μSR study on the Kondo semiconductor $(Ce_xLa_{1-x})Ru_2Al_{10}$

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The Kondo semiconductors CeT_2Al_{10} (T = Fe, Ru, and Os) have been attracting much attention because of their unusual antiferromagnetic (AFM) ordering at $T_0 \sim 30$ K for T = Ru and Os .[1,2] Below T_0, the AFM moment (m_{AF}) is parallel to the orthorhombic c axis[3,4] although the easy magnetization axis is the a axis with a large magnetic anisotropy, $\chi_a \gg \chi_c \gg \chi_b$. By substituting magnetic Ce ($4f^1$) with nonmagnetic La ($4f^0$), a further unusual ordered state is realized; the direction of m_{AF} is switched from the c to b axis, although the b axis is the magnetic hardest axis.[5] Nonetheless, T_0 is not significantly reduced, and the Kondo semiconducting behavior is maintained by the substitution. On further reducing the Ce concentration, T_0 decreases smoothly and disappears at a critical Ce concentration of $x \sim 0.45$. This indicates that the interaction of the transition is long-ranged, like the RKKY interaction. However, the transition temperature, $T_0 \sim 30$ K, is too high for an usual magnetic transition because (1) the T_N of isomorphous GdT_2Al_{10}, which is expected to show the highest ordering temperature in a series of RT_2Al_{10} systems, is only 16−18 K, and (2) the distance between the nearest Ce sites is greater than 5 Å. These imply that magnetic interactions are not key parameters for the transition, but there could be an unknown parameter related to the $c-f$ hybridization effect.

Previously, we examined the microscopic magnetism of $CeRu_2Al_{10}$ and the related Rh−doped one by means of μSR in RAL,[6] together with numerical calculations by using the density functional theory.[7] By substituting Ru with Rh which possesses an extra $4d$ electron compared to Ru, electronic properties are drastically changed, and $m_{AF} \parallel a$ is realized instead of $m_{AF} \parallel c$.[8] From our results, we have concluded that (1) the critical Rh concentration is less than 3%; (2) there are two muon stopping sites, which is supported by the DFT calculation; (3) internal fields, H_{int} (H_{Large} and H_{Small}), are very sensitive to spin structure; and (4) transferred hyperfine field could be essential for their non-mean field like behavior.

In order to examine the microscopic magnetism in $(Ce_xLa_{1-x})Ru_2Al_{10}$, we performed zero-field μSR using randomly mounted small single crystals. Figure 1 shows the preliminary results of the temperature dependence of H_{int} in $(Ce_{0.9}La_{0.1})Ru_2Al_{10}$. The data for $x = 1$ are also shown for comparison.[6] For $x = 1$, H_{Large} exhibits the usual mean-field behavior, whereas H_{Small} shows non-mean-field behavior. For $x = 0.9$, a similar behavior is obtained in H_{Large}. On the other hand, H_{Small} exhibits a behavior significantly different from that of H_{Small} for $x = 1$. Thus, H_{Large} is robust, while H_{Small} is strongly affected by the substitution. Considering the mean-field behavior of H_{Large}, the development of m_{AF} should be regarded a mean-field type. Thus, the non-mean field behavior of H_{Small} for $x = 0.9$ could also be related to the hyperfine anomaly. It should be noted that the temperature dependence of H_{Small} for $x = 0.9$ is very similar to that of H_{Large} in the Rh-doped $CeRu_2Al_{10}$, aside from a large difference in magnitude.[6] This could be a key to identify the muon sites and the origin of the hyperfine anomaly.

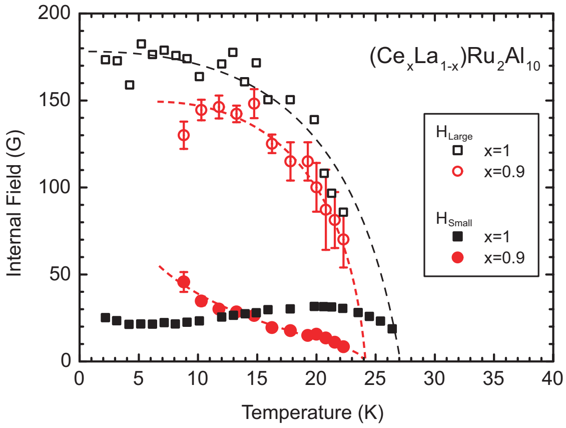

Fig. 1. Preliminary results of the temperature dependence of the internal magnetic fields in $(Ce_{0.9}La_{0.1})Ru_2Al_{10}$. The data for $x = 1$ are also shown for comparison.[6] Dotted curves are guides to the eyes.

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