Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR (29–30 January 1986)

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A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR was held on January 29 and 30, 1986, at the S. I. Vavilov Institute of Physical Problems, Academy of Sciences of the USSR. The following reports were presented at the session:

January 29

1. *M. I. Kaganov and V. B. Fiks*. Conversion of electromagnetic energy into acoustic energy by electrons in metals (theory).

2. *A. N. Vasil'ev and Yu. P. Gaĭdukov*. Contactless excitation of sound in metals (experiment).

3. *V. A. Komarov*. Electromagnetic-acoustic conversion—a method of nondestructive testing.

January 30

4. *A. A. Komar*. The x-ray lithography method in microelectronics—problems and prospects.

5. *A. P. Silin*. Semiconductor superlattices.

6. *A. I. Golovashvin and A. N. Lykov*. Submicron superconducting structures. Summaries of five of these reports are published below.

M. I. Kaganov and B. V. Fiks. *Conversion of electromagnetic energy into acoustic energy by electrons in metals (theory)*.

1. Conversion of electromagnetic energy into acoustic energy can be caused by various forces[1] which act on the lattice of a metal when its surface is exposed to an incident electromagnetic wave.[8] If a metal is placed in a sufficiently large constant field $\mathbf{H}_0$, then the conversion is caused mainly by the ponderomotive (induction, or Farday) force $\mathbf{F}^i = (1/c)\mathbf{jH}$, where $\mathbf{j}$ is the density of the current induced by an electromagnetic wave in the skin-layer of the metal. When $\omega_{co} < (\delta/\delta_0)^2 l^2/(l^2+\delta^2)$, where ω_{co} is the cyclotron frequency of an electron in the field H_0, δ is the depth of the skin-layer, l is the mean free path, and δ_0 is the plasma penetration depth, the conversion is caused by the deformation force

$$\mathscr{F}_i^{d} = -\frac{\partial}{\partial x_k}\langle \Lambda_{ik}\chi\rangle,$$

where $\Lambda_{ik} = \lambda_{ik} - \langle\lambda_{ik}\rangle/\langle 1\rangle$ is the tensor of the deformation potential renormalized by the condition of quasineutrality, $(\partial f_0/\partial\varepsilon)\chi$ is the nonequilibrium correction to the Fermi distribution function of electrons, and the brackets denote averaging over the Fermi-surface (FS). "Deformation force", "deformation conversion mechanism" are not entirely precise terms, since in the described conversion mechanism the main role can be played by the transfer of momentum of electrons: after acquiring momentum from an electromagnetic wave in one place, electrons "give it away" to the lattice at another place (at a distance of the order of l), with the result that "a force dipole" acts on the lattice. In the free electron approximation the deformation force is one of the manifestations of the "electron wind" (Ref. 2).[1)] The nonlocal character of the deformation force is evident from the estimate of the order of magnitude of this force

$$\mathscr{F}^{d} \sim \frac{n\omega\delta}{c}\,\frac{l^2}{l^2+\delta^2}\,e\tilde{H}$$

($\tilde{H}$ is the magnetic field in the wave on the surface of the metal, n is the electron density). The total force acting on the metal is equal to zero because of the metal neutrality. In the case of diffuse reflection of electrons from the surface of a metal, the metal surface is exposed to a δ-type surface force, caused by the loss of electron momentum on their collision with the surface

$$\mathbf{F}^{\text{surf}} = -\int_0^\infty \mathbf{F}^{d}(z')\,dz'\cdot\delta(z),$$

where $\mathbf{z}$ is the normal to the metal surface.[3]

2. The deformation force is especially large under the conditions of anomalous skin-effect. Analysis shows that even when $\delta \ll l$, all electrons on the Fermi surface, and not only those along the "belt" $v_z = 0$, participate in the conversion of electromagnetic energy into acoustic energy. We recall that the impedance of a metal is determined only by the electrons of the "belt". A special role, as will be clear later, is played by the electrons leaving the surface of a metal with maximum speed.

3. It is natural to define the conversion coefficient as the ratio of the flux of acoustic energy to the flux of electromagnetic energy, incident on the surface of a metal:

$$\gamma = \frac{4\pi s\omega^2\rho|u_\infty|^2}{cE_{\text{inc}}^2}.$$

The goal of the theory is the calculation of the value u_∞ of

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the displacement field amplitude in the wave zone "far" (at an infinite distance) from the surface of the metal.

We shall give here the expressions for the conversion coefficient for one of the "favorable" cases[3] (the case of specular reflection and $l \gg l_0 = \delta_0 (v_F/s)^{1/2}, \tau\omega \approx (s/v_F)(l/l_0) \ll 1$)

$$\gamma_{\max} \approx \frac{3}{2\pi} \frac{mZ}{M} \frac{v_F}{c};$$

where Z is the "valency" of a crystal cell, M is its mass (calculations were performed using the free electron model).

The analysis of the temperature dependence $\gamma = \gamma(T)$ has shown that it correctly (at any rate qualitatively) describes the experiment.

4. The transition to super-clean samples makes the consideration of the high-frequency case $\omega\tau \gg 1$, when the attenuation length of the sound $D \sim v_F/\omega$ is smaller than l, quite relevant. The asymptotic behavior of an acoustic field under these conditions is determined by the quasiwaves (the "drawn-in" waves), formed by ballistic electrons with $v_z = v_z^{\text{extr}}$. Nonexponential attenuation of these waves[4] depends on the local geometry of the Fermi surface.

5. An analysis of the interaction of electrons with boundaries of crystallites[5] shows that along the boundaries there must exist an internal "surface" force $F^{\text{surf}} \sim jp_F/e$, which can be important in estimating the conversion ability of a polycrystalline metal.

6. The conversion of electromagnetic energy into acoustic energy must be taken into consideration in calculating the acoustic Cherenkov radiation from charged particles moving through a metal.[6]

7. Nonlinear electromagnetic excitation of ultrasound in metals[7] under the conditions of normal skin-effect is the result of the inductive force $F_2^i \sim \tilde{H}^2/\delta$, and under the conditions of anomalous skin-effect is the result of the deformation force $(F_2^D \sim (l/\delta)^2 \tilde{H}^2/\delta)$. The observation of nonlinear together with linear excitation would allow one to determine, in one experiment, the diagonal and nondiagonal tensor components of the deformation potential λ_{ik}.

[1)] In the free electron model the transfer of the momentum is the only cause of the existence of the "deformation" force.

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