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ELECTROACOUSTIC EFFECT AND ELECTRICAL SUPERCONDUCTIVITY OF METALS

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The paper discusses the conditions under which superconductivity of metals would be detected at atmospheric pressure and at room temperature. One of the possible directions of research to achieve these conditions is to change the phonon spectrum of metals in order to increase the Debye temperature, and therefore to increase the temperature of the superconducting transition T_c. According to the idea of the work and to the estimates made in it, the maximum frequency of phonons ν_{max} in metals can be increased by the short-term action of an external constant electric field (electric pulse). The duration of the pulse should be (10^{-5}–10^{-7}) s. The voltage of the constant electric field source is $U \approx 1V$. A decrease in the crystal lattice parameter should be accompanied by an increase in the maximum phonon frequency ν_{max} and, accordingly, by an increase in the Debye temperature. The characteristic size of the sample, in which the change in electron concentration can be realized, should not exceed the length of electron shielding in metals, i. e. $\approx 10^{-8}$ m. The sequential action of a certain number of electric field pulses can maintain a superconducting state in a metal sample for some finite time.

Key words: *metals, superconductors, change of the phonon spectrum of metals.*

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INTRODUCTION

The electrical superconductivity of metals (zero electrical resistance) is an unique physical property, the study of which is extremely important, both from the point of view of the development of fundamental science and from the point of view of using this phenomenon in practice [1]. Microscopic theory of superconductivity of metals was published in 1957 (BCS theory) (Bardeen, Cooper, Schrieffer) [2]. According to this theory, the main mechanism of superconductivity of metals is the electron-phonon interaction, which causes the formation of special quantum particles – bosons (paired electrons), capable of carrying an electric charge in a metal without energy loss. According to the BCS theory, the critical temperature T_c at which bosons can be formed (a quantitative estimate of the transition temperature of a metal to the superconducting state) is described by the following relation:

$$T_c \approx \theta \exp(-1 / \lambda). \quad (1)$$

Here θ is the characteristic temperature (Debye temperature), the value of which is determined by the maximum value of the oscillation frequency of atoms (phonons) ν^{max}: $\theta \approx (h\nu^{max}) / k$, h is Planck's constant, k is Boltzmann's constant, and λ is the so-called pairing constant. For most metals $\lambda \approx (0.1 - 0.3)$, $\theta \approx 300$ K and, thus, the temperature T_c is characterized by the range of values $\approx (1–10)$ K, which is in good agreement with the experimental data.

Such a small value of T_c significantly limits the possibility of using metallic superconductors for technical purposes. Therefore, the most important task of researchers and materials scientists is to search for conditions under which the superconductivity of metals would manifest itself at higher temperatures up to room temperature. In accordance with the theory, it is obvious that one of the possible directions of research to achieve this goal is to change the phonon spectrum of metals in order to increase the Debye temperature [see. formula (1)].

Previously, we considered the possibility of changing the value of ν^{max} and, accordingly, the value of T_c under the conditions of generation of a sound wave in metals by a laser pulse (photoacoustic effect) [3]. In this paper, we discuss the possibility of increasing ν^{max} and, accordingly, increasing the Debye temperature, and hence the temperature T_c, as a result of a short-term action of an external electric field (electric pulse).

CHANGES IN THE PHONON SPECTRUM OF METALS AND THE TEMPERATURE OF TRANSITION TO THE SUPERCONDUCTING STATE UNDER THE ACTION OF AN EXTERNAL ELECTRIC FIELD PULSE

It is known that the existence of a stable metallic phase is due to the interaction between "collectivized" valence electrons and a sublattice of ionized atoms. In other words, "collectivized" electrons form a "gas" of free electrons, the pressure of which ensures the stable state of the metal crystal lattice. The value of this pressure is described by the relation:

$$P \approx 0.1 h^2 n / m r^2. \qquad (2)$$

Here h is Planck's constant, m is the electron mass, r is the radius of the electron orbit in the atom (Bohr radius), n is the concentration of the electron "gas" [4, 5]. Substituting into (2) the numerical values of the constants, and taking into account that $n \approx n_{at}$, where $n_{at} \approx 1/a^3 \approx 10^{28}$ 1/m^3, a is the crystal lattice parameter, we have: $P \approx 10^2$ GPa.

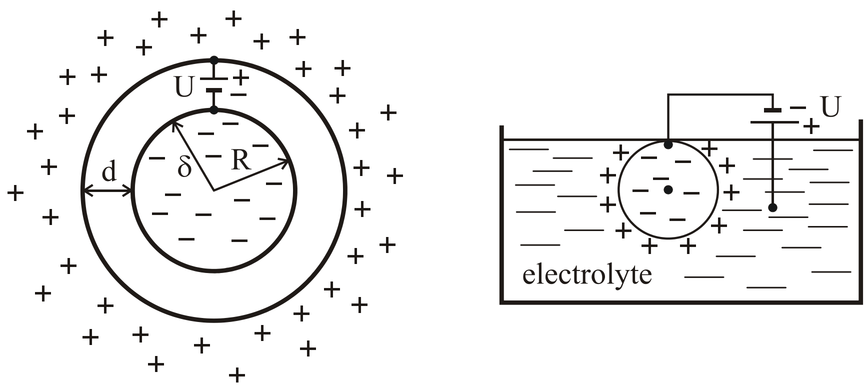
From relation (2) it follows that by increasing the concentration of electrons in the metal, it is possible to cause an additional pressure of the electron "gas" on the atomic lattice. In turn, the action of additional pressure should be accompanied by a decrease in the crystal lattice parameter and, accordingly, an increase in the value ν^{max}. It is possible to increase the concentration of “free” (“collectivized”) electrons in a metal using an external source of a constant electric field. In this case, it is obvious that the characteristic size of the sample R, in which a change in the electron density can be realized, should not significantly exceed the electron screening length δ.

For metals, the average screening length is $\approx 3\cdot 10^{-9}$ m (Thomas-Fermi model). Using the simplest experimental scheme shown in Fig. 1 (spherical capacitor), the increase in the electron concentration in the sample per atom under the action of an external source can be characterized by the dimensionless coefficient χ [6]:

$$\chi \approx 3\varepsilon U \Omega / d e R. \qquad (3)$$

Here ε is the permittivity of the electric field source medium (capacitor), U is the voltage value, $\Omega = a^3$, d is the distance between the electrodes, and e is the electron charge. Substituting in (3) the values of the constants and the real values of the quantities: $\varepsilon \approx 1$, $d \approx 10^{-9}$ m, and also assuming that $U \approx 1$ V, and $R \approx 3\delta \approx 10^{-8}$ m, we have: $\chi \approx 0.1$.

This estimate indicates that using a constant electric



a b

Fig. 1. Scheme of the experiment for the realization of the manifestation of the electroacoustic effect in metals, which leads to an increase in the temperature of the transition to the superconducting state. a) Schematic cross-section of a spherical capacitor. b) Scheme of the experiment, which allows changing the electronic structure of the sample, the size of which is R≈δ (δ is the shielding length).

field source, it is possible to increase the electron concentration and, accordingly, to cause an additional pressure ΔP in the metal sample, the value of which is ≈ 10 % of the internal pressure of the electron "gas", i.e. $\Delta P \approx 10$ GPa. This pressure, in accordance with Hooke's law, should cause the elastic deformation of the crystal ($\Delta a/a \approx \Delta P/K$, where K is the elastic modulus of the crystal. Since for most metals the value of the elastic modulus K is characterized by a value of $\approx 10^2$ GPa, then $(\Delta a/a) \approx 0.1$.

Thus, the action of a source of an external constant electric field at a voltage of ≈ 1 V can reduce the crystal lattice parameter in metals by about 10 %. This decrease in the crystal lattice parameter should be accompanied by an increase in the maximum phonon frequency ν^{max} and, accordingly, an increase in the Debye temperature. At the same time, it is obvious that the change in the Debye temperature associated with the elastic deformation of the metal sample as a result of the additional pressure of the electron "gas" is not very significant in absolute value.

A more significant change in the value of ν^{max} can be realized using a short-term action of an electric field (impulse). Indeed, a short-term action of the pressure of the electron "gas" with a value of $\Delta P \approx 10$ GPa can cause the generation of a "shock" sound wave, the frequency of which is determined by the relation: $\nu \approx 3\,\Delta P/hn$. Substituting the numerical values of the quantities included in the written formula, we have: $\nu \approx 10^{13}\,s^{-1}$, which is approximately 5 times greater than the value of ν^{max} characteristic of metals in the absence of an external electric field. Accordingly, for this reason, the Debye temperature should also increase from the value of $\theta \approx 300$ K to the value of ≈ 103 K. The duration time of the pulse, which causes the generation of a "shock" sound wave of the specified frequency, should be $\tau \approx (10^{-5} - 10^{-7})$ s [7]. It should be kept in mind that this change in the phonon spectrum is also accompanied by an increase in the pairing constant to the values $\lambda \geq 1$. For such values of θ and λ, the temperature of the transition to the superconducting state T_c is characterized by a different relation, which differs from relation (1) [8]:

$$T_c \approx 0.2\theta\lambda^{1/2}. \quad (4)$$

From relation (4) it follows that the impulse of the electric field at the specified parameters can cause an increase in the value of T_c up to the value $\approx (200 - 300)$ K. In this case, it is obvious that the successive action of a certain number of electric field pulses can maintain the superconducting state in a metal sample for some finite time.

CONCLUSIONS

1. The action of electric field pulses can cause the transition of metals to the superconducting state at temperatures close to room temperature at atmospheric pressure.

2. The duration of the pulse must be $\approx (10^{-5} - 10^{-7})$ s.

3. Electric field source voltage $U \approx 1$ V.

4. The characteristic size of a sample that can be transferred to the superconducting state should not significantly exceed the electron screening length in metals, i.e. $R \leq 3\delta \approx 10^{-8}$ m.

CONFLICT OF INTEREST

The authors tell about the current conflict of interest.

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ЕЛЕКТРОАКУСТИЧНИЙ ЕФЕКТ І ЕЛЕКТРИЧНА НАДПРОВІДНІСТЬ МЕТАЛІВ

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У роботі обговорюються умови, за яких виявлялася б надпровідність металів при атмосферному тиску і кімнатній температурі. Один із можливих напрямів досліджень для досягнення зазначених умов – зміна фононного спектру металів з метою підвищення температури Дебая, а отже, і температури надпровідного переходу T_c. Відповідно до ідеї роботи та зроблених у ній оцінок, підвищити максимальну частоту фононів ν^{max} у металах може короткочасна дія зовнішнього сталого електричного поля (електричного імпульсу). Час дії імпульсу має становити (10^{-5} – 10^{-7}) с. Напруга джерела постійного електричного поля $U \approx 1V$. Зроблені у роботі оцінки свідчать, що, використовуючи джерело постійного електричного поля, можна збільшити концентрацію вільних електронів і, відповідно, зумовити в металевому зразку дію додаткового тиску ΔP, величина якого становить ≈ 10 % від внутрішнього тиску електронного «газу», тобто $\Delta P \approx 10$ GPa. Цей тиск має зумовити пружну деформацію кристала $(\Delta a/a) \approx 0.1$. Зменшення параметра кристалічної ґратки має супроводжуватися збільшенням максимальної частоти фононів ν^{max} і, відповідно, збільшенням температури Дебая. Характерний розмір зразка, в якому може бути реалізована зміна концентрації електронів, не має перевищувати довжину екранування електронів у металах, тобто $\approx 10^{-8}$ м. Послідовна дія певної кількості імпульсів електричного поля може підтримувати надпровідний стан у металевому зразку протягом деякого кінцевого часу.

Ключові слова*: метали, надпровідники, зміна фононного спектру металів.*