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Electron spin resonance of dense Yb-based heavy-fermion compounds: New experimental data

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ABSTRACT

We report the more recent advances in electron spin resonance (ESR) of few undoped Yb-based intermetallic compounds with heavy fermions (HF). The X-band ESR spectra of the Kondo lattices YbBiPt, $YbRh_2Pb$, and YbT_2Zn_{20} (T = Fe, Co) are presented. A comparison with earlier ESR studies in $YbRh_2Si_2$ and $YbIr_2Si_2$ shows that the exchange interactions between the Yb 4f electrons and relevant conduction electron (d-, s-, or p-like) bands as well as the hybridization crystalline electric field (CEF) effects should be taken into account in order to develop a reliable model of spin dynamics in the Yb-based HF systems.

1. Introduction

ESR has been used the last three decades as a powerful method to investigate very different HF compounds [1]. Usually, it is necessary to dope HF systems with small concentrations of rare-earth ions in order to detect any measurable ESR signal because of a very fast spin-lattice relaxation of the Kondo ion. However, the ESR measurements on the $YbRh_2Si_2$ and $YbIr_2Si_2$ crystals [2–4] demonstrate the observability of the ESR line in a dense Kondo lattice system. Intriguing physical properties of these compounds give unique possibility to explore the possible interplay and the role of the Kondo effect, quantum criticality, intermediate valence, Rudermann–Kittel–Kasuya–Yoshida (RKKY) interaction, CEF, and Fermi surface effects using the ESR method. Although the origin of the ESR signals in both systems remained a mystery, it has been very recently related to the existence of ferromagnetic fluctuations [5]. To our best knowledge, we present in this communication the first ESR spectra of several other undoped Kondo lattices YbBiPt, $YbRh_2Pb$, and YbT_2Zn_{20} (T = Fe, Co).

2. Experimental results and discussion

The ESR measurements were performed using a standard ESM/plus Bruker X-band (frequency ∼9.45 GHz) spectrometer. The temperature was varied between $4.4\,K \le T \le 300\,K$ by using a He-flow cryostat. We used single-crystalline platelets (0.5–0.8 mg weight; 2–4 mm^2 surface area) of all investigated intermetallics, the preparation, magnetic, transport properties, and the CEF effects of which have been described elsewhere [6–8]. Fig. 1 shows the "raw" ESR spectra which we succeeded to observe in YbBiPt and $YbRh_2Pb$ at $T = 4.4$ K with the same experimental conditions at the resonance field position H_{res} near 2150 Oe similar to the cases of $YbRh_2Si_2$ and $YbIr_2Si_2$ [2–4]. An intensity of the cavity background signals at $H_{res} \sim 3300$ Oe was comparable with that of both detected ESR spectra. The ESR peak-to-peak line width ΔH_{pp} which is marked by vertical arrows in Fig. 1 increased at this temperature from ∼200 Oe

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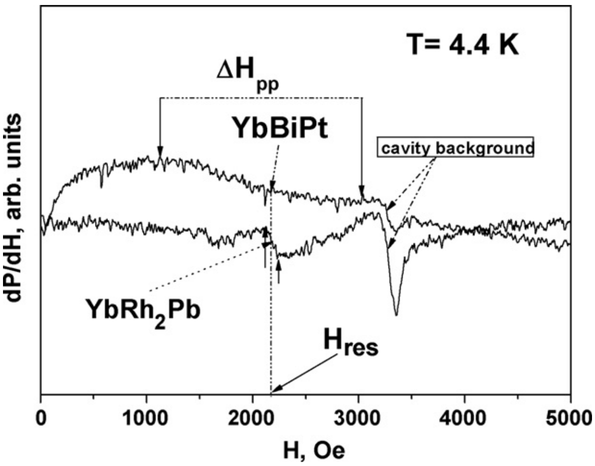

Fig. 1. Derivatives of the ESR signals in YbBiPt and $YbRh_2Pb$ at 4.4 K. Vertical arrows indicate the peak-to-peak ESR line width ΔH_{pp}. A cavity background signals near 3300 Oe should be taken into account in both compounds.

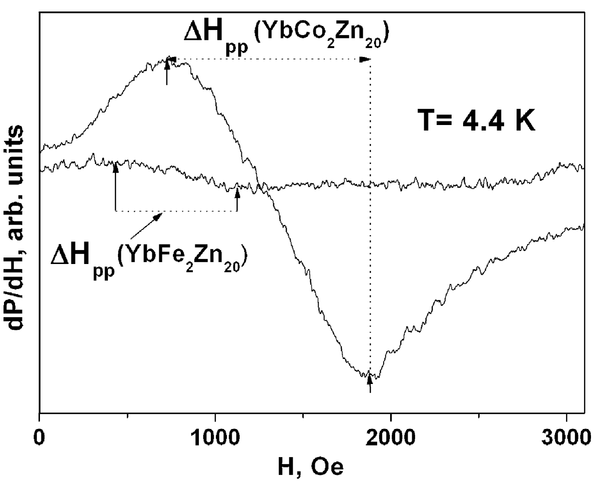

Fig. 2. ESR spectra of $YbCo_2Zn_{20}$ and $YbFe_2Zn_{20}$ at 4.4 K.

in $YbRh_2Pb$ to ~2000 Oe in YbBiPt. ESR signals fully disappeared above 30 K in $YbRh_2Pb$ and above 110 K in YbBiPt. A detailed investigation of the temperature dependence of the ESR line width in both systems will be a subject of future publications. The comparison of the ESR properties and the proposed CEF sublevel structures of the Yb^{3+} ion in $YbRh_2Pb$, $YbRh_2Si_2$, and $YbIr_2Si_2$ [2,4,9] suggest the extremely weak hybridization between the Yb moments and conduction electrons (CE) and a smaller RKKY interaction in $YbRh_2Pb$ which have been established after heat capacity, magnetic susceptibility, and resistivity studies [7]. It is worthwhile also to mention that YbBiPt as a prototypical HF compound has been examined using ESR because of its strongly broadened CEF levels due to hybridization effects [6]. Clearly, the CEF degrees of freedom are active on the same energy scale as the correlation or any exchange energy.

Recently, six strongly correlated Yb-based HF compounds, YbT_2Zn_{20} (T = Fe, Co, Ru, Rh, Os, and Ir) were prepared in order to study how the degeneracy of the Yb ion at Kondo temperature, T_K, effects the low-temperature correlated state [8]. Here, the near spherical distribution of neighboring Zn atoms gives rise to the possibility of the low CEF split levels. Clear ESR signals (effective g-factor ~4–7; ΔH_{pp} ~ 600–1000 Oe) have been detected with the identical conditions of the ESR measurements up to room temperature in $YbFe_2Zn_{20}$ (T_K = 33 K) and $YbCo_2Zn_{20}$ (T_K = 1.5 K), only (Fig. 2). These values of g-factor which show a complicated temperature dependence cannot be assigned to the ytterbium ions. As a result, most likely, they can be related to the Fe or Co local moments, correspondingly. One can suppose that the larger ESR absorption in $YbCo_2Zn_{20}$ due to relaxation of the CE to the spin subsystem is caused by increasing number of 3d-electrons when we pass from Fe- to Co-containing compound. Similar effects have been observed on going from $YbIr_2Si_2$ to $YbRh_2Si_2$ [3,4]. However, the resistivity which is 10 times higher in $YbCo_2Zn_{20}$ than in $YbFe_2Zn_{20}$ as well as the higher quality of the $YbFe_2Zn_{20}$ sample can lead also to the more intense ESR spectrum in the Co-containing system. Interestingly, all three HF intermetallics ($YbRh_2Si_2$, YbBiPt, and $YbCo_2Zn_{20}$) which exhibit an effective ESR absorption with the involvement of CE are situated in the very close region at the right upper corner on the Kadowaki–Woods plot [8]. We believe that the exchange interactions between the 4f electrons and the relevant CE (d-, s, and p-) bands as well as the hybridization CEF effects should be taken into account in order to advance our understanding of the exchange narrowed ESR lines in dense Yb HF systems. The multiband scenario including electron–electron exchange correlations which has been recently proposed for the Gd^{3+}-ESR in $YbAl_3$ [10] can be useful in the following theoretical studies. A strong influence of the 3d itinerant electrons on the ESR spectra in $YbFe_2Zn_{20}$ and $YbCo_2Zn_{20}$ strongly supports the possible relation of ferromagnetic fluctuations to the existence of the ESR absorption in several undoped Kondo lattice systems. In conclusion, we suppose that the corresponding ESR response is caused by mutual influence of the 4f local magnetic moments and conduction electrons as it was shown as a result of very recent experimental [11] and theoretical [12] studies. However, the deeper investigation is necessary to understand its origin and to interpret properly the corresponding experimental data.

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