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Application of MSS-neutron spin echo spectrometer to pulsed neutron sources

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Abstract

A multilayer spin splitter (MSS) is a neutron device that gives phase difference between field-parallel and -antiparallel spin component of a superposing state. Since the phase difference is equivalent to the Larmor precession angle, MSS enables us to construct a new type of neutron spin echo (NSE) spectrometer. The new NSE spectrometer has its properties that 1.since the phase shift is neutron flight path length, the spectrometer can be drastically small, 2.the neutron spin echo time is proportional to the neutron wavelength.

1 Introduction

The multilayer spin splitter (MSS) is a neutron device which consists of magnetic mirror, gap layer and non-magnetic mirror as shown in Fig. 1 and works equivalently to the Larmor precession magnet. When a neutron in superposition of magnetic-parallel and -antiparallel spin state, which is interpretted as Larmor precessing neutron, is incident to a MSS, since the parallel and antiparallel component are reflected by the different mirror, the MSS gives a phase difference between these states.

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

The basic idea for the new spin echo spectrometer is that the Larmor precession magnet is replaced by the MSS's.

In the new NSE spectrometer four MSS's are utilized as shown in Fig. 2. [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

$$\tau_{\rm NSE} = \frac{4D\sin\theta}{v}, \tag{1}$$

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) thick gap layer and large

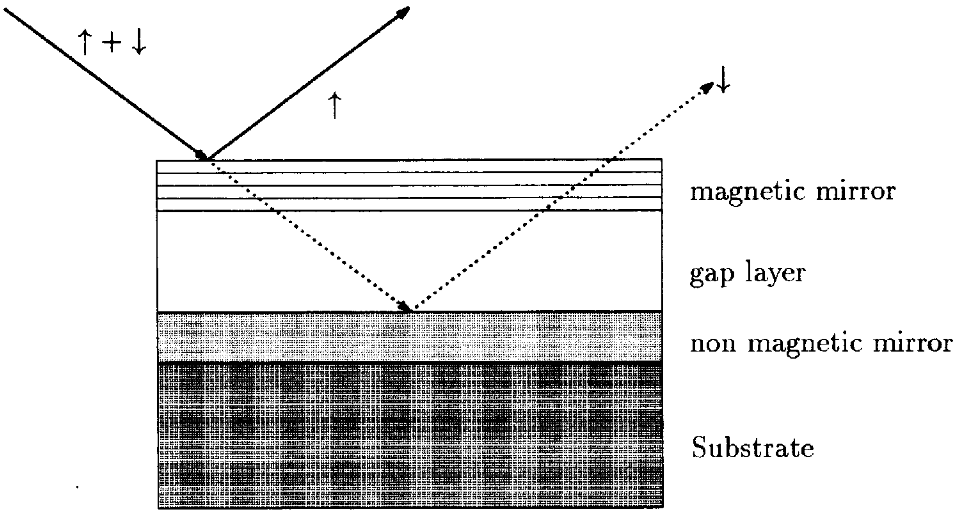

Figure 1: Structure of multilayer spin splitter (MSS).

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.

2 Properties of MSS

We fabricated four MSS's with the vacuum evaporation. [4] 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 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 150Gauss

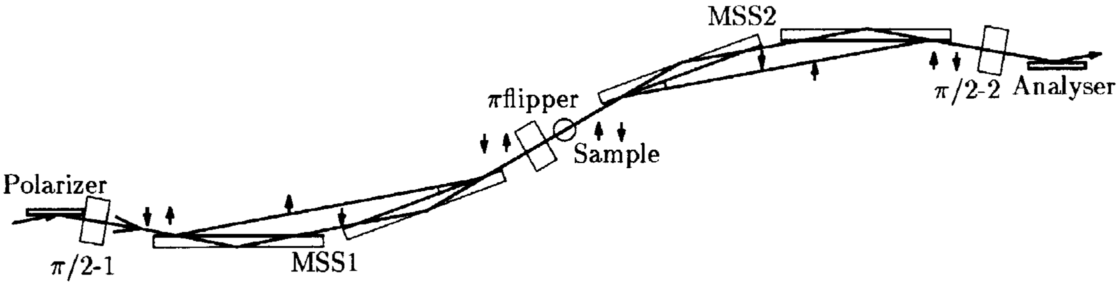

Figure 2: Structure of spin echo spctrometer using MSS.

magnetic field in order to be magnetically saturated in less than 10Gauss.

All experiments described below were performed at C3-1-2 port of JRR-3M reactor in Japan Atomic Energy Research Institute, where 12.6Å(resolution 3.5%) neutron beam is available.

The experimental set up for the neutron reflectivity is shown in Fig. 2. Neutron beam from the C3 neutron guide of JRR-3M reactor is first polarized by the polarizing mirror (P). To avoid the depolarization, 8 Gauss vertical magnetic field is applied to the whole system. The reflectivity is measured with π-flipper OFF (polarized) and ON (antipolarized).

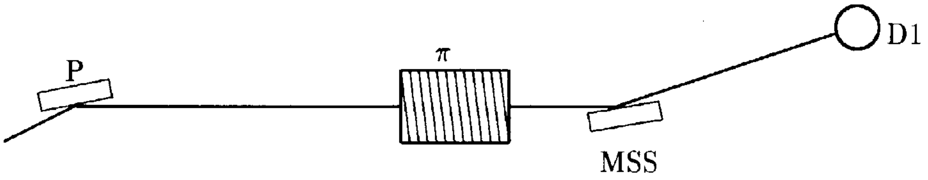

Figure 3: Set up for the neutron reflectivity.

An example of the reflectivity of a MSS with polarized neutron is shown in Fig. 2. The solid line and dotted line represent polarized and antipolarized reflectivity, respectively. There are peaks at 1.95 and 2.075deg in the polarized reflectivity. Since the peak at 1.95 deg disappears in the antipolarized reflectivity, peak at 1.95 and 2.075 deg come from PA/Ge and Ni/Ti mirror, respectively. This result implies reflectivity peak from the magnetic and nonmagnetic mirror do not match. Since in the MSS a neutron should be reflected from both mirrors, neutron incident angle should be precisely tuned.

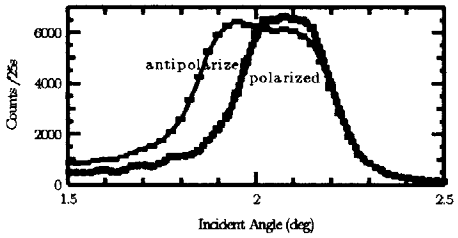

Figure 4: Neutron reflectivity of an MSS.

Thickness and homogeneity of the gap layer are experimentally estimated with the set up shown in Fig. 2. Homogeneity is estimated from the reduction of visibility in the interference pattern, where visibility V is defined as

$$V = \frac{C_p - C_v}{C_p + C_v}, \tag{2}$$

where C_p and C_v are neutron counts at the peak and the valley in the interference frings, respectively. The visibility of the spin echo signal without MSS was equal to 0.767 in the above seu-up. If difference 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

$$r = \exp\left[-\frac{4\pi^2\sigma^2\sin^2\theta}{\lambda^2}\right]. \tag{3}$$

Examples of the spin echo signals are shown in Fig. 2. Since the visibility without and with MSS was equal to 0.767 and 0.18, respectively, evaluated deviation is 66.2Å 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 50Å.

The thickness of the gap layer is estimated from the shift of the NSE signal due to the change of the angle of an MSS. From the results shown in Fig.2, the thickness for the above MSS's is estimated as 8889Å.

In the present stage, the MSS fabricated using vacuum evaporation is not suitable due to the inhomogeneity of the gap layer.

We are planning a few way to solved this problem: 1. stacking the gap layer usign sputtering method, with which a smoother layer can be fabricated, 2. independent two substrates are faced and tuned precisely using piezo-actuators.

3 Applicability to the pulsed neutron sources

In order to apply the MSS-NSE spectrometer to pulsed neutron sources, some technical problems should be solved.

1. Polarizer and analyer mirrors shoud become supermirror. Maximum stacking thickness of PA/Ge multilayer is limited with vacuum evaporation (less than about 8000Å). This can be improved with sputtering method.
2. Both magnetic and nonmagnetic mirrors in MSS should be supermirrors, in order to reflect wide wavelenghth range of neutron.
3. The spin flippers should deal with 'white' neutron spectrum or with Time Of Flight mode. We are planning to examine the latter method.

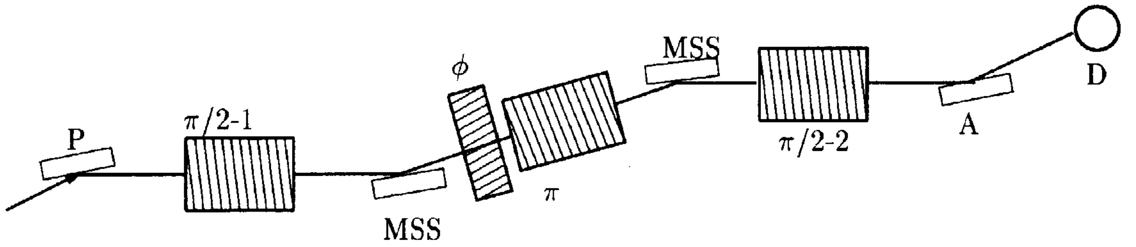

Figure 5: The set up for estimation of thickness and homogeneity of the gap layer.

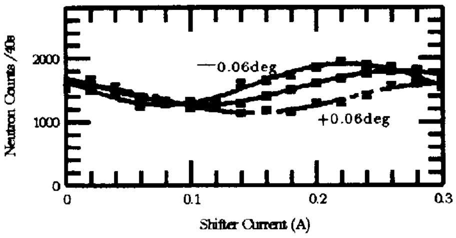

Figure 6: Neutron spin echo using a pair of MSS's.

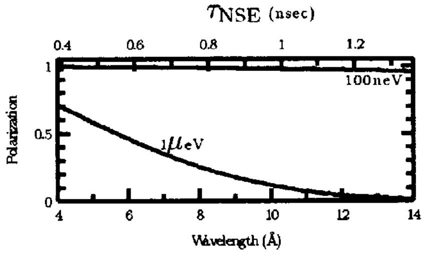

Figure 7: Polarization of NSE signal for MSS-NSE via neutron wavelength.

For the MSS-NSE spectromter, the spin echo time $\tau_{\rm NSE}$ is represented in the following equation,

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

v:velocity of the netron, θ:neutron incident angle to MSS. The most difference from the other spin echo methods is that the spin echo time is inversely proportional to v, not v^3.

If we assume that the quasi-elastic scattering in the sample obeys Gaussian distribution with standard deviation σ, the polarization $P_{\rm NSE}$ of the spin echo signal is represented with $\tau_{\rm NSE}$,

$$P_{\rm NSE} \propto \exp\left[-\frac{\tau_{\rm NSE}^2\sigma}{\hbar^2}\right]. \tag{5}$$

A simulated polarizability of NSE signal for MSS-NSE spectrometer via neutron wavelength is shown in Fig. 7. Here we assume gap layer thickness of the MSS's as 10 μm, neutron incident angle 1.1 deg, and σ as 100 neV and 1 μm. The upper axis in the figure represents $\tau_{\rm NSE}$.

Since v-dependence of $\tau_{\rm NSE}$ is different from conventional spin echo spectrometer, MSS-NSE spectrometer has its advantages that it can give detailed information on the quasi-elastic scattering, as well as its smallness.

Acknowledgements

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References

[1] F.Mezei, Neutron Spin Echo, Lecture Notes in Physics, (Springer, Berlin, 1980)

[2] R.Golub, 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] S.Tasaki, T.Ebisawa, T.Akiyoshi, T.Kawai, S.Okamoto, Nucl. Instr. & Meth. A **355** (1995) 501.