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Amorphous Fe_xNb_{100-x} with wide composition range*

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Sputtered amorphous Fe_xNb_{100-x} ($30 \leq x \leq 85$) has been studied by Mössbauer spectroscopy and resistivity measurements. The samples with $x < 60$ are nonmagnetic. The magnetic ordering temperatures of the samples with $x \geq 60$ increase with Fe content. Small magnetic hyperfine fields are observed in the magnetic samples, consistent with the small Fe moments measured. The resistivity of the magnetic and nonmagnetic samples show different temperature dependences. Only the magnetic samples exhibit a resistivity minimum, indicating a Kondo-like mechanism.

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I. INTRODUCTION

It has recently been shown that vapor deposition techniques (e.g. evaporation and sputtering) provide a very effective means for fabricating amorphous solids over wide ranges in composition; far wider than those achieved by liquid-quench methods [1-4]. An example of such a system is amorphous Fe-Nb. Fukamichi and Gambino recently reported a study of the magnetic properties of co-sputtered a-Fe_xNb_{100-x} in the range $68 \leq x \leq 83$ [3]. In this work we report the results of a study of the magnetic properties, resistivity, and hyperfine interactions of a-Fe_xNb_{100-x} over the wider composition range of $30 \leq x \leq 85$.

II. EXPERIMENTAL

Amorphous Fe_xNb_{100-x} samples were deposited on liquid-nitrogen cooled substrates of copper, glass and saphhire using a high rate sputtering device [4]. Samples of Fe_xNb_{100-x}, sputtered from disks made from homogenous mixtures of Fe(99.9%) and Nb(99.8%), with $x \leq 90$ were made. Sample of $Fe_{90}Nb_{10}$ was partially crystalline. Only samples in the range of $30 \leq x \leq 85$ are discussed here.

The films deposited on copper substrates were typically 5-10 μm thick. The films were subsequently removed and stacked together to form the Mössbauer absorber. The resistivity samples, about 2 μm in thickness, were deposited on the glass and sapphire substrates on which Cu electrical contacts had been previously deposited. Masks placed over these substrates provided the desired geometry.

Mössbauer spectra were taken on a conventional constant acceleration spectrometer with a ^{57}Co in Rh source. A standard four-probe technique for the resistivity measurements was used. DC resistance data with both forward and reverse currents were recorded and averaged by a computer controlled data-logger.

III. RESULTS AND DISCUSSION

A. Magnetic Ordering Temperature

Magnetic ordering temperatures (T_C) have been determined from the onset of the magnetic hyperfine interaction by using the zero velocity thermal scan method [5]. Fig. 1 shows the results of such a scan on a sample of a-$Fe_{80}Nb_{20}$ while Fig. 2 shows all the measured values of T_C as a function of Fe content. It should be noted that our values of T_C are lower than those reported by Fukamichi and Gambino although in both cases the composition dependence is essentially linear [3].

The composition dependence of T_C in a-Fe_xNb_{100-x} differs significantly in two respects from that found in amorphous Fe-metalloid systems. First, the values of T_C for all the magnetic Fe-Nb samples are several hundred degrees lower than those in the amorphous Fe-metalloid systems with the same Fe content. Secondly, the critical composition for magnetic ordering (x_C)

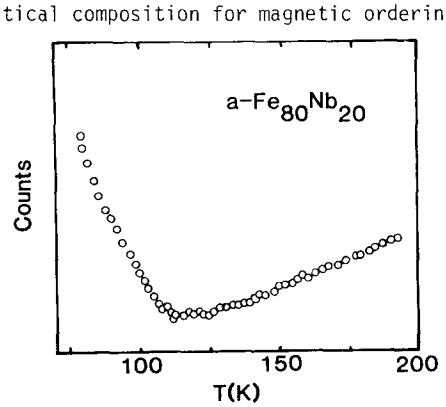

Fig.1 : Counts versus temperature in a thermal scan of amorphous $Fe_{80}Nb_{20}$.

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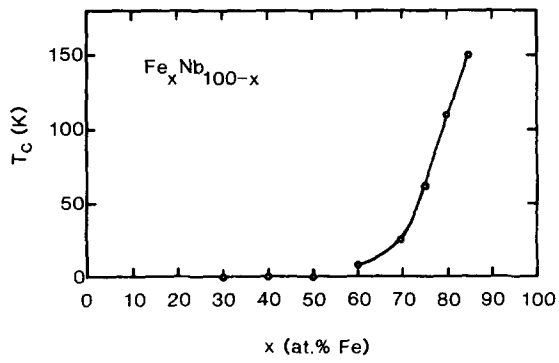

Fig.2 : Magnetic ordering temperatures of amorphous Fe_xNb_{100-x} as a function of Fe content.

of $x_c \simeq 60$ in amorphous Fe-Nb is much higher than the value of $x_c \simeq 40$ found in amorphous Fe-B, Fe-Si and Fe-Ge [1,6]. A likely cause for the high value of x_c in amorphous Fe-Nb is suggested from the magnetic properties discussed below.

B. Hyperfine Interactions

Room temperature spectra of several a-Fe_xNb_{100-x} samples are shown in Fig. 3. In every case one finds a partially resolved quadrupole-split doublet. In addition one notes that the asymmetry of the spectra changes sign in going from the Fe-rich to the Fe-poor samples with a-$Fe_{40}Nb_{60}$ showing little if any asymmetry. This asymmetry is a feature often found in the spectra of amorphous solids and can be empirically explained by a correlation between the isomer shift (IS) and the electric field gradient.

The average IS's (relative to α-Fe) at room temperature as a function of Fe content of both a-Fe_xNb_{100-x} and a-Fe_xB_{100-x} are shown in Fig. 4. It is evident that the IS's in the metal-metal system are much lower than those of the metal-metalloid system. However by extrapolating both curves to the amorphous pure Fe limit the two curves do seem to converge.

Fig. 5 shows the spectra of various a-Fe_xNb_{100-x} samples measured at 4.2 K. Sampes with $x < 60$ are non-magnetic and exhibit quadrupole-split spectra with splittings slightly larger than those at room temperature. Samples with $x \geq 70$ clearly show the presence of magnetic hyperfine interactions although the effective hyperfine magnetic field is rather small. The sample with $x = 70$, for example, has an effective field of less than 80 kOe and the largest hyperfine field, found in a-$Fe_{85}Nb_{15}$, is only about 160 kOe. The spectrum of the sample with $x = 60$ shows no obvious signs of being magnetic at 4.2 K. A

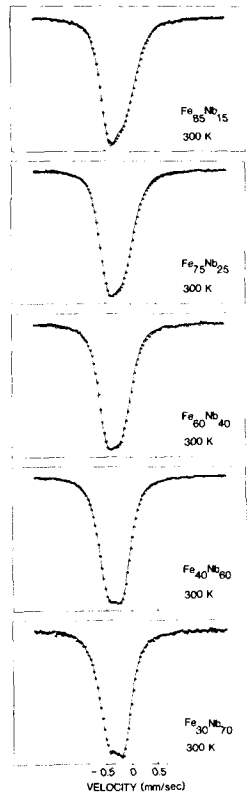

Fig.3: Quadrupole spectra of amorphous Fe-Nb samples at 300 K.

closer examination of the spectrum indicates that it is nevertheless magnetic but with a very small hyperfine field. Indeed, a thermal scan showed that the magnetic ordering temperature is about 8 K.

The small hyperfine field values found in the magnetic samples are consistent with the anomalously small Fe moments measured by Fukamichi and Gambino [3].

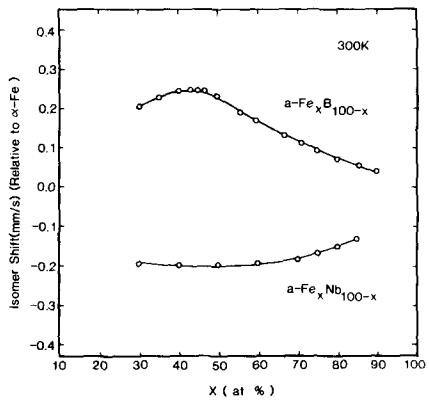

Fig.4 : Isomer shifts (relative to α-Fe) of amorphous Fe_xB_{100-x} and Fe_xNb_{100-x} as a function of Fe content.

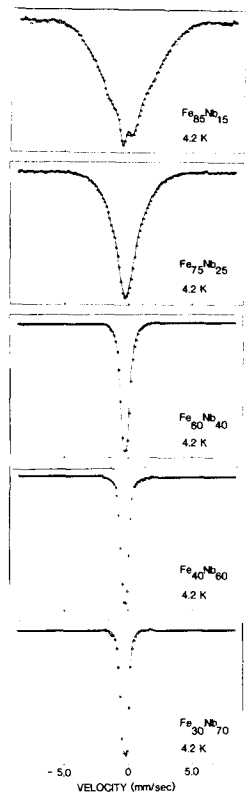

Fig. 5: Mossbauer spectra of amorphous Fe-Nb samples at 4.2 K.

In their work, the Fe moment increase from 0.15 μ_B to 0.9 μ_B as the Fe concentration is increased from $x = 68$ to $x = 83$. Thus both the hyperfine field and the Fe moment values indicate a rapid decrease to zero in the vicinity of $x = 60$. The vanishing Fe moment therefore accounts for the high value of x_c.

Resistivity

The temperature dependence of the resistivity has been measured from 2 K to 300 K. The values shown in Fig. 6 are normalized to the resistances at 300 K. In every case, as is typical in almost all metallic glasses, the resistivity only changes by a few percent over a large temperature range. However, the individual temperature dependences are clearly different. Some qualitative features are immediately apparent. The ρ vs. T curve for samples with $x \geq 60$ are all concave upward whereas for the samples with $x < 60$, the curves are all concave downward. For the samples with $x \geq 60$, there is always a resistivity minimum, which occurs at a successively higher temperature for samples with increasing Fe content. For the samples with $x < 60$, there is a maximum occurring at a successively lower temperature for samples with decreasing Fe content.

It is important to note that the composition of $x \simeq 60$, which divides the samples with different

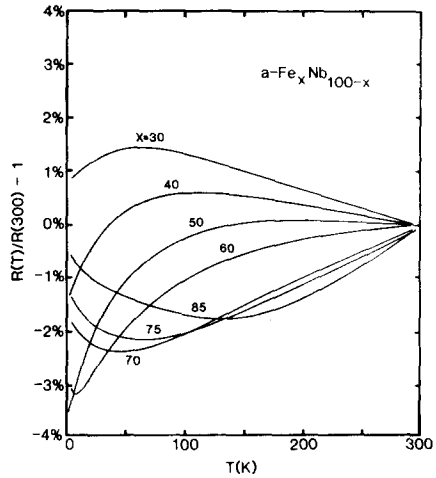

Fig.6 : Temperature dependences of resistivities of amorphous Fe_xNb_{100-x}.

resistivity characteristics also divides the magnetic and the non-magnetic samples. Only the magnetic samples exhibit a resistivity minimum.

The cause of the resistivity minima in amorphous metallic solids has been a perplexing subject for some time. Scattering of conduction electrons by weakly coupled magnetic moments (Kondo-type mechanism) [7], amorphous structure [9] and temperature dependence of the structure factor (Ziman-type theory) [9,10] are among the most often quoted mechanisms. The present study of amorphous Fe-Nb solids over a wide composition range indicates that the resistivity minimum is associated only with the magnetic samples. It is therefore most likely caused by the Kondo-like mechanism.

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