Grain size dependence of magnetostriction effects on excess loss in nanocrystalline soft magnetic materials

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Micromagnetic simulations were carried out to clarify a grain size dependence of energy losses due to magnetostriction in nanocrystalline soft magnetic materials. Local strains near magnetic domain walls generate a resistance force acting on the domain wall, and this force dissipates the magnetic energy of the material. The local strain increases with an increase in grain diameter when it is smaller than the domain wall width. In contrast, the strength of the local strain becomes constant when the grain diameter exceeds the domain wall width. This local strain affects the energy loss through magnetostriction. The energy loss also increases with the grain diameter, but it becomes a constant when the grain diameter exceeds the domain wall width. These results show that the local strain depends on the grain diameter and provide suggestions on the mechanism of the energy loss of soft magnetic materials.

Keywords: magnetostriction; excess loss; micromagnetic simulation; grain size; nanocrystalline soft magnetic materials

1. Introduction

Energy losses of soft magnetic materials are classified as hysteresis loss, classical eddy current loss, and excess loss. The excess loss has been discussed by anomalous eddy current loss caused by magnetic domain wall motion. G. Bertotti suggested that the anomalous eddy current loss has a relation with coercivity and thus, the grain size is an important parameter [1]. On the other hand, it was recently reported that the excess loss is caused by magnetostriction in nanocrystalline soft magnetic ribbons [2]. When the magnetic material has magnetostriction, the magnetic domain wall causes local strain, and the viscosity of the material causes a resistance force acting on domain wall motions. This force can dissipate magnetic energy induced in soft magnetic materials. However, the grain size dependence of this energy loss due to magnetostriction is still unclear. In this work, we performed micromagnetic simulations to clarify how the grain size affects the excess loss due to magnetostriction.

2. Results and discussion

We simulated magnetization dynamics by solving Landau-Lifshitz-Gilbert equation and also calculated lattice dynamics simultaneously involving magnetostriction effect [3]. In the series of simulations, we changed mean grain diameter from 12.7 nm to 147.9 nm. The number of the grains in the model becomes small as the grain size increases. Hence, we used two simulation model sizes of $2048 \times 2048 \times 2$ nm^3 and $4096 \times 4096 \times 4$ nm^3 when the mean grain diameter is lower and higher than 50.8 nm, respectively. We simulated oscillations of the magnetic domain wall by using these simulation models to calculate the energy loss. The smaller and larger models have 4 and 8 stripe domains, respectively. We chose α-Fe parameters of saturation magnetization, exchange stiffness constant, and elastic constants. In these simulations, we neglected crystal magnetic anisotropy to focus on the magnetostriction effect.

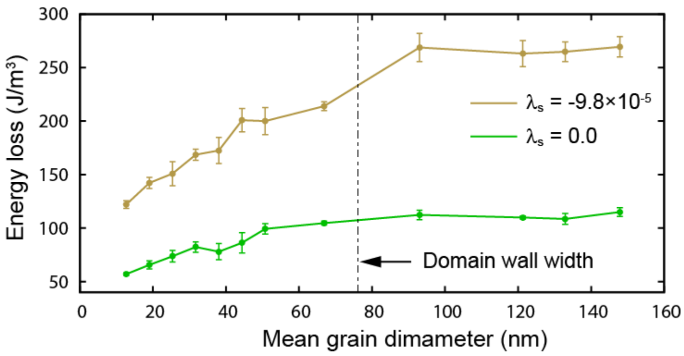

Figure 1: the energy losses due to magnetostriction as a function of the grain diameter. Gold and green colours indicate the energy loss when mean saturation magnetostrictions are -9.8×10^{-5} and 0.0, respectively.

Figure 1 shows the calculated energy loss for different values of mean saturation magnetostriction as a function of the grain diameter. The energy loss due to magnetostriction is increased by the grain diameter when it is smaller than the magnetic domain wall width. However, the energy loss becomes insensitive with the grain size when the mean grain diameter exceeds the magnetic domain wall width. This grain size dependence can be weakened by reducing the mean saturation magnetostriction, but the energy loss weakly increases due to the grain size even if the mean saturation magnetostriction is zero.

References

[1] G. Bertotti, IEEE Trans. Magn. 24 621 (1988).
[2] H. Huang, et. al., Phys. Rev. B 109 104408 (2024).
[3] H. Tsukahara, et. al., NPG Asia Material 14 44 (2022).

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