Nuclear Instruments and Methods in Physics Research A 744 (2014) 69–72

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

An improved prism energy analyzer for neutrons

J. Schulz [a,*], F. Ott [b], Th. Krist [a]

[a] Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany
[b] Laboratoire Leon Brillouin, Bât 563 CEA Saclay, 91191 Gif sur Yvette Cedex, France

ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form
23 January 2014
Accepted 24 January 2014
Available online 2 February 2014

Keywords:
Neutron optics
Energy analysis
Prisms

ABSTRACT

The effects of two improvements of an existing neutron energy analyzer consisting of stacked silicon prism rows are presented. First we tested the effect of coating the back of the prism rows with an absorbing layer to suppress neutron scattering by total reflection and by refraction at small angles. Experiments at HZB showed that this works perfectly. Second the prism rows were bent to shift the transmitted wavelength band to larger wavelengths. At HZB we showed that bending increased the transmission of neutrons with a wavelength of 4.9 Å. Experiments with a white beam at the EROS reflectometer at LLB showed that bending of the energy analyzing device to a radius of 7.9 m allows to shift the transmitted wavelength band from 0 to 9 Å to 2 to 16 Å.

Contents

1. Introduction

Energy analyzing devices are based on energy dispersive interactions like refraction or the interaction with a magnetic field gradient. This way neutrons with different energies are separated while passing through the device. This allows to measure at different wavelengths at the same time and so to enhance the usable flux. This can be done e.g. in a reflectometer which is normally used in time-of-flight mode by setting the analyzer behind the sample and measure the reflectivity of a white neutron beam. The aim is to achieve a high wavelength resolution, a high deflection and a small broadening of the beam.

In the last years several energy analyzing devices had been developed, tested and improved (summarized in [1,2]) e.g. refraction based devices such as stacked prism rows [3] and very flat prisms [4]. The refraction angle increases with the square of the neutrons wavelength. Flat prisms provide high refraction power because they take advantage of the refraction at small angles which is several orders of magnitude higher than the refraction at angles around 45° [5]. For neutrons that are refracted at an incident angle of 0.23° the deflection is 2×10^{-1} degree for silicon whereas the refraction by a single prism with side walls at an angle of 55° is only 6×10^{-4} degree for 4.9 Å neutrons.

However, the latter prisms can also be used to analyze the energy of neutrons. Such a device was built and tested by Schulz et al. [3]. They used prism rows consisting of 191 Si prisms and stacked the rows upon each other. The advantage of such a prism system is its flexibility. More prisms can be added to achieve higher deflections and to handle broader beams. The disadvantages of a system with stacked prism layers are the total reflection and the refraction at small angles which occur when neutrons interact with the back of the prisms in the next prism layer at an angle close to the critical angle of the total reflection. Since in both cases the neutrons are scattered in opposite direction compared to

* Corresponding author. Tel.: +49 30 8062 43048.
E-mail address: jennifer.schulz@helmholtz-berlin.de (J. Schulz).

http://dx.doi.org/10.1016/j.nima.2014.01.049
0168-9002

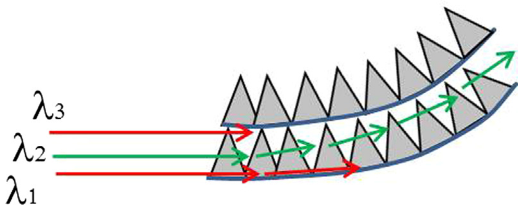

Fig. 1. By bending the prism rows the transmission can be optimized for a wavelength band. Neutrons outside this wavelength band are removed by an absorbing coating at the back of the prisms.

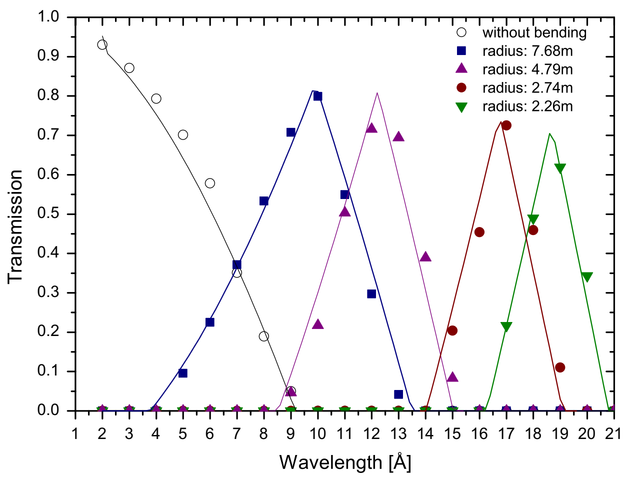

Fig. 2. VITESS simulations (symbols) show that by bending prism rows with 191 Si prisms to smaller radii the transmitted wavelength band can be shifted to higher wavelengths. The curves are calculated with Eq. (11).

the one of the refraction at the sides of the prisms these neutrons are lost for the energy analysis and are counted as background. Measurements show that they lead at the detector to an intensity increase at small wavelengths and reduce the useful wavelength band to 2–9 Å, which makes the application of the device in a reflectometry measurement less useful [3]. In the proposed prism energy analyzer these background neutrons are removed by coating the back of the prisms with an absorbing layer, cf. Section 3.

To increase the transmission of neutrons with larger wavelengths a bending, which follows the deflection of the neutrons inside the prism rows was applied (see Fig. 1). This way neutrons with larger wavelengths can pass through the prism rows without interacting with the back of the prisms in the next row. The intensity is maximal for neutrons with such a wavelength that their path follows the bending of the prism stack. Neutrons outside a wavelength band around this ideal wavelength get absorbed when they hit the coated back of the prisms below or above their entry row. VITESS [6] simulations show that the wavelength band can be shifted to longer wavelengths by increasing the bending radius to values between 1 and 10 m (see Fig. 2). This way the wavelength band from 0 to 20 Å can be covered with five different bending values. It should be noted that the widths of the wavelength bands become smaller for increasing wavelengths since the refraction angle is proportional to the square of the neutron wavelength. The experimental verification of this idea is shown in Section 4.

2. Theory

In this section we want to derive a formula for the attenuation of a neutron beam in a bent prism energy analyzer where the backs of the prisms are coated with an absorbing material.

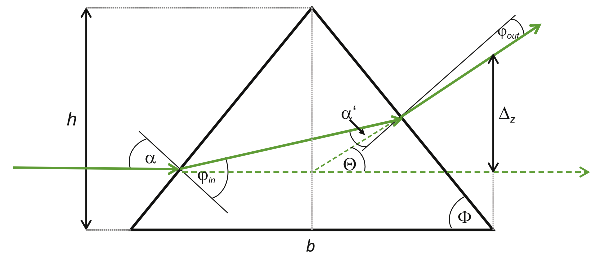

Fig. 3. Refraction by a single prism with the incident angle α, the incident angle after the first refraction $\alpha'$and φ_{in} and φ_{out} the refraction angles of the neutrons when entering and leaving the prism.

For the prism rows the refraction angle and thus the wavelength resolution increases with the number of prisms. The angular dispersion of the system is given by the wavelength dependence of the refraction angle according to the wavelength dependence in the index of refraction n, which is

$$n = 1 - \frac{\lambda^2}{2\pi} Nb \tag{1}$$

where λ is the wavelength of the neutron and Nb the scattering length density of the prism material. The refraction angles φ_{in} and φ_{out} at both sides of the prism (see Fig. 3) are given by Snells law

$$\varphi_{in} = \sin^{-1}\left(\frac{\sin\alpha}{n}\right), \quad \varphi_{out} = \sin^{-1}(n \sin\alpha') \tag{2}$$

with α the incident angle at the entrance and $\alpha' = 2\alpha - \varphi_{in}$ at the exit side.

The absorption in the material is given by the linear attenuation coefficient μ and the material thickness:

$$d = \frac{b}{2} \cdot i \tag{3}$$

where b is the base width and i the number of the prisms. For the whole prism system this leads to a transmission of

$$T_{Abs.} = e^{-\mu \cdot b/2 \cdot i} = e^{-\mu \cdot ih/\tan(\Phi)} \tag{4}$$

where h is the constant height of the prisms and Φ is the angle between the base and the sides of the prisms.

The absorption due to losses at the back of the prisms is given by the number of neutrons which arrive at the back of the prisms in the next layer. This is given by the geometry of the prism system and the refraction per prism. For small wavelengths only neutrons close to the next prism layer will touch it. For a fixed number of prisms the deflection in height, Δ_z, of the neutrons inside the prism rows should be calculated here. Assuming the neutrons enter the prism rows parallel to the prism bases, homogeneously distributed over the whole height and without divergence the ratio of Δ_z/h gives the losses due to absorption at the absorbing layer at the back of the prisms. For the first prism in a row the deflection is given by

$$\Delta_{z_1} = \frac{b}{2} \tan(\Theta_1) \tag{5}$$

with the refraction angle $\Theta = \varphi_{in} - \alpha + \varphi_{out} - \alpha'$ for a single prism. Over the length of the following prisms the deflection Δ_z increases due to the refraction in the first prism by $b \tan \Theta_1$ per prism. The total deflection for a prism row with i prisms is given by

$$\Delta_z = \sum_{j=1}^{i} \left(\frac{b}{2} \tan(\Theta_j) + (j-1) b \tan(\Theta_j)\right) \tag{6}$$

$$\Delta_z \approx b \tan(\Theta_1) \sum_{j=1}^{i} \left(\frac{1}{2} + j - 1\right) \tag{7}$$