Optimization of a polarizer device for SANS-2 instrument at PIK reactor

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Abstract. V-cavity type of polarizer for small angle diffractometer considered. The device performance was simulated in McStas ray tracing package using the input parameters for supermirrors of PNPI home production (CoFe/TiZr, $m = 2.13$). Two replaceable devices with lengths 0.75 m and 1.8 m proposed to cover the wavelength range from 4 to 25 Å for beam polarization no less than 95%.

Introduction

A small-angle neutron scattering diffractometer SANS-2 was transferred to Petersburg Nuclear Physics Institute (PNPI) from Helmholtz Zentrum Geesthacht (HZG) after a reactor shutdown. At the moment the instrument is being reconstructed for being installed at the PIK reactor, PNPI, Gatchina. Among other parts, a new polarizer for SANS-2 has to be developed. In Geesthacht SANS-2 used a bender in reflection geometry as a polarizer. That device provided inconvenience in use since when switching to polarizing operation mode one should move and align the entire instrument of about 40 m length. Furthermore, a new device could be developed having better transmission rate whereas a mentioned bender provided no more 70 % due to losses in glass walls. Thus required is a new transmission polarizer adapted to the new (PIK) source spectrum. The V-cavity type [1, 2, 3] of a polarizer was chosen for simulations since a single mirror appears to be too long for assembly and adjusting considering a spectral range specified, and benders couldn't increase the transmission comparing to the old device.

Here we consider the device based on polarizing supermirrors. Compare to ^{3}He polarizers [4] it is relatively simple in construction and need no service when been used. The technology of polarizing supermirrors production is available at the moment at PNPI. The m-values available at the moment are not extremely high but these coatings were never applied in optics for wide spectral range, and the aim of this work is to set whether is it possible to implement.

1. Input parameters

The neutron ray-tracing package McStas [5, 6] used to calculate the flux and polarization after polarizer. A sketch of a model used is shown at figure 1. As the input parameters we used a real spectrum of HEC-3 reactor channel equipped with cold neutron source and a model of neutron guide being now developed for SANS-2 ($m = 1$, cross-section 30×30 mm^2). To simulate the instrument optical scheme we used a velocity selector component and a collimation line consisted of 8 exchangeable sections of 2 m length corresponding to SANS-2 layout.

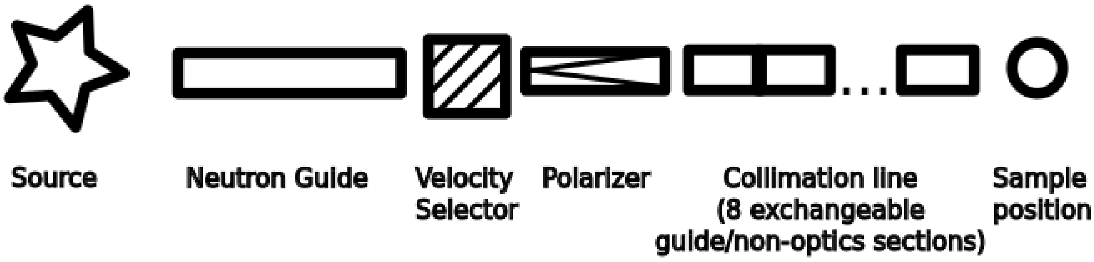

Figure 1. A sketch of model used in simulations.

Corresponding to McStas reflectivity description [6], a number of parameters is to be set: critical Q-vector Q_c, supermirror index m, supermirror range (area from Q_c to mQ_c) slope α and mQ_c drop width W. These values were obtained from the best fit of the experimental curves from CoFe/TiZr multilayer structures, produced by PNPI [7, 8]. These parameters are given in table 1. In this table $R^{\pm}$ stands for two components of polarization, and R^+_{dbl} is the reflectivity of double coated (both sides) supermirror we used. To take into account the reflections from both sides, we added the contribution to the intensity the fraction which was once transmitted and then reflected. Mathematically this simple assumption holds

$$R^+_{dbl} = R^+ + (1 - R^+)R^+, \tag{1}$$

and as a result it sufficiently changes the slope, α, of the supermirror region (see third line in table 1). Different slope gives new improved magnitude of the cut-off reflectivity $R_m = 0.90$ instead of $R_m = 0.75$ for single coated supermirror. For negative component R^- there are no changes since a reflectivity curve has no sloping region corresponding to multilayer structures: the reflectivity is 0.99 up to Q_c and then drops dramatically.

Table 1. McStas parameters for CoFe/TiZr supermirror

Pol. comp.	Q_c[Å^{-1}]	m	R_0	α [Å]	W [Å^{-1}]
R^+	0.0219	2.13	0.995	13.87	0.00187
R^-	0.0102	1	0.99	0	0.001
R^+_{dbl}	0.0219	2.13	0.995	3.43	0.00187

The polarizer must provide polarization not less than 95% with the maximal transmission in the whole spectral range which operates an instrument. SANS-2 planned to work in the wavelength range from 4.5 to about $20 - 25$ Å. Covering such a wide range with one optical polarizer with in-house coating $m = 2.13$ was found impossible as it is shown below, so we came to two exchanging polarizers for short and long wavelength ranges. For optimization of monochromatic beam we used a velocity selector model adjusted to 4.5 Å and to 10 Å with 10% resolution.

2. Results and discussions

First we optimized the short wavelength range polarizer. Figure 2 shows the dependence of polarizer performance on its length for five different beam collimations. The minimum length

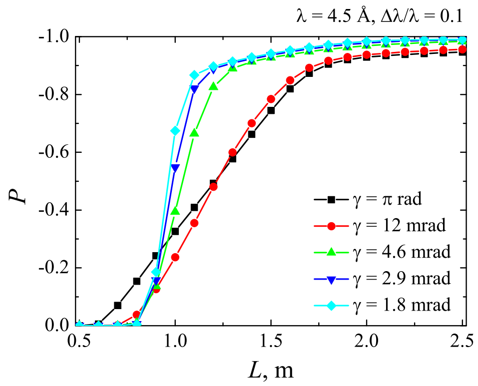

Figure 2. Polarizer length dependence of polarization for different beam collimations for $\lambda = 4.5$ Å.

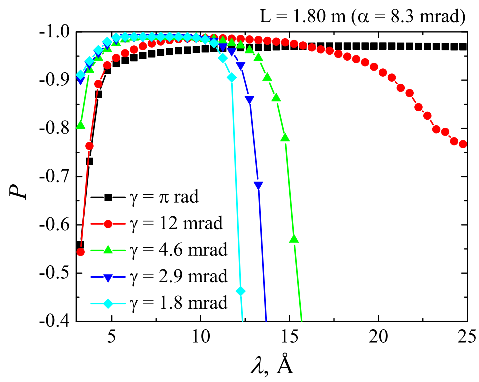

Figure 3. The polarization spectral dependence of 1.8 m long polarizer.

for polarizer corresponds to the value of $L = 1.8$ m where all the curves saturates. This length is strictly coupled to the inclination angle of supermirror plate. The corresponding angle is 8.3 mrad. Figure 3 shows the spectral dependence of polarization. It is well seen that such polarizer provides good polarization in the wavelength range from about 4.5 Å to about 11 Å for all the values of beam divergence.

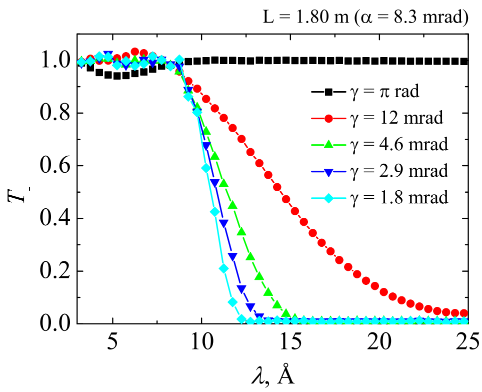

Figure 4. Spectral dependence of the transmission of R^{-} component of polarization.

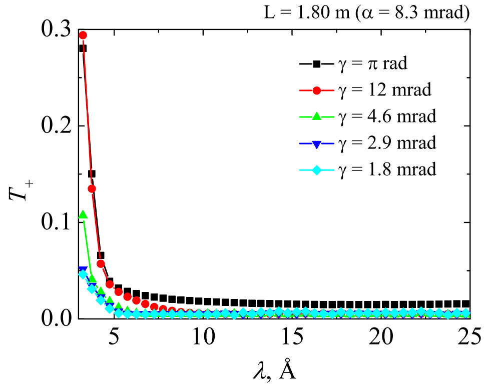

Figure 5. Spectral dependence of the transmission of R^{+} component of polarization.

Figures 4 and 5 shows transmission spectral dependencies for R^{-} and R^{+} components respectively. As it is clearly seen from these figures, this polarizer performs well in the range from about 4.5 to about 10 Å. A limit at shorter wavelengths is induced by the R^{+} reflectivity drop-off at high Q-values: neutrons of short wavelehgth doesnt't reflect at all and the polarization degree in the transmitted beam is low. In the opposite way, the long-wavelength bound is caused by the full-reflectivity area in silicon: both spin components are reflected and the transmission of a device drops to zero. It couldn't be seen for non-collimated beam simulations ($\gamma = \pi$ rad) since without beam divergence restrictions there still are trajectories with falling angle exceeding critical angle. Therefore is very important to optimize optics considering individual instrument beam requirements and setting divergence bound essential.

Exactly the same procedure was done for the second polarizer optimized for the long wavelength range (from about 10 to about 20 Å). Corresponding pictures are figures 6-9.

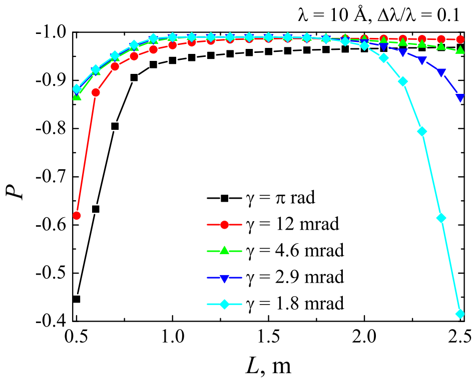

Figure 6. Polarizer length dependence of polarization for different beam collimations for $\lambda = 10$ Å.

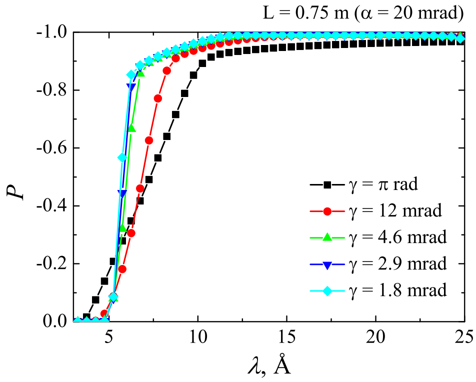

Figure 7. The polarization spectral dependence of 0.75 m long polarizer.

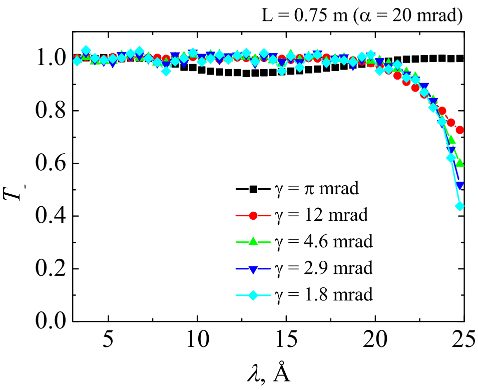

Figure 8. Spectral dependence of the transmission of R^- component of polarization.

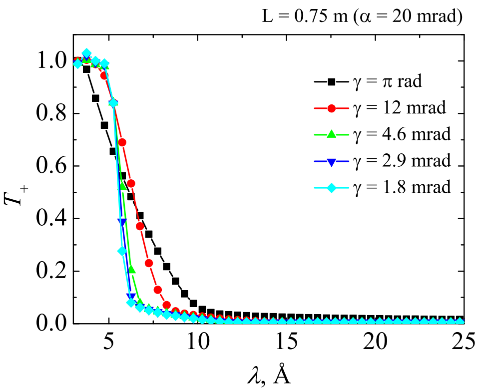

Figure 9. Spectral dependence of the transmission of R^+ component of polarization.

The optimal length of the second polarizer found to be 0.75 m. This corresponds to the inclination angle of 20 mrad.

3. Conclusions

Using the coatings considered doesn't allow to make a single polarizer for a wide spectral range. Our calculations show that to cover the wavelength range from about 4.5 to about 25 Å two exchangeable devices are needed. The first one (figures 3, 4, 5) works in a range from about 4.5 to about 10 Å, the second (figures 7, 8, 9) fits the area from about 10 up to about 25 Å. Both of them provide good beam polarization - no less than 0.95 in any monochromatic beam with monochromaticity 0.1. The transmission of negative spin component is also satisfactorily high: no less 0.95 for the most part of operating range and no less than 0.7 at the range edges. It is also to be noted that the operation of PNPI in-house supermirror coatings was first simulated and shown to be applicable in optics for wide spectral range.

In principle it is possible to cover entire range of wavelengths with the only one polarizer, but for this purpose one need the supermirror with higher m coefficient. We chose for an example a coating with a highest m available at the moment and made simulations using parameters provided by SwissNeutronics [9].

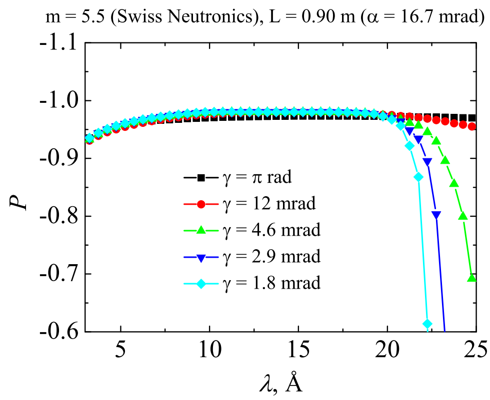

Figure 10. Polarization spectral dependence for V-cavity type polarizer with $m = 5.5$.

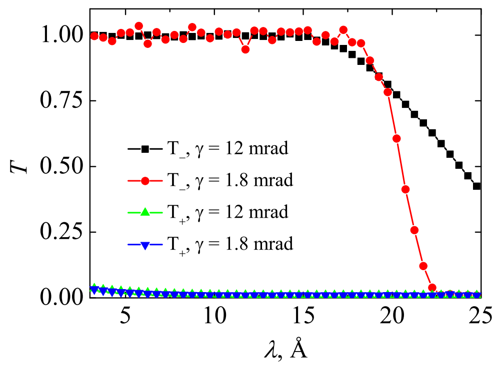

Figure 11. Transmission spectral dependence for V-cavity type polarizer with $m = 5.5$.

Figures 10-11 shows the performance of V-shaped polarizer of 0.9 m length. It is clear from the pictures that such a device could cover the desired wavelength range. But one thing should be pointed out. If we take a closer look at figures 3, 7 and 10 we could see that the polarization degree is better for low m value polarizers. This could be caused by lower reflectivity in supermirror area (from Q_c to mQ_c). Higher m makes this region wider and the part of neutrons reflected this these Q-values increases. This leads to the fall of positive spin component reflection efficiency, and the polarization degree decreases. So the spectral range widening in this case brings losses in polarization.

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