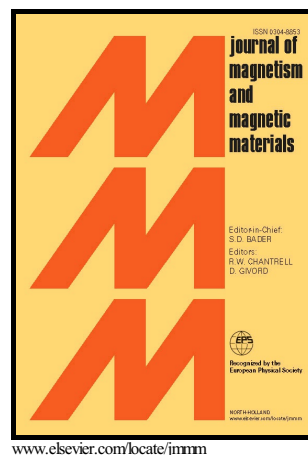


07Magnetic, dielectric and microwave absorption properties of rare earth doped Ni-Co and Ni-Co-Zn spinel ferrites

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Magnetic, dielectric and microwave absorption properties of rare earth doped Ni-Co and Ni-Co-Zn spinel ferrites

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stergiou@cperi.certh.gr**Abstract**

In this article we analyze the electromagnetic properties of rare earth substituted Ni-Co and Ni-Co-Zn cubic ferrites in the microwave band, along with their performance as microwave absorbing materials. Ceramic samples with compositions $\text{Ni}_{0.5}\text{Co}_{0.5}\text{Fe}_{2-x}\text{R}_x\text{O}_4$ and $\text{Ni}_{0.25}\text{Co}_{0.5}\text{Zn}_{0.25}\text{Fe}_{2-x}\text{R}_x\text{O}_4$ ($\text{R}=\text{Y}$ and La , $x=0, 0.02$), fabricated with the solid state reaction method, were characterized with regard to the complex permeability $\mu^*(f)$ and permittivity $\varepsilon^*(f)$ up to 20 GHz. The rare earth substitutions basically affect the microwave $\mu^*(f)$ spectra and the dynamic magnetization mechanisms of domain wall motion and magnetization rotation. Key parameters for this effect are the reduced magnetocrystalline anisotropy and the created crystal inhomogeneities. Moreover, permittivity is increased with the Y and La content, due to the enhancement of the dielectric orientation polarization. Regarding the electromagnetic wave attenuation, the prepared ferrites exhibit narrowband return losses (RL) by virtue of the cancellation of multiple reflections, when their thickness equals an odd multiple of quarter-wavelength. Interestingly, the zero-reflection conditions are satisfied in the vicinity of the ferromagnetic resonance. As the rare earth doping shifts this mechanism to lower frequencies, loss peaks with $RL > 46$ dB occur at 4.1 GHz and 5 GHz for Y and La-doped Ni-Co-Zn spinels, whereas peaks with $RL > 40$ dB appear at 18 GHz and 19 GHz for Y and La-doped Ni-Co spinels, respectively. The presented experimental findings underline the potential of cubic ferrites with high Co concentration in the suppression of electromagnetic reflections well above the 1 GHz region.

Keywords: magnetic materials; ceramics; magnetic properties; dielectric properties.

1. Introduction

From the application point of view, when the efficient operation of soft magnetic materials at high frequencies is required, cubic ferrites of Ni-Zn type and hexagonal ferrites are considered as the basic candidates. This design direction is valid for applications above 1 MHz because ferrites with Ni-Zn composition and spinel structure possess higher electrical resistivity and larger effective anisotropy constant compared to their Mn-Zn counterparts [1,2]. Moreover, ferrites with hexagonal structure and mainly with a sufficiently high Co content may exhibit easy magnetization directions on a conical or planar surface, which allows the maintenance of relatively high permeability up to the GHz region [3,4,5]. Thus, for both mentioned ferrite groups, sufficiently high magnetic response with low magnetic losses can be attained in the high frequency range of interest.

However, we notice that ferrite producers and application designers do not follow the considerable interest of materials scientists in soft hexaferrites. Despite the dramatic growth of electronic and telecommunication systems and their operation at increasingly high frequencies, there is still a limited practical interest in the usage and production of these materials. A major reason for this obvious inconsistency is the technical impediments posed by the thermally excited chemical instability, due to the comparable chemical formulas of the different types of hexaferrites [5,6]. In fact, the production of pure hexaferrite materials could be a time consuming, costly and not always successful procedure, which involves process modifications, multiple milling and sintering cycles. On the contrary, stable Ni-Zn ferrites are fabricated with the typical solid-state reaction route, which is similar to the massively applied production method of Mn-Zn ferrites. In that case, it remains an open challenge to expand the useful frequency range of Ni-Zn ferrites.

To this end, it is advisable to increase the cut-off frequency limits, which are set by the magnetic loss mechanisms taking place in ferrites. In the high frequency regime, domain wall oscillation and ferromagnetic resonance may occur, which result in enhanced magnetic losses, expressed by the high imaginary part of permeability μ'' [7]. The first option to affect the electromagnetic (EM) performance of ferrites is to control the developed microstructure in the ceramic samples. Adjustment of the processing parameters has been widely involved by ferrite industry in order to tailor the morphological features of ferrite products [1,2,8], whereas various recently published research works have explored the impact of grain size, porosity and density on the high frequency magnetic properties of Ni-Zn ferrites [9-15]. In addition to this option, the frequency dependence of ferrite properties can be also determined through compositional control. Especially, the introduction of Co as a substitution element in spinel ferrites is effective in extending their operation band to higher frequencies. Cobalt has a strong positive contribution to the ferrite anisotropy, which stems from its unquenched orbital moment in the octahedral sites [3]. Thus, the induced anisotropy hinders the domain wall bowing and shifts the ferromagnetic resonance to higher frequencies, which can be exploited in the design of Ni-Zn ferrites with low losses above 1 MHz [16-19]. Furthermore, we should remark the increasing use of rare earth oxides as additives to spinel ferrites, which offer an additional design tool for the adjustment of their static and dynamic magnetic properties [20-23].

In this context, we have previously investigated the impact of the nonmagnetic Y and La substitution on the crystal structure, microstructure and static magnetic properties of Ni-Co and Ni-Co-Zn ferrites [24]. We have thus identified the

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