Observation of phonon structural features of a tunnel type in the characteristics of superconductor-(normal metal) point contacts with an excess current

A. A. Zakharov and M. B. Tsetlin
I. V. Kurchatov Institute of Atomic Energy, Moscow

(Submitted 17 October 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **41**, No. 1, 11–13 (10 January 1985)

Experiments with Tc-Ag point contacts show that when there is a pronounced mismatch of the Fermi velocities at an *S-N* boundary, even in the absence of an insulating barrier, the derivative current-voltage characteristics exhibit clearly defined phonon structural features due to the tunnel state density of the superconductor.

The characteristics of contacts of a superconductor and a normal metal (*S-N* contacts) can range from tunnel characteristics with a gap feature to the characteristics of an ideal point contact with an excess current corresponding to the theoretical value (which we will call "clean microcontacts").[1,2] On the derivative *I-V* characteristics of tunnel contacts, there are structural features at voltages of a few tens of millivolts corresponding to the state density of the superconductor; these structural features can

0021-3640/85/010011-03$01.00

be used to reconstruct the Éliashberg electron-phonon interaction function.[3] The contribution of the electron-phonon interaction to the I-V characteristics of clean microcontacts is determined by the large-angle inelastic scattering of electrons. By measuring d^2I/dV^2 for clean microcontacts, we can find the microcontact function of the electron-phonon interaction.[4,5] There has been no theoretical study of how the electron-phonon interaction of the superconductor will be manifested on the I-V characteristics of contacts of an intermediate type, and no corresponding experimental data are available. In this letter we report a study of technetium-silver point contacts of an intermediate type at voltages corresponding to phonon energies.

The superconducting electrode is a technetium ball produced by arc melting and annealed in a vacuum at 1000 °C for 2 h. The sample is held in a helium-filled weighing bottle and is not subjected to any chemical treatment. The normal electrode is a piece of silver wire 1 mm in diameter, which is etched in dilute nitric acid just before the measurements. The contact is produced by the standard displacement technique used in microcontact spectroscopy.[4] The curves of $dI(V)/dV$ and $d^2I(V)/dV^2$ of the contact are studied; the first derivative is calibrated with the help of an MSR-65 resistance box. The measurements are carried out at 4.2 K.

Figure 1 shows characteristics of a Tc-Ag point contact of the intermediate type. The I-V characteristic found by integrating the first derivative is shown in the inset. It can be seen from the characteristics that, in addition to the excess current, which we estimate to reach half the theoretical value for a clean microcontact, there is a gap feature of the tunnel type. On the dI/dV, d^2I/dV^2 curve we can clearly see structure corresponding to peaks in the phonon state density of technetium.[6] The shape of the dI/dV curve at $V > 10$ mV is similar to the shape of the energy dependence of the superconducting state density, and the appearance of the phonon structural features is apparently due to a "tunnel component" of the current through the contact. This hypothesis is supported by the slight increase in dI/dV with increasing voltage in the region beyond the phonon structural features, which is typical of tunnel contacts.

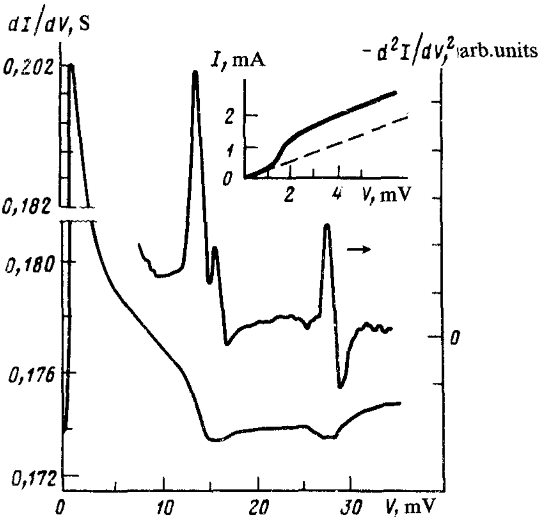

FIG. 1. Curves of dI/dV and $-d^2I/dV^2$ for a Tc-Ag point contact. The peaks on the $-d^2I/dV^2$ curve are at 14.3 and 27.5 mV. The inset shows the I-V characteristic of the contact and an ohmic I-V characteristic, which runs parallel to the former at high voltages.

From the shape of the characteristics at voltages up to 10 mV, we can estimate the "tunnelness" of the contact, by determining the effective potential barrier Z_{eff}. According to Blonder *et al.*,[1] at $Z_{\text{eff}} > 10$ the contact is almost completely a tunnel contact, while at $Z_{\text{eff}} = 0$ we have the case of a clean microcontact. From Ref. 2 we have

$$Z^2_{\text{eff}} = Z^2 + (1-r)^2/4r, \tag{1}$$

where the dimensionless parameter Z is a characteristic of the potential barrier due to the insulating interlayer, and r is the ratio of the electron Fermi velocities of the superconductor and the normal metal. The second term in (1) is due to the reflection of electrons from the S-N boundary, which occurs in the case $r \neq 1$ even in the absence of an insulating barrier. The characteristics shown in Fig. 1 correspond to the curves calculated in Ref. 1 for $Z_{\text{eff}} = 0.6$. The experimental conditions rule out essentially entirely any possible appearance of a tunnel insulating layer in our contacts. Setting $Z = 0$ in (1), we then find the value 3.1 for r^{-1}. Using $v_F^{(\text{Ag})} = 1.3 \times 10^8$ cm/s from the free-electron model, we find the estimate $v_F^{(\text{Tc})} = 4.2 \times 10^7$ cm/s. This value is in order-of-magnitude agreement with the data of Ref. 7, which yield $v_F^{(\text{Tc})} = 2.4 \times 10^7$ cm/s.

In examining these results from the standpoint of using them to study the electron-phonon interaction spectra of superconductors, we should note that the clear definition of these structural features corresponds to the best spectra that can be obtained with ordinary tunnel contacts. Consequently, electron-phonon interaction spectroscopy by means of S-N contacts of the intermediate type may find independent applications along with tunnel and microcontact spectroscopy, especially for transition metals and their alloys having a high state density and a low Fermi velocity.

We wish to thank O. A. Balakhovskiĭ for furnishing the technetium samples and M. N. Mikheeva and I. K. Yanson for a discussion of these results.

[1] G. E. Blonder, M. Tinkham, and T. M. Klapwijk, Phys. Rev. B **25**, 4515 (1982).
[2] G. E. Blonder and M. Tinkham, Phys. Rev. B **27**, 112 (1983).
[3] N. V. Zavaritskiĭ, Usp. Fiz. Nauk **108**, 241 (1972) [Sov. Phys. Usp. **15**, 608 (1972)].
[4] I. K. Yanson, Fiz. Nizk. Temp. **9**, 676 (1983) [Sov. J. Low Temp. Phys. **9**, 343 (1983)].
[5] V. A. Khlus, Fiz. Nizk. Temp. **9**, 985 (1983) [Sov. J. Low Temp. Phys. **9**, 510 (1983)].
[6] A. A. Zakharov, M. G. Zemlyanov, M. N. Mikheeva, G. F. Syrykh, and M. B. Tsetlin, Materialy 23-go Vsesoyuznogo soveshchaniya po fizike nizkikh temperatur HT-23 (Proceedings of the Twenty-Third All-Union Conference on Low-Temperature Physics, LT-23), Tallin, 1984, Ch. II, p. 190.
[7] S. T. Sekula, R. H. Kernohan, and G. R. Love, Phys. Rev. **155**, 364 (1967).

Translated by Dave Parsons
Edited by S. J. Amoretty