# 論文 / 著書情報
# Article / Book Information

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| 題目(和文) | Nd、Pr、DyおよびTb削減のためのNd-Fe-B焼結磁石における粒界相の微細構造設計 |
| Title(English) | Microstructural design of grain boundary phases in Nd-Fe-B sintered magnets for Nd, Pr, Dy and Tb reduction |
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# 論 文 要 旨

THESIS SUMMARY

| 系・コース：<br>Department of, Graduate major in | 材料<br>ﾗｲﾌｴﾝｼﾞﾆｱﾘﾝｸﾞ | 系<br>コース | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of | （ 工学 ） |
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| 学生氏名：<br>Student's Name | 榎戸 靖 | | 指導教員（主）：<br>Academic Supervisor(main) | 北本 仁孝 | |
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


This thesis, titled "Microstructural design of grain boundary phases in Nd-Fe-B sintered magnets for Nd, Pr, Dy and Tb reduction" is written in English and consists of 5 chapters.

Chapter 1 "General introduction" summarizes the background to the birth of Nd-Fe-B magnets, the expression principles of their magnetic properties, market requirements, and the social background surrounding rare earth elements. The purpose and significance of this research are described by extracting related technical problems and proposing original solution methods to solve them.

Chapter 2 "Microstructural design of Ga-added grain boundary phase for Dy and Tb reduction" describes Ga added magnets for the purpose of improving the coercivity of both Dy- and Tb-free Nd-Fe-B sintered magnets by microstructural design of grain boundary phase. It is shown that the $Nd_6Fe_{13}Ga$ phase was formed as a grain boundary phase by Ga addition together with the known R-rich phase. The magnetization of this phase is as low as 0.05 T, as estimated by holography and STEM-Lorentz techniques. The formation mechanism of this phase was investigated by high temperature in situ XRD measurements using high intensity synchrotron radiation at SPring-8, indicating that it was formed during annealing procedure. In addition, the influence of the formation of the $Nd_6Fe_{13}Ga$ phase on the R-rich phase was investigated, and the mechanism in which these two grain boundary phases improve the coercivity was clarified. The coercivity of 1998 kA/m was successfully obtained in the Nd-FeB sintered magnet without Dy and Tb.

Chapter 3 "Microstructural design of Ce-added grain boundary phase for Nd and Pr reduction" describes Ce added magnets for the purpose of improving the coercivity of Nd-Fe-B sintered magnets with reduced Nd and Pr by half through microstructural design of grain boundary phase. For the purpose of searching for rare earth elements which can substitute for Nd and Pr, a high-throughput thin film magnet composition search method based on the concept of combinatorial chemistry was developed, and a magnetic characteristic measurement method in a micro region was developed. Based on the results of the composition search, Nd-Fe-B sintered magnets in which Nd and Pr are replaced with Ce and Y were prepared and the microstructure of their grain boundary phases were analyzed. In addition to the R-rich phase, the introduction of the $R_6Fe_{13}Ga$ phase was attempted, and the magnetization and microstructure of the Ce-added $R_6Fe_{13}Ga$ and $RFe_2$ phases were investigated in detail. As a result, the coercivity of 1063 kA/m was successfully obtained in the Nd-Fe-B sintered magnet in which Nd and Pr were reduced by half.

Chapter 4 " Grain boundary protection in near-net shaping" discusses the introduction of granulation processes for the purpose of near-net-shaping of Nd-Fe-B sintered magnets without compromising the grain boundary phase and reducing Nd, Pr, Dy and Tb waste. In order to prevent oxidation and carbonization of the grain boundary phases, a new liquid-bound granulation method was developed, which utilizes the liquid cross-linking ability of a high vapor pressure liquid. The granulation process consisted of mixing two liquids and vacuum drying. A small amount of terpineol was added to the granules to successfully protect the grain boundary phases. Sintered magnets with both high coercivity and residual flux density was successfully fabricated and verified in the mass production process. As a result, a coercivity and a residual flux density of 99.3% were realized compared with the case where near-net shaping is not performed. In the arc shaped magnet used for the surface permanent magnet motor, the waste of Nd, Pr, Dy and Tb was successfully reduced by 34 to 68%.

Chapter 5 "General conclusions" describes the conclusions of this thesis along with the findings from this study.

In short, this study attempts to reduce the usage of Nd, Pr, Dy, and Tb as a result of achieving an intrinsic magnetic property in Nd-Fe-B sintered magnets in an extrinsic manner based on the microstructural design of the grain boundary phases. The relationship between the magnetic properties such as magnetization and coercivity and the microstructure of the grain boundary phases is clarified, and thereby the coercivity is improved. As a result, the microstructural design of the grain boundary phases proposed in this thesis reduced the amount of Nd, Pr, Dy, and Tb used for Nd-Fe-B sintered magnets.