Evaluation of the exchange magnetic coupling nanocomposite magnetic materials

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OVERALL AIMS OF THE RESEARCH

- ✓ To get more insights into the nature of the exchange magnetic coupling between grains through the amorphous boundaries in Fe-based amorphous magnetic materials subjected to heat treatment.
- ✓ To characterize the magnetic properties of the sample in relation to the giant magneto-impedance (GMI) profiles

NEW MAGNETIC MATERIAL

- The discovery of Finemet-type nanocomposite magnetic materials with a composition of $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ provided some new insights into the science and technology of soft magnetic materials [1]. This kind of materials, routinely obtained by some appropriate heat treatment of a amorphous precursor, exhibits excellent magnetic properties due to its unique microstructure, namely, ultrafine nanocrystalline α-Fe(Si) grains embedded in an amorphous matrix (**Fig. 1**). This is directly depending on the exchange magnetic coupling between the grains through the amorphous boundaries. However, the exchange magnetic coupling is not thoroughly understood.

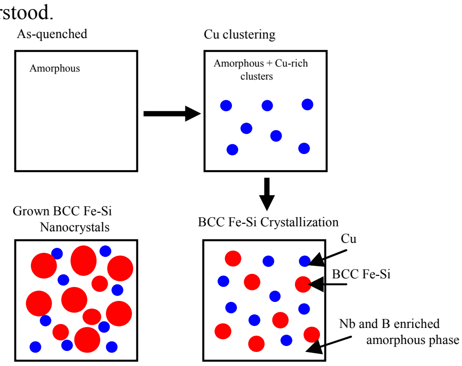

Fig. 1. A proposed sequence of events in the nanocrystallization of the material.

THEORETICAL CONSIDERATIONS

The exchange magnetic coupling in such a nanocrystalline material can be evaluated by considering the relationship between the magnetic exchange length (L_{ex}) and the average diameter of individual grains (D) within the framework of the random anisotropy model [2]. Accordingly, the effective anisotropy (H_K) and the coercivity (H_c) are deduced to relate to D as following:

$$H_c \sim H_K \sim D^6 \qquad (1)$$

and

$$\mu \sim D^{-6}, \qquad (2)$$

where μ is the magnetic permeability.

Furthermore, it was pointed out [3]:

$$\Delta Z/Z \sim \mu\,, \qquad (3)$$

where $\Delta Z/Z$ is the magnetoimpedance (MI) profile.

Taking the three above equations into account, it is possible to deduce the following relations:

$$\mu \sim 1/H_c \sim 1/H_K \qquad (4)$$

$$\Delta Z/Z \sim 1/H_K \sim D^{-6}. \qquad (5)$$

In short, from Eq (5), it is possible to evaluate the exchange magnetic coupling in the material.

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EXPERIMENT

- Sample : $Fe_{73.5}Si_{15.5}Nb_3Cu_1B_7$ (4mm in width, 20 μm in thickness)
- Preparation : the rapid quenching method
- Annealing : 350, 450, 540, 600, 650 ^{0}C for 30 min in vacuum
- Measurements : X-ray diffraction, DSC, TEM, Magnetoimpedance

RESULTS AND DISCUSSION

- Structural and magnetic characteristics have been analyzed in terms of the X-ray, DSC, TEM, Magnetization and Magnetoimpedance data (**Figs. 2-3**).

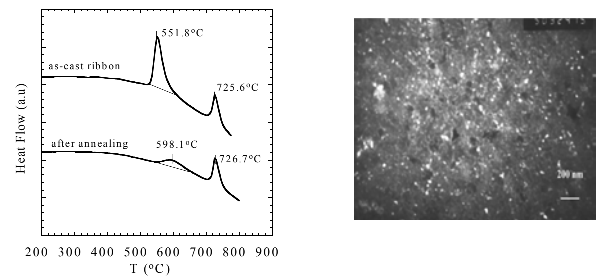

Fig. 2. (a) DSC curves for $Fe_{73.5}Si_{15.5}Nb_3Cu_1B_7$ ribbons (as-cast and annealed at 540 ^{0}C) and (b) Nanosize α-Fe(Si) particles embedded in the amorphous matrix are evidenced by TEM image.

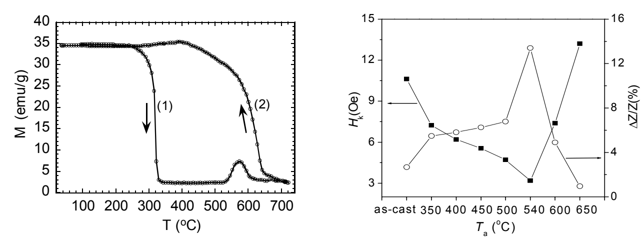

Fig. 3. (a) Thermomagnetic curves of the sample (1)- heating cycle, (2)- cooling cycle and, (b) variation of the anisotropy field and magnitude of GMI with annealing temperature.

- As expected from Eq (5), with increasing temperature up to 540 ^{0}C, a decrease of the anisotropy field and an increase of GMI were observed, but an opposite tendency was found when the annealing temperature exceeded 600 ^{0}C [see **Fig. 3**(b)].
- In view of the experimental data, it is reasonable to claim that the nanocrystalline grains in nanocrystalline alloys are strongly coupled through magnetic exchange interactions, and the local magnetocrystalline anisotropies of grains are averaged out. Meanwhile, the intergranular amorphous phase plays an indispensable role, because, only through it, can the exchange coupling be conveyed. Thus, any variation in the magnetic nature of the amorphous phase will consequently change the intergrain exchange coupling, then alter the magnetic softness and the effective anisotropy, and finally modify the GMI features.

References

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