Evidence of an electron–phonon interaction in vanadium on the characteristics of V–oxide–Au tunneling junctions

S. I. Vedeneev and A. V. Pogrebnyakov

P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow

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The current-voltage characteristics of V–oxide–Au film tunneling junctions have been studied. The minima on the second derivatives of the I-V characteristics coincide with structural features in the phonon state density of vanadium.

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The difficulties, which have been encountered in tunneling studies of vanadium,[1-3] impose stringent requirements on the quality of the samples, the cleanliness of their surfaces, and the tunneling barrier at the tunneling junctions. In this letter we are reporting a study of the first and second derivatives of the current-voltage (I-V) characteristics of vanadium film tunneling junctions with a vanadium oxide tunneling barrier. The technique used to fabricate the vanadium films, the characteristics of these films, and measurements of the energy gap and its temperature dependence are all described in Ref. 4.

To study the structure of the I-V characteristics of the tunneling junctions in the phonon frequency region, we used vanadium films with $T_c = 5.1$-5.2 K, $2\Delta(0)/k_BT_c = 3.5$, and $R_{300\,K}/R_{6\,K} = 13$-15, where T_c is the temperature of the superconducting transition, $\Delta(0)$ is the energy gap, k_B is the Boltzmann constant, and $R_{300\,K}$ and $R_{6\,K}$ are the resistances of the film at 300 K and 6 K.

We studied tunneling junctions of the type V–oxide–M, where the second electrode (M) is a film of lead, gold, or silver. Despite many attempts, we did not succeed in fabricating V–oxide–Pb or V–oxide–Ag tunneling junctions with reproducible tunneling characteristics in the phonon frequency region of vanadium (20–30 mV). The leakage currents in the V–oxide–Pb junctions, for example, amounted to $(7$-$8)\times 10^{-3}$ of the tunneling current, and the first and second derivatives of the I-V characteristics in all cases exhibited a structure resulting from an electron–phonon interaction in the lead (see the inset in Fig. 1). These results show that the vanadium films and the tunneling junctions with a vanadium oxide barrier are of good quality, but at voltages above 15-20 mV the characteristics of these junctions are still not satisfactorily reproducible from sample to sample. The characteristics of the V–oxide–Au junctions were more reproducible, and the results reported below refer to these junctions.

The area of the tunneling junction was 5×10^{-3} mm^2, and the resistance of the junction in its normal state was about 1 Ω. A reproducible structure stemming from the electron–phonon interaction in vanadium was observed on the characteristics

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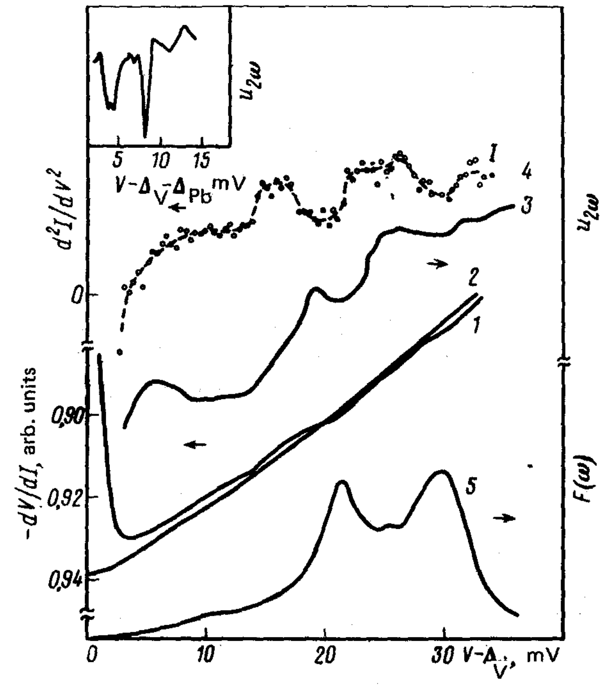

FIG. 1.

of only those tunneling junctions which were made from samples with T_c above 5.1 K, and only if the vanadium films were oxidized in air for no longer than 50 min. When the better tunneling junctions were heated from liquid-helium temperature to room temperature, however, their resistance decreased substantially, making them unsuitable for further study (a high measurement current distorted the characteristics of the tunneling junction). This problem nearly prevented us from carrying out the entire program of measurements required for each sample (i.e., measuring the I-V characteristic, the first derivatives of this characteristic with vanadium in the superconducting and normal states, and the second derivative of this characteristic). We were primarily concerned with recording the first derivatives in the superconducting and normal states, because these derivatives incorporate most of the pertinent information on the tunneling state density. For an accurate determination of the energy position of the structural features observed on the first derivatives of the I-V characteristics of the tunnel junctions, we supplemented the experimental measurement of the voltage dependence of the second-harmonic signal $u_{2\omega}$ with a numerical differentiation of all the experimental first-derivative curves, dV/dI, followed by an averaging over all the curves and all the samples.

Figure 1 shows the voltage dependence of the first derivatives in the superconducting state (curve 1; $T = 1.45$ K) and the normal state (curve 2; $T = 6$ K). Curve 3 is the experimental curve of the second-harmonic signal $u_{2\omega}$ (which is proportional to d^2V/dI^2) at $T = 1.45$ K, while curve 4 is the result found by taking the average of the results of the numerical differentiation of the first derivatives. Also shown in Fig. 1 is the phonon state density $F(\omega)$ in vanadium (curve 5) found from neutron data.[5] The reproducibility of the basic structural features on experimental curves 2 and 3, which correspond to a single sample, and on the average curve 4 (curve 3 was not used for the averaging), on the one hand, and the coincidence of the minima at 20 and 30 mV on curves 3 and 4 with the maxima in the phonon spectrum of vanadium, $F(\omega)$, on the other, suggest that the structure observed on the characteristics of the V–oxide–Au tunneling junctions reflects an electron–phonon interaction in the vanadium.

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