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High-field magnetization process of Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ compounds

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Abstract

The high-field magnetization process of Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ compounds ($x = 0$–$0.5$) has been investigated. Substitution of Ga for Fe leads to an increase of the spin reorientation temperature. A tentative spin phase diagram is proposed. The magnetization of magnetically aligned samples was measured at 4.2 K in quasi-static fields up to 21 T.

Since the discovery of the intermetallic compound Sm$_2$Fe$_{17}$N$_4$, produced by gas–solid reaction [1], a large improvement of intrinsic properties has been achieved by the introduction of interstitial nitrogen or carbon atoms into R$_2$Fe$_{17}$ compounds. Besides this, substitution of many elements such as Nb and Al for Fe in R$_2$Fe$_{17}$ compounds [2,3] also have significant influence on the magnetic properties. In the present investigation, we have focussed our attention on the crystal structure and magnetic properties of the Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ series, especially on the magnetization and magnetocrystalline anisotropy.

Alloys with composition Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ ($x = 0.0, 0.07, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4$ and $0.5$) were prepared by arc melting, followed by annealing in argon atmosphere at 1200°C for 4 h.

X-ray diffraction patterns of randomly and magnetically aligned powder samples have been obtained.

The high-field magnetization was measured in fields up to 21 at 4.2 K at the University of Amsterdam [4]. The magnetic isotherms were recorded with the external field applied either parallel or perpendicular to the alignment direction of cylindrical samples.

The spin reorientation transition temperatures were measured in a SQUID magnetometer from 4.2 K to room temperature and in a magnetic balance from room temperature up to the Curie temperature.

The X-ray diffraction patterns show that all prepared samples are single phase with a Th$_2$Zn$_{17}$-type of structure, except for a small amount of impurity in a few samples.

The X-ray diffraction patterns of aligned samples of the Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ compounds (Fig. 1) show that the samples with $x = 0.15, 0.20,$ and $0.25$ exhibit uniaxial anisotropy at room temperature. For $x = 0.1$ and $0.3$, the samples are isotropic. For $x = 0.4$, cone-type anisotropy appears. This result is consistent with the spin phase diagram in Fig. 2. From Fig. 2 one can see that up to $x = 0.2$ substitution of Ga for Fe in Sm$_2$Fe$_{17}$ compounds enhances the spin reorientation temperature. At $x = 0.2$, the spin reorientation temperature has a maximum value of

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about 475 K. In Sm$_2$Fe$_{17}$ compounds, the anisotropy is
determined by the competition between the c-axis
anisotropy of the Sm sublattice and the planar anisotropy
of Fe sublattice. Ga substitution for Fe at a sufficient
content reduces the planar anisotropy of Fe sublattice.

The Curie temperature $T_c$ of the Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$
compounds, also shown in Fig. 2, increases with Ga
concentration up to $x = 0.2$, where $T_c$ has a maximum at
592 K, then $T_c$ decreases. It is interesting to note that both
$T_c$ and $T_{sr}$ have their maximum at $x = 0.2$. In Fig. 3, the
high-field magnetization of the Sm$_2$(Fe$_{1-x}$Ga$_x$)$_{17}$ com-
 pounds is shown. For $x = 0.1$ and 0.3, the two magnetiza-
tion curves measured with the field parallel and perpendic-
ular to the alignment direction coincide, which indicates
that the anisotropy has disappeared. This is in good agree-
ment with the results of the X-ray diffraction on aligned
samples mentioned above. Values for the saturation mag-
etization were derived from the easy-direction magnetiza-
tion by means of $\alpha-1/B$ plots. The saturation magnetiza-
tion decreases linearly with Ga concentration, from 155.2
A m$^2$/kg for $x = 0.0$ to 59.2 A m$^2$/kg for $x = 0.5$, which
is easy to understand because the Ga atoms have no
magnetic moment. From the magnetization curves in Fig. 3
it can be seen that Sm$_2$(Fe$_{0.5}$Ga$_{0.5}$)$_{17}$ has the largest
anisotropy field $B_a$, amounting to 21 T. The Curie tem-
perature and spin reorientation temperature have maximum
values of 592 and 475 K, respectively, for 20% of the Fe
substituted by Ga. These results suggest that these com-
pounds may be used for practical application as starting
material for permanent magnets.

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