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Fabrication and Performance of a Large Wavelength Band Multilayer Monochromator

P. Høghøj, I.S. Anderson, *T. Ebisawa, **T. Takeda

Institute Laue Langevin, BP156,38042 Grenoble Cedex, France
**Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-04, Japan*
***Faculty of Integrated Arts and Science, Hiroshima University, Higashihiroshima 739, Japan*

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A multilayer monochromator of the double reflection type has been constructed and installed on the Neutron Spin Echo spectrometer at the JRR-3M reactor. The monochoromator comprises 12 silicon wafers each with 438 Ni/Ti layers, giving a multilayer wavelength resolution of 30% and a reflectivity between 85 and 90%. Flux tests on the instrument indicate a fivefold increase in flux at the sample compared to the previous configuration.

KEYWORDS: Multilayer monochromator, Double reflection monochromator, Large wavelength band, Neutron optics, Neutron spin echo spectrometer

§.1. Introduction

The neutron spin echo spectrometer which has been installed at the C_{2-2} guide port at the JRR-3M reactor, JAERI by the Institute of Solid State Physics(ISSP), Tokyo University has been described in previous publication.[1,2] As indicated in Fig.1, an Fe/Ge multilayer monochromator deflects the beam through a 9m guide section to a polariser constructed using Fe-Co/V supermirrors. The monochromator has a wavelength resolution of 10-20% in the wavelength range 5-10Å. Due to the low take-off angle of the monochromator the performance of the two optimal field shape precession coils[3] which follow the polariser is compromised by the presence of iron shielding material surrounding the nearby C_{2-3} guide port.

An optimum separation of the precession coils from the iron shielding would require a monochromator take off angle $2\theta_m$ of the order of 7 degrees and thus a multilayer d-spacing of 50Å for a wavelength of 6Å. The production of such a multilayer monochromator with high reflectivity (>80%) would not be possible even using modern sputtering techniques, so it was decided to use a double reflection monochromator as first described by Ebisawa et al.[4] The double reflection monochromator, the principle of which is shown in Fig.2, has the following characteristics.

- nominal wavelength: $\lambda_0 = 2d\theta$
- the wavelength resolution (FWHM) is given by: $\Delta\lambda/\lambda_0 = \Delta d/2d$
- the outgoing beam divergence is also given by: $\Delta\theta = \theta\,\Delta d/2d$
- the total deflection of the beam: 4θ

where $\Delta d/d$ is the distribution of d-spacings in the multilayer. The interesting property of the double reflection monochromator is that both the wavelength resolution and the beam collimation are determined by the $\Delta d/d$ of the multilayer which can be selected to suit the instrument specifications. In order to reduce the length of the monochromator, a Soller type device was foreseen using two parallel multilayer monochromators to cover the 20mm wide beam in the guide with the characteristics listed in the Table I.

Simulations of the performance of such a monochromator, shown in Fig.3, predict a neutron yield ratio in the peak of 0.61 (normalized to a beam divergence of $\pm\Delta\theta$).

§.2. Fabrications

The Ni/Ti multilayers were deposited onto 12 silicon wafers of dimension $112\times76\times1.5\mathrm{mm}^3$ using a DC magnetron sputtering facility at ILL. X-ray reflection measurements on the pure silicon substrates showed that the surface roughness varied between 7 and 11Å(RMS) hence limiting the minimum roughness of the deposited layers. Experience with magnetron sputtered films has shown that optimum values of the film density and the surface interface roughness can be achieved by minimizing the working gas pressure in the system. Both the Ti and the Ni were deposited using argon at 1.1 microbar and power densities of 2.4 and 2.1 Watts/cm^2, respectively. The film thickness was determined, at constant power, by the speed of translation of the substrates below the sputter target, and a thickness uniformity of ±1% was easily achieved. Calibration of the deposition rates and determination of the film roughness was made using X-ray reflection measurements on periodic Ni/Ti multilayers. These measurements showed that the roughness at both Ni/Ti and Ti/Ni interfaces was approximately 8.5Å(RMS) under the deposition conditions used.

Table I. Required characteristics of the double reflection monochromator.

Center wavelength λ_0	5.9Å
Total wavelength resolution ($\Delta\lambda/\lambda_0$ FWHM)	15 %
Beam divergence $\Delta\theta$	± 4.7 mrad.
Deflection angle 4θ	7.0 deg.
Beam size (H × W)	50×20 mm^2
Multilayer characteristics	
Nominal d spacing	98Å
Wavelength band $\Delta\lambda/\lambda$	30%
Reflectivity	85%

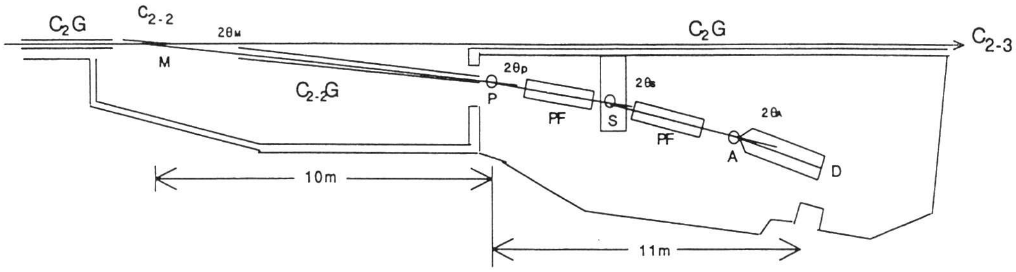

Fig. 1. The whole view of the neutron spin echo at JRR-3M; C_2G: C_2 cold neutron guide, $C_{2\text{-}2}G$: $C_{2\text{-}2}$ neutron guide, $C_{2\text{-}2}$: $C_{2\text{-}2}$ cold neutron guide port, $C_{2\text{-}3}$: $C_{2\text{-}3}$ cold neutron guide port, M: monochromator, P: polarizer PF: precession coil, S: sample, A: analyzer D: detector.

As described previously, the specifications for the monochoromator demand multilayers with a nominal *d*-spacing of 98Å and a band width of 30%. Allowing for refraction corrections this leads to bilayer periods ranging from 84.3 to 114.3Å. The layer thickness sequence was calculated using the algorithm of Hayter and Mook[5] adapted to take into account the measured film roughness of 8.5Å. The final sequence used for the depositions was made up of 438 layers with a total thickness of approximately 2 microns and yielding a theoretical maximum reflectivity of 90%.

Figure 4 shows a typical neutron reflectivity profile measured with 7.5Å neutrons on the T3 instrument at ILL. The absolute reflectivity has been evaluated by normalization to the direct beam intensity. The profile shows a peak reflectivity of the order of 85% across a wide plateau region. The width of the peak, $\Delta\theta/\theta$(FWHM), was measured to be 28%. The 2% difference between the measured and the targeted width can be explained by a systematic and known decrease in the sputtering rate with target usage. Depositions were also made concurrently on test wafers having a surface roughness of 6Å. The low Ni/Ti interface roughness of 8.5Å was only achieved on these test wafers and the 1.5mm wafers with the low surface roughness(7Å).

§3. Performance

The 12 multilayers were mounted in a support and installed at the $C_{2\text{-}2}$ neutron guide port. Following careful alignment the flux at the end of the $C_{2\text{-}2}$ guide(beam cross section $50\times20\text{mm}^2$)was measured using a $25^{w}\times5^{h}\text{mm}^2$ slit in front of a 1 inch ^{3}He detector set horizontally. The flux was also measured at the sample position, 4m from the end of the $C_{2\text{-}2}$ guide(and about 3.5 m from the polariser), using a vertical slit of 25×5 mm^2. The results are summarized in Table II.

The measured flux at the end of the $C_{2\text{-}2}$ guide is somewhat lower with the new monochromator than with the old one, however at the sample position a flux increase by a factor 3.8 is observed. This may be explained by the fact that the old single reflection monochromator produces a beam with a divergence given by the critical angle of the incoming Ni guide resulting in a beam width at the sample position of about 10cm (FWHM). The beam profile also shows significant large angle tails. However due to the collimating effect of the double reflection arrangement the new monochromator delivers a well collimated beam with a width of 5cm at the sample position (FWHM unpolarized beam). The polarizer further focusses the beam resulting in a width of 1.5cm at the sample position for a polarized beam. As a result of the improved collimation the radiation

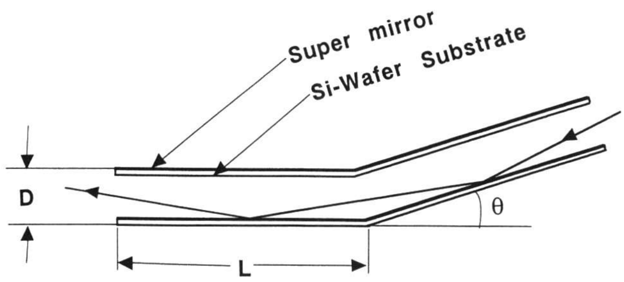

Fig. 2. The principle of a double reflection monochromator.

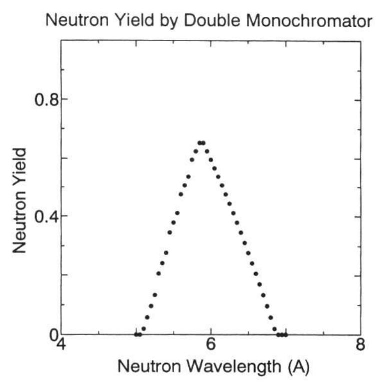

Fig. 3. Simulated yield of a double monochromator with a $\Delta d/d$ of 30% and reflectivity of 90%. The yield has been normalized to a beam divergence of ±4.7 mrad.

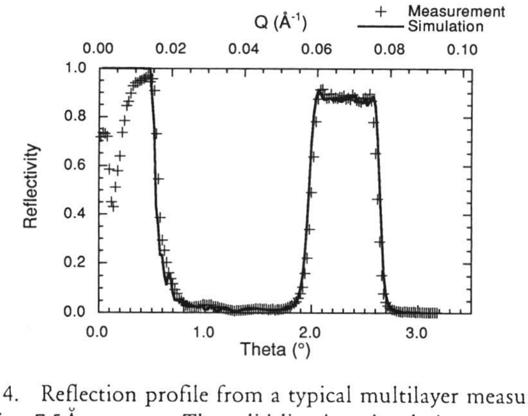

Fig. 4. Reflection profile from a typical multilayer measured using 7.5Å neutron. The solid line is a simulation assuming an interface roughness of 8.5Å. The measured reflectivity is above 85% over an angular range $\Delta\theta/\theta$ of 28%.

level due to gamma rays emmitted by the polarizer is also significantly reduced.

§.4. Conclusion

A double reflection multilayer monochromator with a scattering angle of 7 degrees for 6Å neutrons has been constructed for the neutron spin echo spectrometer at the JRR-3M reactor. The individual multilayers reflect a wavelength band $\Delta\lambda/\lambda$ of ~30% with a reflectivity between 85 and 90%. Due to the double reflection set-up, the beam after the new monochromator is well collimated, leading to a lower total flux at the exit of the $C_{2\text{-}2}$ and hence a reduction in the background radiation levels. Furthermore, the neutron flux at the sample position has been increased by a factor 3.8.

Table II. Performance of the new monochromator compared to the old one.

	Previous	New
Monochromator	Fe/Ge	Ni/Ti
Deflection angle 4θ(deg.)	6.02	7.0
Wavelength λ(Å)	6.14	5.9
Wavelength distribution $\Delta\lambda/\lambda$	~19%	~15%
Flux at the exit of the $C_{2\text{-}2}$ guide (n/cm^2·sec)	7×10^6	4.7×10^6
Flux at the sample position (n/cm^2·sec)		
direct beam	2.6×10^5	9.8×10^5
polarized beam	1.3×10^5	5.0×10^5

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