Development of Nd reduced high coercivity magnet and expectation for future research

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1.Background

Recently, vehicle electrification expands rapidly. It is well known that electrified vehicle has additional component compare to conventional gasoline vehicle, i.e. battery, inverter and electric motor. At this moment, supply and demand seems to be acceptable for all additional electric component. However, most of future forecast says that amount of electrified vehicle become two to five times larger than current vehicle sales. This means that we need number of electrified unit, at least, more than two times compare to current demand. For example, IEA scenario described in Energy Technology Perspective 2017 forecasts electrified vehicle increase from 14 million in 2020 to 40 million in 2030 [1]. When we look at even only around vehicle technological shift, it is easy to forecast enormous number of rare-earth magnet will be needed. From this circumstance, we research coerciviy mechanism of rare-earth magnet and consider what we can do for balancing global supply and demand of rare-earth materials. In these ten years, we discovered molten Nd based alloy with low melting point infiltrate spontaneously into bulk magnet and enhance coercivity in 2010[2,3]. Using established technique, we vary coercivity by varying nano-structure of magnet samples for understanding coercivity mechanism. From our research activity, we successfully fabricate relatively high coercivity magnet than expected from rare-earth composition, at that moment we focused on Nd-Ce, in 2013[4,5]. Then we move to investigate intrinsic properties to understand role of rare-earth element for magnetization and curie temperature. All attempts that we made for understanding coercivity mechanism [6,7,8] inspire ideas for development of Nd reduced high coercivity magnet to us.

2.How to realize high coercivity with reduced Nd amount

In order to reduce Nd from NdFeB magnet, we focused on light rare earth (here after LRE) Lanthanum and Cerium. It is well known that adding substituting from Nd to LRE, both magnetization and anisotropy are weakened and performance get worse. Therefore, we noticed mechanism of magnetic properties and combining three techniques, two for nano-structural control and one for alloying technique, for exhibiting high performance even using LRE element [9]. For enhancing coercivity, we control nano-sturcuture of magnet, grain refinement, include magnetic insulation between main phase grains, and Core/Shell structure of grains. When we noticed coercivity model, i.e. Kronmuller's micro-magnetics model, $Hc = \alpha H_a - N_{eff} M_s$. One can easily understand increasing α parameter and/or decreasing N_{eff} work for enhancing coercivity. In this development, we employ grain refinement and magnetic insulation for improving N_{eff}, smaller is better in this case. Furthermore, we put magnetically harder shell, Nd enriched $RE_2Fe_{14}B$ phase, for each grain.to enhance α value. From TEM/EDX observation, one can easily found that Nd enriched region located at surface of each grains and poor in inside grain. This nano-structural control is same as former work reported Ito et al [5]. For improving magnetization, we adopt compositional design for magnet. We start with Nd-Ce alloyed $RE_2Fe_{14}B$ phase, it is well known that magnetization decrease with alloying Ce to $RE_2Fe_{14}B$ phase. In order to slowing deterioration of magnetization by Ce, we focused on La as co-alloying element. Co-alloying La to Nd-Ce seems to have good effect to magnetization relative amount of LRE element of $RE_2Fe_{14}B$ phase.

3. Performance of magnet and discussion

Temperature dependence of coercivity of Nd reduced high coercivity magnet are shown in Fig.1. Comparing NdFeB and Ce alloyed and Ce-La co-alloyed magnet, temperature dependence of coercivity, LRE alloyed magnets, Ce alloyed and Ce-La co-alloyed magnet, are better than NdFeB magnet especially in temperature range around 373K. From Fig.1, Nd infiltrated samples show higher coercivity, therefore it seems that Nd enriched shell harden grain surface magnetically and enhance coercivity. In Fig.2, Temperature dependences of normalized magnetization of various sample with different composition are shown. Magnetizations are normalized by room temperature value and several Nd reduced composition samples are plotted. When we look at temperature dependence of magnetization, $Ce_2Fe_{14}B$ has worst temperature dependence. When we add La to $Ce_2Fe_{14}B$, temperature dependence, or curie temperature, drastically improved, even though La destabilize $RE_2Fe_{14}B$ phase. This behavior is same as Nd alloying to $Ce_2Fe_{14}B$. Finally, we co-alloy Ce and La to $Nd_2Fe_{14}B$, temperature dependence of magnetization seems to have peak in certain ratio of Ce and La, or La improve magnetization in elevated temperature. From our experimental results, temperature dependence of both coercivity and magnetization seems to be affected by LRE alloying.

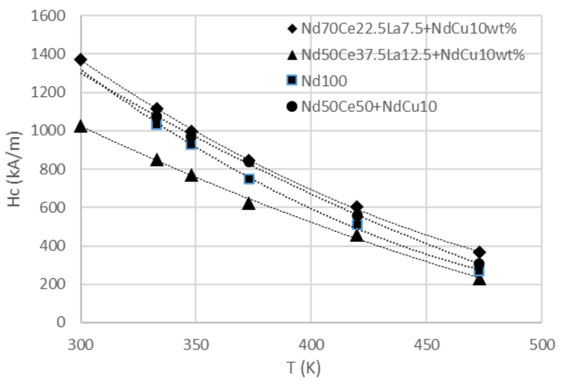

Fig.1 Temperature dependence of various magnet coercivity. Sample name correspond to RE composition. Sample with NdCu infiltration. Infiltration condition is 853K 165min.

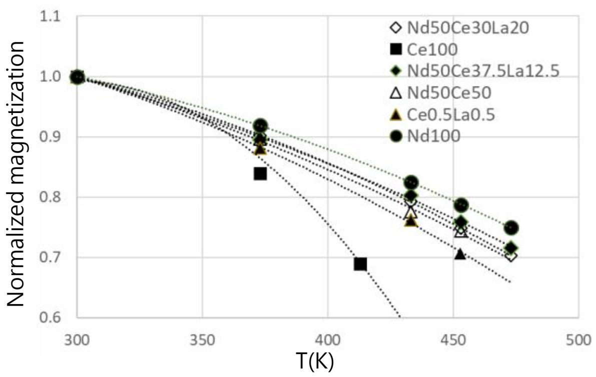

Fig.2 Temperature dependence of normalized magnetization. Sample name correspond to RE composition

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Reference

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