New aspect in employing magnetic anisotropic FeCo thin films as neutron polarizers

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ABSTRACT

Reversal of the beam polarization vector is a necessary procedure in carrying out experiments with polarized neutrons. At present a number of methods and set-ups (spin-flippers) are widely used in experiments utilizing thermal polarized neutrons. A new way to achieve neutron beam polarization of a necessary sign during the process of neutron specular reflection from ferromagnetic anisotropic mirrors is proposed. The results of its check-up testing with a polarized neutron beam are given. The measured spin reversal probability by this method is near to unity, and, practically, it does not depend on the neutron wavelength. The application of the given way lets one exclude the spin-flipper as an element of polarized neutrons set-ups.

INTRODUCTION

Neutron reflection from the surface of ferromagnetic films is a widespread method of getting thermal polarized neutron beams. D.Hughes and M.Burgy were the first to use a ferromagnetic mirror as a neutron polarizer[1]. Hereafter this technique was being extensively developed (see[2], for instance). Polarizing mirrors on the base of the FeCo alloy sputtered on the absorbing sublayer TiGd, multilayer thin film structures with alternate layers of ferromagnetic and non-ferromagnetic materials are much used nowadays. Mirror polarizers make it possible to choose the right ferromagnetic alloy reflecting only the neutrons which spins are parallel to a magnetic induction vector of a mirror. As a result the spins of the reflected neutrons are directed towards an external magnetic field. A high value of polarizability ($95 - 97\%$), weak spectral dependence of polarization and ease of operation make wide use of neutron mirror polarizers at stationary as well as at pulsed neutron sources.

A change of sign of a polarization beam, i.e. mutual reverse of a polarization vector and an external magnetic field is very important during polarized neutron experiments. To realize this one needs spin-flippers - the devices for mutual reverse of the external magnetic field and beam polarization. Spin-flippers impair polarization spectral characteristics and limit the luminosity of set-ups. For example, a well-known Drabkin spin-flipper has a bounded region of neutron spin reverse.

A new way of obtaining beams of different polarization signs with the help of thin magnetic anisotropic films is discussed in this paper. The experimental results of the check-up are presented.

THE GROUND OF THE NEW METHOD OF POLARIZATION

As it is known, the ferromagnetic with a flat boundary can be described by the following jump of the neutron optical potential

$$U\pm = U_n \pm \mu(4\pi M_p), \tag{1}$$

where $U_n = 4\pi\frac{\hbar^2}{2m} \cdot N \cdot b$ is a neutron nuclear optical potential, N is a number of nuclei per unit volume, b is an average neutron scattering length, M_p is the projection of a magnetic moment on a reflecting surface. The fact that a neutron spin is equal to one half results in the existence of two potentials. Thus, if one chooses the right ferromagnetic alloy, then

$$U_- = U_n - 4\pi\mu M_p = 0.$$

As a result only the neutrons with a magnetic moment facing away from the vector $\vec{M_p}$ will be reflected from the matter boundary, because $U_+ = U_n + 4\pi\mu M_p > 0$. A very important fact should be noted here: during the neutron magnetic moment interaction with the boundary of ferromagnetic matter, the derection of polarization in the reflected beam is determined only by the direction of the vector $\vec{M_p}$. The magnetic field vector does not enter into the equation (1). Thus, it is easy to show that in the system of coordinates connected with the external magnetic field $\vec{H}$ polarization in the reflected beam will depend on the angle θ between the vectors $\vec{M_p}$ and $\vec{H}$, i.e.

$$P(\theta) = P_o(\lambda) \cdot Cos(\theta), \tag{2}$$

where $P_o(\lambda)$ is mirror polarizability along the $\vec{M_p}$ direction.

From (2) it follows that

$$P(\theta = 0) = -P(\theta = \pi) \tag{3}$$

Therefore, for a polarizer where M_p does not depend on H, the change of mutual orientations of vectors $\vec{P}$ and $\vec{H}$ in a reflected beam can be achieved by the magnetic field reverse.

Single-axis anizotropic magnetic films with a rectangular hysteresis loop, see Fig.1, are the ones which are practically free from the dependence of M_p on H in the interval of $|H| < H_c$. From this it follows that for the films with such a hysteresis loop the change of the field sign at $|H| < H_c$ will result in the change of sign of the reflected beam polarization.

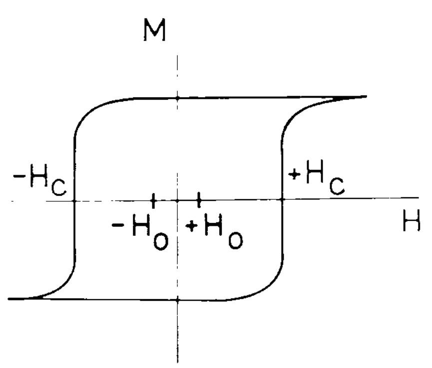

Fig.1. The typical magnetization reversal curve of a single-axis anisotropic film, when the magnetic field is directed to the "easy axis" of anisotropy of a film. In the region $-H_o < H < H_o$ the dependence of the magnetic moment $\vec{M_p}$ of a film on the volume and direction of an external magnetic field H is absent.

EXPERIMENTAL CHECK-UP OF THE METHOD

To examine the suggested technique we have used a polarizing mirror with the $Fe(40)Co(60)$ film (1500Å thick) with the $Ti(85)Gd(15)$ sublayer sputtered on a float glass plate. The film was being sputtered in the magnetic field of 250 Oe at the temperature of a glass plate equal to 150 ^oC. Single-axis anisotropy of the film occurred due to the magnetic field. The value of the film coercive force was $H_c = 95$ Oe. The mirror was placed into a polarized beam behind a polarizing neutron guide. A change of polarization of an incident beam was performed by a spin-flipper. The mirror was put into a gap of the electromagnet allowing one to change both the value and sign of a magnetic field. The $\vec{H}$ vector coincided with the anizotropy axis of the film. Magnetic field behaviour at the electromagnet inlet provided the adiabatic guide of the spin at any field direction in the gap. Reflected intensities N_+ (spin-flipper "off") and N_- (spin-flipper "on") for different values of fields in the electromagnet were measured with the ^3He detector. A combination of the measured intensities was analysed:

$$\frac{N_+ - N_-}{N_+ + N_-} = P_o \cdot P_m(H), \tag{4}$$

where P_o is incident beam polarization, P_m is mirror polarizability. Equation (4) is true for the case that spin reverse probability by a spin-flipper is $f = 1$. In our case the latter condition was realized with an accuracy of $5 \cdot 10^{-3}$ in the region of a neutron wave length $\lambda < 6$Å.

THE MEASUREMENT OF FIELD DEPENDENCE OF P_m

At first the mirror was magnetized by a negative magnetic field of 500 Oe. After that the field decreased to zero and then increased in a positive direction. Fig.2 shows the experimental dependence of $P_o \cdot P_m(H)$ on the magnetic field. Here P_o and $P_m(H)$ are an average over the spectrum beam polarization and mirror polarizability, respectively. It is seen from the shape of a curve that in $H < 80$ Oe $P_o \cdot P_m(H)$ does not depend on the value of an applied field; in this case it is negative. It means that the magnetization vector $\vec{M}_p$ is opposite to the external field. In the fields $H > 80$ Oe the reversal of magnetization begins; the process ends in the fields of ≥ 200 Oe. Then at a decrease of the field $P_m(H)$ does not depend on the field and it is positive. It means that the magnetization vector $\vec{M}_p$ is parallel to $\vec{H}$. Therefore the bottom and top parts of the experimental curve correspond to opposite and unidirectional orientations of the vectors $\vec{M}_p$ and $\vec{H}$, respectively.

The measurements have shown that $P_m = -P_m^{'}$ with a high degree of accuracy (about $5 \cdot 10^{-3}$) in the region $H \leq 70$ Oe, where P_m and $P_m^{'}$ mirror polarizabilities correspond to the bottom and top parts of a hysteresis loop.

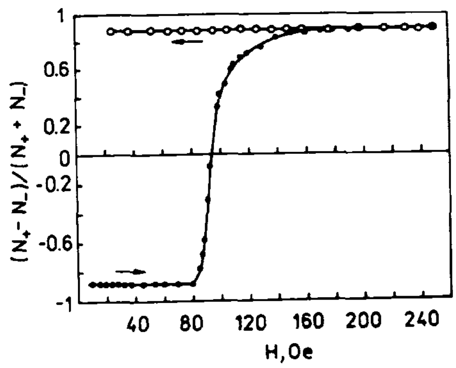

Fig.2. The experimental dependence of $P_o \cdot P_m(H) = \frac{N_+ - N_-}{N_+ + N_-}$ on the external magnetic field parallel to the "easy axis" of the anisotropic $FeCo$ film. At first the film was magnetized in the opposite direction to the external magnetic field. The reversal of magnetization of the film leads to the changing of sign of film polarizability.

THE MEASUREMENT OF WAVELENGTH DEPENDENCE OF P_m

For spectral properties check-up of mirror polarizability we have measured $P_o \cdot P_m$ according to a neutron wave length in the fields $H_1 = -8$ Oe and $H_2 = +8$ Oe.

Fig.3 shows experimental functions $P_o \cdot P_m$ for these values of the fields. The ratio $\frac{P_m(\lambda, H_1)}{P_m(\lambda, H_2)}$ got from the experimental curves 1 and 2 differs from -1 no more than $5 \cdot 10^{-3}$ in the measured interval of neutron wave lengths $\lambda = 1.5 \div 6 \mathring{A}$.

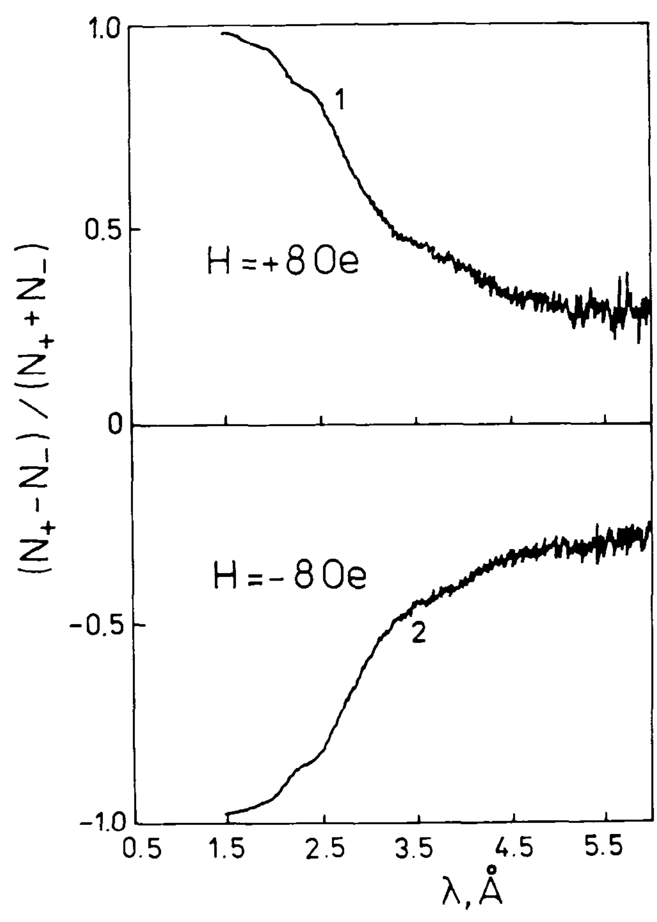

Fig.3. The experimental wavelength dependence of $P_o \cdot P_m(H) = \frac{N_+ - N_-}{N_+ + N_-}$ for the $FeCo$ single-axis anisotropic film: curves 1,2 correspond to the magnetic field equal to +8 Oe and −8 Oe, respectively. The changing of sign of the external magnetic field leads to the changing of sign polarizability of the film in a wide range of the wavelengths.

CONCLUSION

A new method of getting polarized neutrons with a necessary sign of polarization by specular reflection from a magnetic anisotropic film is suggested. Its checkup on the single-axis anisotropic $FeCo$ film have shown that the reflected beam polarization and the external magnetic field change their sign simultaneously. The efficiency of the change of sign of neutron beam polarization due to the change of sign of an external magnetic field is near to unity and is independent of a neutron wave length.

The application of the given method allows one to perform the mutual reverse of a neutron spin and external magnetic field not using a spin-flipper.

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REFERENCES

1. D.J.Hughes, M.T.Burgy, "Reflection of Neutron from Magnetized Mirrors", *Phys.Rev.*, 81, 498, (1951)
2. W.G.Williams, *"Polarized Neutrons"*, Oxford, Clarendon Press, (1988)