Superconductivity at Very High Temperatures

Hyperconductivity

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Abstract

The mechanism of superconductivity caused by the electron-vibrational centres and their inherent oscillations in crystals and solid-state structures near room temperature and at higher temperatures - hyperconductivity is discussed and actualized. The experimental data about hiperconductivity in some semiconductors are presented. Hyperconductivity arises and exists from normal-superconducting temperature $T_c$ to 800K (probably up to temperature of a crystal melting and is higher). $T_c$ in various materials varies from hundred up to several hundreds degrees on Kelvin scale depending on size of average nuclear number of a material.

The phenomenon of superconductivity was open in 1911 \[1\] and till now was observed in various materials when their temperature below normal-superconducting transition temperature $T_c$, density of electrical current and magnetic intensity are below critical meanings $J_k$ and $H_k$ \[2, 3\]. The meanings $J_k$ and $H_k$ tend to zero at increasing of temperature and her approaching to the $T_c$. The first superconductors had small meanings of the $T_c$: 4.1K (Hg), 7.3K (Pb). To the present time many classes of superconductors are open. The greatest meanings of the $T_c$ have layered like perovskite metal oxide. $T_c$ has reached 134K...136K. The critical meanings of the $T_c$, $J_k$ and $H_k$ limit applications of superconductors. In this connection the increasing of the $T_c$ up to room temperature and above is an essential problem. Solution of the problem would allow superconductive devices to work at room temperatures without cooling. This important problem while was solving experimentally, by selection of chemical structure and technological processings of materials with the purpose of achievement of high meanings of $T_c$. Till now there was no reliance in possibility or impossibility of superconductivity near to room temperature or at higher temperatures.

The expectations of superconductivity just at temperatures less than $T_c$ are traditionally based on available experimental data and according to known physical mechanisms which was called for explanation of superconductivity. Among these mechanisms the leading position probably occupies the mechanism underlying the known theory of superconductivity (BCS) \[4\] and based on interaction between electrons by means of an interchange of phonons (which nevertheless does not explain high meanings of the $T_c$ noticed on experience). According to this theory electrons exchanges with each other by virtual phonons that gives rise to an attraction between them which determines magnitude of $T_c$. For increasing of the $T_c$ was offered to use phonons with large energies as virtual phonons (Larkin A.I.) but unfortunately such mechanism of superconductivity was not carried out.
The opportunity of existence in the solid materials of inherent oscillations and waves of \( \alpha - , \beta - \) and \( \gamma - \) types is known \cite{5, 6}. The elementary quantums of inherent oscillations and waves of \( \alpha - \) type considerably exceed energy of acoustic and optical phonons. The inherent oscillations effectively cooperate with electrons (holes) and crystal phonons providing strong electron-phonon coupling in crystals and structures. Such properties of inherent oscillations and waves have given hope to use them together with crystal phonons as virtual phonons for realization of superconductivity at very high temperatures.

The purpose of the given work is to investigate an opportunity of inherent oscillations and waves for realization of superconductivity.

The researches were executed on samples of silicon monocrystal because the silicon is rather well investigated, his many characteristics and parameters are known, Si for a long time is used as a model material and widely is applied in electronics. In particular it is known about an opportunity of existence in silicon of the electron-vibrational centres (EVC) whose presence is essentially important for realization of superconductivity. Also in experiments were used samples on the basis of other semiconductors: InP, InAs, InSb, Ge, CdHgTe in whose EVC supposedly are formed by impurity atoms of oxygen.

1. Some properties of inherent oscillations and waves

The traditional models of molecules and crystals in which the atoms are replaced by physical points with masses of atoms do not correspond to adiabatic Born-Oppenheimer’s theory \cite{6} and do not give opportunities to study inherent oscillations. The opportunity of inherent oscillations and waves existence in the condensed materials can be proved by using of adiabatic model of solids \cite{3}. In such model each atom is submitted as a nucleus and electron shell connected with each other by elastic force and capable to carry out oscillatory movements (\( \alpha - \) type of oscillations). Each atom in adiabatic model of a crystal can be submitted as inherent \( \alpha - \) oscillator consisting from a nucleus and electron shell. Elastic force of inherent oscillator is almost proportional to displacement of a nucleus from the centre of an electron shell. The value of appropriate factor depend on electrical potential field which is created by electron shell near her centre. The frequency of inherent oscillations depends on conditions in which there is an atom. In particular the collective properties of electrons in a crystal can be expressed so that their displacements (displacements of electron shells) are coherent (synchronous), within the some length (\( \lambda \)) and the coherent area acquire superconductive properties. The size \( \lambda \) can exceed tens of space lattice and to achieve significant size. In such conditions the nucleus of each atom has an opportunity to oscillate relatively common mass of coherent area. The amplitude of a nucleus oscillations is insignificant (\( \sim 10^{-2} \text{A} \)).

The energy spectrum of (\( \alpha - \)type) inherent oscillations in harmonic approach can be presented by the expression

\[
E_\nu = E_\alpha (1/2 + \nu)
\]

where oscillatory quantum number \( \nu = 0, 1, 2,... \), the elementary oscillatory quantum is defined by mass of a nucleus \( M_z \) with number \( Z \): \( E_\alpha = \hbar (\zeta/M_z)^{1/2} \), \( \zeta \)- factor connecting force with displacement of a nucleus from an equilibrim position at the centre of an electronic envelop,
\( h = \frac{h}{2\pi} \), \( h \) - Plank’s constant. According to accounts (conformable to experimental data) at increasing \( Z \) magnitude \( E_\alpha \) decreases from 0.402 eV at \( Z = 2 \) up to 0.22 eV at \( Z = 8 \) and then increase up to 0.406 eV at \( Z = 80 \). The inherent oscillations of a \( \beta \)-type caused by joint displacements of nucleus and K - electron subshell relatively other part of an electron shell and also inherent oscillations of a \( \gamma \)-type caused by joint displacement of a nucleus, K - and L - electron subshells relatively other part of an electron shell of atom are possible also. The elementary quantums of inherent oscillations \( \beta \)- and \( \gamma \)-types are less than the appropriate quantums of \( \alpha \)-oscillations: \( E_\alpha > E_\beta > E_\gamma \). Thus energy of some inherent oscillations with small \( \nu \) in a crystal can not exceed energies of the solved electron transitions between various electronic states \( i \) and \( j \): \( E_\nu < |E_i - E_j| \). This inequality is a condition of applicability an adiabatic principle in correspondence with [8]. Thus in adiabatic approach in the condensed materials the inherent oscillations \( \alpha \)-, \( \beta \)- and \( \gamma \)-types can exist and propagate. They represents the oscillatory displacement of nucleuses relatively electronic environments. The speeds of inherent oscillations waves can achieve speed of a sound.

The theoretical opportunity of existence of inherent oscillations and waves followed from adiabatic model of a crystal, based on adiabatic Born-Oppenheimer’s principle, is confirmed by experimental data about temperature dependence of crystals resistivity, about phonon drag at high temperatures and about optical electron-vibrational spectra formed with participation of inherent oscillations. The energy levels of inherent oscillations are shown as deep energy levels and the electron transitions between these levels or on these levels or from these levels are electron-vibrational. Electron-vibrational transitions are accompanied by absorption or emission several (on the average \( S \)) crystal phonons, where \( S \) - constant of electron-phonon interaction.

The following ways of excitation of inherent oscillations can be practically important:
- thermal, at the expense of phonons energy;
- optical, at the expense of absorbed photons energy;
- shock, for the account of kinetic energy of (hot) electrons or holes;
- recombination, at the expense of energy recombination;
- combined, as a combination of two or several specified ways.

In semiconductors it is convenient to raise inherent oscillations at the expense of recombination energy of electrons (holes). For this purpose is necessary rather strong interaction of electrons with lattice oscillations. The constant \( S \) equal to an average number of phonons participating in the act of electron-phonon interaction and serves a measure of electron interactions with phonons. The size \( S \) in ideal silicon monocrystal calculated on the data on meaning of deformation potential constants does not exceed 0.03 for optical phonons and 0.15 for acoustic phonons [9, 10]. Hence excitation of inherent oscillations at the expense of interaction with electrons in ideal crystals is rare event that are in agreement with adiabatic theory according to which electrons and the oscillations of a lattice in an ideal crystal do not interact with each other. The effective production of inherent oscillations at the expense of recombination energy is possible in crystals containing such defects of a lattice for which the strong interaction of electrons with phonons is characteristic. These defects have received the name of the electron-vibrational centres (EVC). EVC are the Jan-Teller’s centres. They represents local defects of
a crystal which equilibrium position or frequencies of oscillations depends on their electronic condition. For EVC the large meanings \( S > 1 \) are characteristic. According to the theory \cite{11}-\cite{13} the quantity of \( S \) is close to an average phonons participating in electron-vibrational transition to energy levels of EVC. By the theoretical estimations \( S \) can exceed 50. The inherent oscillations of atoms of the basic substance can exist and to spread in crystals and crystal structures but effectively to raise such fluctuations and waves at the expense of electrons or holes energy is possible at presence EVC. In this connection the inherent oscillations and waves caused by atoms of the basic substance and also inherent oscillations and waves caused by impurity atoms are possible in crystals.

2. Impurity oxygen atoms in silicon

Impurity oxygen atoms in silicon monocrystals are electrical inactive and their presence can be established on characteristic optical absorption on length of a wave about 9 micrometer \cite{16}-\cite{18}. The intensity of the specified band of absorption reflects the contents of oxygen atoms on an optical path in a crystal. The increase of concentration of oxygen in silicon is accompanied by occurrence of quartz disseminations and by displacements of a maximum of the characteristic optical band of absorption to 10...11micrometers \cite{19}. This absorption is characteristic for Si oxides and it is explained traditionally in the literature by optical excitation of chains Si-O-Si oscillations. In the monography \cite{20} (p. 179) was shown convincingly that the reason of the specified optical band which determine a kind of a spectrum in the field of 9...11 micrometers consist not simply in specified chains of atoms but is contained in structure of a lattice (probably in structural defects containing atoms of oxygen). The similar bands of optical absorption in the specified spectral area are characteristic for oxides of InAs, InSb, InP \cite{21} and oxides of other semiconductors that also allows to connect these bands with defects of a lattice containing atoms of oxygen. Moreover there are weighty bases to believe that these defects containing atoms of oxygen are the Jan-Teller’s centres and they are EVC.

The presence of EVC inherent oscillators determine an optical properties of crystals. The oscillatory model describing optical spectra of crystals and supposing interaction of oscillators with a wide set of crystal phonons is stated in \cite{22}. In accordance to \cite{22, 23} the optical reflectivity

\[
R_\infty = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2},
\]

where \( n \) - optical factor of refraction and \( k \) - parameter of absorption are defined from the following expressions:

\[
n^2 - k^2 = \varepsilon_{opt} + \omega_p^2 \left( \frac{\Omega^2 - \omega^2}{(\Omega^2 - \omega^2)^2 + \omega^2\nu^2} \right),
\]

\[
2nk = \omega_p^2 \frac{\omega\nu}{(\Omega^2 - \omega^2)^2 + \omega^2\nu^2},
\]

where: \( \Omega \) - frequency of oscillator, \( \nu \) - frequency of phonon, \( \omega \) - optical frequency, \( \omega_p = \sqrt{Ne^2/(M\varepsilon_0)} \), \( N \) - concentration of oscillators, \( e \) - charge of oscillator, \( M \) - mass of oscillator, \( \varepsilon_0 \) - electrical constant, \( \varepsilon_{opt} \) - optical dielectric permeability. The optical reflection spectra
of silicon oxides and reflection spectra of specified semiconductors oxides can be presented as sum of separate oscillators reflection spectra. Such decomposition of a spectrum corresponds to the quantum theory \cite{24,25}. These theories can be applied to the analysis of IR reflection by inherent oscillators of EVC.

Every separate oscillator have ”zero” frequency of oxygen inherent $\alpha$-oscillators ($\hbar \Omega = 0.11$ eV) which cooperate mainly with various lattice frequencies between $\Omega$ and $\omega_p$. The greatest contribution in oxides reflection spectra is brought by frequencies appropriate to ”zero” fluctuations of inherent oxygen oscillators and phonons for which $(\Omega/\omega_p) = 0.25$, $\varepsilon_{\text{opt}}=1.2$, $G/\Omega=0.011$, $G$ - factor of attenuation. The rather small meaning $\varepsilon_{\text{opt}}$ allows to carry him only to the local centre but not to all crystal. The experimental spectrum of polarized light reflection and calculated on the Eq. (2-4) spectrum of reflection are given on fig. 1. The experimental spectrum was measured at a corner of fall of the linearly polarized radiation of 45 degrees for oriented along an axis $C$ quartz monocrystal. The comparison of spectra submitted in a fig. 1 specifies presence of oscillators in quartz with oscillatory energy which is equal to energy of ”zero” oscillations of inherent oxygen oscillators, calculated on the Eq. (1) at $v = 0$ for atom of oxygen. Such transitions with frequency of ”zero” oscillations are forbidden for quantum oscillator but EVC are capable to show duality of properties \cite{6}. The conditions in a minimum of oscillator potential and transitions with frequency of ”zero” oscillations for EVC are accordingly allowable. The excess of experimental absorption above calculated absorption at energies of quants more than 0.11 eV is determined by the contribution with participation of frequencies $\omega_p$ conterminous with frequencies of inherent $\alpha$-oxygen oscillators calculated on the Eq. (1) at other meanings of $v$. The same conclusion can be made as a result of similar approach of reflection spectra for melted quartz, silicate glasses and oxides of a number of semiconductors. According to this result the optical band which is characteristic for quartz and others oxides of semiconductors is possible to identify with excitation of ”zero” inherent oscillations of oxygen atom ($v = 0$).

Impurity atoms of oxygen in silicon irradiated by radiation formes associations with vacancies of a crystal lattice known as A-centres. As a result of study of electron spin resonance spectra and his dependence from orientation data and about energy levels of defects, items of information on a situation of oxygen atoms in silicon lattice in \cite{20} the model of A-centre was constructed. A-centre represents anisotropic defect whose electrical dipole moment is directed lengthways [110]. A-centre have deep electron-vibrational energy levels in the forbidden energy zone of silicon which are distant from boundaries ($E_c$ and $E_v$) of the forbidden energy zone on sizes multiple 0.11 eV and are close to calculated on the Eq. (1) for oxygen atom. It allows to identify them with inherent $\alpha$-oscillations of oxygen atoms. Acceptor $E_c$ - (0.16...0.22) eV and donor $E_v + (0.27...0.33)$ eV levels are most active at low concentration of A - centres. These levels are close to the calculated energy levels of inherent oscillations of oxygen atom. Specified changes of the energy levels are explained by change of complete oscillatory energy of A - centre caused by the interaction of the centres with each other at changing of their concentration from $5 \cdot 10^{17} cm^{-3}$ up to $10^{13} cm^{-3}$ and depends on average distance (R) between them as $R^{-3}$. It coordinates with aeolotropic structure of A - centre and specifies one-dimensional character of interaction between them. The given result corresponds to oscillatory model of
A-centre as one-dimensional oscillator that justifies application Eq. (1) for the description of his electron-vibrational energy levels.

The application of the linearly polarized radiation and monocrystals with rather low concentration of EVC allows to create necessary conditions for measurement of electron-vibrational spectra with participation of one phonons type. Such spectra may be analysed on the basis of the Pekar-Huang- Rhys theory [11] - [15]. The typical spectra of photoconductivity and optical transmittance connected with photoionization of A - centre by polarized IR radiation with an electrical vector \( E_{\parallel [110]} \) are given on a fig. 2. One can see on fig. 2 that spectra are modulated by phonons. The minima of optical transmittance (maxima of optical absorption) correspond to minima of photoconductivity. The established conformity of extremums in spectra of photoconductivity and absorption [27] is explained by characteristic negative photoconductivity when electron-vibrational transitions (from valence band on A - centre) occur and proves the fact of auto localization of electrons and holes on EVC simultaneously. If EVC interacts only with one type oscillations of a lattice (similar to spectra on a fig. 2) then in according to [15] the spectral distribution of electron-vibrational transitions depends from \( S \), function Bose (\( f \)), contains product of the modified Bessel’s function of the order \( p \) on \( \sum n \delta(n-p) \), where \( n = 1, 2,... \) and \( \delta \) - delta function, \( p \) - number of phonons participating in electron-vibrational transition. Because of presence \( \delta \) - functions \( p \) accepts only integer meaning. \( p>0 \) corresponds to absorption of optical quantum and \( p<0 \) corresponds to radiation of optical quantum with emission of \( p \) phonons. Accordingly spectrum contains two wings adequate electron-vibrational transitions with absorption and emission of phonons. One wing lays below than energy of transition without phonons \( (p=0) \) another wing lays higher than energy of transition without phonons. The wing of a spectrum appropriate to absorption phonons disappears with downturn of temperature . At participation of one type phonons the spectrum represents a series of discrete lines which energy differ on size multiple phonons. Expression for spectral distribution includes only one parameter \( S \). Size of \( S \) may be selected to approach conveniently a contour of an experimental spectrum and thus to determine \( S \). The number of phonons which are emitted by the centre in a maximum of an optical band is equal \( S \). The energy level on which the electron-vibrational transition is carried out corresponds to transition without phonons \( (p = 0) \). In the field of high temperatures when \( 4S[f(f+1)]^{1/2} > p > 1 \) the discrete lines extend the periodic structure in spectra disappears and the contour of a spectral band can be approached by function of Gauss:

\[
G(\hbar\omega) = \exp\left\{-\frac{1}{4S[f(f+1)]}\frac{\omega - \omega_{\text{max}}}{\omega_0}\right\}^{2}
\]

(5)

where \( \omega \) - optical frequency, \( \omega_{\text{max}} \) - frequency in a maximum of spectral distribution, \( \omega_0 \) - optical frequency of electronic transition at \( f = 0 \). In the region of low temperatures when \( f\rightarrow0 \) and \( > > Sf(f+1) \) contour of a spectral band follow the dependence

\[
G(\hbar\omega) = S^p/p!.
\]

(6)

Approach to spectra on basis of expressions [3, 3] has allowed us to determine \( S = 5 \) for A - centre, types and energy of phonons connected with the centres, energy levels of A - centre
corresponding to transitions with \( p = 0 \). In particular, data about TA phonons received from the analysis of experimental spectra connected with A- centre are given in Table 1 together with the appropriate literary data.

| Direction of phonon wave vector | Energy of phonons (meV) determined by methods: |
|-------------------------------|-----------------------------------------------|
|                              | calculating | dissipation of neutrons | indirect absorption | photoconductivity on A-centre |
| 100                           | 23.0        | 21.0                  | 22.0                | 22.0                          |
| 110                           | 18.0        | 17.9                  | 18.0                | 18.3                          |
| 111                           | 16.5        | 16.7                  | 17.0                | 16.9                          |

On an insertion of a fig. 2 are given the experimental data about energy splitting of connected with A- centre LO and TA phonons arising as a result of interaction A- centres among themselves depending on their concentration (N). The size S also changes from 5 up to 2 at increase N up to \( 5 \cdot 10^{17} \text{cm}^{-3} \). Electrons and holes carrying out transitions to levels EVC inevitably cooperate with \( p=S \) phonons. In result at energy levels of EVC, which are inherent oscillatory energy levels of these centres and are shown as deep energy levels, appears located electrons, holes and phonons. Hence EVC represents complex formation consisting from impurity atom, his inherent oscillations , electrons, holes and phonons. These particles in structure EVC form the interconnected auto localized system submitting other statistical and dynamic laws versus free phonons and electrons of conductivity. In this connection EVC can cause unusual physical properties to crystals and crystal structures which are poorly connected to a structure of energy bands of a crystal and properties of conductivity electrons. The similar conclusion was made earlier as a result of research of phonon drag in semiconductors where the phonon drag is caused only by those phonons which are strongly connected with electrons and consequently have other properties \([30, 31]\).

The modulation of spectra by phonons stops in samples on the basis of various semiconductors when the concentration of free charge carriers at room temperature (concentration of doping impurity) exceeds \( n_{\text{max}} = 2 \cdot 10^{17} \text{cm}^{-3} \). It gives the basis to consider that concentration of electrons and holes which are auto located on EVC and capable to be superconducting does not exceed \( n_{\text{max}} \).

A- centre arise at technological processings of silicon and silicon structures, in particular, in structures metal - oxide of silicon - silicon (MOS-structures). The presence of A- centres in structures is shown on characteristic negative photoconductivity in silicon under oxide, modulation of spectra by phonons and on kinetics of photo-emf which is described by not less than triad of time constant (t). These constants are mutually connected by proportions \( t_1 : t_2 : t_3 = 1! / S^1 : 2! / S^2 : 3! / S^3 \) at \( S = 2 \) also corresponds to probability of electron-vibrational transitions which are described by Eq. (1) at participation \( p = 1, 2 \) and 3 phonons. A - centres also influence on volt - capacitance characteristics of MOS-struktures. On the fig. 3 are submitted typical volt - capacitance (C-V) characteristics of aluminium contact by the area \( 4.9 \cdot 10^{-4} \text{cm}^2 \) to a plate of silicon containing A- centres in the concentration \( \sim 5 \cdot 10^{15} \text{cm}^{-3} \).
The characteristics are measured at room temperature $T (< T_c)$ on various frequencies. The submitted characteristics are depended from frequency. The dependence of the characteristics from frequency is defined by available A-centres in samples. On various frequencies the capacitance is nonmonotonic function of back bias that does not correspond to traditional theory of capacitance for ideal contact metal-semiconductor with Schottky barrier. Untraditional physical model of contact metal-semiconductor is necessary for the analysis of such C-V dependences. It is possible to approximate the experimental C-V curves submitted in a fig. 3 by known dependence of contact capacitance ($C$) from the enclosed voltage ($V$): $C = \frac{S(V) \cdot \varepsilon \varepsilon_0}{L}$, where $\varepsilon$ - relative dielectric permeability of the semiconductor and $\varepsilon_0$ - electrical constant, L - thickness of depletion region, accounting that the effective area of contact ($S$) depends on a voltage: $S = S(V)$. Such dependences corresponds of contact model which is taking into account the presence of fine regions (embedments) with high conductivity in the semiconductor under a field electrode which are coherent areas. In process of penetration of an electrical field into the semiconductor (at increase of back-biasing voltage) the border of depletion region achieves some of these embedments and area of equipotential surface grows. Thus differential capacitance of contact is accordingly increased. On experience the smooth increase of capacitance is observed at achievement of some bias voltage that it is possible to explain by volumetric distribution of the embeddings which serially achieves equipotential surface of depletion region border. The unmonotonous dependence $C(V)$ with several extremums in such model can be explained by presence of several layers of embeddings. Identical high-resistance and low-resistance layers, as it is well known, exists in such and similar structures strongly influences conductivity by elastic waves arising in depletion region of contact. Besides it is known that the periodicity of layers also depends on a voltage on contact and from voltage frequency. It brings contribution in frequency dependence of contact capacitance. The appropriate model of contact which allow to explain frequency dependence of capacitance contains coherence areas of the small size in the semiconductor under a field electrode. These areas are distributed disorderly and are grouped in layers parallel to a field electrode. It is possible to explain the experimental C-V curves just by a discrete structure of layers formed by fine coherence areas. Monolithic low-resistance layers are unsuitable because in this case the differential capacitance can not change in relation to capacitance of depletion region of the semiconductor. The presence of embeddings with conductive (superconductive) pieces in the semiconductor under field contact quite corresponds to an opportunity of formation of coherence areas with the characteristic size $\lambda$. Experimentally observable frequency dependence of differential capacitance in semiconductor contacts confirms presence of coherence areas in samples with electron-vibrational centres.

3. Estimation of parameters

Superconductive property of a material are doubtlessly connected to occurrence of coherence areas which possess of superconductive properties due to coherence of electronic displacements. The law of occurrence of coherence areas is defined by concentration those EVC in which the inherent oscillations are exited and also by concentration of phonons. The interaction between EVC determines occurrence of coherence areas and is executed by means of an exchanging of
the centres with each other by phonons. It is possible to assume that for an estimation of the minimal concentration ($N_{\text{min}}$) of EVC at which the formation of coherence areas is possible when such interaction is effective on distances between EVC about length of phonon wave ($\Lambda$). The minimal concentration of exited EVC can be estimated as $\Lambda^{-3}$. Accepting the maximal speed of a sound in silicon $V = 9.13 \cdot 10^5$ cm/c and phonon frequency $F = 1.25 \cdot 10^{10}$ c$^{-1}$ we shall receive $N_{\text{min}} = 2.56 \cdot 10^{12}$ cm$^{-3}$.

Normal-superconducting transition temperature ($T_c$) can be estimated proceeding from the following reasons. If to consider the intrinsic semiconductor material with effective mass for density of conditions for electrons ($m_{nd}$) and holes ($m_{pd}$) when at certain temperature ($T$) speed of thermal generation of electrons and holes ($G$) in individual volume and at time of life ($\tau_i$) according to the statistical theory define inherent concentration $n_i = \sqrt{N_cN_v\exp(-\frac{E_g}{2kT})}$ = $G\tau_i$. $N_c = 2(\frac{2\pi m_{nd}kT}{h^2})^{3/2}$ and $N_v = 2(\frac{2\pi m_{pd}kT}{h^2})^{3/2}$ - effective number of conditions in conduction energy band and in valence energy band, $E_g$ - width of energy forbidden gape of the semiconductor. In a stationary condition for the same time $\tau_i$ carriers of charges recombine with the same rate G. If recombination occurs on energy levels of EVC then each recombination act gives rise to EVC inherent oscillations with energy determined by Eq. (1) and else S phonons is rised. Let’s consider that it is enough for synchronization of electronic displacement in coherence areas of one phonon per one EVC. Therefore for formation coherence area is necessary not less $n = \frac{(N_{\text{min}}/S) \cdot f(E)}{n_i}$ recombination acts in time $\tau_i$, where $f(E)$ - the function Bose for given oscillation energy $E(\mu)$. It is possible to write down a condition for existence of the minimal concentration of exited EVC as $n_i = n$. By substituting in this equality the expressions for $n_i$ and $n_k$ we shall receive a relation which is possible to consider as the equation for definition of temperature $T = T_c$:

$$\sqrt{N_cN_v\exp(-\frac{E_g}{2kT})} = \frac{N_{\text{min}}}{S(\exp\frac{E(\mu)}{kT} - 1)},$$

where $E(\mu)$ - discrete oscillatory energy of EVC. It is necessary to tell more about possible meanings of $E(\mu)$. $E(\mu)$ can not exceed $E_g/2$ as in this case she will be transferred with a high probability to electrons and is spent on electronic transitions through the forbidden zone of the semiconductor. It is known EVC show quantum and classical properties [6]: $E(\mu)$ can accept meanings conterminous with energies of charmonical quantum vibrator according to Eq. (1) and also meanings multiple $E_\alpha$. Therefore for $\alpha$-type inherent EVC oscillator $E(\mu) = (E_\alpha/2) \cdot \mu < E_g/2$, $\mu = 1,2,3,...$

Using known tabulated meanings of parameters and also $S = 5$, $v=0$ and $E_\alpha = 0.22$ for A-centre in silicon by numerical way is received from (7) the meaning of the $T_c=305$K at $\mu=1$, $T_c=235$K at $\mu=2$ and $T_c=162$K at $\mu=3$ for silicon. The similar estimation for Ge with the oxygen centres gives meaning of the $T_c=182$K, $T_c=130$K and $T_c=33$K. According to this results the superconductivity in silicon with $\mu = 2$, $E(\mu) = E_\alpha$, for A-centres necessary to expect at temperatures above 235K and in germanium - at temperatures is higher 130K.

The estimation of critical density of current ($J_k$) can be executed proceeding from the data about possible concentration of superconducting charges ($n$) and about maximal their drift speed ($v$). The meaning of $n$ can be in limits from $n = n_k$ up to $n_{\text{max}} = 2 \cdot 10^{17}$ cm$^{-3}$ and the speed of drift is probably limited by dissipation on borders of coherence areas and can not
exceed speed of a sound $V$. Believing $J_k = e n V$ we come to the following estimation of critical density of a current in silicon at room temperature: $0.55/cm^2 < J_k < 73 A/cm^2$.

For an estimation of critical magnetic intensity it is possible to involve the following experimental data received at constant density of a current in silicon samples in a magnetic field. Such data are given on fig. 4 and represent typical dependence of derivative of voltage $V$ ($V$ - on sample) with respect to magnetic induction ($B$), that is $dV/dB$ from $B$ when current density $J = \text{const}$, measured in a normal condition of Si sample (at $T < T_c$) containing EVC with concentration $5 \cdot 10^{15} cm^{-3}$. The dependence submitted on fig. 4 contains periodic maxima and can be explained by influence of a magnetic field on charged oscillators as electron connected with EVC by means of crystal phonon. The movement equation of such oscillator can be written down as follows:

$$\frac{d^2X}{dt^2} + \left(\frac{e}{m^*}\right) \frac{dX}{dt} B - \omega^2 X = 0,$$

where $X$ - generalized coordinate, $e$ - charge and $m^*$ - effective mass of electron, $\omega$ - cyclic frequency of fluctuations, $B$ - magnetic induction. Component containing $dX/dt$ takes into account action of Lorentz’s force when $dX/dt$ and $B$ is mutually orthogonal. The given equation (8) supposes oscillating solution only under condition: $\{4\omega^2 - \left(\frac{eB}{m^*}\right)^2\} > 0$.

The oscillatory movements of oscillator are possible when $B < \frac{2m^*\omega}{e}$ that is when $B$ is not too great. Otherwise oscillations are suppressed by a magnetic field and are impossible.

Maxima of dependences submitted on fig. 4 are possible to identify with frequencies those phonons which provide a coherence condition. If to accept for silicon $m^* = 0.98 m_0$, where $m_0$ - mass at rest of electron, then the appropriate frequencies multiple $2.1 \cdot 10^{10} c^{-1}$, lay in limits from $2.1 \cdot 10^{10} c^{-1}$ up to $1.26 \cdot 10^{11} c^{-1}$ and correspond to acoustic fluctuations of a crystal. It is seen from these data that the frequency $F = 1.25 \cdot 10^{10} c^{-1}$ accepted for an estimation of the minimal concentration of A- centres ($N_{\text{min}}$) is less but close to $2.1 \cdot 10^{10} c^{-1}$. Oscillations with the large frequencies are absent when $B > 1.3$ tesla hence coherence area can not arise also superconductivity is impossible. Therefore it is possible to expect that in magnetic fields with $B < 1.3$ tesla the superconductivity caused EVC is possible but at $B > 1.3$ tesla she may be impossible.

### 4. Experimental results and discussion

The experimental temperature dependences of resistance for two Si samples are submitted on fig. 5. Within the separate temperature areas the resistance is described by some activation energies which equal to energies of phonons cooperating with inherent oscillations of oxygen atoms. One can see on fig. 5 when the temperature is raised up to $T = T_c$ the resistivity sharply decreases up to zero (superconductivity arises at $T = T_c$). The superconductivity exist up to rather high temperatures (probably up to temperature of a crystal melting and is higher). One can see on fig. 5 else that curve 1 contains two steps of resistance sharp reduction (at $T = 250K$ and at $T = T_c = 309K$) but curve 2 contains one such step (at $T = T_c = 389.6K$). The similar characteristics of some samples can contain 3 or 4 such steps. The presence of such steps resistance reduction at approach of temperature to $T_c$ specifies discrete (quantum) character of superconductivity arising. The occurrence of such steps can be connected with processes of
arising, reorganization and cooperation of coherence areas with each other. In some samples alongside with the specified steps of resistance reduction the steps of sharp resistance increase are observed also and in such case superconductivity does not arise that it is possible to explain by deformation or destruction of coherency areas. In any case the sharp changing of samples resistance at discrete temperatures can definitely be connected with changing of a role of various quanta of EVC inherent oscillations because at absence of EVC the sharp jumps of resistance and superconductivity is not observed.

Because the given superconductivity arises due to oscillations of a crystal with very high frequencies appropriate to hypersound it is expedient to name the given superconductivity, caused by the electron-vibration centres, as hyperconductivity to distinguish her mechanism from other mechanisms of superconductivity.

In silicon samples we observed hyperconductivity in magnetic fields with B up to 0.5 tesla that does not contradict an estimation of allowable intensity of a magnetic field. Hyperconductivity existed at density of a current up to 10 \( A/cm^2 \) that not contradicts estimations of critical density for a current density.

The occurrence hyperconductivity is connected to occurrence of thermopower (TEP) features. On fig. 6 are given temperature dependences of TEP for the sample designated by 2 on fig. 5. Such alternating-sign of temperature dependence TEP is characteristic for normal-hyperconducting transition. It seems the behaviour TEP reflects complex dynamic processes of formation and interaction of coherence areas among themselves.

Occurrence of superconductivity is accompanied by huge increase of thermal conductivity. In accordance with experimental data the meaning of thermal conductivity in some samples increase more than \( 10^5 \) times. Probably the hyperconductivity is accompanied by heat superconductivity.

Hyperconductivity arises in various crystals containing EVC. On fig. 7 the available experimental data about meanings of the \( T_c \) in various hyperconductor samples are submitted. One can see on fig. 7 that normal-hyperconducting transition temperature \( T_c \) shows the tendency to reduction at increasing of average size of the basic substance nuclear number (\( Z_{mid} \)). Straight lineses a and b on fig. 7 restrict the area in which the experimental points are placed. One can see on fig. 7 that the experimental meanings \( T_c \) for every material can change over a wide range between lineses a and b. On the other hand situation of straight lineses a and b differs on insignificant size of energy \( kT \simeq 17 \) meV appropriate to acoustic phonons. It speaks about importance not only inherent oscillations of EVC but acoustic phonons simultaneously for formation of hyperconductivity in different materials. The minimal experimental meanings of \( T_c \) for Si and Ge are in agreement with given estimation of \( T_c \) when \( \mu=2 \) for \( \alpha \)-inherent oxygen oscillator. According to Eq. (7) the increase \( S \) corresponds to reduction \( T_c \) and promotes hyperconductivity existence in wide area of temperatures. The meanings \( S \gg 1 \) are necessary for existence hyperconductivity from near to room temperatures up to higher temperatures that it is possible to provide by introducing EVC in crystals. The experimental data about meanings \( T_c \) for semiconductors with small \( E_g \) can be coordinated with Eq. (7) only by taking into account \( \beta \)-type or \( \gamma \)-type of inherent oscillations because solutions of Eq. (7) with participation of \( \alpha \) - inherent oscillations are absent.
5. Conclusion

The superconductivity caused by electron-vibrational centres - hyperconductivity can exist in the field of room temperatures and at higher temperatures in various materials in wide electrical current density and magnetic intensity intervals. That allows ones to hope on opportunity of hyperconductivity application in science and engineering.

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Figure captions

Fig. 1. Experimental spectrum IR reflection of polarized light from a surface of quartz (1). The calculated spectrum of reflection by "zero" inherent fluctuations of oxygen (2).

Fig. 2. Spectrum of photoconductivity (1) and spectrum of IR transmittance (2) aused by photoionization of A-centres in silicon at $T = 80K$. The arrows designate the appropriate each other minima of spectra and the number participating phonons is specified by figures. On an insertion the experimental data about splitting LO and TA phonons are given depending on concentration of A-centres.

Fig. 3. Characteristics volt-capacitance of contact Si-Al containing A-centres are measured at room temperature $T < T_c$ on various frequencies: 0.2 MHz (1); 0.5 MHz (2); 1.0 MHz (3); 5.0 MHz (4); 10.0 MHz (5); 20.0 MHz (6).

Fig. 4. Derivative of voltage on Si sample with respect to magnetic intensity (B) at room temperature $T < T_c$.

Fig. 5. Temperature dependences of resistance for two of Si samples containing various concentration of A-centres: $N_1 \approx 5 \cdot 10^{14} cm^{-3}$ and $N_2 \approx 6 \cdot 10^{15} cm^{-3}$.

Fig. 6. Temperature dependence of thermopower for the same Si sample whose characteristic is designated on fig. 5 by number 2.

Fig. 7. The experimental meanings of normal-hyprconducting transition temperatures ($T_c$) according to average meanings of nuclear number ($Z_{mid}$) in various samples containing electron-vibrational centres. Straight lines a and b limit area in which the experimental points lay.
Fig. 2

[Graph showing data points and curves for energy and optical transmission]
Fig. 4
Fig. 5.

- $T_c = 309\text{K}$
- $T_c = 389.6\text{K}$
Fig. 6
