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Microstructure of Fe-based amorphous and nanocrystalline soft magnetic alloys investigated by Doppler broadening positron annihilation technique

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Abstract –The microstructural defects in Fe-based amorphous and nanocrystalline soft magnetic alloy has been investigated by Doppler broadening positron annihilation technique. Amorphous alloys (Type I) which can form a nanocrystalline phases have more defects than alloys (Type II) which cannot form this microstructure. The nanocrystallized Finemet alloy has more defects than the as-quenched state and the nanocrystallization process introduce more defects. The change of line shape parameter S with annealing temperature in Finemet alloy is mainly due to the structural relaxation, the pre-nucleation of Cu nucleus and the nanocrystallization of α-Fe(Si) phase during annealing.

Fe-based nanocrystalline alloys exhibit excellent soft magnetic properties, such as very low coercivity, high permeability, and high saturation magnetization. Since the excellent soft magnetic properties of Fe-based nanocrystalline alloys depend closely on their specific two-phase structure, a profound knowledge regarding the two-phase structure is required for a detailed understanding of their excellent soft magnetic properties. Positron annihilation spectroscopy (PAS) is based on the ability of the positrons to seek open-volume imperfections in the solid, where they become localized and eventually are annihilated by nearby electrons. The techniques of Doppler broadening spectroscopy provide the information about the intensity of positronium and thus the amount of free volume in a sample. In the past, positron annihilation lifetime spectroscopy was used to study the microstructure in many different amorphous and nanocrystalline alloys. But, to our knowledge, few papers describing the microstructure in Fe-based amorphous/nanocrystalline alloys using Doppler broadening positron annihilation technique could be found in the literature. Therefore, in this presentation, the Doppler broadening positron annihilation technique is used to investigate the microstructure in Fe-based amorphous/nanocrystalline soft magnetic alloys. It is hoped that the present investigation would shed additional light into the nanocrystallization mechanism of Fe-based amorphous alloys.

The as-quenched Fe-based amorphous alloy ribbons with 10mm wide and about 30μm thick were produced by means of the melt-spinning technique on a single copper roller. The isothermally annealing was achieved in a vacuum furnace (10^{-5}Torr) at a set of temperatures from 20℃ to 580℃. The Doppler broadening measurements (with a total count of 10^6 for each spectrum) were performed at room temperature using a solid-state detector (pure Ge).

Amorphous alloys (Type I, Finemet type: $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, $Fe_{73.5}Cu_1Nb_2V_1Si_{13.5}B_9$, $Fe_{73.5}Cu_1Nb_2Mo_1Si_{13.5}B_9$) which can form a fixed microstructure with amorphous and nanocrystalline phases after traditional annealing have more defects than alloys (Type II: $Fe_{78}Si_9B_{13}$, $Fe_{78}Si_5B_{17}$, $Fe_{76}Si_{15}B_9$) which cannot form this microstructure after the same heat treatment Also, the nanocrystallized Finemet alloy has more defects than the as-quenched state and the nanocrystallization process introduce more defects. The change of line shape parameter S with annealing temperature in Finemet alloy (as shown in Fig.1) is mainly due to the structural relaxation, the pre-nucleation of Cu nucleus and the nanocrystallization of α-Fe(Si) phase during annealing. In addition, nanocrystalline Finemet alloy has good thermal stability at temperature range of 500℃~580℃ and good aging stability at room temperature.

In addition, this work shows that positrons are very sensitive to the variation of defects associated with different amorphous alloys and can be applied as a useful tool to the investigation of their structural changes during crystallization.

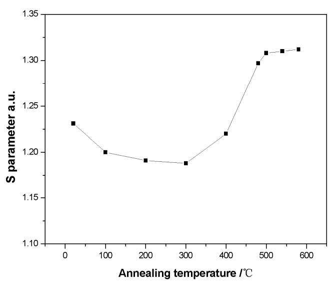

Figure 1: Dependence of line-shape parameter S on annealing temperature for amorphous Finemet alloys.