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# Effect of Silica Embedding on the Structure, Morphology and Magnetic Behavior of $(Zn_{0.6}Mn_{0.4}Fe_2O_4)_\delta/(SiO_2)_{(100-\delta)}$ Nanoparticles

**Thomas Dippong [1,*], Iosif Grigore Deac [2], Oana Cadar [3] and Erika Andrea Levei [3]**

[1] Faculty of Science, Technical University of Cluj-Napoca, 76 Victoriei Street, 430122 Baia Mare, Romania
[2] Faculty of Physics, Babes-Bolyai University, 1 Kogalniceanu Street, 400084 Cluj-Napoca, Romania; iosif.deac@phys.ubbcluj.ro
[3] INCDO-INOE 2000, Research Institute for Analytical Instrumentation, 67 Donath Street, 400293 Cluj-Napoca, Romania; oana.cadar@icia.ro (O.C.); erika.levei@icia.ro (E.A.L.)
* Correspondence: dippong.thomas@yahoo.ro

**Abstract:** The effect of $SiO_2$ embedding on the obtaining of single-phase ferrites, as well as on the structure, morphology and magnetic properties of $(Zn_{0.6}Mn_{0.4}Fe_2O_4)_\delta(SiO_2)_{100-\delta}$ ($\delta$ = 0–100%) nanoparticles (NPs) synthesized by sol-gel method was assessed. The phase composition and crystallite size were investigated by X-ray diffraction (XRD), the chemical transformations were monitored by Fourier transform infrared (FT-IR) spectroscopy, while the morphology of the NPs by transmission electron microscopy (TEM). The average crystallite size was 5.3–27.0 nm at 400 °C, 13.7–31.1 nm at 700 °C and 33.4–49.1 nm at 1100 °C. The evolution of the saturation magnetization, coercivity and magnetic anisotropy as a function of the crystallite sizes were studied by vibrating sample magnetometry (VSM) technique. As expected, the $SiO_2$ matrix shows diamagnetic behavior accompanied by the accidentally contribution of a small percent of ferromagnetic impurities. The $Zn_{0.6}Mn_{0.4}Fe_2O_4$ embedded in $SiO_2$ exhibits superparamagnetic-like behavior, whereas the unembedded $Zn_{0.6}Mn_{0.4}Fe_2O_4$ behaves like a high-quality ferrimagnet. The preparation route has a significant effect on the particle sizes, which strongly influences the magnetic behavior of the NPs.

**Keywords:** silica matrix; sol-gel synthesis; zinc-manganese ferrite; magnetic properties

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## 1. Introduction

Zinc ferrite ($ZnFe_2O_4$) has a normal spinel structure and remarkable magnetic, electrical, electrochemical and sensing properties, making it suitable for a wide-range of applications [1–4]. Its excellent magnetization is attributed to the inversion of $Fe^{3+}$ and $Zn^{2+}$ ions between tetrahedral (A) and octahedral (B) sites [4]. Manganese ferrite ($MnFe_2O_4$) has a partially inverse spinel structure and numerous applications due to its tunable magnetic properties, small-sized particles, possibility to be controlled by an external magnetic field, easy synthesis process and biocompatibility. It is also an inorganic heat-resistant, non-corrosive, non-toxic and environmentally friendly material with coloristic properties [5–7].

Due to their unique properties, the Mn-Zn ferrites are widely used in many fields such as medicine, environmental depollution, energy storage, gas sensors and photocatalysis [8–10]. The use of nanoferrites in medicine is possible due to their ability to locally heat up the tissues under an external variable magnetic field as a consequence of thermal losses. The high sensitivity to oxidation and cytotoxicity of pure metal particles makes them inadequate for medical applications, while iron oxide nanoparticles are promising candidates, due to their biocompatibility, especially if they are covered with inorganic or organic biocompatible coatings (i.e., alcohol, esters, $SiO_2$) [11]. Recently, due to their low toxicity, Mn-Zn ferrites become a center of attraction for hyperthermia, electrical, electronic and telecommunication devices [12,13]. Cubic spinel Mn-Zn ferrites belonging to soft