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NEUTRON DEPOLARIZATION STUDY OF STATIC MAGNETIZATION FLUCTUATIONS IN FERROMAGNETS

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Abstract. – 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 \( \text{(Fe}_{50}\text{Ni}_{50})_{96} \text{Cr}_4 \) and \( \text{MnZn-ferrit} \) was studied by analysing the field dependence of depolarization parameters.

1. Introduction

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 the dependence of neutron depolarization on the wavelength gives the possibility to obtain simultaneously the value of the mean magnetic induction, its orientation relative to the external field direction and the magnetization fluctuations caused by 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 was produced and analysed by polarizing neutron guides in the wavelength range from 0.15 to 0.6 nm. 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 \( \mathbf{P}_0 \) and the mean magnetic induction of the sample \( \mathbf{B} \) (see Fig. 1), the sample surface was set a fixed angle \( \alpha \) with respect to the external field direction. In the case of a soft magnetic thin plate-like sample the magnetization direction was, therefore, mainly determined by the form anisotropy described by the demagnetization tensor.

It can be shown that the measured neutron depolarization \( P(\lambda) / P_0(\lambda) \) involves in this arrangement simultaneously at least two components of depolarization \( D_\perp \) and \( D_{\parallel} \), perpendicular and parallel to the magnetic induction:

\[
P(\lambda) / P_0(\lambda) = D_\parallel \cos^2 \alpha + \sin^2 \alpha D_\perp \cos \omega_\lambda \lambda, \quad (1)
\]

were \( \alpha \) is the angle between \( \mathbf{P}_0 \) and \( \mathbf{B} \).

The perpendicular component of the polarization performs Larmor precessions in the mean internal field \( \langle \mathbf{B} \rangle \) resulting in oscillations of polarization on the neutron wavelength scale with the frequency

\[
\omega_\lambda = c \langle \mathbf{B} \rangle d \approx 0.04633 \text{ T}^{-1} \mu \text{m}^{-1} \AA^{-1} \langle \mathbf{B} \rangle d. \quad (2)
\]

Fig. 1. – Scheme of measuring method.

This gives the possibility to derive \( \langle \mathbf{B} \rangle \) knowing the effective sample thickness \( d \).

The depolarization quantities \( D_\parallel \) and \( D_\perp \) depend on the domain structure parameters and the mean square induction fluctuations \( \langle \mathbf{B}^2 \rangle \), \( \langle \mathbf{B}_x^2 \rangle \) parallel and perpendicular of \( \langle \mathbf{B} \rangle \), respectively, and the mean size of inhomogeneities \( R \).

A recently developed scattering theory of neutron depolarization for arbitrary orientations of \( \mathbf{P}_0 \) and \( \mathbf{B} \) and small depolarization effects [8] gives expressions for \( D_\perp \) and \( D_{\parallel} \), but a wavelength dependence different from the one experimentally observed by us. In agreement with the experimentally obtained wavelength dependence and according to the assumptions of the simple classical model of Halpern and Holstein [9] the depolarization coefficients are approximated by exponentials:

\[
P(\lambda) / P_0(\lambda) = \cos^2 \alpha \exp (-c_1 \lambda^2) + \sin^2 \alpha \exp (-c_2 \lambda^2) \cos (c_3 \lambda + D). \quad (3)
\]

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

The experiments were performed on \( \text{(Fe}_{50}\text{Ni}_{50})_{96} \text{Cr}_4 \) \((195 \times 60 \times 0.182 \text{ mm}^3)\), \( \text{Mn}_{0.65}\text{Zn}_{0.26}\text{Fe}_{2.08}\text{O}_4 \) \((30 \times 14 \times 0.455 \text{ mm}^2)\), \( \text{Fe}_{98}\text{Dy}_2 \) \((50 \times 50 \times 0.030 \text{ mm}^3)\) at room temperature \( (T = 290 \text{ K}) \).

3. Measurement and discussion

First, the integrated depolarization \( \lambda = 0.2 \text{ nm} \) was measured as a function of applied field (Fig. 2).

Fig. 2. – Integrated polarization \( \lambda = 0.2 \text{ Å} \) \( P / P_0 \) as a function of applied field, \( \alpha \) \( \text{(Fe}_{50}\text{Ni}_{50})_{96} \text{Cr}_4 \); \( b \) \( \text{Mn}_{0.65}\text{Zn}_{0.26}\text{Fe}_{2.08}\text{O}_4 \); \( c \) \( \text{Fe}_{98}\text{Dy}_2 \).

With \( \alpha = 0 \) it clearly indicates in a qualitative manner the different approach to saturation for the three

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considered materials. In the region of domain wall motion the depolarization change is considerable. As expected also from the magnetization curve, smaller changes in the mean polarization value due to magnetization fluctuations were observed in the region of "technical" saturation. This mean depolarization effect does not allow one to distinguish between the influences of different quantities.

In the perpendicular depolarization component the obtained polarization in the region of saturation of high permeability polycrystalline materials is caused by imperfections which are responsible for induction fluctuations. The oscillation frequency a mean induction \( B \) 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 \( \text{Fe}_{89}\text{Dy}_2 \) with a perpendicular anisotropy resulting from the preparation process (c.f. Tab. I and Fig. 3c). The observed angle between \( \text{H}_{\text{ext}} \) and \( B \) and the value of \( B \) indicative a domain structure with mean magnetization out of plane in the considered field region, still exists. 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.

Acknowledgment

We are grateful to J. Weniger for fruitful discussions. The ZnMn - ferrite sample was kindly provided by KWH Hermsdorf, GDR.

The field dependence of the depolarization parameters derived using a least squares fit procedure according to equation (3) for the MnZn-ferrite are shown in figure 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-ferrite sample is 6 % higher than that resulting from the macroscopic measurement.

The field dependence of the angle \( \alpha \) in the considered case the shape induced anisotropy. 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 perpendicular depolarization component \( D_{\perp} \) are greater than those in the parallel one. As we get from

\[ \alpha = 45 \, \text{deg.}, \ (\text{Fe}_{89}\text{Ni}_{50})_{96} \text{Cr}_4, \ \mu_0 \text{H}_{\text{ext}} = 0.060 \, \text{T}; \]

\[ (\text{b}) \ \text{Mn}_{0.88}\text{Zn}_{0.12}\text{Fe}_{0.86}\text{O}_{4}, \ \mu_0 \text{H}_{\text{ext}} = 0.040 \, \text{T}; \]

\[ (c) \ \text{Fe}_{89}\text{Dy}_2, \ \mu_0 \text{H}_{\text{ext}} = 0.085 \, \text{T}. \]

Additional details about the magnetization state of the sample follow from the wavelength dependence of the polarization. The measured polarization for \( 45 \, \text{deg.} \) is shown as an example for a certain field strength relative to the sample surface (c.f. Tab. I and Fig. 3c).

We are grateful to J. Weniger for fruitful discussions.

The parameters obtained from the measurement for the \( (\text{Fe}_{89}\text{Ni}_{50})_{96} \text{Cr}_4 \) and the \( \text{Fe}_{89}\text{Dy}_2 \) sample are summarized in table I.

\[ \text{Table I. - Depolarization parameters derived from curve fitting.} \]

<table>
<thead>
<tr>
<th>( \mu_0 \text{H}_{\text{ext}} )</th>
<th>( \langle B \rangle )</th>
<th>( \alpha )</th>
<th>( \langle R / d \rangle^{1/2} )</th>
<th>( \langle (\Delta B^2) \rangle^{1/2} / \langle B \rangle )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mT)</td>
<td>(T)</td>
<td>(deg.)</td>
<td>(\parallel)</td>
<td>(\perp)</td>
</tr>
<tr>
<td>( \text{Fe}<em>{89}\text{Ni}</em>{50}\text{Cr}_4 )</td>
<td>0.21</td>
<td>0.928</td>
<td>54.0</td>
<td>1.02 \times 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>0.71</td>
<td>1.040</td>
<td>44.0</td>
<td>2.85 \times 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>1.42</td>
<td>1.055</td>
<td>43.5</td>
<td>9.00 \times 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>4.24</td>
<td>1.070</td>
<td>42.6</td>
<td>1.67 \times 10^{-3}</td>
</tr>
<tr>
<td>( \text{Fe}_{89}\text{Dy}_2 )</td>
<td>6.34</td>
<td>0.631</td>
<td>31.0</td>
<td>9.7 \times 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>8.45</td>
<td>0.764</td>
<td>31.8</td>
<td>5.1 \times 10^{-2}</td>
</tr>
</tbody>
</table>

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