

The role of α -Fe and metal oxides nanoparticles on the structural properties of high-temperature spintronic EuO:Fe composite

Abstract

Based on the available experimental and theoretical data, the role of the α -Fe nanoparticles and higher metallic oxides in the structure of the EuO: Fe composite on the formation of a complex of inherent physical parameters is tracked. That along with the presence of a limited solid solution $\text{Eu}_{1-x}\text{Fe}_x\text{O}$ in its structure contributes to the chemical stability of this high-temperature spin injector under normal conditions.

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Introduction

It is considered that metallic iron does not dissolve in europium monoxide and does not form an independent crystalline phase with it as a solid solution (SS) $\text{Eu}_{1-x}\text{Fe}_x\text{O}$.¹ However, this does not mean that such SSs are not able to originate at least partially or in limited regions of compositions in more complex multiphase composites containing europium and iron oxides. In particular, in the spintronic composite material synthesized from higher oxides of europium (Eu_2O_3) and iron (Fe_2O_3) by the high-temperature solid-phase reduction method. It has been experimentally confirmed² that several more independent crystalline phases co-exist in such composite in addition to the above-mentioned SS: from nanosized super paramagnetic particles of metallic iron to oxides of both metals in different oxidation states. However, it is the presence of this SS that determines the outstanding physical characteristics of this composite – its high specific magnetization (40–60emu/g at the room temperatures, T_r) and the Curie temperature, $T_c = 480\text{K}$. Under the conditions of its inherent semiconductor conductivity at the range of compositions $0.15 < x < 0.25$, this composite material is promising in the creation of semiconductor spintronic devices capable of stable operation at the room temperature. At the same time an increased degree is achieved of spin current transfer, $P \approx 60\%$.^{3,4} To the latter in a great extent contributes the chemical stability of this composite, located both in bulk and in thin-film states in normal environmental conditions. Such stability is largely ensured by the adherence to the composite of the aforementioned nanoparticles.

Experimental

In support of the above, we present the results of the experimental studies of resonance (nuclear magnetic resonance, NMR) and magnetic parameters of this composite. Thus, the spectra of nuclear magnetic resonance (or the Mössbauer effect) of a bulk sample of the EuO:Fe composite for the ^{57}Fe isotope, taken at room temperature are presented in Figure 1. It characterizes a typical ferromagnet and contain at least two sixes of Zeeman lines which are related to α -Fe nanoparticles and Eu-Fe-O clusters, respectively.

In the same conditions the Mössbauer spectra of ^{57}Fe of the composite films represent a singlet with an isomeric shift of $\delta = +0.20\text{mm/s}$ and with a very weak splitting, typical for the display of super paramagnetism of α -Fe nanoparticles. This data exemplifies that the high-temperature magnetism of the composite is caused by the presence of the ferromagnetic ordering of Eu-Fe-O clusters and super paramagnetic α -Fe nanoparticles. This is fully confirmed by magnetic studies of the composite.

The cation state of the europium atoms in the composite illustrates the NMR spectrum of ^{151}Eu . It is an overlap of two lines characterized by isomeric shifts of $\delta = -12.6\text{mm/s}$ and $\delta = +0.02\text{mm/s}$. The first line corresponds to the paramagnetic ion of the Eu^{2+} matrix. The second line is responsible for the manifestation of the valence state of Eu^{3+} .

The studies of the magnetization dependence upon cooling of the composite films at low temperatures in an external magnetic field (the FC condition) and without a field (the ZFC condition) revealed another feature.⁴ Namely, the presence of an inflection of this dependence in the temperature region of $T = 25 \div 30\text{K}$ (Figure 2) in the latter case. This so-called “blocking temperature” (T_{bl}) – is the transition from the antiferromagnetically ordered state (at $T < T_{bl}$) to super paramagnetism (at $T > T_{bl}$) of α -iron nanoparticles in the composite.

Physically this means that the magnetic moments of such nanoparticles at $T \leq T_{bl}$ are antiferromagnetically in relation to ferromagnetically ordered state of the matrix Eu^{2+} ions. At $T > T_{bl}$, the situation changes – superparamagnetism of α -Fe nanoparticles promotes the growth of the magnetic moment of the Eu-Fe-O clusters.

In conclusion, we note that this combination of phase components, which form the outstanding properties of this composite as a high-temperature spintronic material, may be reproduced only when it is synthesized from higher oxides. Attempts to synthesize the aforementioned single-phase SS from the metals corresponding to the properties of the composite have so far been unsuccessful.⁵

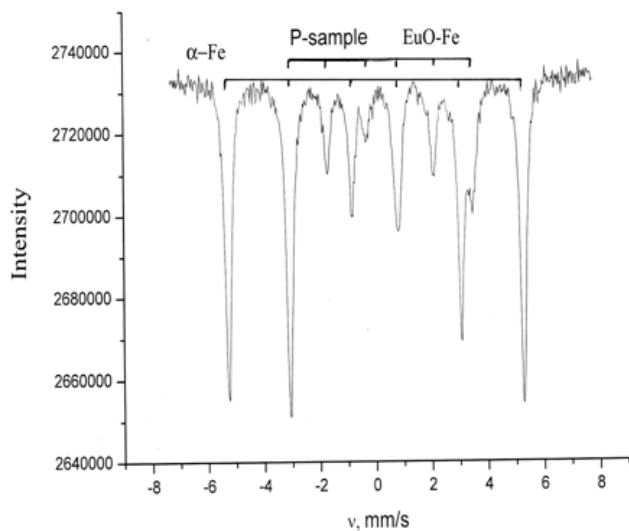


Figure 1 NGR spectra of ^{57}Fe powder of the EuO:Fe composite at room temperature.

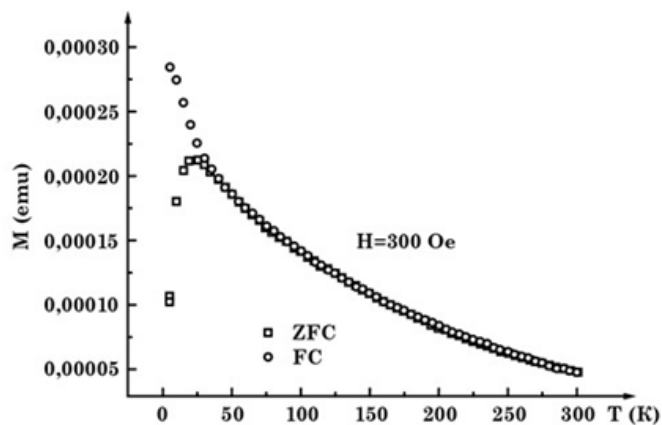


Figure 2 The magnetization of the $(\text{EuO})_{0.75}\text{Fe}_{0.25}$ composite film under conditions of ZFC and FC.

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Conflict of interest

The author declares there is no conflict of interest.

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