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Phase transition and extended X-ray absorption fine structure of melt-spun amorphous $Fe_{100-x}Y_x$ alloys

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Abstract

The phase diagram and local structure of melt-spun amorphous (a-) $Fe_{100-x}Y_x$ ($22 \leqslant x \leqslant 62$) alloys were investigated using AC and DC magnetic and extended X-ray absorption fine structure (EXAFS) measurements. The a-Fe–Y system shows reentrant spin glass (RSG) behavior for $42 \leqslant x \leqslant 58$ and spin glass (SG) behavior for $60 \leqslant x$. Two SG transition temperatures, T_g and T_f, were obtained in the RSG state. The T_g, T_f and Curie temperature T_C decrease with increasing x, and the T_C and T_g vanish at $x = 60$. A new magnetic phase diagram for the melt-spun a-$Fe_{100-x}Y_x$ alloys was obtained from magnetic measurements for higher Y concentration. The magnetic states of the a-$Fe_{100-x}Y_x$ alloys change remarkably around $x = 60$ and an EXAFS study revealed that the average atomic distance between nearest-neighboring Fe atoms changes at approximately $x = 60$.
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1. Introduction

The Fe–Y system is one of the most fascinating materials in order to investigate the magnetic properties of iron-rare earth metal alloys, because Y, which is considered to be non-magnetic, enables the magnetic structure of this system to be simplified. In the amorphous (a-) Fe–Y system, a striking discovery was made by Rhyne et al. [1] for Fe_2Y alloys, in that no clear Curie temperature could be defined, and this has led to an increase in investigations of a-Fe–Y alloys. It is well known that the a-Fe–Y alloys show two different magnetic phase diagrams depending on the sample preparation method. A sputtered a-Fe–Y alloy was reported to have no ferromagnetic (FM) transition and to show only the transition from the paramagnetic (PM) to the spin glass (SG) state [2,3]. A melt-spun a-Fe–Y alloy was found to show reentrant spin glass (RSG) behavior.

Fukamichi et al. [2] investigated the effect of annealing on the SG state in sputtered a-Fe–Y alloys. They made it clear that after annealing, these alloys exhibited RSG behavior, and both the atomic distance of Fe–Fe and the coordination number of Fe–Fe pairs increased. On the other hand, Tange et al. [4] studied the magnetic phase diagram of melt-spun a-$Fe_{100-x}Y_x$, and found it to be different from that for sputtered a-Fe–Y. Their magnetic phase diagram showed that the critical concentration of Y for the FM state was approximately $x = 50$, and the PM–SG transition occurred for $50 < x < 70$; this diagram was similar to that of sputtered a-Fe–Y after annealing, and many other sputtered a-Fe–R systems (R = Zr, Hf, Ce, Lu, La) [2]. However, Tange et al. [4] did not provide detailed data and discussion. In our previous study [5], we performed magnetization measurements on melt-spun a-$Fe_{100-x}Y_x$ alloys of various

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concentrations and proposed a phase diagram. It was shown that the Y concentration dependence of the SG transition temperature and the critical concentration of the FM state were different from those reported by Tange et al. The differences seemed to correspond to qualitative changes of structure, which were studied using extended X-ray absorption fine structure (EXAFS) measurements with laboratory-based EXAFS (Labo-EXAFS) apparatus.

In this paper, we report AC magnetic susceptibility measurements together with DC magnetization measurements including differential magnetic susceptibility, and discuss the phase diagram of melt-spun a-Fe–Y alloys in detail. Three characteristic critical temperatures, T_f, T_g and T_C, were derived as a function of the Y concentration, and the differences with the diagrams of Tange et al. and Fukamichi et al. are discussed. In addition, quantitative local structural information was obtained from not only the Fe K-edge but also the Y K-edge using high-resolution EXAFS measurements with synchrotron radiation. Employing this information, the relationship between the magnetic states and structures of the melt-spun a-Fe–Y alloys are investigated by combining both of these magnetic measurements.

2. Experimental procedure

Amorphous $Fe_{100-x}Y_x$ alloys were prepared by a melt-spinning method with a single-roller system. Y concentrations were prepared for $x = 22$, 33, 42, 52, 58, 60, 62 and 67. The X-ray diffraction patterns of the prepared samples showed so-called broad halo patterns and no crystalline peaks were detected. A commercial SQUID magnetometer ($MPMS_2$, Quantum Design) was used to measure the DC magnetization and AC magnetic susceptibility. Measurements of the magnetic cooling effect at 30 Oe were carried out for $x = 42$, 52, 58, 60 and 62. The DC magnetization was also measured for $x = 42$, 52 and 60 at various field strengths between 0 Oe and 8 kOe. The differential magnetic susceptibility dM/dH was calculated numerically from the adjoining two points of the magnetization curves measured at each temperature. AC susceptibility measurements were carried out for $x = 58$ and 62 in a field of 1 Oe at 80 Hz.

EXAFS transmission measurements were carried out at the BL01B1 beamline of SPring-8. Two monochromators of Si(1 1 1) and Si(3 1 1) crystals were used for the Fe K-edge and Y K-edge EXAFS measurements, respectively. Complementarily, Labo-EXAFS measurement of Fe K-edge spectra were carried out for some samples including a Laves (L-) phase Fe_2Y compound at room temperature using a R-EXAFS Super (Rigaku). In order to determine the local structure around Fe and Y atoms, the EXAFS spectrum of L-Fe_2Y was compared with a FEFF simulation, which is an automated program for *ab initio* multiple scattering calculations of X-ray absorption fine structure.

3. Results and discussion

3.1. DC and AC magnetic susceptibility

The magnetic cooling effects for a-$Fe_{100-x}Y_x$ alloys of $x = 42$, 52, 58, 60 and 62 in a field of 30 Oe are shown in Figs. 1–5, respectively. The insets of Figs. 3 and 5 show temperature dependence of the AC susceptibility at 1 Oe for $x = 58$ and 62, respectively. With cooling, the DC susceptibility for $x = 42$ at 30 Oe increases around 250 K and shows a maximum at approximately 82 K. The zero-field-cooled magnetization (ZFCM, open circles) decreases rapidly with decreasing temperature. The discrepancy between the ZFCM and the field-cooled magnetization (FCM, closed circles) occurs around 100 K and increases below 60 K. A similar temperature dependence of the DC susceptibility can be seen in Figs. 2 and 3 for $x = 52$ and 58, respectively. The temperature of the maximum DC susceptibility is denoted as T_g. Another characteristic temperature T_f is assigned by the temperature dependence of the differential magnetic susceptibility dM/dH as described in Section 3.2. The irreversibility between ZFCM and FCM seems to become clear at around T_f. In an Arrott plot, the isotherms at higher fields are normally straight [1] and the Curie temperature T_C is determined by the isotherm, which passes through the origin. Arrott plots are shown in the inset of Fig. 2. T_C for $x = 42$, 52 and 58 were determined to be 210, 100 and 66 K, respectively. The DC susceptibility behavior, of which there are three characteristic temperatures T_f, T_g and T_C, indicate that

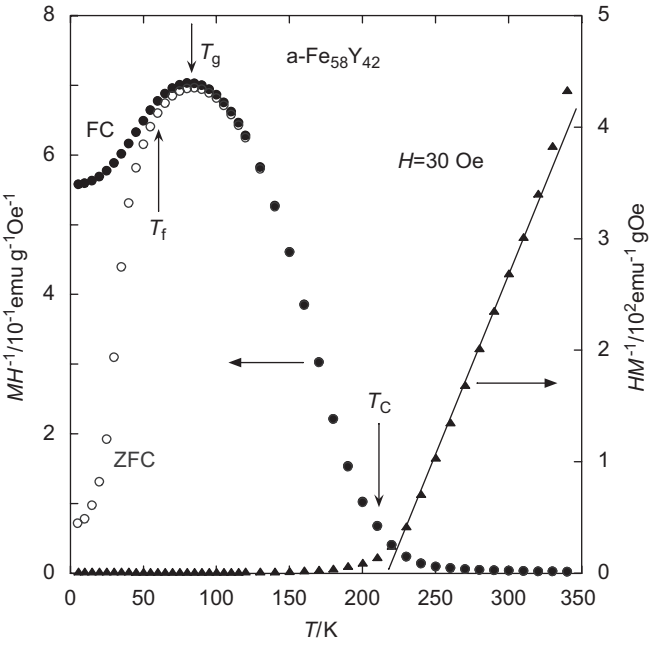

Fig. 1. Magnetic cooling effect for a-$Fe_{58}Y_{42}$ at 30 Oe. Closed and open circles show the field-cooled and zero-field-cooled susceptibility, respectively. Closed triangles represent the inverse of the field-cooled susceptibility. The straight line fitted to the H/M data is intended as a guide. T_g and T_f were obtained from the dM/dH vs T plot in Fig. 6, and T_C was determined by Arrott plots.

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