4.4 Neutron spin polarisers

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Project description and motivation:

For almost all experiments using cold neutrons multilayer-based devices are of great importance. *E.g.* supermirror-coated beam guides allow for a set up, where the experiment is placed far away (up to several hundred meters) from the source and they still deliver more neutrons and a larger divergence compared to Ni coated guides. An other field is the use as optical devices or filters, examples are focusing mirrors and spin polarisers. Often several aspects are combined like in curved or polarising guides (energy or spin filter).

In this project the aspect of polarisation is stressed. As explained in section 4 it is possible to build supermirrors (SMs) with a total external reflection range up to 4 times of that of Ni ($m = 4$).[1] The decisive parameter for the reflectivity is the contrast in the mean scattering length densities between the spacer material ($\rho_{\rm s}\bar{b}_{\rm s}$) and the high density material ($\rho_{\rm m}\bar{b}_{\rm m}$). For ferromagnetic materials the magnetic contribution has to be added, leading to $\rho_{\rm f}(\bar{b}_{\rm f} \pm \bar{p}_{\rm f})$. This fact can be used to design and build supermirrors fulfilling the requirements

$$\rho_{\rm f}(\bar{b}_{\rm f} + \bar{p}_{\rm f}) \gg \rho_{\rm s}\bar{b}_{\rm s} \qquad \text{and} \qquad \rho_{\rm f}(\bar{b}_{\rm f} - \bar{p}_{\rm f}) \approx \rho_{\rm s}\bar{b}_{\rm s} \quad .$$

This means that the contrast for neutrons with spin antiparallel to the magnetisation of the ferromagnetic layer almost vanishes and thus the reflectivity for these neutrons ($R_\downarrow$) is much lower compared to those with spin parallel ($R_\uparrow$). The ratio of the reflectivities, called *flipping ratio* $R_\uparrow/R_\downarrow$, is of the order of 20 to 200.

Conventional SM polarisers have to be magnetised permanently in an external magnetic field of up to 800 Oe. This magnetisation field has to be parallel to the guide field $B_{\rm g}$. (The guide field of about 15 Oe guarantees, that the neutron spin polarisation is preserved along the flight path.) This has the consequences that an additional spin-flipper is required to switch the polarisation of the neuron beam, and that the rather strong magnetisation field may interfere with the sample or the sample environment.

The usage of supermirrors with a close-to-rectangular shaped magnetic hysteresis and a sufficiently high coercitive field strength $B_{\rm c}$ allows to build neutron spin polarisers with switchable polarisation. If $|B_{\rm c}| > |B_{\rm g}|$, the SM can be magnetised both, parallel or antiparallel to $B_{\rm g}$. Changing the magnetisation in the SM by a short magnetic pulse (*e.g*: $B_{\rm m} \approx 200\,{\rm Oe}$, $t \approx 1\,{\rm s}$) allows for a switching of the polarisation of the transmitted (reflected) neutrons from spin up (down) to spin down (up) and vice versa.[1]

In the recent years polarisers of this type have been designed and finally produced on the sputtering plant in our laboratory.[1, 2] Because the polarisers will be used in transmission geometry, material combinations with low absorption have been chosen. The most promising results with respect to the magnetic behaviour were obtained with the system Fe/Si. After optimisation of the sputtering parameters and after calibration of the thicknesses, several magnetically remanent supermirror coatings were produced. Of these the following two examples are ready to use:

1. The new V-shaped white-beam transmission polariser [3] installed in the first collimator tube of SANS I consists of 40 Si-wafers, coated on both sides with 299 layers of Fe and Si. This SM with $m = 2.5$ has a polarisation efficiency of $95\,\% < P_T < 97\,\%$ ($B = 15\,{\rm Oe}$).

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[1] The performance of SM polarisers is given by the following parameters: The polarising efficiencies $P_I = \pm(I_\uparrow - I_\downarrow)/(I_\uparrow + I_\downarrow)$, where the sign of P depends on the spin state, $I = R$ for reflectivity and $I = T$ for transmittance; The range of total external reflection (m), conventionally measured relative to that of natural Ni: $0 < q < q_{\rm c}^{\rm SM} = m\, q_{\rm c}^{\rm Ni}$; And the reflectivity at $q \le q_{\rm c}^{\rm SM}$.

2. A prototype spin analyser for the neutron reflectometer and diffractometer TOPSI at SINQ consists of a Si-wafer, coated on both sides with a Fe/Si SM ($m = 3$ with 599 layers). This waver is mounted inside the gap of a small electromagnet which provides the guide field and allows to switch the magnetisation. For this device the polarisation efficiencies are $92\,\% < P_T < 95\,\%$ and $95\,\% < P_R < 98\,\%$ ($B = 15\,\mathrm{Oe}$).

[1] J. Stahn and D. Clemens. A Remanent Fe/Si Supermirror Transmission Polarizer. *Applied Physics A* **75**, S1532–S1534, 2002.

[2] J. Stahn and D. Clemens. A remanent transmission neutron polarizer. *Advances in Neutron Scattering Instrumentation, Proceedings of SPIE* **4785**, 126–133, 2002.

[3] T. Keller, T. Krist, A. Danzig, U. Keiderling, F. Mezei and A. Wiedenmann. The polarized neutron small-angle scattering instrument at BENSC Berlin. *Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip.* **451**, 474–479, 2000.

Medium term goals:

The magnetic remanence in the ferromagnetic layers is a consequence of anisotropic strain. This in turn results from anisotropic conditions in the sputter chamber. A modification of the geometry, *i.e.* of the aperture in between sputter target and substrate, may result in an increase of the anisotropic stress in the ferromagnet layers and a decrease of the overall stress. This is possible because the stress in the spacer layers might be of opposite sign.

If this approach of tuning the remanence turns out to be successful, new possibilities are opened for the production of more stable coatings reaching higher ranges of total external reflectivity. A systematic investigation of this topic in cooperation with T. Krist, HMI, is planed within the 6th framework program of the EC.

An other item we will work on in collaboration with P. Böni, TUM, is the improvement of neutron beam focusing devices (without polarisation).

Specific goals for the year 2003:

As soon as the reconstruction of the sputtering plant will be finished, tests are planed about the influence of the shape of the aperture upon in-plane stress in single layers. If these tests are positive, a guest scientist (Ahmed Ashfaq) will work on this field during his 3 months stay in our laboratory.

Ph.D. students (LNS) involved:

- J. Padiyath (since 01. 06. 2002)

Support by external funding:

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Collaborating scientists:

- T. Krist, HMI, Berlin

Other remarks:

Within this work a series of trainees have been and will be engaged: Lucy Hallpike, Mogens Christensen, Peter Kailbauer, Harpreet Singh and Justin Hoppler, and the guest scientist Ashfaq Ahmed.