A Switchable Neutron Spin Filter

European Conference ess, Bonn, 16-17 May 2002 — european spallation source

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Introduction

Aim: provide a neutron spin polarizer

- switchable
  ⇒ no need for an additional spin flipper;
- not altering the beam path
  ⇒ simpler lay-out;
- low absorption.

Approach: remanent Fe/Si supermirrors

- Fe and Si show low absorption;
- transmitted and reflected beam can be used;
- high remanence
  ⇒ operation in a weak guide field $\mathbf{B}_{\mathrm{guide}}$, no permanent strong field needed;
- high coercitivity
  ⇒ operation with magnetization $\mathbf{M}$ antiparallel to $\mathbf{B}_{\mathrm{guide}}$;
- switching $\mathbf{M}$
  ⇒ exchange of the polarization of transmitted and reflected beam.[1]

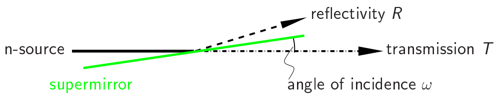
Preparation: magnetron sputtering on Si waver

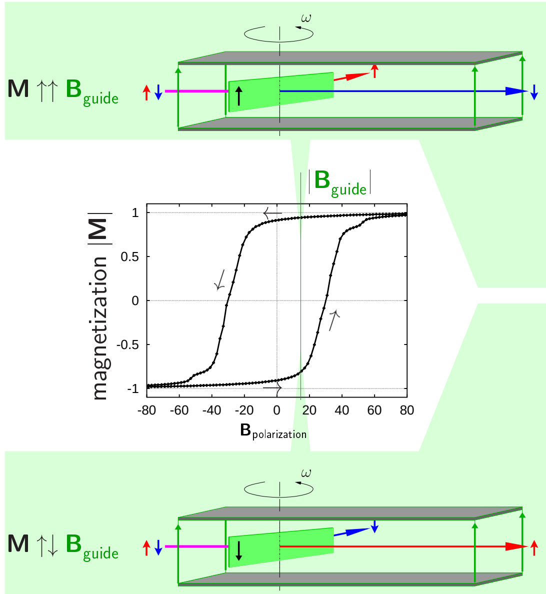
- Fe layers show anisotropic stress leading to an easy axes of magnetization.[2]
- reactive sputtering of Si with O_2 and N_2 to
  – improve the matching for spin down neutrons,
  – reduce stress,
  – tune magnetic properties.

n-Measurements

The neutron intensity is measured as a function of ω and of $\mathbf{M}$ for incoming spin up and spin down neutrons separately.

Top view of the set up for transmission and reflectivity measurements:

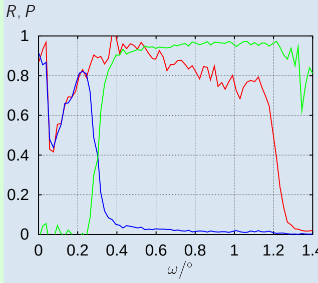




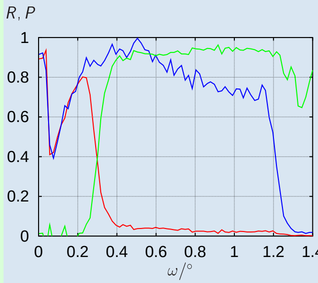
Results

- Sample: Fe/Si supermirror on Si, 299 layers ($m = 2.5$)‡;
- polarized reflectivity measurements were performed on the 2 axis neutron spectrometer TOPSI at SINQ, Switzerland, $\lambda = 4.74$ Å;
- magnetic hysteresis measured with a vibrating sample magnetometer at the PSI;
- no corrections were applied to the shown data.

reflectivity R — polarization P

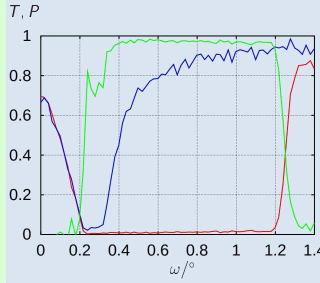


$$P = \frac{R_\uparrow - R_\downarrow}{R_\uparrow + R_\downarrow} = 91 - 96\,\%$$

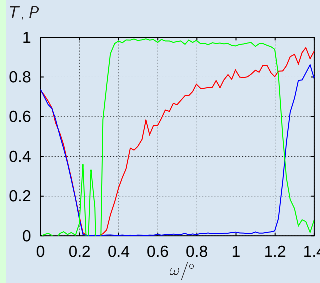


$$P = \frac{R_\downarrow - R_\uparrow}{R_\downarrow + R_\uparrow} = 90 - 94\,\%$$

transmission T — polarization P



$$P = \frac{T_\downarrow - T_\uparrow}{T_\downarrow + T_\uparrow} = 96 - 98\,\%$$



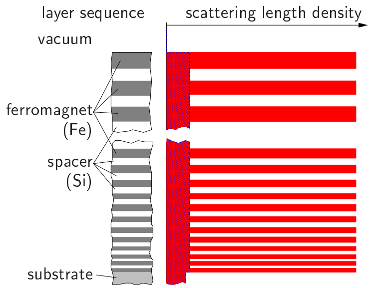
$$P = \frac{T_\uparrow - T_\downarrow}{T_\uparrow + T_\downarrow} = 96 - 99\,\%$$

A transmission polarizer using the presented supermirrors will be built for the SANS at SINQ.

Supermirrors

Supermirrors consist of an alternating stack of two materials with different refractive indices. The thickness of the layers is chosen in a way so that interference leads to reflection of the neutrons up to an angle of incidence of a few degree.[3]
In spin polarizing supermirrors the refractive indices are different only for neutrons of one spin state. This can be fulfilled if one of the materials is magnetic. [4]

Schematic profile of the scattering length density of a supermirror for neutrons with spin parallel
s ↑↑ **M**:
$\rho_{\mathrm{Fe}}(b_{\mathrm{Fe}} + p_{\mathrm{Fe}}) \gg \rho_{\mathrm{Si}} b_{\mathrm{Si}}$
⇒ high contrast grid
⇒ reflection†
and spin antiparallel
s ↑↓ **M**:
$\rho_{\mathrm{Fe}}(b_{\mathrm{Fe}} - p_{\mathrm{Fe}}) \approx \rho_{\mathrm{Si}} b_{\mathrm{Si}}$
⇒ 'one' thick layer
⇒ transmission
to the magnetisation **M**.



References

[1] D. Clemens et al. *Physica B* **213 & 214**, 942 (1995).
[2] M. Senthil Kumar et al. *IEEE Transactions on Magnetics* **35**, 3067 (1999).
[3] J. B. Hayter et al. *J. Appl. Cryst.* **22**, 35-41 (1989).
[4] P. Høghøj et al. *Physica B* **268**, 355 (1999).

† for angles within the range of 'total reflection'
‡ m gives the maximum angle of 'total' reflection as a multiple of the critical angle of total reflection of Ni.

Acknowledgments

These results were obtained within the project TECHNI of the EU program IHP / Networks with financial support from the BBW Switzerland (No. 99.0593).

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