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Magnetic properties of $Sm_3(Fe, Mo)_{29}N_X$ interstitial nitride

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Abstract

$Sm_3(Fe, Mo)_{29}N_X$ nitride has been synthesized at 823 K for 2.5 h by gas phase reaction under 1 atm of nitrogen. The nitride retains the structure of parent compound. The unit cell volume of the nitride is 4.7% greater than that of the parent compound. Introduction of nitrogen leads to an increase of Curie temperature T_C from 445 K for the parent to 704 K for the nitride, and an increase of saturation magnetization M_s from 135 A m^2/kg for the parent to 152 A m^2/kg for the nitride at 4.2 K, and from 107 A m^2/kg for the parent to 137 A m^2/kg for the nitride at 300 K. The nitride exhibits uniaxial anisotropy with an anisotropy field B_a of 20.5 T at 4.2 K and 14.6 T at 300 K.

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Keywords: Rare-earth transition-metal compounds; Saturation magnetization; Curie temperature; Interstitial nitride

1. Introduction

In recent years, much attention has been paid to the iron-rich edge of the R–Fe (R = rare earth) phase diagram in the field of permanent magnet materials. This has led to the discovery of a new type of rare-earth iron intermetallic compound $R_3(Fe, M)_{29}$ (R = Ce, Nd, Sm, Gd, Tb, Dy and Y; M = Ti, V, Mn, Cr, and Mo) [1–10]. Among them, the $Sm_3(Fe, M)_{29}N_X$ nitrides (M = V, Ti and Cr) have excellent magnetic properties with high Curie temperatures, high room saturation magnetization and large anisotropy fields and are potential candidates for permanent magnet applications [8–11]. In the present paper, we report the synthesis of the Mo representative of this series, the $R_3(Fe, Mo)_{29}N_X$ nitride, and study its intrinsic magnetic properties.

2. Experimental details

Ingots of $Sm_3(Fe_{0.966}Mo_{0.034})_{29}$ compound were prepared by argon arc melting using starting elements of at least 99.9% purity, and with an excess amount of Sm element to compensate for its loss during melting. The ingots were melted in a water-cooled copper hearth and remelted at least

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five times for homogenization. The ingots were annealed at 1453 K for 48 h under argon atmosphere, then quenched in water. In order to prepare the nitride, the ingots were pulverized into fine powders with an average size of 10–15 μm, and then the nitrogenation was performed by heating the fine powder in nitrogen at 1 atm at a temperature of 823 K for about 2.5 h. The nitrogen content was determined from the difference between the mass before and after nitrogenation.

X-ray diffraction with Cu K_α radiation was used to identify the phases present in the compounds and to determine the lattice parameters. Thermomagnetic analysis (TMA) was performed in a low field of about 0.04 T in the temperature range from 300 K to above the Curie temperature. The Curie temperatures T_C were determined from σ^2–T plots by extrapolating σ^2 to zero. The magnetization curves were measured by extracting sample magnetometer (ESM) with a superconducting magnet with maximum magnetic field up to 7 T. Saturation magnetizations M_s were derived from M–$1/B$ plots based on the magnetization curves. The anisotropy fields B_a were estimated from the extrapolated intersection point of two magnetization curves measured with the magnetic field applied parallel and perpendicular, respectively, to the alignment direction of the cylinder samples.

3. Results and discussion

The unit cell parameters a, b, c, β and unit cell volume V of $Sm_3(Fe,Mo)_{29}N_X$ nitride are 10.713 Å, 8.666 Å, 9.839 Å, 96.57°, and 907.40 Å^3, respectively, which is 4.7% greater than that of the parent compound and similar to that of $Y_3(Fe,Mo)_{29}N_X$ nitride [12]. The nitrogen content X is about 3.9 which is also similar to that of $Y_3(Fe,Mo)_{29}N_X$ nitride [12].

Fig. 1 shows the thermomagnetic curves of $Sm_3(Fe,Mo)_{29}N_X$ nitride and the parent compound. The Curie temperature of $Sm_3(Fe,Mo)_{29}$ nitride is 704 K according to Fig. 1, which is 58.2% higher than that of the parent compound. It is higher than that of $SmFe_{10.7}Mo_{1.5}N_X$ nitride [13] but lower than that of $Sm_2Fe_{17}N_X$ nitride [14], and similar to that of $Sm_3(Fe,Ti)_{29}N_X$ nitride [11]. The strong increase in Curie temperature T_C upon nitrogenation may partly be explained in terms of lattice expansion of the nitride which leads to an increase in the average nearest-neighbor Fe–Fe exchange interaction. A theoretical analysis shows that the increase in T_C may also be ascribed to the increase in magnetization upon nitrogenation and the decrease in the spin up density of states at the

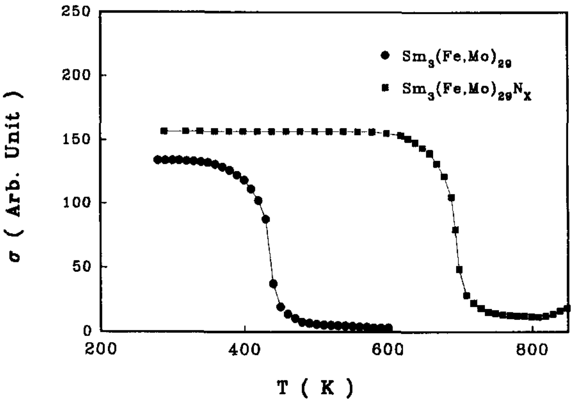

Fig. 1. The magnetization as a function of temperature for $Sm_3(Fe,Mo)_{29}N_X$ nitride compared with that of the parent compound.

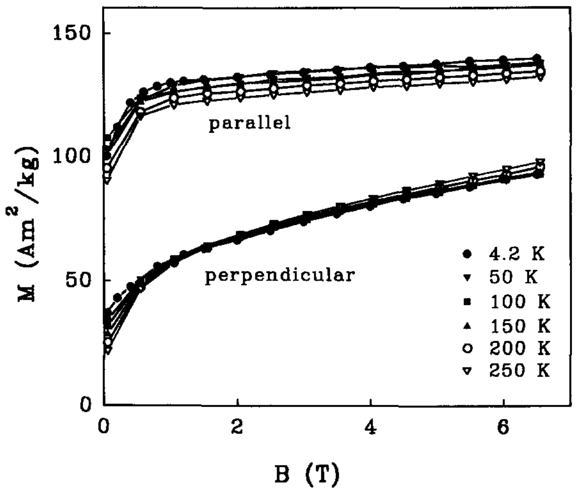

Fig. 2. The magnetization curves for $Sm_3(Fe,Mo)_{29}N_X$ nitride with applied field parallel or perpendicular to the aligned direction of the samples measured at 4.2, 50, 100, 150, 200 and 250 K.

Table 1
The saturation magnetization M_s and anisotropy field B_a of $Sm_3(Fe, Mo)_{29}N_X$ nitride at various temperatures

Compounds	4.2 K	50 K	100 K	150 K	200 K	250 K	300 K
M_s (A m^2/kg)	152.0	150.5	148.00	146.0	144.4	141.8	137.0
B_a (T)	20.5	19.7	18.5	17.3	16.5	15.5	14.6

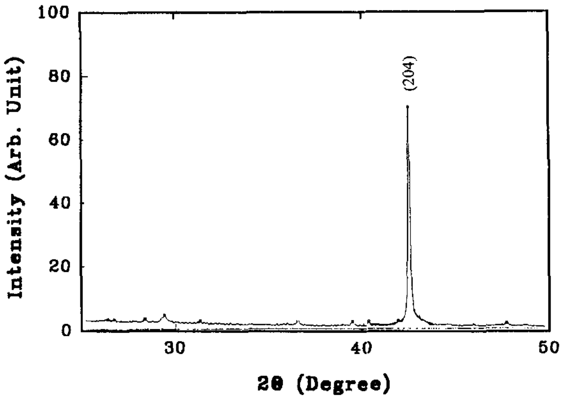

Fig. 3. The X-ray diffraction pattern on a magnetically aligned sample of $Sm_3(Fe, Mo)_{29}N_X$ nitride.

Fermi level E_F associated with narrowing of the 3d band [15].

Fig. 2 shows the magnetization curves for $Sm_3(Fe, Mo)_{29}N_X$ nitride measured at 4.2, 50, 100, 150, 200 and 250 K with the applied field parallel or perpendicular to the aligned direction of the samples. The saturation magnetization M_s of $Sm_3(Fe, Mo)_{29}N_X$ compound derived from the M–$1/B$ plots are listed in Table 1. The saturation magnetization M_s of $Sm_3(Fe, Mo)_{29}N_X$ nitride are 152 Am^2/kg at 4.2 K and 137 A m^2/kg at 300 K which are higher than those of corresponding 1 : 12 nitride [13] but similar to those of the corresponding 2 : 17 nitride [14]. It can be seen from the Table 1 that the saturation magnetization M_s of $Sm_3(Fe, Mo)_{29}N_X$ nitride decreases slowly with increasing temperature.

The X-ray diffraction pattern for a magnetically aligned powder sample is shown in Fig. 3. It can be seen that the easy-magnetization direction of $Sm_3(Fe, Mo)_{29}N_X$ nitride is uniaxial along [1 0 2], which corresponds to the [0 0 1] direction in the related crystal structure of $CaCu_5$. Introduction of nitrogen leads to the occurrence of uniaxial anisotropy in the nitride. The temperature dependence of the anisotropy field B_a is also listed in Table 1. The value of the B_a decreases monotonically with increasing temperature.

4. Conclusions

In conclusion, a new $Sm_3(Fe, Mo)_{29}N_X$ nitride has been successfully prepared by gas-phase reaction under nitrogen at 823 K for 2.5 h. The investigated nitride has the same structure as the parent compound. For the nitride, the Curie temperature T_C is 704 K, the saturation magnetization is 152 A m^2/kg at 4.2 K and 137 A m^2/kg at 300 K, and the anisotropy field B_a is 20.5 T at 4.2 K and 14.6 T at 300 K. The high Curie temperature T_C, large saturation magnetization M_s, and strong uniaxial anisotropy make $Sm_3(Fe, Mo)_{29}N_X$ nitride a good candidate for permanent magnet applications.

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