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NEUTRON DEPOLARIZATION STUDY OF STATIC MAGNETIZATION FLUCTUATIONS IN FERROMAGNETS

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1. INTRODUCTION

The neutron depolarization analysis represents a common tool for the investigation of magnetization processes to derive information about domain structures or large-scale magnetic inhomogeneities in the bulk of ordered and disordered magnetic materials/1-5/.

Detailed information about the magnetization distribution in ferromagnetic samples was so far obtained from three-dimensional neutron depolarization experiments/1-5/. Further experimental progress was achieved by use of the TOF-method at pulsed neutron sources which exploited the dependence of depolarization on neutron wavelength/6,7/.

The aim of this work was to demonstrate that the analysis of neutron depolarization with respect to the wavelength dependence gives the possibility of obtaining simultaneously the value of the mean magnetic induction, its orientation relative to the external field direction and the magnetization fluctuations caused by magnetic inhomogeneities.

The study of the approach to magnetic saturation of polycrystalline soft magnetic materials using this neutron depolarization technique allows one to get information about the stress or defect induced magnetic inhomogeneities.

2. EXPERIMENTAL METHOD

Neutron depolarization measurements were carried out using the TOF-spectrometer SPN-1 at the pulsed reactor IBR-2 /7/. The polarization of the beam has been produced and analysed by polarizing neutron guides in the wavelength range from 1,5 to 6Å. During the transmission of the beam polarized perpendicular to the propagation direction of the neutrons, the polycrystalline rectangular sample was placed between the pole-pieces of an electromagnet. In order to realize a noncollinear orientation of the incident polarization P_0 and the mean magnetic induction of the sample $<\vec{B}>$ (see fig. 1) it has been adjusted a fixed angle α between the sample surface and the external field direction. In the case of a soft

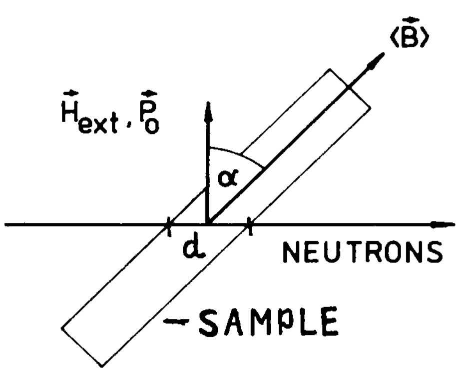

Fig. 1. Scheme of measuring method.

magnetic thin plate-like sample the magnetization direction was, therefore, mainly indented by the form anisotropy described by demagnetization tensor.

One has to keep in mind, however, that the magnetization behaviour of the sample changed also due to demagnetization effects. It can be shown, that the measured neutron polarization $P(\lambda)/P_0(\lambda)$ contains in this arrangement simultaneously at least two components of depolarization $D_\perp$ and $D_{||}$, perpendicular and parallel to the magnetic induction:

$$P(\lambda)/P_0(\lambda) = D_{||} \cos^2\alpha + D_\perp \sin^2\alpha \cos(\omega_\lambda \lambda) , \qquad (1)$$

where α is the angle between $\vec{P}_0$ and $\langle\vec{B}\rangle$. The perpendicular component of the polarization performs Larmor precessions in the mean internal field $\langle B\rangle$ resulting in oscillations of polarization on the neutron wavelength scale with the frequency

$$\omega_\lambda = c\langle B\rangle d = 0.04633\langle B\rangle d, \text{where } \omega_\lambda \text{ in} [\text{Å}^{-1}], \langle B\rangle \text{ in } [\text{T}], d \text{ in} [\mu\text{m}]. \qquad (2)$$

This gives the possibility of deriving $\langle B\rangle$ knowing the effective sample thickness d. The depolarization quantities $D_{||}$ and $D_\perp$ depend on the domain structure parameters and the mean square induction fluctuations $\langle B_{||}^2\rangle$, $\langle B_\perp^2\rangle$ parallel and perpendicular to $\langle\vec{B}\rangle$, respectively, and the mean size of inhomogeneities R.

A recently developed scattering theory of neutron depolarization for arbitrary orientations of $\vec{P}_0$ and $\langle\vec{B}\rangle$ and small depolarization effects/8/ gives expressions for the $D_\perp$ and $D_{||}$, but a different wavelength dependence, as it has been experimentally obtained by us. In connection with the experimentally obtained wavelength dependence and according to the simple classical model assumptions of Halpern and Holstein/9/ the depolarization coefficients $D_{||}$, $D_\perp$ are approximated by exponentials:

$$P(\lambda)/P_0(\lambda) = \exp(-B\lambda^2)\cos^2\alpha + \exp(-A\lambda^2) \sin^2\alpha \cos(\omega_\lambda \cdot \lambda). \qquad (3)$$

This suggested dependence corresponds, on the other hand, to a Gaussian distribution of induction fluctuations in the sample.

The experiments were performed on $(Fe_{50}Ni_{50})_{96}Cr_4$ (195x60x x0.180 mm³), $Mn_{0.654}Zn_{0.262}Fe_{2.084}O_4$ (30x14x0.455 mm²), $Fe_{98}Dy_2$ (50x50x0.030 mm³) at room temperature (T = 290K). A Cd-diaphragm confined the neutron beam to the central part of the sample (10x2.5 mm²).

3. MEASUREMENT AND DISCUSSION

First, the integrated depolarization ($\bar{\lambda} = 2$ Å) was measured as a function of applied field (fig. 2) with $\alpha = 0$. It clearly indicates in a qualitative manner the different approach to saturation for the three considered materials. In the region of domain wall motion the depolarization change is considerable. As expected also from the magnetization curve in the region of "technical" saturation, smaller changes in the mean polarization value due to magnetization fluctuations were observed. This mean depolarization effect does not

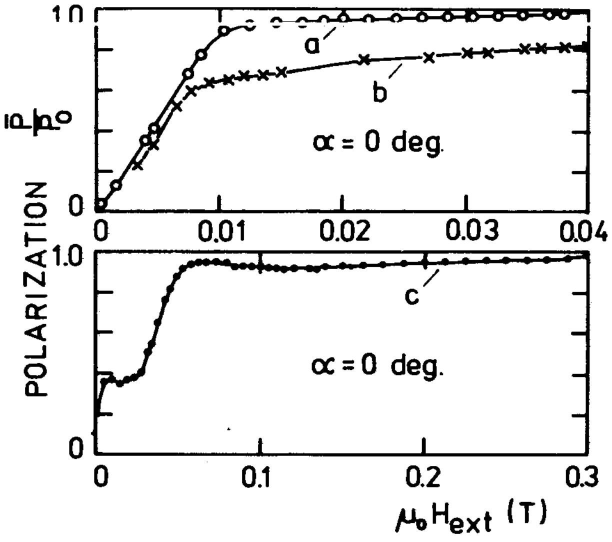

Fig. 2. Integrated polarization ($\bar{\lambda} = 2$ Å) $\bar{P}/\bar{P}_0$ as a function of applied field, a – $(Fe_{50}Ni_{50})_{96}Cr_4$, b – $Mn_{0.65}x$ $xZn_{0.2629}Fe_{2.0843}O_4$, c – $Fe_{98}Dy_2$.

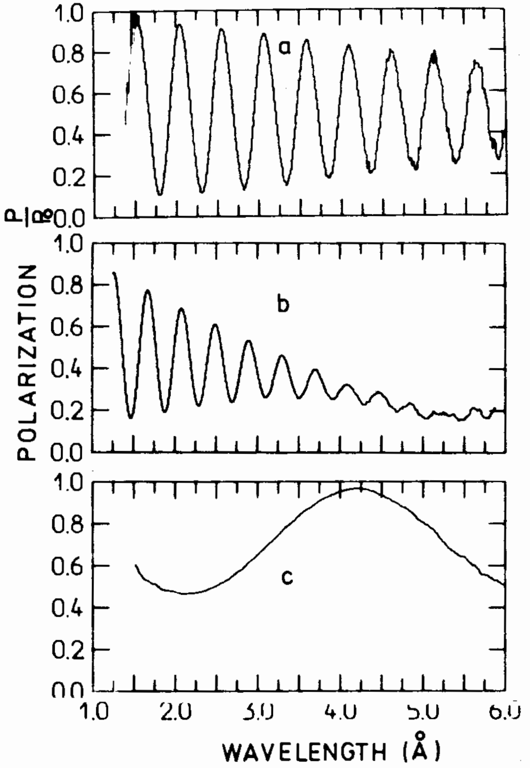

Fig. 3. Polarization P/P_0 *versus neutron wavelength for a certain applied external field,* $\alpha = 45$ *deg., a –* $(Fe_{50}Ni_{50})_{96}Cr_4$, $\mu_0H_{ext} = 0.060$ *T, b –* $Mn_{0.65}Zn_{0.2629}Fe_{2.0843}O_4$, $\mu_0H_{ext} = 0.040$ *T, c –* $Fe_{98}Dy_2$, $\mu_0H_{ext} = 0.085$ *T.*

allow one to distinguish between the influences of different quantities.

Additional details about the magnetization state of the sample follow from the wavelength dependence of the polarization. The measured polarization for α=45 deg. is shown as an example for a certain field value in fig. 3. The parameters obtained from the measurement for the $(Fe_{50}Ni_{50})_{96}Cr_4$ and the $Fe_{98}Dy_2$ sample are summarized in the Table. The derived field dependence of depolarization parameters using a least square fit procedure according to eq. (3) for the MnZn-ferrit is shown in Fig. 4. The obtained <B> curve with a small slope shows the typical approach to saturation under the action of an external field, and its value for the MnZn-ferrit sample is 6% higher than that resulting from the macroscopic measurement. An essential advantage of the TOF-depolarization measurements is the determination of the mean saturation induction with a high accuracy of about 10^{-3} and without calibration procedures.

The field dependence of the angle α characterizes in the considered case the shape induced anisotropy. Especially at low external fields the demagnetizing field gives a remarkable contribution to the resulting guide field outside the sample. Further, at saturation the direction of magnetization is aligned in the sample plane. In this field range the magnetization fluctuations are not canceled down. It can be seen that in this case the fluctuations which are contained in the per-

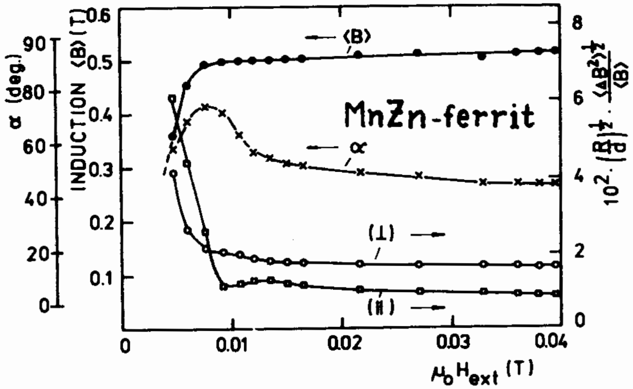

Fig. 4. Dependence of neutron depolarization parameters from applied external field, <B> *– mean magnetic induction,* α *– angle between field direction and mean induction,* $(R/d)^{1/2} \cdot (\langle \Delta B^2 \rangle)^{1/2} / \langle B \rangle$ *– depolarization parameter for parallel (∥) and perpendicular (⊥) component (R – size of inhomogeneity, d – sample thickness,* $\langle \Delta B^2 \rangle$ *– mean square induction fluctuation).*

Table

μ_oH_{ext} (mT)	<B> (T)	α (deg.)	$(R/d)^{1/2}(\langle \Delta B^2 \rangle)^{1/2}/\langle B \rangle$ (∥)	(⊥)
		$(Fe_{50}Ni_{50})_{96}Cr_4$		
0.21	0.928	54.0	$1.02\ 10^{-1}$	$7.11\ 10^{-2}$
0.71	1.040	44.9	$2.83\ 10^{-2}$	$2.06\ 10^{-2}$
1.42	1.055	43.5	$9.00\ 10^{-3}$	$1.04\ 10^{-2}$
4.24	1.070	42.6	$1.67\ 10^{-3}$	$9.05\ 10^{-3}$
		$Fe_{98}Dy_2$		
6.34	0.631	31.0	$9.7\ 10^{-2}$	$1.0\ 10^{-1}$
8.45	0.764	31.8	$5.1\ 10^{-2}$	$7.6\ 10^{-2}$

pendicular depolarization component $D_\perp$ are greater than those in the parallel one. As we get from oscillation frequency the mean induction $\langle B \rangle$ comparable with the macroscopic measured one, a domain structure with opposite magnetization directions can be excluded. It means, that mainly magnetization fluctuations due to orientation distribution of crystallites or local imperfections determine the depolarization. This is not the case for sputtered $Fe_{98}Dy_2$ with a perpendicular anisotropy resulting from the preparation process (c.f. Table and fig. 3c). The observed angle between $\vec{H}_{ext}$ and $\langle \vec{B} \rangle$ and the value of $\langle B \rangle$ indicates in the considered field region, that still exists a domain structure with mean magnetization out of plane. Detailed information about the domain structure could be obtained by changing systematically the beam direction relative to the sample surface /5/ .

In conclusion, the TOF neutron depolarization technique is suitable for the study of the magnetization state of bulk ferromagnetic materials. The neutron depolarization in the region of saturation of high permeability polycrystalline materials is caused by imperfections which are responsible for induction fluctuations. Analysing the wavelength dependence one gets simultaneously information on the mean induction and the disorder.

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REFERENCES

1. Drabkin G.M., Okorokov A.I., Runov V.V. - JETP Lett., 1972, 15, p.458.
2. Rekveldt M.Th. - Z.Phys., 1973, 259, p.391.
3. Rekveldt M.Th., van Schaik F.J., Kraan W.H. - Nucleonika, 1979, 24, p.809.
4. Badurek G., Janeschitz G., Weinfurther H., Hammer J., Rauch H., Steiner W. - Journ.de Physique Coll., 1982, 43, p.C7-57.
5. Stuesser N., Builtjes J.H., Rekveldt M.Th. - JMMM, 1987, 67, p.207.
6. Mitsuda S., Endoh Y. - J.of the Phys.Soc.Jap., 1985, 54,4, p.1570.
7. Ostanevitch Ju.M., JINR Preprint P-85-310, Dubna, 1985.
8. Toperverg B.P., Weniger J. 6th Int.Seminar on Magnetism, Wiss.Zeitsch.der HfV Dresden, 1987, H.31, p.159.
9. Halpern O., Holstein T. - Phys.Rev., 1941, 59, p.960.

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on June 27, 1988.

Докукин Е.Б. и др. E3-88-459
Исследование статических флуктуаций намагниченности в ферромагнетиках методом деполяризации нейтронов

Исследование деполяризации нейтронов в ферромагнетиках с использованием методики времени пролета на импульсном источнике нейтронов дает возможность получать информацию о средней намагниченности, статических флуктуациях намагниченности и магнитной анизотропии в тонких ферромагнетиках. Исследовалась зависимость параметров деполяризации от внешнего магнитного поля для поликристаллических образцов $(Fe_{50}Ni_{50})_{96}Cr_4$, MnZn-феррит и $Fe_{98}Dy_2$ в области магнитного насыщения.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1988

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Neutron Depolarization Study of Static Magnetization Fluctuations in Ferromagnets

Neutron depolarization studies using pulsed polarized neutrons have been performed to get information on mean magnetization, static magnetization fluctuations and magnetic anisotropy in plate-like ferromagnetic samples. The approach to magnetic saturation of polycrystalline ferromagnets ($(Fe_{50}Ni_{50})_{96}Cr_4$, MnZn-ferrit,and $Fe_{98}D_{42}$) was studied by analysing the field dependence of depolarization parameters.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

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