MAGNETIC VISCOSITY IN NI/CU COMPOSITIONALLY-MODULATED ALLOYS

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The existence of a magnetic aftereffect ("magnetic viscosity") in Ni/Cu multilayered alloys was established using a vibrating sample magnetometer at room temperature and at 86 K. It was shown that the effect is strongly dependent on the step field, H_2 (i.e., the value the field is reduced to after the magnetic moment has been aligned in high field) and exhibits a maximum relaxation rate for values of H_2 around the reverse coercive field, $-H_c$. Aftereffect behavior of this type has been observed in other materials, though most often for systems composed of superparamagnetic particles, where the relaxation freezes out at low temperatures. In contrast, the relaxation in the CMA was shown to be enhanced at 86 K over its value at room temperature. New measurements over a wider temperature range show that the enhancement in this sample reaches a maximum near 120 K, but below that temperature the relaxation does freeze out. The temperature of maximum enhancement varies from sample to sample.

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**Supported by the Division of Materials Sciences, U.S. DOE under contract DE-AC02-76CH00016.

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INTRODUCTION

A variety of thin nickel¹ and iron² films, fine particles³ and spin glasses⁴ display magnetic "viscosities" or "aftereffects". These involve the rather slow relaxation, over hundreds of seconds, of a sample's magnetization when that sample is suddenly taken from a large externally applied magnetic field to a zero-valued field or one of a few tens of oersteds. The phenomenon has implications for magnetic recording and, even without such technological relevance, would be of interest because of the richness of the behavior which is seen. Preliminary results were reported¹ previously for compositionally modulated Cu-Ni films and the behavior of such films is explored more completely here.

Cu-Ni multilayers of 40 to 90Å repeat thickness were made by electro-deposition onto an annealed polycrystalline copper substrate from a single electrolyte, involving Ni plus a very dilute (1:100) amount of Cu, using an advanced pulsed electrodeposition system⁵. At low potential, only the more noble Cu metal is deposited, while, when the potential is set at a value corresponding to Ni, both metals will be reduced at rates limited by their relative concentrations. The result is a structure of unalloyed Cu alternating with Ni having low Cu content. More details of the deposition process and of the diffraction patterns and static magnetic properties of such films have been described elsewhere.⁶ The films compare favorably with those obtained by other means

and films manufactured by sputtering display⁷ similar aftereffects to those to be observed here.

The rate at which the magnetization decays from a common initial field depends on the final field. Two such decays are plotted in the insert to Fig. 1a. The sample used for these measurements is the same as that reported on in Reference 6, having a repeat distance or wavelength of 68Å with equal Cu and Ni layers of 34Å. (This sample has the best static magnetization behavior, suggesting the least interdiffusion between Cu and Ni, though it does not display the best diffraction pattern, of the samples we have obtained.) Note that the abscissa of the figure is the logarithm of the time, with the plotted points spanning from 7 to 170 sec after the high field was initially turned off. At shorter times, the decay is affected by the time needed for the external field to obtain its new value, and for any eddy currents to decay--effects seen in bulk foils of Ni which does not display the longer time aftereffects. Although there is an indication of curvature, at short times in one data set, it is quite clear that single straight lines can reasonably be fitted to the data. Experimental slopes have been determined by fitting the data between 20 and 170s and these are plotted in Fig. 1a as a function of H_2 at $T=290K$ for the sample in question. The slope, A , vs H_2 data can be characterized by (i) a peak value of A , A_{max} , (ii) the field, H_2 , at which this maximum occurs, H_{max} , and (iii) a

lineshape. The maximum falls at a final field corresponding to the sample's coercive field $H_c \approx 100$ Oe. In the case at hand, a Lorentzian provides a better fit to the data: some samples are better fit by Lorentzians at high temperatures and by Gaussians at low, while other samples are best fit by Gaussians throughout. This may be indicative of competing decay mechanisms. As was discussed previously¹ the various models of relaxation effects tend to peak when the final field equals the coercive field, just as seen here.

Given results, such as Figure 1a, taken as a function of temperature, one may ask how the maximum slope A_{max} , the field H_{max} at which A_{max} occurs, and the line width vary with temperature. Although it has not been verified in detail, experimentally, it would appear the H_{max} simply traces the temperature dependence of the coercive field.

RESULTS AND DISCUSSION

A_{max} is plotted as a function of temperature in Figure 1b for the sample represented in Figure 1a. Also shown are results (scaled by a factor of 2 so as to bring the plot on scale) for the (110) textured sample of Reference 1. The scaling implies greater maximum relaxation rates in the second sample. These two samples have A_{max} which go through extrema at different temperatures. These extrema were not observed by us previously since the experiments had not been taken at enough different temperatures to pick up the turnaround. Among the samples which we have measured, for

which results are not displayed, one shows only a low temperature increase without a turnaround up to room temperature where the measurements stop. Presumably it would go through an extremum at high temperatures and, if so, this extremum is a feature of all the Cu/Ni multilayers.

The widths of the A vs H_2 curves roughly track the behavior of the coercive field which decreases monotonically with increasing temperature although, in some cases, the widths go through minima at temperatures well above those at which the extrema in the A_{max} vs T curve occurs. This, too, may be indicative of competing relaxation processes at play.

The maximum values of the relaxation rates (that is, the A_{max}) have been found to vary from sample to sample by somewhat less than an order of magnitude and the temperatures at which the maxima occur vary substantially (particularly if the sample discussed above does peak above room temperature). No simple correlation can be made between these variations and what is known of the samples, such as Cu or Ni layer thicknesses. More samples and better sample characterizations are required to disentangle this. We intend, for example, to view domain pattern behavior in the future.

Starting at low temperatures, relaxation rates increase with increasing temperature and this is readily understandable since such processes tend to be frozen out at low temperatures. What is remarkable is that the rates go

through an extremum and decrease, as well at high temperatures. To our knowledge, these Cu/Ni multilayers are the first case where the magnetic viscosity behaves in this way. Some other factor in addition to freezing, is affecting the relaxation rates at high temperatures. This issue remains to be disentangled.

CONCLUSIONS

We have found that compositionally-modulated Ni/Cu alloys exhibit magnetic after-effects. At any given temperature, the magnitude of the aftereffect, A_{max} , exhibits a maximum at a stepped field near the coercive force. The magnitude of A_{max} is found itself to have a maximum at a temperature ranging from ~100K to >300K, depending on the sample tested.

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