.I.Baranskii, S.L.Korolyuk, and P.G.Ostafiychuk, Concentration Dependence Concentration Dependence of Phonon Drag ThermoEMF Anisotropy in *n-Si, Semiconductors* 18(11), 2053–2056 (1984).
13. C.Herring, T.H.Geballe, and J.E.Kunzler, Analysis of Phonon Drag Thermomagnetic Effects in *n*-Type Germanium, *Bell System Tech. J.* **38**(3), 657–747 (1959).
14. P.I.Baranskii, I.S.Buda, V.V.Kolomoyets, A.G.Samoilovich, and B.A.Sus, Study of Electron Phonon Drag Effect Anisotropy in *n-Ge, Semiconductors* **8**(11), 2159–2163 (1974).
15. I.S.Buda, V.V.Kolomoyets, B.A.Sus, and L.A.Scherbina, Determination of Drag ThermoEMF Anisotropy Parameter in *n-Ge, Ukrainian J. of Physics* **22**(8), 1375–1378 (1977).
16. A.G.Samoilovich, I.S.Buda, Influence of Elastic Deformations on ThermoEMF in *n-Ge* in Drag Effect Region, *Semiconductors* **3**(3), 400–408 (1969).
17. P.I.Baranskii, A.V.Fedosov and G.P.Gaidar, *Physical Properties of Silicon and Germanium Crystals in the Fields of Effective External Influence* (Nadstyria, Lviv, 2000).
18. P.I.Baranskii, G.P.Gaidar, Anisotropy of Electron-Phonon Drag ThermoEMF in *n-Ge*, *J. Thermoelectricity* **2**, 29–38 (2012).
19. P.I.Baranskii, I.S.Buda, I.V.Dakhovsky, V.V.Kolomyets, and A.G.Samoilovich, Piezoresistance of *n-Ge* in [111] Direction under Mixed Scattering Conditions, *Semiconductors* **8**(5), 984–986 (1974).
20. L.S.Stilbance, *Physics of Semiconductors* (Sov. Radio, Moscow, 1967).

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