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STRUCTURE OF Er | Y SUPERLATTICES

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Abstract. – The magnetic structure of Er | Y superlattices has been determined by neutron diffraction and squid magnetometry on single crystal samples grown on sapphire substrates by molecular-beam-epitaxy techniques. The turn angle in the Er layers is magneto-elastically "clamped" , and in fact locks-in to the commensurate state $\omega = 2\pi / 7$ below about 35 K. For the [Er_{13} | Y_{26}] superlattice the low temperature state is not $2\pi / 7$ but can be shifted to that value by a magnetic field, since this state has a net moment of 8 μ_B / 7 atoms along the c-axis.

We have previously obtained the structure in zero field of Er | Y single crystal superlattices grown by molecular-beam-epitaxy techniques [1]. Sapphire substrates were used with buffer layers of approximately 1000 Å of Nb and 300 Å of Y, so that the hcp c-axis of the superlattice is perpendicular to the growth planes. We found long range order of the c-axis Ising-like Er moments extending through the "magnetically dead" Y layers as was found for the X-Y superlattices Dy | Y [2]. The Er layer turn angles for the linear-spin-density-wave are nearly temperature independent at $\omega \approx 2\pi / 7$, the high temperature commensurate lock-in value in bulk Er [3], although we could not claim with certainty that the lock-in state is stabilized. The ferromagnetic transition is completely suppressed, because the magneto-elastic energy density is considerably reduced in the superlattice compared to the bulk.

We have now studied the magnetic structure of these materials in an applied field along the c-axis by neutron diffraction and SQUID magnetometry. The bulk magnetization is plotted *vs.* internal field for two of the superlattices in figure 1. The low field ($\leq$ 15 kOe) low temperature ($\leq$ 35 K) states have a magnetization of $\approx 1/7$ of the saturation value. The [Er_{13} | Y_{26}] superlattice shows evidence of an intermediate fan state.

In figure 2 we show neutron diffraction data for [Er_{13} | Y_{26}]. The overlap of superlattice peaks results from the poor resolution for scans directed out of the scattering plane. At $T = 10$ K (Fig. 2a) the application of a 10 kOe field (7 kOe internal) slightly shifts the centroid of the scattering for the magnetic superlattice peaks on each side of $\tau = (110)$. This indicates that the Er layer turn angle increases. Our data analysis shows that the field-induced state has the commensurate value $\omega = 2\pi / 7$ (51.4°), which is shifted from the zero field value (50.3° in agreement with our previous analysis in Fig. 3). The original analysis [1] (Fig. 3) of the zero field low temperature data suggested that $\omega = 2\pi / 7$ is the stable value of the turn angle. The absence of any shift in q at 10 kOe (a slight broadening is evident) confirms this as the stable state.

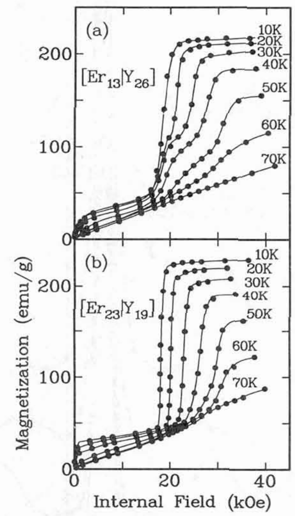

Fig. 1. – Magnetization *vs.* internal field along the c-axis for the (a) [Er_{13} | Y_{26}] and (b) [Er_{23} | Y_{19}] superlattices. The low field low temperature states have a magnetization of approximately 1/7 of the saturation value corresponding to the net c-axis moment of the $2\pi / 7$ lock-in state. The [Er_{13} | Y_{26}] superlattice shows evidence of an intermediate fan state.

At 40 K (Fig. 2b), the zero-field ω has the stable value $2\pi / 7$ and is not shifted by a 10 kOe field. Higher fields strongly shift the magnetic scattering to smaller q, indicating the development of the linear fan state. The average turn angle for the Er layer in this state is $\approx 35°$, which is much lower than found in any bulk Er state. Of the superlattices we have studied this is the one with the smallest ratio of Er to Y, and thus has the least magneto-elastic energy density. This is consistent with the theories of fan states where large anisotropy or magneto-elastic energies favor a direct transition

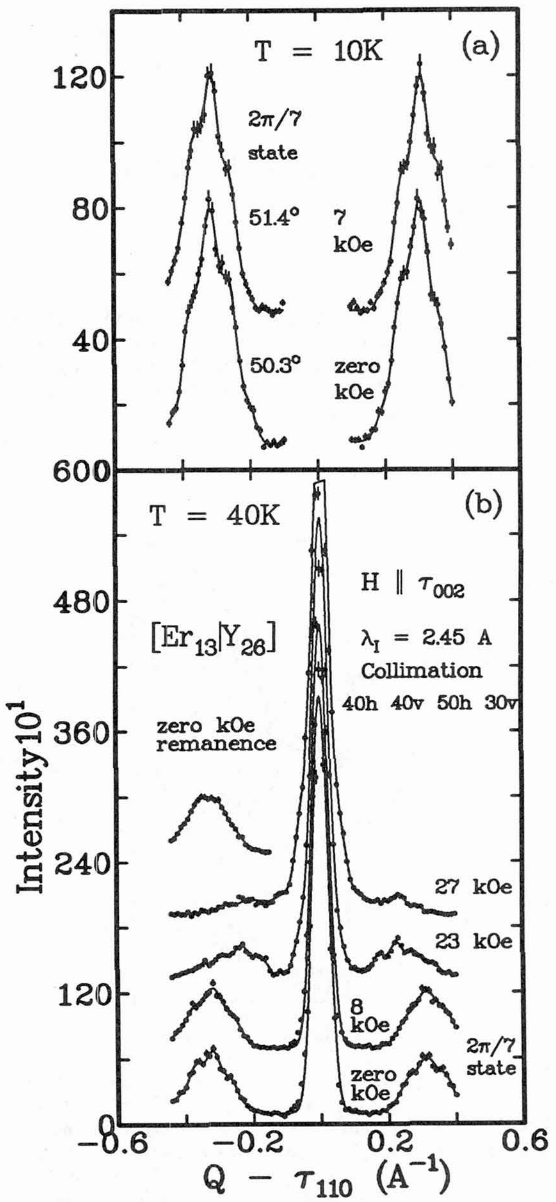

Fig. 2. – (a) Neutron diffraction scans along (11 ξ) for [Er_{13} | Y_{26}] at $T = 10$ K with the applied field along the c-axis. The calculated Er turn angle shifts from 50.3° to the commensurate value, $2\pi / 7 = 51.4°$, with little or no loss of coherence when the field is raised from zero to 10 kOe (7 kOe internal). (b) At $T = 40$ K there is no shift in the Er layer turn angle as the field is raised, indicating that $\omega = 2\pi / 7$ is the zero-field state. The sharply reduced q of the peaks ($\omega \approx 35°$) at 23 and 27 kOe internal field indicates the development of fan states corresponding to the magnetization plateaus in figure 1a.

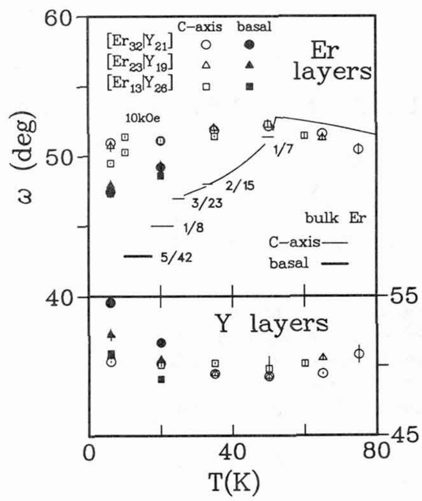

Fig. 3. – The turn angles in the Er and Y layers of [Er_x | Y_y] superlattices are shown and compared to bulk Er. In the Er layers ω is "clamped" and in fact locks-in to the commensurate state $\omega = 2\pi / 7$ below about 35 K, except for [Er_{13} | Y_{26}] where the lowest temperatures state is not $2\pi / 7$.

from the modulated to ferromagnetic states [4]. These theories do not yet take into account the perturbation of the turn angle by magneto-elastic effects in the fan state.

Finally, the zero-field remanence state returns to the zero-field-cooled value of ω, but with a reduced coherence length.

Acknowledgment

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