NONLINEARITY OF RESISTANCE OF A METALLIC POINT CONTACT AND DETECTION OF MICROWAVES AT HELIUM TEMPERATURES

M. S. Khaikin and I. Ya. Krasnopolin
Institute of Physics Problems, USSR Academy of Sciences
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Recent communications report investigations of the nonlinearity of the electric resistance of point contacts cooled with liquid helium, with one of the electrodes made either of a semimetal [1,2] or a superconductor [3,4]. In this letter we report some results of a study of the properties of contacts of ordinary pure metals which are in the normal state at low temperatures.

The objects of the investigation were contacts made of thin Pt wire (10 μ dia) and a bulky Sn sample (other materials were also tested). The contact was produced at liquid-helium temperature by letting the wire touch the bulk sample and welding the two with a weak

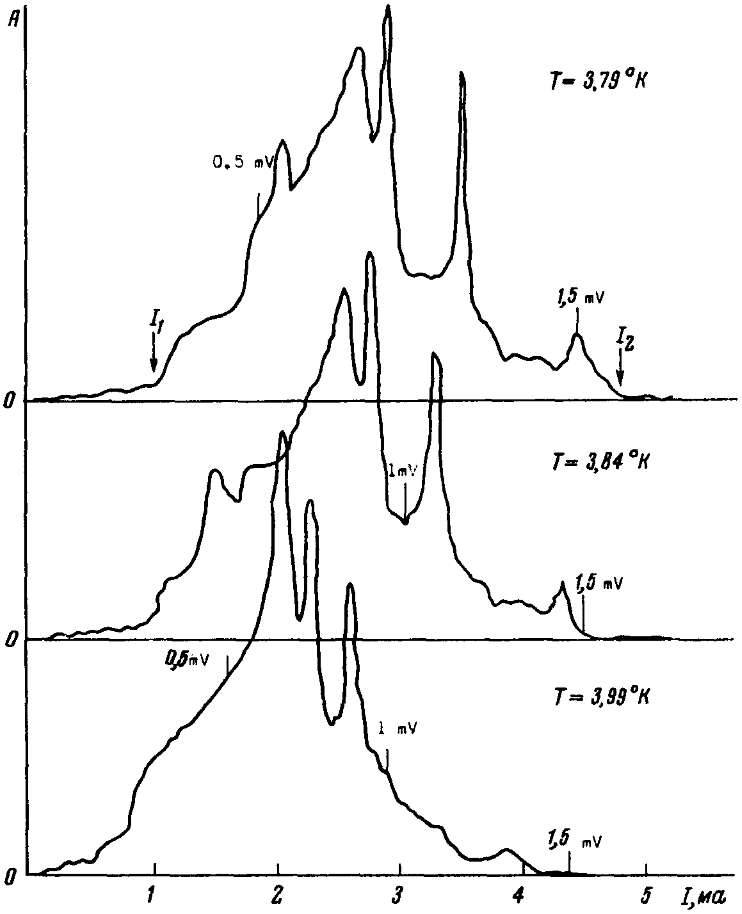

Fig. 1. Plots of A(I) for a Pt + Sn contact, in relative units, at the temperatures T indicated to the right of the curves. The numbers indicate the voltage drop on the contact (in mV).

electric discharge at the instant of touching to make the contact stable. Such a contact had a resistance 0.3 - 1.5 ohm at helium temperature and transverse dimensions 10^{-5} - 10^{-6} cm. The dimensions were estimated from the current necessary to destroy the superconductivity of the contact when cooled below the critical temperature of the tin.

To study the behavior of the resistance R of the contact, two methods were mainly used: plotting the static voltage-current characteristics V(I), and measurement of the low-frequency voltage A obtained by detecting in the contact modulated radiation of 40 GHz frequency. The voltages V and A were recorded as functions of the dc bias current I flowing through the contact. Microwave radiation of 10 - 100 μW power, obtained from the open end of a waveguide introduced into the Dewar vessel, was beamed on the investigated contact, which was placed in liquid helium.

Figure 1 shows an A(I) plot typical of welded contacts: the region of observation of the detected signal lies between I_1 and I_2. The values of I_1 for different contacts range from 0.1 to 1 mA, and those of I_2 from 1 to 10 mA. When the temperature T is raised, the region of nonlinearity of R shifts toward smaller I and the amplitude of A(I) decreases. The detected signal (meaning also the nonlinearity of R) vanishes at a temperature 5.5 - 6°K. Figure 2 shows a sample I_2(T) plot.

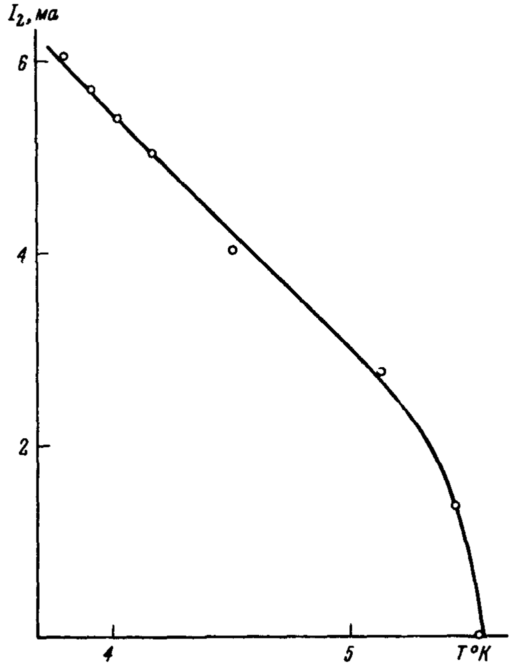

Fig. 2. Temperature dependence of the limit I_2 of the region of the Pt + Sn contact-resistance nonlinearity.

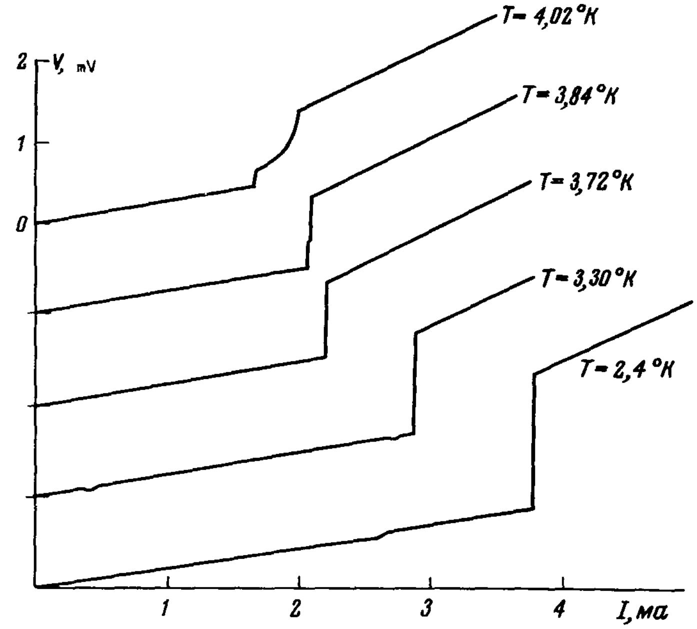

Fig. 3. Static voltage-current charactersitics of Pt + Sn contact at the temperatures T indicated to the right of the curves.

The static characteristics V(I) of welded contacts offer evidence that R changes in the region from I_1 to I_2, the jumps in R corresponding to the peaks on the A(I) curve. Figure 3 shows an example of the static characteristics of the contact, which differs in the fact that the region of nonlinearity of R has narrowed down and has degenerated in practice into a jump of R. As seen from this characteristic, $R_2(I > I_2) \simeq 2.8R_1(I < I_1)$. For other contacts, which have a broader region of resistance nonlinearity (Fig. 1), the ratio R_2/R_1 amounted to 2 - 3. The jump in R, corresponding to destruction of the superconductivity of the contact, is quite different for different contacts; this jump is not noticeable on **Fig. 3**. This circumstance apparently depends on the metal which prevails in the thinnest place of the contact (Pt or Sn). Application of a magnetic field in any direction decreases I_1 and I_2; for example, a 6 kOe field decreases I_2 by ~1.5 times.

Effects similar to those described above were observed also in contacts produced without welding from Pt, Sn, Al, Cu, Au, Nb, and Bi, merely by slightly touching the sharp point and the bulky sample. Increasing the area of the contact by pressing against the point led to vanishing of the nonlinearity of the resistance of the contact and of the detection effect. These facts give grounds for assuming that the nonlinearity of the resistance of the point contact is due principally to the contact geometry and not to individual properties of the metals constituting the contact.

To explain the nonlinearity of the resistance of the structures investigated by them, Esaki and Stiles proposed [1] that superconductivity is produced in the region of contact between the normal metal and the semimetal. Nanney [2] attempted to attribute this phenomenon to the occurrence of thermal instability within the volume of the crystal. However, the question of the nature of the effect still remains unclear; this pertains all the more to the contact between two ordinary metals in the normal state.

We therefore call attention to the following fact, which was observed in our investigation. Whereas the resistance R of the different Pt + Sn contacts ranges between 0.3 and 1.5 ohm (a ratio of 5:1) and the current I_2 ranges from 1.6 to 7.4 mA (a ratio of 4.6 to 1), when $I = I_2$ the voltage drop on the contact differs from the mean value of 1.9 mV by not more than ±25% (current density 10^7 - 10^9 A/cm^2, temperature 4.1°K). It follows from this that the drift velocity acquired by the electrons moving through the contact region, whose dimensions are much smaller than the mean free path, is $v_{dr} \simeq \Delta\epsilon/p \simeq 3 \times 10^5$ cm/sec, i.e., of the order of the speed of sound for Sn, $s = 1.9 \times 10^5$ cm/sec (in this estimate we took for the increase in electron energy $\Delta\epsilon \simeq 2$ MeV and for its momentum $p \simeq 10^{-20}$ g-cm/sec). Such fast electrons should radiate effectively hypersonic phonons of wavelength $\sim 10^{-6}$ cm, i.e., of the order of the dimensions of the contact. This favors excitation of coherent induced emission of phonons from inside the contact, and this should cause deceleration of the electrons in the contact, i.e., an increase of resistance. The foregoing considerations present only a qualitative hypothetical picture of the effect. In any case, however, the occurrence of nonlinearity of the electric resistance of the metal should be regarded as perfectly feasible when the carrier drift velocity reaches and exceeds the speed of sound in the metal. The observed jumps in contact resistance are probably manifestations of the peculiarities of the phonon spectrum [5,6] of the metallic crystal serving as the contact electrode.

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PHOTOELECTRONIC EMISSION FROM ALUMINUM - ALUMINUM OXIDE - GOLD FILM SYSTEM

T. M. Lifshitz and A. L. Musatov
Institute of Radio Engineering and Electronics, USSR Academy of Sciences
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We observed photoelectronic emission from the system Al-Al_2O_3-Au when a strong electric field was applied to the dielectric.

The film system was prepared in the following manner: An aluminum film approximately 1000 Å thick was evaporated in high vacuum (~10^{-7} mm Hg) on a polished glass plate and then oxidized by anodizing in a 3% solution of ammonium citrate [1]. The thickness of the oxide film was determined by the anodizing voltage and monitored by measuring the capacitance of the three-layer system at low frequency (100 Hz). The low-frequency dielectric constant of the aluminum oxide was assumed equal to 8.4 [2]. The thickness of the Al_2O_3 film measured in this manner was 170 Å. The work function of the upper electrode (Au) was lowered by adsorption of BaO molecules [3] to a value 2.6 eV. The investigated samples were illuminated through the upper semitransparent electrode with monochromatic light from a spectrophotometer (SF-4A) with an incandescent lamp as a light source. All measurements were made with direct current.

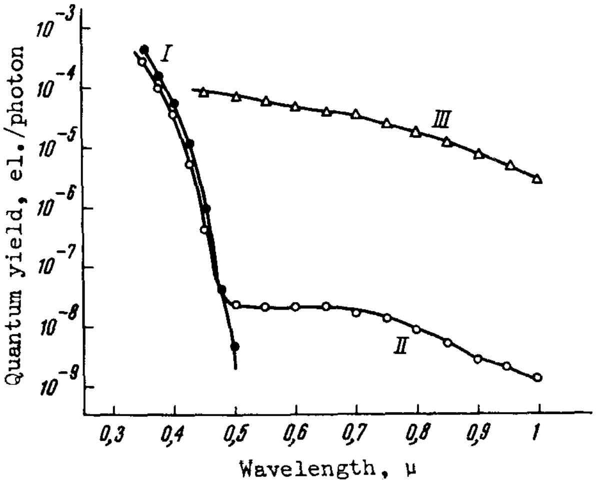

Fig. 1

Figure 1 (curve I) shows the spectral characteristic of the photoelectronic emission from the Al-Al_2O_3-Au film system to the vacuum without applied voltage. The long-wave photoemission limit is 2.6 eV and is equal to the work function of the upper gold electrode, which was measured independently. Photoelectrons are thus emitted only from the upper electrode in the absence of an electric field.

When a voltage of several volts is applied to the film system (with the upper electrode positive), noticeable photoemission