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PROCEEDINGS

Mössbauer study of the El Hammami olivine-bronzite meteorite

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Abstract The phase composition of the El Hammami meteorite was investigated by X-ray, magnetostatic, Mössbauer effect and environmental scanning electron microscopy methods. Performed investigations indicated that this meteorite consists of aluminosilicates, olivine $(Mg,Fe)_2SiO_4$, pyroxene $(Ca,Mg,Fe)SiO_3$, kamacite (bcc Fe-Ni alloy) and troilite (FeS). Some inclusions of Ti and Cr were observed by scanning electron microscopy. The concentration of Ni in kamacite was determined by comparison of the Mössabauer spectra of Fe-Ni phase in the meteorite with those for synthetic bcc Fe-Ni alloys (5, 10, 25% Ni).

Key words meteorite • XRD • scanning electron microscopy • Mössbauer spectroscopy • kamacite

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Introduction

The El Hammami meteorite was found in 1997 at the base of the El Hammami Mountains in Mauritania. It is classified as olivine-bronzite chondrite of the H5 class, petrologic type 5, shock stage 2. The total mass of this meteorite was probably 240 kg [2]. The chondrites of the H5-type are stone meteorites containing mainly silicates, low-Ca pyroxene, sulphides, oxides and metal-rich veins [4, 5]. The chondrites were formed from small grains (chondrules) condensed from the gas in the cooling solar nebula [4].

In this work we present results of the investigations of the El Hammami meteorite performed by X-ray diffraction (XRD), magnetostatic, Mössbauer effect and environmental scanning electron microscopy (SEM) methods. The aim of the studies was to work out a method of evaluation of the Ni concentration in kamacite in meteorite.

Experimental

Part of slices of the El Hammami meteorite were powdered for the XRD, magnetostatic and Mössbauer spectroscopy investigations.

XRD measurements were carried out at room temperature using a high resolution Siemens diffractometer D5000 with Cu K_α radiation. The phase analysis was performed on the base of the International Centre for Diffraction Data.

Magnetic measurements were carried out in the temperature range of 77–1000 K in magnetic fields up to 1.2 T using the Faraday balance.

Mössbauer absorption spectra were recorded at room temperature using a constant acceleration spectrometer with a ^{57}Co:Pd source. The metallic iron powder (α-Fe) absorber was used for velocity and isomer shift calibration of the Mössbauer spectrometer. The mineralogical analysis of the spectra was based on the Mössbauer Handbook Mineral Data [6].

One part of the El Hammami meteorite slice was studied by environmental scanning electron microscopy coupled with energy dispersive spectroscopy (ESEM-EDS) using Philips XL30 ESEM instrument with EDAX analyser (Sapphire). The environmental SEM retains all of the performance advantages of a conventional SEM (superior resolution, depth of field and microanalytic capabilities), but removes the high vacuum constraint on the sample environment. The vacuum environment of the electron column is separated from the environment of the sample chamber. The sample environment vary through a range of pressures, temperatures and gas compositions. Wet, oil, dirty, non-conductive samples may be examined in their natural state without modification or preparation.

A sample of the meteorite was placed on an aluminium plate with a carbon adhesive tape and viewed uncoated. Experimental conditions: accelerating voltage 15 kV, mode environmental, H_2O vapour pressure in the sample chamber 0.3 *T*r, room temperature.

Both SE image showing morphology of the sample surface and BSE images, carrying compositional information were registered to document analysed objects. For a few points, chosen on the bases of BSE images qualitative microanalyses EDS were carried. The presence of characteristic peaks of some elements in analysed EDS-spectra enabled to determine elemental composition in examined points.

The polycrystalline bcc Fe-Ni alloys with 5, 10 and 25% of Ni were synthesized by arc melting under an argon atmosphere to estimate the Ni concentration in Fe-Ni phase (kamacite) in the meteorite. The synthetic Ni-Fe alloys were checked by XRD and magnetic measurements. After that, the Mössbauer measurements of those alloys were done at room temperature. Results of the investigations of these Fe-Ni alloys were compared with those of the meteorite.

Results and discussion

XRD measurements showed that the investigated meteorite is a good crystallized multiphase system. The mineralogical phase analysis of the diffraction pattern showed the existence of minerals like aluminosilicates (do not contain iron), olivine $(Mg,Fe)_2SiO_4$, pyroxene $(Ca,Mg,Fe)SiO_3$, kamacite bcc Fe-Ni alloy and troilite FeS.

Figure 1 shows different phase grains, their shapes, sizes and distribution on the SE image of the El Hammami meteorite slice.

Observed BSE images help us to identify phases of different chemical composition and pre-determine the points where EDS analysis should be made. Figure 2 presents BSE image showing various components of the meteorite with indication of EDS analysis points.

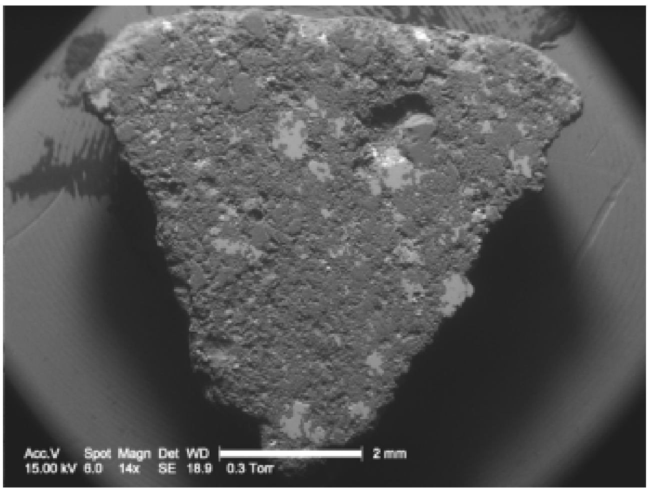

Fig. 1. A global SE image of the El Hammami meteorite slice.

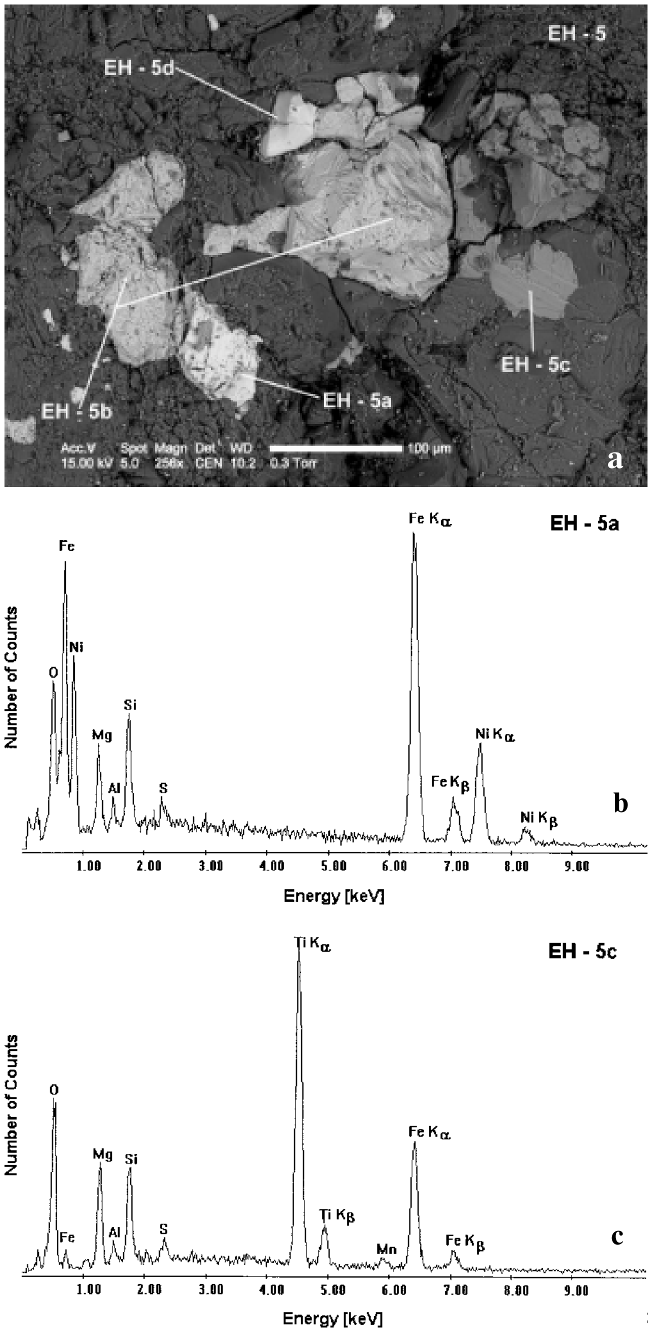

Fig. 2. BSE image of El Hammami meteorite (a) with points of EDS analysis marked; EDS spectra presenting results of chemical microanalysis in points described as 'EH-5a' and 'EH-5c' (b) and (c).

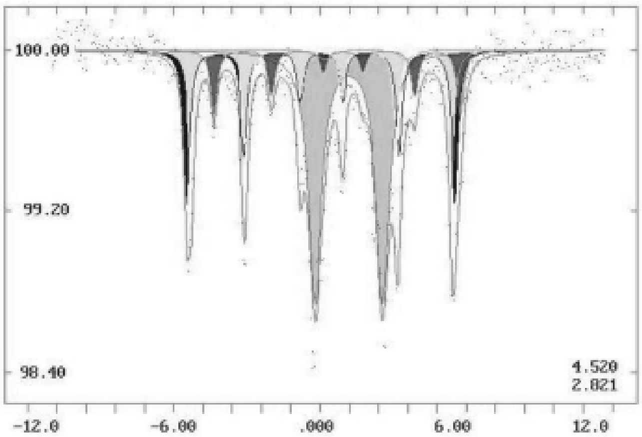

Fig. 3. Room temperature Mössbauer spectrum of the El Hammami meteorite.

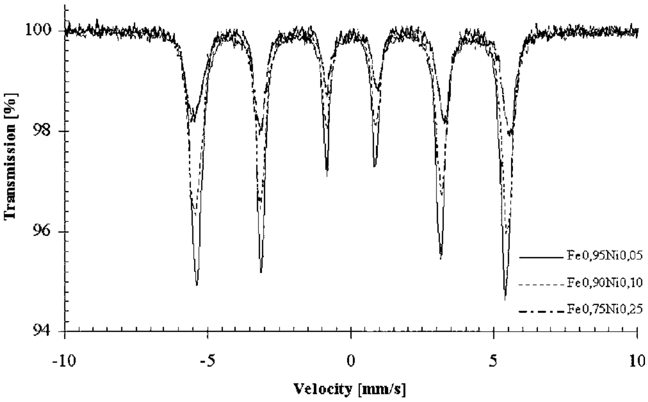

Fig. 4. Room temperature Mössbauer spectra of the synthetic Fe-Ni alloys with 5, 10 and 25% of Ni concentration.

The sequence of the characteristic line of X-ray radiation suggests the presence of such minerals as olivine, pyroxene, silicates, kamacite and troilite. A significant amount of Ti and Cr in some grains was observed. The investigations performed by the SEM showed a strong inhomogeneity of the chemical composition in the meteorite and that even at small distances the composition varies drastically from grain to grain. The presence of medium temperature condensates (olivine, piroxene) and high temperature condensates (kamacites) and low temperature condensates (troilite) allows to assume that the chondrules have formed before being evaporated in the chondrite [1, 3].

Magnetostatic measurements indicated the presence of a strong ferromagnetic phase with the Curie temperature higher than 1000 K. Basing on the XRD phase analysis, it was recognized that this ferromagnetic phase is kamacite. Saturation magnetization at nitrogen temperature of the powdered meteorite was 60.5 Am^2/kg. We estimated that this meteorite contains about 25 at.% of kamacite by comparison of saturation magnetization of the meteorite with that of α-Fe and bcc Fe-Ni alloys. Remaining phases were para- or antiferromagnetic and did not changed the value of the magnetization significantly.

Figure 3 shows a Mössbauer spectrum for the El Hammami meteorite obtained at room temperature.

The Mössbauer spectrum of the meteorite consists of two sextets connected with the kamacite and next one linked with the troilite. There are also two doublets in the centre of the spectrum; one with high intensity arises from the olivine and the second one with low intensity comes from the pyroxene [6]. The hyperfine interaction parameters for the meteorite obtained for the best fitting are listed in Table 1. The contributions of the given phase was estimated from the area of the suitable subspectrum.

Figure 4 presents the Mössbauer spectra of the synthetic bcc Fe-Ni alloys. Each spectrum was described by a single sextet. It can be seen that the spectral lines became wider and the hyperfine magnetic field increases as the Ni concentration rises from 0 to 25%. The kamacite subspectrum in the meteorite was described by a single sextet also. The results of the analysis of the spectra are given in Table 2.

The change of the half width of the sextet line and the value of the hyperfine magnetic field H_{hf} for the synthetic Fe-Ni alloys *vs.* Ni concentration was shown in Fig. 5.

The changes of the half width of the sextet line and H_{hf} for the synthetic Fe-Ni alloys caused by increasing of Ni concentration were described by an exponential function (Fig. 5). The Ni concentration C_{Ni}, in the kamacite of the El Hammami was calculated using this function and values of the half width 0.191 mm/s and H_{hf} = 337.23 kOe for the sextet attributed to kamacite in the meteorite. The calculation gives C_{Ni} = 6.7 ± 0.1%. The method described above may be a good way to estimation of the Ni concentration in kamacites in meteorites.

Magnetic and Mössbauer investigations allowed to estimate the percentage of the mineralogical phases in the meteorite. The investigated fragment of the meteorite contains 45% aluminosilicates, 25% kamacite, 24% olivine and pyroxene and 6% troilite.

Table 1. Hyperfine interaction parameters obtained from the analysis of the Mössbauer spectrum for the El Hammami meteorite.

	H_{hf} [kOe]	IS [mm/s]	QS [mm/s]	Area [%]
Kamacite	342.0±0.5	0.017±0.003	0.013±0.004	24.9
	331.5±0.5	0.016±0.004	–0.006±0.004	21.0
Troilite	315.1±0.5	0.788±0.007	0.095±0.007	10.6
Olivine		1.149±0.040	1.382±0.004	42.1
Pyroxene		1.851±0.090	1.673±0.090	1.4

Table 2. Hyperfine interaction parameters of the synthetic Fe-Ni alloys and the kamacite in the El Hammami meteorite.

Mineral	Ni concentration [%]	H_{hf} [kOe]	IS [mm/s]	Half width [mm/s]
α-Fe	0	330.00±0.02	0.000±0.001	0.120±0.001
$Fe_{0.95}Ni_{0.05}$	5	335.96±0.02	0.013±0.001	0.177±0.001
$Fe_{0.90}Ni_{0.10}$	10	339.32±0.07	0.022±0.0019	0.206±0.001
$Fe_{0.75}Ni_{0.25}$	25	343.51±0.11	0.038±0.001	0.239±0.002
Kamacite	**6.7**±0.1	337.23±0.16	0.012±0.002	0.191±0.003

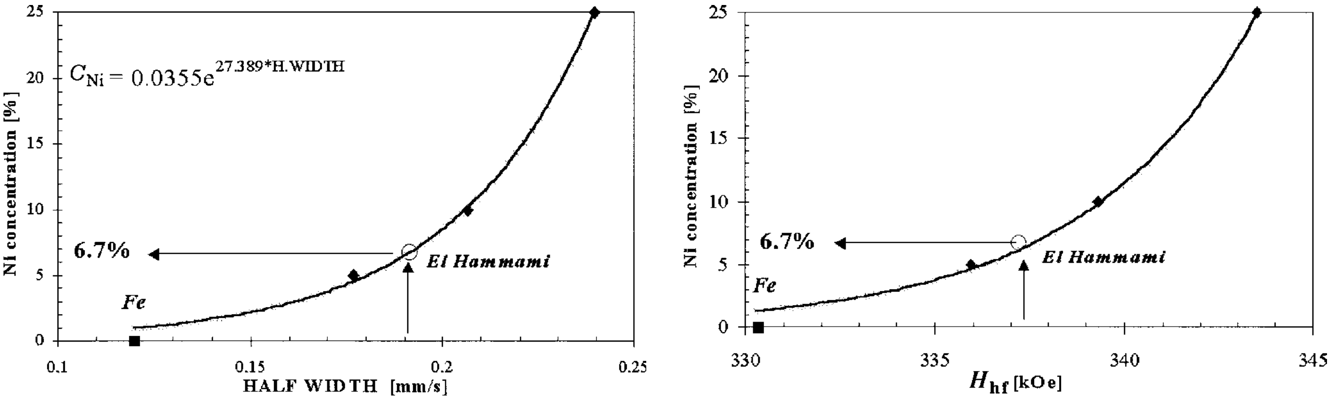

Fig. 5. The plot of the half width of the sextet line (left) and the value of the hyperfine magnetic field H_{hf} (right) *vs*. Ni concentration for synthetic Fe-Ni alloys obtained from Mössbauer spectra at room temperature.

Conclusion

Performed investigations showed that the tested fragment of the El Hammami meteorite is a good crystallized multiphase system with chemical composition consistent with [5]. The investigated fragment of the meteorite contains 45% aluminosilicates, 25% kamacite, 24% olivine and pyroxene and 6% troilite. In the investigated slice of the El Hammami meteorite, the concentration of Ni in kamacite is about 6.7%. Grains containing Ti were found in the meteorite what was very rare in chondrite meteorites.

The method of evaluation of the Ni concentration in kamacite in meteorite has been proposed.

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