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Magnetic Barkhausen Noise in amorphous $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons

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Abstract

Magnetic Barkhausen Noise (MBN) measurements were performed on the as-quenched and annealed (heated at 540°C for 1 hour) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons. These amorphous nanocrystalline ribbons (commercially named FINEMET) gradually change from amorphous to nanocrystalline phase on heat treatment around their crystallization temperature. We have studied this phase transformation in these ribbons using MBN technique. The two peaks of the $MBN_{envelope}$ (which characterizes the MBN activity) for the annealed sample corresponds to the nanocrystalline and amorphous phase. The axial hysteresis loops of the samples were measured up to a maximum field of 2000 Oe. The phase structure of both as-quenched and annealed samples was verified by XRD measurements.

Keywords:

Magnetic Barkhausen Noise;
Amorphous Ribbon;
FINEMET;

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1. Introduction (12pt)

The application of an alternating magnetic field to a ferromagnetic material induces small discontinuous changes in the magnetization of the material. These sudden localized changes in magnetization are produced by the abrupt motion of domain walls from one pinning site to the next. The corresponding voltages induced in a pick-up coil on the sample are referred to as Magnetic Barkhausen Noise (MBN) [1]. Since its discovery in 1919 [2], this effect has been investigated extensively by many researchers, chiefly because of the scientific and technological interest in the study of various ferromagnetic domain structure and magnetization processes [3]-[4]. Barkhausen effect is found to depend on various physical properties of the material including the state of mechanical stress and microstructural parameters such as grain size, composition, texture and phase[5]-[6]. MBN arises primarily due to the interaction of domain walls with the pinning sites, hence any parameter such as stress, heat treatment, altering the distribution or configuration of domain walls or pinning sites affects the MBN. This principle is utilized for the non-destructive evaluation of stress and heat treatment in various magnetic materials using MBN [7]-[9].

In the present work MBN is investigated in amorphous $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons. These amorphous nanocrystalline ribbons (commercially named FINEMET) gradually change from amorphous to nanocrystalline phase on heat treatment

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around their crystallization temperature [10]. These amorphous ribbons are prepared from molten alloys by rapid quenching. MBN is a direct consequence of domain wall interactions with microstructural defects and hence it can give detailed information on material structure. Microstructural characterization of materials by Non-Destructive Evaluation (NDE) technique is essential for the assessment of initial heat treatment and subsequent degradation in microstructure and mechanical properties. Here we have studied the amorphous to crystalline phase transformation in amorphous $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons by using this non-destructive technique.

2. Research Method

Generation, detection and analysis of Barkhausen noise were accomplished using a home-fabricated Barkhausen noise measurement set-up. The instrument consists of a pair of Helmholtz coils for applying a time varying magnetic field to the sample to generate Barkhausen noise. The signal to the Helmholtz coil was produced by a 15 MHz Function/Arbitrary Waveform Generator (Agilent-33120A) and amplified by a Bipolar Operational Power Supply/Amplifier (Kepco, BOP 72-3M). The sample used in the present study was an amorphous ribbon (known under its commercial name FINEMET) with nominal composition $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ having dimensions 40mm × 2mm × 25μm. It is a conventional nanocrystalline material composed of ultrafine bcc FeSi grains embedded in a residual amorphous matrix. These amorphous materials gradually change from amorphous to nanocrystalline phase on heat treatment around their crystallization temperature. The $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbon was isothermally heated in a furnace in nitrogen atmosphere at 540^oC for 1 hour.

A magnetic field is generated by passing a low frequency (4 Hz) sinusoidal current through the Helmholtz coil. Barkhausen noise was detected using a pick-up coil (with 100 turns) wound around the samples located at the centre of the Helmholtz coil, with the samples aligned parallel to the direction of the magnetic field. The MBN signal was sampled at intervals of 25μs and eight traces were taken for each measurement. The signal received by the pick-up coil was amplified by 1000 times using a low noise preamplifier (Stanford Research Systems, Model SR560) and then passed through a band pass filter (3 – 300 kHz). Finally, it was interfaced with a personal computer. Only those voltage signals having amplitudes higher than a selected threshold were considered for analysis. The MBN activity was characterized by $MBN_{envelope}$, which represents the locus of the absolute values of MBN signal as a function of time. The axial hysteresis loops of the samples were measured by a vibrating sample magnetometer (Lakeshore) up to a maximum field of 2000 Oe. The phase structure of both as-quenched and annealed samples was verified by X-ray diffractometer (XRD, X'Pert Pro, Panalytic).

3. Results and Analysis

In this section, the change in phase transformation (from amorphous to nanocrystalline phase on heat treatment) in $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbon have been studied using MBN technique. Fig.1 shows the signal from the as-quenched and annealed (isothermally heated at 540^oC for 1 hour in nitrogen atmosphere) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons.

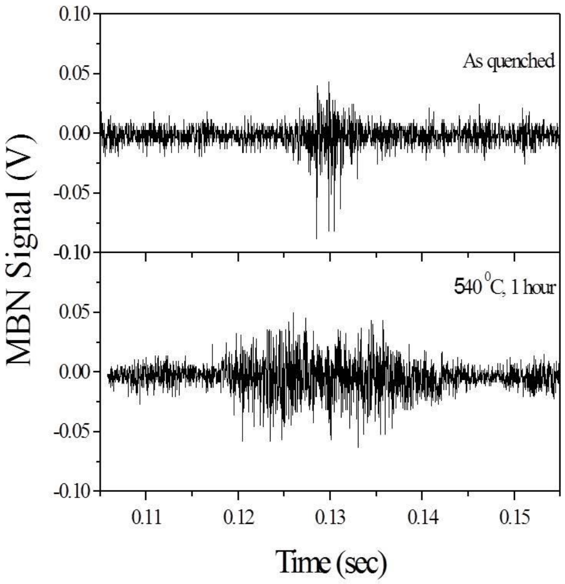

Figure 1.*MBN signal from the as-quenched and annealed (heated at 540°C for 1 hour) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons*

$MBN_{envelope}$ from the as-quenched and annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons are shown in Fig.2. It is observed from the figure that the $MBN_{envelope}$ show a single-peak and a double-peak for the as-quenched and annealed ribbons respectively.

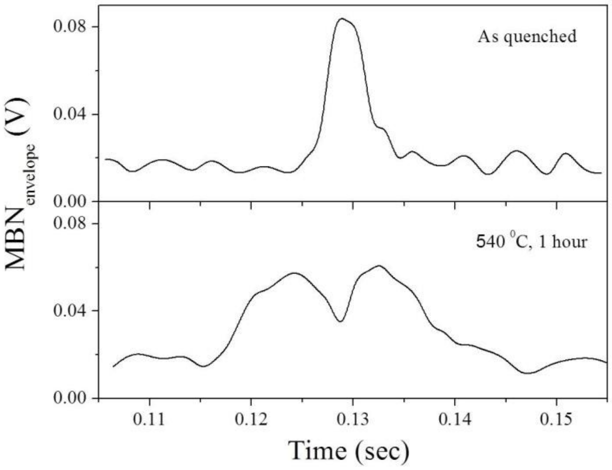

Figure 2.*$MBN_{envelope}$ from the as-quenched and annealed (heated at 540°C for 1 hour) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons*

The variation of the normalized magnetization as a function of the magnetic field of the as-quenched and annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons is shown in Fig.3. On annealing the sample, there is a jump in magnetization at low magnetic field as compared to the as-quenched sample.

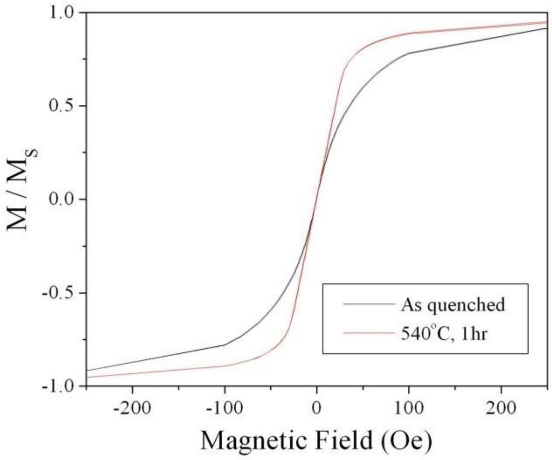

Figure 3.*Normalized magnetization as a function of the magnetic field of the as-quenched and annealed (heated at 540°C for 1 hour)* $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ *ribbons*

The X-ray diffraction patterns for the as-quenched and annealed (heated at 540°C for 1 hour) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons is shown in Fig.4.

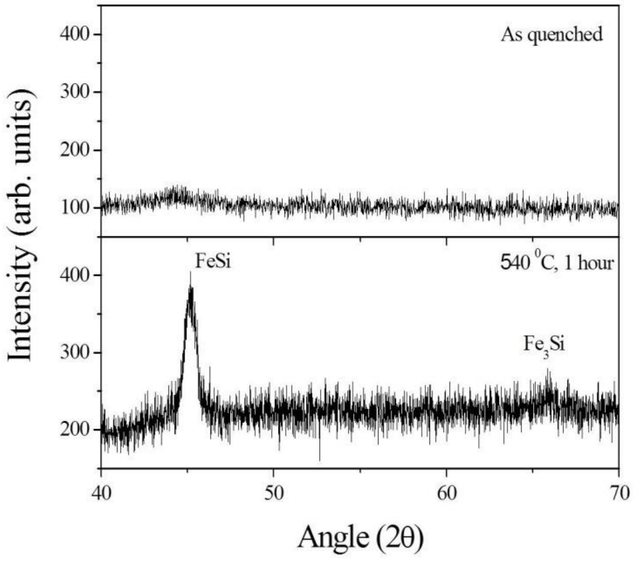

Figure 4.*X-ray diffraction patterns for the as-quenched and annealed (heated at 540°C for 1 hour)* $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ *ribbons*

The XRD pattern for the as-quenched ribbon exhibited only one very broad peak around 2θ = 45° (often known as diffuse halo) indicating that the ribbon is amorphous. XRD patterns of the annealed sample show two peaks at around 2θ = 45°and 2θ = 68°corresponding to α FeSi phase and Fe3Si phase respectively.

4. Conclusion

Magnetic Barkhausen Noise (MBN) measurements were performed on amorphous $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons both in the as-quenched and annealed (heated at 540°C for 1 hour) conditions. Experimental results (MBN signal and hence $MBN_{envelope}$)

show a single-peak and a double-peak for the as-quenched and annealed sample respectively. The single-peak can be attributed to the single amorphous phase of the ribbon. On annealing at 540°C for 1 hour, nanocrystalline α FeSi phase is formed in the amorphous matrix. Therefore, the two-peaks of the $MBN_{envelope}$ (for the annealed sample) correspond to the nanocrystalline and the amorphous phases. The phase structure of both as-quenched and annealed samples was verified by XRD measurements and hence supported our MBN results. This study shows that the MBN technique was successfully employed to study the phase transformation in amorphous $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline ribbons.

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