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MÖSSBAUER STUDIES OF UNIAXIALLY LOADED FERROMAGNETIC SAMPLES

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UDC 539.56

Practically all constructions and materials are structurally inhomogeneous. In some cases this inhomogeneity is attributable to the material production technology, and in others it is caused by the introduction of a second phase for the purpose of investing the material with new properties. Regardless of the properties of the material, these inhomogeneities become stress concentrators, which have a powerful influence on the ductile—brittle transition temperature. The ductile—brittle transition always shifts toward positive temperatures when materials with stress concentrators are subjected to various kinds of loading [1, 2].

We have therefore undertaken a study of uniaxially stressed samples, using Mössbauer spectroscopy. We chose ferromagnetic materials whose spectra had a well-resolved Zeeman sextet. Electric quadrupole and magnetic dipole hyperfine interactions, magnetic texture modifications, relaxation phenomena [3], and hence variations of the electronic structure in uniaxial loading are easily resolved in such spectra.

EXPERIMENTAL PROCEDURE AND RESULTS

A special test stand consisting of a movable clamp and a fixed clamp was developed for the Mössbauer investigation of uniaxially loaded samples. The movable clamp is connected to the loading machine, which sets the value of the applied load.

The samples were prepared from alloys of the binary system Fe—Si with the following compositions: Fe—0.2%Si; Fe—1.0%Si; Fe—2.0%Si; Fe—3.6%Si. Foil samples were made by the standard technique in the form of ribbons of length 20-30 mm, width 20-25 mm, and thickness ~60 μm. A constant-acceleration electrodynamic spectrometer was used to obtain the Mössbauer spectra.

Figure 1 shows the Mössbauer spectra of different compositions of the binary system Fe—Si (the channel number is plotted along the horizontal axis, and the relative intensity along the vertical). Figure 1a gives the spectra of samples loaded uniaxially in the elastic domain with mass fractions of silicon equal to 2% (spectra 1-3 for σ = 0, 0.4, 6 kg/mm^2) and 3.6% (spectra 5-7 for the same values of σ). A characteristic feature is the fact that the usual Zeeman sextets for the given composition under loading exhibit an increase in the effective magnetic field, a change in the intensity ratio, and a positive isomer shift.

Figure 1b gives the Mössbauer spectra of samples with mass fractions of silicon equal to 0.2% (spectra 1-3 for σ = 0, 14, 28 kg/mm^2), 1% (spectra 4-6 for the same values of σ), and 3.6% (spectra 7 and 8 for σ = 0 kg/mm^2 and 14 kg/mm^2). These spectra exhibit changes in the intensity ratio and isomer shifts without any significant changes in the effective magnetic field as the loads are increased.

We calculated the Mössbauer spectra according to the model postulated in [4]. The results of processing of the spectra by this procedure are shown in Fig. 2, where ΔE_Q is the

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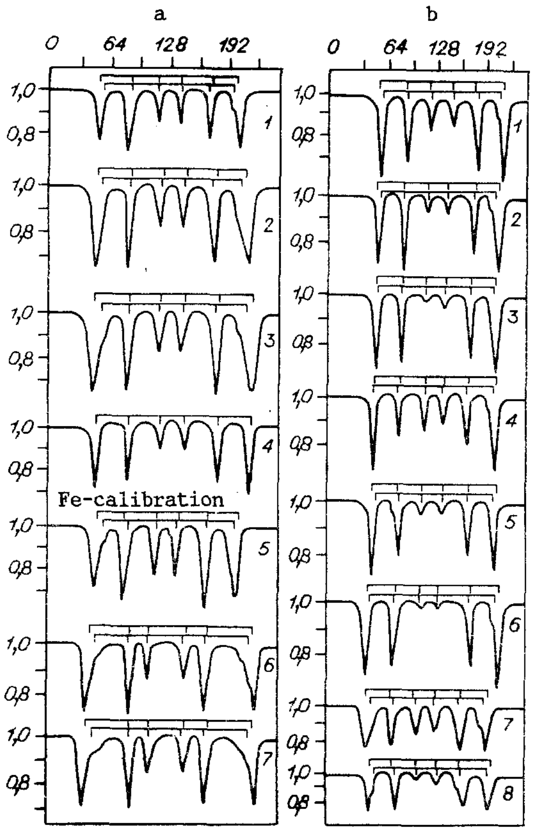

Fig. 1

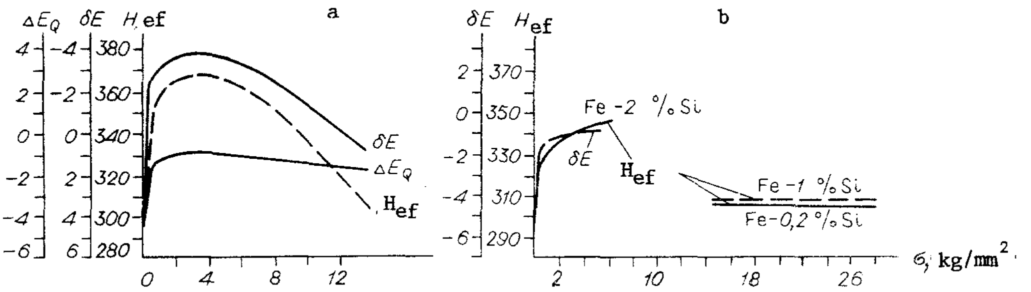

Fig. 2

magnitude of the electric quadrupole interaction, δE is the isomer shift, and H_{ef} is the magnitude of the effective magnetic field. The parameters ΔE_Q, δE, and H_{ef} undergo anomalous variations as functions of the load. We can infer from this fact that loading in the elastic and microplastic domains is characterized by different mechanisms, which alter the parameters of the γ-resonance spectra. We know [5] that the magnetic fields are mainly attributable to Fermi contact interaction between nuclear spin and electron spin polarization, which is the sum of: the polarization of inner s-electrons of the ion core, which produces the resultant spin of 3d-electrons; the polarization of unpaired 4s-electrons hybridized with 3d-electrons; the polarization of 4s-electrons by the resultant spin of 3d-electrons.

Consequently, the variation of the resultant spin of 3d-electrons changes the effective magnetic field due to deformation of the Fermi surface under the influence of the applied stresses, which distort the bcc lattice. The last two mechanisms are responsible for the increase in the effective magnetic field in this case. Indeed, upon deformation of the spherical distribution of 4s-electrons, polarization induced by an ellipsoidal distribution takes place, along with strong overlapping of the 3d- and 4s-shells which leads to hybridization of the 3d–4s configuration. The effective magnetic field around the nucleus then comprises the sum of the strain-induced contributions to the unperturbed field $H_{ef} = H_0[1 + f(\varepsilon)]$ [$f(\varepsilon)$ is the strain contribution to the effective magnetic field; see Fig. 2a].

A distinctive feature of the spectra recorded in the elastic and microplastic strain zones is an anomalous redistribution of the intensities of the extremal lines, which correspond to the transitions ±3/2 → ±1/2 and ±1/2 → ±1/2. As the load is increased, the intensity ratio of the ±3/2 → ±1/2 lines to the ±1/2 → ±1/2 lines becomes much smaller than 3:2. The greatest difference in the intensities I_1 and I_2 (I_5 and I_6) is observed in the spectra recorded in the zone of elastic strains.

The intensities of the extremal spectral lines are redistributed under the influence of strain and the attendant magnetic texture, along with the onset of quadrupole splitting induced by the formation of large electric field gradients in the crystal. The first factor has already been discussed and is responsible for increasing the effective magnetic field. Quadrupole splitting is the most conspicuous effect with increasing stress (see Fig. 1a). Deformation of the lattice produces the field gradient [6]

$$V_{ij} = (2/3)(F_{11} - F_{12})(1 + \nu)\varepsilon_{ij},$$

where F_{ij} denotes the components of the field gradient–stress tensor, ε_{ij} is the strain tensor, and ν is the Poisson ratio.

The Hamiltonian for quadrupole interaction in the deformed lattice is now written in the form

$$\widehat{\mathscr{H}}_Q = \frac{2eQ\left[3I_z^2 - I(I+1) + \eta\left(I_x^2 - I_y^2\right)\right]}{12I(2I-1)}\left[1 + B(F_{11} - F_{12})(1 + \nu)\varepsilon_{ij}\right].$$

The onset of a positive isomer shift δE (Fig. 2a) is governed by 3d-electrons. The hybridization of the 3d- and 4s-shells increases the statistical weight of 3d-configurations, thereby increasing the density of electrons in the 3d-shells.

Thus, the application of uniaxial stress distorts the crystal lattice, causing the iron inner shells to overlap with the wave functions of the ligands. In this case distortion-induced overlap provides the dominant mechanisms of volume and stress-dependent isomer shifts, tending on the whole to increase the average density of electrons in the 3d-shells. This produces the experimentally observed positive isomer shift (see Fig. 2a).

A further increase in the stresses, beginning with σ_0 = 6 kg/mm², takes us into the domain of microplastic strains. The resulting spectra (see Fig. 1b) exhibit a sharp reduction in the intensities of the lines I_3 and I_4. According to [7], the intensity reduction of these lines indicates the occurrence of the spin-flip effect. Spin flip is brought about by relative movements of the atomic planes, which corresponds to the generation and movement of dislocations in microplastic strain.

In summary, we have determined the following in the Mössbauer investigation of uniaxially loaded binary Fe–Si alloys.

1. In the elastic strain region of Fe–Si alloys the effective magnetic field increases, electric field gradients appear, a positive isomer shift takes place, and a magnetic texture is formed. The case of a 45° angle between H_{ef} and V_{zz} occurs for a sample of composition Fe–3.6%Si.

2. Spin-flip effects, large electric field gradients, and an isomer shift are detected in the microplastic domain.

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SPECTRAL COMPOSITION OF LIGHT SCATTERED IN FLUID FLOW AROUND A ROTATING DISK

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The experimental investigation of the spectral composition of laser radiation scattered by a volume of turbulent fluid motion is a widespread means of studying the spatial and temporal correlations of thermodynamic parameters and turbulent velocity fluctuations characterizing fluid flow. The results provide information about the amplitude, characteristic frequencies, and lifetimes of these fluctuations. Such experiments can be used to obtain data on very small fluctuation scales (which are not accessible to investigation by other methods) of turbulent origin without introducing disturbances in the investigated flow. They can be divided into two groups according to the nature of the scattering inhomogeneities: 1) scattering by particles that are introduced artificially or exist naturally in the flow, where the intensity of the particle-scattered light is much greater than the intensity of light scattered by fluctuations of the dielectric constant of the medium; 2) scattering in a pure fluid by turbulent fluctuations of the refractive index in the flow itself.

The first group exploits the well-developed methods of laser Doppler anemometry, which are widely used in present-day experimental fluid dynamics [1, 2].

Development of the second group has been thwarted by the difficulties of creating flow of a pure fluid and the low intensity of the radiation scattered by density fluctuations. However, strong light scattering is possible in well-developed turbulent fluid flow, even without suspended particles. The feasibility of such an investigation was first noted by Frisch [3], who estimated that the ratio of the turbulence-induced scattered light intensity to the molecular scattering intensity becomes greater than unity for sufficiently large Reynolds numbers.

It has been brought to our attention [4, 5] that experiments of this kind could prove to be most interesting. The wave number q of the scattering vector corresponds to the characteristic space scale of scattering inhomogeneities $\ell = 1/q$. The scattering angle θ is related to the wave number q by the Bragg equation $q = (2/\lambda)\sin(\theta/2) = 2k\sin(\theta/2)$ (λ is the wavelength of the incident radiation). Accordingly, by varying the scattering angle it is possible to investigate the regions corresponding to a large set of scales of cascade-decaying vortices, all the way from the outer turbulence scale L down to the smallest vortex length ℓ_m and the dissipation interval $q > 1/\ell_m$. Larger-scale fluctuations are observed by decreasing the angle, and smaller-scale fluctuations are observed by increasing it. The width of the scattering line should yield information about the lifetime of the scattering fluctuations in this case. Consequently, by studying dynamic light scattering in a pure fluid, we obtain information not only about the velocity distribution in turbulent flow, but also about the nature of the damping of turbulent fluctuations.

1. Laser Heterodyne Spectroscopy. The spectral composition of the scattered radiation can be investigated experimentally by laser heterodyne (optical mixing) spectroscopy, in which part of the unscattered laser beam is used as a reference beam for mixing with the scattered radiation on the surface of a photodetector. The output in this case is an electric signal proportional to the modulus squared on the total electric field incident on the sensing area of the photodetector. We write the electric field vector of the radiation in

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