Spin-wave excitations in amorphous $Fe_{78}B_{13}Si_9$

S. C. Yu and J. W. Lynn
Department of Physics, University of Maryland, College Park, Maryland 20742 and National Bureau of Standards, Gaithersburg, Maryland 20899

J. J. Rhyne
National Bureau of Standards, Gaithersburg, Maryland 20899

G. E. Fish
Allied Signal, Inc., Morristown, New Jersey 07969

Inelastic neutron scattering measurements have been used to study the long wavelength spin dynamics of the high T_c amorphous ferromagnetic alloy $Fe_{78}B_{13}Si_9$ (Metglas 2605S2). Spin waves were observed over the accessible wave-vector range of $0.06\ Å^{-1} \leqslant q \leqslant 0.12\ Å^{-1}$, for temperatures between 473 K (0.67 T_c) and 705 K (0.99 T_c). The magnon dispersion curves exhibit the conventional quadratic relationship $E = D(T)q^2 + \Delta$, typical of an isotropic ferromagnet, where the small energy gap $\Delta \approx 0.05$ meV is attributed primarily to the dipole-dipole interaction. An estimate of the $T = 0$ value of $D \approx 156$ meV $Å^2$ was obtained from a plot of $D(T)$ vs T extrapolated to low temperatures, while the Curie temperature of 710 K was obtained from the extrapolation of $D(T)$ to zero at high temperatures. Spin-wave linewidth data for $T/T_c \approx 0.95$ showed the q^4 wave-vector dependence expected for magnon-magnon interactions.

INTRODUCTION

The magnetic properties of metallic glasses produced by rapid quenching have been the subject of considerable scientific and technological interest. Alloys, of composition near $TM_{80}M_{20}$, can exhibit very low coercive fields, quite high permeability, and have Curie temperatures well above room temperature. Allied Signal has found that the metallic glass having the nominal atomic composition $Fe_{78}B_{13}Si_9$ (Metglas 2605S2) has extremely low core loss at power transformer frequencies and inductions. The Curie temperatures and the crystallization temperatures of this alloy are found to be higher than any of the other Fe-B-Si amorphous systems.[1]

In order to obtain a better understanding of the high T_c amorphous alloys, we have undertaken detailed neutron scattering studies of commercially available $Fe_{78}B_{13}Si_9$ to determine the temperature and wave-vector dependence of the spin-wave excitations. Previous neutron scattering studies on ferromagnetic metallic glass systems showed that conventional spin-wave excitations are found at small wave vectors.[2] The present results confirm the basic conclusion that spin-wave theory is quite successful in describing the long wavelength magnetic excitations in amorphous $Fe_{78}B_{13}Si_9$.

EXPERIMENT

The sample of $Fe_{78}B_{13}Si_9$ used in our measurements was prepared in ribbon form from the melt by rapid quenching techniques in vacuum. Approximately 17 g of the ribbons 20 μm thick and 2.5 cm wide were loosely wound between two aluminum posts to produce a flat platelike sample. This was mounted in a vacuum furnace, and the neutron scattering measurements were taken on a conventional triple-axis spectrometer at the National Bureau of Standards Reactor. The amorphous nature of the system required that measurements be taken near the forward (000) beam position, and precautions were taken to minimize air and sample-container scattering at the small wave-vector (q) transfers required in the experiments. A fixed incident energy of 13.5 meV was used and a pyrolytic graphite (PG) filter was placed after the PG(002) monochromator to suppress high-order wavelength contaminations. Soller slit horizontal collimators of 12′-11′-12′-16′ were used to produce a FWHM (full width at half maximum) energy resolution ΔE of 0.35 meV at the elastic position. The wave-vector transfers examined were in the range $0.06\ Å^{-1} < q \leqslant 0.12\ Å^{-1}$ and the temperature range was from approximately 473 K (0.67 T_c) to 705 K (0.99 T_c). At lower temperatures the spin-wave energies were too high to measure with these experimental conditions.

RESULTS AND DISCUSSION

Values of the spin-wave energies and linewidths were obtained by convoluting a theoretical cross section with the instrumental resolution and least squares fitting to the observed spectra. Additional experimental details are given in Ref. 3. The spectral weight function used in the convolution was a double Lorentzian-type cross section. Figure 1 shows a set of typical constant-q neutron scans at 0.08 $Å^{-1}$ for 635, 660, and 698 K. The background and elastic scattering which arises principally from the furnace have been subtracted. Spin waves for both neutron energy gain ($E < 0$) and energy loss ($E > 0$) are easily observable and well resolved until they merge into a single central peak close to T_c. The solid lines are the result of the least-squares fits, and the spin-wave positions are indicated by arrows. The actual spin-wave energies occur at an energy which is lower than the observed peak position due to resolution effects.[3] We also observe a broadening of the peaks with increasing temperature.

 0021-8979/88/084083-03$02.40

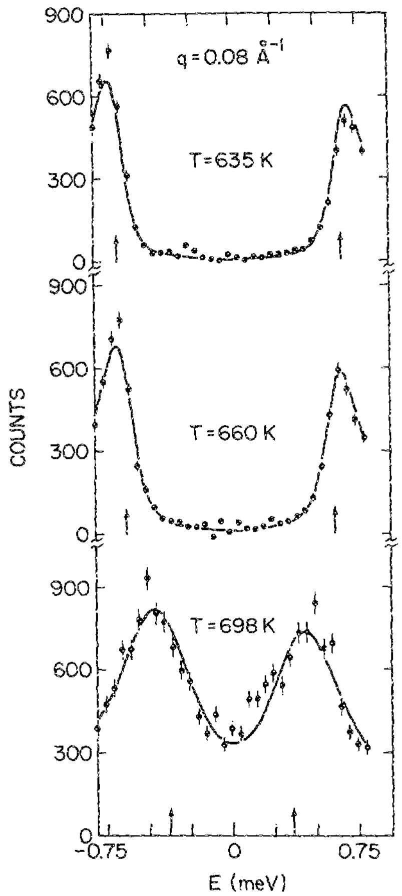

FIG. 1. Temperature dependence of spin-wave excitations in amorphous $Fe_{78}B_{13}Si_9$ at $q = 0.08$ Å^{-1}. The solid lines are the least-squares fits to the convolution of the cross section with the instrumental resolution. Background has already been subtracted.

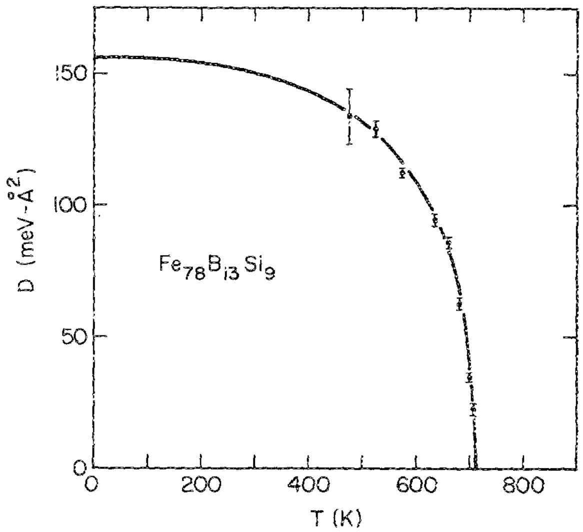

FIG. 2. Temperature dependence of the spin-wave stiffness constant obtained from the slopes of the dispersion relations.

The spin-wave energies obtained from the fits yielded the quadratic dispersion relation expected for an isotropic ferromagnet:

$$E_q = D(T)q^2 + \Delta + \cdots, \qquad (1)$$

where $D(T)$ is the spin-wave stiffness constant, q is the magnon wave vector, and Δ is an effective anisotropy gap which originates mainly from the dipolar interactions. We found a gap of $\Delta \approx 0.05$ meV independent of temperature over the range of the measurements. The stiffness constant D obtained from the slopes of the dispersion relation curves is shown in Fig. 2 as a function of temperature. The renormalization of the spin-wave stiffness is typical of isotropic ferromagnetic systems. The Curie temperature of 710 K was obtained from the extrapolation of $D(T)$ to zero at high temperatures, while the estimation of the $T = 0$ value of $D \approx 156$ meV Å^2 was obtained from the plot of $D(T)$ vs T extrapolated to low temperatures. From the extrapolated values $D(0)$ and T_c, the ratio (D/T_c) was determined to be about 0.22 meV Å^2/K, which is quite similar to values found in other amorphous transition metal ferromagnets.[2] In the Heisenberg model this ratio is directly related to the range of the exchange interaction.[4] The values of D obtained in the present measurements are somewhat smaller than the values measured for $Fe_{81}B_{10}Si_9$ and $Fe_{75}B_{10}Si_{15}$ by Minor *et al.*[5]

The observed spin-wave scattering will also have an intrinsic linewidth which can be measured if the instrumental resolution is sufficient. The magnitude of these linewidths can be extracted from the spin-wave data by convoluting the cross section with the instrumental resolution and least-square fitting the energy, linewidth, and scattering strength to the data. Typically, reliable linewidth data can be obtained in this manner when the linewidths Γ_q (FWHM of the Lorentzian spectral weight function) are greater than about 30% of the instrumental energy resolution. As can be seen in Fig. 3, spin-wave linewidth data for $T/T_c \approx 0.95$ (698 K) show the usual q^4 wave-vector dependence expected for thermally induced magnon-magnon interactions. The error bars shown are statistical only.

In summary, the overall results indicate that conventional hydrodynamic spin-wave theory provides an appro-

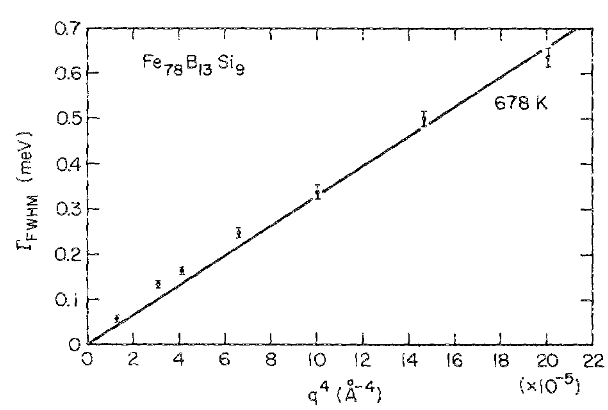

FIG. 3. Intrinsic spin-wave linewidth Γ_q (FWHM of the Lorentzian spectral weight function) vs q^4 for $Fe_{78}B_{13}Si_9$ ($T_c = 710$ K) at $T = 678$ K. The instrumental energy resolution (FWHM) was $\Delta = 0.35$ meV.

priate description of the long wavelength magnetic excitations in the soft amorphous ferromagnetic alloy $Fe_{78}B_{13}Si_9$.

ACKNOWLEDGMENT

The research at the University of Maryland was supported by the National Science Foundation grant No. DMR 86-20269.

[1] A. K. Bhatnagar and N. Ravi, Phys. Rev. B **28**, 359 (1983).
[2] J. W. Lynn and J. J. Rhyne, in *Spin Waves and Magnetic Excitations*, edited by A. S. Borovik Romanov and S. K. Sinha (North-Holland, Amsterdam, 1988), Part II, Chap. 4.
[3] J. A. Fernandez-Baca, J. W. Lynn, J. J. Rhyne, and G. E. Fish, Phys. Rev. B **36**, 8497 (1987).
[4] Further discussion of this point can be found in Ref. 3.
[5] W. Minor, B. Lebech, K. Clausen, and W. Dmowski, *Rapidly Quenched Metals*, edited by S. Steeb and H. Warlimont (Elsevier, New York, 1985), p. 1149.