Magnetic Properties of Amorphous $Mn_{100-x}Ce_x$ Alloys

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Abstract

We have measured the magnetization and thermal expansion coefficient α on sputtered amorphous $Mn_{100-x}Ce_x$ alloys in various concentrations of Ce. In Mn-rich samples we observe a small anomaly and thermal hysteresis between field-cooling and zero-field-cooling in the low-temperature magnetization, suggesting a spin-glass ordeing, and an anomalously large α value with normal Debye-like temperature dependence. In Ce-rich samples we observe typical Curie-Weiss behavior in the magnetization, but α increases with the decrease of temperature below 100K, suggesting $4f$-electron contribution of the Ce atom.

Key words: magnetization; thermal expansion; amorphous alloys; Mn-Ce

Magnetic properties of Mn-based rare-earth (RE) binary amorphous alloys have not been much investigated in comparison with those of other $3d$ magnetic element- (such as Fe-, Co- and Ni-) based RE amorphous alloys. Recently, amorphous (a-)Mn-Y alloys have been investigated and found to show typical spin-glass properties with the ordering temperature T_g increasing linearly as a function of Mn concentration [1]. This would be reasonable because Y is assumed to be non-magnetic and Mn is only a magnetic element in this disordered system. Kakehashi and Yu have investigated the nature of the spin glass in a-Mn-Y theoretically on the basis of the itinerant electron model [2]. In this study, we replace non-magnetic Y atom in a-Mn-Y with another RE element Ce with $4f$-electron and investigate magnetic and thermal properties in order to see how the Mn-based amorphous system changes its magnetic characters and how the $4f$-electron behaves.

Bulk ingots of $Mn_{100-x}Ce_x$, nominally x=20,30,40, 60,70 and 80, were made by melting stoichiometric amount of Mn 99.9% and Ce 99.9% in an argon-arc furnace. Amorphous $Mn_{100-x}Ce_x$ alloys were prepared by a dc high-rate sputtering method from the arc-melted ingots onto water-cooled Cu substrate. The amorphous structure of sputtered samples was confirmed by an X-ray diffraction analysis. Table 1 shows nominal and chemically analyzed compositions of the sample, respectively. Hereafter, the nominal composition will be used for sample identification. The magnetization has been measured by a conventional SQUID magnetometer in field of 100Oe from 4.2K to 300K. The thermal expansion measurements have been done by a strain gauge method for rectangular samples with a typical size of $10\times4\times0.4$mm^3 in a He gas-flow cryostat from 20K to 300K.

Figure 1 shows the temperature dependence of the magnetization for a-$Mn_{100-x}Ce_x$ alloys. In higher temperature region above 20K it shows a typical Curie-Weiss behavior for all the samples. With decreasing temperature below 20K the magnetization for Mn-rich samples (x<50) exhibits an anomaly and then indicates difference between field-cooled (FC) and zero-field-cooled (ZFC) magnetization. This would suggest a spin glass ordering, as observed more clearly at higher temperature in a-Mn-Y alloys for the same Mn concen-

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Concentration				
Nominal		Analyzed		Notation
Mn	Ce	Mn	Ce	
20	80	21.1	78.9	$Mn_{20}Ce_{80}$
30	70	29.1	71.0	$Mn_{30}Ce_{70}$
40	60	40.9	59.1	$Mn_{40}Ce_{60}$
60	40	50.0	50.0	$Mn_{60}Ce_{40}$
70	30	66.8	33.2	$Mn_{70}Ce_{30}$
80	20	75.0	25.0	$Mn_{80}Ce_{20}$

Table 1
Results of quantitative analysis for $Mn_{100-x}Ce_x$ samples by optical emission spectrochemical analysis

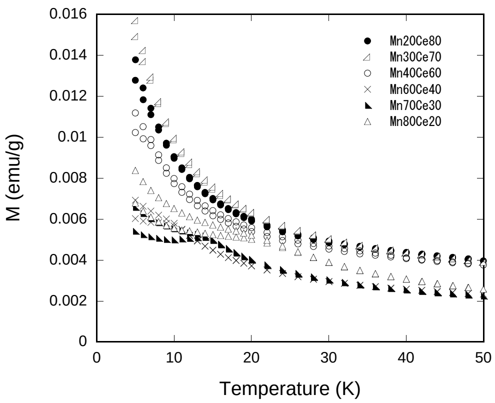

Fig. 1. Temperature dependence of the FC and ZFC magnetization of a-$Mn_{100-x}Ce_x$ alloys in field 100Oe.

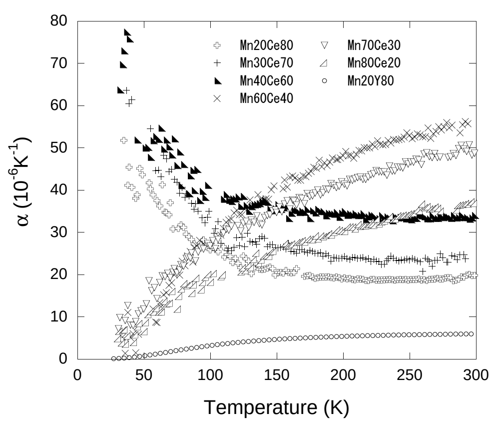

Fig. 2. Temperature dependence of the thermal expansion coefficient α of a-$Mn_{100-x}Ce_x$ alloys

tration. With increasing Ce concentration the anomaly becomes smaller with a decrease in the temperature of the anomaly and finally disappears in Ce-rich samples (x>50), though very small difference between FC and ZFC magnetization remains observable. Therefore, the Ce atom plays a role of reducing Mn-Mn spin interactions in this a-Mn-RE system compared to the Y case.

The thermal expansion coefficient α of a-$Mn_{100-x}Ce_x$ is shown in Fig. 2. For Mn-rich samples (x<50) the temperature dependence of α shows a Debye-like curve, however, its value is anomalously large compared to a-$Mn_{100-x}Y_x$alloys as shown for x=80 in Fig. 2 as an example. The α increases with increasing Ce concentration above 100K. According to recent specific heat measurements on these samples [3], the data for a-$Mn_{50}Y_{50}$ also show a Debye-like curve and become almost temperature independent at around room temperature with the value close to $3R$, indicating negligible magnetic or electronic contribution. But those for a-Mn-Ce is much larger than this value and still increasing with increasing temperature around room temperature, suggesting large magnetic contribution. The present results of α are consistent with the specific heat and suggests that a-Mn-Ce are itinerant magnetic alloys with large spin fluctuations. Such spin-fluctuation contribution to α has already been reported to exist in a-Mn-Y for Mn-rich concentration[4]. For Ce-rich samples (x>50), α largely increases with decreasing temperature below 100K as shown in Fig. 2. Although the α value decreases with increasing Ce concentration, the temperature variation of α does not depend on x very much for x>50. We suppose that this anomalous behavior below 100K is due to $4f$-electron contribution of the Ce atom. There should be two possible explanation for such $4f$-electron contribution. One is the crystalline-electric-field (CEF) splitting of the 6-fold degenerate level of Ce^{3+} ion with local $4f$-electron character [5]. The other is the dense Kondo effect and formation of itinerant $4f$-electron state, that is, the heavy-fermion state [6]. The recent specific heat measurements show existence of a dense-Kondo-like behavior with a large linear-specific-heat coefficient γ as ~260 mJ/molK^2 for a-$Mn_{20}Ce_{80}$. Quite recently, the resistivity for a-$Mn_{20}Ce_{80}$ has been measured and found to exhibit a large initial increase with T^2-like behavior at low temperature followed by a logarithmic-like decrease with the increase of temperature[7]. The present anomaly in α for Ce-rich samples at low temperature would also suggest the dense-Kondo-like effect observed in the specific heat and resistivity measurements on a-$Mn_{20}Ce_{80}$.

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