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論 文 の 内 容 の 要 旨

Nd-Fe-B sintered magnets exhibit the highest maximum energy products (50MGOe) among various permanent magnets.. However, the coercivity of the sintered magnets (~12 kOe) is only 15% of the anisotropy field (~ 75 kOe), which is too low for certain applications like traction motors for hybrid and electric vehicles. The current Nd-Fe-B high coercivity sintered magnets for traction motor applications contain approximately 40% of Dy with respect to the entire rare earth elements to increase the coercivity to the level of 30 kOe. However, due to the increasing cost and depleting natural resources of Dy, finding a way to enhance the coercivity of Nd-Fe-B magnets without Dy is needed. Since the coercivity of Nd-Fe-B magnets is strongly related to the structure and chemistry of grain boundaries in sintered magnets, a comprehensive multi-scale structural characterization is required to understand the coercivity enhancement mechanism. Such a microstructure- coercivity correlation studies will immensely contribute to the development of high coercivity Dy free Nd-Fe-B magnets. The main aim of this thesis was to understand the coercivity mechanism of Nd-Fe-B magnets to develop high coercivity Dy free Nd-Fe-B magnets by characterize micro/nano structures of various commercial and experimental Nd-Fe-B permanent magnets using high resolution scanning electron microscopy (HRSEM), high resolution transmission electron microscopy (HRTEM), and three-dimensional atom probe (3DAP). This thesis comprises of 8 chapters. Chapter 1 explain the motivation of this work. In chapter 2, the details of the experimental methods employed in this work are briefly explained. Chapter 3 reports detailed characterization results of the microstructure of as-sintered and optimally heat treated commercial sintered magnets and discuss the mechanism of the coercivity enhancement by the post-sinter annealing. In Chapter 4, the mechanism of the coercivity enhancement in Dy diffusion processed magnets are discussed based on detailed characterization results of the microstructures. Chapter 5 reports microstructure of hydrogenation- disproportionation- desorption-recombination (HDDR) processed Nd-Fe-B magnetic powder and the reason for the low coercivity for the ultrafine grain size is discussed. Based on the results in chapter 5, we developed a method to enhance the coercivity of HDDR processed

powders using the grain boundary diffusion of Nd-Cu alloys, which were reported in chapter 6. The microstructure of HDDR processed powders were studied during HDDR process in different stages to understand the development of the anisotropy mechanism which is described in chapter 7. In chapter 8, the work carried out in the thesis is reviewed and general conclusions are drawn.

審 査 の 結 果 の 要 旨

本論文はNd-Fe-B焼結磁石ならびにHDDR磁石粉の微細組織と保磁力を評価した研究結果をまとめた学術研究であり、下記の3点から高く評価される。(1) さまざまなプロセスにより製造されたNd-Fe-B磁石の微細構造をSEM, TEM, 3DAPによりマルチスケールで解析し、微細構造、特に結晶粒界組成と保磁力の因果関係を明らかにした。(2) これらの解析研究はNd-Fe-B系磁石の最も包括的な微細構造解析であり、磁石研究に極めて有用な知見を与えた。(3) 本研究で確立された微細構造と保磁力の因果関係から、Dyを用いずにNd-Fe-B磁石の保磁力を高める方法を提案し、Dyを含まないNd-Fe-B系で最高の保磁力を達成した。以上のことから、極めて工学的価値の高い論文と判断される。

よって、著者は博士（工学）の学位を受けるに十分な資格を有するものと認める。