Gilbert Damping Oscillations Induced by Quantum Well States in Ultrathin Iron Films

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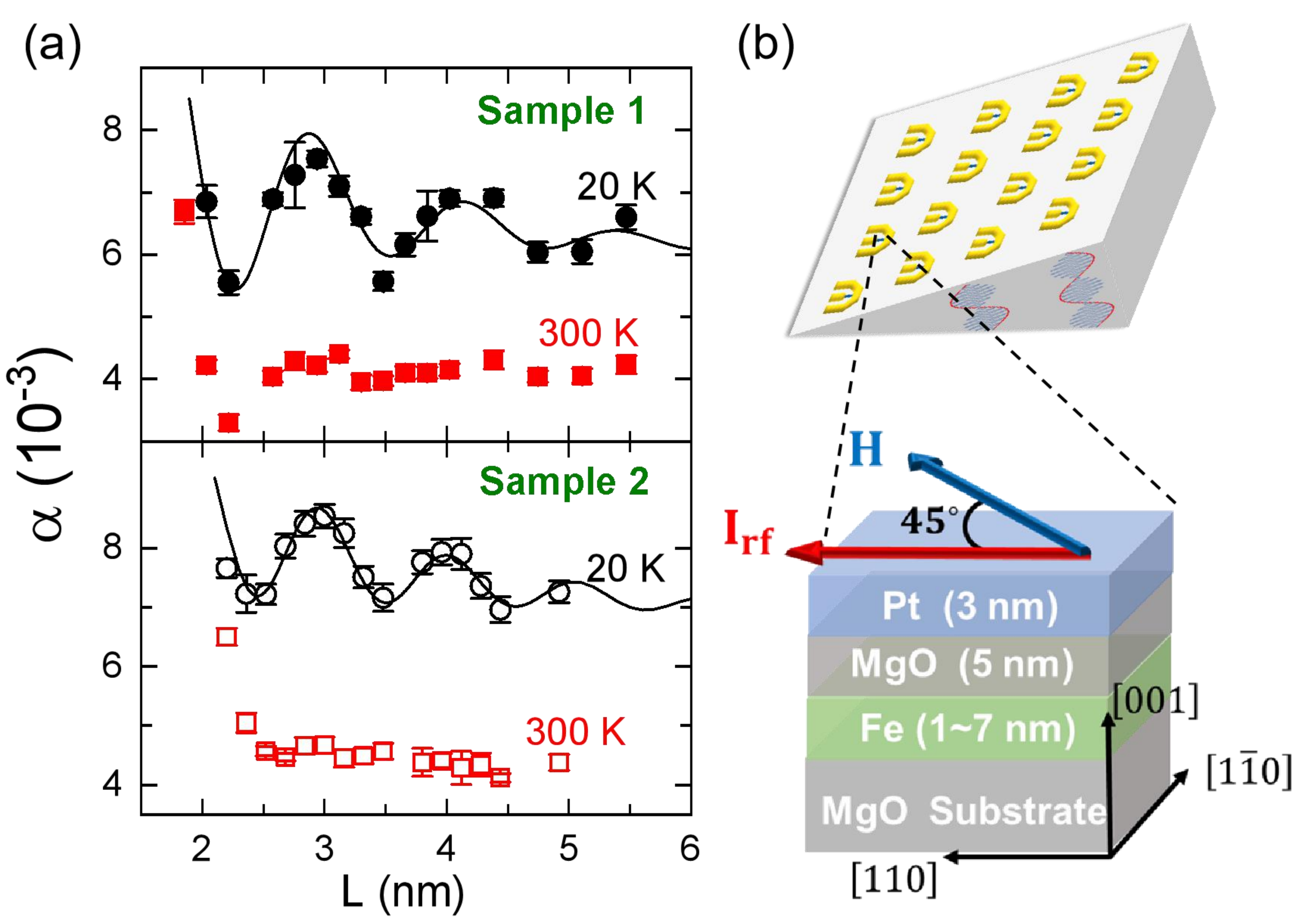
Abstract: The effects of quantum well states (QWSs) in Gilbert damping oscillation in ultrathin Fe films are systematically investigated by ferromagnetic resonance experiments and first principle calculations. The corresponding relationship between the quantum well states and the low temperature conductivity-like damping oscillation is analyzed. The $\Delta_5^{\uparrow}$ band is indentified to be the dominant energy band leading to the oscillation of Gilbert damping. A period of 8~10 monolayer (ML, 1ML=1.433 nm) obtained in experiments is well reproduced by band structure calculations.

Experiments

Gilbert damping is measured in two Fe film samples with different thicknesses at 20 K and 300 K.



A significant damping oscillation can be measured at low temperature of 20 K. The period of the two samples we obtained are 8.8 ± 0.4 and 7.4 ± 0.3 monolayers.

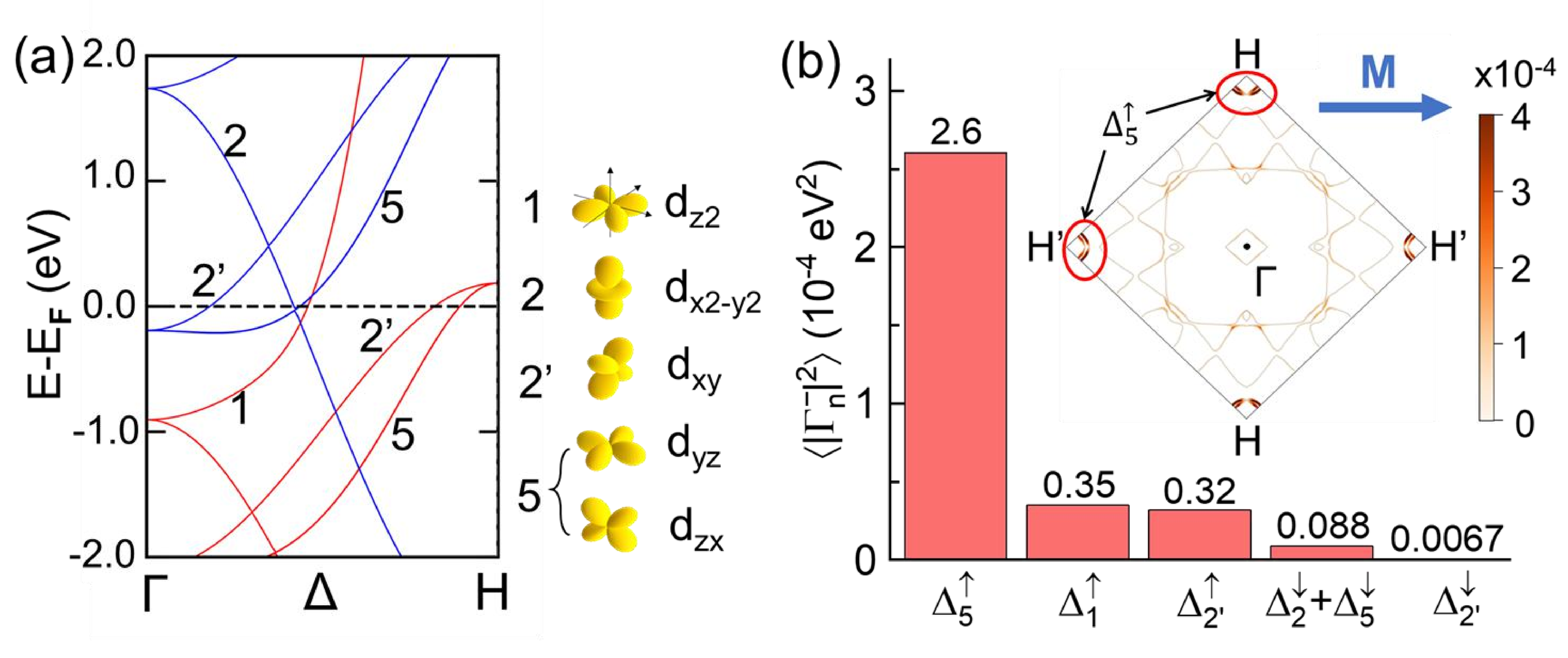
Theoretic Mechanism

I. Torque Correlation Model (TCM)

$$\lambda = \pi\hbar\frac{\gamma^2}{\mu_0}\sum_n\int\frac{d^3\mathbf{k}}{(2\pi)^3}|\Gamma_n^-(\mathbf{k})|^2\times\int dE A_{n\mathbf{k}}(E)A_{n\mathbf{k}}(E)\eta(E)$$

II. Band Resolved Contribution

$$|\langle nk|\Gamma^-|nk\rangle|^2=\left(\frac{\partial E}{\partial\widehat{\mathbf{M}}_x}\right)^2+\left(\frac{\partial E}{\partial\widehat{\mathbf{M}}_y}\right)^2$$



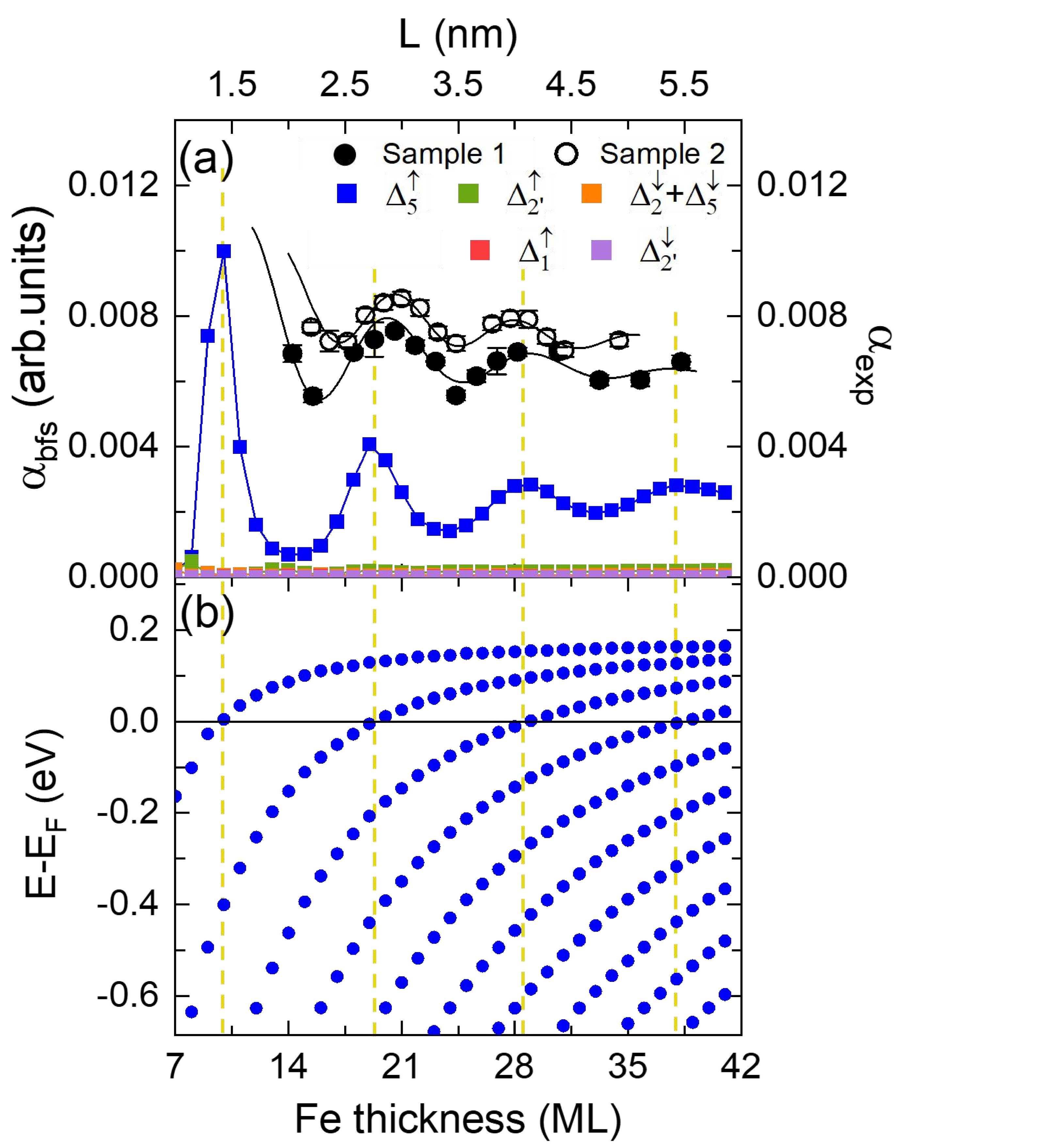
$\Delta_5^{\uparrow}$ gives the dominant contributions to damping.

III. Damping Oscillation Induced by QWSs

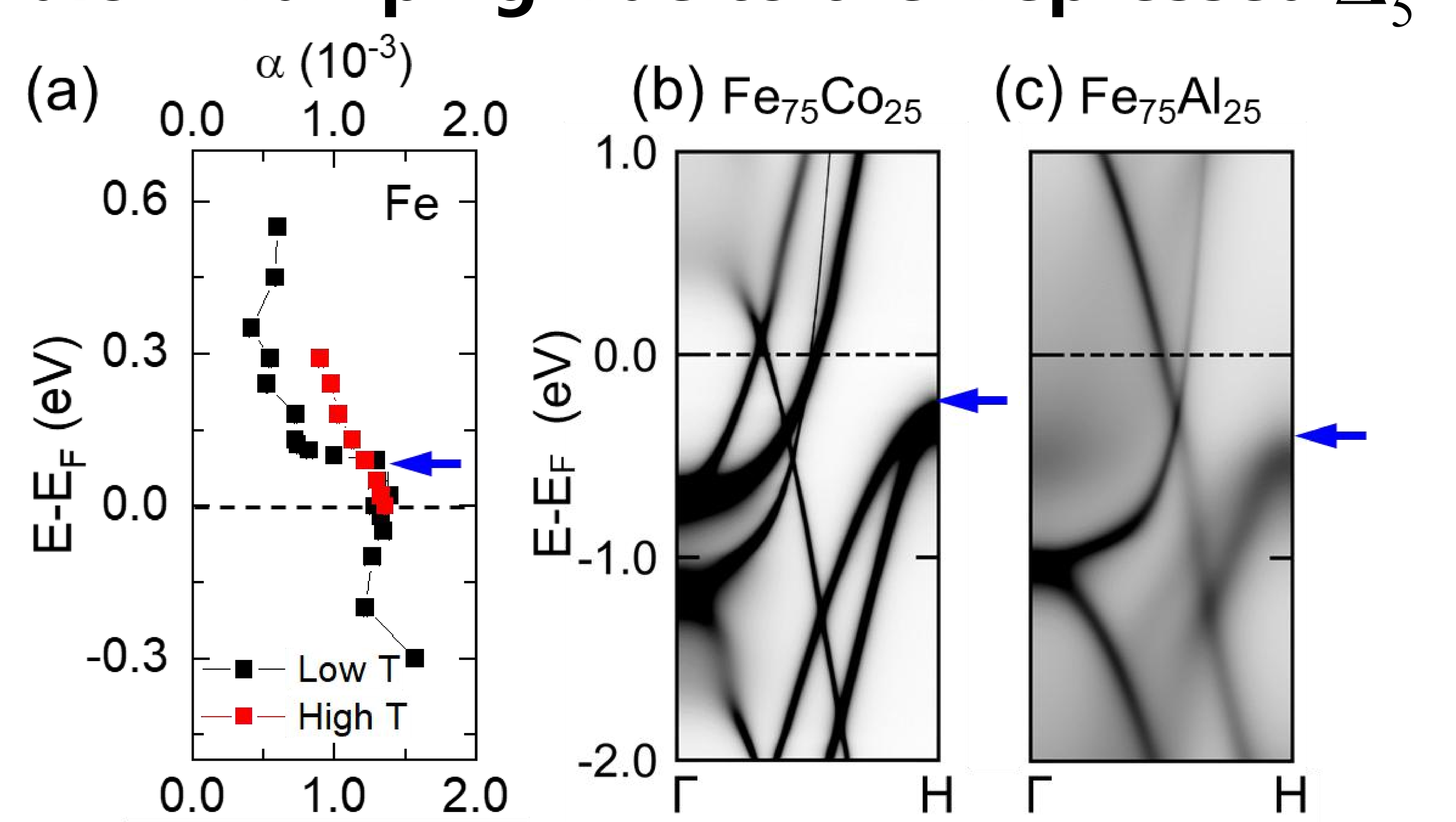
We focus on the contribution at Γ-point and the dimensionless damping constant α can be calculated as,

$$\alpha=\frac{g\mu_B\pi}{M(N)}\sum_n\langle|\Gamma_n^-|^2\rangle\left(A_n^{\Gamma}(E_F)\right)^2$$

$\Delta_5^{\uparrow}$ dominantes the damping oscillation and has the QWSs consistent period of 8~10 ML with experiments.



Ultralow Damping Due to the Depressed $\Delta_5^{\uparrow}$



$\Delta_5^{\uparrow}$ gives the dominant contribution to Gilbert damping in Fe. And the ultralow damping in FeCo or FeAl alloys then could be attributed to the depressed $\Delta_5^{\uparrow}$.

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