Probing internal fields induced by Ru and Nd spin ordering on $Nd_2Ru_2O_7$ using continuous muon beam

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Pyrochlore oxides have the general formula $A_2B_2O_7$ (A = trivalent rare-earth ion; B = tetravalent transition metal ion), with corner-sharing tetrahedral lattice networks of A and B sites.[1)] The magnetic frustration, competition between the exchange and dipolar interactions, and crystal electric field effect control the nature of the ground state of the pyrochlore oxide.[2)]

Nd pyrochlores have been intensively investigated owing to their exotic properties exhibiting the coexistence of static ordering and the dynamic behavior of Nd spin.[3–5)] $Nd_2Ru_2O_7$ is a stable Nd pyrochlore, in which both Nd and Ru are magnetic ions. The magnetic ground state of $Nd_2Ru_2O_7$ is interesting from the perspective of research, as we may investigate the coupling between Nd and Ru spins and how it affects the coexistence of static and dynamic Nd spins. $Nd_2Ru_2O_7$ exhibits a magnetic transition around 1.8 and 146 K, corresponding to the ordering of Nd and Ru spins, respectively.[6–8)] In addition to macroscopic measurements using, for example, the Magnetic Properties Measurement System (MPMS), the magnetic properties of $Nd_2Ru_2O_7$ were investigated using a local magnetic probe such as muon spin relaxation (μSR) measurement. We explore the ordering of both Ru and Nd spins using μSR and determine the internal field induced by the ordered spins.

Polycrystalline $Nd_2Ru_2O_7$ was prepared using a solid-state reaction method. From previous μSR measurements using a pulsed muon beam, we confirmed the ordering of Ru and Nd spins based on the decrease in the initial asymmetry.[9)] The decrease in the initial asymmetry indicates fast muon spin precession in the early time spectra. The expected internal field surrounding the muon-stopping site is higher than 500 G, beyond the time window of the pulsed muon beam. Therefore, a continuous muon beam is necessary to determine the internal field induced by the ordering of Ru and Nd spins. In this report, we present the μSR data obtained using a continuous muon beam on the DOLLY and GPS spectrometers at Paul Scherrer Institute (PSI), Switzerland. We measured the μSR time spectra in the zero-field (ZF) condition in the temperature range of 2–250 K on GPS, whereas the time spectra below 3 K down to 0.3 K were obtained on DOLLY.

Figure 1(a) and (b) display the ZF-μSR time spectra. The appearance of the Ru order state was confirmed by the appearance of muon spin precession below 145 K. Below 120 K, a beating pattern appears in the oscillating time spectra, indicating two frequencies of muon spin precession associated with the two internal fields. The origin of these two internal fields might be attributed to two muon-stopping sites or two sources of the field. Because at a high-temperature range, only the Ru spins were ordered, the internal fields were attributed to the two muon-stopping sites. A linearity exists between the two internal fields down to 2 K. Below 2 K, one frequency becomes more prominent than the other one, and the linearity of these two fields is broken. The enhancement of the internal field below 2 K might be related to the ordering of Nd spins.

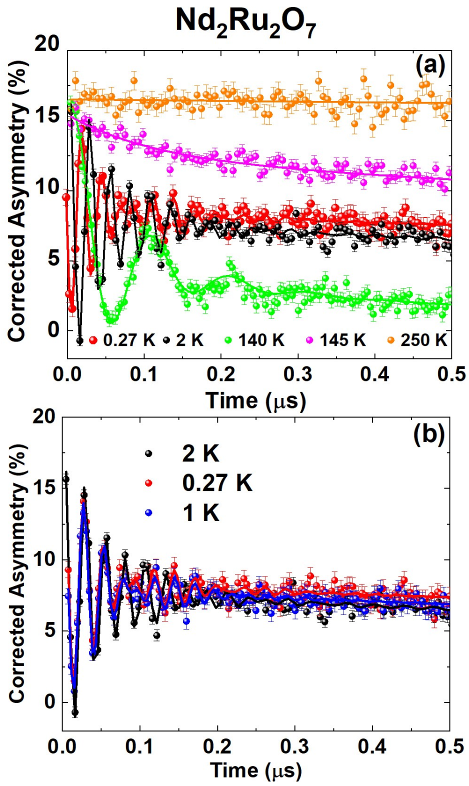

Fig. 1. (a) ZF-μSR time spectra of $Nd_2Ru_2O_7$ from 250 K down to 0.27 K. (b) ZF-μSR time spectra of $Nd_2Ru_2O_7$ below 2 K indicates a change in the frequency of the muon spin precession.

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