POINT-CONTACT SPECTROSCOPY OF PHONONS IN METALS
I. Yanson, I. Kulik

To cite this version:
I. Yanson, I. Kulik. POINT-CONTACT SPECTROSCOPY OF PHONONS IN METALS. Journal de Physique Colloques, 1978, 39 (C6), pp.C6-1564-C6-1566. <10.1051/jphyscol:19786601>. <jpa-00218095>

HAL Id: jpa-00218095
https://hal.archives-ouvertes.fr/jpa-00218095
Submitted on 1 Jan 1978

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
POINT-CONTACT SPECTROSCOPY OF PHONONS IN METALS

I.K. Yanson and I.O. Kulik

Physico-Technical Institute of Low Temperatures of the Ukr SSR Academy of Sciences, Lenin's av. 47, Kharkov 310164, U.S.S.R.

Abstract.- Both experiment and theory of new type of spectroscopy of phonons in normal metals, called "point-contact spectroscopy", is presented. The second derivative of current over voltage for the point-contact junction is shown to be proportional to the "transport function of electron-phonon interaction" $G(\omega) = \beta^2(\omega) F(\omega)$, where $F(\omega)$ is the density of phonon states and $\beta^2(\omega)$ the squared matrix element of electron-phonon interaction averaged over the Fermi surface of the metal. The data reveal the anisotropy effects, and the role of the elastic scattering processes, are presented and discussed for the number of metals, including Pb, Sn, In, Al, Cu, Ag, Au, Zn, Cd and partly Na. For the polyvalent metals, the $\beta^2(\omega)$ is nearly constant quantity, whereas in the noble metals, it is a strongly decreasing function of the energy. For Na, $\beta^2(\omega)$ increases as $\omega$ increases.

In the experiments described in /1/, for the first time the non-Ohmic I-V dependences for shorted tunnel junctions of normal metals were revealed, and close resemblance of $d^2I/dV^2$ vs $V$ dependences with the phonon density of states, $F(\omega)$ at $\omega = eV$ had been established. The observed I-V-characteristics were related to the nonequilibrium phonon generation by "hot" electrons transiting through a small $(d \sim 50 \text{Å})$ orifice connecting two metals (figure 1) /2,3/. The constriction resistance within the Knudsen limit $d \ll l_1$ ($l_1$ is the impurity scattering length, $d$ the orifice diameter) is given by the formula

$$R_0 = \frac{e^2 S_\text{F}}{2 (2\pi h)^3}$$

(1)

which by the order of magnitude coincides with the Sharvin formula /4/ $R_0 \sim \rho l_1/\delta^2$. Here, $S = \pi d^2/4$ and $S_\text{F}$ is the Fermi surface area. This expression results from integrating over the trajectories of electrons, which represent the exact solution of the collisionless Boltzmann equation. The trajectories fall into transit type (1), and screen-reflected ones (2) (see figure 1). The distribution of electrostatic potential in the vicinity of the orifice is

$$\phi(\vec{r}) = \frac{V}{2} (1 - \Omega(\vec{r})/2\pi).$$

(2)

where $\Omega(\vec{r})$ is the solid angle at which the orifice is seen from the point $\vec{r}$. Taking into account the nonelastic collisions of electrons transiting through the orifice, with phonons one gets at $T = 0$

$$\frac{d^2I}{dV^2} = -4e^2N(0)D_{\text{eff}} G(eV),$$

(3)

where $D_{\text{eff}} = \frac{8}{3} a^3$ is the effective volume of generation of phonons which are responsible for the ob-

Fig. 1: The model of the point contact: a circular orifice of the diameter $d = 2a$ in the nontransparent screen $\Sigma$ separating two metals. (1) - transit trajectories of electrons, (2) - trajectories of electrons reflected at the screen. $\Omega(\vec{r})$ is the solid angle at which the orifice is seen from the point $\vec{r}$. Taking into account the nonelastic collisions of electrons transiting through the orifice, with phonons one gets at $T = 0$
served nonlinear behavior. \(G(\omega)\) the "transport" spectral function of the point contact:

\[
G(\omega) = \frac{N(\omega)}{2} \int \frac{d \mathbf{p}}{v_{\perp}} \int \frac{d \mathbf{p}'}{v_{\perp}'} \delta(\omega - p \cdot p') K(\mathbf{v}, \mathbf{v}')
\]

Here, \(K(\mathbf{v}, \mathbf{v}')\) is the structural factor making allowance for the constriction geometry.

\(G(\omega)\) differs from the known fundamental electron-phonon interaction (EPI) function \(g(\omega) = a^2(\omega) F(\omega)\) in the \(\lambda\)-factor, taking into account a momentum change in the electron-phonon scattering process. It should be noted that finding the \(G(\omega)\) function from the point-contact spectroscopy (4), i.e. by measuring \(d^2V/dV^2\) vs \(V\) dependence, is also possible in the Maxwell limit \(d \ll 1\). In the latter case, the formula for \(K(\mathbf{v}, \mathbf{v}')\) is different from (5), and the effective volume \(V_{\text{eff}}\) in (4) is \(a^2\) rather than \(a^3\). The intensity of "point-contact spectrum" is weaker in the dirty limit than in the clean one. It is necessary that inequality \(d \ll \lambda\) should hold, where \(\lambda = L_{\text{ph}}/L\) is the diffusion length of energy relaxation.

The experiments were carried out on the number of metals, including Pb, Sn, In, Al, Cu, Ag, Au, Zn, Cd, Na. The point contacts were formed by puncturing a thin insulating layer separating two polycrystalline metallic films, or by "needle-anvil" type pressure junction made of Al, Cu, Zn single crystals of various orientations. The dependence of second harmonic of small modulating voltage, \(V_2\), on the contact voltage, \(V\), was measured. In the case of pure junctions \((d \ll 1)\) the positions of the maxima in the point-contact spectrum \(V_2(\text{eV})\) show some discrepancies due to possible uncertainties of the models used to process neutron scattering data and to the energy dependence of \(a^2(\omega)\), the overall agreement is quite satisfactory, which supports the theoretical predictions. In the region of low energies, the \(V_2(\text{eV})\) dependence is quadratic in energy, which contradicts the theoretically predicted forth power law.

The point-contact spectra of Cd are almost identical to those of Zn-junctions, with the appropriate change in the energy scale. The studies of point-contact spectra of Cu and Zn single crystals revealed anisotropy corresponding to that of phonon spectrum. In figures 2c,d, the Zn single-crystal point-contact spectra are shown for two basic orientations.
References

/2/ Kulik, I.O., Shekhter, R.I., Omelyanchouk, A.N., Sol. State Comm. 23 (1977) 301