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Preliminary Experiments of New Spin Echo Spectrometer Using Multilayer Spin Splitters

Seiji TASAKI, Toru EBISAWA, Masahiro HINO, Takeshi KAWAI, Dai YAMAZAKI[1], Norio ACHIWA[2]

Research Reactor Institute Kyoto University, Osaka 590-0494, Japan
[1] *Graduate School of Engineering Kyoto University, Kyoto 606-8501, Japan*
[2] *Faculty of Science Kyushu University, Fukuoka 812-0053, Japan*

The results of preliminary experiments of a new neutron spin echo (NSE) spectrometer using multilayer spin splitters are presented. The multilayer spin splitter (MSS) is a device, based on quantum mechanical representations of the Larmor-precessing neutron, which works equivalent to the precession magnetic field in very small volume. It is expected that if the precession magnet is replaced by a set of MSS's then the spin echo machine will be much smaller than the conventional NSE spectrometers, and it has the possibility of improving the energy resolution of the NSE spectrometer.

KEYWORDS: neutron spin echo, spectrometer, multilayer

§1. Introduction

Neutron spin echo (NSE) spectrometer becomes one of standard methods to measure quasi-elastic scattering of neutrons.[1)] NSE method has a feature that very small energy transfer down to several nano eV is measurable without the loss of neutron intensity. It requires, however, huge but uniform magnets and hence the whole system becomes quite large.

One way to avoid this problem is Neutron Resonance Spin Echo, in which high frequency rf-neutron spin flippers are utilized instead of precession magnets.[2)] The other way is to use the multilayer spin splitter (MSS), which consists of magnetic mirror, gap layer and non-magnetic mirror as shown in Fig. 1. When a neutron in superposition of magnetic-parallel and -antiparallel spin state is incident to MSS, since the parallel and antiparallel component are reflected by the different mirror, the MSS gives a phase difference, equivalent to Larmor precession angle.

Since the 'precession' by MSS is independent from the magnetic field intensity, NSE spectrometer using MSS can be constructed within 1m long.

In the new NSE spectrometer four MSS's are utilized.[3)] In order to avoid polarization reduction due to the beam divergence, (++) arrangement of MSS is adopted. In this set up, the spin echo time $\tau_{\rm NSE}$ for this set up is given by

$$\tau_{\rm NSE} = \frac{4D\sin\theta}{v}, \tag{1.1}$$

where D, θ and v are the thickness of the gap layer, incident angle of neutron to the MSS, and neutron velocity. [3)] It should be noted that from eq.(1.1) thick gap layer and large incident angle are desirable for higher energy resolution. The problems of the former is uniformity over entire surface, peel off problem, and surface roughness. Those for the latter is the interface roughness in the multilayers in the magnetic and nonmagnetic mirror.

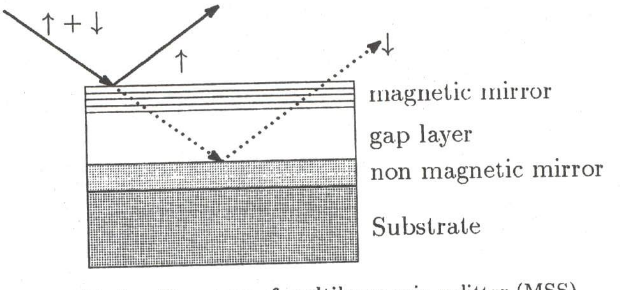

Fig. 1. Structure of multilayer spin splitter (MSS).

We report here the result of a set of new MSS's with gap layer of 2μm, and discussion on NSE spectrometer using these MSS's.

§2. Fabrication of MSS

We fabricated four MSS's, each of which is evaporated at slightly different position in the vacuum evaporation chamber. As nonmagnetic mirrors, we adopt Ni/Ti multilayer of 180Å-d-spacing and number of bilayers of 30. As the gap layer, Ti is evaporated onto the surface of the Ni/Ti multilayer with the thickness of 1μm. As the gap layer material, we used to use Ge. The reasons that Ti is adopted here are 1. the optical potential is lower than Ge and lower potential is preferable to get larger phase difference, 2. on Ni layer the adhesion of Ti is better than that of Ge.

For magnetic mirrors, permalloy (PA) and Ge multilayer is adopted with 180Å-d-spacing and number of bilayers of 30. The magnetic mirrors are evaporated under 150 Gauss magnetic field in order to be magnetically saturated in less than 10 Gauss.[4)]

All experiments described below were performed at C3-1-2 port of JRR-3M reactor in Japan Atomic Energy

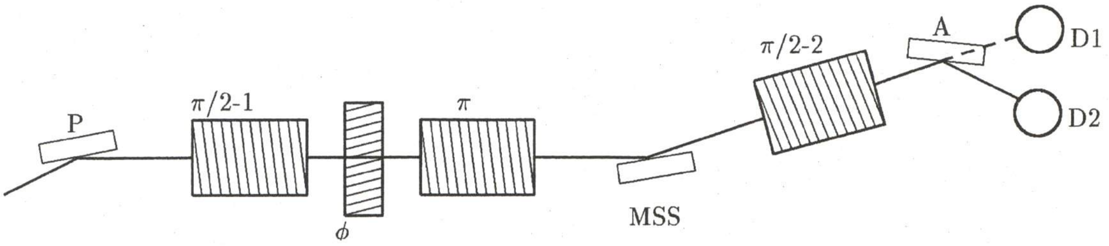

Fig. 2. Experimental arrangement for reflectivity measurement (D1) and MSS function check (D2). P:polarizer, $\pi/2$-1,2:$\pi/2$ flipper, ϕ:phase shifter coil, π:π flipper, MSS:sample MSS, A:spin analyzer.

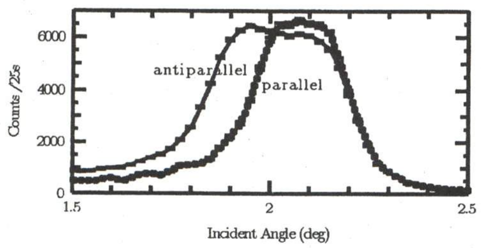

Fig. 3. Reflectivity of a MSS.

Research Institute, where 12.6 Å(resolution 3.5%) neutron beam is available. The neutron reflectivity measurement and function check were performed with the arrangement shown in Fig. 2. For reflectivity measurements current to all flippers was set to zero, detector was set at D1 position and analyzer was removed. The reflectivity of a MSS is shown in Fig. 3.

Incident neutron for the reflectivity measurement is polarized parallel (solid line) and antiparallel (dotted line) to the magnetic field, respectively. In the reflectivity for polarized neutron, there are two peaks at 1.95 and 2.075 deg. Since the peak at 1.95 deg disappears in the reflectivity for antiparallel neutron, it can be concluded that the peak at 1.95 deg comes from magnetic mirror and that from 2.075 deg comes from nonmagnetic mirror. Since in the MSS a neutron should be reflected from both mirrors, this MSS may work when the incident angle lays between 1.9 and 2.00 deg.

After measuring the reflectivity, then the flippers were switched on and the spin analyzer was inserted to measure the spin interference fringe by changing the current of phase shifter coil. The resultant interference fringes for the sample MSS in Fig. 3 is shown in Fig. 4.

Interference is characterized by the value V called 'visibility', which is defined as

$$V = \frac{C_p - C_v}{C_p + C_v}, \tag{2.1}$$

where C_p and C_v are neutron counts at the peak and the valley in the interference pattern. Visibility becomes zero when the interference fringe disappears, and unity when the interference is complete.

If MSS does not work, i.e. a neutron is reflected from either magnetic or nonmagnetic layer only, then the visibility becomes unity except for some depolarization effects. If MSS works, on the other hand, then the visibility vanishes since over 1000 rad-phase is introduced between field parallel and antiparallel state and interference is smoothed out due to the wavelength resolution of 3.5% in the neutron beam. From Fig. 3 incident angle of 1.9deg should be adopted, with which the visibility comes close to zero (0.068). Same measurements were performed for other three MSS's and determined suitable incident angle for each MSS. Such restriction will be alleviated when we adopt supermirrors for the magnetic and nonmagnetic mirror.

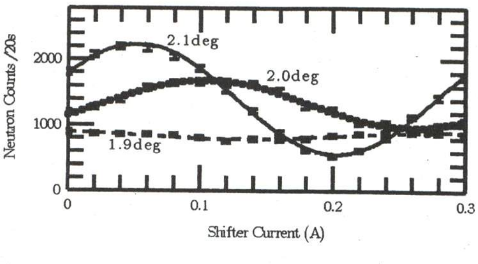

Fig. 4. Some results for function check of MSS.

§3. Neutron Spin Echo with MSS's

In the next stage, simple neutron spin echo was measured in the arrangement shown in Fig. 5. In this set-up, properties such as thickness, homogeneity and surface roughness of the gap layers in two MSS's can be evaluated.

Neutron is polarized, $\pi/2$ flipped and reflected before and after π flipper. Then the neutron is $\pi/2$ flipped again and polarization analysed. The NSE signal is measured as a function of the current of the phase shifter ϕ. A

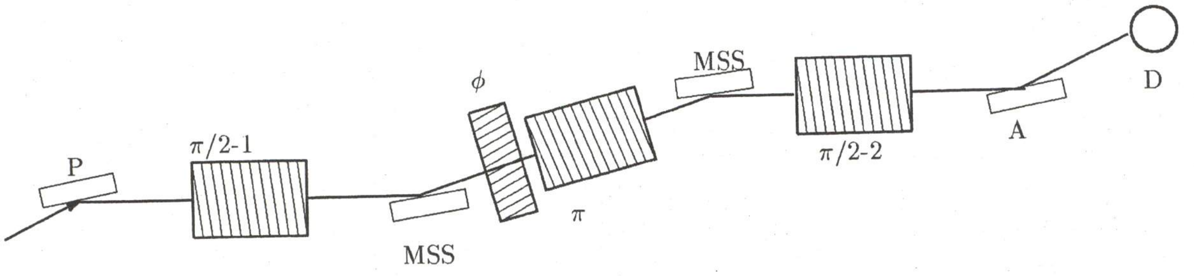

Fig.5. The arrangement for NSE with two MSS's. NSE signal enable us to evaluate fluctuation in D and the thickness of D.

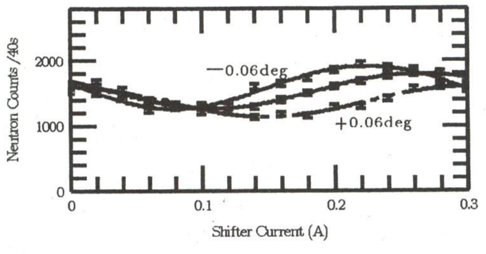

Fig.6. Some of the experimental results of NSE signal.

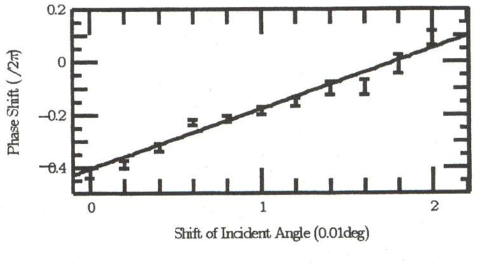

Fig.7. Shift of interference fringe via shift of incident angle to the second MSS. The gradient of the line is proportional to the thickness of the gap layer in MSS.

part of the experimental results are shown in Fig. 6.

Since the homogeneity and surface roughness of the gap layer give the same effect in NSE signal, we refer both as 'deviation of D' in the followings. It reduces the visibility of NSE signal. If deviation in D obeys gaussian distribution with standard deviation σ and σ takes the same value for both MSS, then the visibility reduction r comparing to the visibility without MSS's is given by

$$r = \exp\left[-\frac{4\pi^2\sigma^2\sin^2\theta}{\lambda^2}\right]. \tag{3.1}$$

Since the visibility without MSS was equal to 0.767 and with MSS's was 0.18, evaluated deviation is 66.2 Å for each MSS.

According to this result, visibility is reduced by a factor 0.48 with a single reflection by a MSS. After four sequential reflections it would be reduced to about 5%. To construct a spectrometer at least 20% visibility should be kept. It means that the deviation should be less than 50 Å.

The gap layer thickness is evaluated from the shift of NSE signal via incident angle of neutron to the second MSS. The results of the relation between incident angle shift and phase shift is shown in Fig. 7.

Including the neutron refraction, the shift $2\pi\delta N$ of the interference fringe is given by

$$\delta N = \frac{2D}{\lambda}\sqrt{1-\frac{\lambda^2}{\lambda_c^2\sin^2\theta}}\delta\theta, \tag{3.2}$$

where λ_c is the critical wavelength of Ge and equal to 925.75 Å. From the fit to the experimental data, D is evaluated as 8889 Å.

The NSE spectrometer using these MSS's, the spin echo time τ_{NSE} equals 4.4nsec (eq. 1.1) with 12.6Å-neutron.

In the course of these experiments, we tried to measure the NSE signal with the NSE spectrometer arrangement. The NSE signal, however, was not found. The possible reasons are 1. visibility becomes too low (less than 5%) to measure, 2. incident angle is slightly different from the optimal angle, especially for two of the four samples.

In the next step, we will make use of supermirror thickness distribution in magnetic and nonmagnetic mirror to avoid the matching problem.

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1) F. Mezei: Neutron Spin Echo, Lecture Notes in Physics, (Springer, Berlin, 1980)
2) R. Golub and R. Gäher: Phys. Lett. A **123** (1987) 43.
3) M. Hino, T. Ebisawa, S. Tasaki, Y. Otake, H. Tahata, M. Hashimoto, T. Takahashi and N. Achiwa: J. Phys. Chem. Solids **60** (1999) 1603.
4) T. Kawai, T. Ebisawa, S. Tasaki, Y. Eguchi, M. Hino and N. Achiwa: J. Neutron Research **5** (1997) 123.