Heat treatment of metastable $Nd_2Fe_{17}B_x$ phase formed from undercooled melt of Nd–Fe–B alloys

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Alloys of $Nd_{10}Fe_{85}B_5$, $Nd_{12}Fe_{82}B_6$, and $Nd_{14}Fe_{79}B_7$ were melted and then solidified without a container using a drop tube. In the as-dropped sample, a large amount of the metastable $Nd_2Fe_{17}B_x$ phase was contained. Particularly in relatively large samples, the metastable phase, which was partially decomposed into the $Nd_2Fe_{14}B$ and α-Fe phases, shows a microstructure similar to that of normalized low-carbon steel. The heat treatment of the as-dropped samples induces a dual-stage phase transformation. The first stage of the phase transformation, which is dominant in the $Nd_{14}Fe_{79}B_7$ alloy, is the diffusive phase transformation from $Nd_2Fe_{17}B_x$ and Nd-rich phases into the $Nd_2Fe_{14}B$ phase at 950 K, and the second stage of the transformation, which is dominant in the $Nd_{10}Fe_{85}B_5$ alloy, is the decomposition of the metastable phase into the $Nd_2Fe_{14}B$ and α-Fe phases at 1100 K. Although the rate of the phase transformation in either stage is controlled by the diffusion of Nd atoms, the diffusivity at the first stage of the phase transformation, being large due to the existence of the Nd-rich phase adjacent to the $Nd_2Fe_{17}B_x$ phase, results in a decrease of the transformation temperature. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2386943]

I. INTRODUCTION

Neodymium-iron-boron (Nd–Fe–B) magnets with excellent magnetic properties have been widely used in various applications such as computer devices and acoustic equipment since their discovery in 1983.[1,2] The superiority of the magnets originates from the $Nd_2Fe_{14}B$ intermetallic compound, which has a large saturation magnetization and a high magnetocrystalline anisotropy field.[3,4]

As shown in the Nd–Fe–B quasibinary phase diagram sectioned along the tie-line from Fe to Nd_2B (Fig. 1), the ferromagnetic $Nd_2Fe_{14}B$ phase is formed *via* the peritectic reaction between the properitectic γ-Fe phase and the residual liquid if the alloy composition is close to that of stoichiometric $Nd_2Fe_{14}B$.[5] In the casting alloy, therefore, the α-Fe phase, which was transformed from γ-Fe, inevitably remains as a soft magnetic phase, deteriorating the hard magnetic properties of magnets.[6]

In order to suppress the peritectic reaction, two approaches have been used; one is the rapid cooling of the melt with the rate higher than that of the nucleation of the properitectic phase, and the other is undercooling the melt deeply below the peritectic temperature. Melt spinning and gas atomizing that have achieved the $Nd_2Fe_{14}B$ microstructure free from γ-Fe are the typical example of the former case.[2,7] Containerless processing, on the other hand, such as electromagnetic levitation and free falling in a drop tube, is that of the latter case.[8–16] Comparing these two cases, the containerless processing seems to have an advantage at the point that bulk samples can be produced. In fact, after the work on the electromagnetic levitation of $Nd_2Fe_{14}B$ done by Hermann and Loeser in 1998, several investigations[8–12] have suggested that the bulk phase of $Nd_2Fe_{14}B$ is directly crystallized from the undercooled melt. Gao *et al.*, however, reported that in $Nd_xFe_{100-1.5x}B_{0.5x}$ ($x=14-22$) alloys the metastable $Nd_2Fe_{17}B_x$ ($x\sim1$) phase is formed as the primary

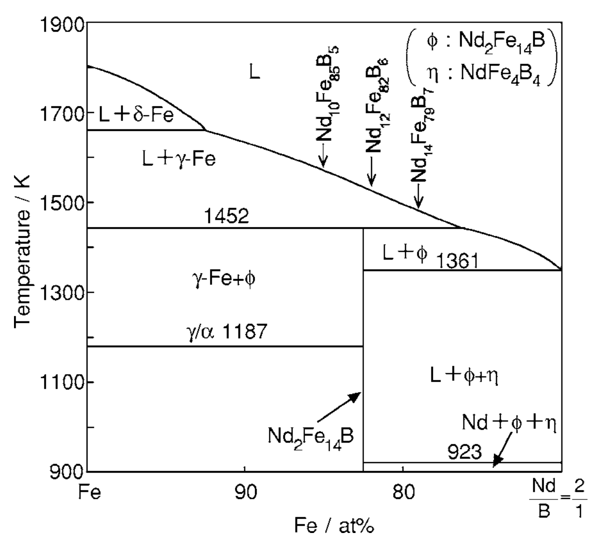

FIG. 1. Nd–Fe–B quasibinary phase diagram sectioned along the tie-line from Fe to Nd_2B. Samples used in this study are indicated by arrows.

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