Magnetization reversal cluster size under microwave field excitation

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We study the effect of microwave field applications on the cluster size of magnetization reversal by numerical calculation. Averaged grain diameter of 6 nm is assumed and the exchange interaction between grains is varied from 0 to 10 % of the bulk values. The exchange interaction between grains tends to increase the assistance effect, although the critical frequency significantly decreases. The analysis of the cluster size during magnetization reversal based on the autocorrelation function revealed that the microwave field reduces the cluster size of magnetization reversal, and the effect also vanishes at critical frequency. The result suggests that the both effect has to be considered for designing media.

***Index Terms*—Microwave assisted magnetic recording, microwave assisted switching, thermal activation, LLG equation.**

I. Introduction

MICROWAVE ASSISTED recording (MAMR) is one of the promising techniques to enhance magnetic recording densities [1]. By applying microwave field with GHz frequency, excited magnetization can be switched under reduced magnetic field. The switching behavior, so-called microwave assisted switching (MAS), allows us to employ magnetic media with higher magnetic anisotropy. Analytical and numerical calculations have predicted that the switching field decreases linearly with increasing microwave frequency. The ratio between the assistance effect (switching field reduction) and microwave frequency is given by $-2\pi/\gamma$ [2, 3], where γ is the gyromagnetic ratio. The reduction of switching field has been widely observed in experiments with various materials including granular media. It is widely known that exchange interaction between grains modifies the switching behavior of granular media [4-8]. In the previous studies, we have reported experimental results that the frequency dependence of the microwave assistance effect is strongly affected by introducing exchange interaction between grains in CoCrPt-SiO_2 granular films [6]. The introduced exchange interaction enhances assistance effect at low microwave frequency region, although the critical frequency moves toward lower frequency. It can be expected that the exchange interaction helps excitement of cooperative presession, while the reversal cluster size increases.

In this study, we have carried out quantitative evaluation of cluster size under microwave field by micromagnetics simulations.

II. Calculation method

Numerical calculations were carried out using a GPU-based micromagnetics software mumax3 [9]. In the calculation, a film of 512×512 nm^2 were divided into Voronoi cells with average grain size of 6 nm as shown in Fig. 1. The film thickness is set to be 12 nm. The saturation magnetization M_s and the uniaxial anisotropy constant K_u are M_s = 600 kA/m and 6×10^5 J/m^3, respectively. The exchange stiffness constant inside grain A_{bulk} is set to be 1×10^{-11} J/m, while the exchange stiffness constant between grains were varied between grains A_{ex} is varied from 0 to 1×10^{-12} J/m, corresponding to A_{ex}/A_{bulk} = 0 – 0.1. The temperature T is set as 300 K, to introduce the effect of thermal activation. The easy axis is along the film normal. Magnetization reversal behavior is calculated in an external dc magnetic field H_{dc} swept from μ_0H_{dc} = 0 to 2 T. Microwave field H_{rf} is applied in-plane direction with the amplitude of μ_0H_{rf} = 50 mT. The microwave frequency f_{rf} is varied from 0 to 32 GHz.

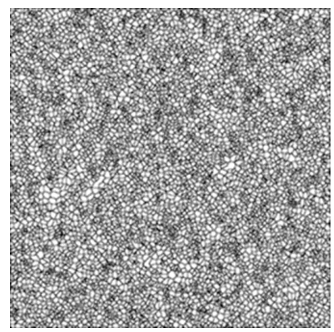

Fig. 1. Voronoi cells used for calculation. The total area is 512×512 nm^2 and the averaged grain diameter is 6 nm.

III. Results and Discussion

Figure 2 shows the magnetization configuration under external dc field around coercivity for f_{rf} = 0 and 14 GHz. The results for the exchange interaction between grains A_{ex}/A_{bulk} = 0, 0.02, 0.05 and 0.1 are shown. The bright area corresponds to the reversed region, while the dark area corresponds to the unreversed region. It is clearly seen that the increase of the exchange interaction causes the increase of the magnetic cluster size. The cluster size under microwave field application looks slightly smaller, but the difference is not significant. We evaluated the cluster size by calculating the spatial autocorrelation of the magnetization configuration. Figure 3 shows autocorrelation as a function of the radius r for f_{rf} = 14 GHz and A_{ex}/A_{bulk}= 0.05. We defined the autocorrelation length

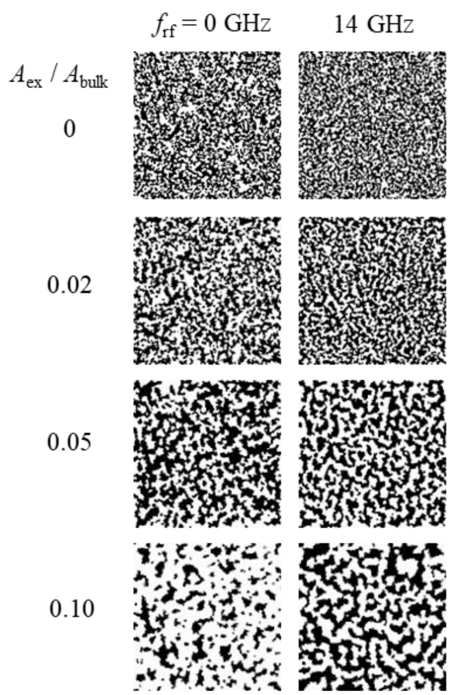

Fig. 2 Magnetization configuration under external dc field around coercivity. The microwave frequency f_{rf} = 0 and 14 GHz, and the ratio of exchange constant between grains and bulk are A_{ex}/A_{bulk} = 0 – 0.1, respectively. Each image corresponds to the area of 512×512 nm^2.

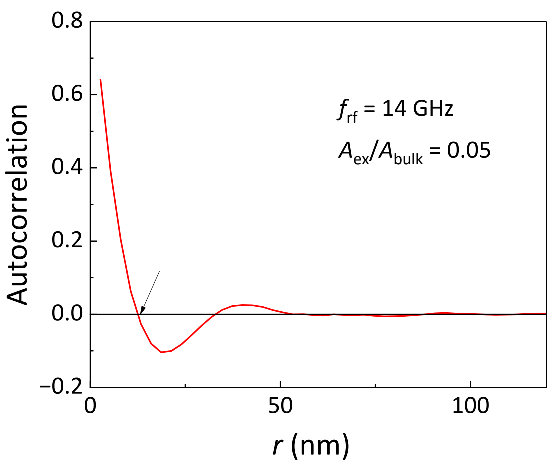

Fig. 3 Spatial autocorrelation as a function of radius r for f_{rf} = 14 GHz and A_{ex}/A_{bulk} = 0.05. The arrow indicates the autocorrelation length r_0 at which autocorrelation becomes zero.

r_0 at which the autocorrelation becomes zero, as indicated by the arrow in Fig. 3. The autocorrelation length r_0 is expected to reflect the magnetization cluster size. In Fig. 4 (a) and (b), coercivity and autocorrelation length are plotted as a function of microwave frequency for A_{ex}/A_{bulk}= 0 and 0.05. As shown in Fig. 4 (a), coercivity decreases with increasing the microwave frequency, and shows the rather clear critical frequency for both values of A_{ex}/A_{bulk}. The critical frequency becomes lower by the exchange interaction between grains. The cluster size also decreases with increasing the microwave frequency and returns to the value at f_{rf} = 0 GHz above the critical frequency. The two parameters, coercivity and autocorrelation length, show very similar frequency dependence. The results suggest that the

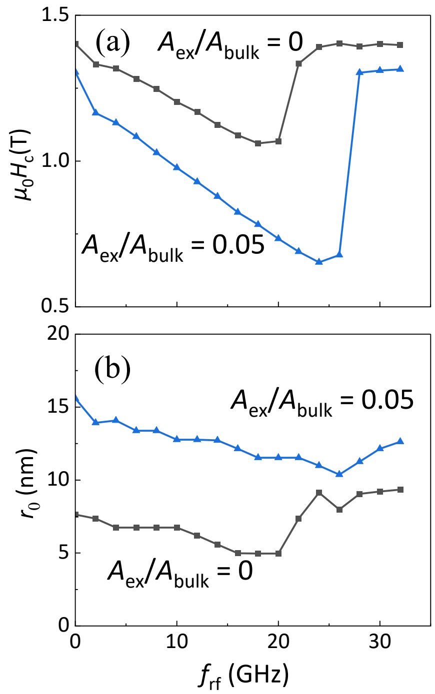

Fig. 4 (a) Coercivity and (b) autocorrelation length r_0 as a function of microwave frequency f_{rf} for A_{ex}/A_{bulk} = 0 and 0.05.

application of microwave field is effective not only for the reduction of switching field, but also for controlling the magnetic cluster size.

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REFERENCES

[1] J.-G. Zhu, X. Zhu, and Y. Tang, IEEE Trans. Magn., Vol. 44, pp. 125-131, 2008.

[2] G. Bertotti, I. D. Mayergoyz, C. Serpico, M. D'Aquino, and R. Bonin, J. Appl. Phys., Vol. 105, pp. 1-5, 2009.

[3] S. Okamoto, M. Igarashi, N. Kikuchi, and O. Kitakami, J. Appl. Phys., Vol. 107, p. 123914, 2010.

[4] S. Okamoto, N. Kikuchi, M. Furuta, O. Kitakami, and T. Shimatsu, Phys. Rev. Lett. Vol. 109, p. 237209, 2012

[5] H. Suto, T. Kanao, T. Nagasawa, K. Mizushima, and R. Sato, Sci. Rep. Vol. 7, p. 13804, 2017

[6] N. Kikuchi, K. Sato, S. Kikuchi, S. Okamoto, T. Shimatsu, O. Kitakami, H. Osawa, and M. Suzuki, J. Appl. Phys. Vol. 126, 083908, 2019.

[7] N. Kikuchi, K. Sato, S. Okamoto, O. Kitakami, T. Shimatsu, and H. Suto, Phys. Rev. B, Vol. 105, p. 054430, 2022.

[8] H. Suto, K. Kudo, T. Nagasawa, T. Kanao, K. Mizushima, R. Sato, S. Okamoto, N. Kikuchi, and O. Kitakami, Phys. Rev. B, vol. 91, p. 094401, 2015.

[9] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez B. Van Waeyenberge, AIP advances, Vol. 4, p. 107133, 2014