



Spin Dynamics in Ion-beam Sputtered Co₂FeAl/Mo Bilayers

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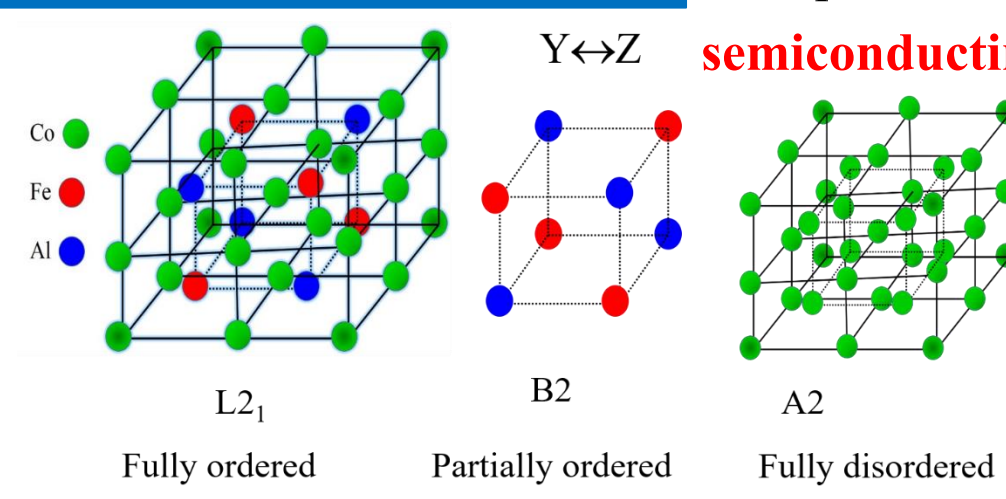
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- Spin pumping mechanism associated interfacial Gilbert damping is demonstrated in ion-beam sputtered Co₂FeAl (CFA)/Mo bilayer thin films employing ferromagnetic resonance spectroscopy.
- Real **spin mixing conductance and the spin-diffusion length** are estimated to be **1.56(±0.30)×10¹⁹ m⁻²** and **2.61(±0.15) nm**, respectively.
- The **damping constant is found to be 8.8(±0.2)×10⁻³** in the Mo(3.5nm) capped CFA(8nm) sample corresponding to a ~69% enhancement of the **original Gilbert damping 5.2(±0.6)×10⁻³** in the Al capped CFA thin film

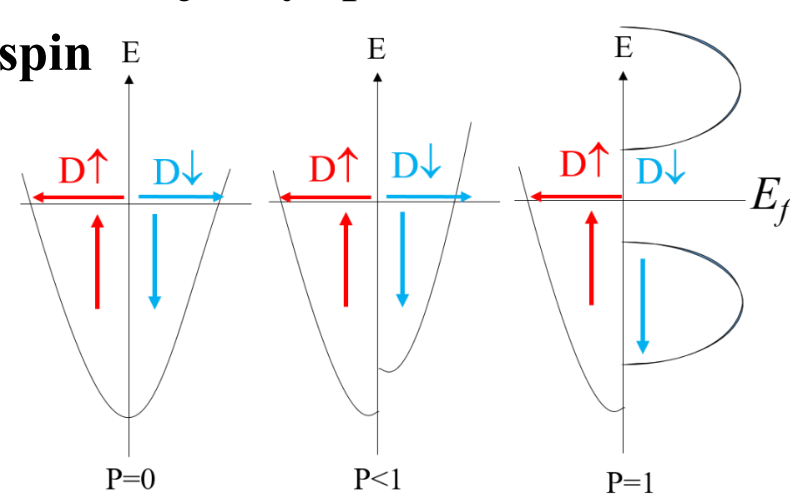
INTRODUCTION

Heusler Alloy(X₂YZ)



Half Metallicity: Spin band structure exhibits different behavior for the two spin orientations - **Metallic** for majority spin band and

semiconducting for minority spin



Spin band structure

Why Heusler Alloy?

- 100% spin polarization (Theoretically)
- High Curie temperature (~1000K)
- Very small damping constant (~0.001)

Storage
Materials requirement for high density storage

PMA

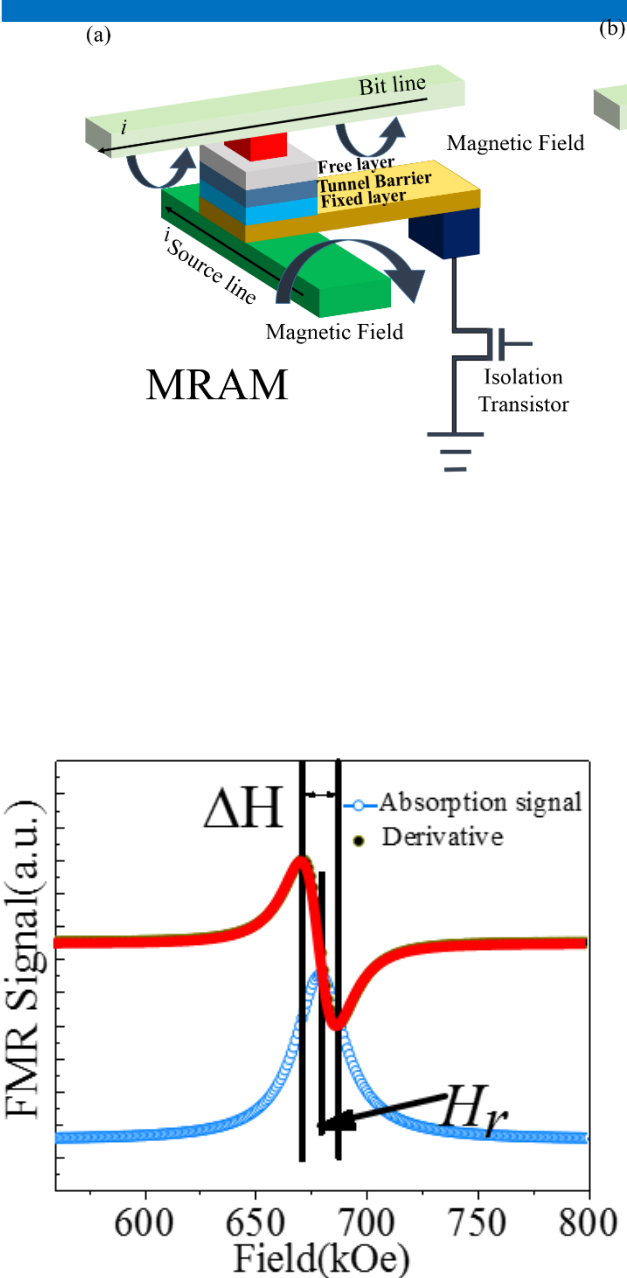
Writing
Magnetization switching with low current

Low damping constant

Reading
High sensitivity for high density data storage

MTJs and CPP-GMR

Spin Dynamics: FMR

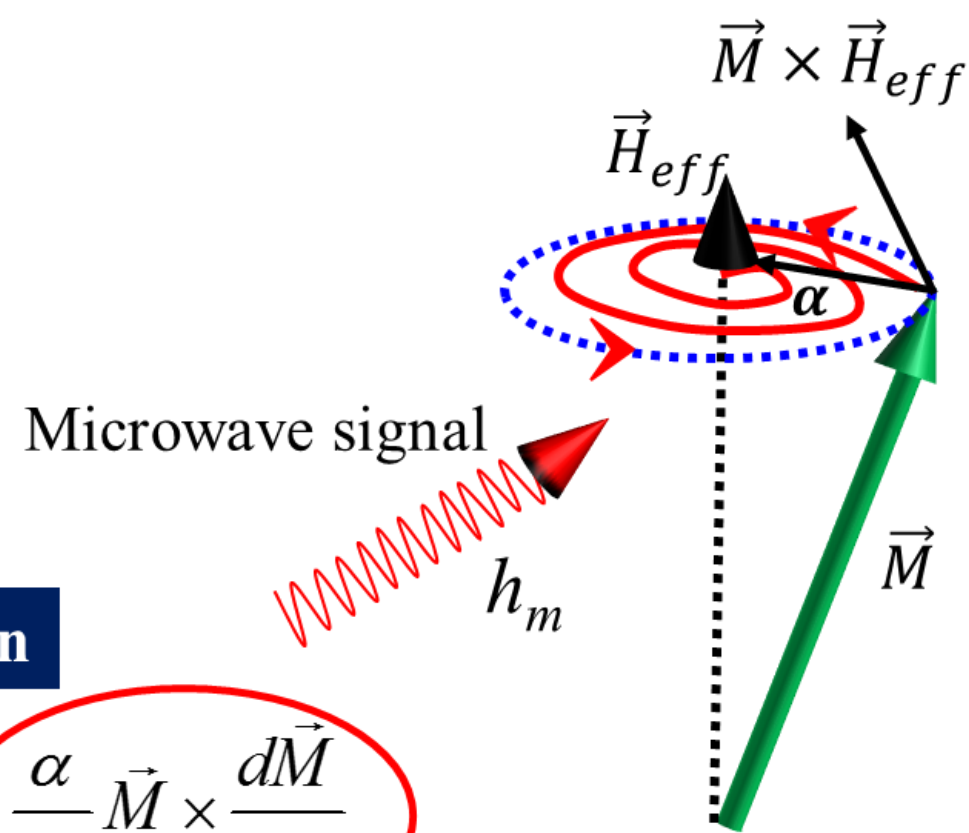


LLG equation

$$\frac{d\vec{M}}{dt} = -\gamma\vec{M} \times \vec{H}_{eff} + \frac{\alpha}{M} \vec{M} \times \frac{d\vec{M}}{dt}$$

$$I_{FMR} = \frac{\partial(U)}{\partial H} = S \frac{\partial(F_S(H_{ext}))}{\partial H_{ext}} + A \frac{\partial(F_A(H_{ext}))}{\partial H_{ext}}$$

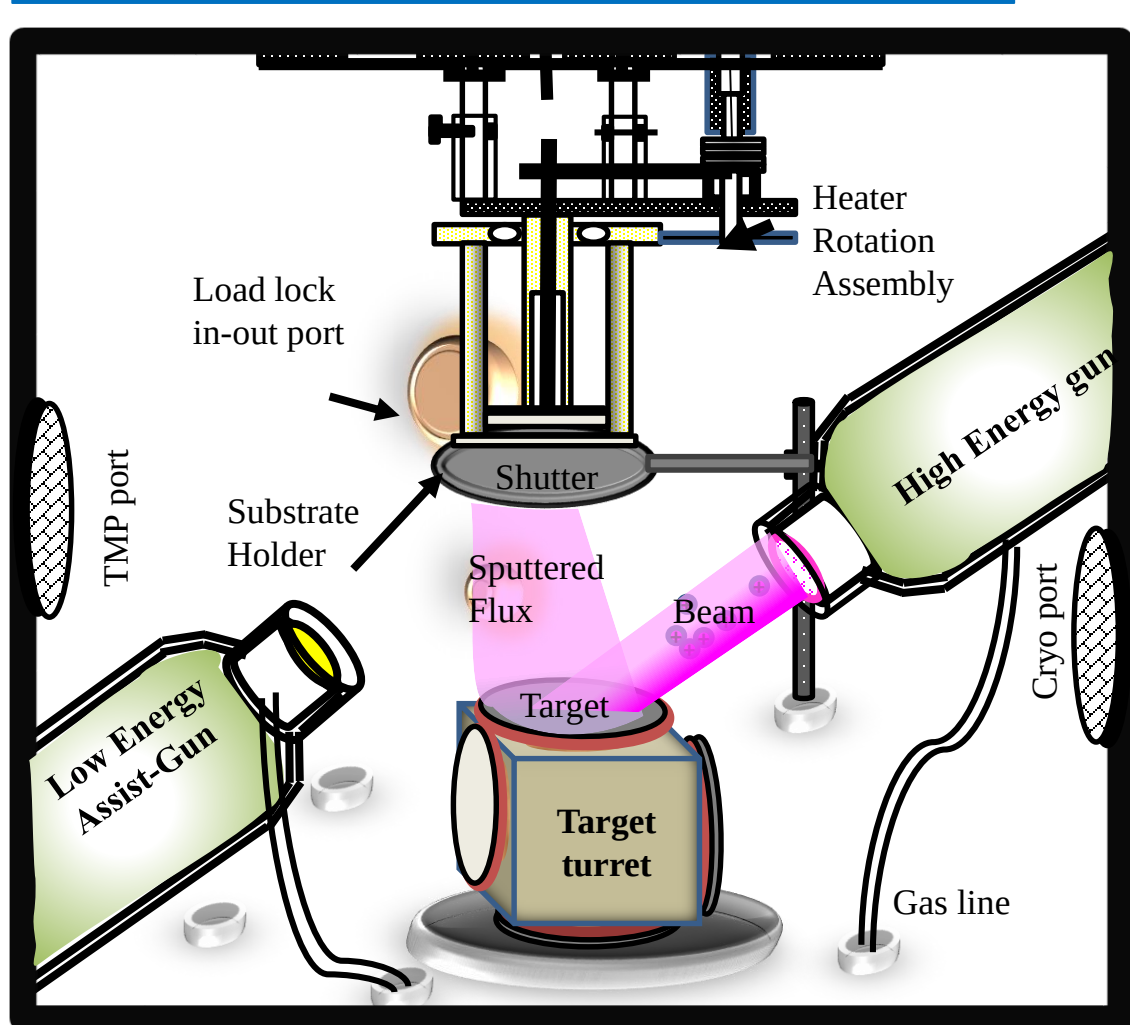
$$= -S \frac{\left(\frac{\Delta H}{2}\right)^2 (H_{dc} - H_r)}{\left[(H_{dc} - H_r)^2 + \left(\frac{\Delta H}{2}\right)^2\right]^2} + A \frac{\frac{\Delta H}{2} \left[\left(\frac{\Delta H}{2}\right)^2 - (H_{dc} - H_r)^2\right]}{\left[(H_{dc} - H_r)^2 + \left(\frac{\Delta H}{2}\right)^2\right]^2}$$



Microwave signal h_m

THIN FILM GROWTH / FABRICATION

Dual ion-beam Sputtering



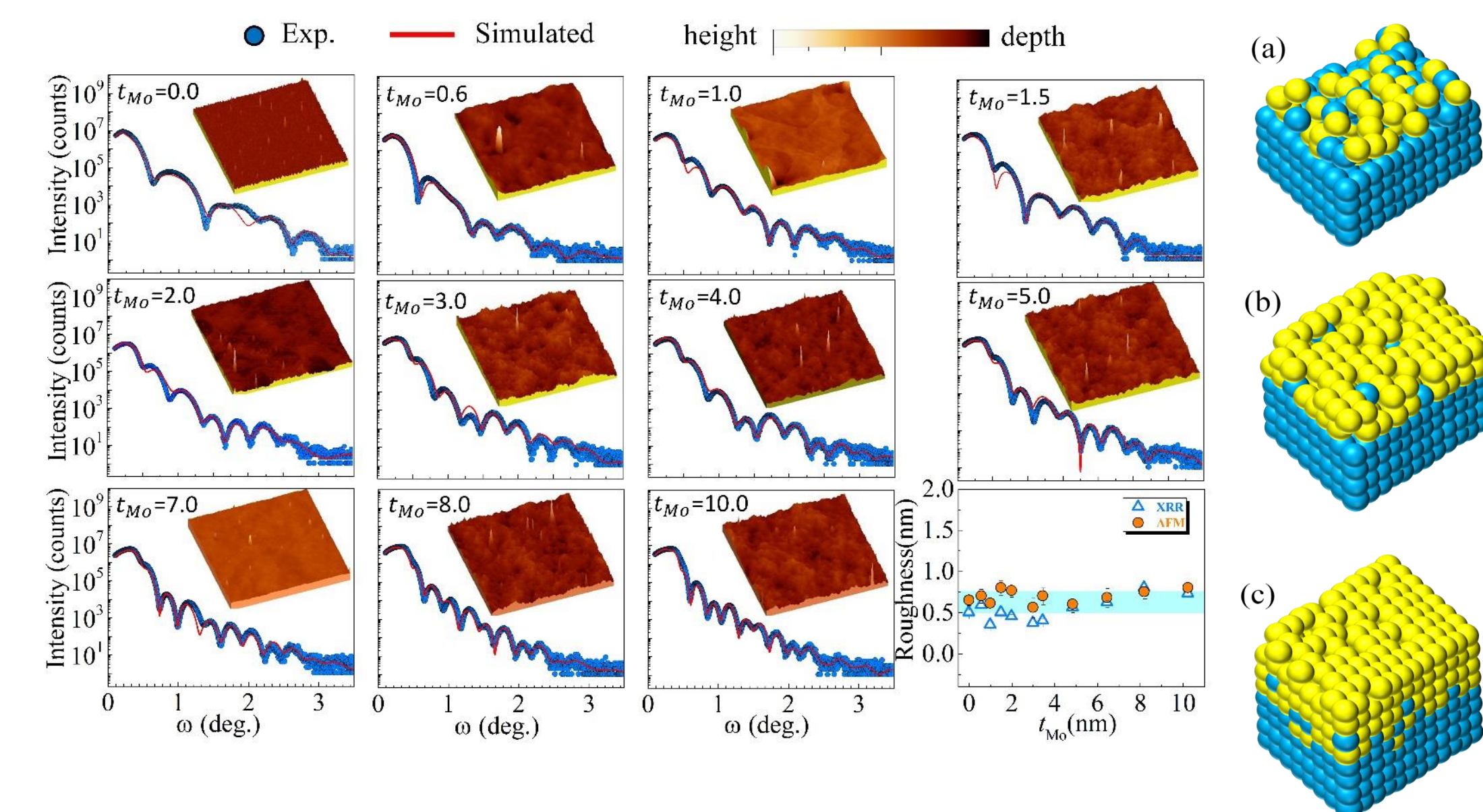
Thin film layer stack

Figure: Schematic illustration of dual ion beam sputtering system. The process for the ion-beam sputter deposition of metal/alloy is shown (without using the assist-gun).

Deposition Conditions:

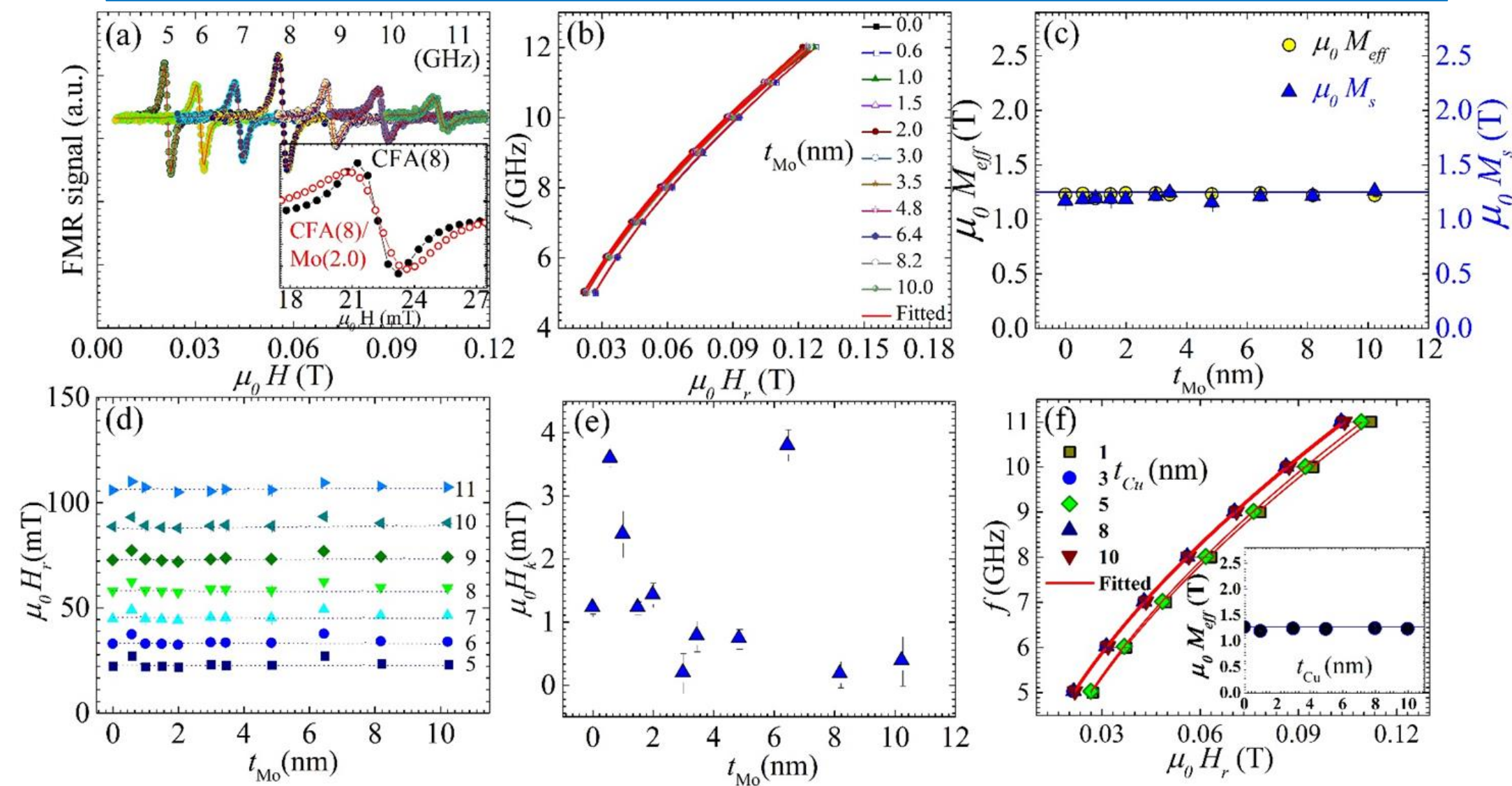
Base pressure	: ~1.2×10 ⁻⁷ Torr
Working pressure	: ~7.5×10 ⁻⁵ Torr
Ar ion energy	: 500 eV
Target substrate gap	: 27 cm

Thickness and Roughness: X-Ray Reflectivity and AFM



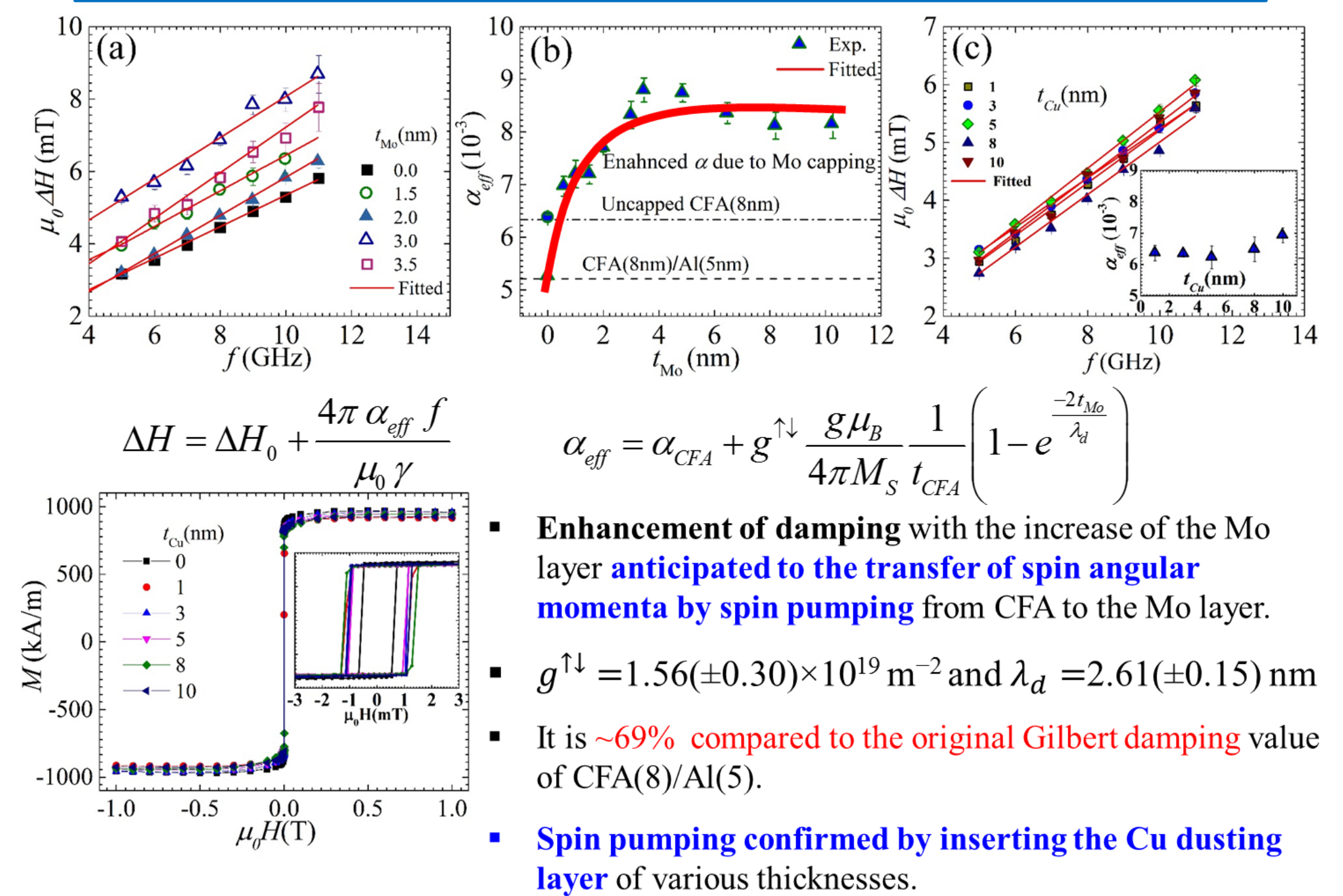
RESULTS

Effective magnetization and anisotropy



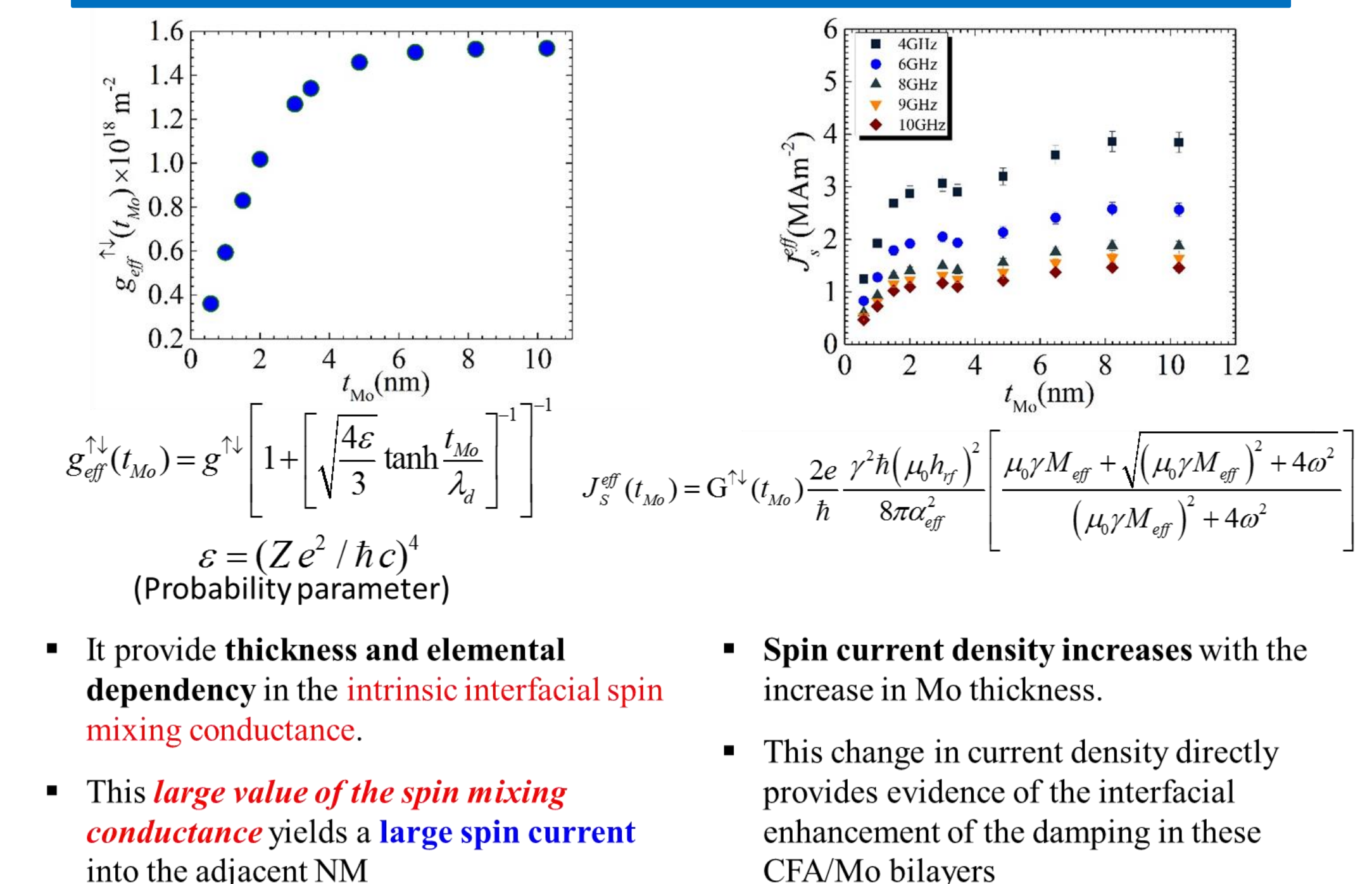
- $\mu_0 M_{eff}$ and $\mu_0 M_s$ are comparable to the bulk value of CFA 'horizontal line'.
- Reduction in anisotropy field with Mo thickness indicates the **increase in the spin accumulation**; spin pumping get saturated at diffusion length.

Spin pumping and effect of Cu dusting layer



- Enhancement of damping** with the increase of the Mo layer **anticipated to the transfer of spin angular momenta by spin pumping** from CFA to the Mo layer.
- $g^{\uparrow} = 1.56(\pm 0.30) \times 10^{19} \text{ m}^{-2}$ and $\lambda_d = 2.61(\pm 0.15) \text{ nm}$
- It is ~69% compared to the original Gilbert damping value of CFA(8)/Al(5).
- Spin pumping confirmed by inserting the Cu dusting layer** of various thicknesses.

Effective mixing conductance and current density



- It provide **thickness and elemental dependency** in the **intrinsic interfacial spin mixing conductance**.
- This **large value of the spin mixing conductance** yields a **large spin current** into the adjacent NM
- Spin current density increases** with the increase in Mo thickness.
- This change in current density directly provides evidence of the interfacial enhancement of the damping in these CFA/Mo bilayers

CONCLUSIONS

- The overall effect of the **damping constant enhancement** observed when Mo is deposited over CFA is remarkably comparable to the **far less-abundant non-magnetic metals** such as Pt.
- We have systematically investigated the changes in the spin dynamics in the ion-beam sputtered Co₂FeAl (CFA)/Mo(t) bilayers for various at constant CFA thickness of 8nm.
- Increasing the Mo layer thickness to its spin diffusion length; CFA(8)/Mo(t), the effective **Gilbert damping constant increases to 8.8(±0.2)×10⁻³ which corresponds to about ~69% enhancement** with respect to the value of 5.0(±0.3)×10⁻³ for the uncapped CFA layer (i.e., without the top Mo layer).

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