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POLARIZING MULTILAYER SPECTROMETER FOR NEUTRONS

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ABSTRACT

Polarizing neutron monochromators were prepared by sputtering thin-film multilayers with d-spacings from 40 to 85Å on large float-glass substrates. Peak reflectivities as great as 90% and polarizing efficiencies of 98% were measured. Increased angular acceptances were obtained by fabricating multilayers with multiple d-spacings. A planned polarized beam spectrometer which incorporates the multilayers and which has a variable energy resolution independent of angular beam divergence is described.

INTRODUCTION

It has long been known that polarization analysis can enhance the sensitivity and selectivity of many inelastic neutron scattering experiments. Nevertheless, the technique is rarely employed because those monochromating crystals which are capable of polarizing neutrons have relatively low reflecting efficiencies and consequently do not yield adequate beam intensities.

Recently, a new type of neutron polarizing monochromator has been developed. Lynn et al.[1] demonstrated that a composite of alternating thin films of Fe and Ge (with the Fe layers magnetized to saturation) is not only an efficient polarizer but has a high reflectivity as well. However, the multilayers they made (by evaporation on 1x6 inch substrates) had relatively large d-spacings, typically of the order of 150Å. Thus for neutrons of wavelength $\lambda = 1.5$Å-a wavelength commonly employed-the angle of reflection θ (given by the Bragg condition $\lambda = 2d\sin\theta$) turns out to be $\simeq 0.25°$. This requires a multilayer length in excess of 8 feet in order to reflect a beam 1/2 inch wide!

Using a specially constructed radio frequency sputtering apparatus, we have deposited Fe-Ge multilayers with d-spacings between 40 and 85Å uniformly on 2x18 inch float-glass substrates (up to 3x36 inch substrates can be accommodated). With these multilayers, peak reflectivities as large as 90% and polarizing efficiencies of 98% have been measured in applied magnetic fields of 100 Oersted. For $\lambda = 1.5$Å and d=40Å, the angle of reflection $\theta \simeq 1.0°$ and 1/2 inch beam widths can now be obtained with a multilayer only 2 feet long. We will discuss the angular acceptance of these multilayers and a method of improving their energy resolution in the following sections.

MULTILAYER REFLECTIVITY

A mosaic crystal can be described in terms of an angular distribution of perfect microcrystallites which reflect a given wavelength over a finite range of incident angles. The angular acceptance of a multilayer (with parallel layers) depends, for a particular wavelength,

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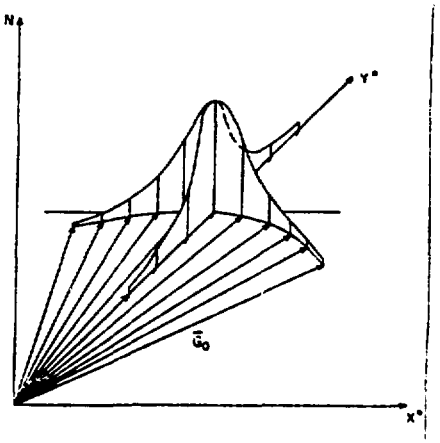

FIG. 1. Distributions of reciprocal lattice vector lengths and directions.

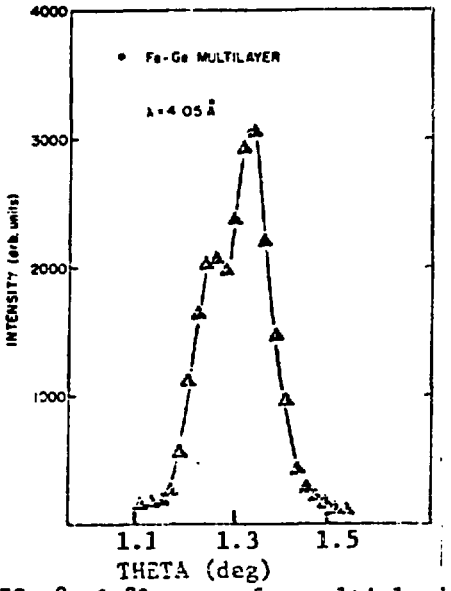

FIG. 2. θ:2θ scan of a multiple-d multilayer.

not on an angular mosaic but on a distribution of d-spacings. Fig.1 shows a plane in reciprocal space in which lie two distributions (taken to be Gaussian for the purpose of illustration) of reciprocal lattice vectors: one of the directions of the vector $\vec{G}_0$; the other of reciprocal lattice vector magnitudes along a single direction. The former characterizes a mosaic crystal while the latter corresponds to a multilayer with a distribution of d-spacings. Position along the vertical axis labeled N is proportional to the number of reciprocal lattice vectors. Ideally, to measure directly the peak reflectivity and angular acceptance first requires a perfectly parallel and monochromatic incident beam. To make such a measurement on a mosaic crystal then requires that it be rotated about an axis perpendicular to $\vec{G}_0$ through the mean Bragg angle θ with a detector fixed at a scattering angle of 2θ. This is the well-known "rocking curve" scan which traverses the circular path of radius $|\vec{G}_0|$ in Fig. 1. For multilayers, on the other hand, a θ:2θ scan tracing a path along the y* axis is appropriate. In practice, the peak reflectivity and angular acceptance of our multilayers were measured in two ways: first, using a conventional triple-axis spectrometer in the elastic scattering mode; second, by placing two identical multilayers on a double-axis spectrometer with one as monochromator and the other as analyser. Peak reflectivity and angular acceptance were obtained by deconvoluting the data with the spectrometer resolution functions. Both methods yielded consistent results. Angular acceptances of about 4 minutes of arc(full width at half maximum) in θ for a θ:2θ scan were obtained for multilayers made with one nominal d-spacing; the width is presumably due to a spread in d-spacings corresponding to deposition rate fluctuations in the sputtering system . Smaller θ widths for rocking curve scans were also detected which are probably due to deviations of the substrate surface from perfect

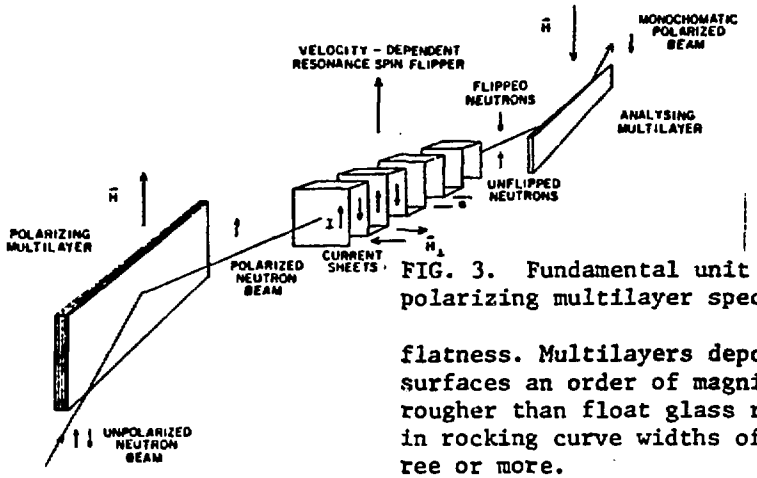

FIG. 3. Fundamental unit of the polarizing multilayer spectrometer.

flatness. Multilayers deposited on surfaces an order of magnitude rougher than float glass resulted in rocking curve widths of a degree or more.

As discussed above, the angular acceptance of a multilayer can be increased by additional d-spacings. Numerical calculations of the dynamical structure factor were performed in order to determine the interference effects to be expected for a particular sequence of d-spacings. These calculations are analogous to those encountered in the solution of thin-film optical interference problems.[2] One scheme is to deposit N_1 bilayers with d_1, N_2 with d_2 and so on. Another is to increment the d-spacing continuously as done by Mezei[3] in constructing "supermirrors," but without overlapping the region of total mirror reflection.

Fig. 2 shows a θ:2θ scan for a multilayer with approximately 900 bilayers and 2 nominal d-spacings in an incident beam of 1' divergence and $0.006\Delta\lambda/\lambda$ wavelength resolution at λ=4.05Å. The peak reflectivity was measured to be greater than 90% at both this wavelength and at λ=2.46Å (multilayer peak reflectivity is independent of wavelength, if true absorption effects are neglected). We are now preparing high reflectivity multiple d-spacing multilayers which are expected to have angular acceptances of 30'. Space limitations unfortunately prohibit any discussion of the technical problems associated with the actual fabrication of these multilayers here.

POLARIZING MULTILAYER SPECTROMETER

In a Bragg reflection process, the limiting wavelength resolution $\Delta\lambda/\lambda$ is given by $\cot\theta\Delta\theta$ where $\Delta\theta$ represents the angular divergence of a polychromatic incident beam. $\Delta\lambda/\lambda$ is therefore relatively poor for a typical multilayer since the angle θ is small. If the beam is polarized, however, the wavelength or energy resolution can be significantly improved by using a wavelength dependent flipper such as the one developed by Drabkin.[4,5] The fundamental unit of the polarized-neutron spectrometer we propose to build consists of a pair of polarizing multilayers between which a corrugated, current carrying Al foil is inserted as shown in Fig. 3. The foil produces a small, spatially oscillating magnetic field perpendicular to the beam direction. A larger, uniform magnetic field H_c is superimposed

perpendicular to both the oscillatory field and the beam direction. The resultant magnetic field acts as a velocity selective resonance flipper; i.e., only those neutrons with velocities in the neighborhood of $v_o = a\gamma H_o/\pi$ (where γ is the gyromagnetic ratio) undergo a spin flip. Neutrons with other velocities are unaffected and are subsequently not reflected by the second multilayer in which the magnetization direction is opposite to that of the first. Together, the pair of multilayers and flipper produce polarized monochromatic beams with an energy or wavelength spread which can be varied by simply changing the length of the current carrying section of the corrugated foil (the energy resolution $\Delta E/E \propto 1/M$ where M is the number of reversals in the oscillatory magnetic field direction). We believe such a device to be practical for wavelengths $\gtrsim$ 1.5Å. It should also be noted that multilayers strongly discriminate against higher-order beam components and thus will act as higher-order filters as well.[1] The fundamental unit described above would function as monochromator of a triple-axis spectrometer with a second identical unit serving as analyser following the sample. Our expectation is that intense, polarized beams of high quality and adjustable energy resolution will be obtained with this system.

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