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Point-Contact Spectroscopy of Crystalline Electric Field of Heterocontacts PrB_6 and NdB_6 with Pt

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Point-contact spectra of single crystals PrB_6 and NdB_6 are presented. We observed maxima connected with crystalline electric field excitations in agreement with previous results for applied voltage $V > 8$ mV. Moreover, we observed maxima at 6 mV (PrB_6) and 3 mV (NdB_6), which are probably connected with phonon modes. Moreover, we observed phonon peak at 10.6 mV in PrB_6. Further measurements in magnetic fields and crystalline electric field calculations are necessary.

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1. Introduction

Rare-earth hexaborides with a simple cubic CaB_6-type structure have been attracting much attention because of their variety of electronic and magnetic properties. Both investigated compounds exhibit complex phase diagram at low temperatures. In PrB_6 the multiplet $J = 4$ splits into 4 crystalline electric field (CEF) energy levels — two triplets Γ_5 and Γ_4, a non-magnetic doublet Γ_3, and singlet Γ_1, which was confirmed by measurements of inelastic neutron scattering (INS) [1] and by the Raman scattering [2]. This compound shows antiferromagnetic (AF) phases at $T_{N1} = 7$ K and $T_{N2} = 4.3$ K [3, 4]. The ground state is a triplet Γ_5. NdB_6 is interesting due to its complicated magnetic transport properties, namely the anomalous large variation of the Hall coefficient in the neighborhood of critical temperature [5]. NdB_6 orders in an A-type collinear antiferromagnetic structure below $T_N \approx 8$ K [6]. The ground state of the Nd^{3+} ions ($J = 9/2$) in crystalline electric field is the $\Gamma_8^{(2)}$ quartet. There are other two CEF levels — quartet $\Gamma_8^{(1)}$

and doublet Γ_6. This scheme was experimentally proved by both INS [1] and measurements of the Raman scattering [7]. All experimental information have been obtained only in the paramagnetic region above T_N. Moreover, the incident energy of 37 meV produced a quasielastic peak, covering the region below ≈ 5 meV. Therefore, we have used point contact (PC) spectroscopy in order to determine the evolution of CEF in magnetically ordered phases of both compounds. PC spectroscopy enables us to measure energy spectrum of quasiparticles like phonons, magnons, CEF excitations by injection of conduction electrons through a metallic PC [8].

2. Experimental

PC spectroscopy experiments were performed on the cubic intermetallic compounds PrB_6 and NdB_6. Both PrB_6 and NdB_6 are single crystals. They were prepared by the floating zone method. The point contacts were made at liquid helium temperatures by bringing a Pt needle (heterocontacts arrangements) in touch with the surface of the PrB_6 or NdB_6 sample. Derivatives $d^2V/dI^2(V)$ and $dV/dI(V)$ of the $I-V$ characteristics were measured using a standard PC technique [8] in the temperature range 1.5–10 K.

3. Results

In Fig. 1 the characteristic temperature behaviour of point-contact spectra of PrB_6 is shown (above T_{N1}, between T_{N1} and T_{N2}, and below T_{N2}). One can see the first peak, present at all temperatures, which is moving from 4.7 mV in paramagnetic region to 5.8 mV in low temperature ordered phase. In the incommensurate (IC) phase it lies at 5.4 mV. This peak cannot be connected with CEF structure neither with phonon structure determined by PC spectroscopy in isomorphous LaB_6 compounds, because the lowest phonon peak is at about 12 mV [9]. Therefore, taking into account the molecular weight correction, the peak at 10.5 mV (not shifted with changing temperature) is connected with phonons of PrB_6. However, below 10 meV the Raman scattering data [2] showed the peak, which is connected with the displacement of the Pr-ion (phonon origin). Therefore, we suppose a phonon origin of the first peak. To confirm this, measurements in magnetic fields are necessary.

The positions of transitions within the CEF scheme in paramagnetic phase [1] are marked by arrows in Fig. 1. When we pass into the incommensurate phase the maximum at about 33 mV appears, which could be connected with the transition into the Γ_4 level. After passing to the ordered phase (below T_{N2}) the maximum at 28 mV appears which can be connected with transition into the Γ_3 level. The appearing and disappearing of both maxima can be explained by different transition probabilities in different magnetic phases. The peak at 23 mV is connected probably with the existence of IC phase. The observed structures are reproducible.

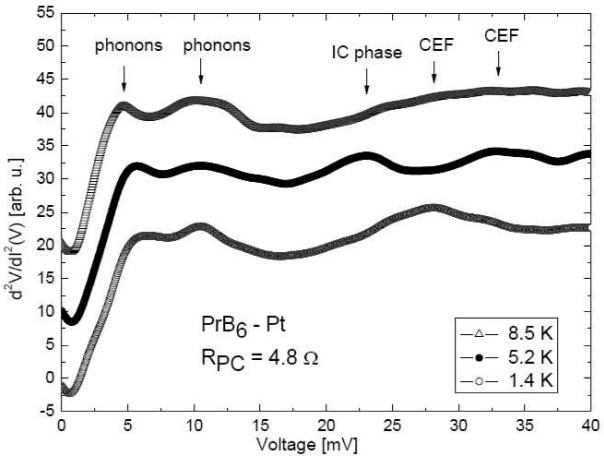

Fig. 1. Characteristic temperature behaviour of point-contact spectra of PrB_6–Pt.

In Fig. 2 the characteristic temperature behaviour of the point-contact spectra of NdB_6 is shown (above and below T_N). Similar to PrB_6, we have observed the peak at 2.8 mV (lower energy) in the magnetically ordered phase. This peak remains as a shoulder in paramagnetic region, too. Due to the same arguments as in the case of PrB_6 we suppose that it is due to the electron–phonon interaction. In agreement with the CEF scheme determined from INS [1] we have observed a peak at 12.2 mV in paramagnetic state, which is connected with CEF excitations from ground state into the excited state $\Gamma_8^{(1)}$. This peak is shifted to 12.5 mV in the magnetically ordered phase in agreement with the calculations of CEF splitting caused by the magnetic ordering.

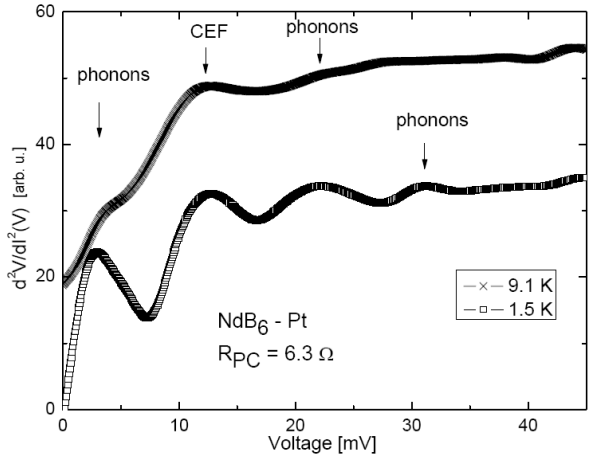

Fig. 2. The characteristic temperature behaviour of point-contact spectra of NdB_6–Pt.

In magnetically ordered phase we have seen another 2 maxima at ≈ 22 and ≈ 31 mV which are less pronounced in the paramagnetic state (due to thermal smearing of PC spectra). Taking into account the phonon point-contact spectra of LaB_6 [9] we conclude that this structure is due to the interaction of conduction electrons with phonons in NdB_6.

In order to confirm the origin of the first observed peak in both compounds we need to do measurements of homocontacts, too, and in magnetic fields. Moreover, new calculations of CEF splitting, taking into account the IC phase, are necessary.

In conclusion, we have measured point-contact spectra of heterocontacts between PrB_6, NdB_6, and Pt. We have observed the low energy peaks in both compounds (5.8 and 2.8 mV) not previously observed in INS measurements. They have probably a phonon origin. Therefore, measurements of homocontacts, and in magnetic fields are necessary. Other observed peaks and maxima, connected with the scattering of conduction electrons on phonons and with CEF excitations are in agreement with previous results.

Acknowledgments

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