Superparamagnetic Interlayer Formation in AFM/FM Exchange Coupled Films

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**Conclusion**

In-plane isotropic reversible $M$-$H$ curves with zero remanence, characteristic of superparamagnetism, were observed in various FM layers on IrMn.

Ferromagnetic nature is more deteriorated when a FM layer with a lower value of $M_s$ is exchange coupled with the IrMn layer.

The effective critical thickness $t_{c_{eff}}$ for exhibiting superparamagnetic nature increases exponentially with decreasing $M_s$.

**G/Ta(20)/Cu(20)/IrMn(10)/(NiFe)$_{71}$Cu$_{29}$(t nm)/Cu(2)/Ta(5)**

Abnormal $M$-$H$ Curves in IrMn/(NiFe)$_{71}$Cu$_{29}$ Films

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<table>
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<tr>
<th><em>Ferromagnetic and Antiferromagnetic Materials Used</em></th>
<th>$M_s$ (emu/cm$^3$)</th>
<th>$T_c$ (°C)</th>
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<tbody>
<tr>
<td>FeCo</td>
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<td>1910</td>
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**M-H Curves with Zero Remanence in Various FM Layers**

$H_{po} = M_s / \chi_\perp = H_K F M + (H_{eb} + \Delta H_c)$

where, $\Delta H_c = H_{c AFM/FM} - H_{c FM}$

$V_{cluster} = \mu / M_s = \mu H_{po}$

Estimation of a Magnetic Dead Thickness $t_{dead}$ and $M_s$

$M$-$H$ Curves with zero remanence, characteristic of superparamagnetism, were observed in various FM layers on IrMn.

The non-hysteretic $M$-$H$ curves for single and (NiFe-Co)Cu/IrMn films were fit quite well to the formula using the Langevin function.

Squareness Ratio (SQ)

$V_{cluster} = \mu / M_s$

Estimation of a Superparamagnetic Cluster Volume

Langevin Function $MM_0 = \coth(\mu H/k_BT) - 1/(\mu H/k_BT)$

$\nu_{cluster} = \mu / M_s$

Effect of Ferromagnetic Thickness on SQ and $H_{eb}$

There was strong dependence of $M_s$ on magnetic alignment in the FM layer and $H_{eb}$.

Estimation of a Magnetic Dead Thickness $t_{dead}$ and $M_s$

$M$-$H$ curves with zero remanence, characteristic of superparamagnetism, were observed in various FM layers on IrMn.

Effect of $M_s$ on the Effective Critical Thickness $t_{c_{eff}}$

The smaller the $M_s$ value, the weaker the exchange stiffness, thus, the stronger the frustration.

$H_{eb} = M_s / \chi_\perp = H_{K F M} + (H_{eb} + \Delta H_c)$

where, $\Delta H_c = H_{c AFM/FM} - H_{c FM}$

$V_{cluster} = \mu / M_s = \mu H_{po}$

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**Experiment**

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**Introduction : In-plane Isotropic Reversible $M$-$H$ Curves**

$G/Ta(20)/Cu(20)/IrMn(0 or 10)/(NiFe)$_{71}$Cu$_{29}$(t nm), $M_s = 200$ emu/cm$^3$

IrMn/(NiFe)$_{71}$Cu$_{29}$ films showed deteriorated ferromagnetic nature, compared to single (NiFe-Co)Cu/IrMn films.

The non-hysteretic $M$-$H$ curves for single and (NiFe-Co)Cu/IrMn films were fit quite well to the formula using the Langevin function.

The value of $M_s$ was found to be close to its bulk value for each FM material.