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ORIGINAL PAPER

Hyperfine interactions in $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ compounds at 295 K

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Abstract. ^{57}Fe Mössbauer effect studies were performed for the cubic C15, *Fd*3*m*, $MgCu_2$-type $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ intermetallics. Hyperfine interaction parameters: isomer shift, magnetic hyperfine field and quadrupole interaction parameter were obtained from the fitting procedure of the collected ^{57}Fe Mössbauer effect spectra. As a result of Co/Ni substitution, a Slater-Pauling type curve for the average magnetic hyperfine field vs. Ni content in the $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series is observed.

Key words: hyperfine interaction • intermetallics • Mössbauer effect • Slater-Pauling dependence

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Introduction

Ferromagnetic heavy rare earth (R) – 3*d* transition metal (M) compounds with formula RM_2 have been widely studied for scientific and practical reasons [1–3]. It has been found that magnetic hyperfine field at the ^{57}Fe nuclei in the $Dy(Mn_{1-x}Fe_x)_2$ and $Dy(Fe_{1-x}Co_x)_2$ intermetallic series behave according to the Slater-Pauling curve. That is, the magnetic hyperfine field in the $Dy(Mn_{1-x}Fe_x)_2$ series increases with x, and this increase is continued for the $Dy(Fe_{1-x}Co_x)_2$ series. The maximum field is observed for the $Dy(Fe_{0.7}Co_3)_2$ compound and at this Co-content the filling-up of the majority 3*d* subband by 3*d*-electrons is terminated (weak ferromagnetism of the M sublattice). Further increasing of the Co-content cause the filling-up of the minority subband and the observed magnetic hyperfine field decreases gradually with Co content (strong ferromagnetism of the M sublattice) [4, 5, 7, 8].

It was interesting to test Co/Ni substitution on the hyperfine interaction parameters for the $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series which starts in the weak ferromagnetism region. In order to study 4*f*(5*d*)-3*d* magnetism, and especially the magnetism of the 3*d* metal sublattice Mössbauer effect studies were performed at 300 K and the hyperfine interaction parameters were obtained.

^{57}Fe Mössbauer effect studies

A new series of intermetallic compounds $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ (x = 0, 0.1, ..., 0.35 and 0.4) was prepared by arc melting in a high purity argon atmosphere

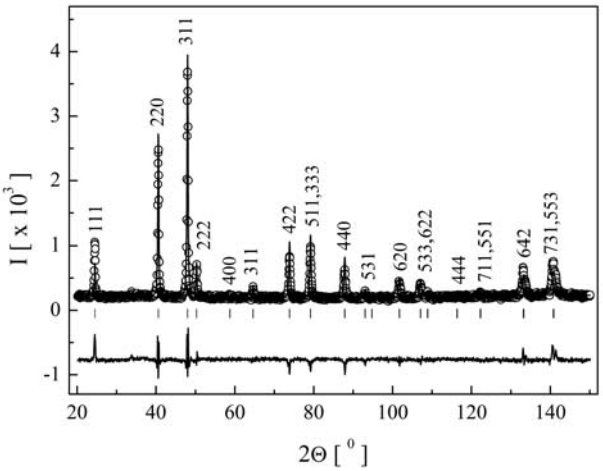

Fig. 1. An exemplary X-ray diffraction pattern for the $Dy(Co_{0.2}Ni_{0.2}Fe_{0.6})_2$ compound.

from the appropriate amounts of the Dy(99.9% purity), Fe, Co and Ni (all 99.999% purity) starting materials. Standard X-ray powder diffraction patterns of good quality were obtained for all the samples using CoK_α radiation at room temperature. An exemplary diffraction pattern for the $Dy(Co_{0.2}Ni_{0.2}Fe_{0.6})_2$ compound is presented in Fig. 1. For all the compounds, single phase X-ray diffraction patterns corresponding to the cubic, *Fd3m*, $MgCu_2$-type (C15) Laves phase were observed. The unit cell parameter decreases monotonically from 7.302(1) for the starting compound $Dy(Co_{0.4}Fe_{0.6})_2$ to the value of 7.288(1) for the $Dy(Ni_{0.4}Fe_{0.6})_2$.

The ^{57}Fe Mössbauer effect (ME) patterns collected for cubic $MgCu_2$-type, *Fd3m* Laves phases of $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series are presented in Fig. 2. A standard ME transmission technique with a ^{57}Co in Rh source was used.

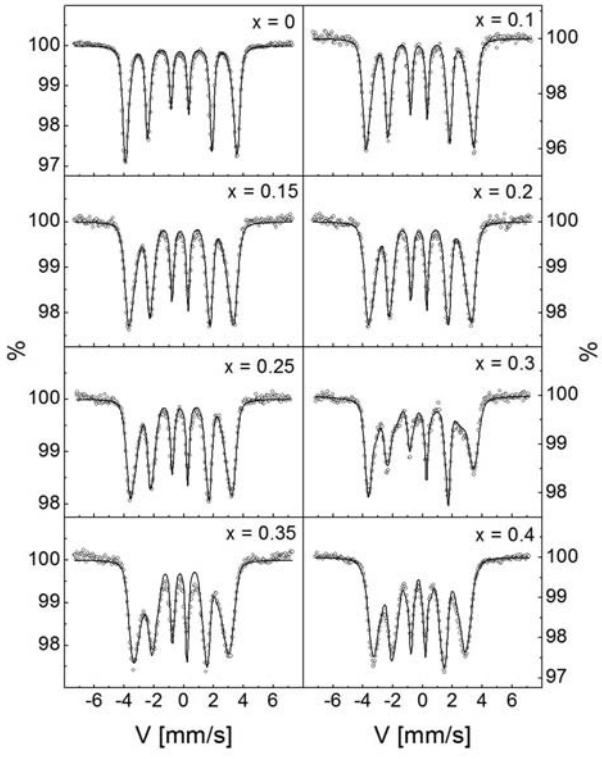

Fig. 2. ^{57}Fe Mössbauer effect spectra of the $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ intermetallics (295 K).

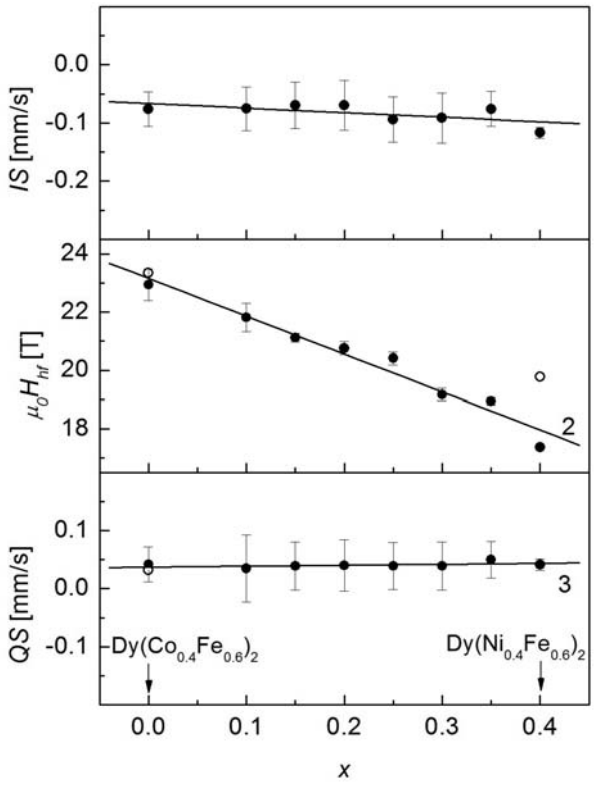

Fig. 3. Hyperfine interaction parameters of the $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series (o – literature data) [5, 6].

The average values of the hyperfine interaction parameters, i.e. the isomer shift IS (with respect to iron metal, at 300 K), the magnetic hyperfine field $\mu_0 H_{hf}$ and the quadrupole interaction parameter QS, determined across the $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series at 295 K, are presented in Fig. 3.

The average isomer shift IS (Fig. 3, line 1) decreases linearly and is described by the numerical formula $IS(x) = (-0.078(4)x - 0.067(3))$ mm/s. It has been previously found for the rare earth-transition metal Laves phases that a reduction of the lattice parameter causes a decrease in the isomer shift at ^{57}Fe nuclei [7, 8]. A similar reduction of both the lattice parameter and the isomer shift is observed in the studied $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series.

The average $\mu_0 H_{hf}$ dependence (Fig. 3, line 2) is reduced strongly by the Co/Ni substitution and is described by numerical formula: $\mu_0 H_{hf}(x) = (-12.98(2)\, x + 23.15(7))$ T. It is expected that Co/Ni substitution in the transition metal sublattice, which is treated as a strong ferromagnet, reduces the magnetic moment of the sublattice and thus reduces the observed ^{57}Fe magnetic hyperfine field. The average QS parameter increases slightly, according to the numerical formula: $QS(x) = (0.016(3)x + 0.037(4))$ mm/s (Fig. 3, line 3). Fig. 3 also contains known literature data [5, 6] for a comparison.

Figure 4 (curve 1 and 2) shows a Slater-Pauling type dependence for the average magnetic hyperfine field vs. n observed previously for the $Dy(Mn_{1-x}Fe_x)_2$ and $Dy(Fe_{1-x}Co_x)_2$ series [5]. Additionally, Fig. 4 (curve 3) shows the $\mu_0 H_{hf}(n)$ dependence (n is the average number of 3*d* electrons per atom) for the $Dy(Mn_{0.4-x}Co_xFe_{0.6})_2$ series and (curve 4) for the studied $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ series. The

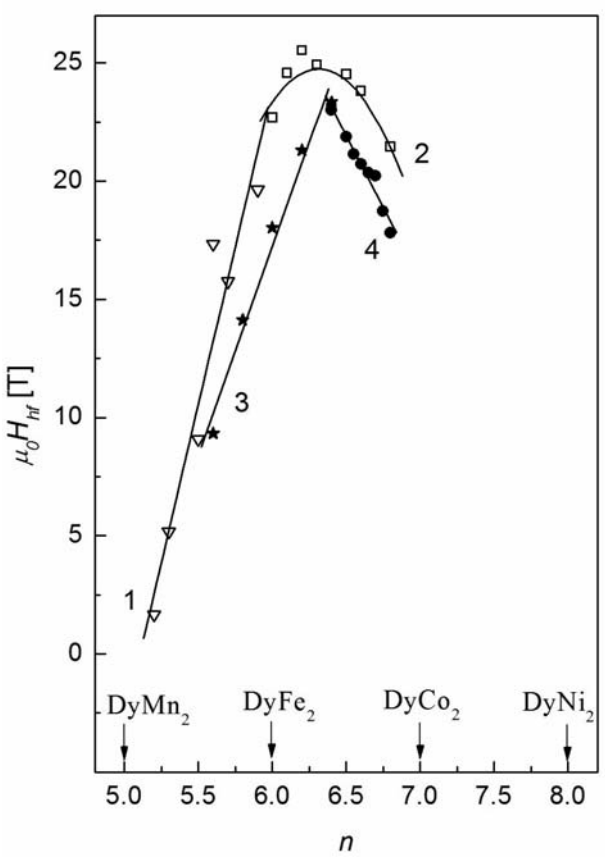

Fig. 4. Magnetic hyperfine field $\mu_0 H_{hf}$ vs. n the average number of electrons 3d compared for the series: 1 – $Dy(Mn_{1-x}Fe_x)_2$, 2 – $Dy(Fe_{1-x}Co_x)_2$, 3 – $Dy(Mn_{0.4-x}Co_xFe_{0.6})_2$ [6] and 4 – $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$.

magnetic hyperfine fields $\mu_0 H_{hf}$ of the last two series also create the Slater-Pauling type dependence which is a certain replica of dependencies 1 and 2.

Summary

The new series of intermetallic compounds $Dy(Co_{0.4-x}Ni_xFe_{0.6})_2$ was synthesized by an arc melting technique. All of the studied compounds crystallize in the $MgCu_2$ type structure whose the unit cell parameter slightly monotonically decreases with Ni content.

The average hyperfine interaction parameters were obtained. The isomer shift and the hyperfine magnetic field are decreasing linearly with Co/Ni substitution and the quadrupole splitting is slightly increasing.

The obtained magnetic hyperfine fields for the studied series and the previously measured $Dy(Mn_{0.4-x}Co_xFe_{0.6})_2$ series create a new Slater-Pauling type dependence.

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