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Development of an in-situ spin-exchange optical pumping ^{3}He neutron spin filter

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Abstract. In order to apply the ^{3}He neutron spin filter (NSF) to experiments at an intense pulsed neutron experimental facility such as the J-PARC, it is important to make the system stable, useful and easy to setup and operate, because the system is located inside a radiation shield for high energy gamma ray and neutrons. In this study, we have developed compact laser optics with a volume holographic grating (VHG) element for a spin-exchange optical pumping (SEOP) system, and composed an in-situ SEOP ^{3}He-NSF. The details of the setup and its performance are reported.

1. Introduction

We have been developing a ^{3}He neutron spin filter (NSF) for efficient utilization of pulsed neutrons, since the ^{3}He NSF is effective for neutrons in the wide energy range. The ^{3}He NSF is effective especially for neutrons with energy higher than several-tens-meV, and can cover a large solid angle and polarize neutrons without deflecting them from their original trajectory. In order to apply the ^{3}He NSF to experiments at a pulsed neutron experimental facility such as the J-PARC, it is important to make the system stable, useful and easy to setup and operate. In this study, we have developed an in-situ spin-exchange optical pumping (SEOP) ^{3}He-NSF with a spin flip function for the ^{3}He polarization based on the adiabatic fast passage (AFP) NMR.

2. A compact laser optics

We have developed compact laser optics with an air-cooled laser diode array (LDA). The output laser power of the air-cooled LDA is about 30 - 40 W, which is much lower than that of a water-cooled one. However, it is enough to polarize ^{3}He gas within a small-sized cell [1]. The laser spectrum of the LDA is broader than the absorption line width of Rb [2]. Thus, we employed a volume holographic grating (VHG) element to compose an external cavity laser (ECL) to sharpen the laser spectrum to

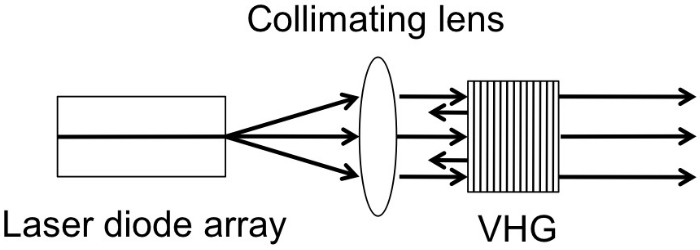

Figure 1. A schematic layout of the external cavity laser with a VHG element.

match it to the Rb absorption line [3] (Fig. 1). The developed laser optics are shown in Fig. 2. The LDA is cooled with a Peltier device and a fan (Fig. 2). Collimating and shaping lenses and a λ/4 wave plate were assembled in a box (Fig. 2). Therefore, the circularly polarized laser is extracted from the box. We have measured the final laser power, and it was found that the total laser power loss was 20 % in the setup.

The measured laser spectra with and without the feedback are shown in Fig. 3. The laser spectrum was narrowed to be a FWHM of 0.35 nm by the feedback, which is 16 % of the original spectrum width without the feedback (Fig. 3). The specification value of the spectrum width of the VHG element is 0.14 nm. The observed spectrum width obtained with the feedback was about 2.5 times that of the specification value of the VHG. This may be due to a mis-alignment of the optical components such as the so-called "smile" of the LDA (The "smile" is defined as the bending of the line of emitters of the LDA [4, 5]).

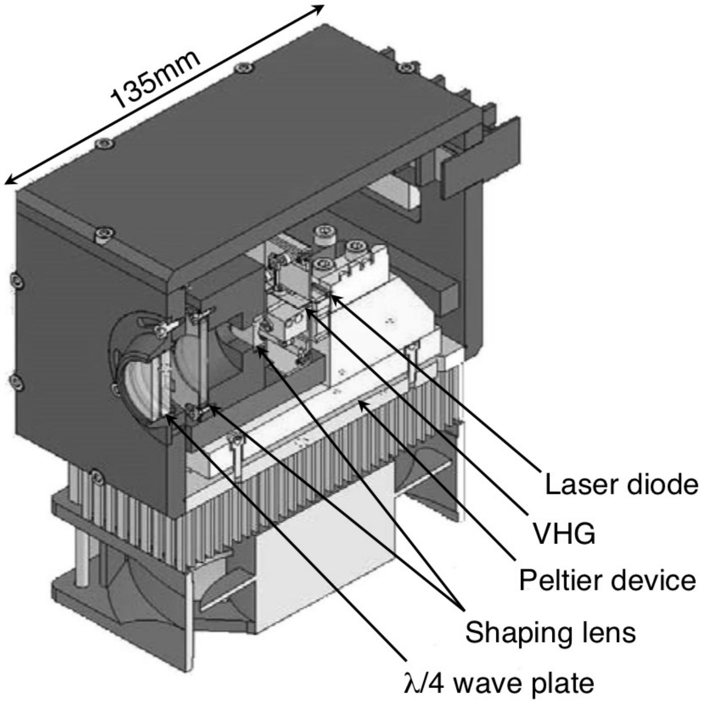

Figure 2. The cross sectional view of the developed laser optics.

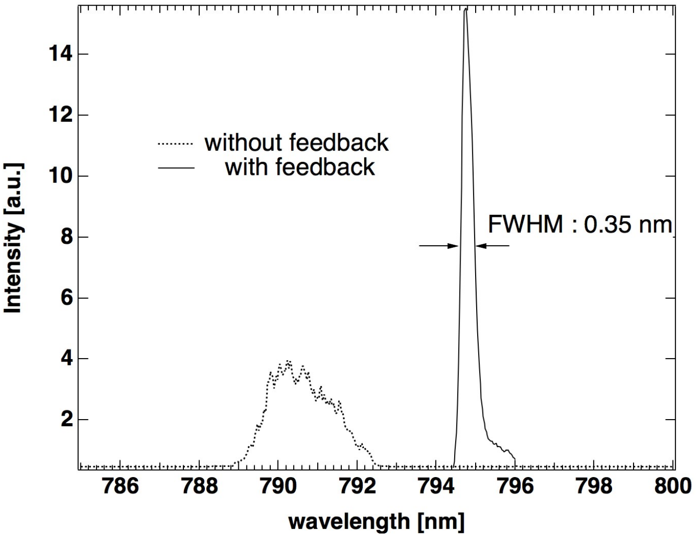

Figure 3. The measured laser spectra with and without feedback to narrow the spectrum.

3. An In-Situ SEOP ^{3}He NSF

We have composed a setup for the in-situ SEOP ^{3}He NSF with the developed laser optics (Fig. 4(a)). Our previous in-situ SEOP setup with the ECL in Littrow configuration is also shown in Fig. 4(b). The new setup has a simpler structure and is easier to set up and operate, because most of the optical components are integrated in the box for the developed laser optics (Figs. 2, 4(a)).

^{3}He gas with a gas quantity of 11 atm-cm is contained in a GE-180 glass cell with a size of 34 mmϕ x 52 mm-L. The cell is located in an Al-oven which is set inside the solenoid coil (Fig. 5). The oven is equipped with RF and pick-up coils for AFP-NMR (Fig. 5). The polarity of ^{3}He can be π-flipped by the AFP-NMR. The AFP-NMR signal is proportional to the polarization degree of ^{3}He, $P_{3\mathrm{He}}$, which can be measured by it [6].

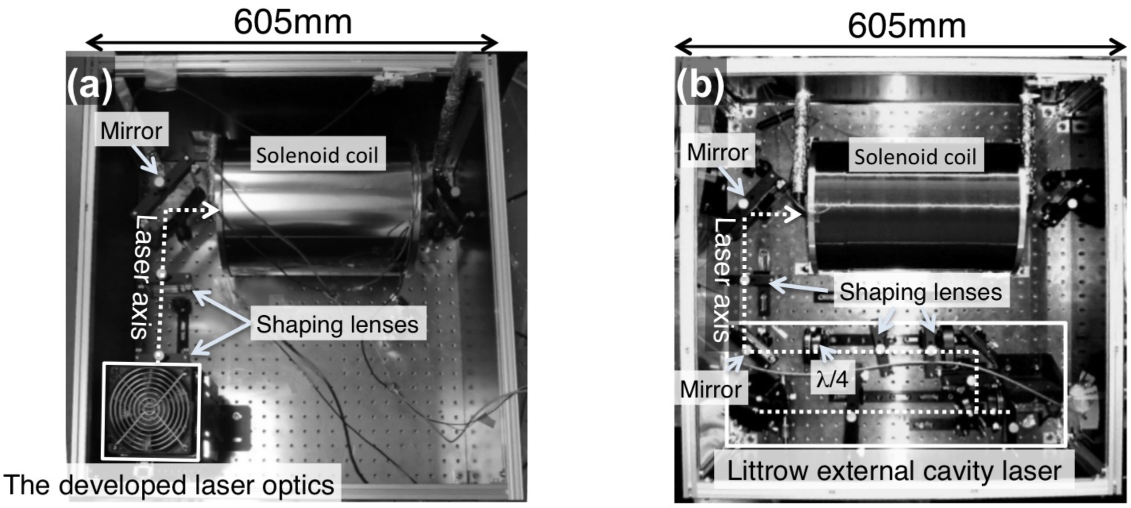

Figure 4. (a) The in-situ SEOP ^{3}He-NSF with the developed laser optics, and (b) the previous setup with the Littrow ECL.

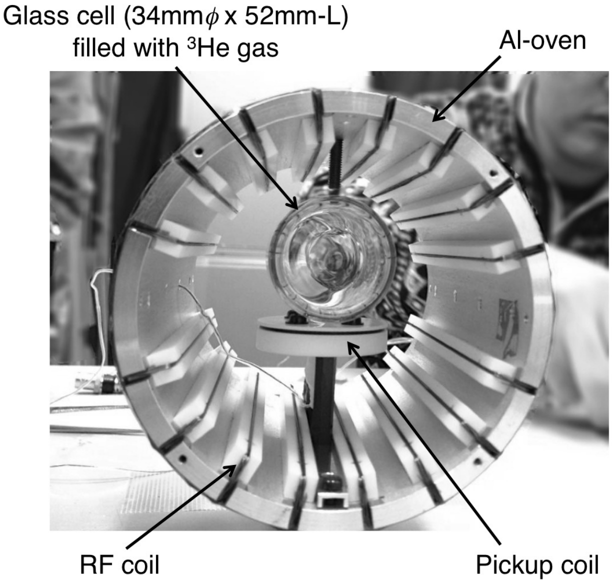

Figure 5. ^{3}He gas in a GE-180 glass cell is located in the Al-oven.

Fig. 6 shows the time evolution of the AFP-NMR signal after we start the laser irradiation to polarize ^{3}He spin. The polarization build-up time constant was 10 h, and we have achieved $P_{3\mathrm{He}}$ = 70% which is high enough for practical applications.

By flipping the polarity of the ^{3}He polarization, the polarity of the generated polarized neutron beam is alternated. Therefore, a flipping system for the ^{3}He spin functions as a neutron spin flipper. By the AFP-NMR, polarity of the ^{3}He polarization can be π-flipped. In the case of the in-situ SEOP ^{3}He-NSF, polarity of the circularly-polarized laser for the SEOP must be flipped to keep the absolute polarization of the ^{3}He spin. To change the polarity of the laser, a half-wavelength plate was installed. The rotation angle of the half-wavelength plate was optimized, and a polarization of 98% was obtained for the circularly-polarized laser. The ^{3}He polarization reached 70% and was confirmed to be stable for over a week.

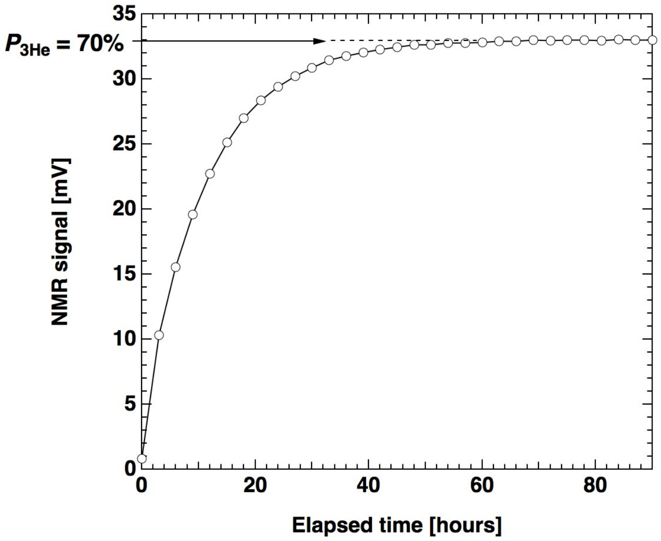

Figure 6. The time evolution of the NMR signal, which is proportional to $P_{3\mathrm{He}}$, after the laser irradiation is started.

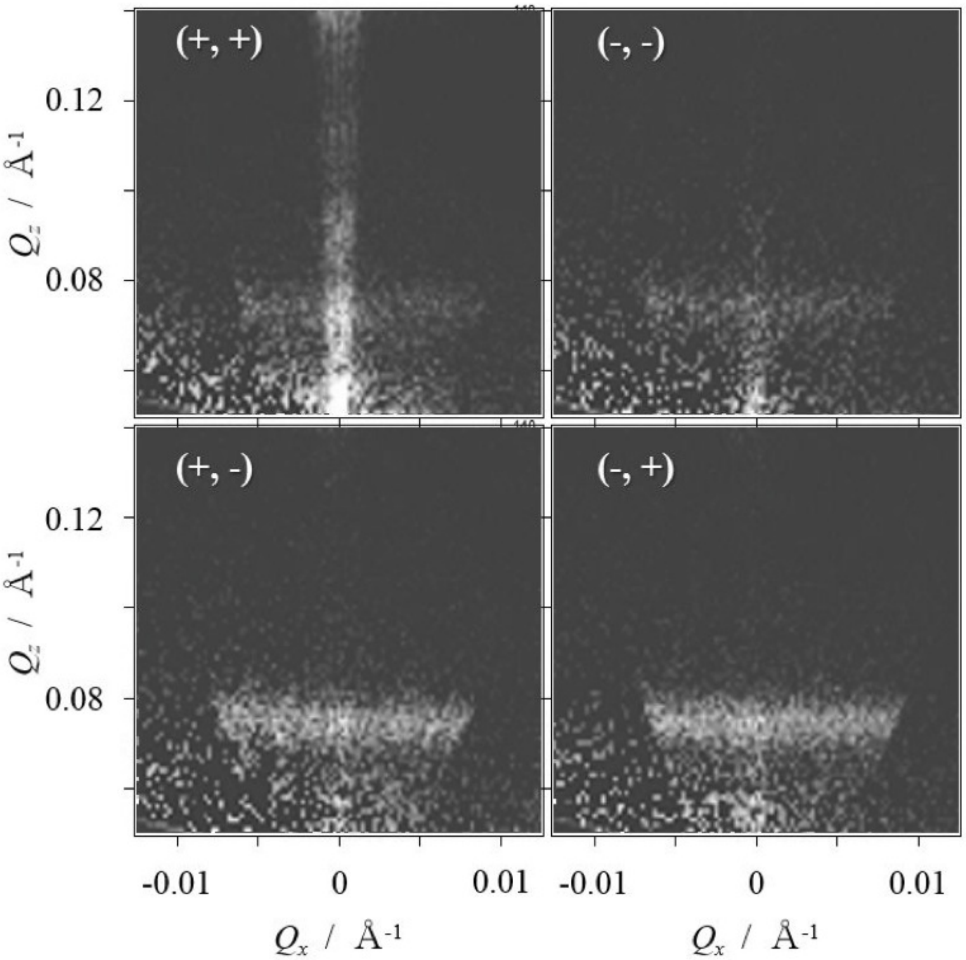

Figure 7. The obtained intensity distributions of the polarized neutron reflectivity from the Fe/Cr thin multi-layers.

4. Demonstration

A demonstration of the ^{3}He-NSF was performed at the neutron reflectometer SHARAKU (BL17) at J-PARC MLF. The in-situ SEOP ^{3}He-NSF was located at 1200 mm downstream of the sample, and used as a neutron spin analyzer. A 2d-PSD was placed after the ^{3}He-NSF. A guide coil was set between the sample and the ^{3}He-NSF for the adiabatic neutron spin transport. We performed polarized neutron reflection measurements from a Fe/Cr multilayered thin film with the giant magneto-resistance effect [7]. By flipping the spin polarity of incident and reflected neutrons, we measured intensity distributions of (+, +), (-, -), (+, -) and (-, +) reflectivities. The first sign in the pair indicates spin polarity of incident polarized neutrons and the second that of reflected ones. Figure 7 shows the reflectivity distributions measured with the applied field of 200 Oe. Off-specular reflections around Q_z=0.08Å^{-1} were clearly measured in the cases of (+, -) and (-, +). This indicates the existence of the antiferromagnetic correlations which align perpendicular to the applied field direction. The obtained data were well consistent with the results of Ref. [7].

5. Conclusion

We have developed compact laser optics with the VHG element for the in-situ SEOP ^{3}He NSF. We used an ECL to narrow the width of the laser spectrum to match it to the width of the Rb absorption line with a laser power loss of 20 %. We have composed the in-situ SEOP ^{3}He NSF with the developed laser optics and achieved the $P_{3\mathrm{He}}$ of 70 %. The AFP-NMR was integrated into the setup to control the polarity of ^{3}He spin and measure $P_{3\mathrm{He}}$. The AFP-NMR and the half-wavelength plate for the the circularly-polarized laser were integrated into the setup to control the polarity of ^{3}He spin of the in-situ SEOP system. The spin flip function for the polarized neutrons were demonstrated by the polarization analysis experiment at the polarized neutron reflectometer SHARAKU (BL17).

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