The effect of doping on the coherence Kondo gap in CeRhSb

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Cerium-based Kondo-lattice systems exhibit unusual physical phenomena such as a strong enhancement of the quasiparticle effective mass (heavy-fermion (HF) behavior) or a Kondo insulating state. Typical examples of cerium-containing insulators with a narrow energy gaps in the electronic density of states (DOS) are CeNiSn [1] and CeRhSb [2]. The nonmagnetic insulating state of both compounds settles down at very low temperatures, but they become HF metals at higher temperature, $T>T_K$. The qualitative picture of both HF metals and the Kondo insulator is based on the idea that the ground state results a competitive character of the Kondo and the RKKY interactions. If the RKKY interaction predominates, various magnetic ground states can occur. If the Kondo interaction predominates, the hybridization between localized *f*-electron and conduction states can lead to a formation of a charge gap or pseudogap at the Fermi energy [4]. A paramagnetic Kondo insulator is usually discussed theoretically within the periodic Anderson model.

The numerical calculations show that the Kondo gap depends strongly on magnitude of the hybridization between Ce-*f* and the transition -*d* metal states [5], whereas the Ce *f* and Sn or Sb *p* mixing is small. In case the momentum-dependent hybridization, the gap may vanish at some points or along lines providing a semimetallic ground state.

The stability of para- or magnetic ground state in the Kondo-lattice limit is also dependent on the number of free electrons. Therefore, the energy gap in Ce-based Kondo insulators is very sensitive to the partial substitution. Previous alloying studies show that replacing Sn ions of CeNiSn by Sb, or Sb ions of CeRhSb by Sn leads to formation respectively a ferromagnetic Kondo lattice, or the non-Fermi liquid (NFL) ground states.

In typical heavy fermion systems, the strength of the *f*-electron-conduction electron exchange interaction can be tuned by composition or pressure, resulting in either dominant intrasite Kondo or intersite RKKY interactions [3]. In the vicinity of the onset of magnetic ordering, the competition between the Kondo and RKKY interactions can induce a zero-temperature magnetic-nonmagnetic transition, which leads to deviations from the standard Fermi liquid scaling of bulk physical properties. For a Landau Fermi liquid (LFL) at temperatures much smaller than the Fermi temperature, the specific heat C divided by temperature *T*, *C/T*, and the magnetic susceptibility χ approach constant values, whereas the electrical resistivity ρ varies as T^2. Materials in which *C/T*, χ, and ρ do not confirm to these Fermi liquid temperature dependencies are referred to as non-Fermi liquids. In recent years, an increasing number of Ce-based HF metals were shown to display pronounced deviations from the properties of conventional LFLs when they are tuned through an antiferromagnetic (AF) quantum critical point (QCP) by varying a control parameter such as chemical composition, pressure or magnetic field [6-8]. In particular, the electrical resistivity rises as a function of temperature ($\Delta\rho \propto T^{\varepsilon}$) with exponents $1<\varepsilon<2$, the specific heat diverges logarithmically with decreasing *T* or shows a T^{-n} dependence with $n<1$, and the magnetic susceptibility varies as T^{-n}.

The compound CeRhSn exhibits a non-Fermi liquid character of the temperature dependency for low-temperature physical properties [9] which were discussed in terms of the Griffiths phase model[10].

In view of the different behavior of CeRhSb with respect to that of CeRhSn, it is of interest to examine the solid solution $CeRhSb_{1-x}$ Sn_x, to see the effect of decreasing the

number of the conduction electrons (with the increasing *x* on the gap formation in CeRhSb, as well as to trace the changes in the ground state properties across the series. It is also important to see how a coherent Kondo-lattice state evolves with the increased substitution of Sn. Our measurements indicate that the gap in CeRhSb is rapidly supperssed even by substitution of a small amount of Sn, although the XPS spectra continue to show a mixed-valent behavior for Ce ions. Further, the NFL behavior in CeRhSn is suppressed even by a small Sb substitution.

We also present a new data of the resistivity and susceptibility of the $Ce_{1-x}La_xPdSb$ series, which for a small Ce concentration exhibit a NFL-like low-T scaling.

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[1] T. Takabatake, F. Teshima, H. Fujii, S. Nishigori, T. Suzuki, T. Fujita, Y. Yamaguchi, J. Sakurai, and D. Jaccard, Phys.Rev.B **41**, 9607 (1990).
[2] S. K. Malik and D. T. Adroja, Phys. Rev. B **43**, 6277 (1991).
[3] S. Doniach, Physica B **91**, 231 (1977).
[4] P. Coleman, Phys. Rev. Lett. **59**, 1026 (1987).
[5] T. J. Hammond, G. A. Gehring, M. B. Suvasini, and W. M. Temmerman, Phys. Rev. B **51**, 2994 (1995).
[6] H. V. Löhneysen, J. Phys.: Condens. Matter **8**, 9689 (1996).
[7] N. D. Mathur, Nature (London) **394**, 39 (1998).
[8] K. Heuser, E. -W. Scheidt, T. Schreiner, and G. R. Stewart, Phys. Rev. B **57**, R4198 (1998).
[9] A. Ślebarski, M. B. Maple, E. J. Freeman, C. Sirvent, M. Radlowska, A. Jezierski, E. Granado, Q. Huang, and J. W. Lynn, Phil. Mag. B **82**, 943 (2002).
[10] A. H. Castro Neto, G. Castilla, and B. A. Jones, Phys. Rev. Lett. **81**, 3531 (1998).

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