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Structural and magnetic properties of the $Fe_{0.7-x}Si_{0.3}Co_x$ alloy system

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Abstract

In this paper we present magnetic and structural studies for the alloy system $Fe_{0.7-x}Si_{0.3}Co_x$, where $0 \leqslant x \leqslant 0.3$. The structural characteristics of the alloys were evaluated using X-ray diffraction and the existence of the single cubic phase was confirmed from the diffraction patterns. The lattice constant was found to depend on the Co concentration with a slight decrease with increasing the concentration, x. The magnetic measurements were performed by using a vibrating sample magnetometer with a maximum field of 13.5 kOe, at temperatures between 77 and 1000 K. The results for all the samples show ferromagnetic behavior up to Curie temperature. The saturation magnetization at low temperatures was found to increase with increasing Co concentration, reaching a maximum at $x = 0.2$ then decreases for $x = 0.3$. The Curie temperature was found to increase from 690 K for $x = 0$ to 972 K for $x = 0.3$.

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Keywords: Lattice constant; Curie temperature; Saturation magnetization; Magnetic moment

1. Introduction

Iron compounds based on the ordered and disordered Fe_3Si and Fe_3Al alloy systems are characterized by many interesting magnetic properties. They play a very useful role in many technological and magnetic applications because of their high-temperature mechanical strength, excellent oxidation and corrosion resistance. They are relatively inexpensive, stable, and easily manufactured. The structural and magnetic properties of the intermetallic Fe–Si alloys depend on Si concentration. $Fe_{1-x}Si_x$ forms a continuous range of solid solution with a BCC structure between $x = 0$ and 0.265 [1]. Previous studies showed that $FeSi_2$ form the tetragonal type structure, FeSi forms the B20 type structure, while Fe_3Si forms the DO_3 type cubic structure, where

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Fe_3Si is a well-ordered ferromagnetic alloy [2]. Mössbauer and NMR [3,4] investigations for this system have yielded information about the hyperfine field and Si site occupation. These studies showed that the hyperfine field and the magnetic moment at the Fe sites strongly depend on the Si occupancy and the number of Fe nearest neighbors, and they decrease with increasing the Si concentration.

Substitution of Fe by any of the transition metal elements affects the magnetic properties, the lattice parameter, and the structural ordering of these alloys [5–10]. Neutron diffraction study for $Fe_{3-x}Mn_xSi$ by Yoon and Booth [9] showed that Mn preferentially occupies the B site of the DO_3-type structure for $x<0.75$, and then starts to occupy the A and C sites for higher Mn concentrations. In addition, they found that this system exhibits ferromagnetic behavior for $x<0.75$ and a complex magnetic behavior evolves for $x>0.75$. It was also found that replacing Fe by Mn decreases the magnetic moment, Fe–Fe exchange interaction, and Curie temperature with increasing the Mn concentration. Waliszewski et al. [10] studied the $Fe_{3-x}Cr_xSi$ alloy system and found that the Curie temperature decreases from 840 K for $x=0$ to 712 k for $x=0.4$, and the magnetic moment of iron at the B site to be $2.44\,\mu_B$, and about $1.18\,\mu_B$ for (A, C) sites, while the magnetic moments of Cr were determined to be $2.03\,\mu_B$ for Cr at the B site and $0.41\,\mu_B$ for the (A, C) sites with orientation antiparallel to the magnetic moments of Fe.

The electronic structure of Fe_3Si was calculated by, Swintendick using non-polarized and non-self-consistent augmented planes method [11]. It was found that the local density of states at the B site has two peaks, while the density of states at the A, C sites has three peaks. This explained the site occupation preference of transition metal impurities in Fe_3Si. Impurities with atomic number less than that of iron occupy the B with electron enough to partially fill the lowest energy sub-band, whereas impurities with higher atomic number occupy the A, C sites with electrons filling the two lowest sub-bands. These features were confirmed by the spin-polarized and self-consistent calculation using the LMTO method [12]. The local magnetic moments at the B and A, C sites were found to be 2.52 and $1.10\,\mu_B$, respectively [12]. In addition, the magnetic properties resulting from adding V to Fe_3Si were calculated and negative magnetic moments were found on V. Negative moments were also found for Cr in $Fe_{3-x}Cr_xSi$ and on Fe at the A, C sites for certain configurations [13].

In the present investigation, the $Fe_{0.7-x}Si_{0.3}Co_x$ alloy system was prepared by arc-melting method. The structural and magnetic properties of all the samples were investigated using XRD and VSM.

2. Experimental methods

A series of polycrystalline bulk samples with composition $Fe_{0.7-x}Si_{0.3}Co_x$ ($x=0$, 0.05, 0.10, 0.15, 0.2 and 0.3) were prepared from high-purity Fe, Si, and Co elements by arc melting under a flowing argon atmosphere. For each sample, the stoichiometric mixture was melted and turned over four to five times for remelting to insure homogeneity. The crystalline phase of the prepared samples was identified by powder X-ray diffraction technique using a Philips diffractometer with $Cu–K_\alpha$ radiation. The magnetic properties of the samples were characterized by a vibrating sample magnetometer (VSM) in magnetic fields up to 13.5 kOe and in the temperature range 77–1000 K.

3. Results and discussion

The X-ray diffraction patterns obtained at room temperature for all investigated samples exhibit lines characteristic for the DO_3-type structure, as shown in Fig. 1 for two representative samples of the alloy system $Fe_{0.7-x}Si_{0.3}Co_x$ with $x=0.0$, and 0.20. All the samples studied have similar behavior with a shift in the peaks' position. The patterns for all the samples are consistent with a single phase of the cubic type with lattice parameter $a=2.829$ Å for $x=0$. The indices for the various peaks are shown in the diffraction patterns. The composition dependence of the lattice constant (a) on the Co concentration are listed in Table 1. The lattice parameter is found to decrease slightly with