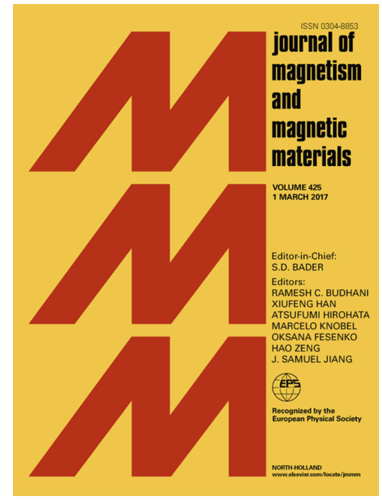
Accepted Manuscript



Magnetic Resonance and Antiresonance in Microwave Transmission through Nanocomposites with Fe_3Ni_2 and $FeNi_3$ Particles

A.B. Rinkevich, M.I. Samoylovich, O.V. Nemytova, E.A. Kuznetsov

PII: S0304-8853(16)31583-9
DOI: http://dx.doi.org/10.1016/j.jmmm.2017.01.095
Reference: MAGMA 62449

To appear in: *Journal of Magnetism and Magnetic Materials*

Received Date: 27 July 2016
Accepted Date: 27 January 2017

Please cite this article as: A.B. Rinkevich, M.I. Samoylovich, O.V. Nemytova, E.A. Kuznetsov, Magnetic Resonance and Antiresonance in Microwave Transmission through Nanocomposites with Fe_3Ni_2 and $FeNi_3$ Particles, *Journal of Magnetism and Magnetic Materials* (2017), doi: http://dx.doi.org/10.1016/j.jmmm.2017.01.095

Magnetic Resonance and Antiresonance in Microwave Transmission through Nanocomposites with Fe_3Ni_2 and $FeNi_3$ Particles

A.B. Rinkevich[a], M.I. Samoylovich[b], O.V. Nemytova[a], E.A. Kuznetsov[c]

[a] *M.N. Miheev Institute of Metal Physics Ural Branch of RAS, 18 S.Kovalevskaya St, Ekaterinburg, 620990 Russia*
[b] *OAO TsNITI "TEKHNOMASH", 4 Ivana Franko St, Moscow, 121108 Russia*
[c] *Nizhny Tagil branch of the Ekaterinburg state social-pedagogical university, 57 Krasnogvardeyskaya St, Nizhny Tagil, 622031 Russia*

Abstract

Investigation of magnetic properties and microwave resonance phenomena in nanocomposites based on opal matrices containing the particles of intermetallide of Fe_3Ni_2 and $FeNi_3$ is carried out. The interactions which lead to the resonance changes of transmission and reflection coefficients are determined. Electromagnetic properties are measured in the millimeter frequency range. Special attention is paid to comparison between static and dynamic magnetic properties of nanocomposites. Frequency dependences of magnitude of lines of resonance features are obtained. Spectra of resonance and antiresonance are studied. The conditions when the magnetic antiresonance is observed are clarified. The X-ray phase analysis of the nanocomposites is performed and their structure is studied.

Keywords: opal matrices, nanocomposite materials, microwave properties, magnetic resonance and antiresonance.

1. Introduction

Anomalies of physical properties of nanocomposite materials based on opal matrices

Nanocomposite materials based on opal matrices have become the topical exploration subject. Due to the periodical structure these materials can be considered either as the metamaterials [1] or as the photonic crystals [2], depending on the chemical composition and frequency range of the electromagnetic waves. Physical properties and structure of the opal matrices filled by the metallic or ferromagnetic nanoparticles have been studied in detail in [3]. There are some prospects of application of nanocomposite based on the opal matrixes as the magnetic metamaterials in the nanoelectronic devices of microwave frequency range [4].

Microwave techniques enable relatively easy to estimate the dynamic and relaxation parameters of such materials. Opal matrices with the embedded magnetic metallic nanoparticles can be considered as the metamaterials which are suitable to create the media with a negative refractive index [5]. Realization of such left-handed medium with the negative real part of magnetic permeability is possible, in the first place, in the region of magnetic resonances. At the resonance field the sign of dynamic magnetic permeability changes and its value can considerably vary. In the work [6] the conditions of realization a negative refractive index in the case of nanocomposite material based on opal matrix filled with the conductive ferromagnetic nanoparticles have been achieved. There are the conditions under which the metamaterials have permeability close to zero. In such media there is a tunnelling effect through the narrow channels and bends under the conditions when the normal transmission of wave is not permitted [7-9].

Microwave properties of 3D-nanocomposites based on opal matrices depend on their phase composition and magnetic state. An influence of contribution of nanoparticles surface to the magnetic anisotropy is typical for the magnetic properties of nanoparticles. As well as the processes of superparamagnetic relaxation are important [10, 11]. The magnetic state of nanocomposite is a factor which defines the microwave properties in magnetic field, in particular, the resonance phenomena.

The dynamics of magnetization under the resonance conditions is carefully studied. Investigation of several parameters, namely, the value of attenuation of electromagnetic waves, spectrum of magnetic resonance and linewidth is required to correctly describe and understand the processes of wave's interaction with magnetic 3D-nanocomposites. Characteristics of resonance line such as the value of field of resonance, the width and shape of line, depend on the size of nanoparticles [12].

The greatest changes of transmission and reflection coefficients of electromagnetic waves in microwave and millimeter-wave bands take place due to the influence of magnetic resonance and antiresonance. Ferromagnetic resonance (FMR) leads to the electromagnetic waves absorption which as usual leads to a minimum in the field dependence of reflection and transmission coefficients. Ferromagnetic antiresonance (FMAR) is realized by changing the sign of permeability of metallic ferromagnet in the fields which are less than the field of uniform mode of magnetic resonance [13]. The antiresonance occurs when the real part of permeability equals zero and the imaginary part is small. Mostly the antiresonance is experimentally observed as anomalous transmission of electromagnetic wave through the ferromagnetic film, which occurs because of considerable increase