

Dielectric Properties of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ Magnetic Alloy

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Abstract: The studied sample is a metallic glass in Fe-Si-B system. It is developed with the nominal composition of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ by single-roller melt spinning technique in air. The dielectric constant and loss factor have been measured both for as cast and annealed samples using Agilent Impedance analyzer. They are found to decrease with frequency up to 10 MHz and remain constant afterwards. The decrease of dielectric constant and loss factor with frequency is due to ceasing of orientational polarizability. Their constancy is owing to presence of only electronic contribution to its polarizability above 10 MHz. Three distinct regions (1-4 MHz, 4-10 MHz and 10 MHz-1 GHz) also noticed from its frequency dependence, which might make it useful in switching and sensor devices. The temperature dependence of dielectric constant and loss factor maintain inverse relationship: (1) dielectric constant increases, and (2) loss factor decreases with annealing temperature for structural relaxation due to thermal agitation.

Key word: Magnetic alloy, dielectric constant, loss factor, dielectric loss $\tan\delta$, annealing temperature.

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1. Introduction

Investigation of dielectric constant and loss factor of metallic glasses as frequency and temperature response is a necessity for most applications in solid state switching and sensor devices. The studied sample is a metallic glass in the $Fe-Si-B$ system. It is developed with nominal composition of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ in the form of ribbon by single roller melt spinning technique in air. Many investigations have thus far been performed on this metallic glass for its soft magnetic properties. But its intense study on dielectric properties is yet to be reported. As such, dielectric constant and loss factor of this metallic glass have been measured both for its as cast and annealed samples using Agilent Impedance analyzer. They are observed to decrease with frequency up to 10 MHz due to ceasing of orientational polarizability and remain constant

afterwards because of only electronic contribution of polarizability. Besides, three distinct regions (1-4 MHz, 4-10 MHz and 10 MHz-1 GHz) are noticed from its frequency dependence, which might make it useful in switching and sensor devices. In their temperature dependence, dielectric constant found to increase and loss factor to decrease with annealing temperatures due to structural relaxation. The annealing temperatures were 150 °C, 250 °C and 350 °C. Hence the objective of this paper is to apprehend a comprehensive study on dielectric properties of the studied sample.

2. Experimental

The ribbon samples with nominal composition of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ were prepared by the single roller melt-spinning technique in air. The ribbons were on an average 6 mm wide and 20-25 μ m thick. The room temperature amorphousness of the sample was verified by JDX-8P GEOL X-ray diffractometer. The complex permittivity (ac dielectric constant) is defined

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as follows [1]:

$$\varepsilon^* = \varepsilon' - j\varepsilon'' = \varepsilon' + (\sigma / \varepsilon_0 \omega) \quad (1)$$

Where ε' and ε'' are the real and imaginary parts of complex permittivity, σ is ac conductivity, ε_0 is vacuum permittivity, ω is angular frequency ($\omega = 2\pi f$) where f stands for frequency and $j = \sqrt{-1}$.

The real part of ε^* is often mentioned as relative dielectric constant or simply dielectric constant, denoted as ε ($\varepsilon = \varepsilon'$). The ratio of imaginary part of ε^* (or loss factor) to real part of ε^* is called loss angle tangent, $\tan \delta$ or dielectric loss, which is mathematically expressed as:

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'} \quad (2)$$

Both the dielectric constant ε' (real part) and dielectric loss, $\tan \delta$ of as cast and annealed samples were measured as a function of frequency that ranges from 1 MHz to 1 GHz while the oscillation level was kept at 500 mV. The measured technique was based on determination of admittance with a ribbon shaped sample using Agilent Impedance Analyzer. The loss factor ε'' has been determined using Eq. (2) in the same frequency range of both as cast and annealed samples. The samples were annealed for 15 minutes at temperatures 150 °C, 250 °C and 350 °C.

3. Results and Discussion

3.1 X-Ray Diffraction

Fig. 1 illustrates the X-ray diffraction pattern. Two broad peaks found to be within scanning angular range of 5° and 65°, which conforms its bi-phase nature. It is notable here that the sample used for amorphous verification was annealed at temperature 350 °C.

3.2 Dielectric Constant

The variation of dielectric constant (ε') for the annealed samples is presented as a function of frequency in logarithmic scale. Fig. 2 represents the frequency dependence of ε' . The trend is seen to be nearly same for both the as cast and annealed samples. The dielectric constant, ε' is found to remain almost constant up to 4 MHz, which is called limiting frequency. Up to 10 MHz, it decreases at high rate and afterwards remains constant. This decrease of ε' with frequency in the range 4 ~ 10 MHz can be attributed to multi-component contributions to its polarizability [2]. Ionic and orientation sources of polarizability are decreased with increase of frequency, and finally disappear due to inertia of grains, embedded in the amorphous matrix. Since electronic polarizability, α_e is the only process which is sufficiently rapid to follow alternating fields; its contribution is only present in ε' after 10 MHz. Furthermore, it is found

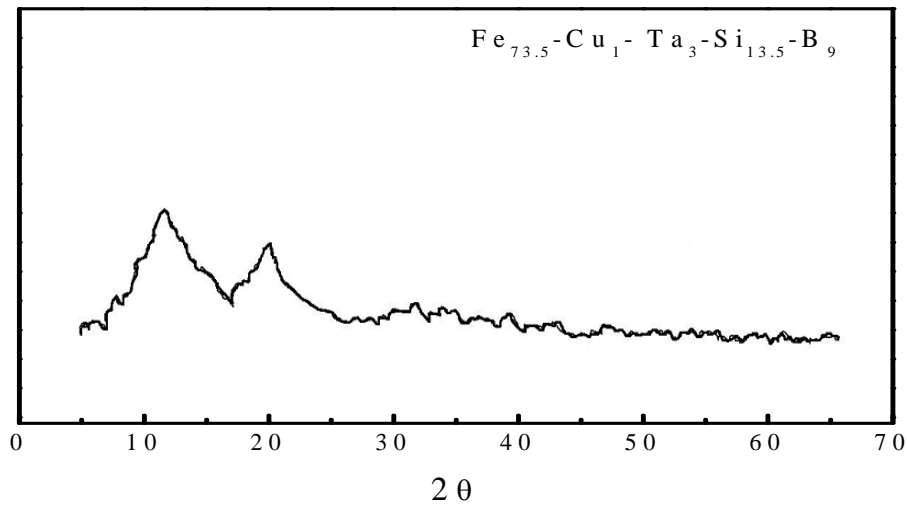


Fig. 1 X-ray diffraction pattern of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ magnetic alloy.

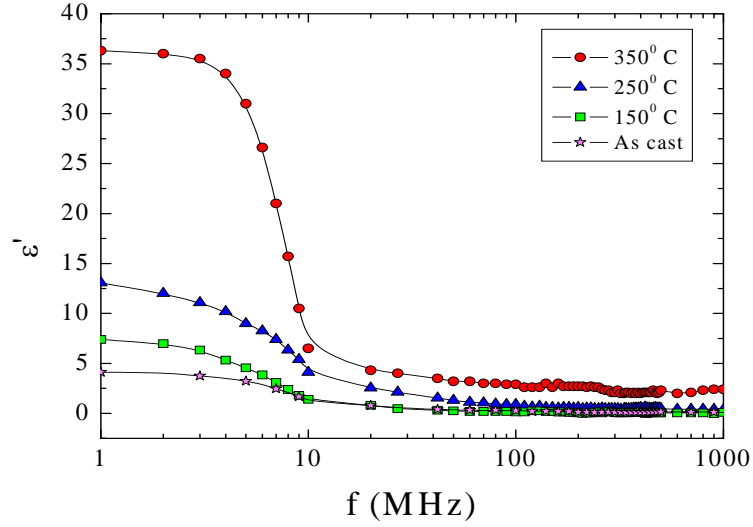


Fig. 2 The dielectric constant ϵ' vs. the frequency f for the samples.

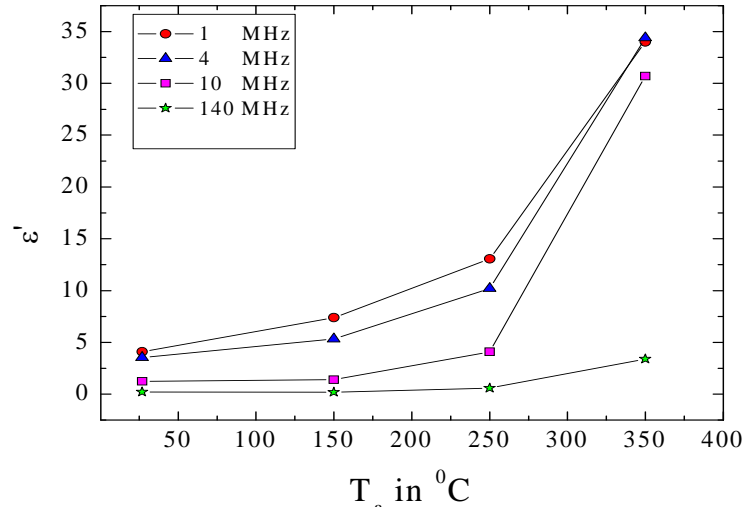


Fig. 3 The dielectric constant ϵ' vs. annealing temperature T_a for the samples.

to increase with annealed temperature T_a at constant frequency, which is evident from the variation of ϵ' with T_a as shown in Fig. 3. This increasing trend is resulted from structural relaxation due to heat treatment [3], which facilitates to increase orientational and electronic contributions to the polarizability. Thus, the strong dependency of ϵ' both on frequency and temperature is interdependent. All three components of polarization play their role in polarizability below 10 MHz. The orientational contribution ceases and only the electronic contribution is present above 10 MHz. The contribution from orientational polarizability is negligible because molecular dipoles are in frozen

state at room temperature. But at high temperature, polarization resulting from molecular dipoles becomes significant due to structural relaxation and adds to other contributions of polarizability. 1-4 MHz, 4-10 MHz and 10 MHz-1 GHz are the three distinct regions, evident from its frequency dependence, which might make it useful in switching and sensor devices [4].

3.3 Loss Factor

The variation of loss factor (ϵ'') for the samples is studied as a function of frequency and annealed temperature. Fig. 4 and Fig. 5 depict frequency dependence and temperature dependence of ϵ'' respectively. From Fig. 4, it is seen that ϵ'' decreases

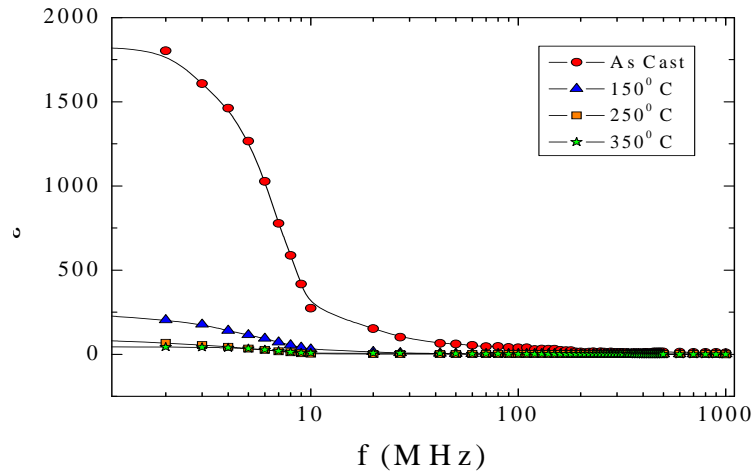


Fig. 4 The loss factor ε'' vs. the frequency f for the samples.

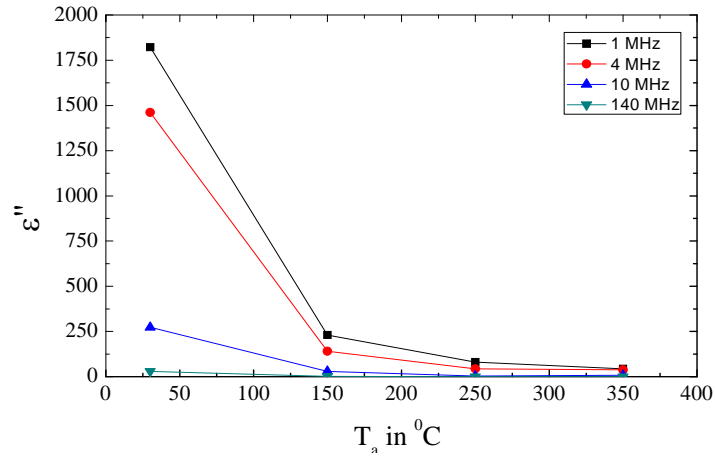


Fig. 5 The dielectric constant ε' vs. annealing temperature T_a for the samples.

with fast rate up to 10 MHz and then becomes almost constant. This type of variation is characterized by the high values due to contribution of conduction loss and electronic polarization loss because of embedded α -Fe (Si) crystallites in the amorphous matrix [5]. The loss factor ε'' is found to decrease with the annealing temperature T_a and thus maintains inverse relationship with the dielectric constant ε' , which is evident from the comparison of the variation of ε' and ε'' with T_a as shown in Fig. 3 and 5 respectively. This annealing temperature dependence of ε'' is because of enhanced dielectric constant ε'' , resulted from the structural relaxation due to thermal agitation. It is also noticed that the loss factor is very small compared to the dielectric constant of the annealed samples.

4. Conclusions

The so far discussion reveals the fact of strong dependencies of both the dielectric constant and loss factor on frequency and temperature. The effects of frequency and temperature are found to be interdependent. In lower frequency (<10 MHz), three components of polarization play a role in increasing dielectric constant as well as dielectric loss but at high frequency (>10 MHz), the orientational contribution is ceased to play and only the electronic contribution is present. At low and room temperature, the contribution from orientational polarizability is negligible because molecular dipoles are in frozen state. But at high temperature, due to structural relaxation, the polarization resulted from

molecular dipoles becomes significant and adds to other contributions of polarizability, and thereby increases dielectric constant and loss factor as well as dielectric loss. However, 1-4 MHz, 4-10 MHz and 10 MHz-1 GHz are found to be the three distinct regions as evident from its frequency dependence, which might make it useful in switching and sensor devices.

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References

- [1] Triantis, D., Stavarakas, L., Anastasiadis, C., Vallianatos, F., and Kershaw, S. 2004. "Bulletin of the Geological Survey." In *Proceedings of the 10th International Congress*.
- [2] Sharaf El-Deen, L. M., and Elkholy, M. M. 2002. "The Dielectric Polarizability of Amorphous $Cu_2O-Bi_2O_3$ Glasses." *Complexity International* 9.
- [3] Hakim, M. A., and Hoque, S. M. 2004, "Effect of Structural Parameters on Soft Magnetic Properties of Two Phase Nanocrystalline Alloy of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$." *Journal of Magnetism and Magnetic Materials* 284: 395-402.
- [4] Ahsan, M. Z., and Khan, F. A. 2008. "Measurement of Dielectric Constant of $Fe_{73.5}Cu_1Ta_3Si_{13.5}B_9$ Biphasic Metallic Glass." *Journal of Bangladesh Academy of Sciences* 32 (1): 107-9.
- [5] Hazra, S., and Ghosh, A. 1997. "AC Conductivity of Unconventional Bismuth Cuprate Glass." *Journal of Physics: Condensed Matter* 9 (19): 3981.