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A DOUBLE REFLECTION MULTILAYER MONOCHROMATOR FOR COLD NEUTRON POLARIZING AND SMALL ANGLE SCATTERING EXPERIMENTS.

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ABSTRACT
A multilayer monochromator using double reflection has been developed for cold neutron polarizing and small angle scattering experiments. It utilizes a successive double reflection by a pair of two identical multilayer mirrors arranged at a designed angle, which have a layer spacing distribution of $d \pm \Delta d$. A number of the pairs are assembled in a Soller type to cover the width of the neutron beam. The double reflection multilayer monochromator functions as a monochromator, polarizer, beam bender and collimator of the beam at the same time. The performance tests gives a promising characteristics of the double reflection monochromator.

I. INTRODUCTION

Multilayer neutron mirror was first reported by Schoenborn et al. for monochromator and by Mesei for supermirror[1,2]. We have developed a various kind of devices for cold neutrons using multilayer mirror during over ten years[3,4]. In the devices are included supermirrors for guide tubes and experimental devices[5,6,7], polarizers and analyzers for polarizing experiments[8] and monochromators for cold, very cold and ultra cold neutron experiments[9,10,11,12].

We present a double reflection multilayer monochromator for a cold neutron polarizing experiment and a small angle scattering experiment.

The device is something that two identical multilayer mirrors connected at a designed angle 2θ are assembled in a Soller type as shown in Fig.1. The successive double Bragg reflection by the two mirrors determines the characteristics of the device. The multilayer mirror is a monochromator with a spacing distribution d ± Δd. We present here only a brief description of it's principle and structure. More detailed discussions are given elsewhere9),10).

Ⅱ. PROPERTIES OF DOUBLE REFLECTION MONOCHROMATOR

We consider Bragg reflection of neutron by a multilayer monochromator. Neutron wavelength λ satisfying Bragg condition is given by the following equation under the assumption of $\theta \ll 1$ and $\Delta\theta \ll 1$,

$$2(d-\Delta d)(\theta-\Delta\theta) < \lambda < 2(d+\Delta d)(\theta+\Delta\theta) \qquad (1)$$

where θ is the neutron incident angle and $\Delta\theta$ is the beam divergence angle. Expressing the permissible neutron wavelength as $\lambda_0 \pm \Delta\lambda$. Then, λ_0 and $\Delta\lambda$ are given by Eq. (2) neglecting $\Delta d\ \Delta\theta$

$$\lambda_0 = 2d\,\theta, \qquad \Delta\lambda = 2(d\,\Delta\theta + \theta\,\Delta d) \qquad (2)$$

Neutrons with longer wavelength are reflected at larger angle and neutrons with shorter wavelength are reflected at smaller angle.

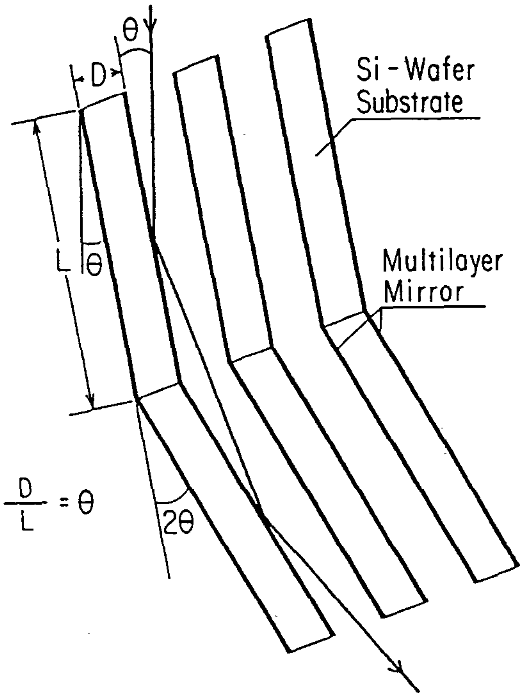

Fig. 1 Structure of a double reflection multilayer monochromator of a Soller type.

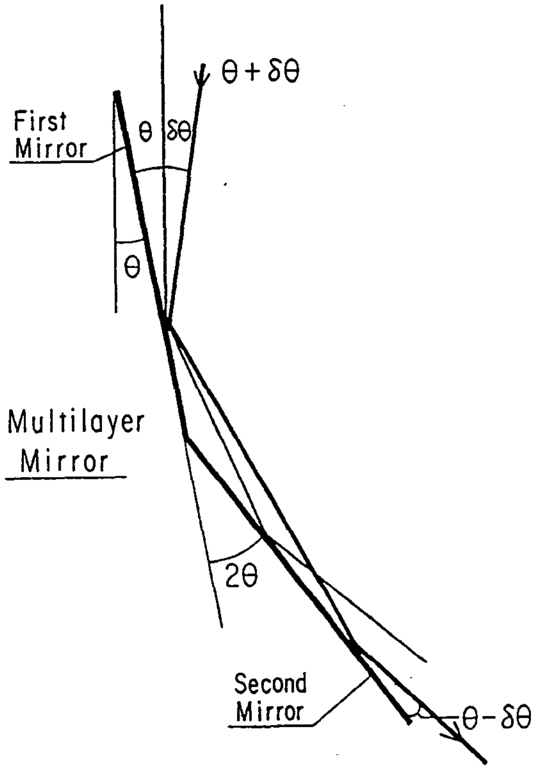

Fig. 2 A neutron trajectory taking a successive double reflection by two identical multilayer mirrors connected at a designed angle.

Next, we consider characteristics of neutrons reflected successively doubly as shown in Fig.2. Two identical mirrors connected at a designed angle 2θ. Angle θ and $\delta\theta$ correspond to the glancing angle and divergent angle of the incident neutron, respectively. Neutrons incident on the first mirror at the angle of $\theta + \delta\theta$ are incident on the second mirror at $\theta - \delta\theta$. Neutron wavelength reflected by the first and the second mirror should satisfy the Eqs. (3) and (4) simultaneously,

$$2(d-\Delta d)(\theta + \delta\theta) < \lambda < 2(d+\Delta d)(\theta + \delta\theta) \quad (3)$$

$$2(d-\Delta d)(\theta - \delta\theta) < \lambda < 2(d+\Delta d)(\theta - \delta\theta) \quad (4)$$

Denoting the allowable wavelength region of neutrons reflected doubly as $\lambda_0 \pm \Delta\lambda$ and it's permissible divergent angle as $\theta \pm \Delta\theta$, respectively, the resolutions of wavelength in FWHM and the allowable divergent angle are given by Eqs. (5) and (6), respectively[10]

$$\Delta\lambda / \lambda_0 = \Delta d/d \quad (5)$$

$$\Delta\theta = \pm \Delta d\, \theta / d \quad (6)$$

These resolutions depend on only Δd and not $\Delta\theta$, different from the single reflection case. Equation (6) indicates the effect of beam collimation by the device.

The properties of the neutron beam reflected successively doubly are summarized as the following.

(1) the neutron wavelength : $\lambda_0 = 2d\theta$
(2) the wavelength resolution in FWHM : $\Delta d/d$
(3) the beam bent angle : $4\theta = 2\lambda_0/d$
(4) the allowable divergent angle : $\Delta\theta = \pm \Delta d\, \theta / d$
(5) the effective reduction of undesirable neutrons with low reflectivity.

In order to shorten the device length of double reflection multilayer monochromator available for a wide neutron beam, pairs of multilayer mirrors connected at a designed angle should be assembled in a Soller type as shown in Fig.1. In this case, two identical mirrors are deposited on both surfaces of a Si-substrate.

Double reflection multilayer monochromators as bender enable a guide tube to install multiple spectrometers for cold neutrons. Larger bent angle could be realized by a multiple reflection more than twice at the small cost of neutron yield by using mirrors with high reflectivity.

The above monochromator device would be useful for small angle scattering, polarizing experiments and various kinds of cold neutron experiments.

III. PERFORMANCE TESTS OF DOUBLE REFLECTION MONOCHROMATOR

Performance tests of a typical double reflection multilayer monochromator are made for cold neutron polarizing experiments. Arrangement for the tests are shown in Fig.3. Parameters of the double reflection multilayer monochromator are given in Table 1. It should be noted that the size of the device is very small (the total length is only 6.2 cm). The analyser mirror with Soller type made of Fe$_{50}$Co$_{50}$-V multilayer have 2d=360 A, Δd/d=0.9 and L=10 cm.

Table 1 Design parameters of double reflection monochromator with Fe50Co50-V multilayer.

2d (A)	Δd/d	θ (rad)	4θ (rad)	$\Delta\theta$ (rad)	λ_0(A)	$\Delta\lambda/\lambda_0$	L (mm)	D (mm)	R$^{1)}$	Y$^{2)}$
280	0.075	1/51.7	1/12.9	1/690	5.4	0.075	31	0.60	0.9	0.69

1) : Reflectivity of mirror

2) : Neutron yield at the peak by double reflection multilayer monochromator estimated numerically[10].

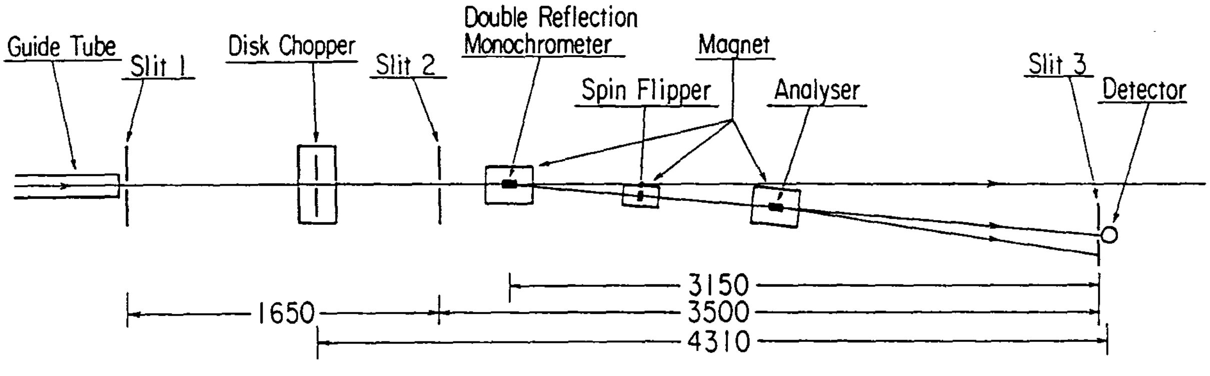

Fig. 3 Arrangement for the performance test of double reflection multilayer monochromator.

The neutron yield, wavelength and resolution are evaluated from TOF data. The results for the single and double reflection are shown in Fig.4 for the incident beam with the divergence of ± 1/400. The neutron yields are normalized by the direct spectrum. The results of the double reflection reproduce the properties listed in Table 1 except the neutron yield. The small reduction in the neutron yield may result from the under reflectivity (about 0.85) of the mirrors indicated by the single reflection data.

Measured divergent angles by the double reflection and the single reflection are given in Fig.5 for the incident beam with the divergence of 1/235. Comparison of the double reflection with the single reflection proves the characteristics of the double reflection multilayer monochromator as collimator for the incident beam as expected in Table 1. Bent angle is given easely from the center position of the beam profile.

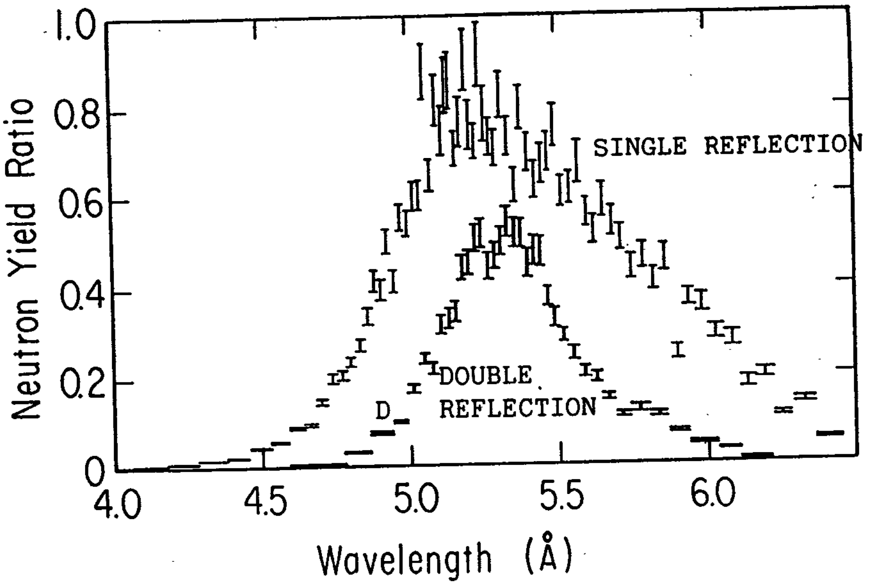

Fig. 4 Neutron yield by TOF methods for single and double reflection.

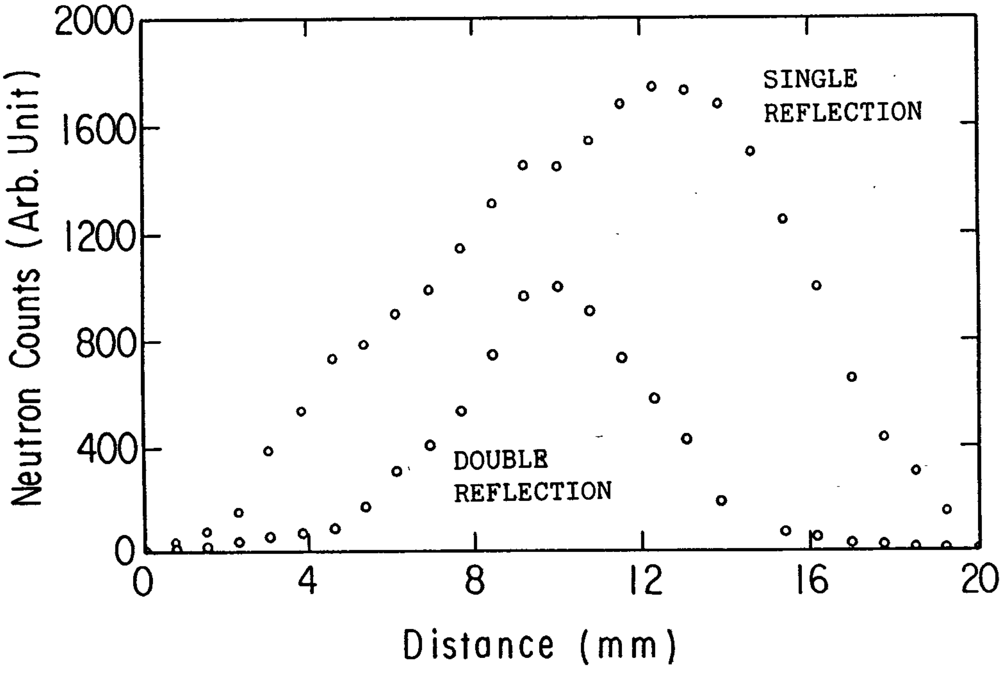

Fig. 5 Spread of the output beam by the single and double reflection for the incident beam divergence of 1/235.

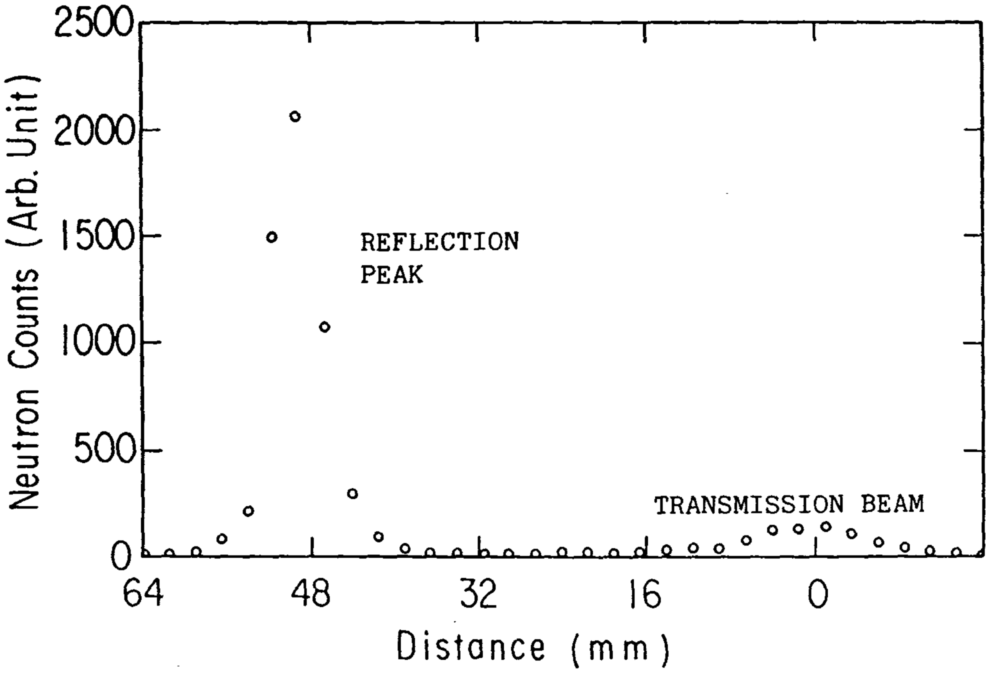

Fig. 6 Beam profile of the reflection and transmission by the analyser mirror.

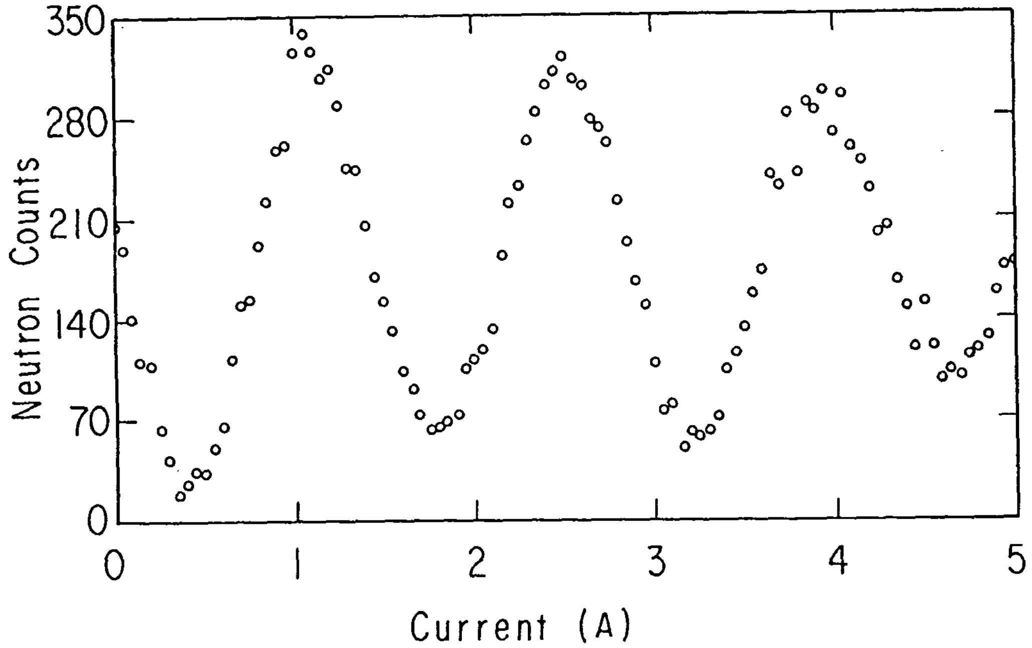

Fig. 7 Spin flipping data. The abcsissa indicates spin precession current of Mesei spin flipper.

When analyser mirror is set, the beam is reflected nearly perfectly (Fig.6). and the system gives the flipping ratio of about 1/20 (Fig.7).

A double reflection multilayer monochromator, with magnetic multilayer functions as a monochromator, polarizer, beam bender and beam collimator simultaneously.

For unpolarizing experiment, double reflection multilayer monochromators with Ni-Ti multilayer mirrors are adequate.

IV CONCLUSION

The double reflection multilayer monochromator with very small size functions as monochromator, polarizer (using magnetic mirror), beam bender and collimator simultaneously. Multiple reflections more than twice would be bring us larger bent angle at the cost of neutron intensity. The device would be useful for small angle scattering, polarizing experiments and various kinds of cold neutron experiments.

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Q(J.B.Hayter): I was interested to see that you used time-of-flight at your reactor to measure reflectivity performance. Since we are at a pulsed source conference, I can admit that G.Williams, J.Penfold and I found time-of-flight the method of choice for our thin-film interferometry work at ILL many years ago. Working at a fixed angle offer significant advantages.

A(T.Ebisawa): I like TOF method for a continuous source, if we have neutron intensity enough for measuring.