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POINT-CONTACT SPECTROSCOPY OF $NdNi_5$*

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The measured point-contact (PC) spectra of the heterocontact between oriented hexagonal single crystal of ferromagnetic $NdNi_5$ and Cu in ballistic regime are presented above and below T_C. We have observed maxima at characteristic energies 1.5 meV and 4 meV which have the crystalline electric field origin. The small shoulder at 9 meV and a broad maximum at about 18 meV are connected with phonons in $NdNi_5$.

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1 Introduction

The intermetallic RNi_5 (R = rare earths) compounds crystallize in the simple $CaCu_5$-type hexagonal structure [1]. They have been the subject of detailed studies during the last years [2]. In this series the Ni atoms are nonmagnetic, although they are very close to the onset of Ni magnetism. Therefore, the R-ions determine the magnetic properties predominantly. The ferromagnetic $NdNi_5$ with T_C = 7 K [3] is interesting because of its large magnetocrystalline anisotropy. Crystalline electric field (CEF) splits the Nd^3 ground state multiplet $^4J_{9/2}$ into 5 doublets including doublet ground state $\Gamma_8^{(2)}$ [3]. The CEF of $NdNi_5$ has been studied directly only in paramagnetic state by inelastic neutron scattering [4] in zero magnetic field. The energies of CEF eigenstates have been obtained from the temperature dependence of magnetization, susceptibility and specific heat also, using a finite procedure to estimate the unknown CEF parameters in the Hamiltonian [3], and from the specific heat [5]. In a magnetically ordered state, the behaviour of the CEF levels can be estimated theoretically by adding a Zeeman term to the Hamiltonian describing the system.

In this paper we have used the PC spectroscopy to study directly the electron-quasiparticle interaction in $NdNi_5$. PC spectroscopy has been shown to be very useful experimental technique

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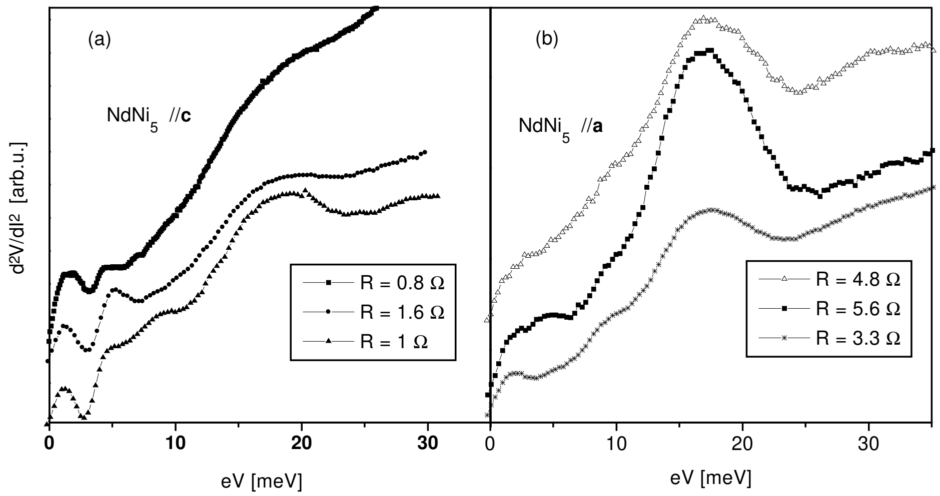

Fig.1. Characteristic PC spectra of $NdNi_5$ - Cu heterocontacts in ballistic regime at 1.5 K. The PC axis is oriented along **c** (a) and **a** (b)

for direct study of the energy dependence of the interaction between conduction electrons and quasiparticles in metalls and metallic compounds [6], [7]. This method is based on the fact that transport of electrons through clean metallic contacts, where both the inelastic l_i and elastic l_e mean free paths of the electrons are larger than the contact diameter d, is ballistic. The applied voltage accelerates electrons and thus it directly defines the energy scale for their scattering processes. Then the second derivative d^2V/dI^2 of PC $I - V$ characteristic is directly proportional to the spectral function for the interaction process under study.

2 Experimental

The PC measurements were performed on heterocontacts between an oriented hexagonal single crystal of $NdNi_5$ and Cu in temperature range 1.5 K - 10 K. $NdNi_5$ has been oriented along the main two of three axes of the hexagonal cell, along **a** (in basal plane) and along **c** (perpendicular to basal plane). The heterocontacts were made by pressing a Cu needle onto the surface of $NdNi_5$. Before measurements the samples were electrochemically polished. The $I - V$ characteristics and their derivatives d^2V/dI^2 and dV/dI were recorded simultaneously by a phase - sensitive detection method [6].

3 Results and discussion

In Fig.1. the characteristic PC spectra of heterocontacts between $NdNi_5$ and Cu in ballistic regime at 1.5 K when the PC axe is oriented along **c** (a) and along **a** (b), are shown. We have observed peaks at 1.5 meV, 4 meV, small maximuma at 9 meV and $\approx$ 13 meV, and the broad peak at about

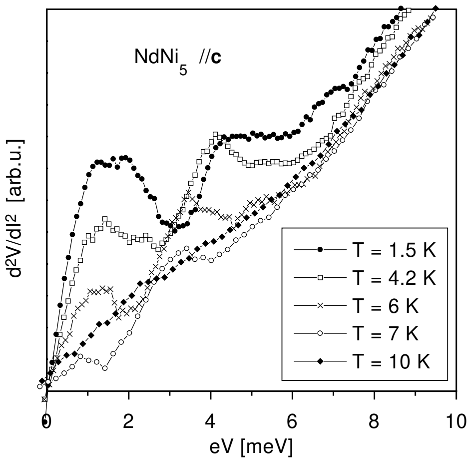

Fig.2. Characteristic temperature dependence of PC spectra of NdNi$_5$ - Cu heterocontact below and above T_C when PC axis is oriented along **c**

18 meV and small maximum at 30 meV. The structure of the spectra is due to the generation of phonons in Cu and NdNi$_5$ and due to excitation of the Nd^{3+} ion from the ground state by the accelerated electrons. The broad maximum at about 18 meV is associated with the energy of transverse Cu phonons [7] and NdNi$_5$ phonons [8]. The small peak at 9 meV is ascribed to phonons in NdNi$_5$. The small peak at 30 meV is connected with the phonons of Cu. One can see that the intensity of the main phonon peak at about 18 meV along **c** differs from that at 18 meV along **a** axis. From this follows the anisotropy of the electron-phonon interaction in single crystal NdNi$_5$ which is more intense along **a**. It means that the CEF (magnetic) contribution to the bulk electrical resistivity of NdNi$_5$ along **c** will be larger than along **a** axis. This phonon related signal does not change with the increasing of temperature. Then the low energy part of PC spectra which is changing with increasing temperature, has the CEF origin. Taking into account the inelastic neutron scattering results on NdNi$_5$ [4] we could explain the peaks at 1.5 meV, 4 meV and $\approx$ 13 meV due to the excitations of $4f$ electrons from CEF ground state to higher states.

In order to associate the CEF peaks with individual transitions we have measured the temperature dependence of PC spectra below and above T_C in the temperature range 1.5 K - 10 K. In Fig.2. such a characteristic behaviour is presented for the PC axe oriented along **c**. Then taking into account the inelastic neutron scattering results [4] and the results of fitting procedure [3] we can conclude that the peak at 1.5 meV (1.5 K) is related to the CEF excitation of the Nd^{3+} ion from the ground state $\Gamma_8^{(2)}$ to first excited state $\Gamma_9^{(2)}$. The peak at $\approx$ 4 meV is associated with the transition to second CEF level Γ_7. Finally, the small peak at $\approx$ 13 meV is due to the CEF transition of the Nd^{3+} ion from the ground state $\Gamma_8^{(2)}$ to $\Gamma_8^{(1)}$.

4 Conclusions

We have measured the electron-quasiparticle interaction function of NdNi$_5$. We have observed anisotropy of the electron-phonon part of PC spectra and have identified the individual CEF transitions.

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