Structural, Magnetic and Transport Properties of Magnetically Ordered $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ Amorphous Alloy

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Abstract – ***The $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ amorphous alloy has been characterized by the structural, magnetic and transport properties measurements. The structural and morphological properties of the alloy were confirmed by the X-ray diffraction experiment and Scanning Electron Microscopy (SEM) respectively. The XRD pattern and SEM confirmed the amorphous nature of the specimen. The transport property is carried out at room temperature and the temperature range of (77-296) K. The magnetic impurities, scattering and topological spin disorder are thought to be responsible for the increase of resistivity of the samples. The magneto-resistance of the samples varied from 0 to 45% up to 1.0 Kilo Gauss of applied magnetic field. Room temperature resistivity measurement shows that the anomalous effect which is attributed to the anisotropic spin scattering centers, magnons and the magnetic impurities. The magnetization measurement shows the saturation magnetization of the sample.***

Key Words: *Amorphous ferromagnetism, X-ray diffraction, Magnetization, Anisotropic spin.*

1. INTRODUCTION

Metallic materials with a disordered atomic-scale structure are known as the amorphous metals. In contrast to most metals, which are crystalline and therefore have a highly ordered arrangement of atoms. Amorphous alloys are non-crystalline materials in which disordered structure is produced directly from the liquid state during cooling are called "glasses", and so amorphous metals are commonly referred to as "metallic glasses" or "glassy metals".

The studies of structural property of the materials are most important for the explanation of behavior of the materials due to engineering and scientific applications. The studies of the magnetic properties of amorphous ribbons are significant for a variety of applications such as power generator transformers, magnetic heads, magnetic shielding, magnetic bubbles for computer memory, amorphous superconductors etc.

The temperature dependence and the stability and cost of materials are to be considered besides their magnetic properties. The dc and ac properties provided characteristics suitable for different types of applications. Generally high electrical resistivity, high mechanical strength, good corrosion resistance, and absence of crystalline anisotropy, structural defects and grain boundaries characterize amorphous ribbons. The magnetic properties such as saturation flux density, Curie temperature, magnetostriction and induced anisotropy can be controlled by the alloy composition and a subsequent heat treatment. The high electrical resistivity and the small thickness of the melt-quenched ribbons lead to low eddy current losses. The low hysteresis losses, results in very low core losses are of interest for power electronics at high frequencies. For application in small electronic devices, the amorphous ribbons have somewhat poorer losses than the conventional Fe-Ni-B ribbon. The design optimization requires lower cost of amorphous ribbons, higher induction compared to Fe-Ni-B ribbons. Amorphous ribbons have many refined applications also like development of magnetic bubbles for computer memory, amorphous superconductors etc. Research in the theoretical understanding, development and application of amorphous ribbons can thus be profitable, especially at its present new phase.

Amorphous ferromagnetism has been a subject of substantial interest in recent years [1-4]. Both experimental and theoretical progress have been made towards a better understanding of the ferromagnetic ordering in solids which do not possess long range periodicity in the atomic arrangement. In recent years, metallic glasses have received considerable experimental and theoretical attention owing to their anomalous magneto-transport and soft magnetic properties. These materials are interesting from both the fundamental and applied viewpoints. Because of various superior mechanical, magnetic and electrical properties, in comparison with those of the crystalline state, metallic glasses form a class of technologically important materials. They have already been put into applications in the devices e.g., choke coils, high frequency transformers and the magnetic thin film heads, reported in 1991 by Yoshizawa et al [5].

1.1 Objectives

The aims of this work are to study temperature and field dependence electrical resistivity, magneto-resistance, transport property and magnetization. The studies involved in the present work would provide useful information about its potentials in high frequency switching, spin wave devices and sensor devices as well as low and high temperature power applications. In order to achieve the aforementioned objective, the following main steps are included in the present work:

(1) X-ray diffraction analysis;
(2) Scanning electron microscopy;
(3) The *I-V* measurement for resistivity and magnetoresistance in different applied magnetic fields that ranges from 0 to 0.57 T at room temperature, low temperature and at a temperature range of (77- 296)K.
(4) B versus Magnetoresistance (MR%) at room temperature.
(5) Magnetization measurement at room temperature with the different applied fields.

2. EXPERIMENTAL

2.1 Structural Analysis

The X-ray diffraction experiment was performed on the sample using D8 Advanced Bruker XRD system with $CuK_{\alpha 1}$ radiation of wavelength λ = 1.5406 Å in the angular range of 2θ = 20° to 80° with a step size of 0.02° at room temperature.

2.2 Microstructural Properties

Scanning Electron Microscopy (SEM) experiments were carried out with a high resolution SEM machine (Model: JSM-7610F, OXFORD); with SEI DETECTOR and High Voltage 25.00 KV and the images were taken in different magnifications for getting better fracture images. The best image is being reported.

2.3 Transport and Magnetic Properties

The transport properties have been investigated through the measurements of electrical resistivity, temperature dependence resistivity and the magneto-resistance of the material. The magnetic properties carried out by the measurement of magnetization. A home-made vibrating sample magnetometer (VSM) was used to measure these properties.

There are various types of electrical methods for resistivity/conductivity measurements. The technique, that has been used here to measure the resistance of the metallic glass ribbon a conventional 4-probe technique.

The current (0-0.20A) passed through the sample and the corresponding voltage was measured. The resistance is then calculated from the slope after fitting the trend (straight) line to *I-V* curve as shown in figure 1.

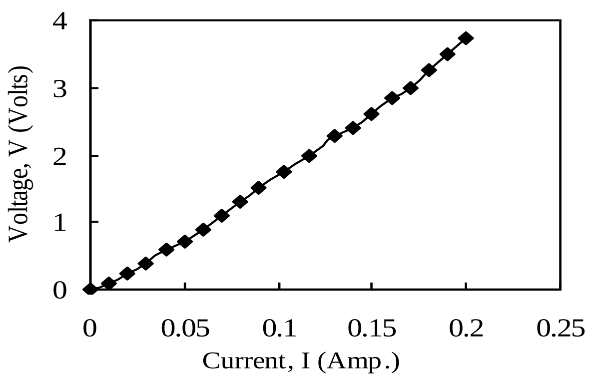

Figure 1: I-V Curve for the determination of resistance.

In this method, two of the probes have been used to measure the potential difference between two points, while the other terminals were used to pass current through the sample. For the electrical contacts silver glue has been used in the present work to avoid the difficulty. In this case the spacing between inner probes has been taken as effective length, *l* to calculate the resistivity as:

$$\rho = R \times \frac{A}{l} ohm - meter \quad (1)$$

where, *R* is the resistance of the sample, *A* is the cross-sectional area, which is the product of the width and thickness.

However, to measure the resistivity as a function of temperature, this 4-probe method has been used with the appropriate experimental setup, and those are discussed. Magnetoresistance measurement is done by the calculation method from the resistivity, measured by the standard 4-probe method as discussed. By the definition of magnetoresistance, it is given by,

$$MR(\%) = \frac{\rho(H) - \rho(H=0)}{\rho(H=0)} \times 100 \qquad (2)$$

Where $\rho_{H=0}$ is the resistivity at magnetic field, H=0 kilogauss and $\rho_{H=x}$ is the resistivity at magnetic field, H = x (x = 0-0.57) T corresponding to current (0-8) Amp.

3. RESULTS AND DISCUSSION

3.1 Structural Properties

3.1.1 X-ray Diffraction

Figure 2 demonstrates the X-ray diffraction patterns of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ sample within scanning angular range from 35° to 80° taking for four different duration or time length of experiments. From figure 2, we see that each pattern contains a small broad peak which confirms that the sample is amorphous in nature.

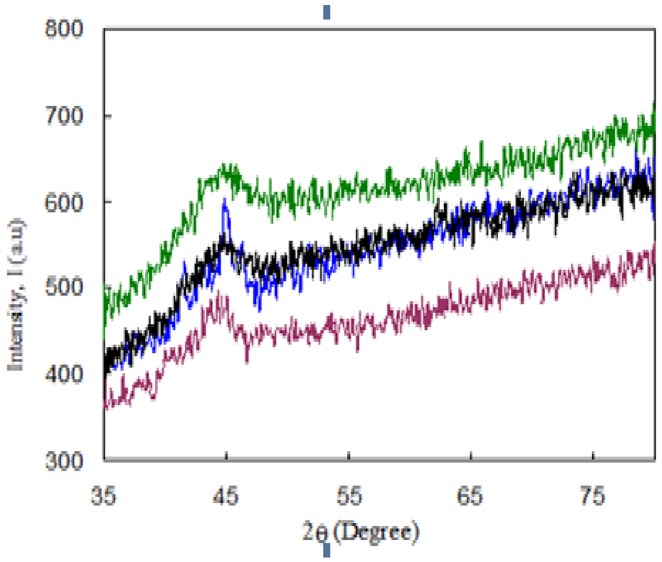

Figure 2: X-ray diffraction pattern of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ varies for different duration of measurements.

3.1.2 Scanning Electron Microscopy (SEM)

Figure 3 demonstrates the SEM fracture surface of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$. This figure is the magnification of 20000 times of the original structure of the amorphous ribbon. In the figure within the 10 μm range we see that SEM micrograph shows not any crystalline or any other grain boundary shape formation. The structure of this fracture surface thus confirms that the sample is amorphous in nature.

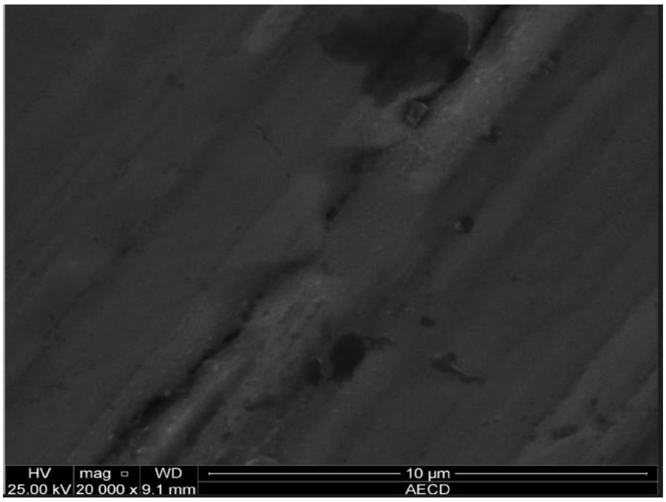

Figure 3: SEM micrograph of the sample (magnified 20000 times of the original).

3.2 Transport and Magnetic Properties

Two vital characteristics of the electrical resistivity of metallic glass are:

(1) their resistivity is relatively high, greater than 1μΩm at room temperature;

(2) their temperature coefficient of resistivity is very small and can be positive or negative.

The combination of these two properties leads to a very high residual resistivity at 0K. The high resistivity of amorphous alloy compared with that of the same alloy in the crystalline state is related to the increased scattering of the conduction electrons due to a random atomic arrangement. In such a random structure, the phonon contribution to the scattering of electrons is small, hence the small temperature coefficient of resistivity. A single theory which not to be able to provide any quantitative description of the low temperature transport properties of the transition metal alloy. Moreover, there are no theoretical grounds for believing that there is common explanation for the anomalous behavior of the resistivity with respect to temperature because of complicated interplay between configuration, thermal and magnetic disorder [6].

3.2.1 Room Temperature Resistivity

Isotropic and anisotropic spin scattering mechanisms should contribute to the resistivity in magnetically ordered amorphous metals [7-11]. For the scattering centers magnons, magnetic impurities and topological spin disorder have been proposed [7, 11, and 12]. In some cases, the structural disorder of the atomic sites introducing magnetic scattering to the resistivity [7, 13].

The relation between current and voltage for standard nickel sample is almost Ohmic and the voltage become steady after 1.2 mA of applied current which is illustrated in Figure 4.

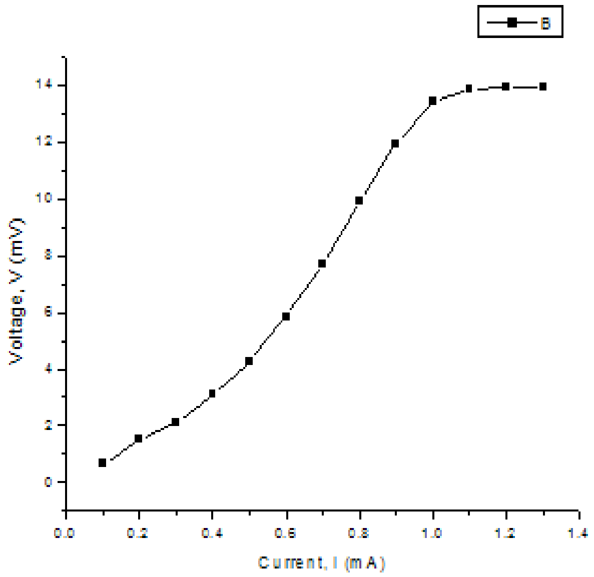

Figure 4: I- V curve for standard Ni sample at room temperature (RT).

At room temperature the voltage is linearly increases with the current through the ribbon but it decrease rapidly for the first case but very slowly in other cases with increasing the applied magnetic fields from 0 to 1.2 Tesla as shown in figure 5 below.

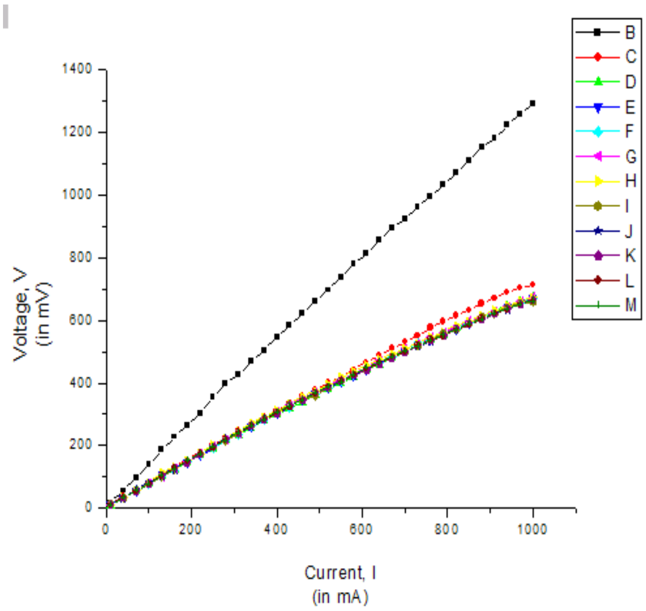

Figure 5: I-V curve of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ at room temperature with different applied magnetic field.

3.2.2 Temperature Dependent Resistivity

The voltage is linearly proportional to the applying current at liquid nitrogen temperature without any applied magnetic field but have a small pick in voltage for 700 mA of applying current as shown in figure 6, which may be as a result of any small noise or any other disturbance of the connecting devices.

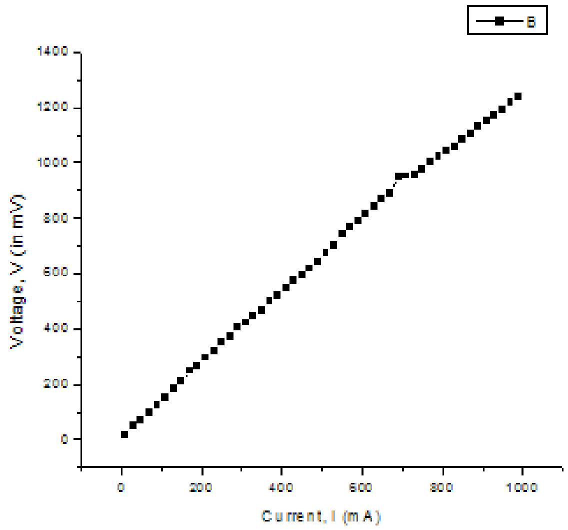

Figure 6: I-V curve in liquid nitrogen temperature for zero applied field.

For a maximum applied field of 1.2 Telsa the amorphous ribbon is almost Ohmic and the voltage slightly falls beyond 900 mA of applied current at liquid nitrogen temperature as in figure of 7 below.

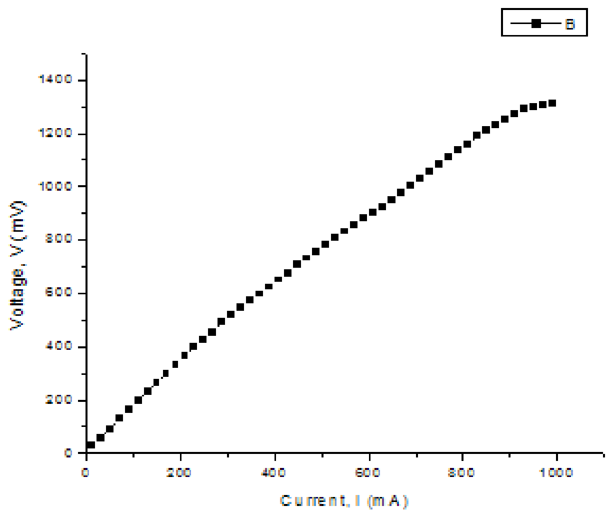

Figure 7: I-V curve at liquid nitrogen temperature (LNT) for maximum applied field.

Figure 8 shows the Ohmic characteristics of the specimen of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ for the temperature of 77 K to 296 K at zero applied field.

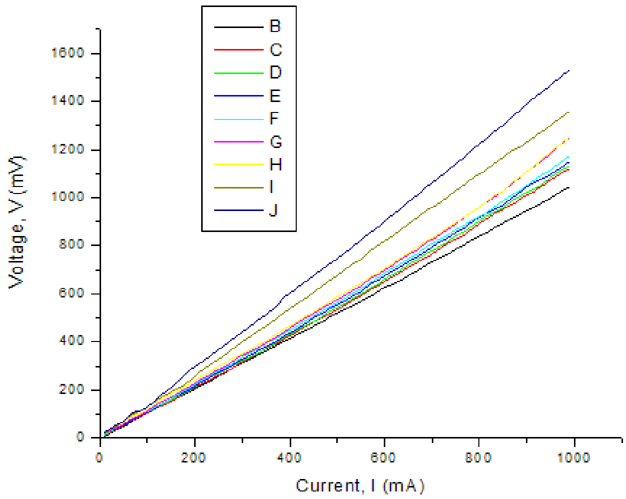

Figure 8: I-V curve of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ at 77K to 296K for zero applied field.

Figure 9 shows the temperature dependent resistivity of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$. At lower temperature the resistivity increases very slowly but at higher temperature (above 275 K) the resistivity increases very sharply.

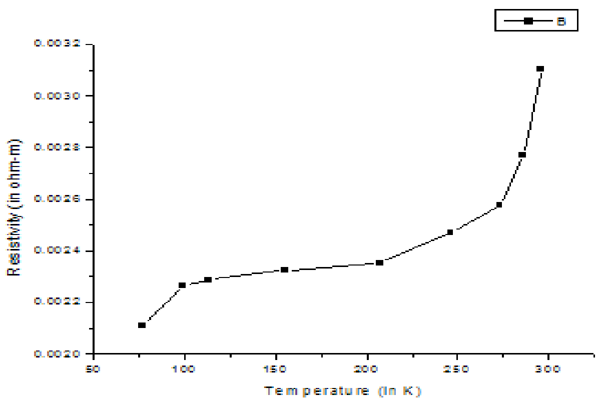

Figure 9: Temperature versus resistivity curve at 77K to 296K with zero applied field.

3.2.3 Magnetoresistance Measurement

The magnetization of the samples was determined with the help of Vibrating Sample Magnetometer. We have calibrated the VSM using a 152mg spherical sample of 99.99% pure nickel of known saturation magnetic moment. The current was applied to the electromagnet by Agilent power supply up to 8 ampere and the corresponding magnetic field was measured by the Gauss meter.

Figure 10 shows the MR% at room temperature for different applied magnetic fields. It is seen from the figure that MR% increases with increase in magnetic field. The MR% varies sharply from 0 to 45% with the variation of magnetic field then changes very slowly and for more than 6.5 Kilo Gauss of applied field it become steady.

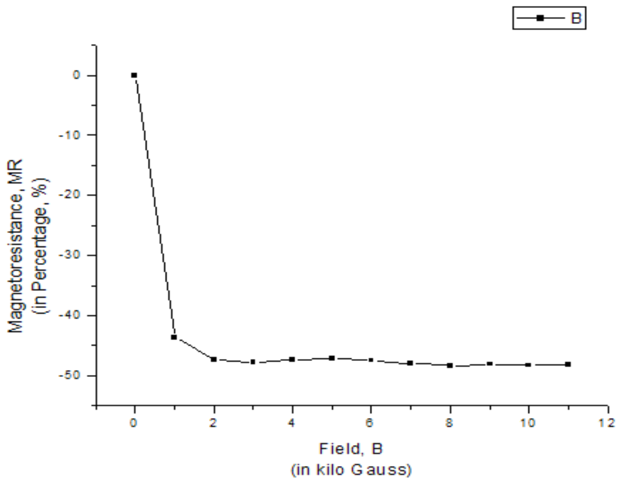

Figure 10: B versus Magnetoresistance (MR%) curve at room temperature.

3.2.4 Magnetization Measurement

Figure 11 shows the magnetization curve of the sample. From this graph we see that the magnetization of the ribbon increases with the increases of applied field and above the value of 0.8 Tesla it becomes saturated, by which we can conclude the nature of this material is somewhat ferromagnetic.

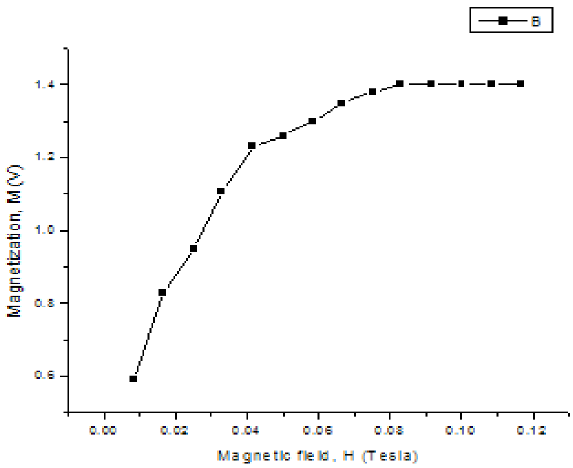

Figure 11: H-M (Magnetization) curve of $(Fe_{95}Cu_5)_{75}P_{15}C_{10}$ at room temperature.

4. CONCLUSIONS

The nanocrystallites in the single domain state have high uniaxial magnetic anisotropy and the electrical resistivity shown a sharp decline in the nanocrystalline state. Spin-flip magnons, magnetic impurities and the topological spin disorder were known contributors to the electrical resistivity. Frustrated spins together with the structural disorder of the atomic sites were the significant contributors to the transport properties of the metallic glasses aside from thermal excitations. However, these contributions to the electrical resistivity and anomalous effect are small in most cases demanding further investigation to these kinds of alloys. A significant contribution to the electrical and the magnetic transport properties of amorphous metallic system is also expected to come from anisotropic spin scattering. The size distribution of the nano grains in the crystalline state was also played a significant role in the electrical properties of this alloy.

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BIOGRAPHIES

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