Comment on "Spin-wave resonance studies in Invar films"

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The data obtained by spin-wave resonance studies in Invar films are suggested to provide no evidence against a description of the spin-wave energy in such alloys based on the random-phase approximation. Other measurements of the spin-wave energy of Invar are summarized. It is suggested that the most valuable future work on this problem would be that based on small-angle scattering of neutrons using bulk specimens.

It is proposed to comment on this paper[1] which raises an important physical question but fails to answer it to any degree of satisfaction. In addition, proposals will briefly be made which may eventually help to resolve the problem more conclusively.

The authors of Ref. 1 have made their spin-wave resonance (SWR) studies on Fe-Ni alloy films with Ni contents between about 10 and 60-at.% and covering the Invar region, about 25 to 40-at.% Ni. The alloys included both bcc and fcc specimens and their properties were sensitive to heat treatment. From the measurements, the spin-wave-energy coefficient D, defined by the relation valid for long wavelengths

$$\hbar\omega_q = Dq^2, \qquad (1)$$

was obtained as a function of the Ni content. For the fcc Invar alloys, D was found to *increase* on lowering the Ni content from about 40 to below 30-at. %.

This result was then stated to be in direct conflict with a random-phase-approximation (RPA) description of D (see, for example, Ref. 2), which would have D vanish as the magnetization vanishes; the disappearance of M in standard bulk samples occurs at about 25–30-at.% Ni. Since this result is very relevant as a test of RPA such as has long been desired, the results of Ref. 1 are at first sight very interesting. However, the authors themselves measure a quantity called "the internal field H_i, which represents the dependence of the magnetization for the fcc material at 300 °K." Between 25 and 40-at.% Ni, H_i varies from about 20 kG, reaches a minimum of as much as 14 kG at 35-at.% Ni (after annealing), and recovers to about 16 kG at 40-at.% Ni. Hence the Invar films being investigated do not have the sharp drop in the magnetization characteristic of bulk Invar specimens.[3,4] Thus in Ref. 4, M drops from about 1.8 μ_B at about 40-at.% Ni to 0.4 μ_B at about 27-at.% Ni, the lowest Ni content investigated there. Other evidence[5–7] also indicates that ferromagnetism disappears at very close to 25–30-at.% Ni, depending on the particular circumstances. It must be concluded, therefore, that (i) the films investigated in Ref. 1 are anomalous in having a high magnetization in the Invar region where much lower values of the magnetization in bulk specimens are well established, and (ii) the large values of D in this same composition range are in no sense anomalous and are thus not an argument against RPA, since this approximation only predicts small values of D when the magnetization is also small, which is not the case for these films. The nature of the films which caused their anomalously high M and D can only be conjectured.

Values of D for Invar have been measured elsewhere but there is no great confidence in any of the data so far obtained. Hatherly *et al.*[8] measured D by small-angle scattering (SAS) of neutrons, but stopped at about 40-at.% Ni. The values decrease even at this rather high nickel content. Rusov[9] obtained a relatively high value of D using SWR on films about 35-at.% Ni, which is, however, not all that out of line with the values of Ref. 8. SWR measurements of the pressure dependence of D of Invar were shown at least to be compatible with RPA.[10] Other SWR measurements, due to Maeda *et al.*,[11] again stop at about 35-at.% Ni and agree reasonably well with those of Rusov. On the other hand, a SAS measurement by Werner *et al.*[12] for a specimen with 30-at.% Ni gives a very low value of D, about $\frac{1}{3}$ that extrapolated from the SWR data of Refs. 9 and 11. Finally, Hiroyoshi *et al.*[13] estimated D from the temperature dependence of the high-field susceptibility of Invar alloys between 34 and 40-at.% Ni. This daring procedure gives rather low values of D lying close to and even slightly below the SAS value of Werner *et al.*[12] and extrapolating to zero D at about 30-at.% Ni.

This very meager evidence thus suggest that (i) SAS neutron measurements on bulk specimens would seem to provide the best hope in the future of obtaining values of D for bulk Invar specimens and thus of testing RPA in this respect, and (ii) SWR measurements on thin Invar films should be regarded with some caution.

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