Structure and magnetic properties of RFe_7Mn_4Ti compounds with R = Y, Tb, Dy, Ho, and Er

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Abstract: The effect of Mn substitution for partial Fe in $RFe_{11}Ti$ on structure and magnetic properties of compounds was researched. RFe_7Mn_4Ti samples (R = Y, Tb, Dy, Ho, Er) were prepared by means of vacuum arc-melting and subsequent vacuum annealing. The structure and magnetic properties of RFe_7Mn_4Ti compounds were investigated by X-ray powder diffraction and magnetic measurements. The following conclusions were obtained: all the RFe_tMn_4Ti compounds crystallize in the $ThMn_{12}$-type structure. The lattice constants and the unit-cell volume changed with the increase of atomic number for R = Y, Tb, Dy, Ho, and Er. The compensation characters appear for the $DyFe_7Mn_4Ti$ and $HoFe_7Mn_4Ti$ compounds, and the compensation temperatures were about 123 K and 90 K, respectively. The Curie temperature, the saturation magnetization, and saturation moment of RFe_7Mn_4Ti compounds were given.

Key words: intermetallic compounds; $ThMn_{12}$-type structure; saturation magnetization; rare earth

Rare earth transition-metal compounds with the $ThMn_{12}$ structure are an important class of magnetic materials. But experiments have confirmed that RFe_{12} (R = rare earth) does not exist. This phase can be stabilized by replacing some of the iron atoms with a small amount of other elements such as Ti, V, Mn, Co, Mo, Nb, Si, Al, etc., and the $RFe_{12-x}M_x$ intermetallic compounds can be obtained. Some of the compounds of the type $R(Fe,Ti)_{12}$ are characterized by fairly high values of the Curie temperature, saturation magnetization, and magnetocrysatlline anisotropy[1-4]. So the iron-rich rare earth transition-metal compounds (R_nT_m) become new potential candidates for permanent magnetic applications, and the study of these compounds is attracting worldwide attention. To understand the influence of these interstitial atoms it is necessary to first understand better the interactions that are presented in the parent compounds.

In this paper, the magnetic properties such as the Curie temperature and the saturation magnetization in RFe_7Mn_4Ti (R = Y, Tb, Dy, Ho, and Er) compounds have been investigated. The Mn element has been chosen because it can show very interesting magnetic behaviors such as a large magnetic moment in some compounds.

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1 Experimental Methods

All the RFe_7Mn_4Ti samples with R = Y, Tb, Dy, Ho, and Er were prepared by arc-melting the piece mix of appropriate amounts of the constituting metals (at least 99.5% purity) in an argon atmosphere with an excess amount of R and Mn elements, to compensate for losses during melting. The compounds were remelted several times to ensure the homogeneity. Subsequently, the samples were wrapped with Mo foil and annealed for 50 h at 1 123 K in evacuated quartz tubes and then quenched into water to avoid a possible phase transition during cooling.

X-ray powder diffraction with Cu Kα radiation was used to check the phases present and to determine their lattice parameters. The thermomagnetic analysis was made on a vibrating sample magnetometer (VSM) at a field of 50 mT in the temperature range of 4.4 to 300 K. The values of the Curie temperature T_C for these RFe_7Mn_4Ti compounds were derived from $M^2 - T$ plots. The magnetization curves of free powders were measured on a VSM from 0 T up to 7 T at 4.4 K. The saturation magnetization data were derived by extrapolating the high field part of $M - \mu_0 H$ curves to zero field.

2 Results and Discussion

Fig.1 shows the X-ray diffraction patterns of RFe_7Mn_4Ti compounds with R = Y, Tb, Dy, Ho, and Er. The lattice constants a, c and the unit-cell volume

V are shown in Tab.1.

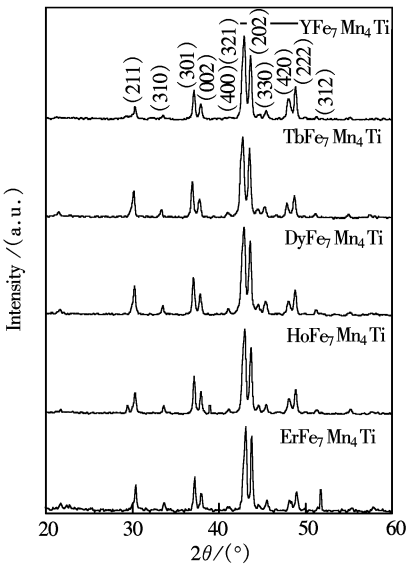

Fig.1 Powder X-ray diffraction with Cu Kα radiation of RFe_7Mn_4Ti compounds at room temperature

Tab.1 Lattice parameters a, c, unit volume V, Curie temperature T_C, saturation magnetization M_s and saturation moment per formula unit μ_s

Compound	a/nm	c/nm	V/nm^3	T_C/K	M_s/(A·m^2·kg^{-1})	μ_s/(μ_B·f.u.$^{-1}$)
YFe_7Mn_4Ti	0.847 1	0.475 9	0.341 5	70	22.09	4.21
$TbFe_7Mn_4Ti$	0.850 3	0.476 5	0.344 5	158	6.96	1.21
$DyFe_7Mn_4Ti$	0.847 4	0.476 8	0.342 4	243	11.40	1.97
$HoFe_7Mn_4Ti$	0.846 3	0.477 1	0.341 7	228	8.16	1.41
$ErFe_7Mn_4Ti$	0.847 2	0.477 1	0.342 4	143	8.10	1.40

It can be seen that all of the investigated compounds are basically single phase and crystallized in $ThMn_{12}$-type structure, an additional α-Fe phase coexists with the $ThMn_{12}$ phase in the samples. The lattice constants and the unit-cell volume change with the increasing atomic number from Tb to Er, partly reflecting the lanthanide contraction. Fig.2 shows the magnetization curves at 4.4 K of RFe_7Mn_4Ti compounds with R = Y, Tb, Dy, Ho, and Er. The values of the saturation magnetization for compounds with R = Y, Tb, Dy, Ho, and Er at 4.4 K derived from these magnetization curves are listed in Tab.1. For these compounds, when the applied field is in excess of a critical value, an almost perfectly linear relationship between M and $\mu_0 H$ exists. The interpretation of this is based on a model[5]. This model describes the magnetization process in ferrimagnetic R-T intermetallics in terms of two magnetic sublattices (R and T) being subject to an interplay between the R-T exchange interaction and the interaction of the magnetic field with the R and T sublattice moments. The powder particles used in the experiment can be regarded as single crystalline so that in an external magnetic field they can rotate freely into their energetically most favorable position[6]. If the anisotropy of the T-sublattice is neglected, the R-sublattice moment always remains in the easy direction. As a consequence of this, no anisotropy effects have to be taken into account in the description of the magnetization process. The only physical quantity involved are the applied field ($\mu_0 H$), the R-, and T-sublattice moments (m_R and m_T), and the mean-field constant (n_{RT}), corresponding to the R-T exchange interaction. In this description, the magnetization at a low field is equal to the saturation magnetization corresponding to the ferrimagnetic (antiparallel) alignment of both sublattices. At a critical field $(\mu_0 H)_{cr1} = n_{RT}|m_R - m_T|$, there is a transition from the ferrimagnetic alignment of the sublattices to a canted sublattice configuration. As the applied field increases, the T-sublattice moment gradually rotates to the direction of the R-sublattice moment. The dependence of the total magnetization $M = |m_R + m_T|$ on the applied field can be expressed as $M = \mu_0 H/n_{RT}$. At a second critical field $(\mu_0 H)_{cr2} = n_{RT}|m_R + m_T|$, the sublattice moments reach the ferromagnetic (parallel) alignment which is being maintained at fields beyond $(\mu_0 H)_{cr2}$. The transition to the ferromagnetic alignment is observed very rarely. According to the formula $n_{RT} = d(\mu_0 H)/dM$, the mean-field constant of these compounds can be calculated.

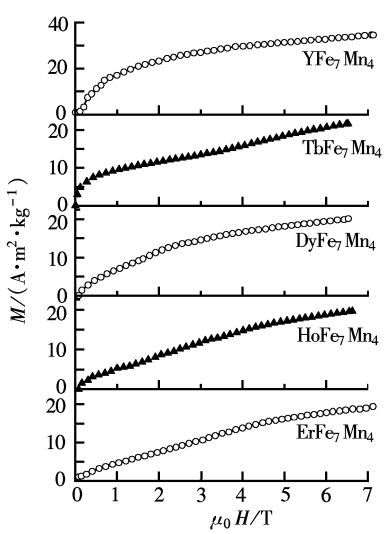

Fig.2 Magnetization curves of RFe_7Mn_4Ti compounds at 4.4 K

Fig.3 displays the results of magnetic measurements showing the temperature dependence of the magnetization of RFe_7Mn_4Ti compounds with R = Y,

Tb, Dy, Ho, and Er. These results clearly demonstrate the ferrimagneitc coupling between R and T sublattices with the compounds for R = Dy and Ho demonstrating compensation temperatures at approximately 123 K and 90 K, respectively; similar phenomena also are observed in other heavy R-T compounds[7-8]. The intrinsic magnetic parameters of RFe_7Mn_4Ti compounds with R = Y, Tb, Dy, Ho, and Er, including Curie temperature T_C, saturation magnetization M_s, and saturation moment per formula unit μ_s are given in Tab.1.

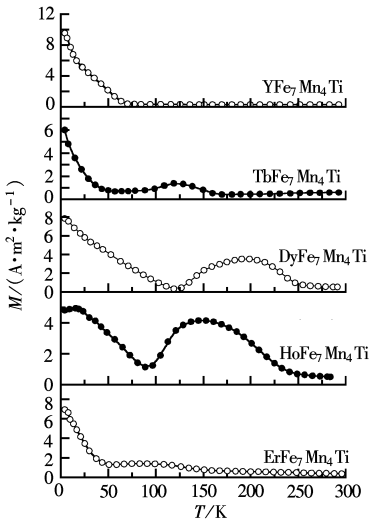

Fig.3 Temperature dependence of the magnetization of RFe_7Mn_4Ti compounds at a field of 50 mT

3 Conclusion

The structural and magnetic properties of RFe_7Mn_4Ti compounds with R = Y, Tb, Dy, Ho, and Er have been investigated. All the RFe_7Mn_4Ti compounds crystallize in $ThMn_{12}$-type structure. The compensation characters appear for the $DyFe_7Mn_4Ti$ and $HoFe_7Mn_4Ti$ compounds. The Curie temperature and the saturation magnetization for these compounds are also reported.

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RFe_7Mn_4Ti 化合物的结构和磁性(R = Y, Tb, Dy, Ho, Er)

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摘 要 研究了 Mn 部分替代 $RFe_{11}Ti$ 中的 Fe 对化合物结构和磁性的影响. 利用真空电弧熔炼和真空热处理制备 RFe_7Mn_4Ti(R = Y, Tb, Dy, Ho 和 Er)化合物样品. 室温粉末样品的 X 射线衍射和热磁曲线测量表明:所有这些化合物都具有单 $ThMn_{12}$ 型结构,且具有良好的单相性,其晶格常数和单胞体积随着稀土元素的不同而变化. 在 $DyFe_7Mn_4Ti$ 和 $HoFe_7Mn_4Ti$ 化合物的热磁曲线上出现了明显的补偿特征,补偿温度分别约为 123 K 和 90 K.同时给出了这些化合物的居里温度、饱和磁化强度及每单位分子式的饱和磁矩.

关键词 金属间化合物; $ThMn_{12}$ 结构; 饱和磁化强度; 稀土

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