Magnetic texture determination by CEMS with polarized radiation

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Abstract. CEMS measurements of a ^{57}Fe foil were performed with unpolarized and polarized radiation. It is shown that the experimental results permit determination of important characteristics of a magnetic texture, an average square of the cosine $\langle(\boldsymbol{\gamma}\cdot\boldsymbol{m})^2\rangle$ and an average cosine $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$.

Key words: magnetic texture • CEMS • polarized radiation

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Introduction

When magnetism of a sample is studied, one of the natural question concerns magnetic texture, that is the distribution of directions of magnetization. In brief, it describes a probability of finding a magnetization directed along certain direction. The problem of magnetic texture determination by polarized and unpolarized radiation was treated in detail in [2]. The angular distribution of magnetic moments (through hyperfine magnetic fields) is characterized by the average square of the cosine $\langle(\boldsymbol{\gamma}\cdot\boldsymbol{m})^2\rangle$ and the average cosine $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$, where $\boldsymbol{\gamma}$ and $\boldsymbol{m}$ are the unit vectors parallel to photon wave vector $\boldsymbol{k}$, and hyperfine magnetic field, respectively.

Mössbauer measurements with unpolarized radiation bring information about the $\langle(\boldsymbol{\gamma}\cdot\boldsymbol{m})^2\rangle$ only, which is a measure of the hyperfine magnetic field component perpendicular to the $\boldsymbol{k}$ vector. When the value of $\langle(\boldsymbol{\gamma}\cdot\boldsymbol{m})^2\rangle = 0$, the perpendicular component of the hyperfine magnetic field (in respect to direction of $\boldsymbol{k}$ vector) has its maximum, while this component is zero when $\langle(\boldsymbol{\gamma}\cdot\boldsymbol{m})^2\rangle = 1$. In the case of polarized radiation, it is possible to obtain in addition an average value of cosine $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$. Sign of the $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$ is related to the orientation of the hyperfine magnetic field vector with respect to the $\boldsymbol{k}$ vector, e.g. positive value of the $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$ corresponds, on average, to parallel orientation of the hyperfine fields and $\boldsymbol{k}$ vector. A negative value of the $\langle\boldsymbol{\gamma}\cdot\boldsymbol{m}\rangle$ indicates antiparallel orientation of the hyperfine fields with respect to $\boldsymbol{k}$ vector.

The conversion electron Mössbauer spectroscopy (CEMS) appears as an extraordinary good technique in case of strongly absorbing samples, thin films or multilayers. CEMS measurements with a linearly polarized radiation were demonstrated for the first time in Ref. [6]. The authors of [6] used magnetically split source, which resulted in quite complicated spectra. In the case of materials exhibiting distributions of hyperfine fields, one can expect additional complications in the spectra analysis. Some of the difficulties may be overcome when monochromatic circularly polarized radiation [3] is used. We show how this technique, combined with CEMS is particularly useful in magnetic texture determination.

Determination of magnetic texture parameters

Mössbauer measurements with unpolarized radiation show Zeeman sextets in which relative line intensities are $I_1{:}I_2{:}I_3{:}I_4{:}I_5{:}I_6 = 3{:}z{:}1{:}1{:}z{:}3$, where the parameter z depends directly on the orientation of $\boldsymbol{k}$ vector of photon with respect to the investigated sample. This allows one to determine the aforementioned average square of the cosine $\langle(\boldsymbol{\gamma}{\cdot}\boldsymbol{m})^2\rangle = [(4 - z)/(4 + z)]$. The measurements with polarized beam show characteristic asymmetry in line intensities, e.g. usually $I_1 \neq I_6$ and $I_3 \neq I_4$. One can easily measure the so-called asymmetry parameter: $A = \{[|I_3 - I_4|/(I_3 + I_4)] = [|I_1 - I_6|/(I_1 + I_6)]\}$, which is related to the average cosine through: $|\langle\boldsymbol{\gamma}{\cdot}\boldsymbol{m}\rangle| = \{4A/[(4 + z){\cdot}p]\}$, where p is the degree of circular polarization of the beam.

The experimental setup

To obtain the circularly polarized beam, the filter technique was used [5]. The device is constructed from ^{57}Co in a Cr matrix source. The polarizer was made of $^{57}Fe_{2.85}Si_{1.15}$ alloy annealed at 850°C for two hours. Then, it was cooled down with the ratio 15°C/h for 17 h and 4°C/h for the next 24 hours. Next, the polarizer with a thickness of 34 mg/cm^2 was made. Crystalline grains mixed with epoxy glue were oriented in the magnetic field of electromagnet. Careful preparation of the polarizer and an annealing procedure better than that reported in [5] resulted in the degree of circular polarization of the beam (0.88 ± 0.03), higher than that reported in [5]. The polarizer was attached to the source on the standard Mössbauer transducer. Permanent magnets were used to produce a magnetic field parallel to $\boldsymbol{k}$ vector. The field acts on the polarizer and aligns the magnetic moments of iron in the ^{57}Fe-Si alloy.

New design of the CEMS detector allows measurements with relative orientation of the $\boldsymbol{k}$ and $\boldsymbol{m}$ vectors covering almost a hemisphere. In particular, it is possible to set the $\boldsymbol{k}$ vector perpendicular or almost parallel (approximately 2°) to the sample plane. Thus, the sign of magnetization in the sample plane can uniquely be determined.

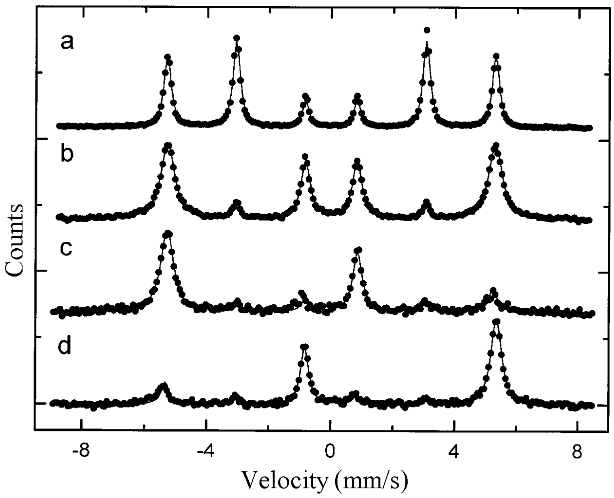

Fig. 1. The CEMS spectrum of α-^{57}Fe measured with unpolarized beam when $\boldsymbol{k}$ vector is (a) perpendicular and (b) almost parallel to external magnetic field and sample plane. The same sample measured with circularly polarized radiation when $\boldsymbol{k}$ vector is almost (c) parallel and (d) antiparallel to the external magnetic field.

Results

CEMS measurements were performed in constant acceleration mode at room temperature with unpolarized and polarized radiations. The α-^{57}Fe foil was magnetized in an external field of 50 mT in the foil's plane. The CEMS spectra measured with unpolarized beam when $\boldsymbol{k}$ vector is perpendicular and almost parallel to the sample plane are shown in Fig. 1 (a and b), respectively. Theoretical fits (solid lines) were corrected for thickness effects [1]. Values of the $\langle(\boldsymbol{\gamma}{\cdot}\boldsymbol{m})^2\rangle$ are presented in Table 1. The results indicate clearly that the magnetic moments are arranged in the sample plane.

To obtain $\langle\boldsymbol{\gamma}{\cdot}\boldsymbol{m}\rangle$ value, the measurements with polarized radiation were performed. They were carried out in two external magnetic field geometries: with $\boldsymbol{k}$ vector almost parallel ($\boldsymbol{k}$ parallel to $\boldsymbol{B}$) and almost antiparallel ($\boldsymbol{k}$ antiparallel to $\boldsymbol{B}$) to external field. The external field was applied in the sample plane. The results of measurements with polarized radiation are shown in Fig. 1 (c and d). The spectra show typical asymmetry in the 1 and 6 lines' intensities. The asymmetry reverses upon the magnetic field reversal. Average cosine $\langle\boldsymbol{\gamma}{\cdot}\boldsymbol{m}\rangle$ determined from the line intensities, corrected for an incomplete beam polarization and the thickness effects, is presented in Table 1. Results of the reported measurements show unambiguously the sign of the hyperfine magnetic field, and thus the sign of the Fe

Table 1. The average square of the cosine and average cosine values determined from CEMS measurements of α-^{57}Fe foil

Radiation	Measurement conditions	$\langle(\boldsymbol{\gamma}{\cdot}\boldsymbol{m})^2\rangle$	$\langle\boldsymbol{\gamma}{\cdot}\boldsymbol{m}\rangle$
Unpolarized	$\boldsymbol{k}$ perpendicular to $\boldsymbol{B}$	0.046 ± 0.014	–
	$\boldsymbol{k}$ parallel to $\boldsymbol{B}$	0.945 ± 0.029	
Polarized	$\boldsymbol{k}$ parallel to $\boldsymbol{B}$	0.968 ± 0.066	0.947 ± 0.054
	$\boldsymbol{k}$ antiparallel to $\boldsymbol{B}$		–0.951 ± 0.059

magnetization, which in the studied case is parallel to the applied external field.

Summary

CEMS technique with monochromatic circularly polarized radiation was employed for investigation of the magnetic texture in α-^{57}Fe foil. CEMS measurement with circularly polarized radiation allow one to estimate two types of averages characterizing arrangements of magnetic moments in a sample. It is hoped that new CEMS technique will be useful in the studies of magnetic structures in thin films or multilayers.

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