Novel approaches of high saturation magnetization nanocrystalline materials for powder and wound core applications

Satoshi Okamoto

Tohoku University, Sendai, Miyagi, Japan

Due to the recent strong demands of downsizing and high-efficiency energy conversion power-electronics systems, it has been expected to develop soft magnetic materials with high saturation magnetization $\mu_0 M_s$ and low core loss for magnetic passive devices of transformers and inductors. Therefore, soft magnetic nanocrystalline alloys with high $\mu_0 M_s$ have been intensively studied. However, there are some drawbacks of these alloys for practical application, such as brittleness and the requirement of rapid thermal annealing. These factors make it very difficult to fabricate powder and wound cores with high packing density. In this work, we have studied novel approaches to overcome these obstacles for both powder and wound core applications using a high $\mu_0 M_s$ nanocrystalline alloy of Fe(-Si)-B-P-Cu. For powder core application, a hot-press process was applied. As a result, plastic deformation and well-nanocrystallization of the powder concurrently occurred during the hot-press process. The packing density of hot-press core increased to 89 % from 70 % of cold-press core, resulting in a high core $\mu_0 M_s$ of 1.55 T. Moreover, the core loss at the frequency of 100 kHz and the excitation flux density of 100 mT decreased down to 146 kW/m^3 from 852 kW/m^3 of the cold press core. These properties are superior compared with the widely used commercial cores, such as Sendust and Fe-Si powder cores. On the other hand, for wound core application of Fe-Si-B-P-Cu ribbon, we have successfully developed a novel approach to realize the very low core loss comparable to that of FINEMET while keeping the elasticity and unnecessary rapid thermal annealing. At the onset of nanocrystallization, the core loss drastically decreased, and simultaneously the very narrow stripe magnetic domain structure with several μm in width was observed. This narrow stripe domain structure indicates the perpendicular magnetization inside the ribbon. The core loss analysis based on the magnetization reversal process revealed that the core loss component corresponding to the irreversible magnetization process significantly decreased. The certain amount of magnetostriction of this ribbon is a key factor for the formation of narrow stripe domain, and this approach expands the material space forward the high magnetostriction region where has not been considered as good soft magnetic materials. A prototype wound core was fabricated using this ribbon, and similar loss reduction in the wound core was clearly confirmed.

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