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Research articles

Optimization of tunable GHz micro-antennas based on Giant magnetoimpedance

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ABSTRACT

The unique magnetic properties of amorphous magnetic microwires (AMMW), in particular its interaction with microwaves by means of Giant Magnetoimpedance effect and its magnetostrictive character allow the development of tunable GHz micro-antennas useful as contactless sensing elements with applicability in many fields including biomedical. The possibility of using a single AMMW for this purpose demands the optimization and control of its electrical and magnetic properties in order to adapt them to our needs. In this work we study the changes on electrical resistance and magnetic permeability due to the stress relaxation and to the nanocrystallization induced by thermal treatments in AMMW of composition ($Fe_{2.25}Co_{72.25}Si_{10}B_{15}$), obtaining important variations in the sensing capability.

1. Introduction

In recent years, much interest and effort has been devoted to develop soft magnetic materials due to their technological potential [1]. The main use of these materials can be found in the sensing industry which includes a broad spectrum of applications ranging from the automotive, mobile communication, chemistry and biochemistry industry among many others [2–7]. Amorphous magnetic microwires (AMMW) are one of the most widely studied soft magnetic materials. They are fabricated using the modified Taylor-Ulitovsky technique [8]. These AMMW are composed by a metallic core and a Pyrex cover both in the micrometer range. The metallic core provides the magnetic behavior while the cover, obtained as part of the preparation method, has a protective and stress-inducting function [9]. The ratio between total diameter and magnetic core diameter, often called aspect ratio, is one of the key parameters of such AMMW since magnetic properties depend dramatically on it [10]. Nanocrystallization techniques are widely used to improve AMMW magnetic properties. In fact, amorphous or nanocrystalline magnetic microwires are among the softest materials. Many properties of these materials have been deeply studied both from the point of view of the basic physics and the applications [11]. This is the case of the giant magnetoimpedance effect (GMI) [12], bistability [13], ferromagnetic [14,15] and magnetoelastic resonance [16,17]. It is easy, also, to find much literature regarding microwave related applications of AMMW or AMMW- based materials [18,19]. Some of these articles have nicely shown how different arrangements of AMMW forming arrays or embedded in different types of matrixes may be used for enhancing their sensitivity as GMI elements or electromagnetic waves absorbing materials [20]. Recent research shows the possibility of using AMMW for tuning metamaterials [21–23] and for magnetic hyperthermia [24].

Recently, some experimental and theoretical studies have been focused in the analysis of the effect of the magnetization on the scattering properties of a single AMMW in the frequency range of GHz [25,26]. These works are experimental evidences of the fact that the microwave scattering by a single AMMW depends on the magnetic permeability, with sufficient strength to be detected as an effect of the GMI. Furthermore, this dependence was also used to show the potential of such AMMW to behave as a tuneable GHz micro-antenna to be used as a wireless field and/or stress sensor. These experimental results are followed by a theoretical approach where the influence of the AMMW magnetic state in its microwave reflection features is taken into account. Based in these studies, further experimental work shows an application of such AMMW as a wireless stress sensor with the particular application of pressure detection in a hydraulic circuit simulating cardiovascular conditions [27]. A review of the applications of magnetic microwires as stress sensors shows its possibilities [28].

The aim of the present work is to maximize the scattering properties of one AMMW based on the combination of the thin antenna behavior [29] and the Giant Magnetoimpedance effect [30]. Annealing processes

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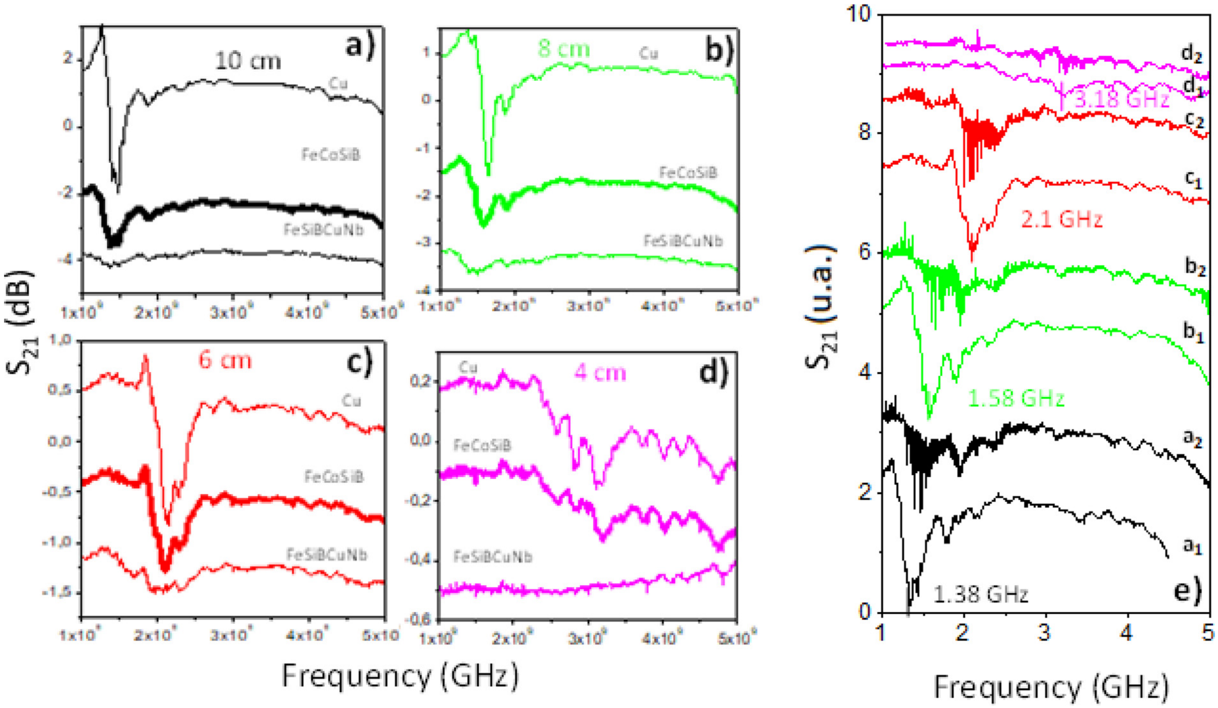

Fig. 1. Frequency domain (FD) measurement of scattering parameter S_{21} for a frequency range between 1 and 5 GHz for 10 (a), 8 (b), 6 (c) and 4 (d) cm respectively microwires of compositions Cu, $Fe_{2.25}Co_{72.25}Si_{10}B_{15}$ and FeSiBCuNb. S_{21} evolution of frequency domain (FD) and frequency domain under bias (FDB) with sample length for $Fe_{2.25}Co_{72.25}Si_{10}B_{15}$ AMMW with sample length between 4 and 10 cm (e).

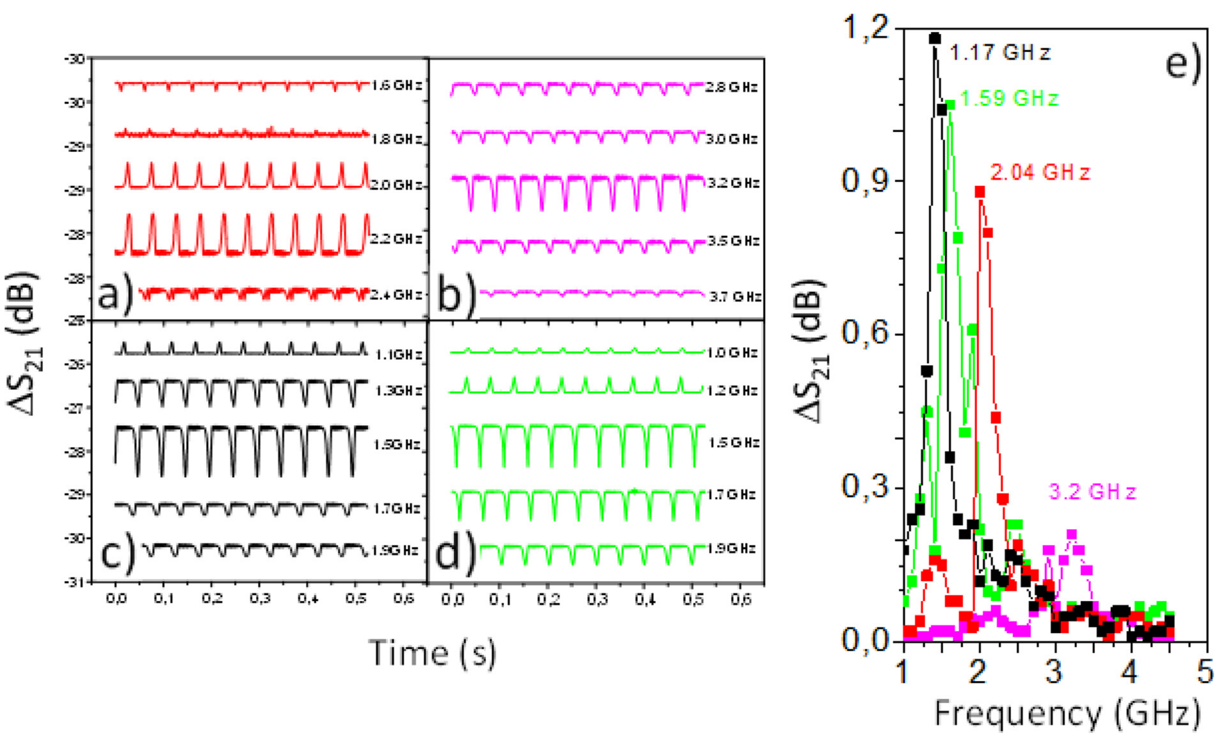

Fig. 2. Experimental S12 parameter time domain measurements in a frequency range of 1 GHz upper and lower around the corresponding antenna resonance for 6 (a),4 (b),10 (c) and 8 (d) cm $Fe_{2.25}Co_{72.25}Si_{10}B_{15}$ AMMW and corresponding peaks height as a function of frequency (e).

help to release internal stresses of the wires and shape their circumferential anisotropy in favour to GMI and to the scattering modulation. Initial states of nanocrystallization dramatically modify AMMW electrical resistivity.

2. Material and methods

AMMW of composition $Fe_{2.25}Co_{72.75}Si_{10}B_{15}$ with total and metallic inner core diameters of 49.7 and 31.4 µm respectively of lengths between 4 and 10 cm have been annealed for one hour in a tubular furnace, under Nitrogen to avoid oxidation, for a temperature range