International Journal of Advanced Materials Science
ISSN 2231-1211 Volume 9, Number 1 (2018), pp. 1-6

http://www.ripublication.com

Determination of Curie Temperature of Cr-substituted Fe based Amorphous $Fe_{73.5-x}Cr_xCu_1Nb_3Si_{13.5}B_9$ (x=10,12.5,15 & 17.5) Alloys Using the ABK (Arrot-Belov-Kouvel) plot Method

Md. Sultan Mahmud

Professor of Physics, Department of Basic Sciences and Humanities, University of Asia Pacific, 74/A, Green Road, Dhaka-1215, Bangladesh.

Abstract

Curie temperature is a primary intrinsic property of magnetic materials. A material is ferromagnetic if it possesses regions of finite magnetization where the external magnetic field intensity H = 0. The temperature at which ferromagnetism occurs is called the Curie temperature (T_c) and depends on the strength of exchange interaction which arises from the overlapping of the electronic wave functions of the interacting magnetic atoms. The Curie temperature of the studied samples has been determined by various methods such as temperature dependence of high and low field dc magnetization, low field ac susceptibility and initial permeability ($H = 10^{-3}$ Oe), Arrott plots etc. This paper focuses the measurement of Curie temperature by the ABK (Arrot-Belov-Kouvel) plot method only.

Key words: Curie temperature, Magnetization, exchange interaction, electronic wave functions, magnetic atoms etc.

INTRODUCTION:

The Curie temperatures determined by both dc and ac techniques are well correlated. More over Curie temperature (T_c) of the samples with x = 10, 12.5, 15 & 17.5 have also been determined from the magnetic isotherm taken around the T_c with an interval of 1-2K using the ABK (Arrot-Belov-Kouvel) plot [1-3]. A standard procedure for determining T_c in ferromagnetic materials is based on symmetry principle. Arrott [4] have pioneered the use of a classical form of expression for magnetization and field near a ferromagnetic phase transition and showed that internal field, H_i, should be an odd power of magnetization M, and is given by

$$H_i = A(T - T_c)M + BTM^3 + CTM^5 \quad (1)$$

where A, B, C are constants.

Since M << Ms, the saturation magnetization around T_c, the terms involving M^5 and higher can be neglected, so that the equation can be written as

$$H_i = A(T - T_c)M + BTM^3 \quad (2)$$

$$\frac{H_i}{M} = A(T - T_c) + BTM^2 \quad (3)$$

At $T = T_c$;
$$\frac{H_i}{M} = BT_C M^2 \quad (4)$$

An approach to T_c is characterized by vanishing of the parameter A. B is the temperature dependent parameter. Therefore, a value of T_c may be determined from the magnetic isothermals by plotting at fixed temperatures $\frac{H_i}{M} vs. M^2$. According to equation (2) these plots should yield straight lines for each value of T and T_c corresponds to that straight line which passes through the origin for a low enough fields, Hi. These plots are called Arrott-Belov-Kouvel (ABK) plots and sometime shortly called Arrott plots. Arrot plots not only determine T_c, but also give spontaneous magnetization M_0^2 ($\frac{H}{M} = 0$) from the intercepts on M^2 axis for $T < T_c$ and reciprocal of initial susceptibility $\frac{1}{\chi_0}$ ($H \to 0$) from the intercepts on the $\frac{H_i}{M}$ axis for $T > T_c$.

EXPERIMENTAL:

In order to prepare amorphous of $Fe_{73.5-x}Cr_xCu_1Nb_3Si_{13.5}B_9$ alloys with x = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12.5, 15 and 17.5, a melt spinning facilities was used at the Centre for Materials Science, National University of Hanoi, Vietnam. Melt-spinning is a widely used production method for rapidly solidifying materials as well as preparing amorphous metallic ribbon [5, 6, 7].

Fig.1. Vacuum arc melting Machine

Fig.1. shows the pictorial view of the Vacuum arc melting Machine. The small pieces of the master alloy samples were inductively remelted inside the quartz tube crucible followed by ejecting the molten metal with an over pressure of 250 mbar of 99.9% pure Ar supplied from an external reservoir through a nozzle onto a rotating copper wheel with surface velocity of 30 m/sec. The resulting ribbon samples had thickness of about 20-25 μm and width of ~6 mm. Processing parameters such as the thermal conductivity of the rotating quench wheel, wheel speed, ejection pressure, thermal history of the melt before ejection, distance between nozzle of quartz tube and rotating wheel, as well as processing atmosphere have influenced on the microstructure and properties of melt-spun ribbons [8, 9, 10].

RESULTS AND DISCUSSIONS:

From magnetic isotherms calculations are made for M^2 and H/M to draw the ABK plots considering low field data which are demonstrated in fig. 2 (a, b, c, d). The estimated T_c values for x = 10, 12.5, 15 & 17.5 are 362, 247, 197 and 143.5 K respectively, which is quite compatible with other methods of measurements. The T_c values of all the studied samples are depicted in table-1. It is observed that the T_c decreases monotonically as in the case of M_s with the increase of Cr content. The reduction of T_c with the substitution of nonmagnetic Cr may be attributed to the simultaneous weakening of the strength of exchange interaction between the Fe magnetic moments. For x = 0, the Curie temperature, T_c = 596K which decreases to T_c = 143.5K for x = 17.5.

Table 1. Curie temperature and magnetic parameters (5K & 300K) of nanocrystalline $Fe_{73.5-x}Cr_xCu_1Nb_3Si_{13.5}B_9$ alloys

Cr content x (at.%)	Curie temperature, T_c in K	Saturation magnetization, M_0 in emu/g at 0K	Saturation magnetization, M_s in emu/g at 5K	Saturation magnetization, M_s in emu/g at 300K	Magnetic moment, n_B in Bohr magneton at 5K	Magnetic moment, n_B in Bohr magneton at 300K
0	596	160.3	160	137	1.41	1.21
1	566	155.3	155	130	1.37	1.15
2	540	147.6	147	115	1.29	1.01
3	517	133.4	133	111	1.17	0.98
4	490	127.8	127	99	1.12	0.87
5	466	122.9	122	89	1.07	0.78
6	435	119.7	119	87	1.04	0.76
7	412	111.2	111	72	0.97	0.63
8	390	107.8	107.6	65.2	0.94	0.58
9	371	103.1	101	56.2	0.88	0.5
10	364	92.8	92.5	48.18	0.81	0.42
12.5	247	72.6	72.5	3.33*	0.63	0.03
15	196	67.2	67	2.42*	0.58	0.02
17.5	143.5	52.8	52.2	2.14*	0.45	0.02

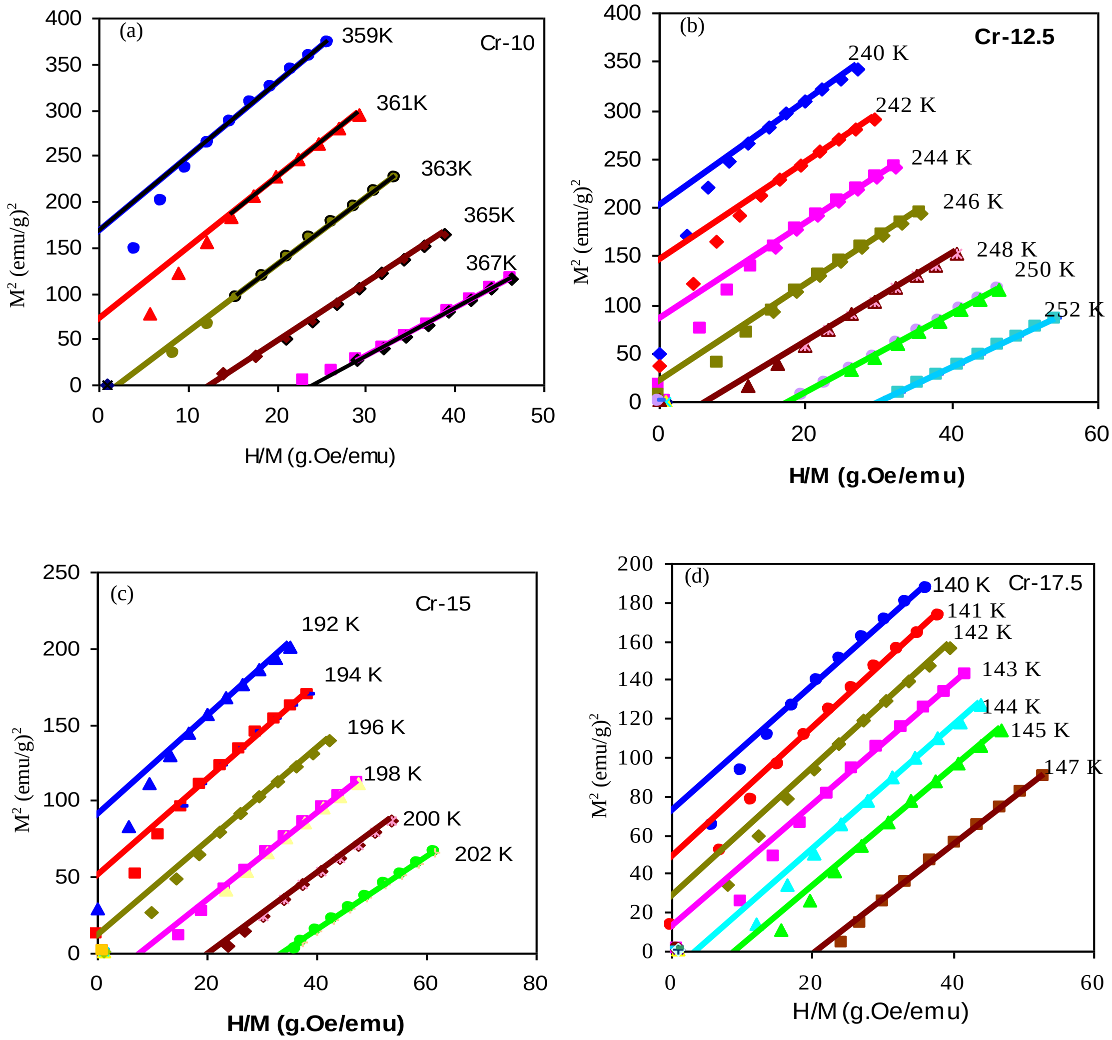

Fig. 2 (a,b,c,d). Arrot plots (M^2 vs. H/M) from the magnetic isotherms with composition $Fe_{73.5-x}Cr_xCu_1Nb_3Si_{13.5}B_9$ (x = 10, 12.5, 15 & 17.5) alloys

However the T_c values depicted in table-1 are average over all types of measurements. The absolute values of all these T_c are within ±2K. In spite of careful determination of T_c of the amorphous alloys by various methods ambiguity of T_c values still remains a open question specially for the amorphous alloys because amorphous glassy metal alloys are basically metastable materials. It has been demonstrated by numerous experimental evidences that when the materials with the same compositions are produced with different quenching rate, magnetic properties, in particular the Curie temperature can vary substantially. This fact prevents a reliable comparison between results obtained by different laboratories [11, 12]. The T_c of original FINEMET has been found to vary from 590K to 630K. Therefore the initial amorphous state should be taken into account.

CONCLUSION

The Curie temperatures of all the amorphous alloys have been determined by various methods like temperature dependence of low and high field dc magnetization, temperature dependence of permeability, ac susceptibility and Arrott plots from magnetic isotherm around T_c. The determined Curie temperatures by various methods are in good agreement within ± 2 K. The Curie temperature of the sample x = 0 has been determined to be T_c = 596 K which decreases to T_c = 143.5 K for x = 17.5.

REFERENCES

[1] A. Arrott Phys. Rev., 108, 1394 (1957)

[2] K.P.Belov, Magnetic transitions, Consultants Bureau, New York (1961)

[3] J.S, Kouvel and M.E.Fisher, Phys.Rev.,136 A, P.1626 (1964)

[4] N. Chau, N. X. Chein, N. Q. Hoa, P. Q. Niew, N. H. Luong, N. D. Tho, V. V. Hiep, JMM 282, 174-179 (2004)

[5] JMD Coey and H Sun, J. Mang. Magn. Mater. 87, L251 (1991)

[6] K Schnitzke, L Schultz,J Wecker and M Katter, Appl. Phys. Lett., 57, 2853 (1990)

[7] Md. Sultan Mahmud, International Journal of Advanced Materials Science, Vol. 5, No. 1 (2014) 5-11.

[8] M Endoh,M Iwata and M Tokunaga, J.Appl.Phys.Lett.,70, 6030 (1991)

[9] Md. Sultan Mahmud, International Journal of Advanced Materials Science, Vol. 5, No. 1 (2014) 61-67.

[10] B Gebel, M Kubis and K-H Muller, J. Magn. Magn. Mat., 174, L1-L4 (1997)

[11] K.Knobel, J.P.Sinnecker, R.Sato Turteli, N.R.Rechenberg, R.Grossinger, J. Appl. Phys., 73, 6603-6605 (1993)

[12] Md. Sultan Mahmud, Asian Transactions on Science & Technology 1(3) (2011) 1-6.