Dependence of spin-polarized proton target performance on microwave resonator thickness parameter and operation temperature

S. Chebotaryov, [*1,*3] S. Sakaguchi, [*1,*2] W. Kim, [*3] E. Milman, [*1,*3] K. Tateishi, [*1] and T. Uesaka [*1]

A spin-polarized proton target provides opportunities to experimentally study spin-dependent interactions with unstable nuclei. Such a target is required because unstable nuclei are short-lived species and have to be provided as an RI-beam. Such an experimental study has not been possible until recently owing to the lack of a polarized target that is applicable to RI-beam experiments. Conventional polarized targets use a high magnetic field of a few tesla and sub-kelvin temperatures to attain high polarization. However, in experiments the energy of recoil protons can be as low as few tens of megaelectronvolts. Thus the maximum magnitude of the magnetic field used has to be constrained to several tens of millitesla to prevent significant distortion of proton trajectories. The Center for Nuclear Study, University of Tokyo, and the RIKEN group has developed a spin-polarized proton target system suitable for use in RI-beam experiments,[1)] which made it possible to conduct an experimental study of spin-dependent interactions in unstable nuclei.

The method of generating spin polarization employed in the target system is based on the cross-polarization technique[2)], where the polarization of an electron system is transferred to the protons in the presence of an oscillating magnetic field. The field is generated as a standing electromagnetic wave using a microwave resonator. The type of resonator employed in our system is the so-called loop-gap resonator (LGR); its schematics is presented in Fig. 1. This resonator is made of a sheet of CuFlon material, which consists of a copper metal clad on both sides of a thin Teflon sheet.[3)].

In this report, we study the polarization performance of the target system at different temperatures, specifically how performance depends on temperature-dependent parameters of an LGR used for creating the oscillating magnetic field. The goal is to choose the optimal parameters of the LGR to obtain maximum polarization at a target normal operating temperature of −173 °C. As for LGR, the use of a thicker copper layer tends to give better results in terms of resonator performance, while for target operation, a thinner copper layer is preferable as it disturbs the trajectories of recoil protons less significantly. For 10 MeV protons, the angular resolution will vary from ±0.5° to ±1.6° (sigma), for an LGR with copper layer thicknesses of 4.4 µm and 36 µm, respectively.

We measured a series of dependences of the polarization signal intensity P as a function of the square root of microwave power $\sqrt{P_{MW}}$ supplied to the LGR from an RF amplifier. The magnetic field generated inside the LGR is proportional to $\sqrt{P_{MW}}$: $H_1 \propto \sqrt{P_{MW}}$. Measurements were performed at −40 °C, −80 °C, and −173 °C using two types of LGRs with copper layer thicknesses of 4.4 µm and 36 µm with all other conditions being equal. In Fig. 2 the results of the measurements are presented.

Fig. 1. Schematics of the loop-gap resonator.

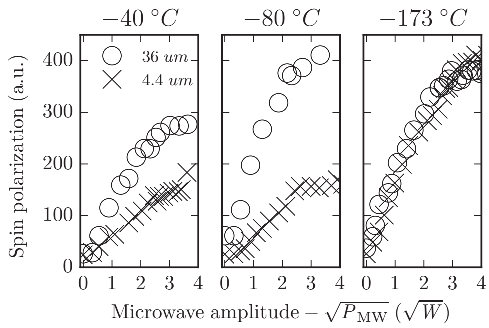

Fig. 2. Dependence of polarization on microwave amplitude at different temperatures (measurement error is comparable to symbol size).

At a temperature of −173 °C, the thickness of the LGR copper layer does not play an important role, while at higher temperatures measurable difference starts to appear. In the case of the 4.4 µm LGR, a decrease in polarization performance vs. temperature is more pronounced in comparison to the 36 µm one. If the temperature is above −173 °C, to maximize polarization performance, the use of the LGRs with a thicker copper layer is preferable. To better understand the performance of the polarized target at different temperatures and to be able to build a quantitative model, a more detailed study of magnetic field dependence from temperature in the LGR itself is required.

*1 RIKEN Nishina Center
*2 Department of Physics, Kyushu University
*3 Department of Physics, Kyungpook National University

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