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AC Magnetic Field Effect on the Complex Permeability Spectra of Soft Magnetic $Fe_{73}Cu_1Nb_3Si_{16}B_7$ Powder Cores

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In this work, two soft magnetic $Fe_{73}Cu_1Nb_3Si_{16}B_7$ powder core samples were investigated. Samples were prepared by milling of amorphous $Fe_{73}Cu_1Nb_3Si_{16}B_7$ ribbon at different temperature conditions: sample R, by milling at room temperature and sample L, by cryomilling at temperature of liquid nitrogen. Influence of applied exciting AC magnetic field with various amplitudes on the complex permeability spectra was studied. Obtained results are explained by the dynamics and relaxation phenomenon of domain walls under the influence of AC magnetic field.

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1. Introduction

Soft magnetic powder cores of amorphous and nanocrystalline alloys are well-known ferromagnetic materials with excellent soft magnetic properties, e. g. high magnetic permeability, low coercivity and low core loss. Powder cores offer prospective supersession of traditional ferrite materials and electrical steels in high-frequency electromagnetic applications [1]. The amorphous Vitroperm ($Fe_{73}Cu_1Nb_3Si_{16}B_7$) material is produced by rapid solidification as an originally amorphous ribbon, which is subsequently annealed above its crystallization temperature [2]. The material significantly embrittles upon this treatment which limits the application. One of the ways to prepare bulk material is the compaction of powder produced by milling of amorphous or nanocrystalline ribbons [3-4]. The soft magnetic properties of bulk Vitroperm samples were already reported in our earlier paper [5]. The present article shows complex permeability as a function of AC magnetic field.

2. Experimental

Amorphous ribbon with nominal composition $Fe_{73}Cu_1Nb_3Si_{16}B_7$ was produced via melt spinning technique (Vitroperm® 800, provided by Vacuumschmelze GmbH & Co. KG Hanau, Germany). Afterwards the ribbon was milled or cryomilled using a planetary ball mill (RETSCH PM4000). The milling was performed under Ar atmosphere with speed of 180 rpm at a ball-to-powder mass ratio of 6:1 in hardened steel vials. Handling of the powder was done in a glove box with controlled atmosphere (O_2 < 1 ppm, H_2O< 1 ppm). We prepared sample R – amorphous ribbon milled for 6 hours, consolidated at 500° C for 5 min, annealed at 540° C for 60 min, and sample L – amorphous ribbon cryomilled for 6 hours, consolidated at 500 °C for 5 min, annealed at 540 °C for 60 min, respectively.

From the previous experiments [5] the particle size of over 95% of particles after milling at room temperature is between 50 μm and 300 μm. However the cryomilled powders have smaller particle sizes, ranging from 20 μm to 150 μm. The samples were consolidated at 700 MPa for 5 min at 500 °C into cylinders with diameter of 10 mm and thickness of 3 mm. An axial hole with diameter of 5 mm was drilled into the disc, which produced ring-shaped samples.

We have prepared a coil with 20 turns for AC complex permeability measurement. The coil was wound around the toroidal sample and complex permeability spectra were measured with an impedance analyzer (HP 4194A) from 100 Hz to 40 MHz with the contact electrodes in two-terminal connection configuration. All measurements were carried out at room temperature.

3. Results

Both samples (R and L) under investigation consist of a large number of ferromagnetic powder particles with a broad limited size distribution and accordingly their macroscopic magnetic properties are the mean values of contributions from the entire statistical ensemble of particles.

Figures 1 and 2 show the complex permeability spectra of the samples R and L, respectively, under various amplitudes of applied AC magnetic field. The real part, μ', of complex permeability of the sample L shows a low-frequency plateau. On the contrary, the real part of complex permeability of the sample R decreases relatively steeply, but its static value is approximately four times higher than for the sample L. The main reason for the lower value of the low-frequency real permeability of small particles is the high demagnetization factor. Additionally, structural defects induced during ball milling process of small particles also cause the deterioration of magnetic properties.

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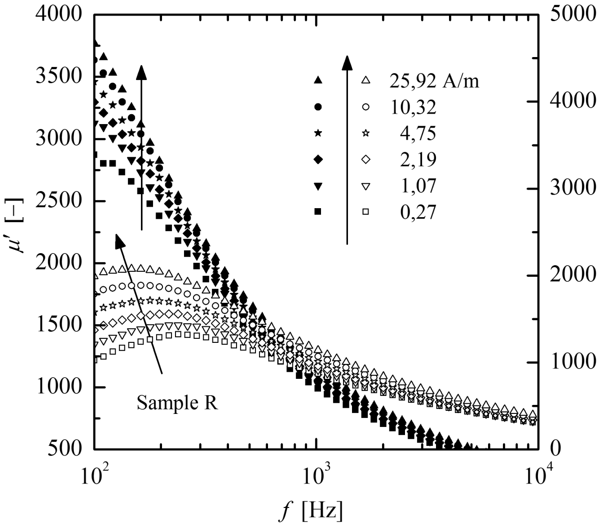

Fig. 1. Frequency spectra of real μ' parts (solid symbols) and imaginary μ'' parts (open symbols) of relative complex permeability of the sample R for selected amplitudes of AC magnetic field.

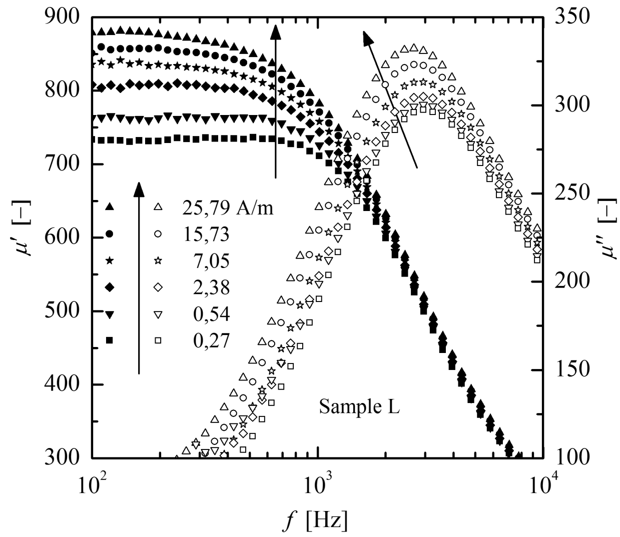

Fig. 2. Frequency spectra of real μ' parts (solid symbols) and imaginary μ'' parts (open symbols) of relative complex permeability of the sample L for selected amplitudes of AC magnetic field.

However, as the amplitude of AC magnetic field increases, a decreasing frequency dependence of real parts of complex permeability of both samples is observed in the whole measured frequency band and their static values increase.

Imaginary parts, μ'', of complex permeability show a single maximum, which position is clearly connected to so-called relaxation frequency. This frequency is associated with deactivation of domain walls movement magnetization process contributions to the total magnetization of ferromagnetic sample. At frequencies higher than the relaxation frequency, domain walls become unable to follow the high-frequency excitation of AC magnetic field [6]. The relaxation frequency of the sample R shifts toward lower values with increase of the amplitude of applied AC magnetic field. A similar behaviour is observed for the sample L.

All these phenomena can be explained as the result of domain wall motion under the "pressure" of applied AC magnetic field with various amplitudes. Increasing of the AC field amplitude causes that domain walls move rapidly over larger distances. This effect creates larger contributions to the total magnetization and results in increasing values of real parts of complex permeability. This periodic movement is longer under the larger AC field amplitudes and the relaxation frequency consequently decreases.

4. Conclusion

The influence of the AC magnetic field on the complex permeability spectra of soft magnetic bulk powder $Fe_{73}Cu_1Nb_3Si_{16}B_7$ cores prepared by milling and compaction of the alloy were studied. With the increase of AC magnetic field, the values of real and imaginary parts of complex permeability increase, mainly at low frequencies, and the relaxation frequency of both samples shifts toward lower values.

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