Development of enlarged spin-polarized proton target for RI beam experiments

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Spin-dependent interactions play an important role in nuclear structure and reactions. Spin-orbit coupling is one of manifestations of spin-dependent interactions. One of the most straightforward approaches to investigate spin-orbit coupling is the determination of the spin-orbit potential through the nuclear optical model analysis of the vector analyzing power in the $p-A$ scattering (proton elastic scattering from nuclei).

At RIBF in experiments involving short-lived unstable nuclei, a spin-polarized proton target is required, since unstable nuclei are supplied as RI beams. Center for Nuclear Study, Univ. of Tokyo and RIKEN groups have developed a spin-polarized proton target system.[1)] The target material is a crystal of naphthalene doped with a small amount pentacene (0.005%), which serves as a polarization agent. The method of production of spin polarization employed in our target system, is based on the cross-polarization technique,[2)] where polarization of electrons system is transferred to protons by means of dipolar interaction in the presence of microwave irradiation.

Several RI beam experiments have been done with this polarized proton target.[3,4)] For further application the size of the target (14 mm in diameter) is a limiting factor because the typical position spread of RI beams is as large as 20-30 mm. This leads to loss of statistics and also increase in background events from the surrounding materials such as a target holder. Due to the above reasons the crystal size needs to be enlarged.

We performed upgrade of the polarizing system to accommodate an enlarged sample and successfully obtained spin polarization signal from a sample of 24 mm and 3 mm in diameter and thickness, respectively. This is the largest sample that has been polarized with this method. Measurement of a spin polarization was performed by means of the pulsed-NMR method.

To facilitate polarization transfer based on the cross-polarization technique, the energy gaps of electron and proton systems should be made equal, so that these two systems are coupled. This condition: $\hbar\omega_{\text{eff}} = \hbar\omega_I$, is known as the "Hartmann-Hahn condition"[5)]. Here, ω_{eff} is the electron effective Larmor frequency in a coordinate system rotating with frequency ω - the frequency of oscillating microwave magnetic field, and ω_{I} is proton Larmor frequency. ω_{eff} is written as

$$\omega_{\text{eff}} = \sqrt{(\omega_{\text{s}} - \omega)^2 + \omega_{\text{R}}^2}, \tag{1}$$

where ω_{s} is the Larmor frequency of the electron, $\omega_{\text{R}} = \gamma_{\text{s}} H_1$ is the Rabi frequency which depends on the amplitude of the oscillating magnetic field H_1 and electron gyromagnetic ratio γ_{s}. In actual measurements after a resonance condition $\omega_{\text{s}} = \omega$ was met by adjusting a static magnetic field H_{s} as $\omega_{\text{s}} = \gamma_{\text{s}} H_{\text{s}}$, then ω_{eff} was tuned to satisfy "Hartmann-Hahn condition". Tuning of ω_{eff} is done by changing the H_1 field amplitude, which is proportional to the square root of input power $\sqrt{P_{\text{MW}}}$. The ω_{R} is connected to P_{MW} as $\sqrt{P_{\text{MW}}} \propto H_1 = \omega_{\text{R}}/\gamma_{\text{s}}$.

We note here that a maximum proton spin polarization is produced, provided the "Hartmann-Hahn condition" is met. In the proton spin polarization measured as a function of $\sqrt{P_{\text{MW}}}$ shown in Fig. 1, however, no such maximum was identified as a peak. The peak was not obtained even with the highest power that the currently used source can supply. To achieve "Hartmann-Hahn condition", we are redesigning the microwave resonator in order to reduce power loss due to radiation to the outer region.

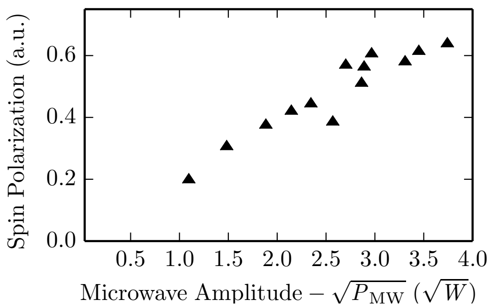

Fig. 1. Dependence of proton spin polarization signal on the square root of applied microwave power.

At the present, we successfully obtained spin polarization signal with very large sample of 24 × 3 mm. Although, magnitude of the polarization can be enhanced by improving the microwave system.

References

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