Effect of Anisotropy Symmetry Property on the Switching Behavior of the Pinned Layer in Exchange Biased Bilayers

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Motivation

• In exchange biased bilayers, switching chirality occurs due to off-alignment of pinned direction and F layer easy axis.
• Motivation of this work is to understand relationship between switching chirality and anisotropy asymmetry.

Switch Initiating Field of A Single Domain Particle

• Free energy density:
\[ F(\alpha, \beta) = E(\alpha, \beta) - \mathbf{H} \cdot \mathbf{M} \]
\[ E(\alpha, \beta); \text{anisotropy energy density} \]
\[ \alpha; \text{polar angle of magnetization} \]
\[ \beta; \text{azimuthal angle of magnetization} \]

• Suppose magnetization initially points to +\( x \) direction, an easy direction of magnetization. If field is applied to +\( x \) direction, the condition
\[ F_{uu}F_{\beta\beta} - F_{u\beta}^2 = 0 \]
gives switch initiating field \( H_{sw} \textsuperscript{[1]} \);
\[ H_{sw} = \min \{ E_{uu}(\pi/2,0), E_{\beta\beta}(\pi/2,0) \} / M_s \]
\[ F_{uu} = \frac{\partial^2 F}{\partial \alpha^2}, F_{\beta\beta} = \frac{\partial^2 F}{\partial \beta^2}, F_{u\beta} = \frac{\partial^2 F}{\partial \alpha \partial \beta}, F_{uu} = \frac{\partial^2 E}{\partial \alpha^2} \]


Switching Chirality

• Given infinitesimal increment of field \( \delta H \) at \( H_{sw} \), if location of energy minimum shifts by infinitesimal amount \( (\delta \alpha, \delta \beta) \), then
\[ F_u(\pi/2 + \delta \alpha, \delta \beta) = 0 \]
\[ F_\beta(\pi/2 + \delta \alpha, \delta \beta) = 0 \]
\[ \Rightarrow \]
\[ \frac{1}{2} [E_{uu}(\pi/2,0)(\delta \alpha)^2 + 2E_{u\beta}(\pi/2,0)(\delta \alpha)(\delta \beta) + E_{\beta\beta}(\pi/2,0)(\delta \beta)^2] \]
\[ - M_s(\delta H)(\delta \alpha) + \eta_1, \eta_2 \in [0,1] \]
\[ \Rightarrow \]
\[ \nabla E_{uu} = 0, \text{min} = 0 \]

Anisotropy Asymmetry in Exchange Biased Bilayers

\[ \nabla E_{uu} = 0 \]
\[ \text{K}_{uu}; \text{unidirectional anisotropy constant} \]
\[ \text{K}_{\alpha\beta}; \text{uniaxial anisotropy constant} \]
\[ E(\alpha) = -K_{uu} \cos(\alpha - \delta_1) + \text{K}_{\alpha\beta} \sin^2(\alpha - \delta_2) \]
\[ E(\alpha) = 3K_{\alpha\beta} \sin(2\delta_2) \]
\[ \Rightarrow \text{Off-alignment of e.d. and e.a. causes switching chirality} \]

Energy Profile

\[ H < H_{sw} \]
\[ \text{energy minimum at } \alpha = 0 \]
\[ H = H_{sw} - \delta H \]
\[ \text{energy minimum at } \alpha = 0 \]
\[ H = H_{sw} \]
\[ \alpha = 0 \text{ becomes metastable} \]
\[ H = H_{sw} + \delta H \]
\[ \text{energy minimum shifts to the right} \]

Conclusion

• Switching behavior of a single domain particle with arbitrary anisotropy is studied. Criterion for determining switching chirality is obtained.
• Difference between switch initiating field \( H_{sw} \) and actual switching field in exchange biased bilayers is caused by off-alignment of pinned direction and F layer easy axis.

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