High Moment Fe$_{65}$Co$_{35}$/IrMn Exchange-Coupled Soft Underlayers for Perpendicular Media

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Historical Development of Soft Underlayers

Target: 200 nm thick ferromagnetic layer and $\mu \sim 100$

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

- Fe$_{10}$Co$_{90}$/IrMn
  - G/Cu/IrMn/[FeCo(50)/IrMn(10)]$_4$/FeCoN(20)
  - 11 layers
  - Low $4\pi M_s$ 15 ~ 16 kG

- Fe$_{65}$Co$_{35}$/IrMn
  - G/Cu/IrMn/[FeCo(50)/IrMn(10)]$_4$/FeCo(25)
  - 11 layers
  - Not enough thermal stability

Increased $H_k$
Enhanced thermal stability

Increased $4\pi M_s$
Improved thermal stability
**Effect of Various Underlayers on $H_c$**

G/Underlayer(t nm)/Fe$_{65}$Co$_{35}$ (50 nm)

- **without underlayer**
- **Ta(2.5 nm)**
- **Cu(2.5 nm)**
- **NiFe(2.5 nm)**
- **Ru(2.5 nm)**
Outstanding Hysteretic Properties

G/Cu(20 nm)/IrMn(10 nm)/[FeCo (50 nm)/IrMn(10 nm)]₄/FeCo (25 nm)

As-deposited

Annealed at 225 °C for 10 min. in H = 500 Oe

A single domain remanent direction, a high \( H_{po} \), and a high \( 4\pi M_s \)

Annealing enhanced the single domain condition of \( H_{eb} > H_c \).
Thermal Instability of FeCo/IrMn Multilayer Films

Dependence of $H_{eb}$ and $H_c$ on Temperature without an orienting field

G/Cu(20 nm)/IrMn(10 nm)/[FeCo(50 nm)/IrMn(10 nm)]4/FeCo(25 nm)

As-deposited

Annealed at 225 °C in H = 500 Oe

Problems: An irreversible reduction in $H_{eb}$ after measurement, a low $T_{max}$. of $H_{eb} > H_c$, and a low $T_B$
Thermally Stable FeCo/IrMn Multilayer Films

- Requirement
  1. Maintenance of the single domain condition of \( H_{eb} > H_c \) at a temperature of \( \leq 120 \, ^\circ C \)

- Previously reported works:
  - Either the enhanced (111) texture [1] or the increased grain size of IrMn [2] increased \( T_B \) up to \( \sim 300 \, ^\circ C \).
  2. Ta/Cu or Ta/NiFe underlayer maintained soft properties of FeCo films [3].

- In order to achieve this goal, the effect of Ta/Cu underlayers on crystallinity in IrMn and thermal stability in FeCo/IrMn systems is investigated.

Significant Enhancement of Crystallinity in IrMn

Bottom Interface:
G/Ta(t nm)/Cu(20 nm)/IrMn(10 nm)/FeCo(50 nm)/Cu(10 nm)

A small lattice mismatch of 0.3 ~ 3.8 % between β-Ta and Cu enhanced crystallinity in Cu, IrMn, and FeCo.
Effect of Ta Underlayer on Magnetic Properties

Top Interface
G/Ta(t)/Cu(20)/FeCo(50)/IrMn(10)
Bottom Interface
G/Ta(t)/Cu(20)/IrMn(10)/FeCo(50)

Magnetic properties in the as-deposited state were independent of the Ta thickness.
Thermal Stability in the Top Interface of FeCo/IrMn

Dependence of $H_{eb}$ and $H_c$ on Temperature without an orienting field

$G/Ta(t\ \text{nm})/Cu(20\ \text{nm})/FeCo(50\ \text{nm})/IrMn(10\ \text{nm})/Cu(10\ \text{nm})$

$t_{Ta} = 0\ \text{nm}$

$t_{Ta} = 20\ \text{nm}$

The sample with Ta showed more irreversible reduction in $H_{eb}$ and $H_c$ than the sample without Ta but slightly higher $T_B$. 
Thermal Stability in the Bottom Interface of IrMn/FeCo

Dependence of $H_{eb}$ and $H_c$ on Temperature without an orienting field

$G/Ta(t \text{ nm})/Cu(20 \text{ nm})/IrMn(10 \text{ nm})/FeCo(50 \text{ nm})/Cu(10 \text{ nm})$

$t_{Ta} = 0 \text{ nm}$

$t_{Ta} = 20 \text{ nm}$

The bottom interface enhanced $H_{eb}$ after thermal cycle. $T_B$ in the sample with Ta was significantly improved to > 250 °C.
Outstanding Hysteretic Properties in FeCo/IrMn Multilayer with Ta

G/Ta(20 nm)/Cu(20 nm)/IrMn(10 nm)/[FeCo(50 nm)/IrMn(10 nm)]4/FeCo(25 nm)

The Ta underlayer maintained outstanding hysteretic properties. Annealing enhanced the single domain condition of $H_{eb} > H_c$.
Significant Improvement of Thermal Stability
Dependence of $H_{eb}$ and $H_c$ on Temperature without an orienting field

$G/Ta(t\text{ nm})/Cu(20\text{ nm})/IrMn(10\text{ nm})/[FeCo(50\text{ nm})/IrMn(10\text{ nm})]4/FeCo(25\text{ nm})$

As-deposited samples

No irreversible reduction in $H_{eb}$, an increase in $T_{\text{max}}$, to maintain $H_{eb} > H_c$ from 75 to 150 °C, and an increase in $T_B$ from 175 to > 250 °C.
Conclusion

- The enhanced crystallinity in (111) IrMn by β-Ta/Cu underlayers significantly improved thermal stability.

In the optimized structure of G/Ta(20)/Cu(20)/IrMn (10)/[FeCo(50)/IrMn(10)]₄/FeCo(25),

- Outstanding hysteretic properties
- No irreversible reduction in $H_{eb}$ after thermal cycle
- An increase in $T_{max.}$ to maintain $H_{eb} > H_{c}$ from 75 to 150 °C
- An increase in $T_B$ from 175 to > 250 °C