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Effect of Ce，Co，B on formation of $LaCo_{13}$-structure phase in $La(Fe,Si)_{13}$ alloys

Xiang CHEN[1,2], Yun-gui CHEN[1], Yong-bai TANG[1], Ding-quan XIAO[1]

1. School of Materials Science and Engineering, Sichuan University, Chengdu 610065, China;
2. College of Engineering and Technology, Neijiang Normal University, Neijiang 641002, China

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Abstract: The effect of Ce, Co, and B on the formation of 1:13 phase in La(Fe, Si)$_{13}$ alloys was investigated by XRD, SEM and EDS. The results show that Co can improve the formation of 1:13 phase in as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys, but in as-cast and annealed $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys, it will hamper the formation of 1:13 phase and help the formation of α-Fe(Co, Si) solid solution. Ce_2Fe_{17} phases will form when x reaches a certain value in as-cast and annealed $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys. B can improve the formation of 1:13 phase accompanied with Fe_2B phase in as-cast $LaFe_{11.6-x}B_xSi_{1.4}$ alloys. B improves the formation of α-Fe solid solution in $LaFe_{11.6}Si_{1.4-x}B_x$ alloys, and there is almost only α-Fe in as-cast and annealed $LaFe_{11.6}Si_{0.9}B_{0.5}$ alloy. In all, the introduction of Co, B, and Ce cannot eliminate the α-Fe phases in corresponding alloys prepared by the high-temperature and short-time annealing process.
Key words: $LaFe_{13-x}Si_x$ alloys; high-temperature and short-time annealing; 1:13 phase

1 Introduction

The $LaFe_{13-x}Si_x$ alloys with $1.1 \le x \le 1.6$ have several advantages in comparison with the other magnetic refrigeration materials with giant magnetocaloric, such as the low price of starting materials and excluding deleterious elements, which have been investigated extensively [1−4]. In $LaFe_{13-x}Si_x$ alloys, Si element is very important to form and stabilize $LaCo_{13}$-type phase, lower the content of Si, and prolong the annealing time. In fact, the binary $LaFe_{13}$ alloy does not exist due to a positive formation heat between La and Fe. In hypothetical $LaFe_{13}$ alloy, the Fe atoms would be located at two different crystals sites: Fe I at the Wyckoff position 8b (0, 0, 0) and Fe II at 96i (0, y, z) in a ratio of 1:12. The La atoms are located at 8a (1/4,1/4,1/4) surrounded by 24 Fe II atoms, and one central Fe I atom and its nearest neighbors of 12 Fe II atoms form a cluster. In the $LaCo_{13}$-type $LaFe_{13-x}Si_x$ alloys, Si atoms in $LaFe_{13-x}Si_x$ randomly occupy both 8b and 96i sites [5]. The substitution of elements with similar chemical properties is the common way of improving comprehensive properties of materials. Ce substituting La in $La_{1-y}Ce_yFe_{13-x}Si_x$ alloys has been investigated extensively [6−9]. The reason is that the single $LaCo_{13}$-type structure can be obtained when the $CeFe_{13-x}Si_x$ ($2.4 \le x \le 2.6$) alloys are annealed only for 12 h [10]. For Fe element, most researches are on the Co substitution [11−14]. The reason may be that $LaCo_{13}$ with T_C=1297 K is the only stable alloy among the RT_{13} alloys (R=rare earth elements, T=transition elements) [15]. The result shows that the preferential substitution of Co atoms at Fe II 96i site effectively lowers the La−Fe positive formation heat to stabilize the cubic $LaCo_{13}$-type structure in $La(Fe,Co)_{13-x}Si_x$ alloys [16]. Besides the $LaFe_{11.7}Si_{1.3-x}Cu_x$ alloys [17], the investigations on the nominal substitution for Si were rarely reported. As grain refining agents in steel, boron atoms are also introduced in the form of interstitial atoms in $LaFe_{13-x}Si_xB_y$ alloys. Addition of boron improves formation of the $LaCo_{13}$-type phase in as-cast $LaFe_{13-x}Si_x$ alloys [18]. In addition, the result of the introduction of B as the substitution element for Fe or Si in $LaFe_{13-x}Si_x$ alloys shows that all the annealed samples exhibited a cubic $LaCo_{13}$-type structure with a few percent of α-Fe and La-rich phases in $LaFe_{11.9}Si_{1.1}$, $LaFe_{11.5}B_{0.4}Si_{1.1}$, and $LaFe_{11.0}B_{0.5}Si_{1.5}$ samples [19]. Up to now, the studies about the introduction of Ce, Co, B in $LaFe_{13-x}Si_x$ alloys have been focused on the influence of magnetocaloric

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Corresponding author: Xiang CHEN; Tel: +86-28-85405670; E-mail: gxucx@163.com
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properties. However, there are few elaborate studies on the effects of the substitution of Ce and Co for La and Fe, respectively, also the introduction of B as interstitial or substitutional atoms on the formation of $LaCo_{13}$-structure phase in as-cast and annealed $LaFe_{13-x}Si_x$ alloys have not been studied yet.

In this work, the phase and microstructure of the as-cast and annealed $LaFe_{11.6-x}Co_xSi_{1.4}$, $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$, $LaFe_{11.6-x}B_xSi_{1.4}$, $LaFe_{11.6}Si_{1.4-x}B_x$, and $LaFe_{11.6}Si_{1.4}B_x$ alloys are investigated. In addition, based on the random distribution of Si atoms on both of Fe sites in $LaCo_{13}$-type $LaFe_{13-x}Si_x$ alloys, the effects of Co and B on the formation of $LaCo_{13}$-structure phase in $LaFe_{11.6}Si_{1.4-x}Co_x$, $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys are investigated.

2 Experimental

Approximately 10 g polycrystalline $LaFe_{11.6-x}Co_xSi_{1.4}$, $LaFe_{11.6}Si_{1.4-x}Co_x$, $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$, $LaFe_{11.6-x}B_xSi_{1.4}$, $LaFe_{11.6}Si_{1.4-x}B_x$, $LaFe_{11.6}Si_{1.4}B_x$ buttons were fabricated, respectively by conventional arc melting in a high purity argon atmosphere using high purity (La 99.4%, Ce 99.9%, Fe 99.9%, Si 99.9999%, Co 99.9%, B 99.9%) elements after the alloys were re-melted five times to achieve a homogeneous composition. The as-cast alloys were divided into two parts. One part was annealed by different high-temperature and short-time processes in a molybdenum wire furnace of 3×10^{-3} Pa, followed by furnace cooling down to room temperature. The phase purity and crystal structure were determined by powder X-ray diffraction (XRD) using Cu (K_α) radiation (Dandong DX−2600). Scanning electron microscopy (SEM) and energy disperse spectroscopy (EDS) observation were carried out with Hitachi S−3400N.

3 Results and discussion

Figure 1 shows the XRD patterns of as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys. By analyzing and indexing the X-ray diffraction patterns, it can be found that the as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys mainly consist of α-Fe and LaFeSi phases. As non-equilibrium solidification phase, a certain amount of 1:13 phase is also observed, but the amount of 1:13 phase is different in the as-cast alloys. The diffraction intensity ratio of 1:13 phase has no obvious change with x=0.0, 0.3 and 0.5, but there is a sharp increase when x=0.7 in as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys. This indicates that Co can improve 1:13 phase in as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys only when Co reaches a certain amount.

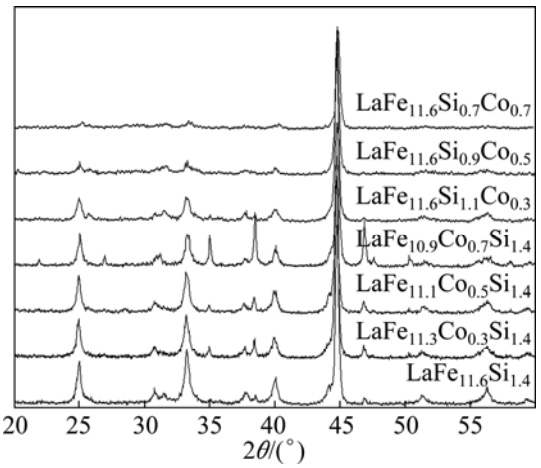

Fig. 1 XRD patterns of as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys

Figure 2 shows the backscattered SEM micrograph of as-cast $LaFe_{10.9}Co_{0.7}Si_{1.4}$ alloy. The mixed matrix consists of the main black (position I) and white (position II) microstructures. According to the result of the EDS analysis of as-cast $LaFe_{10.9}Co_{0.7}Si_{1.4}$, shown in Table1, the black and white microstructures are α-Fe and LaFeSi phases, respectively. There is a certain of grey microstructure around the black grain, and grey microstructure changes gradually from light grey to dark grey with the increase of Fe and the decrease of La and Si, which is corresponding to the diffusion process between α-Fe atom and La and Si atoms of LaFeSi phase. In the grey microstructure, there is a small amount of 1:13 phase around the α-Fe grain, which accords with the character of peritectic reaction: Fe+LaFeSi→$La(Fe,Si)_{13}$ [20]. In addition, Co can substitute Fe to form substitution solid solution in each phase of as-cast $LaFe_{10.9}Co_{0.7}Si_{1.4}$ alloy. Because of the random distribution of Si atoms on both Fe sites in $LaCo_{13}$-type $LaFe_{13-x}Si_x$ alloys, Si can be regarded as the substitution element for Fe in $LaCo_{13}$-type $LaFe_{13-x}Si_x$ alloys like the substitution of Co for Fe.

For further studying the effect of Co on the 1:13 phase formation in $LaFe_{13-x}Si_x$ alloys, Co is introduced

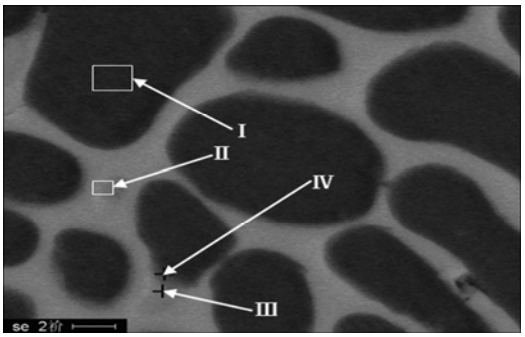

Fig. 2 Backscattered SEM image of as-cast $LaFe_{10.9}Co_{0.7}Si_{1.4}$

Table 1 EDS analysis of different positions in Fig. 1

Position	x(La)/%	x(Fe)/%	x(Co)/%	x(Si)/%	Phase
I	01.18	86.20	05.26	07.36	α-Fe
II	30.59	26.24	08.02	35.14	LaFeSi
III	27.21	37.17	07.64	27.99	Unknown
IV	11.99	69.69	05.80	12.53	1:13 phase

as the substitution element for Si in $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys. The XRD patterns of as-cast $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys show that the amounts of 1:13 and LaFeSi phases gradually decrease and the amount of α-Fe(Co,Si) solid solution increases with the increase of Co content, as shown in Fig. 1. When x reaches 0.7, there is almost only α-Fe(Co,Si) solid solution. This indicates that Co will hamper the formation of 1:13 and LaFeSi phases and improve the formation of α-Fe(Co, Si) solid solution in as-cast $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys.

Figure 3 shows the XRD patterns of $LaFe_{11.6-x}Co_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys annealed at 1523 K for 5 h. One can find that the annealed $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys consist of the cubic 1:13 phase and a small amount of impurity phase of α-Fe. From the backscattered SEM micrographs of the annealed $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys, as shown in Fig. 4, the amount of impurities including α-Fe and LaFeSi phases has no obvious change with the increase of Co content, which indicates that the introduction of Co as the substitution for Fe in $LaFe_{13-x}Si_x$ alloys cannot reduce the amount of impurities with the same annealing time or increase the diffuse reaction speed of Fe + LaFeSi→La(Fe,Si)$_{13}$. In the annealed $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys, there is a certain amount of 1:13 phase when x≤0.5, but α-Fe is also a main phase. The annealed $LaFe_{11.6}Si_{0.7}Co_{0.7}$ alloy mainly consists of α-Fe(Co,Si) solid solution, while the amount of 1:13 phase is quite small.

Because the single $LaCo_{13}$-type structure can be obtained when the $CeFe_{13-x}Si_x$ (2.4≤x≤2.6) alloys are annealed for only 12 h [10], the substitution of Ce for La in $LaFe_{13-x}Si_x$ alloys may improve the formation or reduce the annealing time [21]. Figure 5 shows the XRD patterns of the as-cast $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$ alloys (0≤x≤0.5), from which one can find that the main phases are α-Fe and LaFeSi phases, and the minor phase of 1:13 phase is observed in those alloys. When x=0.33, the amount of 1:13 phase is the largest, the diffraction peaks ratio of 1:13 phase is almost the same as that in other as-cast $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$ alloys. In addition, there is a certain amount of Ce_2Fe_{17} phase when x reaches 0.5, which indicates that the substitution of Ce for La in as-cast $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys has some limits.

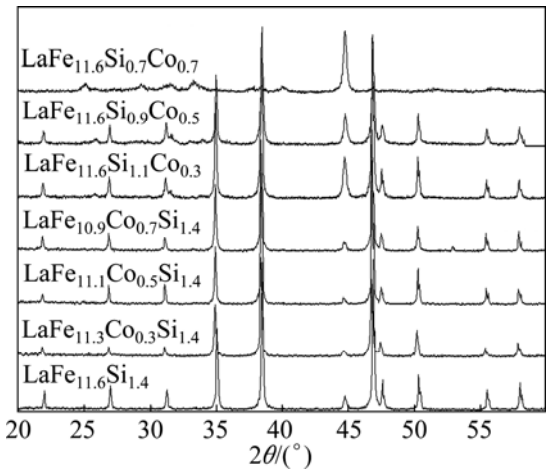

Fig. 3 XRD patterns of $LaFe_{11.6-x}Co_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys annealed at 1523 K for 5 h

Our previous work showed that the Ce_2Fe_{17} phase cannot be eliminated by annealing at 1373 K for 2 h + 1523 K for 5 h and then furnace cooling to room temperature [22]. In this work, the as-cast $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys were annealed at 1523 K for 5 h and then furnace cooled to room temperature. Figure 6 shows XRD patterns of the annealed $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$

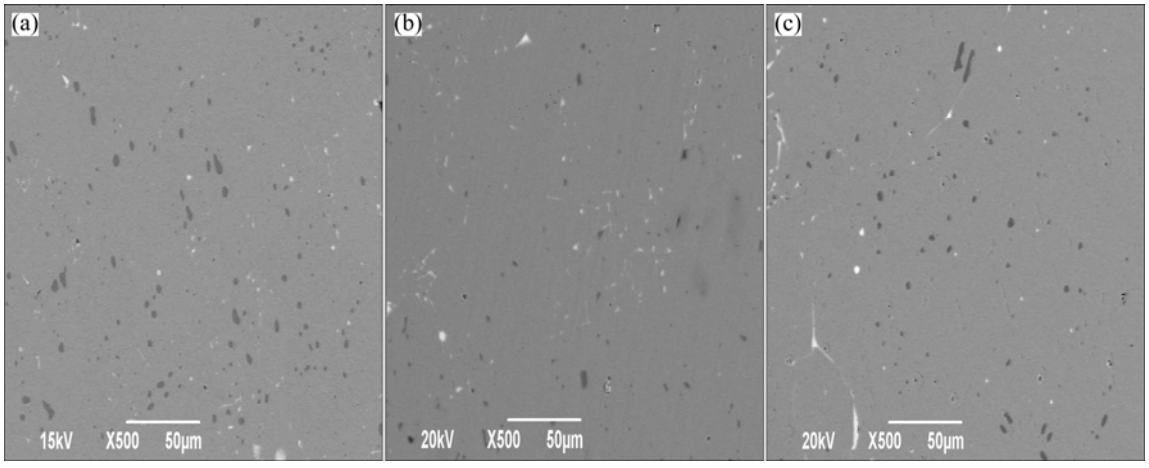

Fig. 4 Backscattered SEM micrographs of $LaFe_{11.6-x}Co_xSi_{1.4}$ annealed at 1523 K for 5 h: (a) x=0; (b) x=0.5; (c) x=0.7

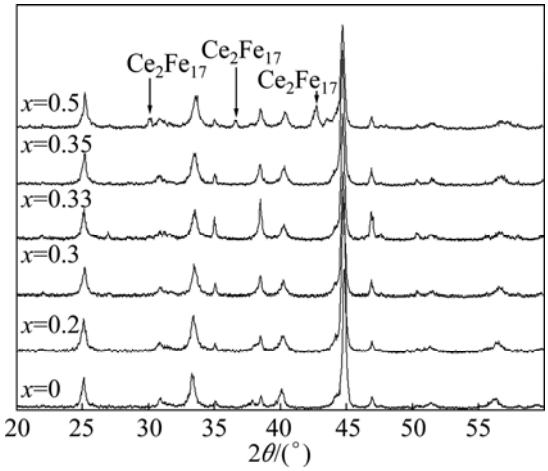

Fig. 5 XRD patterns of as-cast $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys

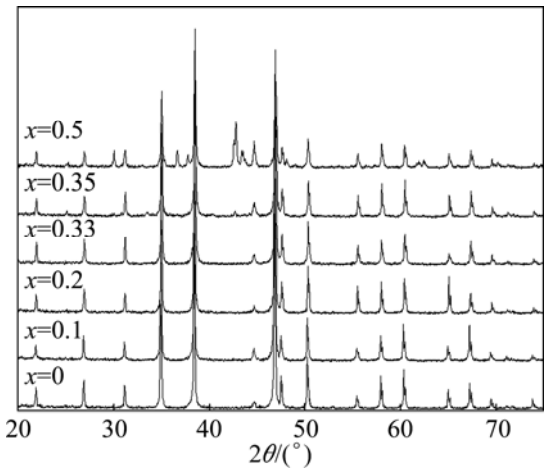

Fig. 6 XRD patterns of $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys annealed at 1523 K for 5 h

alloys with x=0, 0.1, 0.2, 0.33, 0.35, and 0.5, respectively. The main phase is 1:13 phase, and impurity phase is a small amount of α-Fe in $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$ alloys for $0 \le x \le 0.33$. Ce_2Fe_{17} phase begins to appear in $La_{0.65}Ce_{0.35}Fe_{1.5}Si_{1.5}$ alloy. There is a large amount of Ce_2Fe_{17} phase when x reaches 0.5. All of those indicate that the substitution of Ce for La in annealed $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys also has some limits. The maximal Ce substitution for La to form continuous solid solution in annealed $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$ alloys is x=0.33−0.35. In addition, the diffraction peaks of the cubic 1:13 phase have obvious shift to high angle with the increase of Ce content, as shown in Fig. 6. This is a signature of lattice contraction, which attributes to the radius of Ce (0.27 nm) which is smaller than that of La (0.278 nm). This also shows that Ce can substitute La in $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys with $LaCo_{13}$-structure to form solid solution.

The backscattered SEM micrographs of $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ annealed at 1523 K for 5 h are shown in Fig. 7. One can find that there is small amount of Ce_2Fe_{17} in $La_{0.67}Ce_{0.33}Fe_{11.5}Si_{1.5}$, which cannot almost be observed in the $La_{0.7}Ce_{0.3}Fe_{11.5}Si_{1.5}$. When x reaches 0.5, and the Ce_2Fe_{17} occupies about 30% in volume proportion. Those also show that the maximal Ce substitution for La to form continuous solid solution in $La_{1-x}Ce_xFe_{1.5}Si_{1.5}$ alloys is x=0.33−0.35. In addition, the EDS result of the annealed $La_{0.5}Ce_{0.5}Fe_{11.5}Si_{1.5}$ shows that the ratios of La and Ce in α-Fe(Si) solid solution are 1.2% and 0.7%, respectively, which indicates that the solid solution range of La and Ce in α-Fe(Si) solid solution is very small. In Ce_2Fe_{17} alloy, there is certain amount of La and Si, thus Ce_2Fe_{17} alloy should be the $(La, Ce)_2(Fe,Si)_{17}$ solid solution.

As grain refining agents in steel, B atoms are also introduced in the form of interstitial atoms in $LaFe_{13-x}Si_xB_y$ alloys. According to the XRD patterns of as-cast $LaFe_{11.6}Si_{1.4}B_x$ alloys, as shown in Fig. 8, the addition of B improves formation of the $LaCo_{13}$-type

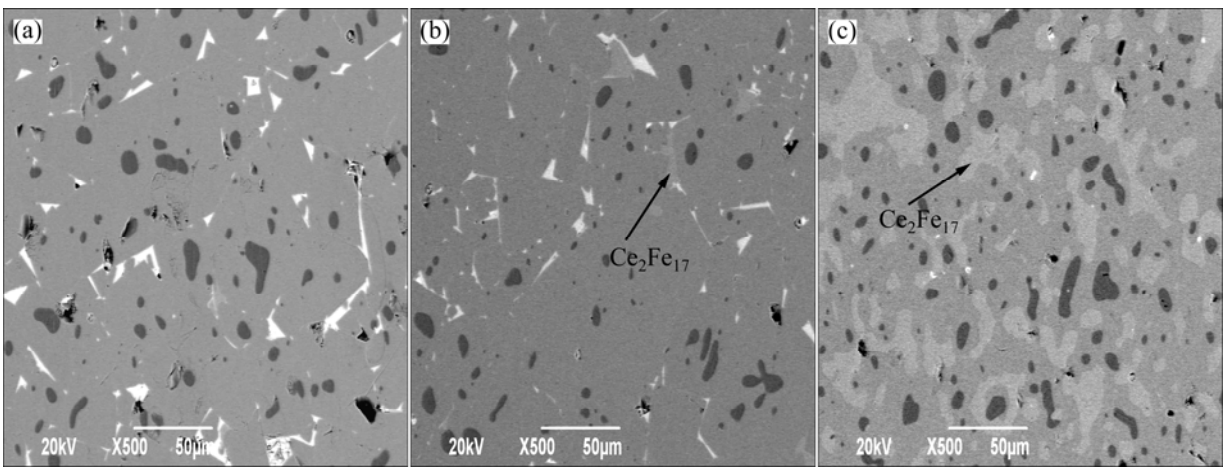

Fig. 7 Backscattered SEM micrographs of $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ annealed at 1523 K for 5 h: (a) x=0.3; (b) x=0.33; (c) x=0.5

phase in as-cast $LaFe_{13-x}Si_x$ alloys, and the amount of 1:13 phase increases with the increase of B content. But the introduction of B will result in the formation of Fe_2B phase and the amount also increases with the increase of B content. The effects of B as the substitution element for Fe or Si in $LaFe_{11.5}B_{0.4}Si_{1.1}$ and $LaFe_{11.6}B_{0.5}Si_{1.5}$ alloys on the magnetocaloric properties were studied in detail in Ref. [19], but the influence on the formation of 1:13 phase and microstructure has few reports. In Fig. 8, the XRD patterns of as-cast $LaFe_{11.6-x}B_xSi_{1.4}$ alloys show that B as the substitution element for Fe can improve the formation of 1:13 phase. The amount of 1:13 phase increases with the increase of B content, and there is a large amount of 1:13 phase when x reaches 0.5. However, there is also Fe_2B phase, and the amount increases with the increase of B content like as-cast $LaFe_{11.6}Si_{1.4}B_x$ alloys. For the substitution of B for Si, the amount of 1:13 phase in as-cast $LaFe_{11.6}Si_{1.3}B_{0.1}$ or $LaFe_{11.6}Si_{1.1}B_{0.3}$ alloys is larger than that in $LaFe_{11.6}Si_{1.4}$, but is less than that in $LaFe_{16-x}B_xSi_{1.4}$ or $LaFe_{11.6}Si_{1.4-x}B_x$ with the same B content. In the as-cast $LaFe_{11.6}Si_{0.7}Co_{0.7}$ alloy, there is almost only α-Fe solid solution [23].

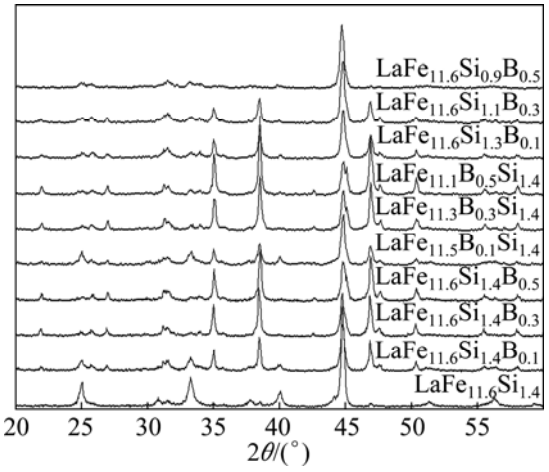

Fig. 8 XRD patterns of as-cast $LaFe_{11.6}Si_{1.4}B_x$, $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys

Our previous work showed that the Fe_2B phase cannot be eliminated by annealing at (1373 K, 1.5 h) + (1523 K, 5 h) and then furnace cooling to room temperature [23]. In this work, the as-cast $LaFe_{11.6}Si_{1.4}B_x$, $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys were annealed at 1523 K for 5 h and then furnace cooled to room temperature. In Fig. 9, the XRD patterns of the annealed $LaFe_{11.6}Si_{1.4}B_x$ and $LaFe_{11.6-x}B_xSi_{1.4}$ alloys show that the main phase is 1:13 phase and the impurity includes α-Fe and Fe_2B phases, and the amount of Fe_2B phase increases with the increase of B content, which indicates that the annealing process in this work cannot eliminate Fe_2B phase. In the annealed $LaFe_{11.6}Si_{1.4-x}B_x$ alloys with x=0.3 and 0.5, there is a large amount of 1:13 phase besides α-Fe, which is different from the annealed $LaFe_{11.6}Si_{0.7}Co_{0.7}$ alloy. In addition, there is a certain amount of Fe_2B phase. In all, the introduction of B as interstitial atoms or the substitution for Fe in as-cast $LaFe_{13-x}Si_x$ alloys can obviously improve the formation of 1:13 phase, but the Fe_2B as accompanying phase of B introduction cannot be eliminated by high-temperature and short-time annealing. Thus there is a certain amount of Fe_2B phase in annealed $LaFe_{11.6}Si_{1.4}B_x$, $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys, and the amount increases with the increase of B content, which is harmful for the magnetocaloric effect [23]. Thus, how to hamper or eliminate Fe_2B phase needs further study.

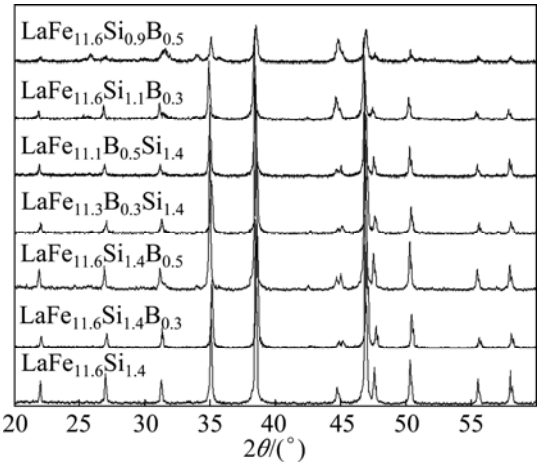

Fig. 9 XRD patterns of $LaFe_{11.6}Si_{1.4}B_x$, $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys annealed at 1523 K for 5 h

Figure 10 shows the backscattered SEM image of the annealed $LaFe_{11.6}Si_{1.4}B_x$ and $LaFe_{11.6-x}B_xSi_{1.4}$ alloys with x=0.1 and 0.3, respectively. Compared with the microstructure of $LaFe_{11.6}Si_{1.4}$ annealed at 1523 K for 5 h, one can find that the grain of 1:13 phase is small and that of α-Fe is much larger. The Fe_2B and α-Fe mix, and locate the boundary of 1:13 phase grain. In addition, there is small white microstructure (LaFeSi phase) at the boundary of 1:13 phase grain.

On a whole, whether the substitution of Co for Si in $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys or the substitution of B for Si in $LaFe_{11.6}Si_{1.4-x}B_x$ alloys both will make the formation of 1:13 phase difficult or the amount of 1:13 phase small compared with the same substituted amount of Co or B for Fe. Si element can be adjusted to the formation heat, and there is a critical value of Si content in $LaFe_{13-x}Si_x$ alloys. The formation heat is positive when the amount of Si is smaller than the critical value, which results in no 1:13 phase and only α-Fe solid solution when Co and B reach a certain amount in as-cast or annealed $LaFe_{11.6}Si_{1.4-x}Co_x$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys. Thus, how to decrease the formation heat in substitution of Si deserves further study.

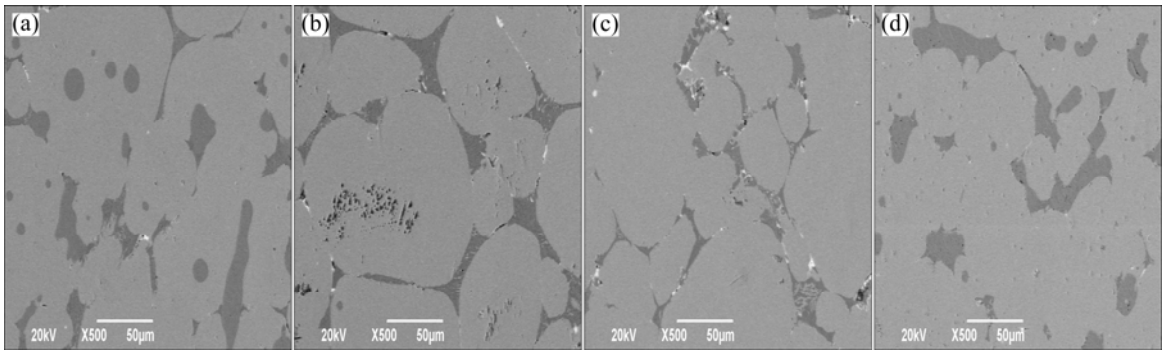

Fig. 10 Backscattered SEM images of $LaFe_{11.6}Si_{1.4}B_x$ and $LaFe_{11.6-x}B_xSi_{1.4}$ alloys annealed at 1523 K for 5 h: (a) $LaFe_{11.6}Si_{1.4}B_{0.1}$; (b) $LaFe_{11.6}Si_{1.4}B_{0.3}$; (c) $LaFe_{11.5}B_{0.1}Si_{1.4}$; (d) $LaFe_{11.3}B_{0.3}Si_{1.4}$

4 Conclusions

Co can substitute Fe in different phases of as-cast $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys and the amount of 1:13 phase increases when x reaches 0.7. But the introduction of Co cannot reduce the annealing time or increase the diffuse reaction speed, which results in the fact that the amounts of impurities including α-Fe and LaFeSi phases have no obvious change with the increase of Co content in annealed $LaFe_{11.6-x}Co_xSi_{1.4}$ alloys. B can improve the formation of 1:13 phase accompanied with Fe_2B phase in as-cast $LaFe_{11.6-x}B_xSi_{1.4}$ and $LaFe_{11.6}Si_{1.4}B_x$ alloys. But the Fe_2B phase is kept and the amount increases with the increase of B in corresponding annealed alloys. Due to the increase of formation heat, the substitution of Co for Si in $LaFe_{11.6}Si_{1.4-x}Co_x$ alloys and the substitution of B for Si in $LaFe_{11.6}Si_{1.4-x}B_x$ alloys both will make the formation of 1:13 phase difficult or the amount of 1:13 phase small, and even no 1:13 phase and only α-Fe solid solution when Co and B reach a certain amount in as-cast and annealed $LaFe_{11.6}Si_{1.4-x}Co_x$ and $LaFe_{11.6}Si_{1.4-x}B_x$ alloys. The substitution of Ce for La has some limits in as-cast and annealed $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys. Ce_2Fe_{17} phase begins to be observed when x reaches 0.35, and the amount increases with the increase of Ce in annealed $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ alloys.

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Ce，Co，B 对 La(Fe,Si)$_{13}$ 合金中 $LaCo_{13}$ 结构 1:13 相形成的影响

陈 湘[1,2]，陈云贵[1]，唐永柏[1]，肖定全[1]

1. 四川大学 材料科学与工程学院，成都 610065；
2. 内江师范学院 工程技术学院，内江 641002

摘 要：通过 XRD、SEM、EDS 等方法，研究 Ce、Co、B 对 La(Fe,Si)$_{13}$ 合金中 $LaCo_{13}$ 结构 1:13 相形成的影响。结果表明，在铸态 $LaFe_{11.6-x}Co_xSi_{1.4}$ 合金中，Co 能够促进铸态 1:13 相的形成。但是在铸态以及热处理后的 $LaFe_{11.6}Si_{1.4-x}Co_x$ 合金中，Co 阻止 1:13 相的形成，同时促进 α-Fe(Co,Si)固溶体相的形成。在铸态 $La_{1-x}Ce_xFe_{11.5}Si_{1.5}$ 合金中，当 Ce 的含量达到一定值后，合金中将有 Ce_2Fe_{17} 相形成，且随着 Ce 含量的增加而增加。在铸态 $LaFe_{11.6-x}B_xSi_{1.4}$ 合金中，B 能够促进 1:13 相的形成，但同时会有 Fe_2B 相产生。在铸态以及热处理后的 $LaFe_{11.6}Si_{1.4-x}Co_x$ 和 $LaFe_{16}Si_{1.4-x}B_x$ 合金中，Co 能够促进 α-Fe(Co,Si)固溶体相的形成。在 $LaFe_{11.6}Si_{0.9}B_{0.5}$ 合金中，基本上只有 α-Fe(Co, Si)固溶体相存在，这点与 $LaFe_{11.6}Si_{0.7}Co_{0.7}$ 合金相似。在高温短时热处理制备的 La(Fe,Si)$_{13}$ 合金中，引入 Ce、Co、B 并不能消除杂相 α-Fe，且同时会伴随新的杂相产生，如 Ce_2Fe_{17} 和 Fe_2B 相。

关键词：$LaFe_{13-x}Si_x$ 合金；高温短时热处理；1:13 相

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