Development of the in-situ electronic-field-application μSR technique and test application to multiferroic systems

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One advantage of the pulsed muon facility is that it can be used to carry out *in-situ* measurements with external conditions applied from outside a sample, which optimizes the timing of the application with the arrival of the injected pulsed muon. One of the important systems for external conditions is the *in-situ* electric-field-application system, which is needed to carry out μSR studies on some multiferroic systems. Since the repetition rate of the pulsed muon beam at the ISIS is 50 Hz and the life of the muon itself is less than approximately 20 μs, there is no need to apply the external electric field continuously for more than 30 μs. These conditions can decrease the duty factor. It is well known that the magnetic properties in the multiferroic systems can be controlled by the electric field and vice-versa. These systems are promising candidates for industrial applications such as storage devices and sensors. The new data acquisition (DAQ) system called DAE-III is now available in the RIKEN-RAL Muon Facility, which consequently supports the development of the electric-field-application condition.

In this study, we intend to apply this in-situ electric-field-application system to investigate the spin dynamics of multiferroic systems. We designed a simple sample holder for the in-situ electric-field-application system, as shown in Fig. 1(b). The sample holder was installed on the sample stick of JANIS cryostat, which can reach the lowest temperature of 1.6 K. A single-crystal sample of $Dy_{0.75}Gd_{0.25}FeO_3$ arranged along the c-direction [Fig. 1(a)] was placed between Ag foils (thickness of 12.5 μm) and then flanked by two Al rings. For electric insulation, Mylar sheets were inserted between the sample holder and metal backing plate of JANIS. In the test experiment, an electric field of approximately 300 V, which is generated from the High Voltage Switching Unit (HVSU) device, was applied between the sample and backing plate. By using this designed sample holder, we aim to apply electric fields up to approximately 300–500 V with a pulse length of approximately 30 μs without any discharges in the He exchange gas.

$GdFeO_3$ is a typical system showing significant multiferroic behavior. This system has been synthesized in 1956,[1)] but its multiferroicity has been recently confirmed.[2)] The spin system enters the static ferromagnetically ordered state below $T_C = 2.5$ K, and its spin direction can be changed by the application of an electric field of approximately 2 kV/cm.[2)] The mutiferroic behavior of this system can be tuned by the substitution of Dy for Gd.[3)] We first performed the measurement under the zero-field condition to check the time spectra of muon polarization. We found that there is no significant difference in the time spectra above and below T_C, as shown in Fig. 2. The spectra were well fitted by a single exponential function, $A(t) = A\exp(-\lambda t)$, where A is the initial asymmetry and λ is the relaxation rate. The absence of spontaneous muon-spin precession below T_C is expected owing to a large magnetic moment of Fe moments in the sample, which therefore cannot be detected using a pulsed muon source. Further test application on multiferroic compounds with a relatively small moment, such as organic multiferroics, is needed to check the in-situ electric-field-application system at RIKEN-RAL Muon Facility.

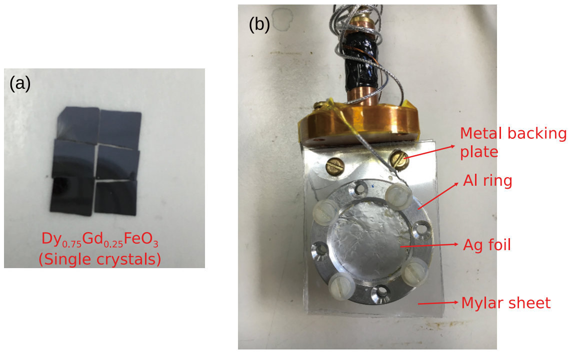

Fig. 1. (a) Six pieces of the single crystal $Dy_{0.75}Gd_{0.25}FeO_3$. (b) The designed sample holder for the *in-situ* electric-field-application μSR at RIKEN-RAL Muon Facility.

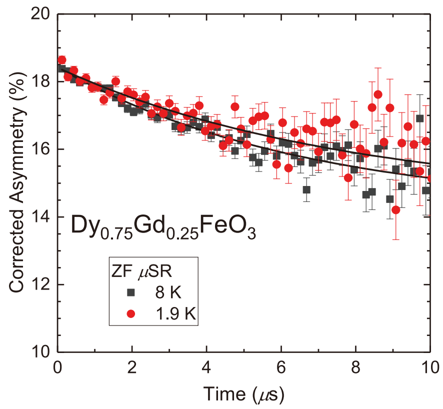

Fig. 2. Time spectra of $Dy_{0.75}Gd_{0.25}FeO_3$ at 8 K and 1.9 K. Solid lines are fitting results as described in the text.

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