POINT-CONTACT SPECTROSCOPY
OF $Ce_{1-x}RE_xNi_5$ (RE = Pr, Nd)

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We report on the study of the electron–quasiparticle interaction function in $Ce_{1-x}RE_xNi_5$ (RE = Pr, Nd) pseudobinary compounds for $x = 0, 0.2, 0.5, 0.8$, and 1 measured by means of point-contact spectroscopy. The measured point-contact spectra (d^2V/dI^2 — directly proportional to the electron–quasiparticle interaction function) of the heterocontacts between $Ce_{1-x}RE_xNi_5$ and Cu in the ballistic regime are presented.

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In this paper we present the results in $Ce_{1-x}RE_xNi_5$ (RE = Pr, Nd) pseudobinary compounds obtained from point-contact (PC) spectroscopy in order to obtain information on the modification of the electron–quasiparticle interaction (EQI) function. In $RENi_5$ compounds the Ni ions are not magnetic and the magnetic properties are determined by RE. $CeNi_5$ is a Stoner enhanced paramagnet which is characterized by the influence of spin fluctuations on its properties [1]. On the other hand, $PrNi_5$ is a Van Vleck paramagnet [2] in which the absence of magnetic order is due to the existence of a singlet nonmagnetic crystalline electric field (CEF) ground state, while $NdNi_5$ is a ferromagnetic compound ($T_C = 8$ K [3, 4]) with a doublet CEF ground state.

In order to study the disappearance of the spin fluctuation effects in $CeNi_5$ [1] and the evolution of the CEF energy level scheme in these series we have measured polycrystalline samples of pseudobinary $Ce_{1-x}RE_xNi_5$ series with $x = 0.2, 0.5$, and 0.8 by means of point-contact spectroscopy. The compounds $Ce_{1-x}Pr_xNi_5$ are all paramagnetic and $Ce_{1-x}Nd_xNi_5$ with $x = 0.2, 0.5$, and 0.8 are ferromagnetic with $T_C = \sim$ 2 K, 3.5 K, and 5.1 K, respectively [5].

The point-contact spectroscopy has proved to be a very useful experimental method for the direct study of the energy dependence of the interaction between conduction electrons and quasiparticle excitations in metals [6, 7]. Small constrictions between two metals show deviations from Ohm's law. For such clean metallic

contacts, where both the inelastic l_i and elastic l_e mean free paths of the conduction electrons are larger than the contact diameter d, the transport of electrons through the constriction is ballistic. With an applied voltage across the contact, the electrons are accelerated when passing through the contact area. Thus, the applied voltage directly defines the energy scale for the scattering process of the electrons. The relaxation of accelerated electrons results in voltage-dependent corrections to the current. These deviations are most clearly visible in a measurement of the second derivative d^2V/dI^2 of the $I-V$ characteristic. This d^2V/dI^2 curve is proportional to the spectral function for the interaction process under study.

The thermal effects start to play a role when the PC diameter is larger than both (l_i, l_e) mean free paths. Then the temperature in the PC region is locally increased by Joule overheating with the applied voltage increasing [8].

The hetero-PCs were made by pressing a Cu needle onto the surface of electrochemically polished $Pr_{1-x}Nd_xNi_5$ polycrystalline surfaces. The derivatives dV/dI and d^2V/dI^2 of the $I-V$ characteristics were measured using a phase-sensitive technique [7] in the temperature range from 1.5 K up to 10 K.
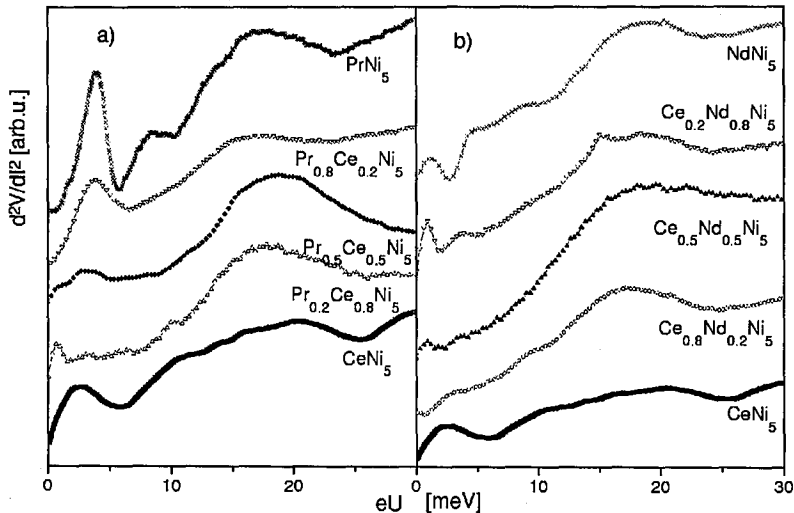

Fig. 1.   The characteristic PC spectra of (a) $Ce_{1-x}Pr_xNi_5$-Cu and (b) $Ce_{1-x}Nd_xNi_5$-Cu heterocontacts ($x = 0$ [1], $0.2, 0.5, 0.8, 1$ [2, 4]) in the ballistic regime at 1.5 K.

In Fig. 1a the measured characteristic PC spectra (directly proportional to the EQI function) for heterocontacts between $Ce_{1-x}Pr_xNi_5$ ($x = 0, 0.2, 0.5, 0.8, 1$) and Cu in the ballistic regime at 1.5 K are shown.

A broad maximum at about 18 meV which is characteristic of all the compounds is observed. Taking into account the previous results on pure $PrNi_5$ [2], $CeNi_5$ [1], and $NdNi_5$ [4] we can conclude that this maximum and the small shoulder at ~ 9 meV are both associated with the scattering of the electrons by phonons in $Ce_{1-x}RE_xNi_5$ at 9 meV and in Cu for at 18 meV. It is noteworthy that the

small shift of the shoulder at ~ 9 meV to a higher energy (10 meV) in the case of $CeNi_5$ is in good agreement with the change of the cell volume in these series of compounds [5]. Moreover, the small shoulder at about 13 meV in $PrNi_5$ is associated with CEF transfers [2].

The main differences found in the EQI functions are observed in the low energy part of PC spectra, contributions which are responsible for most interesting physical properties in these compounds. Therefore, we have shown in Fig. 2 the low energy parts (below 12 meV) for all the spectra.
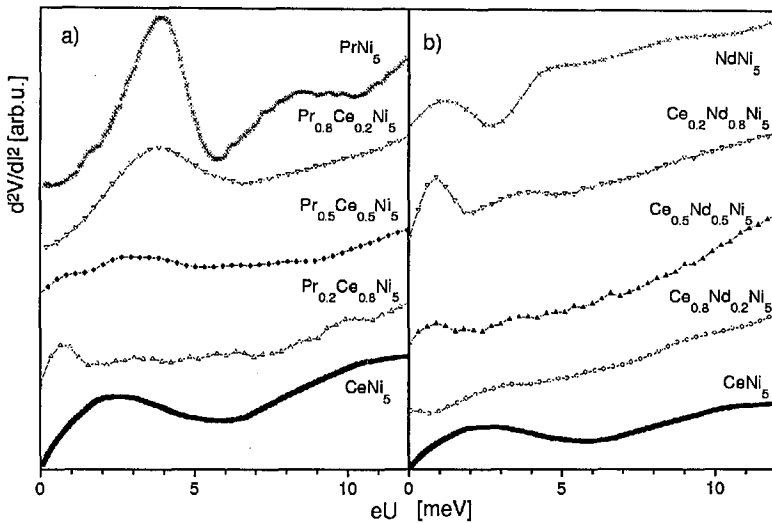

Fig. 2. Low energy parts of characteristic PC spectra of (a) $Ce_{1-x}Pr_xNi_5$-Cu and (b) $Ce_{1-x}Nd_xNi_5$-Cu heterocontacts ($x = 0$ [1], $0.2, 0.5, 0.8, 1$ [2, 4]) in the ballistic regime at 1.5 K.

In this low energy range we have observed that the intensity of the peak at ~ 4 meV (Fig. 2a), which is connected with the CEF excitations of $4f$ electrons from the CEF ground state to the third excited state in $PrNi_5$ [2] is lowering with decreasing the Pr content. This peak is slightly shifted to lower energies (~ 3 meV) for $x = 0.5$ and 0.2 and it vanished only for $x = 0$. In $CeNi_5$ [1] the broad peak at about 2.5 meV is connected with spins fluctuations (paramagnons), while the maximum at 1 meV for $x = 0.5$ which becomes a peak for $x = 0.2$ could be explained as due to CEF excitations, taking into account the CEF level scheme for $PrNi_5$ [2]. It is then probably so that this transition is related to the transfer from the ground state to the first CEF excited state which is now allowed due to modifications of CEF eigenfunctions. Therefore, the spin fluctuations are important only when the Ce content is $\geq 80\%$. In contrast, the peak associated with the spin fluctuation contribution in $CeNi_5$ is present also in $Ce_{0.8}Nd_{0.2}Ni_5$ although at slightly higher energy (Fig. 2b). On the other hand, for smaller Ce content one can see the vanishing of this spin fluctuation contribution, the appearance of a

peak ~ 1 meV for $x = 0.5$ and the slight maximum at 4 meV, which is shifted to 4.8 meV in NdNi$_5$. Taking into account the results on NdNi$_5$ [4], all these peaks could be associated with CEF excitations of $4f$ electrons from the CEF ground state to higher excited states.

From this study it follows that in CeNi$_5$ the spin fluctuations are suppressed more rapidly with the dilution with Pr ions than with Nd ions. In order to get a better insight on the vanishing of the spin fluctuation contribution, further investigations on compounds with Ce concentration more than 80% are needed.

In conclusion, we have measured the EQI function in Ce$_{1-x}$RE$_x$Ni$_5$ series with $x = 0.2, 0.5$, and 0.8 (RE = Pr, Nd). We have observed that the peak associated with spin fluctuation at ~ 2.5 meV in CeNi$_5$ is shifted to higher energies and it disappears for $x = 0.5$ with increasing Nd content while in the case of Pr it disappears already for $x = 0.2$. The other observed contributions could be explained from CEF excitations.

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