Superconductivity in single crystals of λ-$(BETS)_2GaCl_4$ studied by transverse-field μSR

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The superconducting gap structure in λ-$(BETS)_2GaCl_4$ is intriguing and has been consistently studied using μSR. We performed transverse field (TF) μSR at fields of 150 Oe down to 0.3 K using a 120 mg randomly oriented sample, at the ISIS Muon Facility in the UK. The temperature dependence of the superfluid density deduced from that experiment is best described by the $s+d$-wave with a dominant s-wave component.[1] In order to get clearer and more direct evidence in terms of the superconducting gap structure determination, we performed similar measurements using a 75 mg well-aligned sample by applying the external field perpendicular to the conducting ac-plane. Here, we report the TF dependence of the London penetration depth, which leads to the upper critical field H_{c2} estimation, in order to check the quality of the experimental setup in aligned single crystals of λ-$(BETS)_2GaCl_4$.

Figure 1 shows a typical TF-μSR spectra with a field of 150 Oe in the aligned single crystals at T = 0.3 K and 10 K after being cooled through critical temperature $T_c \sim 5.3$ K.

The time spectra were fitted by using Eq. (1),

$$A_{(t)} = 0.3438 \times e^{-(\sigma t)^2} \cos\left(\gamma_\mu H_{int_{1(sample)}} t + \phi\right) + 0.652 \cos\left(\gamma_\mu H_{int_{2(Ag\ foil)}} t + \phi\right) \quad (1)$$

The two oscillation components represent about 35% signal from the sample and 65% signal from the silver package. The damping rate σ becomes prominent once the system enters the superconducting state. The superconducting component of the damping rate σ_{SC} is then given by $\sigma_{SC}^2 = \sigma^2 - \sigma_{NM}^2$, where σ_{NM}^2 is the signal $\sigma_{T=10\,K}$ in the normal state due to the nuclear moments. Furthermore, the TF dependence of σ_{SC} can be used to determine the London penetration depth λ and to give an estimate for the H_{c2}, following Eq. (2),

$$\sqrt{2}\sigma_{SC}(H) = 4.83 \times 10^4 \times (1 - H_{app}/H_{c2}) \times \left[1 + 1.21\left(1 - \sqrt{H_{app}/H_{c2}}\right)^3\right] \lambda^{-2} \quad (2)$$

where H_{app} = 150 Oe and λis in nm.[2)]

Figure 2 shows the estimation of $H_{c2\perp}$ from the measurements of the aligned crystals. The resulting $H_{c2\perp}$, which is parallel to the b-axis, is 41 ± 19 kOe, and the absolute value of the London penetration depth at 0 K, $\lambda(0) = 710 \pm 12$ nm. The estimation of H_{c2} from the previous TF-μSR measurement on a randomly oriented sample was 43±25 kOe.[1)] From magnetoresistance measurements, the H_{c2} of λ-$(BETS)_2GaCl_4$ was reported to have a high anisotropy. The H_{c2} parallel to a, b, and c-axes were 150 kOe, 30 kOe, and ∼ 130 kOe, respectively.[3)] In comparison with the H_{c2} in the randomly oriented crystals, the estimation of $H_{c2\perp}$ is closer to the reference of the magnetoresistance measurement, although the signal we obtained from the sample was smaller than that of the background from silver. It implies that the sample alignment was good enough. Taking into account the low sample mass, we will increase it up to ∼ 120 mg in order to obtain a stronger signal and solid results.

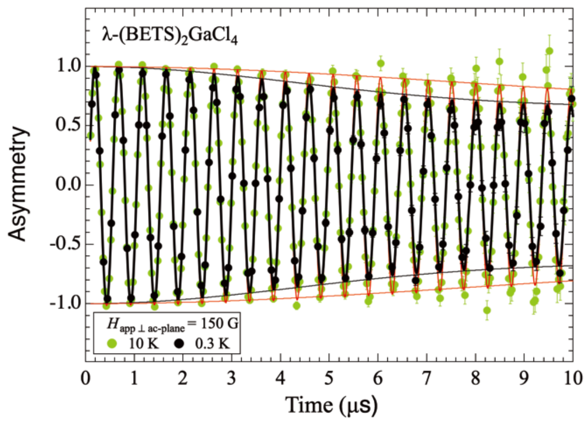

Fig. 1. The normalized TF time spectra in the applied field of 150 Oe measured at T = 0.3 K (black) and 10 K (green). The red and black solid lines are the best-fit results obtained by using Eq. (1). The trace of the envelope of the cosine curve represents the damping rate σ of Eq. (1).

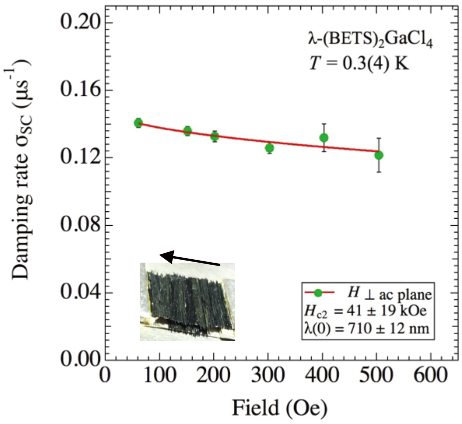

Fig. 2. Transverse-field dependence of damping rate of the muon-spin precession in the superconducting state, σ_{SC}, of λ-$(BETS)_2GaCl_4$ taken at 0.3 K. The red and green circles indicate the data for randomly oriented and well-oriented crystals, respectively. The inset figure shows the aligned crystal mounted in a silver foil. The black arrow indicates the direction of the applied field.

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