

# STRUCTURAL AND MAGNETIC BEHAVIOR OF VAPOR QUENCHED Fe–Mo ALLOYS \*

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Magnetic ordering temperatures ( $T_C$ ) of  $\text{Fe}_x\text{Mo}_{100-x}$  alloys over the entire composition range and magnetic properties at the boundary separating the crystalline and the amorphous phases have been studied. The  $T_C$  of the crystalline bcc alloys shows a percolation threshold at  $x \approx 20$ , and  $T_C$  rises with Fe content towards that of pure Fe. Large differences have been observed in the magnetic moment and  $T_C$  between amorphous and bcc alloys.

## 1. Introduction

New alloys of  $\text{Fe}_x\text{Mo}_{100-x}$  over the entire composition range have been fabricated by a high-rate sputtering device in spite of very small mutual solid solubilities allowed by the equilibrium phase diagram [1]. In this work we report the magnetic ordering temperature ( $T_C$ ) over the entire composition range and magnetic properties near the boundary ( $x = 80$ ) separating the amorphous and crystalline phases.

## 2. Experimental

The films of  $\text{Fe}_x\text{Mo}_{100-x}$  were prepared by sputtering onto liquid nitrogen cooled substrates of various kinds. Samples, typically 8–12  $\mu\text{m}$  thick, were removed from the substrates for accurate measurement of their magnetizations. It was found by X-ray diffraction that samples in the range of  $40 \leq x \leq 80$  are amorphous. The remaining alloys are single phase, having a bcc structure which is shared by both pure Fe and Mo. Magnetic properties were studied using a variable temperature superconducting magnetometer and a conventional Mössbauer spectrometer with a  $^{57}\text{Co}$  in Rh source.

## 3. Results and discussions

Fig. 1a shows the magnetic ordering temperatures of the  $\text{Fe}_x\text{Mo}_{100-x}$  samples. Several features are readily apparent. One notes that the  $T_C$  of the amorphous samples replotted in fig. 1b within the range of  $40 \leq x \leq 80$  are much lower than those of the crystalline samples. For the samples with  $x > 80$ , the metastable crystalline phase can not be maintained at high temperature, thus precluding a direct determination of  $T_C$ . For the samples with  $x \leq 30$ , the  $T_C$  values are all lower than 300 K and can be safely determined without causing irreversible structural changes of the samples. One important feature of the  $T_C$  value of bcc Fe–Mo

alloys is the exhibition of a simple magnetic dilution which is rarely seen in binary Fe-transition metal alloy systems, crystalline or amorphous. The magnetic dilution leads to a percolation behavior with a threshold of

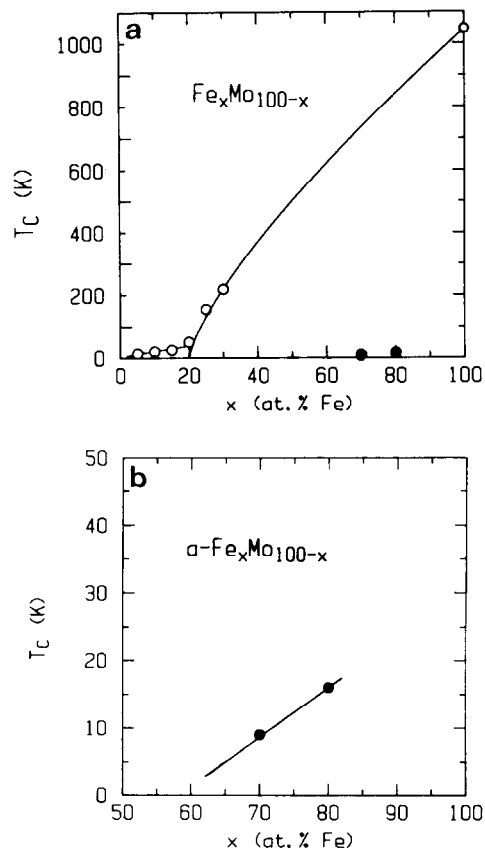


Fig. 1. (a) The concentration dependence of magnetic ordering temperature ( $T_C$ ) for  $\text{Fe}_x\text{Mo}_{100-x}$  alloys; (b) the values of  $T_C$  of  $\text{Fe}_x\text{Mo}_{100-x}$  amorphous alloys.

about  $x_c \approx 20$ . This value is in good agreement with the theoretical prediction for bcc structure if one includes first and second nearest neighbors [2]. The  $T_C$  curve for

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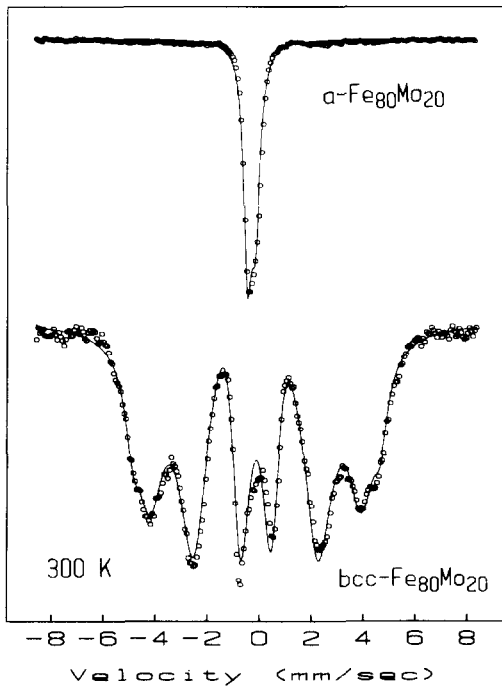


Fig. 2. Mössbauer spectra of amorphous and crystalline  $\text{Fe}_{80}\text{Mo}_{20}$  alloys at 300 K.

the bcc Fe–Mo alloys with  $x \geq 20$  can be fitted by the equation  $T_C(x) = 39(x - 20)^{0.75}$ , which is the solid curve shown in fig. 1a. In this region  $T_C$  rises with a rate of about 12 K/at% towards that of pure Fe. On the other hand, in the low Fe concentration region ( $x < 20$ ), the values of  $T_C$  rise only with a rate of about 2 K/at% which lies on a different curve as shown in fig. 1a. This magnetic phase diagram of Fe–Mo is similar to that of crystalline Fe–Au and amorphous (Fe–Ni)–metalloid alloys [3,4]. Qualitatively, the long tail found in  $T_C$  curve, which is not predicted by percolation theory with nearest or next nearest neighbor interaction, is indication of existence of long-range magnetic interactions.

Under the same fabrication conditions,  $x = 80$  separates the amorphous and the crystalline phases. However, by altering the deposition conditions, the composition of  $\text{Fe}_{80}\text{Mo}_{20}$  can be made both amorphous and bcc crystalline, thus allowing a direct comparison of the two states. The comparison vividly displays the sensitive dependence of the magnetic properties and the hyperfine interactions on structure. Mössbauer spectra at 300

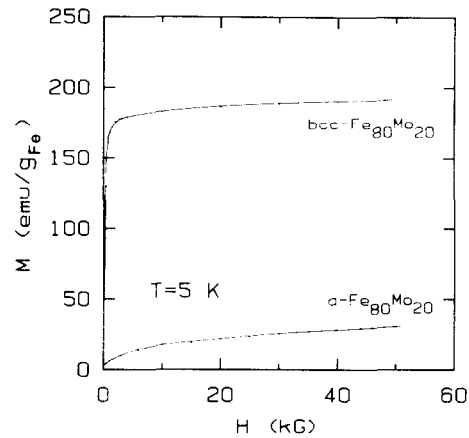


Fig. 3. The field dependence of magnetization of amorphous and crystalline  $\text{Fe}_{80}\text{Mo}_{20}$  alloys at 5 K.

K of these samples are shown in fig. 2. The amorphous sample is in a paramagnetic state and exhibits a quadrupole splitting in the Mössbauer spectrum. On the other hand, the crystalline sample has a much larger magnetic hyperfine field and is strongly ferromagnetic at room temperature. These samples also exhibit distinct differences in their bulk magnetic properties as shown in fig. 3. The crystalline sample, with a large magnetization of 190  $\text{emu/g}_{\text{Fe}}$ , can be easily saturated, (indicating a dominantly ferromagnetic interaction). The amorphous sample, with a much lower magnetization, fails to show moment saturation up to 50 kG. These distinct differences between crystalline and amorphous alloys have also been observed in many other Fe–early transition metal binary alloys (such as Fe–Ti, Fe–Ta, etc.) although less dramatically [5]. These abrupt changes in the magnetic properties can be attributed to structural differences.

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