High temperature soft magnetic properties and domain structure of ultra-rapidly annealed FeCoBSiCu nanocrystalline alloys

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This investigation focuses on high-Bs $(Fe_{64}Co_{21}B_{15-x}Si_x)_{99}Cu_1$ (x = 0 and 5) soft magnetic alloys prepared using the ultra-rapid annealing (URA) technique. The samples were characterized in terms of structure, hysteresis behavior and magnetic microstructure using XRD, HRTEM, VSM magnetometry, high-temperature B-H loop tracer and Kerr microscopy. We demonstrate that partial substitution of boron with silicon promotes the formation of finer nanocrystalline grains, resulting in a reduction of coercivity to 3.1 A/m. The excellent magnetic softness remains stable up to 250 °C, making these ribbons promising candidates for applications at elevated temperatures.

Keywords: nanocrystalline alloys; rapid annealing; soft magnetic properties; domain structure

1. Introduction

Recently, ultra-rapid annealing has been employed to prepare Fe–Co–B–(Cu) nanocrystalline alloys with reduced content of non-magnetic elements [1,2]. Interest in these materials is primarily driven by their high saturation induction combined with low core loss. In this study, we investigate the effect of partially substituting boron with silicon on the structure and high temperature magnetic properties of $(Fe_{64}Co_{21}B_{15-x}Si_x)_{99}Cu_1$ alloys. A deeper understanding of the stability of the magnetic properties at elevated temperatures is essential for evaluating their application potential, particularly in magnetic components exposed to high-temperature environments. Furthermore, Kerr microscopy was employed to image the magnetic domain structure, an area that remains relatively unexplored in nanocrystalline ribbons processed by URA.

2. Results and discussion

The parent amorphous ribbons were prepared by planar flow casting. Ultra-rapid annealing (URA) was carried out in vacuum by compressing the samples between a pair of pre-heated massive copper blocks [3]. The optimal processing parameters were determined to be 0.5 s at 490 °C for the Si-free alloy and 0.5 s at 510 °C for the alloy with 5 at.% Si. HRTEM analysis revealed that the average grain size of the bcc nanocrystalline phase was reduced from 18–20 nm to 15–17 nm upon partial substitution of boron with silicon. Elemental mapping showed that boron is rejected from the bcc grains and becomes enriched in the residual amorphous matrix, while the silicon content is significantly higher within the nanocrystalline grains compared to the amorphous phase.

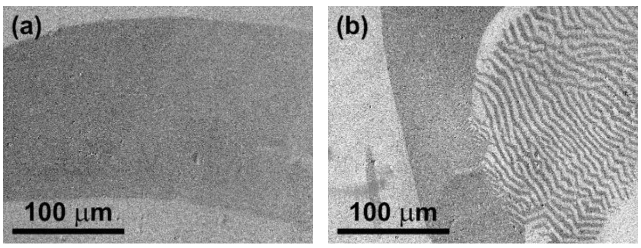

Figure 1: Magnetic domains observed in URA $(Fe_{64}Co_{21}B_{15}Si_5)_{99}Cu_1$ nanocrystalline ribbons.

Domain imaging revealed regions of enhanced internal stress induced by the URA process. Figure 1(a) displays a typical magnetic domain image characterized by regular, wide domains. In contrast, Figure 1(b) shows the coexistence of the wide domains with fingerprint-like stress patterns, which are rather seldom observed in conventionally annealed nanocrystalline ribbons.

The main focus of this study was the characterization of soft magnetic behavior at elevated temperatures. Hysteresis loops were measured from room temperature (RT) up to 425 °C using a quasi-static Förster-type B–H loop tracer. Reference hysteresis loops were recorded at RT after each high-temperature measurement to monitor possible irreversible changes in the microstructure during thermal exposure. The temperature-dependent coercivity, $H_c(T)$, along with the corresponding RT values, $H_c(RT)$, obtained from the hysteresis loops, are presented in Fig. 2. The soft magnetic performance remains relatively stable in the temperature range from RT to 250 °C, with coercivity variations within 1 A/m. Possible mechanisms responsible for the irreversible changes in soft magnetic properties observed at higher temperatures are proposed and discussed.

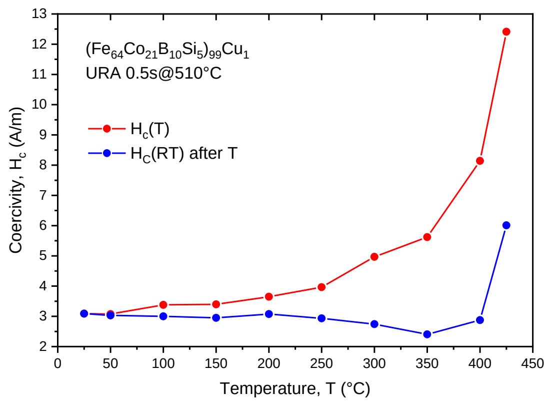

Figure 2: Coercivity of URA $(Fe_{64}Co_{21}B_{15}Si_5)_{99}Cu_1$ nanocrystalline ribbons at selected elevated temperature (-●-) and after subsequent cooling to room temperature from given setpoint temperature (-●-).

References

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