Q-moment measurement of isomeric state of ^{99}Zr using spin-aligned beam

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The ^{99}Zr nucleus with a neutron number $N = 59$ is located at the border of a region where a sudden onset of ground-state deformation occurs for Zr isotopes between $N = 58$ and 60.[1)] This change has been described as a quantum phase transition (QPT) with the neutron number as a control parameter. The ^{99}Zr nucleus closest to the critical point of the QPT has an isomer (^{99m}Zr) with a spin parity of $7/2^+$ at 252 keV. A recent measurement of its magnetic moment showed a surprising result. Namely, the $7/2^+$ state is not of single-particle-like nature but rather collective.[2)] To confirm this collectivity directly, measurement of the quardupole (Q) moment of the same isomer was conducted.

The experiment was conducted at BigRIPS at RIBF in April 2022. The two-step fragmentation scheme with the momentum-dispersion matching technique[3,4)] was employed to produce a highly spin-aligned beam of ^{99}Zr. First, ^{100}Zn was produced by a fission reaction of a 345-MeV/nucleon ^{238}U beam on a ^{9}Be target with a thickness of 1.29 g/cm^2. The secondary ^{100}Zr beam was impinged to a second target of wedge-shaped aluminum with a mean thickness of 0.810 g/cm^2 and a wedge angle of 2.65 mrad, placed at the momentum-dispersive focal plane F5. The ^{99}Zr nuclei, including those in isomeric state ^{99m}Zr, were produced through one-neutron removal from ^{100}Zr. The tertiary ^{99}Zr beam was subsequently transported to F7 while matching the momentum dispersion of ^{99}Zr in F5–F7 to that of ^{100}Zr in F3–F5. F7 slits with a width of ±10 mm were used to extract the region around the center of the momentum distribution for ^{99}Zr.

Prior to the Q-moment measurement, the magnitude of spin alignment realized in ^{99m}Zr was checked by the time-differential perturbed angular distribution (TDPAD) methods. The TDPAD apparatus, placed at F8, consisted of a dipole magnet, Cu crystal stopper, Ge detectors, and plastic scintillator. The dipole magnet provided a static magnetic field of $B_0 = 0.200$ T. ^{99m}Zr was implanted into the Cu stopper, and γ rays were detected with four Ge detectors placed on a plane perpendicular to B_0 at angles of ±45 and ±135 degrees with respect to the beam axis. A plastic scintillator with a thickness of 0.1 mm was placed upstream of the stopper to provide the time-zero trigger.

The $R(t)$ ratio, which represents the change of the γ ray's anisotropy synchronized with the spin precession, associated with the 130-keV γ ray deexciting ^{99m}Zr was obtained, as shown in Fig. 1. Preliminarily, the magnitude of spin alignment realized in this measurement was found to be approximately 10%.

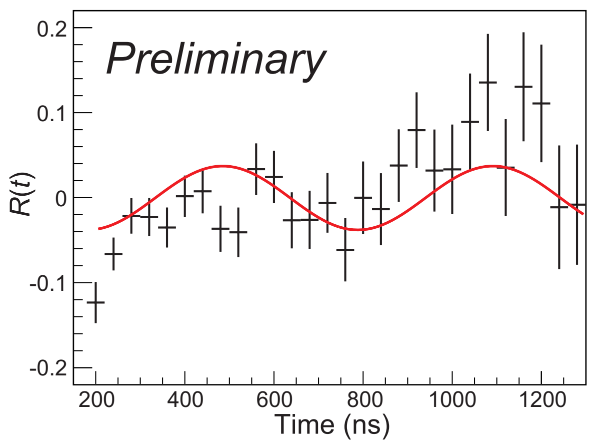

Fig. 1. $R(t)$ ratio associated with the 130-keV γ ray deexciting ^{99m}Zr under a static magnetic field. The magnitude of spin alignment was deduced from the amplitude of the ocscillation.

For the Q moment measurement, the interaction between the Q moment and electric-field gradient in a single crystal of zyrconium metal was used to apply the TDPAD method. The zyrconium crystal was set so that the crystal axis was perpendicular to both the beam axis and detector plane. The ^{99}Zr beam collimated to 10 mm ϕ was implanted into the stopper crystal. Three Ge detectors were arranged at angles of 0 and ±90 degrees with respect to the beam axis. Data analysis on the Q-moment measurement is in progress.

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