PHYSICAL PROPERTIES OF METASTABLE ICOSAHEDRAL $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$

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The results of X-ray diffraction, ^{57}Fe Mössbauer spectroscopy, electrical resistivity, and magnetic susceptibility studies of the metastable icosahedral alloy $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ are presented. The observed broadening of the diffraction Bragg peaks reflects the presence of the topological/chemical disorder. The distribution of the electric quadrupole interactions indicates the existence of a multiplicity of Fe sites. Although the low-temperature value of the electrical resistivity (400 $\mu\Omega$ cm) is rather small, we found that the temperature coefficient of the electrical resistivity is negative. The temperature dependence of the magnetic susceptibility is well described by the Curie-Weiss law with the magnetic moments localized at the transition-metal atoms.

1 Introduction

Soon after discovery of the first icosahedral (i) alloys in the binary Al-TM (TM=transition metal) system, it was found that the addition of a metalloid (Me) improves their structural quality.[1,2] These ternary Al-TM-Me i alloys were mainly studied with respect to their structural properties. The purpose of this paper is to present the results of experimental studies of the physical properties of the $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ i alloy with several techniques. It will be shown that this alloy, in spite of its metastable nature and a significant amount of structural disorder, exhibits a negative temperature coefficient of the electrical resistivity characteristic of high-quality stable i alloys.

2 Experimental

An ingot of composition $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ was prepared by arc melting in an argon atmosphere of high-purity Al, Ge, Cr, and Fe enriched to 95% in an ^{57}Fe isotope. The ingot was melt spun in air by ejecting molten alloy at 1423(10) K through a 0.7 mm orifice in a quartz tube onto a surface of a copper wheel rotating with a tangential velocity of 71(1) m/s. The resulting ribbons were about 2 cm long and 2 mm wide.

X-ray diffraction (XRD) measurements were performed on a Philips X'Pert scanning diffractometer using Cu Kα radiation, the Kβ line being eliminated by using a Kevex PSi2 Peltier cooled Si detector. The ^{57}Fe Mössbauer spectroscopy (MS) measurement at room temperature was conducted using a standard Mössbauer spectrometer operating in a sine mode. The surface density of the Mössbauer absorber was 34 μg ^{57}Fe/cm^2 and it can be regarded as being thin. The electrical resistivity measurement was done with a standard dc four-probe method between 10 and 280 K. Magnetic susceptibility was measured with a SQUID magnetometer in a field of 1 kOe between 4.2 and 300 K.

3 Results and Discussion

The XRD pattern (Fig. 1) exhibits broadened Bragg peaks due to the *i* phase. The two most prominent *i* lines are on a broad background, which indicates the presence of some second phase in the studied sample.[3]

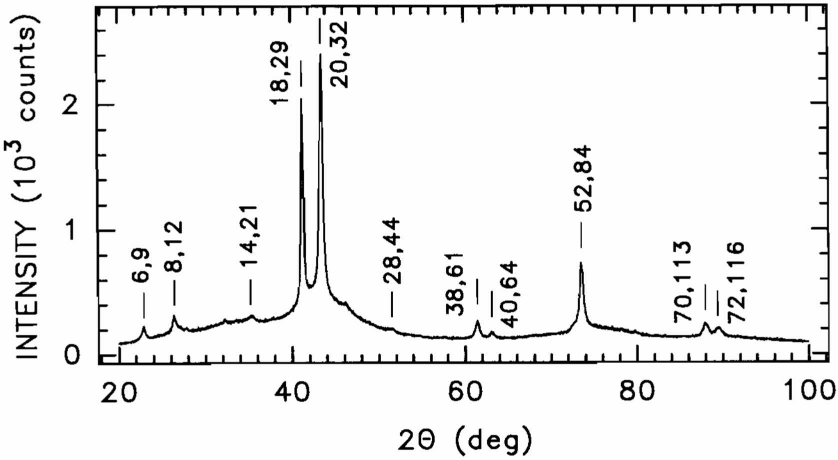

Figure 1: X-ray diffraction pattern of an $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ alloy. The vertical lines above the Bragg peaks label the *i* peaks using the indexing scheme of Cahn *et al.* (Ref. 4).

A Mössbauer spectrum of *i* $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ (Fig. 2) consists of two broad and structureless lines. These broad lines result from the distribution of the electric quadrupole splittings, P(Δ).[5] The spectrum can be fitted relatively well with a structureless Gaussian-like P(Δ) [Figs. 2(a) and (c)]. A close inspection of the residuals in Fig. 2(a) indicates the presence of some structure due to an unknown impurity component, which is consistent with the XRD result. To a first approximation, this component can be taken in the form of a symmetric Lorentzian doublet. Its inclusion in the spectral analysis [Fig. 2(b)] leads to a perfect fit. The occurrence of P(Δ) in the studied sample [Fig. 2(c)] proves that the Fe atoms are distributed among the multiplicity of sites which must result from the presence of a chemical/topological disorder in the investigated sample.

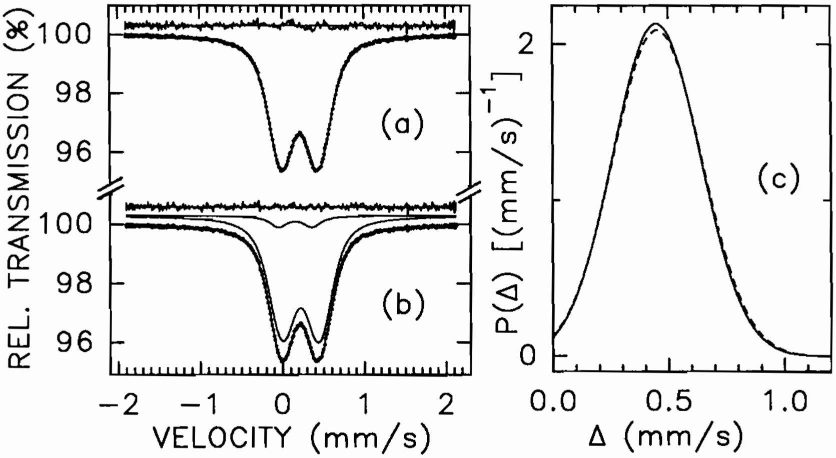

Figure 2: Room-temperature Mössbauer spectrum of *i* $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ fitted with (a) one P(Δ) component [the solid line in (c)] and with (b) the P(Δ) [the broken line in (c)] plus an impurity component. The component spectra are also shown in (b). The residuals, multiplied by a factor of three, are shown above each spectrum. The velocity scale is relative to α-Fe.

The electrical resistivity, ρ, of *i* $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$ (Fig. 3) is much larger than that of ordinary metallic alloys. In spite of the presence of significant structural disorder in the sample, the ρ(T) dependence (Fig. 3) is similar to that observed for high-quality stable *i* alloys.[6] A relatively large value of ρ and an enhanced thermal stability of *i* Al-TM-Me alloys[1,2] can be explained within the framework of the Hume-Rothery mechanism.[7] For the studied alloy the electron-per-atom ratio is 1.67. This leads to the diameter of the Fermi sphere being 2.88 $Å^{-1}$ which compares well with the wave number of 2.87(1) $Å^{-1}$ corresponding to the 18,29 *i* peak (Fig. 1).

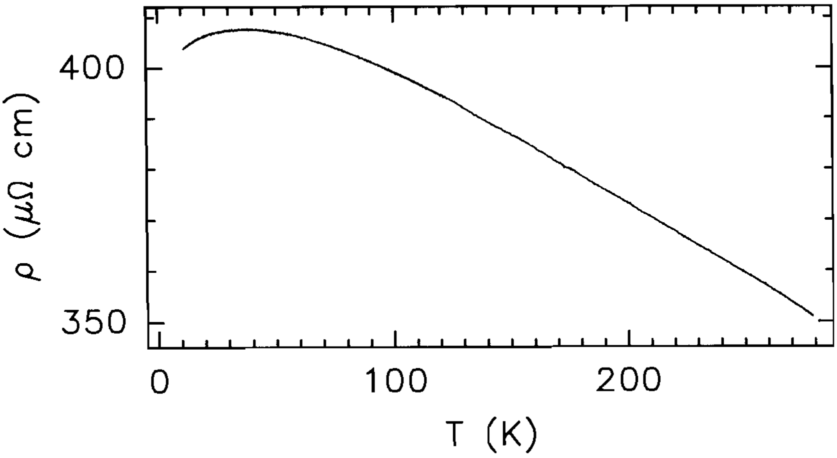

Figure 3: Temperature dependence of the electrical resistivity of *i* $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$.

The temperature dependence of the magnetic susceptibility, χ, follows a Curie-Weiss law $\chi = \chi_o + C/(T\text{-}\Theta)$, where the symbols χ_o, C, and Θ are respectively the temperature-independent magnetic susceptibility, the Curie constant, and the paramagnetic Curie temperature, only for temperatures larger than about 50 K (Fig. 4). The values of χ_o, C, and Θ obtained from the fit are respectively $0.370(1)\times10^{-5}$ cm^3g^{-1}, $31.7(3)\times10^{-5}$ $cm^3g^{-1}K$, and -27.0(6) K. This value of C corresponds to the effective magnetic moment per TM atom of 0.708(3) μ_B. A deviation from the Curie-Weiss law at low temperatures (Fig. 4) may be due to the presence of some magnetic impurity in the sample, as indicated by the X-ray diffraction and Mössbauer data. The presence of such an impurity would also explain the value of χ_o, which is about an order of magnitude larger than that found in other Al-Cr-TM-Me *i* alloys.[8,9] The negative value of Θ indicates the predominantly antiferromagnetic interaction between the TM atoms. The value of the effective magnetic moment per TM atom is similar to that observed for other Al-Cr-TM-Me *i* alloys.[8,9] Its origin is due to the topological disorder[9,10] present in the studied sample, as evidenced in the X-ray diffraction and Mössbauer spectra. This disorder is caused by both the quasiperiodic structure itself, in which no two atoms have exactly the same environment, and by the rapid-quenching process involved in the production of the metastable sample.

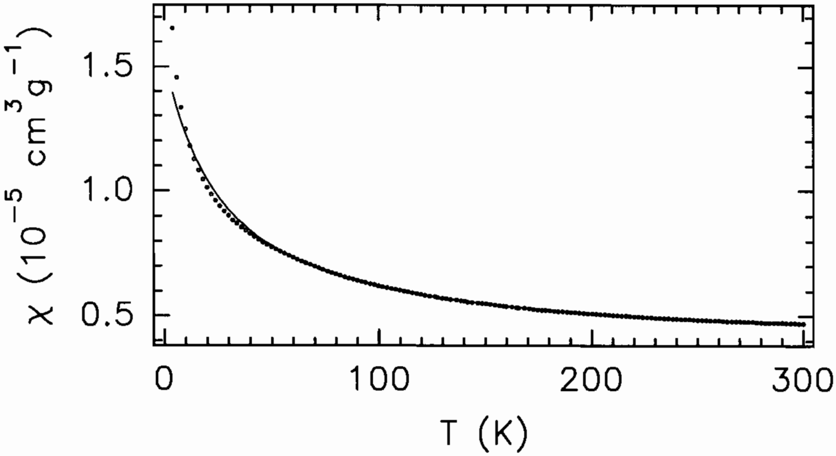

Figure 4: Temperature dependence of the magnetic susceptibility of *i* $Al_{60}Ge_{20}Cr_{19.9}Fe_{0.1}$. The solid line is the fit to a Curie-Weiss law for the susceptibility data at temperatures ≥50 K.

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