INVESTIGATIONS OF MAGNETIC WAVEGUIDES AT REFLECTOMETER REMUR

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A neutron beam width defines a spatial resolution at investigations of local microstructures therefore development of neutron focusing devices is an actual task. The existing focusing devices (bent crystal-monochromators, parabolic mirror waveguides, refractive lenses, etc.) have the following restrictions: the minimal microbeam spot 50 μm, high background and inhomogeneous microbeam.

Neutron tri-layer waveguides (Fig. 1) transform a conventional collimated neutron beam into a very narrow but slightly divergent microbeam exiting from the middle layer of the width d [1]. The advantages of the neutron waveguides are "clean" and narrow (about 1 μm of width) microbeam. Its disadvantages are low intensity and slight angular divergence defined by Fraunhofer diffraction on a narrow slit as $\delta\alpha_f \propto \lambda/d$. Here λ is the neutron wavelength. Resonant enhancement of the standing waves and neutron channelling along the middle layer exist in the waveguides simultaneously. Review on investigations and applications of the planar neutron waveguides is done in [2]. For example, the waveguide with magnetic middle layer was used for characterization of weakly magnetic films, the waveguides with external magnetic layers can be applied for a controlled chain reaction with U inside the guiding layer [3] and the non-magnetic waveguide was used for spatial scanning of an amorphous magnetic wire by the polarized neutron microbeam.

As the neutron microbeam intensity is very low, the optimization of the waveguide structure is the important task. In this work, we investigated the microbeam intensity as a function of the neutron scattering length density (SLD).

Experiment was done at the time-of-flight reflectometer REMUR of the reactor IBR-2 in Dubna. The polarized neutron beam was used. The waveguide structures Py(10nm)/Al(140)/Py(50)//glass(substrate) and Fe(10nm)/Al(140)/Fe(50)//glass(substrate) were saturated in the applied magnetic field 1500 Oe. The substrate sizes are 30 × 30 × 5 mm^3. Py (permalloy) is the magnetic alloy Fe (20.6% at.) and Ni (79.4% at.). The SLD is shown in Figs. 1*b* and 1*c*.

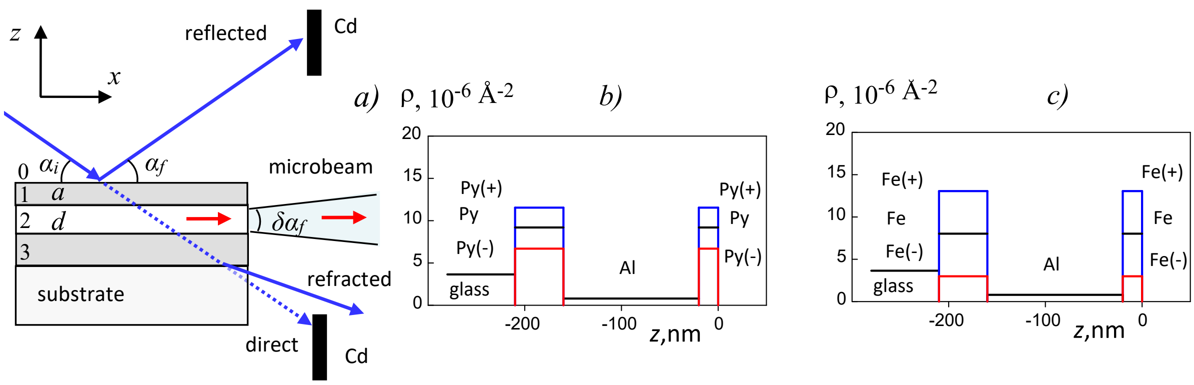

Fig. 1. Neutron planar waveguides: *a)* geometry of experiment; *b)* SLD for Py/Al/Py; *c)* SLD for Fe/Al/Fe.

The grazing angle of the incident beam α_i is equal to 0.236° for Py/Al/Py and 0.228° for Fe/Al/Fe. The angular divergence $\delta\alpha_i$ of the incident beam is 0.009°. Two-dimensional ^{3}He position-sensitive detector (PSD) with spatial resolution 2.5 mm was used. The distance from the sample to PSD was equal to 5030 mm, the time-of-flight distance from moderator to detector was equal to 34030 mm. The width of the time-of-flight channels was equal to 256 μs, the cold moderator was used and the wavelength resolution was equal to 0.02 Å. The microbeam intensity was registered for the polarization of the incident beam UP (or "+") and DO (or "-") in the region between the direct and the reflected beams partially blocked by Cd plates (see Fig. 1*a*). Indices 0, 1, 2 and 3 corresponds to vacuum, upper, middle and bottom layers.

In Fig. 2 experimental results are presented. The resonant enhancement of the neutron wavefunction density$|\Psi|^2$ takes place in the middle layer 2 at the periodic conditions for the phase of the neutron wavefunction $\Phi(k_{0z}) = 2k_{2z}d + arg(R_{21}) + arg(R_{23}) = 2\pi n$. Here $n = 0, 1, 2 \ldots$ is the order of the resonance, $k_{0z} = \frac{2\pi}{\lambda}\sin\alpha_i$, $k_{1z} = \sqrt{k_{0z}^2 - \rho_1}$, $k_{2z} = \sqrt{k_{0z}^2 - \rho_2}$, $k_{0x} = \frac{2\pi}{\lambda}\cos\alpha_i$, ρ_1 is SLD of the layer 1, and ρ_2 is SLD of the layer 2, R_{21} is the amplitude of the neutron wavefunction in the layer 2 at reflection from the layer 1 and R_{23} is the amplitude of the neutron wavefunction in the layer 2 at reflection from the layer 3. The spectra of the microbeam from the waveguide Py/Al/Py is shown in Fig. 2*a*. One can see the peaks UP and DO of the resonance $n = 0$ at the neutron wavelength 4.95 Å. The spectra of the microbeam from the waveguide Fe/Al/Fe is presented in Fig. 2*b*. One can see the peaks UP and DO of the resonance $n = 0$ at the neutron wavelength 5.15 Å.

In Fig. 3 the integrated microbeam intensity of the resonance $n = 0$ is shown as a function of the SLD depth $\Delta\rho = \rho_1 - \rho_2$. One can see that the neutron microbeam intensity is not changed within the experimental errors about ± 15 %. Calculations by the theory of neutron resonances shows that the changing of the integrated square under the resonance peak of $|\Psi|^2$ consists of about 35 %. It is close to the experimental statistical errors 2·15 = 30 (%).

Thus, for the first time we measured the dependence of the neutron microbeam intensity on the structural parameter of the layered waveguides. Farther, we plan the measurements of the neutron microbeam intensity as a function of the thickness a of the upper layer and the width d of the middle layer.

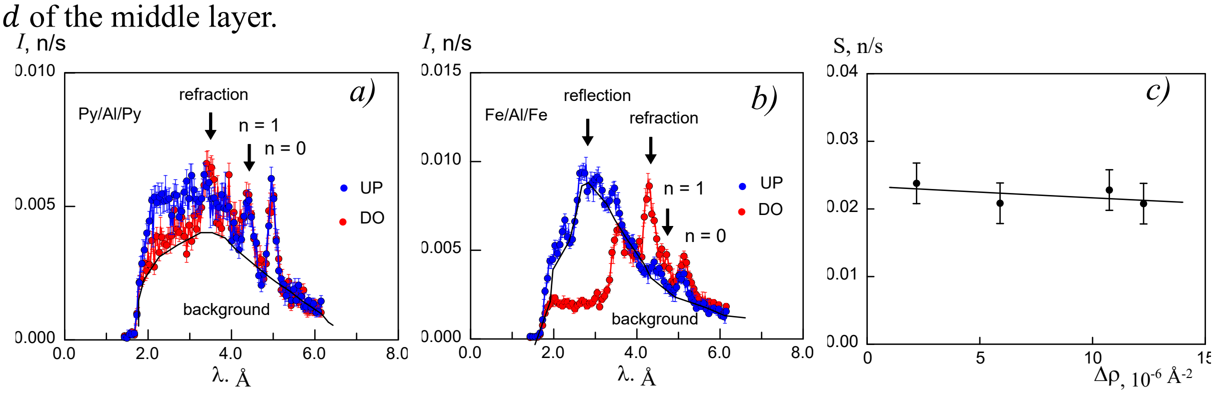

Fig. 2. Experimental results: *a)* neutron microbeam spectrum for UP and DO incident beam polarization for Py/Al/Py; *b)* neutron microbeam spectrum for UP and DO incident beam polarization for Fe/Al/Fe; *c)* integrated microbeam intensity for the resonance n=0 as a function of SLD potential well depth.

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