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Polarization analysis of the magnetic excitations in $Fe_{72}Pt_{28}$ alloys

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Abstract

The discrepancy in Invar alloys between the magnetic excitation spectrum determined directly by neutron scattering and that inferred from magnetization measurements may be due to the significant contribution of longitudinal spin fluctuations to the excitation spectrum for $0 \leq T \leq T_C$. We have performed inelastic polarized neutron measurements about 000 of both ordered and disordered $Fe_{72}Pt_{28}$ single crystals below the critical temperature. As in crystalline $Fe_{65}Ni_{35}$ Invar, longitudinal excitations are observed only near T_C and are diffusive in nature. In contrast, similar measurements on the amorphous Invar alloy $Fe_{86}B_{14}$ found longitudinal propagating excitations below T_C.

The low- and moderate-temperature spin dynamics of isotropic ferromagnets are very well described by linear spin wave theory. The long wavelength excitations exhibit a quadratic dispersion with a stiffness constant D that is related to the coefficient of the leading order temperature dependence of the magnetization [1]. The predictions of spin wave theory have been spectacularly confirmed for many isotropic ferromagnets, including, for example, amorphous alloys [2]. However, for Invar alloys, the predictions of spin wave theory fail in a significant manner.

The Invar effect, originally seen in disordered $Fe_{65}Ni_{35}$ alloys as a magnetization-induced suppression of the thermal expansion, is presently understood as a volume-induced instability of the magnetic moment of certain 3d alloys [3]. Another manifestation of the Invar effect is the discrepancy between the magnetic excitation spectrum as determined directly by inelastic neutron scattering and as inferred from magnetization measurements, [1,2]. In particular, for disordered $Fe_{65}Ni_{35}$ or the amorphous alloy $Fe_{86}B_{14}$ [1], the observed stiffness constant is more than a factor of two greater than can be accounted for by the observed magnetization. Discrepancies of about 20% have been observed between neutron scattering and bulk magnetization measurements in both ordered and disordered Fe_3Pt alloys [4,5].

This discrepancy may occur because there are 'hidden' excitations, in addition to conventional spin waves, that reduce the magnetization. One possible explanation for the 'hidden' excitations is that the transverse spin waves couple to the longitudinal fluctuations, giving propagating longitudinal excitations. We have been performing inelastic polarized neutron measurements on several Invar and non-Invar systems in an effort to explicitly separate the longitudinal excitations from the transverse [6–8]. Here we report on inelastic polarized neutron measurements on the magnetic excitations of both atomically ordered and disordered $Fe_{72}Pt_{28}$.

The inelastic polarized neutron scattering that we have performed is straightforward in principle [9]. The transverse spin wave scattering is represented by raising and lowering operators ($S^{\pm}$) in the Hamiltonian and always causes a neutron spin flip. These cross sections, denoted by $(-+)$ and $(+-)$, are equal in intensity when the neutron polarization is perpendicular to the neutron momentum transfer, $\hat{\mathbf{P}} \perp \mathbf{Q}$. Furthermore, the longitudinal (S^z) scattering is related to the non-spin-flip cross sections $(++)$ and $(--)$, and is visible only if $\hat{\mathbf{P}} \perp \mathbf{Q}$.

The scattering measurements were performed at the NIST BT-2 polarized triple-axis spectrometer with 21′–10′–10′–20′ collimation before and after the Heusler alloy monochromator and analyzer, respectively; a pyrolytic graphite filter before the monochromator removed higher-order wavelength contamination. The incident neutron energy was fixed at 14.8 meV. In this configuration, the energy resolution is 0.33 meV full width at half maximum

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(FWHM), the longitudinal q resolution in the scattering plane is ~ 0.01 Å^{-1}, and the vertical resolution is ~ 0.1 Å^{-1} FWHM. The polarization efficiency of the spectrometer is greater than 90%, given the measured direct beam flipping ratio of 12.

The samples were approximately 20 g single crystals of $Fe_{72}Pt_{28}$, both cylinders of 2 cm length and 1 cm diameter, with the $h\bar{h}0$ axis at about 50° to the cylinder axis. Atomically ordered and disordered $Fe_{72}Pt_{28}$ have Curie temperatures $T_C = 510$ and 375 K, respectively. All the measurements were made well above the premartensitic transition that occurs below $T \approx 70$ K in $Fe_{72}Pt_{28}$. We applied a 5800 Oe field along the cylinder axis with a vertical field electromagnet to avoid the depolarizing effects of the magnetic domain structure and to minimize any nonuniformities due to the sample demagnetization, obtaining a through-sample flipping ratio at room temperature of $R \simeq 6$ and $R \simeq 10$ near T_C.

The constant-q inelastic scans, in the range $0.05 \lesssim q \lesssim 0.10$ Å^{-1}, were made about the 000 position, with several concomitant advantages: the magnetic excitations can be observed without a significant contribution from lattice excitations, and the magnetic form factor is close to unity. Nevertheless, there are several disadvantages to performing measurements about 000. The maximum achievable energy transfer increases linearly with momentum transfer, whereas the spin wave energy increases quadratically with q, thus limiting the possible range of temperature and momentum transfer where the spin waves can be observed. Also, the requisite small scattering angles necessitate tight angular collimation before and after the sample, thus reducing the signal considerably.

At each temperature, we measured the energy-dependent scattering for both spin-flip $(-+)$ and non-spin-flip $(++)$ cross sections. The data (see Fig. 1) were fit to a double-Lorentzian spectral-weight function and an elastic central peak, which were numerically convolved with the triple-axis spectrometer resolution function [10], including the effect of the polarization-dependent cross sections [11]. Since the q-resolution is finite, the spin wave dispersion was assumed to be quadratic in q and the broadening was assumed to increase as q^4 over the resolution volume, according to spin wave theory. The excitation energies are significantly higher in the polarized data than those obtained at the same T and q for unpolarized beam measurements [5]. This is due to the applied field, which opens up a gap $g\mu_B H \approx 0.1$ meV. In the $(++)$ configuration at room temperature, we observed no signal other than leakage due to the imperfect polarization of the instrument and sample.

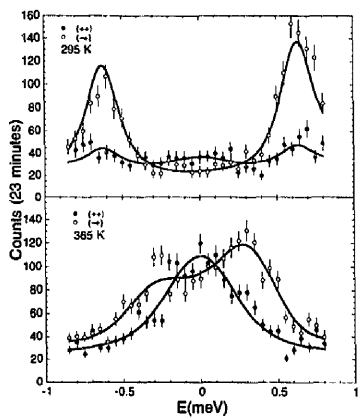

Fig. 1. Constant-q spin-flip (○) and non-spin-flip (●) scans for disordered $Fe_{72}Pt_{28}$ for $q = 0.08$ Å^{-1}; (Top) at room temperature ($T/T_C = 0.79$), (Bottom) at 365 K ($T/T_C = 0.97$).

As the temperature is increased toward T_C, the sample polarization improves, increasing the flipping ratio. The spin wave energies decrease, and a central peak develops for both cross sections. Again, we saw no evidence for propagating excitations in the $(++)$ cross section. This is similar to the behavior observed for crystalline Invar $Fe_{65}Ni_{35}$ [8] and differs dramatically from the behavior observed for amorphous $Fe_{86}B_{14}$, where excitations at finite energy were observed in the $(++)$ cross section. This difference in the behavior of crystalline and amorphous Invar systems leads us to suspect that the observed finite-energy excitations in the $(++)$ cross section are due to the amorphous nature of $Fe_{86}B_{14}$ and not to its Invar nature. In the case of the crystalline Invar systems, the 'hidden' excitations remain hidden and further work is required to resolve this puzzle.

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