Soft Underlayers for Perpendicular Media

H. S. Jung and W. D. Doyle

MINT Center
The University of Alabama

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Ferromagnetic/IrMn Exchange-coupled Multilayers

Target: 200 nm thick ferromagnetic layer with a permeability of \( \sim 100 \)

- **FeTaN/IrMn**
  - G/FeTaN(20)/[IrMn(10)/FeTaN(20)]\( _9 \)
  - 19 layers
  - High \( 4\pi M_s \) \( \sim 20 \) kG
  - Thermal instability

- Increased \( H_k \) to reduce the number of layers and increased thermal stability

- **Co\(_{90}\)Fe\(_{10}\)/IrMn**
  - G/Cu/IrMn/[CoFe(50)/IrMn(10)]\( _4 \)/CoFeN(20)
  - 11 layers
  - Low \( 4\pi M_s \) \( 15 \sim 16 \) kG

- Increased \( 4\pi M_s \)

- **Co\(_{35}\)Fe\(_{65}\)/IrMn**
  - G/Cu/IrMn/[CoFe(50)/IrMn(10)]\( _4 \)/CoFe(25)
  - 11 layers
  - High \( 4\pi M_s \) \( \sim 23 \) kG
Effect of Cu Underlayer on $H_c$

$G/Cu(t \text{ nm})/Co_{35}Fe_{65}(50 \text{ nm})$

- $H_c$ (Oe)
- $t_{Cu}$ (nm)
- EA
- HA
Comparison of Hard and Soft Co$_{35}$Fe$_{65}$ Films

G/CoFe (50 nm)

\[ 4\pi M_s = 22.2 \text{ kG} \]

\[ H_{c\text{,EA}} = 120 \text{ Oe} \]
\[ H_{c\text{,HA}} = 117 \text{ Oe} \]

G/Cu(2.5 nm)/CoFe (50 nm)

\[ 4\pi M_s = 23.2 \text{ kG} \]

\[ H_k = 28 \text{ Oe} \]
\[ H_{c\text{,EA}} = 8.6 \text{ Oe} \]
\[ H_{c\text{,HA}} = 2.3 \text{ Oe} \]
$\gamma$, $4\pi M_s$, and $H_k$ from FMR (C. Alexander)

$G$/Cu(2.5 nm)/Co$_{35}$Fe$_{65}$(50 nm)

Fit to $\gamma = 2.93$ MHz/Oe, $4\pi M_s = 23.2$ kG, $H_k = 27$ Oe

\[ H = -H_K + \frac{3}{2} H_K \sin^2 \phi - 2\pi M_s + \frac{1}{2} \left[ H_K^2 \sin^4 \phi + 8\pi M_s H_K \sin^2 \phi + 16\pi^2 M_s^2 + 4 \frac{f^2}{\gamma^2} \right]^{1/2} \]
Comparison of J in the Top and Bottom Interfaces

Thickness: Cu 20 nm, IrMn 10 nm, and Co$_{35}$Fe$_{65}$ 50 nm

Bottom Interface

G/Cu/IrMn/CoFe

- $H_p = 57.0$ Oe
- $H_{eb} = 21.0$ Oe
- $H_{c,EA} = 28.1$ Oe
- $H_{c,HA} = 1.6$ Oe

$m$ (memu/cm$^2$) vs. $H$ (Oe)

- $J_{bottom} = 0.19$ erg/cm$^2$

Top Interface

G/Cu/CoFe/IrMn

- $H_p = 58.0$ Oe
- $H_{eb} = 24.8$ Oe
- $H_{c,EA} = 20.5$ Oe
- $H_{c,HA} = 1.1$ Oe

$m$ (memu/cm$^2$) vs. $H$ (Oe)

- $J_{top} = 0.23$ erg/cm$^2$

Bottom and Top

G/Cu/IrMn/CoFe/IrMn

- $H_p = 87.0$ Oe
- $H_{eb} = 50.0$ Oe
- $H_{c,EA} = 29.4$ Oe
- $H_{c,HA} = 2.1$ Oe

$m$ (memu/cm$^2$) vs. $H$ (Oe)

- $J_{bottom \& top} = 0.46$ erg/cm$^2$
Comparison of Optimized Structure of CoFe Multilayer Films

Co$_{90}$Fe$_{10}$  G/Cu(20)/IrMn(10)/[CoFe(50)/IrMn(10)]$_4$/CoFeN(20)
Co$_{35}$Fe$_{65}$  G/Cu(20)/IrMn(10)/[CoFe(50)/IrMn(10)]$_4$/CoFe(25)

Co$_{90}$Fe$_{10}$

- $4\pi M_s = 15$ kG
- $H_p = 89$ Oe
- $H_{eb} = 48$ Oe
- $H_{c,EA} = 23$ Oe
- $H_{c,HA} = 1.4$ Oe

Co$_{35}$Fe$_{65}$

- $4\pi M_s = 23$ kG
- $H_p = 111$ Oe
- $H_{eb} = 51$ Oe
- $H_{c,EA} = 22$ Oe
- $H_{c,HA} = 1.7$ Oe
Longitudinal Annealing

G/Cu(20 nm)/IrMn(10 nm)/Co$_{35}$Fe$_{65}$(200 nm)/IrMn(10 nm)/Cu(10 nm)

Annealed for 10 min. in $H = 500$ Oe

$T_{\text{Annealed}} = 220 \, ^\circ\text{C}$

As-deposited

- $H_p = 48$ Oe
- $H_{eb} = 12.5$ Oe
- $H_{c,EA} = 28.6$ Oe
- $H_{c,HA} = 2.1$ Oe

Annealed

- $H_p = 40$ Oe
- $H_{eb} = 12.6$ Oe
- $H_{c,EA} = 9.4$ Oe
- $H_{c,HA} = 1.2$ Oe
Conclusion

- Soft anisotropic Co$_{35}$Fe$_{65}$ films with $4\pi M_s \sim 23$ kG were successfully produced using a thin Cu underlayer.

- Co$_{35}$Fe$_{65}$/IrMn multilayers showed significant advantages as soft underlayers compared to FeTaN/IrMn and Co$_{90}$Fe$_{10}$/IrMn multilayers.
  - Optimized structure
    G/Cu(20)/IrMn(10)/[CoFe(50)/IrMn(10)]$_4$/CoFe(25)
  - Reduced the number of layers from 19 to 11 to achieve a permeability of $\sim 100$.
  - Increased $4\pi M_s$ from 20 kG to $\sim 23$ kG.
  - Improved thermal stability.
  - Kept single domain remanent direction.
Future Work

- Preparation of radially oriented Co$_{35}$Fe$_{65}$/IrMn multilayers.
- Effect of annealing on thermal stability.
- Development of a model to understand the differences between hard and soft Co$_{35}$Fe$_{65}$ films.