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POINT-CONTACT SPECTROSCOPY OF MUTUAL REB_6 (RE = La, Y, Sm, Ce) BY AUTOMATIC IN SITU CLEANING

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We report a systematic investigation of the differential resistance dV/dI vs voltage characteristics of point-contacts between REB_6-needle on one side and the same REB_6 (100)-cleavage surface on the other in which RE = La, Y, Sm and Ce Enough clean and barrierless spectra of the point-contacts are contrary to the results of the barrier-type tunneling on every pair The gap 2Δ of SmB_6 is 16 meV The Kondo gap 2Δ of CeB_6 is 1 2 meV

1. Introduction

The point-contact method is becoming a powerful spectrometer for low energy excitations in metals at low temperature [1] However, as far as valence instability materials are concerned, the resulting electronic structure has no consistency between authors Especially the inconsistency is remarkable between the metal point-contact (MPC) and the barrier-type tunneling (BTT) In this paper we wish to elucidate the inconsistency systematically using an improved point-contact spectrometer in which an automatic in situ cleaning has been attained [2] First the comparison between MPC and BTT of the normal metal LaB_6 and second of the superconducting YB_6 are done for the reference compounds, and third that of the gap-type valence fluctuation SmB_6, last of the dense Kondo CeB_6 are done

2. Experimental procedure

Measurements are done in two types of ^{4}He cryostat, one is a glass dewar type in which the contact is located in liquid helium between 4 2 and 1 8 K, and in the helium gas phase above 4 2 K, the other is a metal dewar type containing a superconducting magnet in which the contact is located in the controlable low pressure helium gas phase As for one electrode the needle was polished into the shape with a sharp cone edge on a motor driven spindle by SiC-powder of #400, #800, #1000, #2000 and #3000 successively, and etched by the dilute nitric acid just before setting the sample in the cryostat Mechanical contact of the sharp needle tip of REB_6 to the (100)-cleavage surface of the same REB_6 was established at each stage of temperature We can control the movement of the needle by 15 Å per pulse in which we use a pulsed motor and two differential screws preventing a loose fit by springs The needle normally is the plus-electrode when the bias voltage is plus side Further details of this experimental arrangement are described in ref [2] We have done the experiments according to our established criterions to judge the junction quality

3. Results and discussion

3 1 LaB_6 needle – LaB_6 (100) contact

Fig 1 shows typical MPC spectra for LaB_6 needle versus LaB_6 (100)-cleavage surface at 1 8 K The differential resistance dV/dI shows a flat bottom within ± 10 mV followed by a weak rise at a certain voltage corresponding to the electron–phonon scattering The second derivative d^2V/dI^2 shows two prominent peaks at about 12 and 24 mV, and a broad peak at around 35 mV, and a noisy structure around 50 mV We compared our measurements with neutron scattering experiments and found good agreement with the results reported there [3] in

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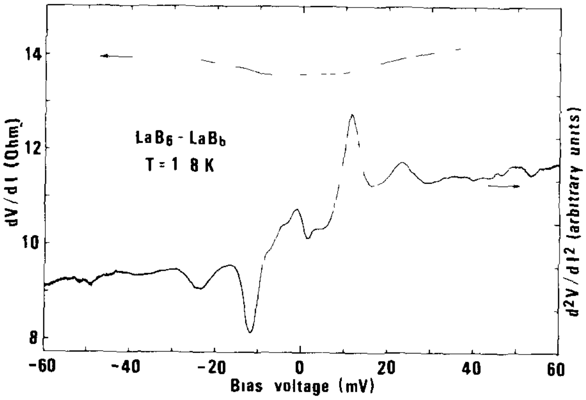

Fig 1 Differential resistance dV/dI and its derivative d^2V/dI^2 as a function of bias-voltage for a point-contact of LaB_6 needle against LaB_6 (100)-cleavage surface at 1 8 K

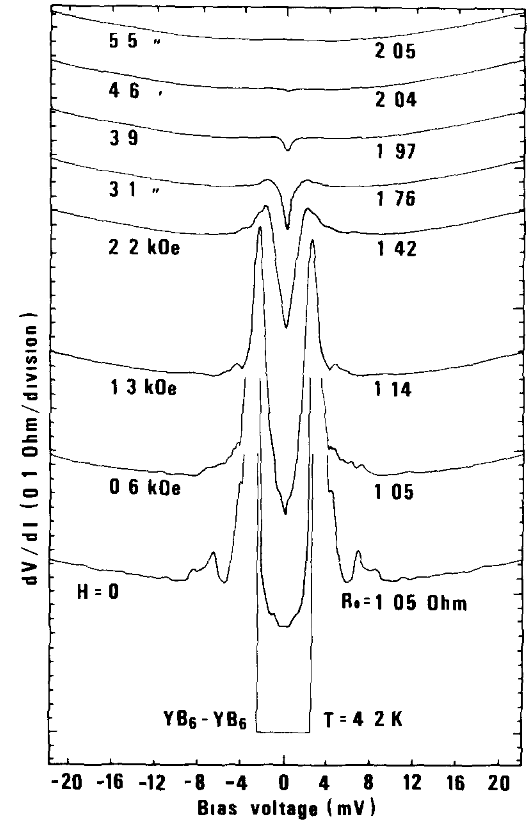

Fig 3 Magnetic field dependence of the differential resistance as a function of bias voltage for a point-contact of YB_6 needle against YB_6 (100)-cleavage surface at 4 2 K

respect to the phonon energy We can easily get these spectra after the suitable automatic in situ cleaning

On the other hand, if we use an intentionally oxydized surface for the electrodes we typically get fig 2 Note that the bias-voltage dependence of the differential resistance is reversed compared with that of fig 1 of the clean surface

3 2 YB_6 needle – YB_6 (100) contact

YB_6 is a type II superconductor with a gap parameter $2\Delta/kT_c = 3\ 8$ and $T_c = 7\ 5$ K [4] Fig 3 shows the spectra of the enough clean contact at 4 2 K At the zero external magnetic field, the differential resistance dV/dI suddenly rises up divergently at $\pm 2\Delta$ As the structures including that of ± 8 mV disappear with increasing magnetic field, they are attributed to the superconductivity At high magnetic field, the spectrum is reduced to that of the clean normal metal contact The sudden increase of the differential resistance dV/dI at $\pm 2\Delta$ is contrary to our GaAs Schottky barrier tunneling in which the sudden increase of the differential conductance dI/dV was observed [4] The reason why we observe such a sudden increase of resistance in MPC is that the electron having the different character and the same phase in the direct coupling system may be strongly repulsive We conclude that the barrierless contact (MPC)

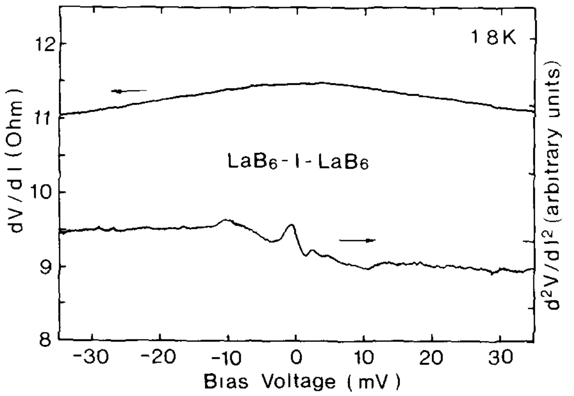

Fig 2 As fig 1, but for leaving samples in the air for one week and no automatic in situ cleaning

shows a reverse energy dependence of dV/dI compared with BTT.

3 3 SmB_6 ⟨110⟩-needle vs SmB_6 (100) contact

For SmB_6–SmB_6 contacts we often obtain the spectra like fig 4 in which the total behavior is similar to the reported spectra of not only MPC [5] but BTT [6] except the energy scale However, the peak width is always scattered depending on the contact resistance as is shown in figs. 4a, b and c We think that these spectra come from the barrier type contact because of the conclusion in section 3 2 and the result of our BTT observation [2] It should be noted that SmB_6 usually has different surface layers from the inside bulk layers [7] Since the tip of the needle is widely surrounded by the surface, on the other the sample surface is rather stable cleavage surface, first we tried to destroy the surface layer of the needle by the repeated automatic in situ cleaning using rather high discharge cleaning voltage Then the position of the needle is moved to another point on the sample surface and the junction is established after the several automatic in situ cleanings Finally we get the spectra as is shown in fig 5 frequently in the cryostat of nearly vacuum stage The peak to peak width of the second derivative d^2V/dI^2 is always constant for any contact resistance Because of the mutual SmB_6 contact in this case we conclude that the gap 2Δ of SmB_6 is 16 meV using the definition Δ of superconductivity

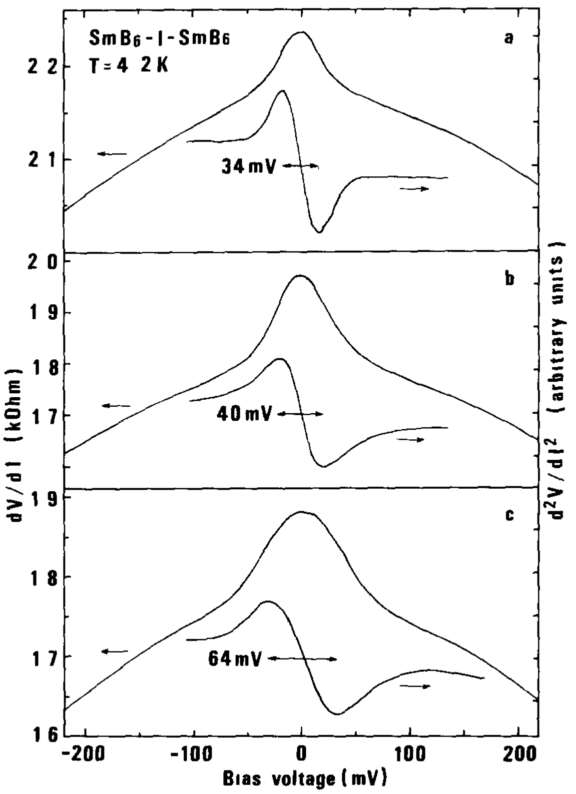

Fig 4 Differential resistance and its derivative as a function of bias-voltage for a point-contact of SmB_6 ⟨110⟩-needle against SmB_6 (100)-cleavage surface at 4 2 K The contact in liquid He stage for different contact resistance a, b and c

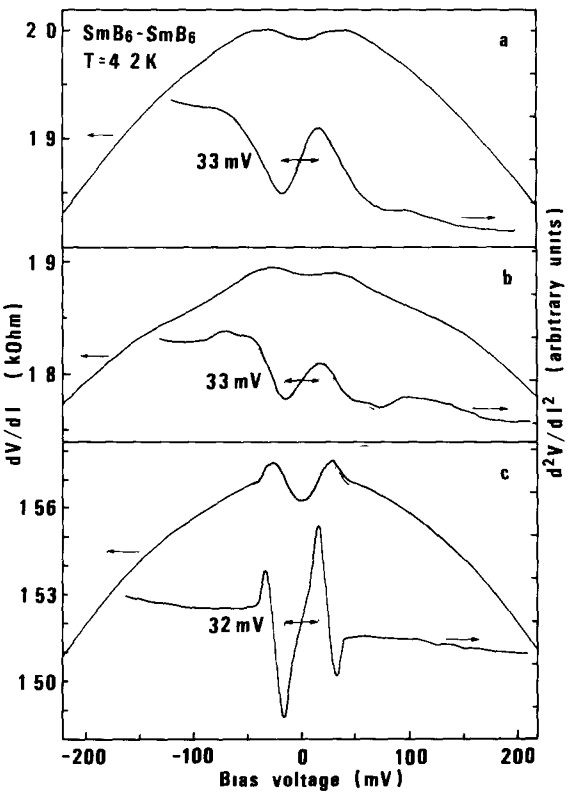

Fig 5 As fig 4, but for the contact in nearly vacuum, and special care was taken for an automatic in situ cleaning (see text)

3.4 CeB_6 ⟨100⟩-needle vs CeB_6 (100) contact

CeB_6–CeB_6 contacts always give the stable and reproducible spectra. In fig. 6 the contact resistance dependence of the normalized differential resistance are shown as a function of the applied voltage at 1.9 K. There is a large resistance minimum around the zero bias as is shown in the figure which is different from our previous report of GaAs Schottky barrier result [2] because of no barrier in this case. The resistance maximum occur at ±1.6 mV. Then the resistance decreases with increasing bias voltage. The decrease of the resistance as a function of the applied voltage in a logarithmic scale shows linear behavior at high bias-voltage which is consistent with the reported Kondo behavior in MPC [8]. It is noted that we clearly observe the differential resistance maximum on 1.6 mV even at 4.2 K, though the static resistivity of CeB_6 only decreases with increasing temperature above 4.2 K [9]. This means that a simple heating model [10] may not be our case. We found the gap-type spectra in CeB_6, we should say that we found the "Kondo gap" in CeB_6. The Kondo gap 2Δ of CeB_6 is 1.2 meV from the second derivative peak to peak width. It should be noted that the energy 1.6 meV of the resistance maximum is two times larger than that of the Pt–CeB_6 contact [10]. The reason is that our contact is mutual CeB_6. We think there should be coherent Kondo states in CeB_6 at the Fermi level at low temperature. The coherent Kondo state is thought to have a long mean free path. The each two coherent Kondo states is broken near the energy up till 1.6 meV and is promoted to incoherent Kondo states, and then becomes normal electrons at high bias-voltage.

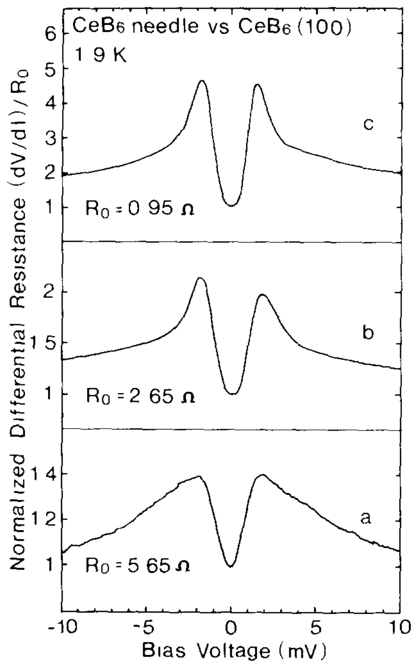

Fig. 6. Contact resistance dependences a, b and c of the differential resistance as a function of bias-voltage for a point-contact of CeB_6 ⟨110⟩-needle against CeB_6 (100)-cleavage surface at 1.9 K.

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