Nano Technology & Nano Science Journal (NTNS)

Research Article

The Inverse of the Magnetic Susceptibility in Amorphous Alloys $Hf_{1-x}Ta_xFe_2$

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Citation: Rikio Konno, Shigeyuki Murayama, Ryo Nakabayashi. (2023) The inverse of the magnetic susceptibility in amorphous alloys $Hf_{1-x}Ta_xFe_2$. *Nano Technol & Nano Sci J 5*: 152.

Received: June 15, 2023; **Accepted**: June 24, 2023; **Published**: June 29, 2023.

Abstract

The inverse of the magnetic susceptibility in amorphous alloys $Hf_{1-x}Ta_xFe_2$ above the Curie temperature was investigated theoretically by using the spin fluctuation parameters determined by the experiment. We find that the inverse of the magnetic susceptibility obtained theoretically is qualitatively consistent with the experimental data.

Introduction

The magnetic properties of itinerant weak ferromagnets have been attracted by many researchers experimentally and theoretically. They are consistent with the theoretical results in spin fluctuation theory [1-5].

Murayama et. al. observed magnetic properties and Mossbauer study of amorphous alloys $Hf_{1-x}Ta_xFe_2$ experimentally [6]. They obtained the Curie-Weiss law. They show that amorphous alloys $Hf_{1-x}Ta_xFe_2$ are itinerant weak ferromagnets. From the broad Mossbauer spectrum below the Curie temperature, they also estimated the average hyperfine field.

Recently, Murayama et. al. obtained spin fluctuation parameters from the magnetic measurement in amorphous alloys $Hf_{1-x}Ta_xFe_2$ [7]. However, its inverse of the magnetic susceptibility is unresolved theoretically. Therefore, it is investigated by using Takahashi's spin fluctuation theory [2] that has the advantage of satisfying the scaling law relation of critical phenomena at the critical point.

This paper is organized as follows: the formulation will be provided in section 2. The numerical results will be given in section 3. The conclusions will be supplied in section 4. Throughout this paper, we use units of energy, such that $\hbar = 1$, $k_B = 1$, and $g\mu_B = 1$ where g is the g-factor of the conduction electron.

Formulation

Let's begin with the following local squared spin amplitude.

$$< S_{loc}^2 >=< S_{loc}^2 >_Z + < S_{loc}^2 >_T \tag{1}$$

where $< S_{loc}^2 >_Z$ and $< S_{loc}^2 >_T$ are the zero point and the thermal components of the local squared spin amplitudes, respectively. The thermal component is represented as follows [2]:

$$< S_{loc}^2 >_T = \frac{9T_0}{T_A} A(y,t), \tag{2}$$

where *A* (*y*, *t*) is given by the following integral with respect to the reduced wave number *x*.

$$A(y,t) = \int_0^1 \mathrm{d}x x^3 \left[\ln u - \frac{1}{2u} - \psi(u)\right], \quad u = x(y+x^2)/t \tag{3}$$

The function $\psi(u)$ in the above integral is the digamma function. In the following, we use the parameters, *t* and *y*, as the reduced temperature and the inverse of the reduced magnetic susceptibility, and the reduced parameter α by

$$t = T/T_0, \; y = 1/(2\alpha T_A \chi), \; \alpha = I\chi(0), \tag{4}$$

The parameters, T_0 and T_A, characterize the spectral widths in wave-vector and frequency spaces, respectively.The zero point component of the local squared spin amplitude is given by

$$< S_{loc}^2 >_Z (y) =< S_{loc}^2 >_Z (0) - \frac{9T_0}{T_A} Z(y) \tag{5}$$

where Z(*y*) in the right-hand side is defined by

$$Z(y) = -\frac{1}{2}[\int_0^1 \mathrm{d}x x^3[(\log \eta_c^2 + v^2) - 2\ln v] + \int_0^1 dx x^3[(\log \eta_c^2 + v_0^2) - 2\ln v_0]], \tag{6}$$

where

$$v = x(y + x^2),$$
$$v_0 = x^3, \qquad (7)$$

$$\eta_c = \omega_c/(2\pi T_0). \qquad (8)$$

ω_c is the cut-off frequency. By performing the integrals,

$$Z(y) = \frac{1}{4}\{\log(1+y) - y^2[\ln(1+y) - \ln y] + y\}. \qquad (9)$$

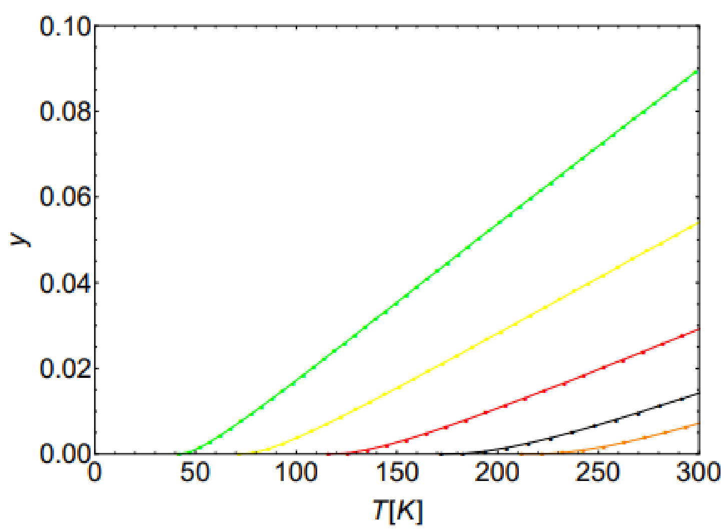
y << 1 because of the weak ferromagnet.

$$Z(y) \approx \frac{1}{2}y. \qquad (10)$$

From Eq. (1), the following conserving spin amplitude is obtained.

$$< S_{loc}^2 > = < S_{loc}^2 >_Z (0) - \frac{9T_0}{2T_A}y + < S_{loc}^2 >_T \qquad (11)$$

Figure 1: The temperature dependence of the inverse of the reduced magnetic susceptibility. The green line, the yellow line, the red line, the black line, and the orange line denote x=0.9, x=0.7, x=0.5, x=0.3, x=0.0, respectively.



$$< S_{loc}^2 > - < S_{loc}^2 >_Z (0) = -\frac{9T_0}{2T_A}y + \frac{9T_0}{T_A}A(y,t). \qquad (12)$$

The left-hand side is the squared spin amplitude at the reduced Curie temperature t_c.Then, we obtained the following spin amplitude conserving equation,

$$A(y,t) - \frac{1}{2}y = A(0,t_c). \tag{13}$$

From this equation, y is determined self-consistently at temperatures.

Results

In this section, the inverse of the reduced magnetic susceptibility is investigated based on section 2. Fig.1 shows the temperature dependence of the inverse of the reduced magnetic susceptibility by using the spin fluctuation parameters that Murayama et. al.determined experimentally [7]. As shown in Fig.1, y shows the clear $(T - T_c)^2$ -linear dependence at very low temperatures above the Curie temperature T_c. Around the Curie temperature, $y \approx 0$. From Eq. (13), the behavior results from the following approximation of the digamma function.

$$\ln x - \frac{1}{2x} - \psi(x) \sim \frac{1}{2x} \tag{14}$$

Then,

$$A(y,t) - A(0,t) \approx -\frac{t}{2}\sqrt{y}\arctan\frac{1}{\sqrt{y}}. \tag{15}$$

From Eq. (15), because of $y \approx 0$,

$$A(y,t) - A(0,t) \approx -\frac{\pi t}{4}\sqrt{y} \tag{16}$$

In this limit, the inverse of the reduced magnetic susceptibility y is therefore analytically represented by

$$y \approx (\frac{4}{\pi t_c})^2[A(0,t) - A(0,t_c)]^2 \tag{17}$$

$$y = [\frac{4}{\pi}\frac{\partial A(0,t)}{\partial t}|_{t=t_c}]^2(\frac{t}{t_c} - 1)^2 \tag{18}$$

being consistent with our numerical results of Fig. 1. The inverse of the reduced magnetic susceptibility has$(T - T_c)^2$ -linear dependence above T_c. Elevated temperatures, the $(T - T_c)$-linear dependence appears in the inverse of the reduced magnetic susceptibility. Fig. 1 shows that this theoretical inverse of the reduced magnetic susceptibility is qualitatively consistent with the experimental data [6].

Conclusions

The inverse of the magnetic susceptibility in amorphous alloys $Hf_{1-x}Ta_xFe_2$ above the Curie temperature has been investigated theoretically. By using the spin fluctuation parameters determined by the magnetic measurement, we find that the behaviors of the inverse of the magnetic susceptibility are consistent with the experimental data.

Acknowledgments

This work is supported by the Kindai University Technical College grants. One of the authors (R.K.) would like to thank Y. Takahashi for fruitful discussions. He would like to also thank Y. Tokunaga, Y. Haga, H. von Lohneysen, M. Brando, F. Steglich, C.Geibel, J. Flouquet, A. de Visser for stimulating conversations.

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