Caged-type superconductor $Sc_5Ru_6Sn_{18}$ probed by μSR

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Superconductors with caged-type structures have attracted considerable attention among researchers because of their fascinating characteristics, such as heavy fermion superconductivity and exciton-mediated superconductivity. These compounds crystallize in the tetragonal structure having space group $I4_1/acd$ and consist of three-dimensional skeletons that surround large atomic cages, in which small atoms are situated. One such type of caged compound is $R_5Rh_6Sn_{18}$ (R = Sc, Y, Lu), which exhibits superconductivity at 5 K (Sc), 3 K (Y) and 4 K (Lu),$^{1)}$ where R occupies sites of different symmetry.$^{2)}$ Superconducting gap structures and ZF-μSR have been studied in $Lu_5Rh_6Sn_{18}$ and $Y_5Rh_6Sn_{18}$,$^{3,4)}$ where the time-reversal-symmetry-broken phenomenon has been observed below T_c in both compounds. However, $Lu_5Rh_6Sn_{18}$ is a strong-coupling s-wave superconductor with isotropic gap; while $Y_5Rh_6Sn_{18}$ reveals an anisotropic superconducting gap with a point node. These experimental results in sharp contrast motivate us to study the time-reversal-symmetry-broken mechanism in the $R_5M_6Sn_{18}$ (R = Sc, Y, Lu; M = Co, Rh, Ru, and Ir) family. $Sc_5Ru_6Sn_{18}$ is the first compound for our studies. $Sc_5Ru_6Sn_{18}$ has $T_c \approx 3.5$ K. The T^3 dependence of electronic heat capacity (C_e) below T_c at zero field clearly indicates that $Sc_5Ru_6Sn_{18}$ has an anisotropic superconducting gap with a point node.

In the ZF-μSR measurement, the sample temperature was changed in the ZF condition from approximately 30 K ($> T_C$) down to 1.6 K ($< T_C$). The sample was cooled down using a helium-flow cryostat in the He exchange gas, maintaining good temperature homogeneity. The time dependence of $A(t)$, which is called the μSR time spectrum, was measured. Figure 1(a) shows the μSR time spectrum measured at various temperatures crossing T_c. Time spectra were analyzed by using the function $A(T) = A_0 G_{\mathrm{KT}} \times \exp(-\lambda t)$, subtracting the background signals coming from the sample holder. Here, A_0 is the initial asymmetry at $t = 0$. G_{KT} is the static Gaussian Kubo-Toyabe function to describe static internal fields, which come from surrounding nuclear moments, and are randomly distributed at a muon site. This term can be treated as a temperature-independent parameter from the viewpoint of the μSR time window.$^{5)}$ λ is the muon-spin depolarization rate, which is considered related to the dynamic spin fluctuation of surrounding electronic spins around the muon. The solid lines are the best-fit results obtained by using this analytical function. Figure 1(b) shows the fitting of time spectra. λ increases with decreasing temperature, which was obtained from temperatures above T_c. This would mean that some electronic spins remain in the sample, causing this muon-spin depolarization behavior.

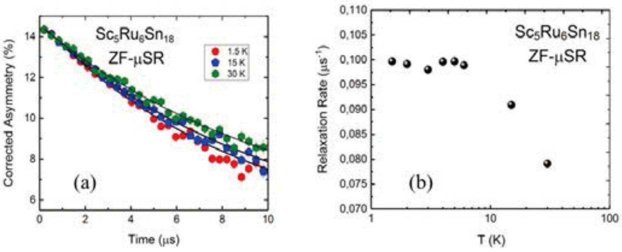

Fig. 1. (a) ZF-μSR time spectra of $Sc_5Ru_6Sn_{18}$ measured at various temperatures. The solid lines are the best-fit results obtained by using the analysis function, $A(T) = A_0 G_{\mathrm{KT}} \times \exp(-\lambda t)$. (b) Temperature dependence of the muon-spin relaxation rate obtained from the analysis by using the function $A(T) = A_0 G_{\mathrm{KT}} \times \exp(-\lambda t)$.

An important observation in this ZF-μSR measurement is the temperature-independent behavior of λ below approximately 10 K, even crossing T_c. No change in λ means that the time spectrum does not change any more below 10 K even in the superconducting phase. In the case of the conventional superconducting state with the BCS type s-wave Cooper pair symmetry, there is no change in the time spectrum and we do not see any effect on the ZF-μSR data from the superconducting electronic state. On the other hand, the ZF-μSR time spectrum is modified by the appearance of a spontaneous internal magnetic field below T_c when the time reversal symmetry (TRS) is broken. Such a case can occur in the case of the p-wave Cooper pair symmetry, as has been proved in the case of Sr_2RuO_4.$^{6)}$ As shown in Fig. 1(b), the time spectrum does not show any changes in its shape within statistical errors; we can conclude that the TRS breaking of the superconducting state is unlikely in this system, even though the appearance of point-node structures on the superconducting gap state is suggested from the heat capacity measurement. This result would restrict the discussion of the model of the superconducting mechanism by excluding the possibility of the formation of the p-wave symmetry.

References

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