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ScienceDirect

Physica B 403 (2008) 2059–2064

PHYSICA B

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Temperature-dependent texture, stress and resistivity in melt spun $Cu_{0.95}Co_{0.05}$ ribbon

S. Majumdar[a], R.K. Singha[a], K. Das[a], M. Chakraborty[b], A.K. Das[a,*], S.K. Ray[a]

[a]*Department of Physics and Meteorology, Indian Institute of Technology, Kharagpur 721 302, India*
[b]*Department of Metallurgical and Materials Engineering, Indian Institute of Technology, Kharagpur 721 302, India*

Received 19 September 2007; received in revised form 5 November 2007; accepted 20 November 2007

Abstract

Ribbon samples of $Cu_{0.95}Co_{0.05}$ were prepared by melt spinning method to perform systematic investigations on structure and transport properties as a function of annealing temperature. X-ray diffraction study shows that the ribbon is polycrystalline with a strong $\langle 2\,0\,0 \rangle$ texture along the surface normal of the as-quenched $Cu_{0.95}Co_{0.05}$ ribbon and the degree of texture is enhanced upon annealing. The compressive stress, which relaxes upon annealing, is observed in as-quenched ribbon. The resistivity, which is higher in as-quenched ribbon, decreases toward the bulk value of Cu upon annealing. The compressive stress and higher resistivity in as-quenched ribbon are attributed to the incorporation of Co atoms/particles in Cu matrix. The decrement of the stress and resistivity upon annealing is due to the precipitation of Co atoms from the Cu matrix, segregating as Co or Co-rich Cu grains as observed from the transmission electron microscopy measurements.

PACS: 61.10.Nz; 75.50Cc

Keywords: XRD; Texture; Stress; Cu–Co ribbon; Grain growth; Resistivity

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1. Introduction

Ferromagnetic granular materials have drawn keen interest after the discovery of giant magnetoresistance (GMR) in multilayers [1,2] as well as granular thin films [3,4] of magnetic and nonmagnetic composites. Magnetic granular solids consist of nanometer-sized magnetic particles uniformly dispersed and embedded in an immiscible insulating or metallic medium. The magnetic granular solids show GMR effects not only in thin film form but also in bulk form like ribbon [5–7]. The origin of GMR in multilayer/granular systems is well established as a spin-dependent scattering of carriers from ferromagnetic layers/grains and their interfaces with nonmagnetic layers/grains [1–10]. Among different combinations of ferromagnetic and nonmagnetic systems, Cu–Co is attractive because of the highest GMR value observed in Cu–Co multilayers [11]. As a granular system, Cu–Co combination is also suitable because of the highly immiscible nature of Co in Cu, thus a separate identity of Co particles in Cu matrix is expected to be easily achievable.

Co and Cu are immiscible at room temperature, but metastable solid solution can be prepared by special methods such as fast quenching, laser ablation, electrodeposition and magnetron sputtering [5,6,12,13]. It is well known that the grain growth in bulk material system occurs due to the reduction of total grain boundary energy, which gives rise to an increase of the mean grain size of a polycrystalline body [14]. It is very difficult to produce a description of grain growth in bulk materials that accurately reflects the behavior of real systems in terms of kinetic coefficients or limiting grain sizes. But grain boundary energy and grain boundary mobilities are the most important factors to control the grain growth in the materials. It was found that grain growth [15], stress [16,17] and texture [18–21] alterations during the heat treatment have a significant influence on the microstructural property

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[*] Corresponding author. Tel.: +91 3222 283824; fax: +91 3222 282700.
E-mail address: amal@phy.iitkgp.ernet.in (A.K. Das).

0921-4526/\$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.physb.2007.11.030

and resistivity. In the present work, various X-ray-based techniques like θ–2θ scans, stress and texture analysis on melt spun $Cu_{0.95}Co_{0.05}$ ribbon have been done. Pole figures have been used for the analysis of the texture in the $Cu_{0.95}Co_{0.05}$ ribbon and observed $\langle 2\,0\,0 \rangle$ texture, which increased upon annealing. The stress analysis has been done by d–$\sin^2\Psi$ method and quantified compressive stress, which relaxed on annealing. The resistivity of the as-quenched ribbon decreases upon annealing. All the results have been explained on the basis of precipitation and segregation of Co from Cu matrix and supported by transmission electron microscopy (TEM) measurements.

2. Experiment

The ingot of $Cu_{0.95}Co_{0.05}$ was prepared with high-purity Cu and Co metal powders by arc melting process under argon atmosphere. The spun ribbon was prepared from ingot by planar flow casting in an argon atmosphere on a Cu drum. The thickness of the ribbon was 140–220 μm. The as-quenched ribbon was annealed at elevated temperatures in the range of 250–650 °C for 30 min in vacuum of 2.5×10^{-4} Torr. The heating rate used was 200 °C/h to reach the desired annealing temperature. The microstructure of the ribbon was investigated by X-ray diffraction (XRD). The θ–2θ geometry was used which collected diffracted X-rays from only $\{h\,k\,l\}$ planes that were parallel to the ribbon surface. We analyzed the texture of the ribbon by comparing the intensities of XRD peaks with that of polycrystalline bulk Cu. To gather the information regarding the spatial distribution of $\{h\,k\,l\}$ planes, we performed pole figure analysis. To obtain a pole figure, the detector and sample geometry were set such that the incident and diffracted X-rays satisfied the Bragg condition for a specific set of $\{h\,k\,l\}$ planes of the ribbon. A one-dimensional (1-D) pole figure was plotted by measuring the intensity of the X-rays diffracted from the sample as a function of the tilt angle (Ψ). A two-dimensional (2-D) pole figure was obtained by fixing the tilt angle first and then measuring the intensity as a function of azimuthal angle (Φ) about an axis perpendicular to the surface of the sample. The sample was rotated from 0° to 360° (Φ). After completing an azimuthal rotation, the sample was tilted by a single tilt-angle step (5°). Azimuthal rotation of the sample was repeated while the intensity of the diffracted beam was recorded. This process was repeated for the entire range of desired rotation and tilt angles. A schematic diagram of the experimental configuration for 2-D pole figure analysis and a corresponding stereographic projection are shown in Fig. 1. Contour plots showing the texture of the ribbon were made using the Philips X'Pert Texture software. The stress analysis was done using d–$\sin^2\Psi$ plot. TEM images were recorded by a high-resolution TEM (JEOL 2010) operated at 200 kV. The resistivity of ribbon was measured by four-probe technique at room temperature.

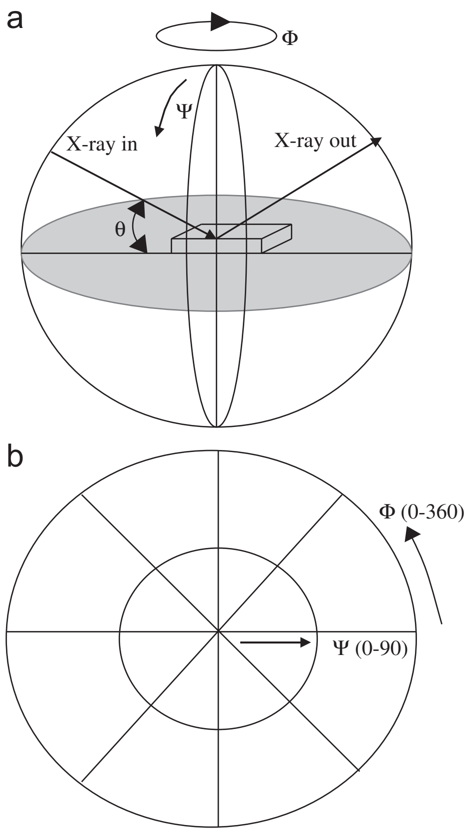

Fig. 1. (a) Schematic diagram of the experimental configuration for pole figure measurements with the diffractometer and (b) the corresponding stereographic projection.

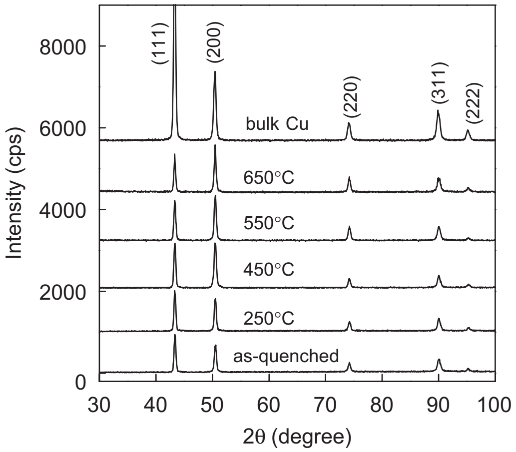

Fig. 2. XRD plots of as-quenched and annealed $Cu_{0.95}Co_{0.05}$ ribbons. Data were taken at $\Psi = 0$, $\Phi = 0$ in θ–2θ configuration. For clarity, the XRD patterns of annealed ribbons and bulk Cu are shifted upward adding arbitrary counts.

3. Results and discussion

The XRD patterns of as-quenched and annealed $Cu_{0.95}Co_{0.05}$ ribbons along with that of pure bulk copper are shown in Fig. 2. The incident intensity of Cu $K_{\alpha 1}$ X-rays was kept constant during the measurement of all