実験報告書様式（プロジェクト利用）

MLF Experimental Report

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実験課題名 Title of experiment
Development and Application of Neutron Optical devices and Detection System at BL10
実験責任者名 Name of principal investigator
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装置名 Name of Instrument/（BL No.）
BL 10
利用期間 Dates of experiments
2013/04/01 - 2014/03/31

１．研究成果概要（試料の名称、組成、物理的・化学的性状を明記するとともに、実験方法、利用の結果得られた主なデータ、考察、結論、図表等を記述してください。

Outline of experimental results (experimental method and results should be reported including sample information such as composition、 physical and/or chemical characteristics.

1. Development of a superconducting detector for neutrons

[Detector device used for this work]

Neutron detectors used for the present researches are composed of Nb nanowires fabricated on SiO_2 coated Si substrate, where Nb layer (grand plane), SiO_2 layer, Nb layer (nanowire), SiO_2 layer, ^{10}B layer are fabricated layer by layer sequentially. The detectors were used after cooling in the superconducting state. The line width is designed as 3 μm, 1 μm, or 0.6 μm so as to fulfill the higher spatial resolution as a neutron detector. The sensitive are of the 22 mm x 22 mm chip is 8 mm x 8 mm.

[Experimental]

In Fig. 1, we show the block diagram of illustrating the operating principle of our detector. First, ^{10}B film deposited on Nb nanowires reacts with a neutron. Nuclear energy released as kinetic energy of two charged particles acts to decrease the density of superconducting electrons. Then, the kinetic energy of Nb nanowire can be probed by monitoring voltage across the sensor biased by a constant current. We used a Gifford-McMahon (GM) refrigerator to cool down the neutron sensor down to 4 K ($< T_c = 9$ K） in BL10 of J-PARC. In Fig. 2, we show the measurement system, where the Nb nanowire was fed by a constant current I_b. We also used a bias-T for extracting a fast signal to amplify a change in kinetic inductance. The time-dependent signals passing through bias-T were measured by a digital oscilloscope to save the whole signal shapes.

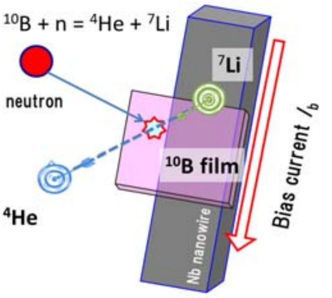

Fig. 1. Operation principle.

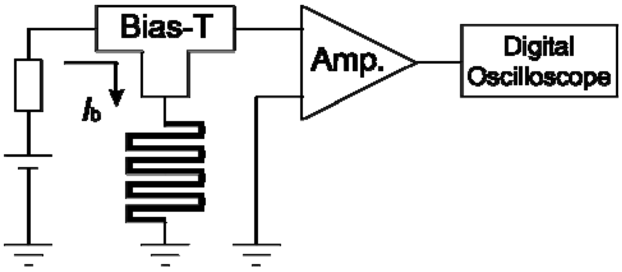

Fig. 2. Measurement system.

1。研究成果概要（つづき） Outline of experimental results (continued).

[Results and Discussion]

We succeeded in observing neutron signals in the range of bias current I_b from 0.1 to 0.8 mA at temperatures below T_c. In Fig. 3, we show a typical signal from neutron at T = 3.4 K and I_b = 0.5 mA. The line width of the signal is roughly 50 ns for various combinations of V_p and I_b. This probably comes from the fact that a signal shape is mainly manifested by reflection of travelling wave signals due to mismatching within the sensor. Inset of Fig. 3 represents a histogram of V_p with rather broad distribution. We interpret it by the dependence on the reaction position with respect to a Nb nanowire to create a signal. If the nuclear reaction between ^{10}B and neutron occurs at the near vicinity of the line, it tends to give a large signal while it becomes small when the position is apart from the Nb line. This is the origin of the wide distribution of the histogram. In addition, it is very plausible to note that the signal appeared when the neutron shutter was opened but it disappears when the shutter was closed. We reasonably conclude that we first observed a clear neutron signal from the pulsed neutron source using a novel superconducting neutron detector.

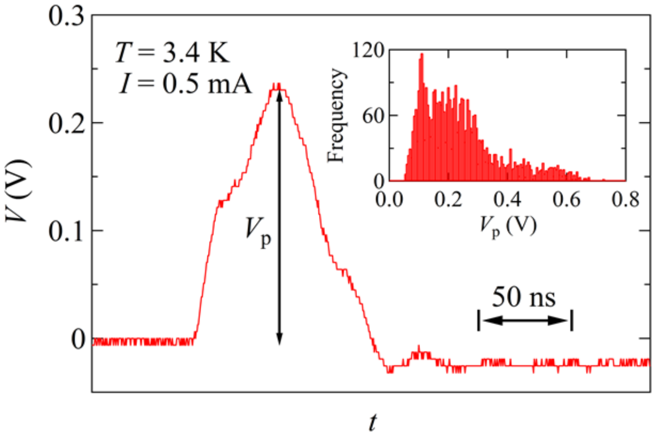

Fig. 3. Signal shape and histogram of V_p.

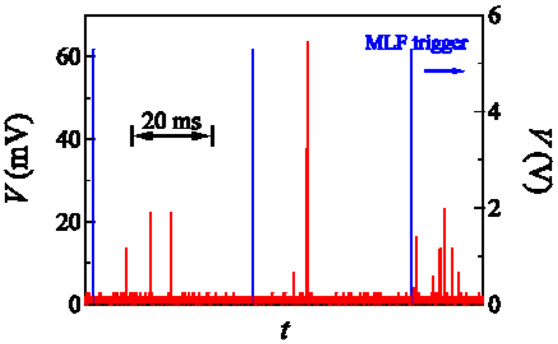

Fig. 4. Signal from detector for a long interval used to obtain Fig. 5.

It is interesting to observe time-dependent neutron intensity during a repetition cycle (40 ms) of the pulsed neutrons. It is necessary to cover the time span longer than 40 ms with high speed sampling rate to recover a 50 ns signal. In Fig. 4, we a typical a time-dependent signal, where we can see a MLF trigger signal three times. We accumulated such signals many times to obtain the histogram of the neutron intensity. In Fig. 5, we a neutron flux as a function of time corrected for velocity-dependent cross-section, and compared with the results obtained by simulation on BL10. We find an excellent agreement between two data. It is noteworthy to mention that we were able to recover a tiny signal from the superconducting sensor even under noise circumstance, suggesting fruitful utilization in the future.

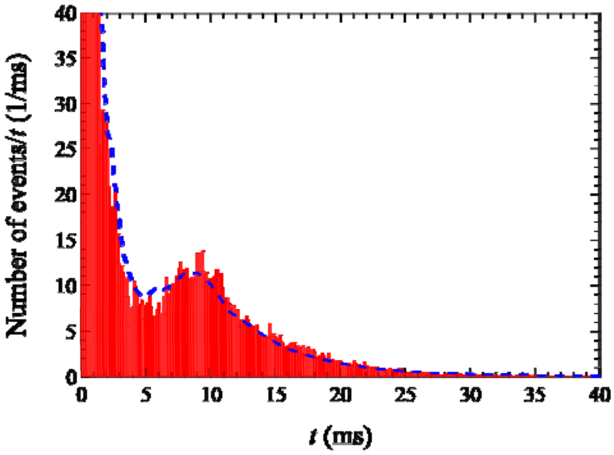

Fig. 5. Time variation of neutron intensity after correcting neutron cross-section. Dashed line is obtained by simulation.

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2. Development of an in-situ spin-exchange optical pumping 3He neutron spin filter

Compact and movable ^{3}He neutron spin filters (NSF) based on the spin exchange optical pumping method (SEOP) have been developed in the MLF at J-PARC. In order to advance the development of ^{3}He NSFs regardless of neutron beams, it is indispensable to tests their feasibilities by using neutron beams [1]. For the purpose, we would attempt to measure the values of ^{3}He gas thickness L and polarization P of the ^{3}He NSFs, and calibrate the nuclear magnetic resonance (NMR) systems installed in the NSF at the BL 10.

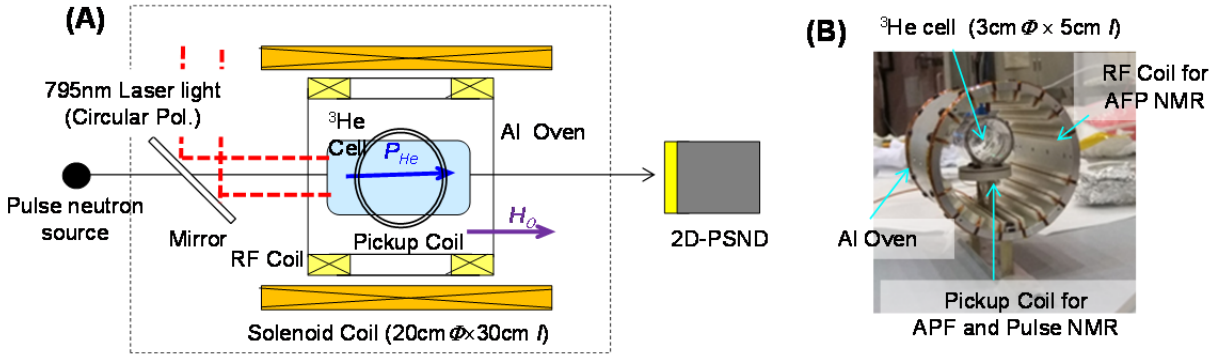

Figure 1 Experimental Setup for evaluating the ^{3}He NSF at the BL10

Figures 1 show the experimental setup for evaluating our ^{3}He NSFs. As shown in figure 1 (A), the NSF consists of a diode laser system, optics and a solenoid coil of 20 cm in diameter and 30 cm in length for sustaining the P. In figure 1 (B), a cylindrical glass cell which contains ^{3}He gas and a small amount of Rb is mounted in an oven of 10 cm in diameter and 20 cm in length. A pickup coil and a radio frequency (RF) coil for the NMR system are mounted around the ^{3}He cell for measuring the NMR signal V. The oven is placed at the center of the solenoid. The temperature in the oven is maintained at approximately 450 Kelvin for vaporizing the Rb while generating the ^{3}He nuclear polarization based on the SEOP.

In figure 1 (A), pulsed neutron beams supplied from a spallation neutron source transmit through the ^{3}He cell, and counted by a two-dimensional position-sensitive neutron detector (2D-PSND) comprising a neutron scintillator and a photomultiplier. A ratio R between neutron transmissions with the NSF polarized and unpolarized is expressed as $R = \cosh(N\sigma LP)$, where N and σ denote a constant and cross section of ^{3}He gas, respectively. The L is derived from the ratio $R_0 = \exp(-N\sigma L)$ of neuron transmissions with the cell containing ^{3}He gas and the empty cell

In the experiment, we evaluated the values of L and P of the three ^{3}He cells with the measurement of R and R_0. The sizes of the cells denoted I and II were 3 cm in diameter and 5 cm in length, and that of the cell denoted III was 5 cm in diameter and 7 cm in length. Table 1 represents the values of L and P of these cells. Figures 2 (A) and (B) show the values of L and P of the cell I as a function of neutron wavelength λ. In order to obtain correlations between the P and V, the NMR measurements based on an adiabatic fast passage (AFP) and a pulse NMR methods, were executed simultaneously. The pickup coils (PC) denoted I, II and III were placed in the ovens with the cells I, II and III. These PCs were fabricated under the same design. Table 2 shows the ratio $Rc = P/ V_{\mathrm{AFP}}$ with the P and the V_{AFP} of the PCs I and II, where the V_{AFP} were measured by the AFP NMR and the values of Rc were normalized by the L of the cell II.

In table 2, the difference of *R*c between 450K and 300K is caused by resistance shift of the coils due to temperature shift. We are also to analyzing the correlation between the *P* and the *V* of the coils I, II and III measured by the pulse NMR. The obtained information will be fed back to the development on our ^{3}He NSFs without neutron beams.

	Cylindrical Cell Size	^{3}He Thickness L (atm·cm)	Typical ^{3}He Polarization P
Cell I	3cm Φ × 5cm L	16.53	0.625
Cell II	3cm Φ × 5cm L	10.80	0.436
Cell III	5cm Φ × 7cm L	9.60	0.415

Table 1 Measured values of L and P of the three ^{3}He cells

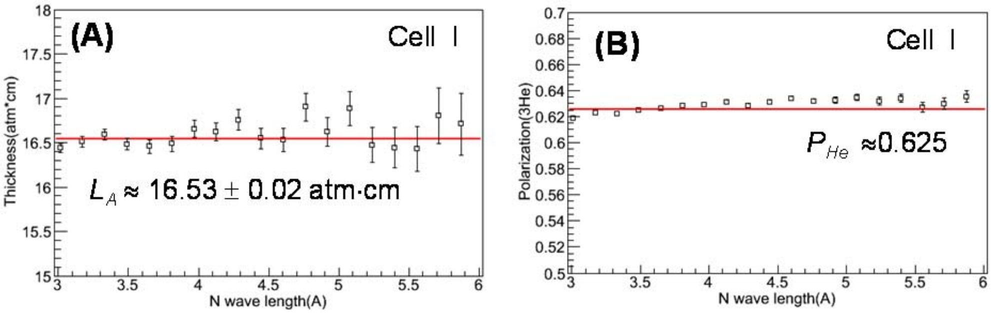

Figure 1 Measured values of (A) L and (B) P of the cell I as a function of neutron wavelength λ

	P_{He}/V_{AFP} (mV) (~450 K)	P_{He}/V_{AFP} (mV) (~300 K)
Pickup Coil I	0.02363	0.02218
Pickup Coil II	0.02137	0.01923

Table 2 Obtained ratio $Rc = P/ V_{AFP}$ with the P and the V_{AFP} of the PCs I and II

[1] K. Sakai, J. Phys.: Conf. Ser. **340,** 012037 (2012)