Hard magnetic behaviour and interparticle interaction in the $Sm_3(Fe,Ti)_{29}N_y$ nitride

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LETTER TO THE EDITOR

Hard magnetic behaviour and interparticle interaction in the $Sm_3(Fe, Ti)_{29}N_y$ nitride

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Abstract. The coercivity of the $Sm_3(Fe, Ti)_{29}N_y$ nitride is controlled by the nucleation mechanism. The phenomenon of a minimum of the coercivity in the angular dependence of the coercivity is found for the $Sm_3(Fe, Ti)_{29}N_y$ nitride. The small magnetizing field required to obtain the saturation coercivity and the small interparticle interaction for the isotropic $Sm_3(Fe, Ti)_{29}N_y$ magnet imply that grains of $Sm_3(Fe, Ti)_{29}N_y$ are well isolated.

Recently a new ternary phase $Nd_2(Fe, Ti)_{19}$ was discovered by Collocott *et al* [1] and a similar phase was also indicated in $R_2(Fe_{0.91}V_{0.09})_{17}$ ($R = Y, Nd, Sm, Gd$) by Shcherbakova *et al* [2, 3]. The crystalline structure of this new phase has been found to be a $Nd_3(Fe, Ti)_{29}$-type structure with monoclinic symmetry (space group $P2_{1/c}$) by Li *et al* [4]. The $Sm_3(Fe, Ti)_{29}N_y$ nitride was first discovered by Yang *et al* [5, 6] with a Curie temperature $T_C = 750$ K, saturation magnetization $M_s = 140$ A m^2 kg^{-1}, anisotropy field $H_a = 12.8$ T and coercivity $H_c = 0.3$ T at room temperature. A large coercivity of 0.8 T for $Sm_3(Fe, Ti)_{29}$ nitride was recently successfully developed by Hu *et al* [7]. In this letter, experimental results of the magnetizing field dependence of the coercivity and remanence and the angular dependence of the coercivity, as well as the interparticle interaction in $Sm_3(Fe, Ti)_{29}N_y$ nitride, are reported.

Figure 1 shows the magnetizing field dependence of the coercivity and remanence for isotropic $Sm_3(Fe, Ti)_{29}N_y$ nitride. H_c^{sat} and B_r^{sat} represent the saturation values of the coercivity and remanence after applying the magnetizing field, respectively. It is evident that the magnetizing field dependence of $H_c(H)/H_c^{sat}$ and $B_r(H)/B_r^{sat}$ are very similar. With increasing magnetizing field, $B_r(H)/B_r^{sat}$ increases and, accordingly, more grains change their multidomain state for the saturation state. Thus the number of positions that favour nucleation decreases, which results in a rise of $H_c(H)/H_c^{sat}$ with increasing magnetizing field. The disappearance of the sharp step in the $H_c(H)/H_c$–H curve indicates that the coercivity of $Sm_3(Fe, Ti)_{29}$ nitride is controlled by the nucleation mechanism. It can be also seen from figure 1 that the magnetizinig fields required to obtain the saturation coercivity and remanence are about 1.5 T, much smaller than the anisotropy field of 12.5 T. Such a result is different from the case in NdFeB ribbons [8], where the magnetizing field for obtaining the saturation coercivity is relatively large, up to 3–5 T. It has been demonstrated that the

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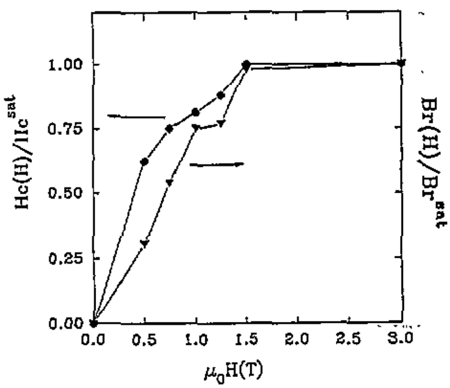

Figure 1. The magnetizing field dependence of the coercivity and remanence for isotropic $Sm_3(Fe,Ti)_{29}N_y$ nitride.

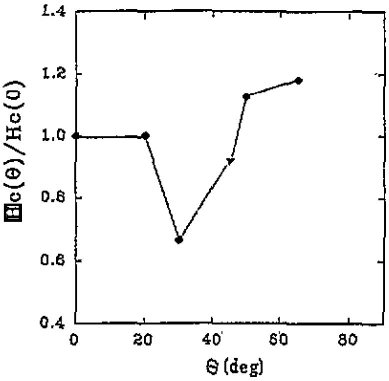

Figure 2. The experimental angular dependence of the coercivity for the $Sm_3(Fe,Ti)_{29}N_y$ nitride (●). The value of the coercivity for isotropic $Sm_3(Fe,Ti)_{29}N_y$ nitride is also plotted at 45° (▼).

magnetizing field dependence of the coercivity is related to the magnetic field required to overcome the critical fields of the individual grains [8]. The critical field required to obtain the saturation coercivity in the $Sm_3(Fe,Ti)_{29}N_y$ nitride is only about 1.5 T, which implies the existence of smaller stray fields around the grains of nitride.

The experimental angular dependence of the coercivity for $Sm_3(Fe,Ti)_{29}N_y$ is shown in figure 2. It is obvious that with increasing angle between the alignment direction and the direction of the external field, the ratio of coercivities $H_c(\theta)/H_c(0)$ maintains the value 1.0 in the range $0 < \theta < 20°$, and then decreases to 0.67 at $\theta = 30°$. At $\theta = 50$ and 65°, this ratio increases up to 1.12 and 1.18, respectively. The ratio of coercivities $H_c(\theta)/H_c(0)$ for the $Sm_3(Fe,Ti)_{29}N_y$ nitride is about 0.92. The minimum of coercivity may occur in the range $30° < \theta < 50°$, which agrees with the theoretical prediction [9, 10]. As we know, another kind of permanent magnet with a minimum of coercivity in the angular dependence of the coercivity is the PrFeB magnet, where the grains of PrFeB are well isolated from each other by another phase surrounding the $Pr_2Fe_{14}B$ grains [11]. For NdFeB [9, 12], $Sm_2Fe_{17}N_x$ [13] and $Nd(Fe,Mo)_{12}N_x$ [14] magnets, however, the coercivity increases with increasing angle between the alignment direction and the direction of external field and no minimum-coercivity phenomenon has been found. The different angular dependences of the coercivity may reflect the different behaviours of the grain surfaces and stray field or interparticle interaction between two kinds of magnet.

In the absence of interparticle interaction, the Wohlfarth relationship holds [15]:

$$B_d(H) = B_r(\infty) - 2B_r(H)$$

where $B_r(H)$ is the remanence after application and removal of a field H to an initially unmagnetized magnet. $B_d(H)$ is the remanence after demagnetizing a fully magnetized magnet. Henkel plotted $B_d(H)$ versus $B_r(H)$, which should give a linear relationship, and attributed any deviations from linearity to the effect of interparticle interaction [16]. Such deviation from linearity can be estimated by the relation [17]

$$\delta m = B_d(H)/B_r(\infty) + 2B_r(H)/B_r(\infty) - 1.$$

Figures 3 and 4 show the Henkel plot and δm plot for isotropic $Sm_3(Fe,Ti)_{29}$ nitride, respectively. The results indicate that the interparticle interaction in this nitride is very small, which implies that the grains of $Sm_3(Fe,Ti)_{29}N_y$ may be well isolated.

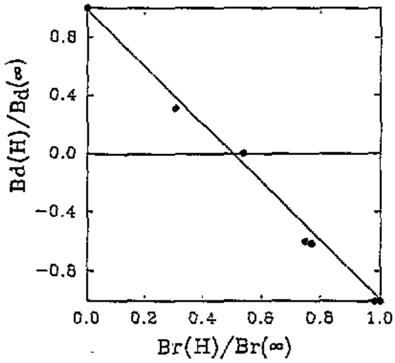

Figure 3. The Henkel plot for the $Sm_3(Fe,Ti)_{29}N_y$ nitride.

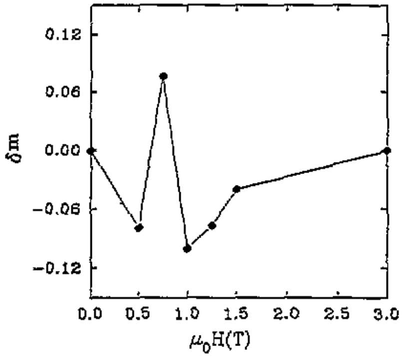

Figure 4. The δm plot for the $Sm_3(Fe,Ti)_{29}N_y$ nitride.

In conclusion, the coercivity of the $Sm_3(Fe,Ti)_{29}N_y$ nitride is controlled by the nucleation model. The phenomenon of a minimum of the coercivity in the angular dependence of the coercivity is found for the $Sm_3(Fe,Ti)_{29}N_y$ nitride. The small magnetizing field required to obtain the saturation coercivity and the small interparticle interactions for the isotropic $Sm_3(Fe,Ti)_{29}N_y$ magnet imply that grains of $Sm_3(Fe,Ti)_{29}N_y$ are well isolated.

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