



Magnetization studies of binary and ternary Co-rich phases of the Co–Si–B system

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ABSTRACT

CoB, Co₂B, CoSi, Co₂Si and Co₅Si₂B phases can be formed during heat-treatment of amorphous Co–Si–B soft magnetic materials. Thus, it is important to determine their magnetic behavior as a function of applied field and temperature. In this study, polycrystalline single-phase samples of the above phases were produced via arc melting and heat-treatment under argon. The single-phase nature of the samples was confirmed via X-ray diffraction experiments. AC and DC magnetization measurements showed that Co₂Si and Co₅Si₂B phases are paramagnetic. Minor amounts of either Co₂Si or CoSi₂ in the CoSi-phase sample suggested a paramagnetic behavior of the CoSi-phase, however, it should be diamagnetic as shown in the literature. The diamagnetic behavior of the CoB phase was also confirmed. The paramagnetic behavior of Co₅Si₂B is for the first time reported. The magnetization results of the phase Co₂B have a ferromagnetic signature already verified on previous NMR studies. A detailed set of magnetization measurements of this phase showed a change of the easy magnetization axis starting at 70 K, with a temperature interval of about 13 K at a very small field of 1 mT. As the strength of the field is increased the temperature interval is enlarged. The strength of field at which the magnetization saturates increases almost linearly as the temperature is increased above 70 K. The room temperature total magnetostriction of the Co₂B phase was determined to be 8 ppm at a field of 1 T.

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1. Introduction

Co–Si–B alloys have been studied for the development of soft magnetic materials [1–3]. The ideal microstructure is constituted by an amorphous matrix embedded with nanocrystals formed during controlled heat-treatments. Since the stable crystals to be formed correspond to the Co-rich phases of the Co–Si–B system, it is important to determine their magnetic behavior as a function of applied field and temperature.

Some magnetic properties of the CoSi, Co₂Si, CoB and Co₂B phases have been found in the literature [4–11]. The Co₂Si phase is reported to be paramagnetic [3], while CoB and CoSi are diamagnetic [9–11]. Only the Co₂B phase is ferromagnetic, with a Curie temperature (T_C) in the 425–433 K [5,6,8] temperature interval and a room temperature saturation magnetization of about 47 A m²/kg

[4], or 378 kA/m (0.48 T) using the mass density of 8050 kg/m³ [5]. Most of these properties were determined by NMR studies.

The magnetocrystalline anisotropy constant K_1 of Co₂B was found to be negative between 77 and ~433 K [12], presents a minimum at 263 K and is zero for temperatures greater than 433 K (T_C). At 77 K, K_1 is very small and the values extrapolated to low temperatures reach zero at about 68 K. Therefore, K_1 vs. T behavior suggests an easy magnetization axis change from a direction within the a – b plane ($T > 68$ K) to a direction along the c -axis for $T < 68$ K [7,8] in the tetragonal structure of CuAl₂ type.

Up to now, it has not been reported any magnetic property data of the ternary Co₅Si₂B phase. The ternary rare-earth metal silicoborides compounds RE₅Si₂B₈ (RE = Y, Gd, Tb and Dy) are paramagnetic at room temperature [13]. Other silicoborides such as Fe₅SiB₂ and Mn₅SiB₂ are ferromagnetic [14,15] with Curie temperatures close to 785 and 410 K, respectively.

In the present work, the magnetic properties of CoSi, Co₂Si, CoB, Co₂B and Co₅Si₂B phase were evaluated by means of magnetization measurements as a function of the applied field and temperature.

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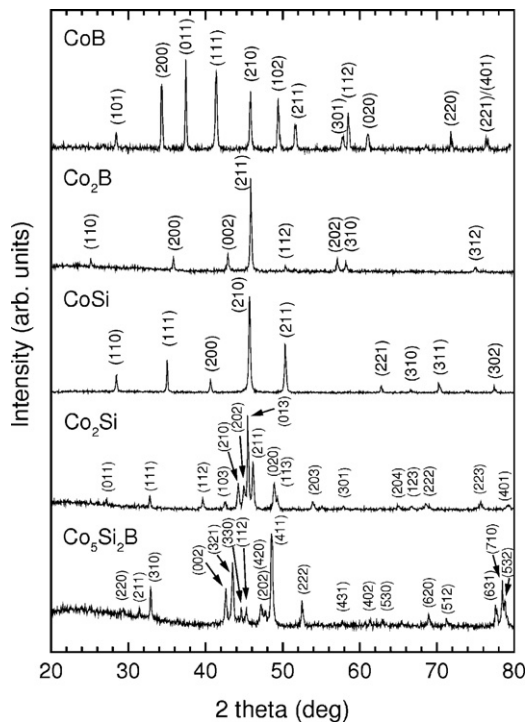


Fig. 1. X-ray diffraction patterns of the samples CoB, Co₂B, CoSi, Co₂Si and Co₅Si₂B single phases.

2. Experimental methods

In order to produce the phases of interest, Co–Si, Co–B and Co–Si–B alloys were prepared by arc melting with non-consumable tungsten electrode under titanium-gettered argon (min. 99.995%) from Co (min. 99.93%), Si (min. 99.999%) and B (min. 99.5%) in a water-cooled copper crucible. Three melting steps were carried out for each alloy in an effort to produce chemically homogeneous samples. After arc melting all the polycrystalline ingots were encapsulated in quartz tubes under argon, heat-treated at 1000 °C for 50 h then air-cooled. The heat-treated samples were characterized through powder X-ray diffraction in a Shimadzu XRD 6000 diffractometer, with Cu K α radiation and graphite monochromator. The measurements conditions were: angular interval 2θ from 20° to 80°, angular step of 0.05° and 5 s counting time.

The magnetic behavior characterization of the heat-treated samples was performed by AC susceptibility as a function of temperature (4–300 K) and DC magnetization measurements as a function of the applied field, using a PPMS system from Quantum Design. The DC magnetization measurements were carried out at fixed temperatures for applied fields up to 1.5 T. The samples masses were in the range of 57–87 mg. The measurements of the longitudinal and transverse magnetostriction of Co₂B (magnetic field parallel and perpendicular to the sample dilatation or contraction direction, respectively) were carried at 290 K using a capacitance dilatometer.

3. Results and discussions

Fig. 1 presents the X-ray diffraction patterns from the different Co–B, Co–Si and Co–Si–B alloys after heat-treatment. In each sample only peaks from the phase of interest were identified, i.e., CoB, Co₂B, CoSi, Co₂Si and Co₅Si₂B.

The DC magnetization vs. applied field (M vs. H) curves at 5 and 100 K and the AC initial susceptibility vs. temperature (χ vs. T curves, insets) of the CoB and Co₂B phases are presented in Fig. 2. It reveals a diamagnetic behavior (negative magnetic moment) of CoB and a ferromagnetic behavior of Co₂B (high value of M) as already observed in other studies [4,6,9]. The change in slope of the Co₂B magnetization curves before saturation for higher temperatures will be discussed later in.

In Fig. 3 the DC magnetization vs. applied field (M vs. H) curves at 4 and 100 K and the AC initial susceptibility vs. temperature (χ vs. T curves, insets) for the CoSi and Co₂Si phases are shown.

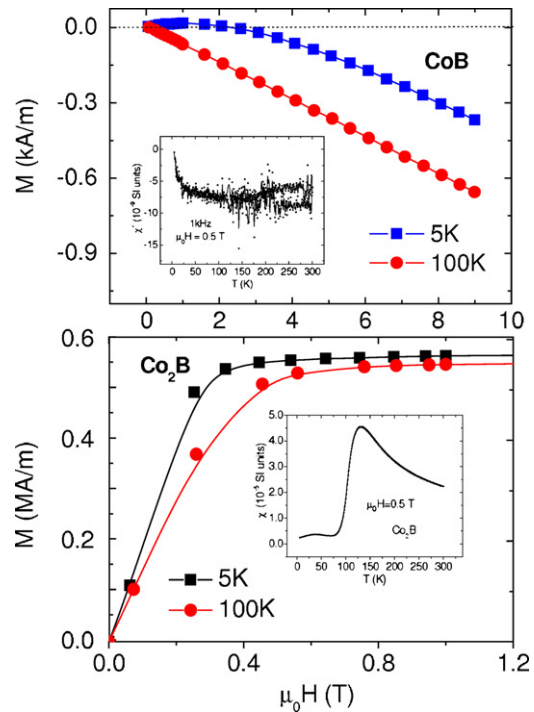


Fig. 2. DC magnetization results vs. applied field and AC susceptibility vs. temperature (inset) of the phases: (a) CoB and (b) Co₂B.

The positive results of the magnetic moments and therefore of the susceptibilities and magnetizations, points to a paramagnetic behavior of both phases. The result for Co₂Si agrees with the literature [4], however, the CoSi-phase was determined from NMR studies to be diamagnetic [10,12]. The Co–Si phase diagram [16] shows that the CoSi-phase has a small solubility range (~ 1.5 at.%), being surrounded by the CoSi + Co₂Si and CoSi + CoSi₂ two-phase

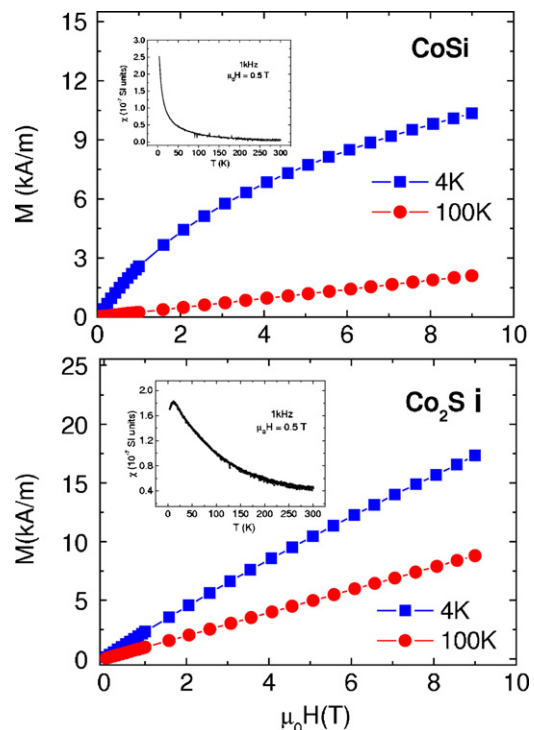


Fig. 3. DC magnetization results vs. applied field and AC susceptibility vs. temperature (inset) of the phases: (a) CoSi and (b) Co₂Si.

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