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Tunneling Spectroscopy Studies of SmB_6 and YbB_{12}

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Reported electron tunneling studies of SmB_6 and YbB_{12} in the temperature region with a strongly temperature activated transport reveal a qualitative change of tunneling regime upon cooling. While the differential conductance curves above 50 K resemble the tunneling between two different metals, the spectra observed at 4.2 K are typical of the tunneling between a metal and a (narrow-gap) valence fluctuating semiconductor.

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1. Introduction

Samarium hexaboride and ytterbium dodecaboride are typical examples of valence fluctuating semiconductors (VFSs) among rare-earth borides. While their electronic properties at high temperatures resemble those of a dirty metal, at low temperatures both systems behave as narrow-gap semiconductors [1]. However, many of their low temperature characteristics, such as the temperature dependence of electrical resistivity, exhibit unusual behavior that cannot be satisfactorily explained using a concept of classic semiconductors [1, 2]. Thus several fundamental aspects, e.g. the origin of their forbidden gaps, or the origin of the metallic-like conductivity of SmB_6 at lowest temperatures [2], are still not understood.

A valuable piece of information that can advance the understanding of the physical properties of SmB_6 and YbB_{12} is a knowledge of the electronic density of states (DOS) in the vicinity of the Fermi energy, E_F. The purpose of this work is to probe this quantity using the electron tunneling spectroscopy in the temperature region below 60 K, where a large resistivity increase is observed in both systems.

2. Experiment

We have studied SmB_6 single crystal prepared by the zone floating, and a sintered polycrystalline YbB_{12} sample. Tunneling measurements were performed

by the scanning tunneling spectroscopy approach using mechanically controlled tunnel junctions. In both cases an annealed gold tip was used as a counter electrode. It should be mentioned that due to the formation of an oxide layer on the surface, the tunnel junction electrodes were in a direct mechanical contact, separated by this native insulating barrier.

3. Results and discussion

Figure 1a shows a temperature evolution of the differential conductance–voltage curves of SmB_6–Au tunnel junction between 56 and 4.2 K. The tunneling spectrum at 56 K has an almost parabolic shape with the minimum at a finite voltage. Such behavior is consistent with Brinkman–Rowell–Dynes model of the tunneling between two different metals [3]. Upon cooling a dip typical of VFSs is formed in the vicinity of the Fermi energy, E_F, and data strongly resemble observations of other authors [4]. In a qualitative agreement with studies of transport and thermal properties [2], the DOS at E_F remains finite down to 4.2 K. The shape of the dip strongly resembles a narrow pseudogap.

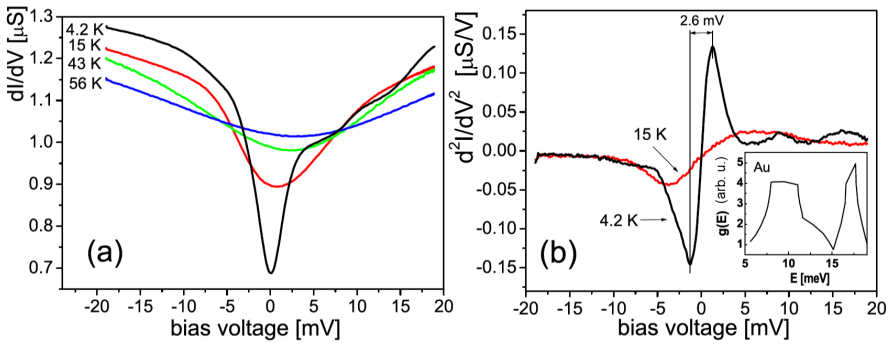

Fig. 1. Tunneling spectra $\mathrm{d}I/\mathrm{d}V$ of SmB_6 at several temperatures between 4.2 K and 56 K (a) and $\mathrm{d}^2I/\mathrm{d}V^2$ curve at 4.2 and 15 K (b). Inset in (b) shows the phonon density of states $g(E)$ of Au obtained by neutron scattering experiments (after [6]).

A qualitatively similar behavior is observed for YbB_{12}, as shown in Fig. 2a. The dip in DOS is clearly seen at 4.2 K. Already at 14 K the steeper decrease in conductance in the vicinity of the zero bias becomes practically invisible, and the spectrum at 55 K shows features typical of the tunneling between two different metals.

A method frequently used for a quantitative derivation of the gap width of VFSs is based on the determination of the energy distance between two extremes (near the zero-bias) in the second derivative $\mathrm{d}^2I/\mathrm{d}V^2$ [5]. Using such a procedure for spectra taken at 4.2 K, where the structure is well defined as demonstrated in Fig. 1b and 2b, we have obtained the gap width 2.6(±0.2) meV and 2.7(±0.2) meV for SmB_6 and YbB_{12}, respectively. These values are in good agreement with the

investigations of other authors [5]. The second derivative $\mathrm{d}^2I/\mathrm{d}V^2$ for SmB_6–Au tunnel junction at 4.2 K shows moreover broad maxima at ≈ 9 and ≈ 17 mV. This might be an intrinsic property of SmB_6, but also a property of the counter electrode, because the second derivative yields the spectroscopic information on the inelastic processes. We prefer the latter case as the corresponding energies well coincide with the peak positions in the phonon density of states for Au (e.g. as obtained from neutron scattering experiments [6], see inset in Fig. 1b).

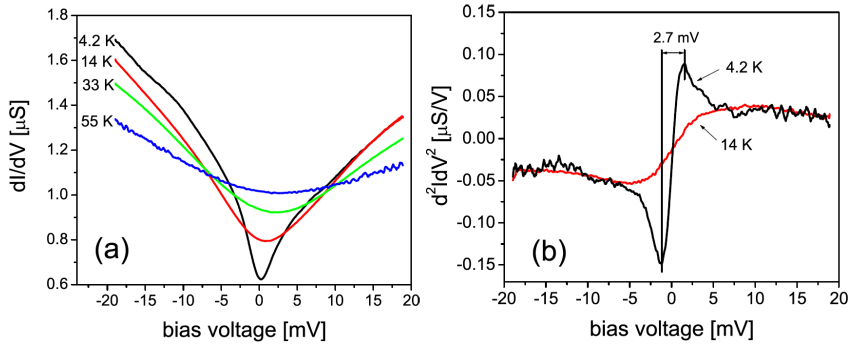

Fig. 2. Tunneling spectra $\mathrm{d}I/\mathrm{d}V$ of YbB_{12} at several temperatures between 4.2 K and 56 K (a) and $\mathrm{d}^2I/\mathrm{d}V^2$ curves at 4.2 and 14 K (b).

4. Conclusions

Based on our experimental observations we infer the following features of the strongly correlated electrons in SmB_6 and YbB_{12}. The continuous qualitative change of tunneling from a *metal(A)–insulator–metal(B)*-type at temperatures $\sim$55 K to a *metal –insulator–VFS*-type at 4.2 K is a clear sign for an increase in correlation effects with temperature decrease, indicating temperature induced a (dirty) metal–VFS transition. Surprisingly (and perhaps coincidentally), just in the temperature region below 50 K a large resistivity increase occurs in both systems [1]. This can be, in principle, alternatively interpreted as a consequence of the localization effects in the vicinity of the Fermi energy. Thus from the point of view of our results at low temperatures SmB_6 and YbB_{12} do not exhibit features of a semiconductor with a well-defined (temperature independent) forbidden gap with zero DOS. They both resemble a system with a correlation (pseudo)gap that opens at sufficiently low temperatures. A similar conclusion was done for SmB_6 by Amsler et al. [4].

Acknowledgments

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