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LAYERED MAGNETIC SUPERLATTICES

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ABSTRACT

The properties of non-lattice matched layered magnetic superlattices are strongly affected by the layering process. D. C. Magnetization measurements exhibit thin film effects and light scattering observation of the magnon spectra shows the existence of superlattice effects. Nuclear magnetic and ferromagnetic resonance experiments imply the existence of a variety of local fields depending on the distance from the interface.

INTRODUCTION

Metallic multilayers have been used for some time in applications relating to magnetic recording.¹ Magnetic multilayers are also useful in basic studies relating to dimensional² and thin film³ effects. In addition, in some cases, it is possible to produce phenomena which depend on the periodic nature of the stack, i.e.,

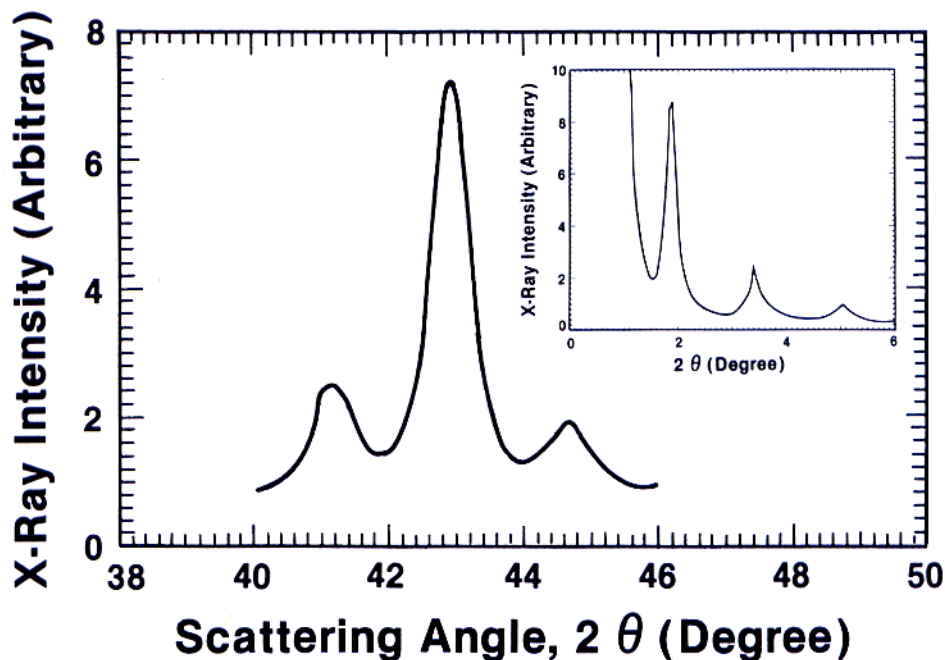


Fig. 1. X-ray diffraction from V/Ni superlattices at high and low (inset) angles.

superlattice effects.⁴ Here we summarize our studies in a variety of magnetic superlattices that are formed from elements whose constituents do not form solid solutions in their binary phase diagram and that are not lattice matched.

STRUCTURE AND MAGNETIC PROPERTIES

The superlattices were prepared using a sputtering technique developed earlier.⁵ In this method the multilayers are prepared by alternate sputtering of two elements on a heated, single crystal substrate (Al_2O_3 , mica, Si, Ge, BaF, MgO, etc.). Structural studies of superlattices are of key importance for the understanding of their physical properties. The importance of the structural studies is emphasized by the fact that not all combinations of elements can be grown on layered form either because of interdiffusion or disorder. Moreover, the reason for layered growth has not been established although some qualitative ideas have been advanced.^{6,7}

Figure 1 shows the results of an X-ray diffraction study of V/Ni superlattices.^{8,9} The inset shows "small angle" diffraction measurements which directly give the amplitudes of the Fourier transform of the composition modulation. These small angle measurements however give no information on the crystallinity of the layers. Information about the crystallinity can be obtained from scattering at high angles. The existence of the various peaks in this measurement can be related directly to the growth of crystalline layers.¹⁰ In particular, for the bcc/fcc superlattices (V/Ni and Mo/Ni) studied to date the structure consists of bcc(110) planes stacked on fcc(111) planes with random orientation in the plane of the film. Recently, a microcleavage technique has been applied to directly image the layers in transmission electron microscopy measurements.¹¹

The magnetic properties are strongly influenced by changes in the layer thicknesses of the magnetic or normal metal constituents.¹² Figure 2 shows the low temperature ($\sim 5^\circ\text{K}$) saturation magnetization of Ni/Mo superlattices using a SQUID magnetometer. These results imply that the decrease in the saturation magnetization is mostly due to a decrease in the Ni thickness although there is some indication of coupling across the normal metal (Mo).

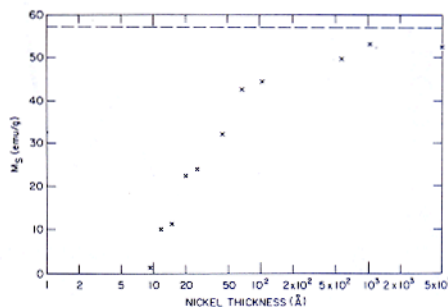


Fig. 2. Saturation magnetization versus nickel thickness of Mo/Ni superlattices.

The Cuire temperature, measured from Arrot plots shows a similar behavior i.e., a strong decrease with Ni layer thickness (Fig. 3). Whether this decrease is due to the existence of dead Ni layers or intermixing at the Ni-Mo interface has not been clarified and is still under study. In any case, it seems that D.C. magnetization changes are mostly due to thin film effects i.e., the changes in the Ni thickness.

The magnons in superlattices exhibit a behavior which is characteristic of the superlattice periodicity. The magnons characteristic of the individual magnetic layers are modified as the layers are coupled via the dipolar interaction across the normal metal. Theoretical predictions^{13,14} have shown the existence of type of modes: a) a band of modes arising from the interaction of surface-like magnons in each magnetic layer and b) modes arising from the interaction of standing spin waves in each layer. The dependence of the frequency of these modes (ν) on magnetic (d_M) and nonmagnetic (d_N) layer thickness, magnetic field (H), saturation magnetization (M_s) and wave vector (Q) has been theoretically predicted.^{13,14} Light scattering measurements⁴ have been performed to study experimentally the dependence of ν on d_N , d_M , H , M_s , and Q . Figure 4 shows the dependence of the magnon frequency on magnetic field for a representative set of Mo/Ni superlattices. The solid lines are fits to the theory using the saturation magnetization as the only adjustable parameter. Independent D.C. magnetization¹² measurements of the saturation magnetization were found to be in close agreement ($\pm 15\%$) with the fits to the light scattering measurements.

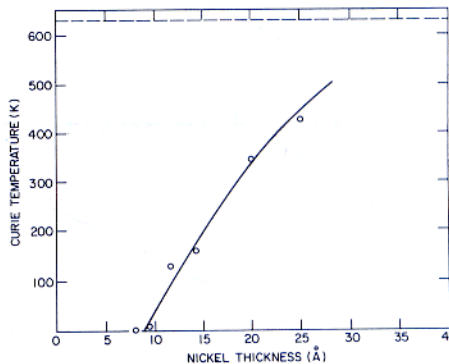


Fig. 3. Curie temperature versus nickel thickness of Mo/Ni superlattices.

The magnetic modulation of Mo/Ni superlattices has been studied using neutron scattering.¹⁵ The results imply that the magnetic modulation is different from the chemical modulation indicating the existence of long range magnetic interactions parallel to the layers. Nuclear magnetic resonance¹⁶ and ferromagnetic resonance¹⁷ measurements show the existence of various local magnetic environments possibly related to the distance from the interface.

In summary, we found that the magnetic properties of metallic superlattices are strongly affected by the layering process. Both thin film and superlattice effects are observable in magnetization, light scattering and/or resonance experiments.

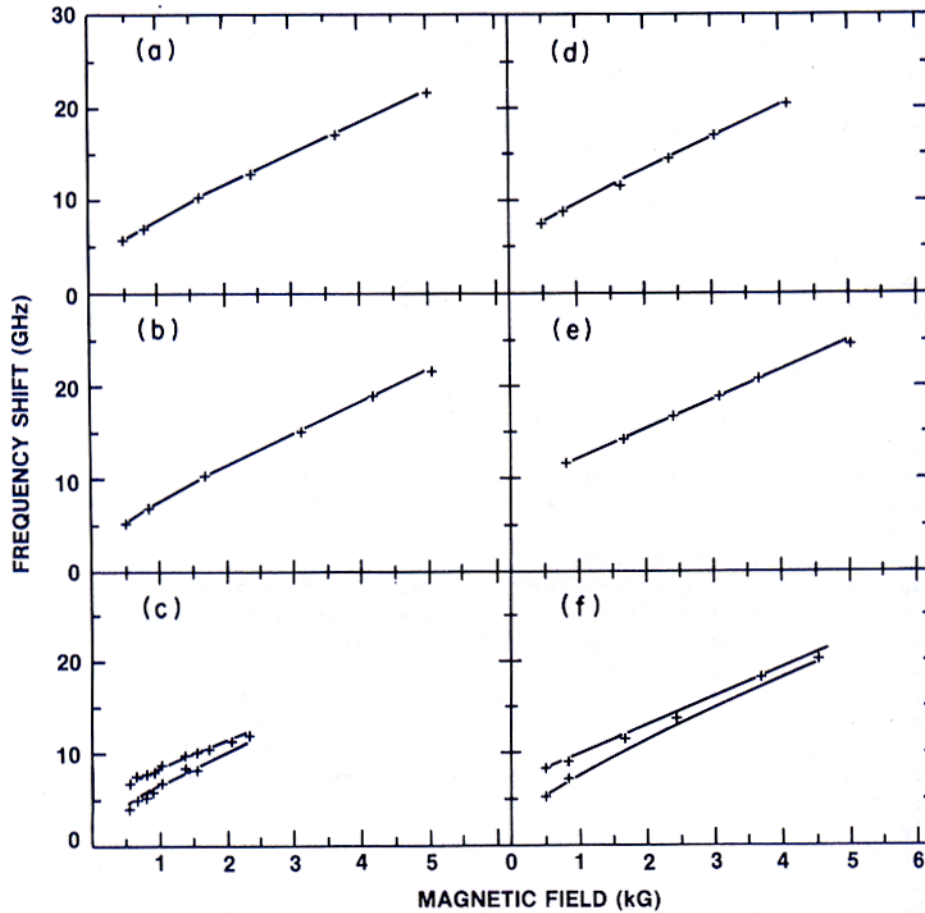


Fig. 4. Field dependence of magnon frequencies in a representative set of Mo/Ni superlattices. The full lines are fits to theory with the saturation magnetization as an adjustable parameter. The samples are as follows: a) $d_1 = 100 \text{ \AA}$, $d_2 = 300 \text{ \AA}$; b) $d_1 = 100 \text{ \AA}$, $d_2 = 100 \text{ \AA}$; c) $d_1 = 138 \text{ \AA}$, $d_2 = 46 \text{ \AA}$; d) $d_1 = 250 \text{ \AA}$, $d_2 = 750 \text{ \AA}$; e) $d_1 = 5000 \text{ \AA}$, $d_2 = 5000 \text{ \AA}$; f) $d_1 = 540 \text{ \AA}$, $d_2 = 180 \text{ \AA}$.

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