New polarizing guide for neutron wavelengths above 2.5 Å

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Abstract. We present a new polarizing system built for the relocated wide angle Neutron Spin Echo instrument SPAN. The new instruments at the second Guide Hall of BENSC and the relocation of SPAN to this hall of BENSC required a new beam extraction system and a new polarizer for SPAN, which replaced the old beam splitter produced in 1994 with FeCo-Si supermirrors with \( m = 2 \). The new polarizer uses Fe-Si supermirrors, which do not run the risk to become activated as the old FeCo-Si supermirrors and was designed to deliver a polarized beam for wavelengths above 2.5 Å. The final polarizing cavity has a length of 9 m with a cross section of 60 mm x 100 mm. Si wafers coated on both sides with \( m = 2.5 \) Fe-Si polarizing supermirrors are glued into the guide at an angle of 0.38° to the walls.

The guide was installed during the second half year of 2006 and the first tests in early 2007 revealed excellent polarization efficiency over the whole wavelength range of the spectrometer of 2.5 Å to 9 Å, amounting to above 95% at 4.5 Å.

1. Introduction

In 2005 the second neutron guide hall at our institute was completed and the relocation of the Spin-Echo instrument SPAN into the new hall required a new polarizer system. At the old position (1992-2004) in the first guide hall the neutron beam was polarized by means of a beam splitter made from FeCo-Si supermirrors with \( m = 2 \) [1], where \( m \) is the supermirror critical angle in units of the nickel critical angle. The old mirrors could not be used again due to their high activation and their size did not fit. Therefore it was decided to build for the new polarizer a transmission cavity [2] with Fe-Si supermirrors. According to the requirements of SPAN the cross section was 60 mm x 100 mm and the lower wavelength limit was set to 2.5 Å. The old analyser only polarized down to 4 Å.

Fe-Si polarizing supermirrors reliably exhibit in transmission average flipping ratios above 40 or a polarization above 95% for coatings with \( m = 2.5 \). Since there was enough space in the guide hall it was decided to use a single line cavity instead of a V-shaped cavity to avoid the loss at the tip of the V, which must be shielded, and to simplify the construction. The cavity was designed on the basis of such coatings with VITESS simulations [3]. To check them as well as the cavity construction, first a test cavity was built and measured. After successful simulation of the experimental results the final cavity was built.

2. Simulations

The simulations were performed with the supermirrors assembly tool of VITESS.

The simulations showed that for these supermirrors a polarization for wavelengths of 2.5 Å and above can be achieved with an inclination angle of the wafers to the guide walls of 0.38°, cf. Figure 1.
Figure 1 VITESS simulations for the ratio of the transmitted to the incoming neutrons through a cavity. The curves refer to different angles of the Si wafer in the cavity which are coated with polarizing Fe-Si supermirrors with $m=2.5$.

Figure 2 VITESS simulations for the polarization of neutrons transmitted through the test cavity together with experimental data.

3. **Test cavity**
To verify the simulations and to test the mechanical feasibility of the construction a test cavity with the wafers provided by our institute was built by the company NTK to the following specifications:
- Length: 1m, width: 7.1 mm, height: 100 mm, wafer angle: 0.38°, wafer coating: both sides with $m=2.5$ Fe-Si supermirrors, wall coating: $^{58}\text{Ni}$ on the sides, natural Ni on top and bottom.

The test cavity was equipped with a magnetic field with a minimum strength of 300 G at each point of the cavity. The ensemble was measured at the reflectometer AMOR at PSI.

Figure 2 shows the measured polarization together with the simulated one for the test cavity in the wavelength range of 2 Å – 9 Å.

The results show that the cavity polarizes for wavelengths above 2.5 Å as simulated. They also verify that this can be achieved for a wafer height of 100mm. The deviation of the experimental data from the simulated curve for wavelengths above 5.5 Å is due to a reduced efficiency of the polarizer used at AMOR for this experiment: The small size of the detector used on AMOR misses some of the neutrons at higher divergence angles. Thus the measured polarization data differs from the simulated values.

4. **Final cavity**
Finally a 9 m long polarizing cavity with a cross section of 60mm x 100mm was built with Si wafers coated on both sides with Fe-Si polarizing supermirrors, the walls were coated with $^{58}\text{Ni}$ on the sides and natural Ni on top and bottom. The total supermirror area was 1.8 m$^2$. The angle of the wafers to the walls was 0.38°. Figure 3 shows a sketch.

The requirements for the wafers were:
- a critical angle of the supermirrors of above $m=2.5$,
- a flipping ratio in transmission above 20 at $m=2.5$,
- a bending radius of the coated wafer larger than 7 m.
Glass

Si wafer

0.38°

9m

60mm

Figure 3. Sketch of the final cavity, not to scale. The glass walls are coated with $^{58}$Ni, the silicon wafers are coated with polarizing Fe-Si supermirrors with $m=2.5$.

The value of the minimum acceptable bending radius was determined from VITESS simulations where the effect of the waviness of surfaces can be determined. Since the wafers are spherically deformed the value refers to vertical as well as horizontal bending. Neutron measurements to test the wafers were performed at the BENS reflectometer V14 with a wavelength of 4.8 Å.

Figure 4 shows the curves for the transmitted intensity of the two spin states of neutrons through a typical wafer, which has a radius of 11 m, together with the polarization and - for the better visibility - also the flipping ratio. The polarization is given by the ratio of the difference of the transmission values for the two spin components over their sum while the flipping ratio is the ratio of the transmission values for the two components. The average values are 96% for the polarization and 50 for the flipping ratio.

The bending measurements were performed on a profilometer DEKTAK 3030. Figure 5 shows a profilometer scan for a wafer with a concave surface having a radius of 325±4 m which corresponds to a tensile stress of 3 MPa.

All the wafers for SPAN had radii between 8 m (350 MPa) and 3260 m (<1 MPa). They all met or exceeded the standards given above.
Figure 5: Profilometer measurement of a Fe-Si supermirror on a silicon wafer substrate showing a radius of 325±4m which corresponds to a tensile stress of 3 MPa. It indicates the precision of the measurement as well as the uniformity of the bending.

The coated wafers were again provided by our institute and built into the cavity by the company NTK.

The guide was installed during the second half year of 2006 and the result of a test in 2007 is shown in Figure 6. The cavity revealed excellent polarization efficiency over the whole wavelength range of the spectrometer of 2.5 Å to 9 Å, amounting to above 95% at 4.5 Å. These values are very well suited to do spin echo experiments. The decay of the polarization for larger wavelengths is an inherent feature of cavities and can be avoided only in a cavity only by a double polarization.

Figure 6. Polarisation of the final cavity for SPAN measured in March 2007. The curve is to guide the eye.

5. References

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