Coercivity change after grain boundary diffusion treatment of Nd-Fe-B sintered magnet using DyF_3mixed with low melting elements Cu and Al

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1. Introduction

Grain boundary diffusion treatment has been a method to save heavy rare-earth (HRE) elements in a NdFeB sintered magnet, where HRE atoms are allowed to diffuse in the magnet through grain boundary [1, 2]{Hirota, 2006 #7}.However, optimization of such diffusion treatment to maximize the improving effect on magnetic properties is still a challenge. Among many candidates for the diffusion treatment, Cu and Al could be beneficial for the diffusion of HRE atoms by improving wettability of Nd-rich grain boundary phase. The solubility of Cu to $Nd_2Fe_{14}B$ is almost negligible, whereas Al has small solubility to the $Nd_2Fe_{14}B$ phase [3, 4]. In this study, we investigated the effect of Cu and Al on the diffusion behavior of Dy in grain boundary by using a mixture of Cu or Al with $DyF_3$for the grain boundary diffusion treatment and corresponding effect in magnetic and microstructural properties.

2. Material and Experiment

Powders of 32.0Nd-Bal.Fe-1.0B-2.4M (wt. %, M= Cu, Al, Co and Nb) having average particle size of 5 μm wereused. The magnet samples were prepared through the powder metallurgical root and sintered at 1060 ºC for 4 hours. The sintered bulk magnet samples were cut into pieces of 10 mm × 10 mm × 5 mm size and polished to remove the oxidized surface layer. Further, the polished samples were dipped in the solution prepared from the powders of DyF_3, Cu or Al, and absolute ethanol. Three kinds of solutions; Cu + DyF_3, Al + DyF_3 and DyF_3 were prepared as the Dy supplier for diffusion treatment. Ultrasonic vibration was provided to make uniform coating layer of Dy-source on the magnet surface. Then the coated magnet samples were annealed in two stages; first stage annealing was performed at temperature of X ºC (where, X = 790, 820, 850, 880, and 910 ºC) and second stage at 500 ºC for 2 hours each in vacuum (~ 10^{-5}Torr). Magnetic properties of the magnet samples were measured using a BH-hysteresis loop tracer. Microstructural investigation was carried out using SEM and EPMA.

3. Results and Discussion

The Dy-source prepared by mixing of DyF_3 with Cu or Al was found to be effective to some extent for the coercivity enhancement. These elements may act as the carrier of Dy atoms so that large number of Dy atoms diffused into the magnet interior from Dy-source coated at a magnet surface. Fig. 1 shows the variation of coercivity of magnets coated with three kinds of Dy-sources; Cu + DyF_3, Al + DyF_3, and only $DyF_3$with respect to heat treatment temperatures. The coercivity of all diffusion-treated magnets was increased with increasing heat-treatment temperature except for the one coated with Cu + $DyF_3$and then heat treated at 910ºC. Moreover, at 880ºC, the coercivity of those magnets which were coated with Cu or Al mixed DyF_3 was increased by 2.5 kOe. Cu and Al had almost similar effect on coercivity improvement particularly in the temperature range of 790ºC to 880ºC. The diffusivity and diffusion depth of Dy was increased in those magnets which were treated with the Dy-source prepared by mixing of Cu or Al with $DyF_{3,}$ mainly due to comparatively easy diffusion path provided by Cu and Albecause of their solubility toNd-rich grain boundary phase. The Cu/Al-rich grain boundary phase might have enhanced the diffusivity of Dy-atoms. Moreover, it seems that relatively a large number of Dy atoms were reached at the interface of $Nd_2Fe_{14}B$ and grain boundary phases covering $Nd_2Fe_{14}B$ grains so that the core-shell type structures were developed. The formation of high anisotropic $(Nd, Dy)_2Fe_{14}B$ phase layer, which acted as the shell in the core-shell type structure, was the cause of enhancing the coercivity of diffusion treated Nd-Fe-B magnets.

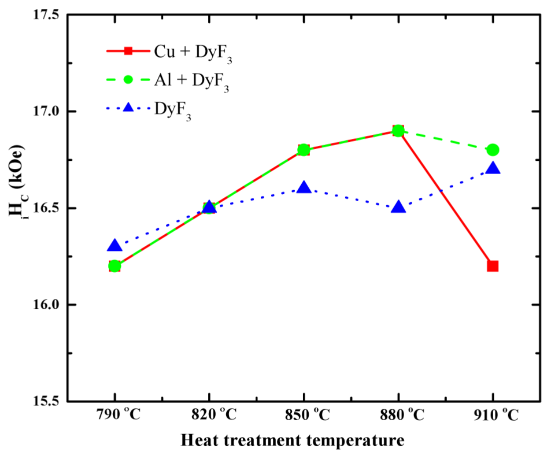

Fig.1. Coercivityof NdFeB magnets treated with three different Dy-source solutions at various heat treatment temperatures.

4. Conclusion

The coercivity of diffusion processed magnet could be enhanced with the aid of low temperature melting elements such as Cu and Al after being mixed with Dy-source. These elements particularly enhance the diffusion depth and diffusivity that are realized as the important aspects of grain boundary diffusion treatment for increasing anisotropy and so as to improve the coercivity.

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6. References

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