SOT switching of PMA layer via SmB_6 thin films

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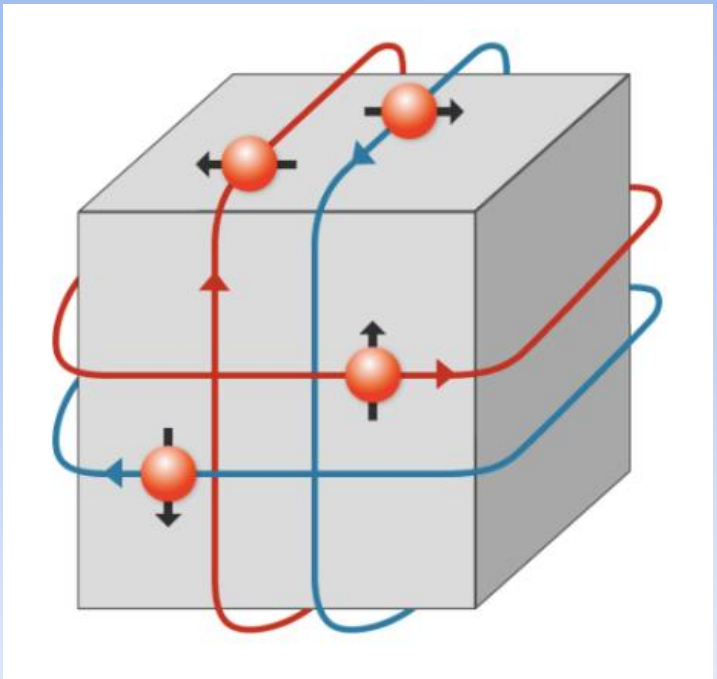
Outline

- Introduction
- Tantalizing suggestions from bulk SmB_6 crystals
- Epitaxial SmB_6 thin films
- Transport properties
- Spin-orbit torque switching of PMA layer assisted by SmB_6
- Summary

Topological Insulators

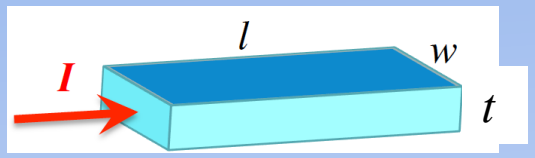


Insulating interior

Surface conduction

Spin-momentum locking

3d bulk conduction vs. *2d* surface conduction



3d conduction

$$R = \rho \frac{l}{wt} = R_{\square} l/w$$

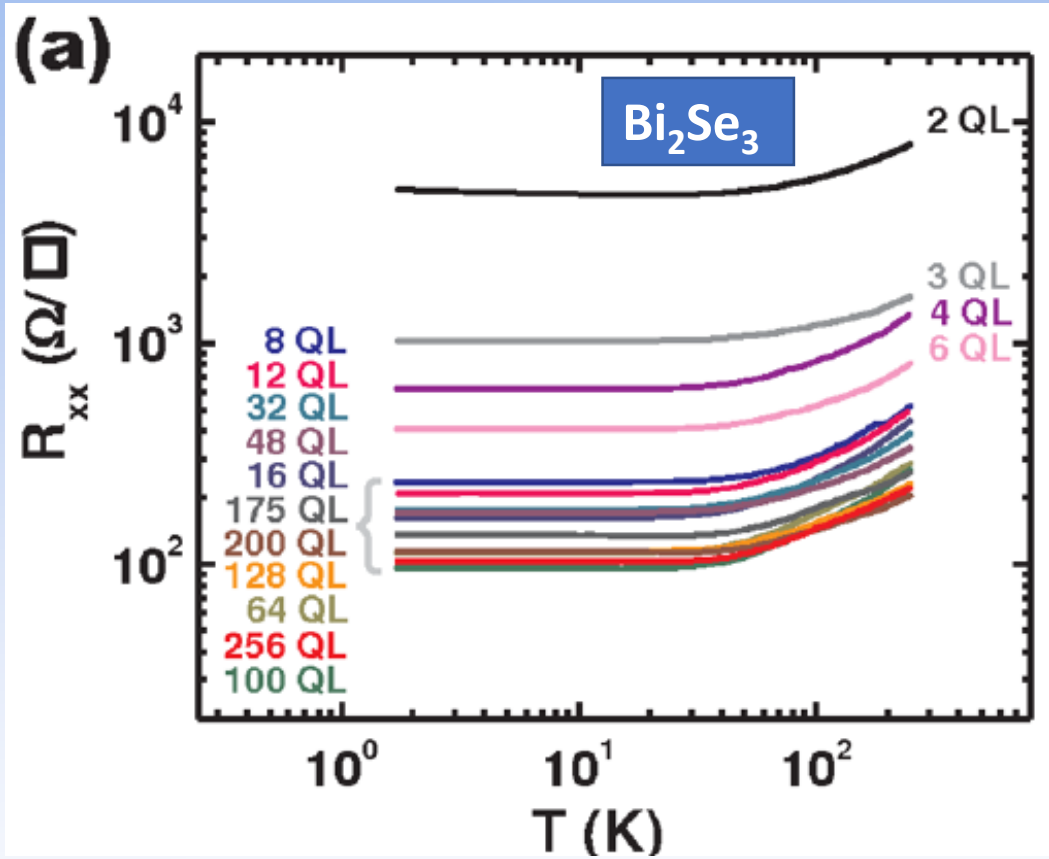
$$R_{\square} = \frac{Rw}{l} = \frac{\rho}{t}$$

Sheet conductance

$$G_{\square} = R_{\square}^{-1} = \frac{R^{-1} l}{w} = \sigma t$$

3d: $G_{\square} \propto t$

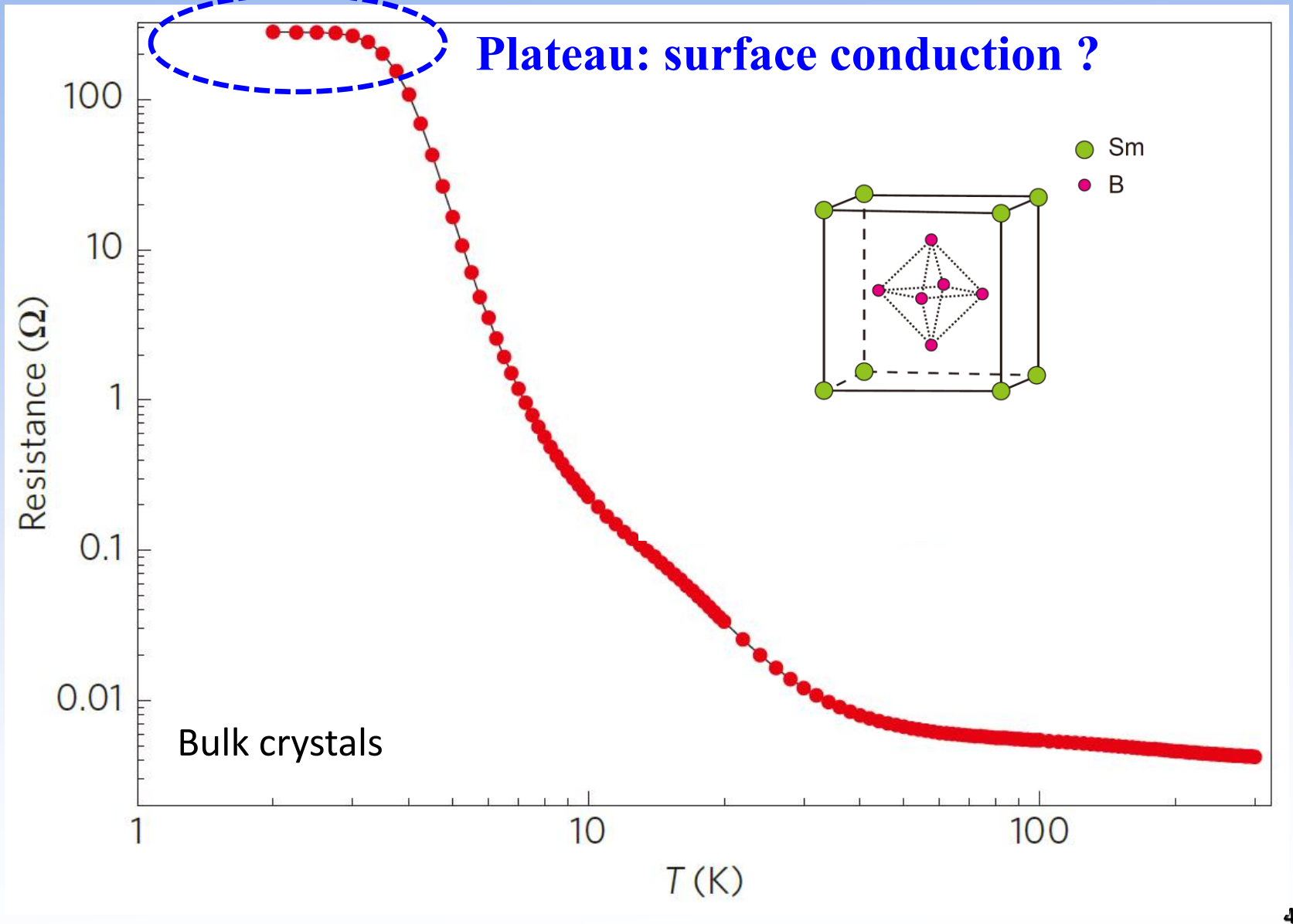
2d: $G_{\square}$ = constant



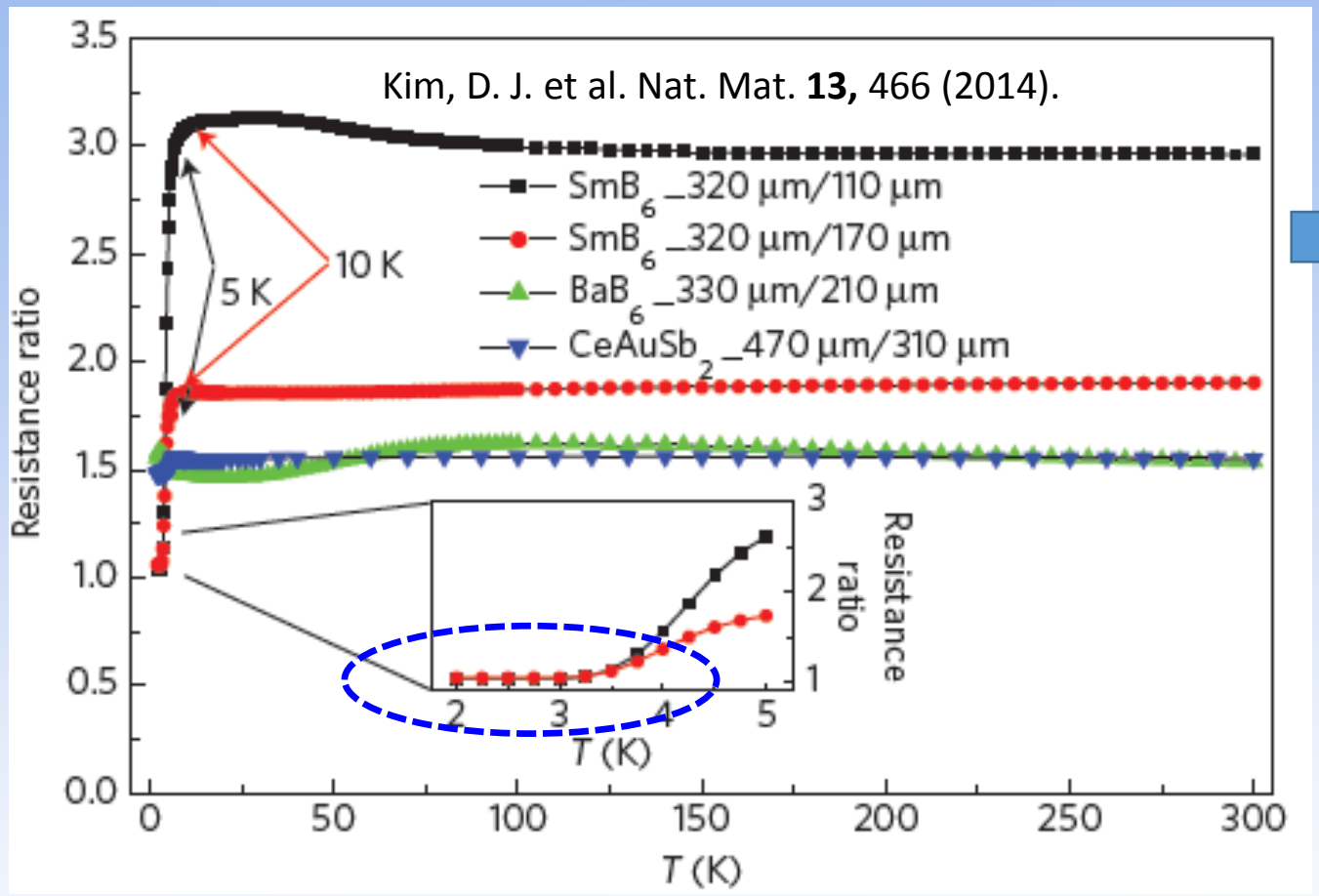
N. Bansal, et al. PRL **109**, 116804 (2012)

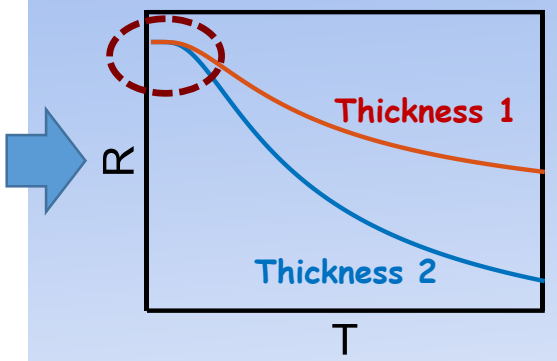
SmB_6: Topological Kondo Insulator ?

D. J. Kim, J. Xia, and Z. Fisk, Nat. Mater. **13**, 466 (2014)



Transport evidences for metallic surface state in SmB_6

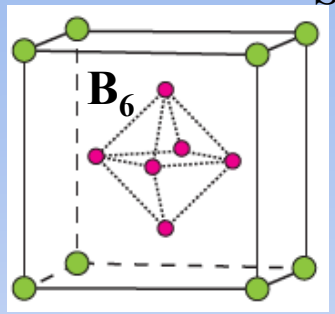




Thickness ***independent*** R_{xx} at low T plateau of bulk crystals

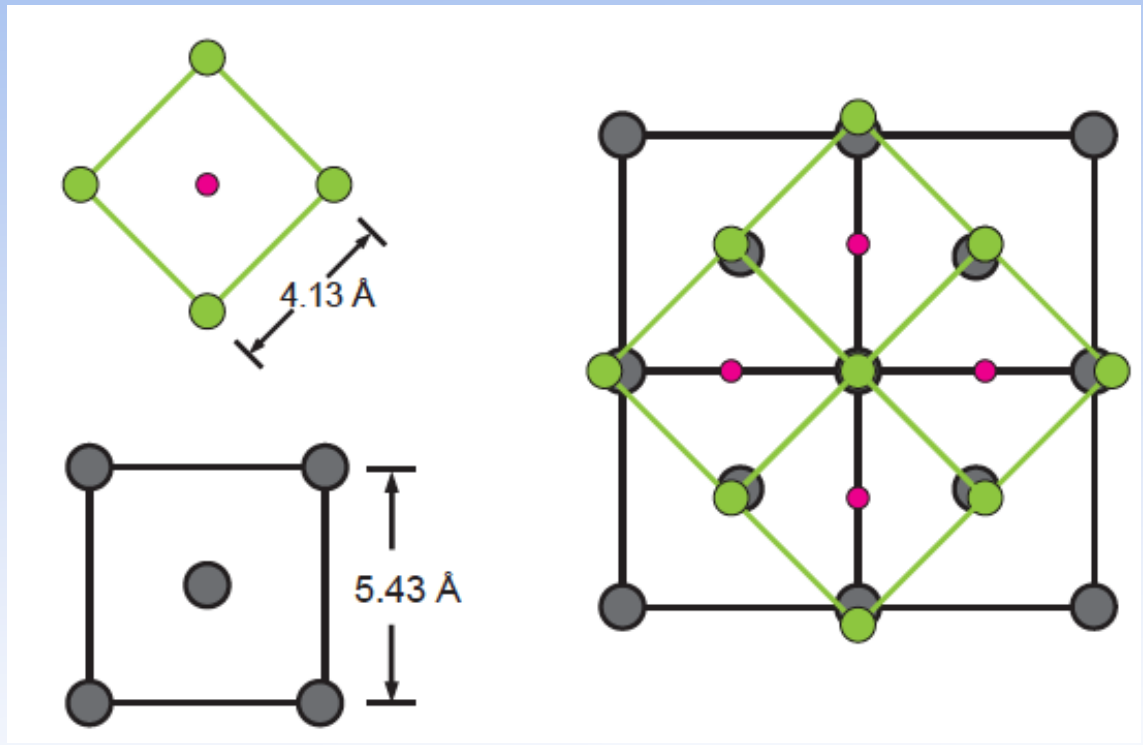
High quality SmB_6 thin films essential

Epitaxial Relationship SmB_6 [100] || Si [110]

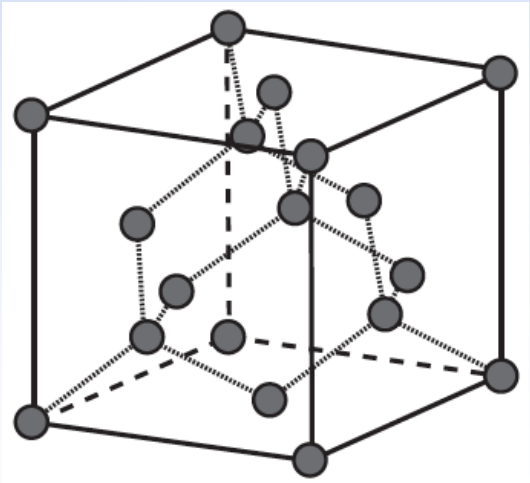


SmB_6 (a = 4.13 Å)

SmB_6 (100)



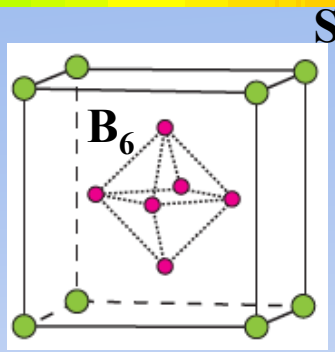
Si (100)



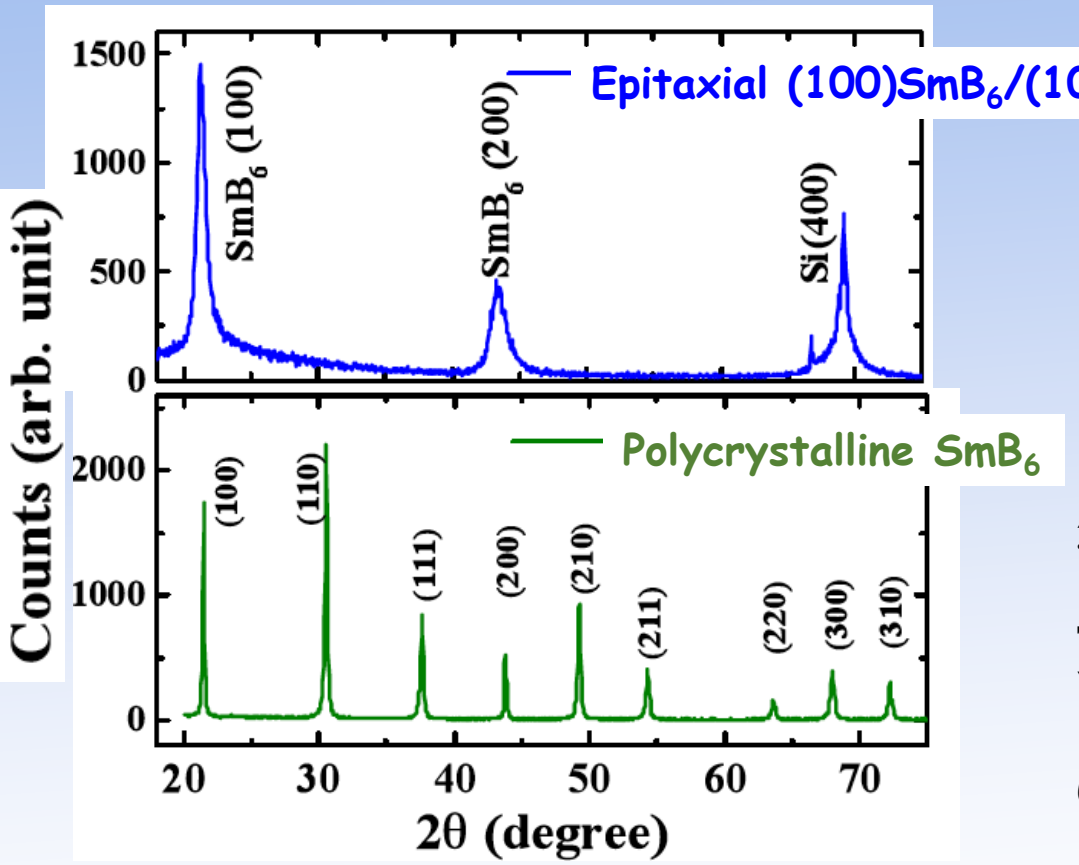
Si (a = 5.43 Å)

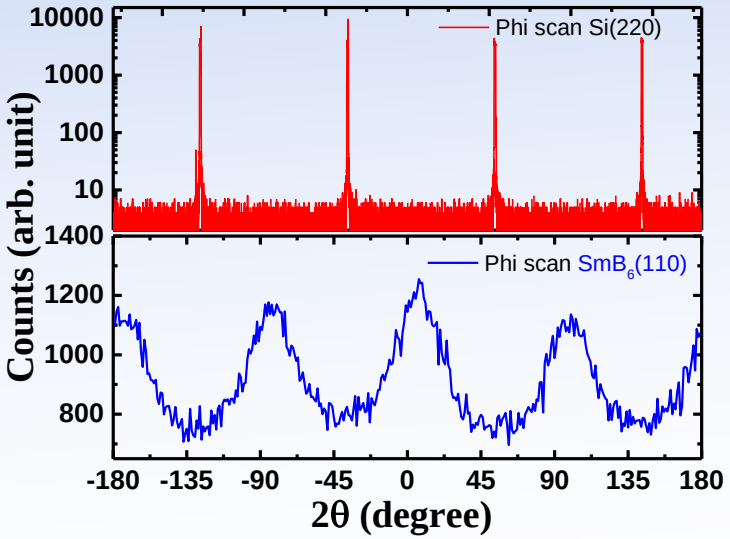
7% mismatch

Epitaxial SmB_6 thin films on Si(001) by biased sputtering



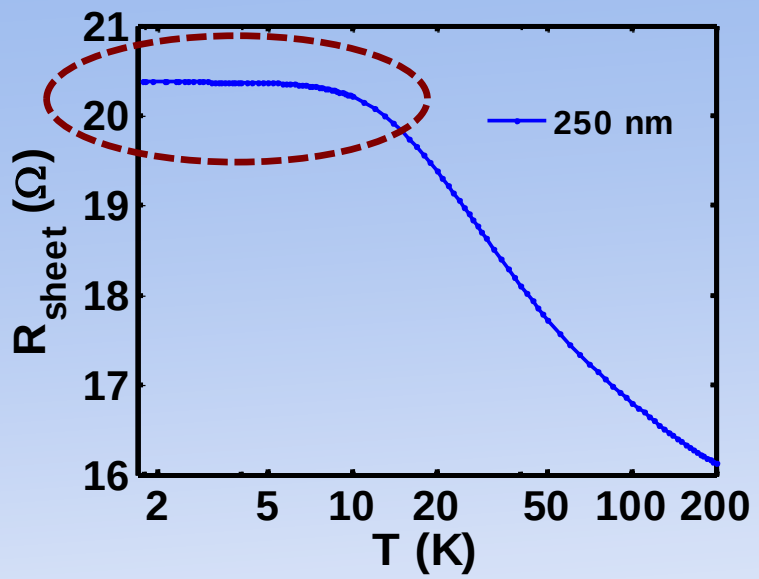
Epitaxy Relationship
SmB_6 [100] || Si [110]





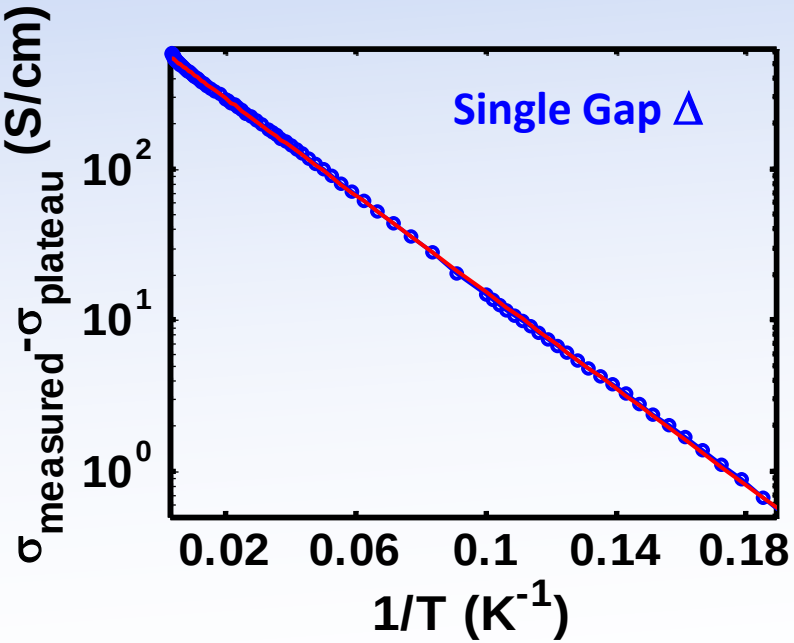
T_S = 550 °C

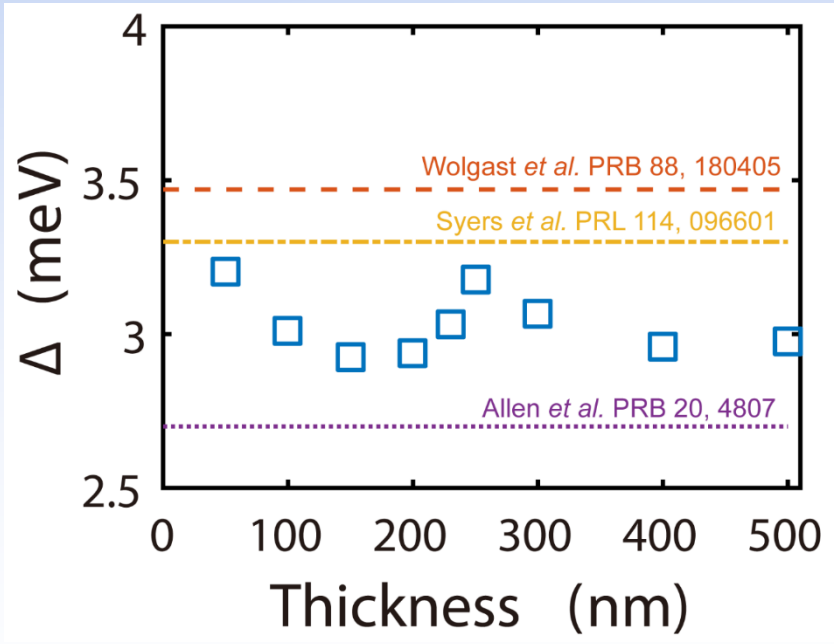
SmB_6 thin films: Plateaus & Gap Δ independent of thickness



$$\sigma_{Measured} = \sigma_{Insulator} + \sigma_{Plateau}$$

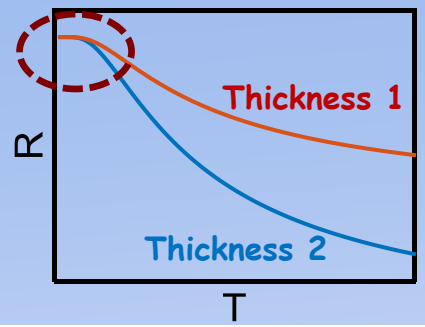
$$\sigma_{Insulator} = \sigma_a \exp(-\Delta/k_B T)$$



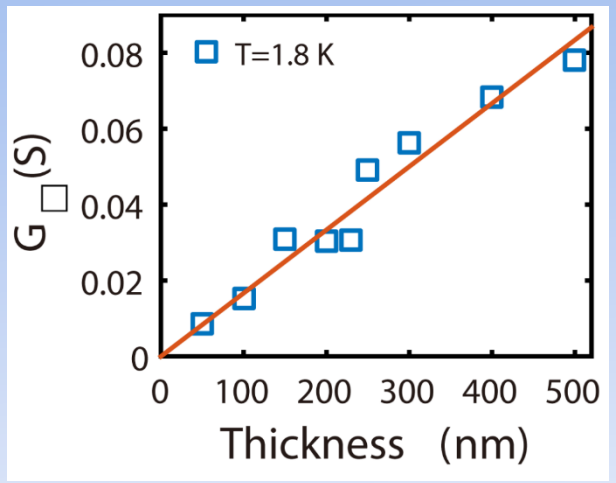


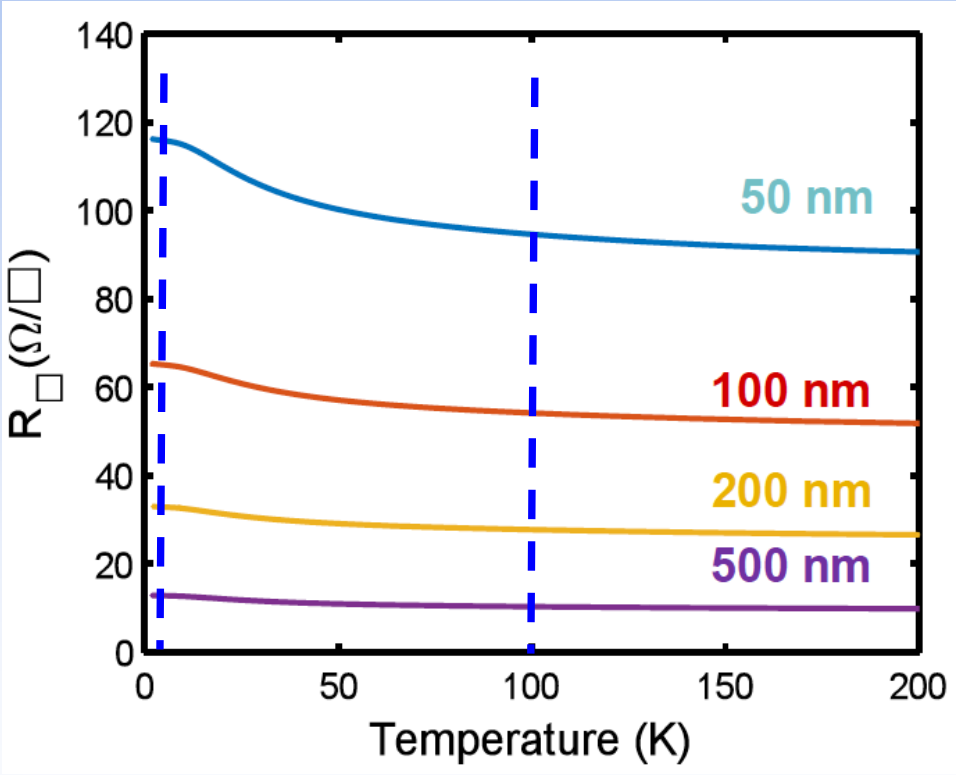
Same Gap Δ for all films

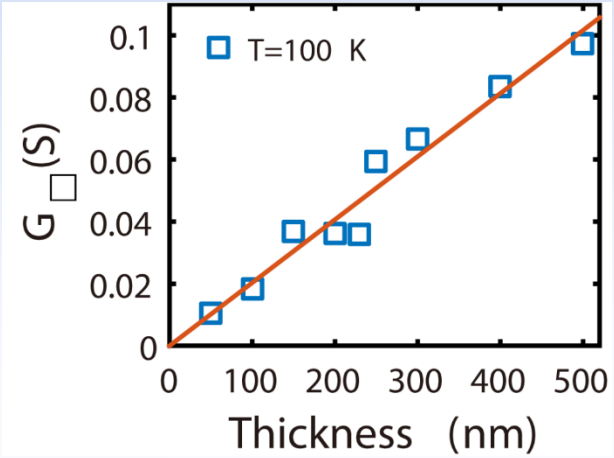
Thickness Dependence: No sign of surface conduction



$3d: G_{\square} \propto t$



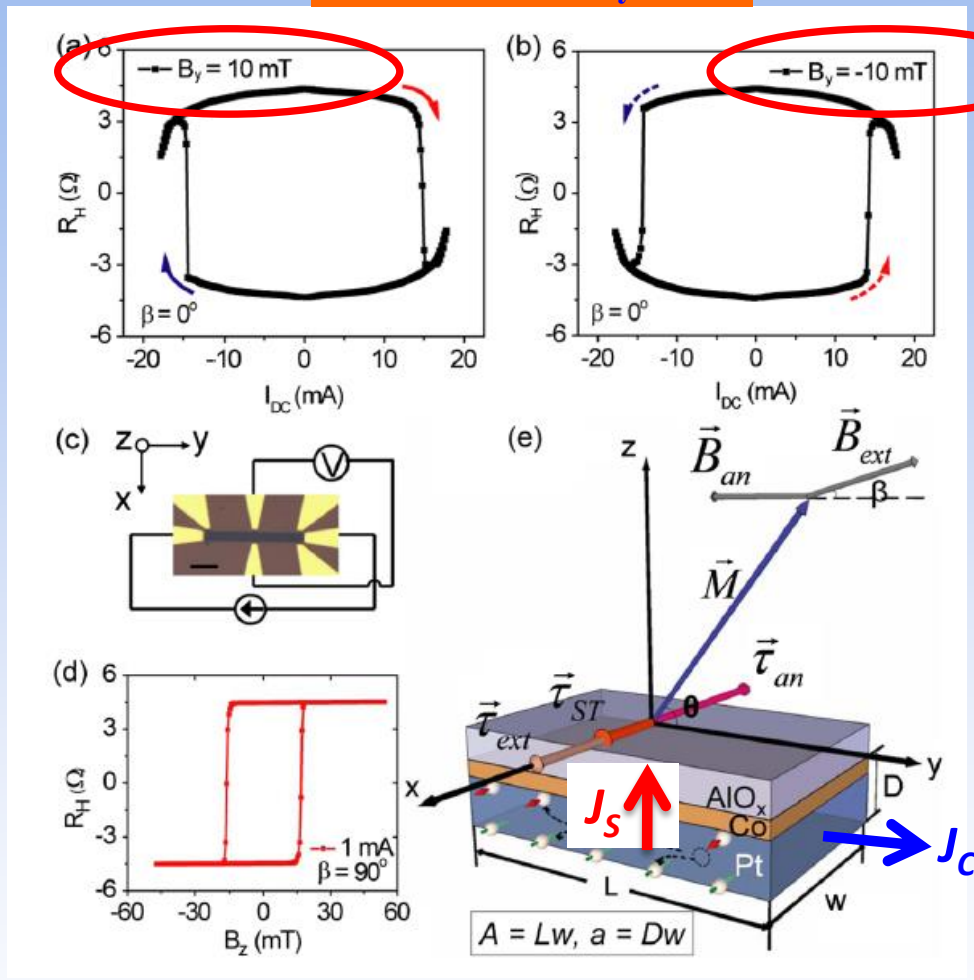




- 3d conduction, No insulating interior in epitaxial SmB_6
- Novel surface topological state may persist

Spin Hall Switching of PMA Layer

Must have $B_y \parallel I_c$



Miron *et al.*, Nature **476**, 189 (2011).
Liu *et al.*, PRL **109,** 096602 (2012)

Pt/Co/AlOx

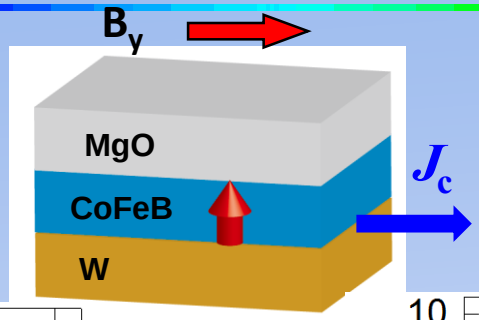
- **B_y lowers I_c**
- **No switching @ $B_y = 0$!**
- **Opposite effect of $\pm B_y$**
- **Curved background**

B_y for breaking symmetry tilting macrospin

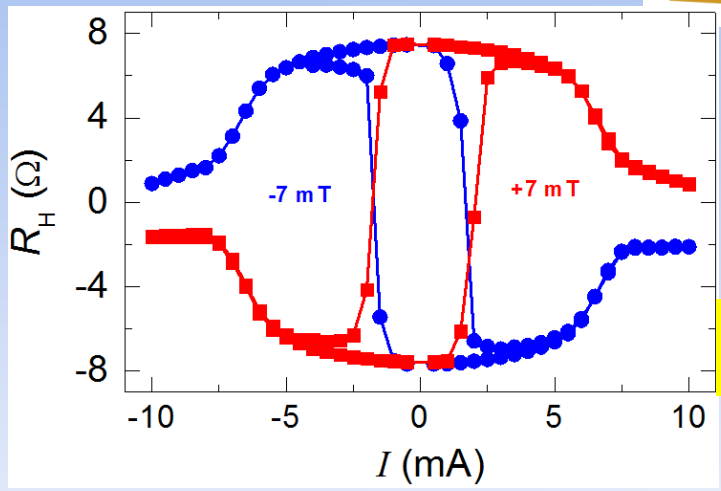
B_y may be avoided by: geometrical shape, exchange bias

Switching Mechanisms ?

Current switching in W/CoFeB/MgO



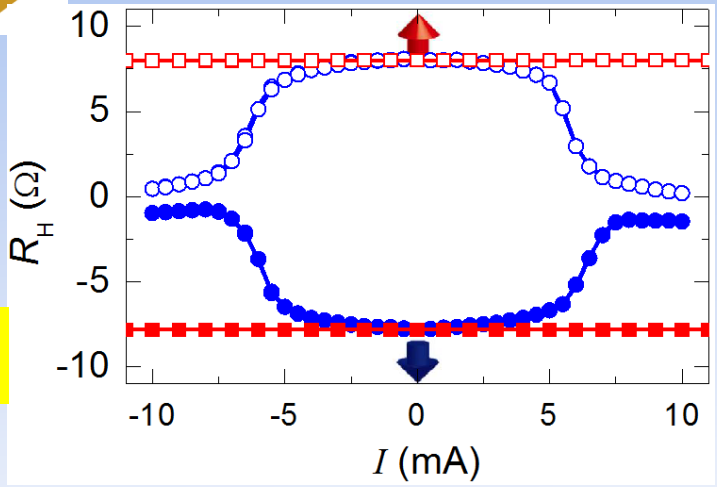
With Domain walls



Switching with B_y

Same R_H

No Domain walls



pulsed I

DC I

No Switching

Same curved background: Reversible M tilting (spin Hall)

No Domain Walls No switching !

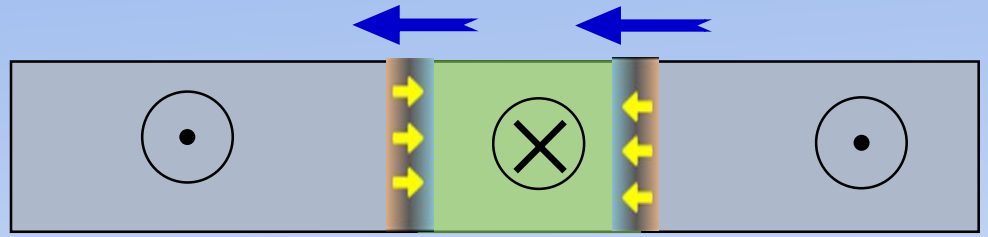
Switching via DW motion *not* macrospin !

Current Switching of PMA FM: DW Motion by I & B_y

Néel DW of one Chirality

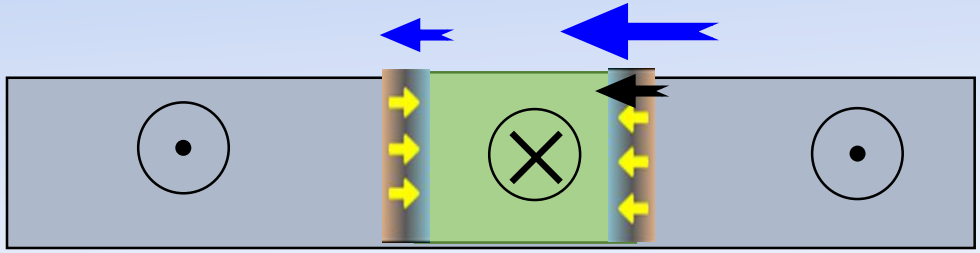
Top view

$B_y = 0$ I



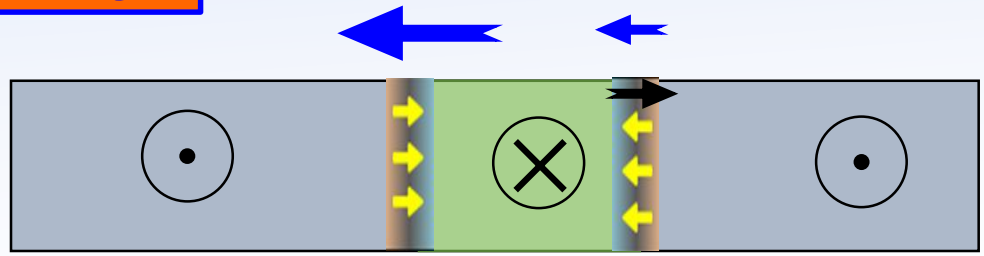
Same speed, no switching

$B_y < 0$ I



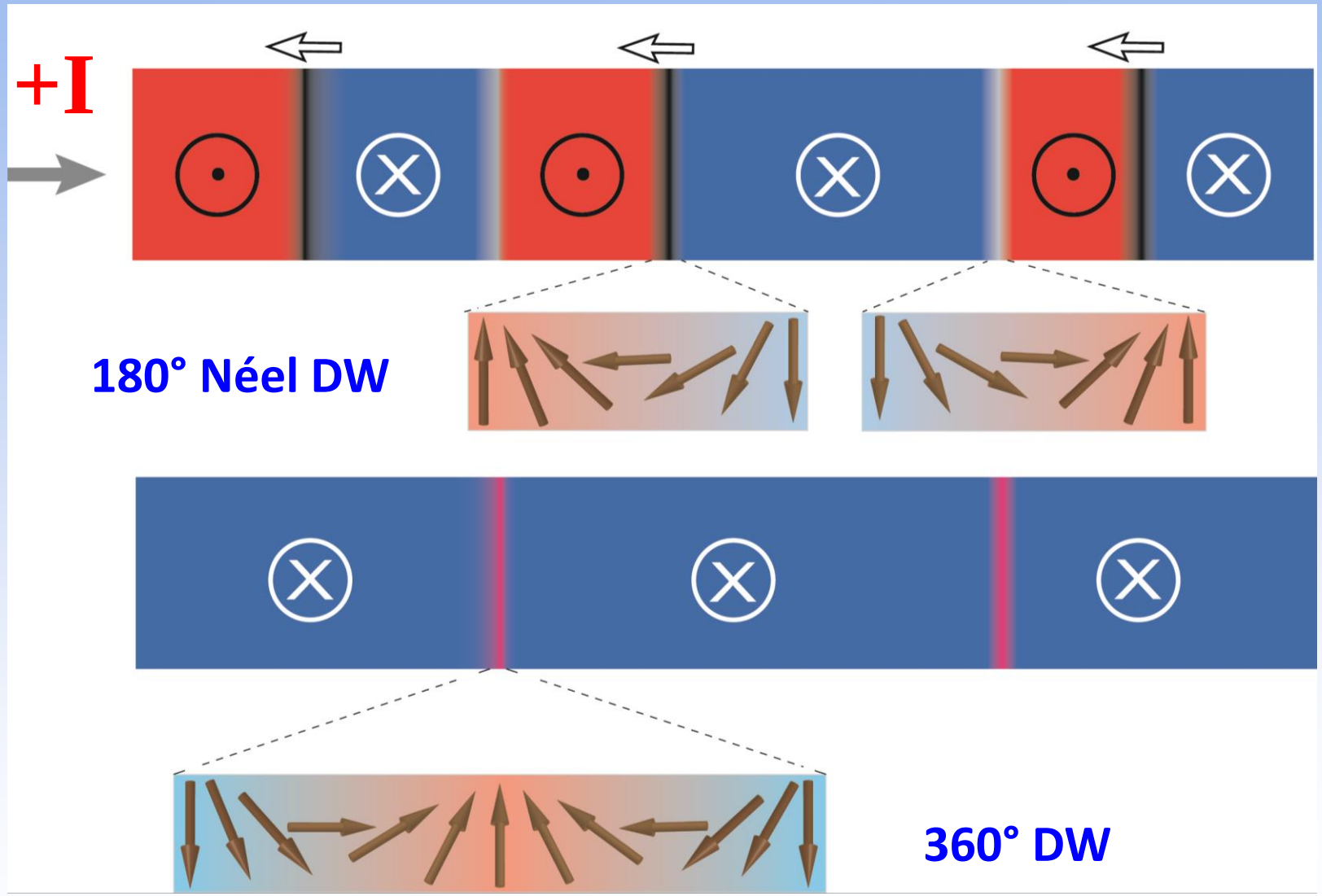
Different speed, switching !

$B_y > 0$ I



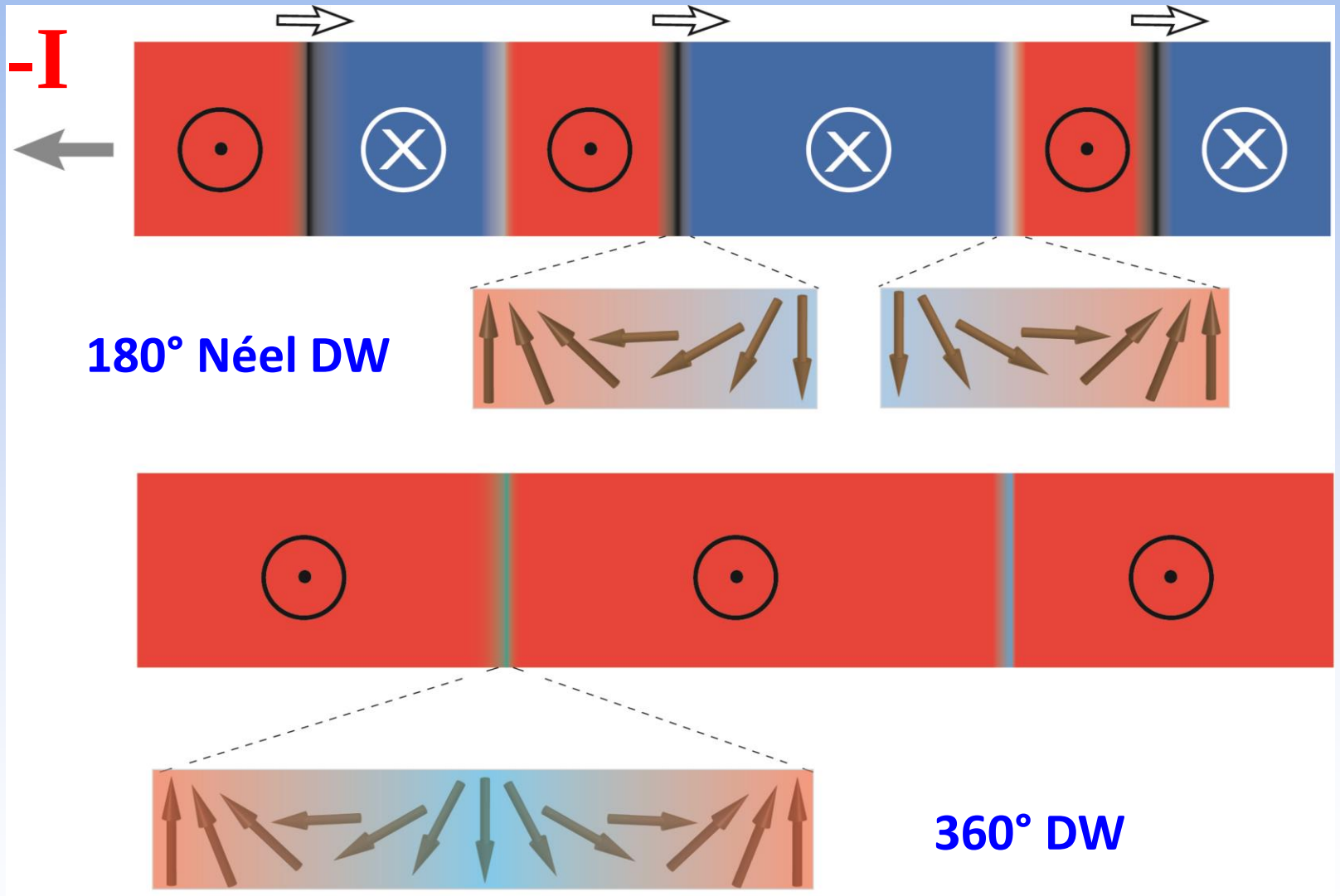
Up-down DW moves much faster than down-up DW (+I)

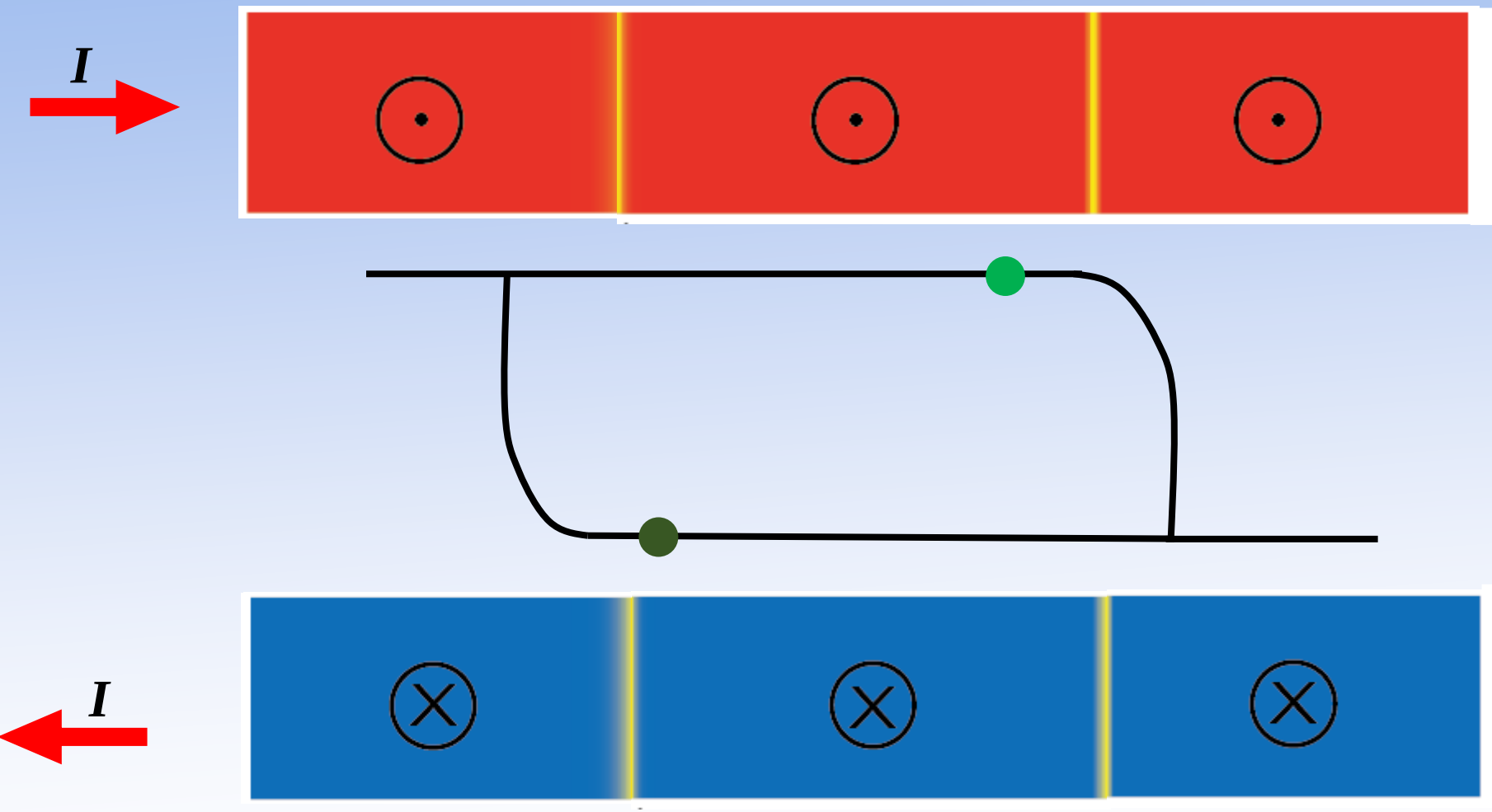
Under B_y



Up-down DW moves much faster than down-up DW (-I)

Under B_y

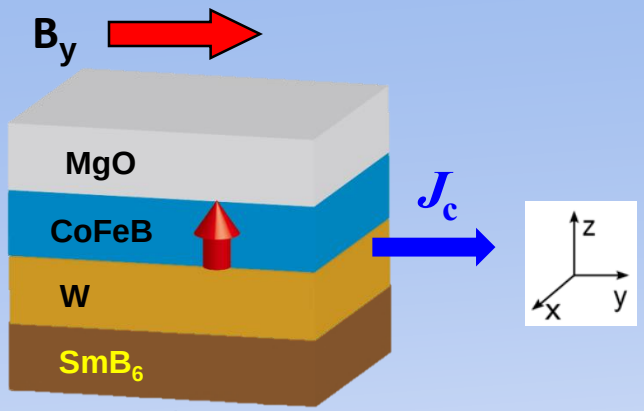




Domains only shrink or expand but not wiped out

Enhanced SOT switching by SmB_6

CoFeB(1)/W(1)/SmB_6(50)/Si (001)

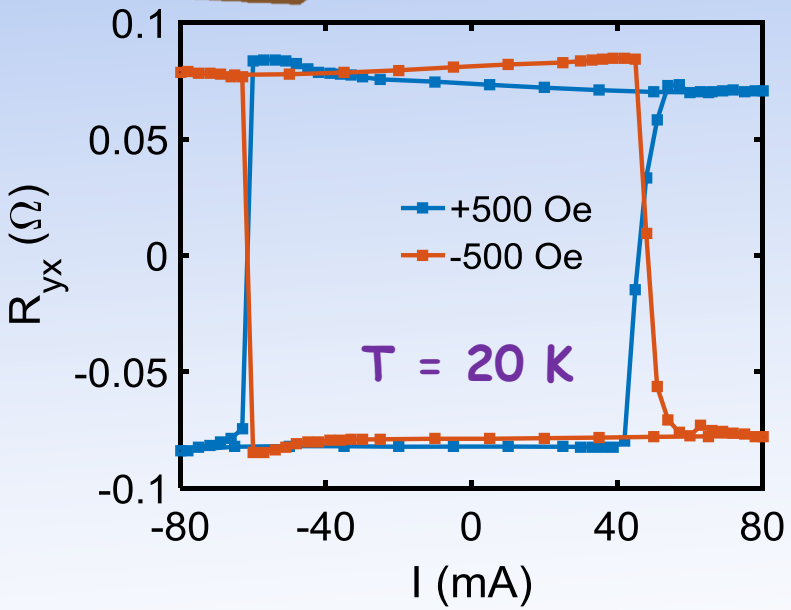


W layer needed for PMA

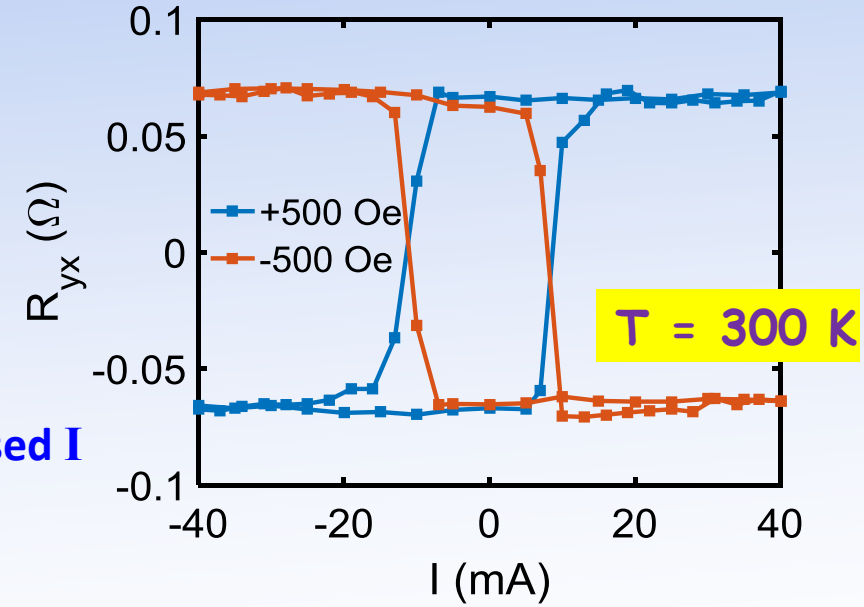
Reduced I_C and J_C with SmB_6

Low T and RT switching

B_y = 50 mT

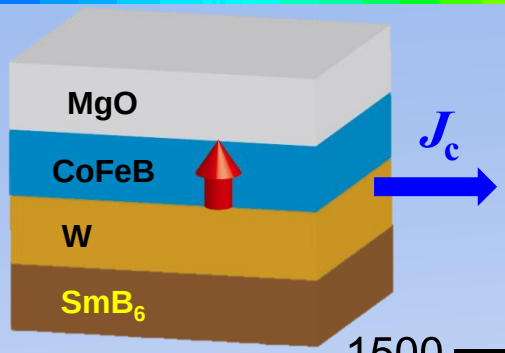


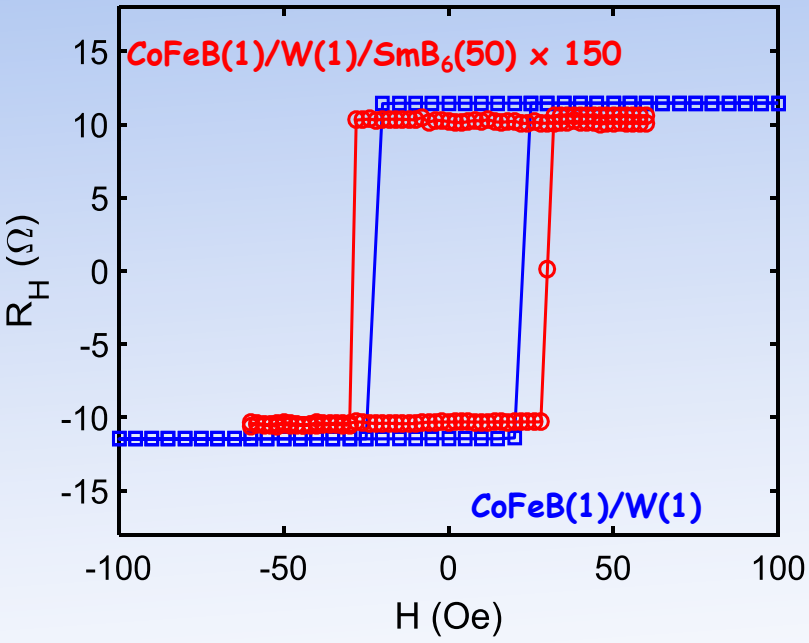
pulsed I

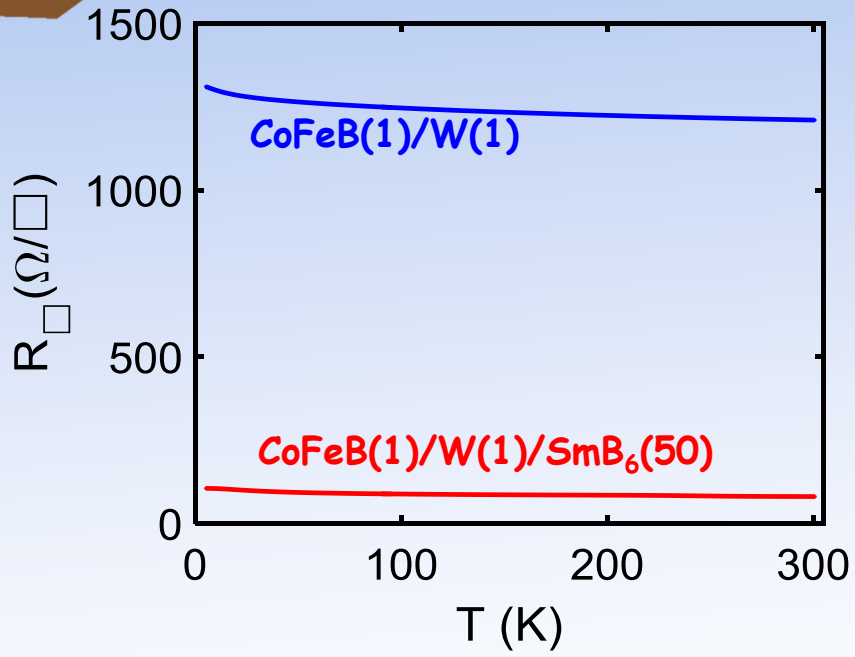


Current switching of PMA layer

Shunting effect of SmB_6(50 nm)







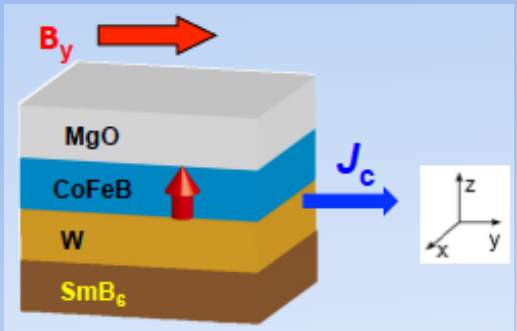
R_H reduces 180x

Current should increase 13x

$R_□$ reduces 13x

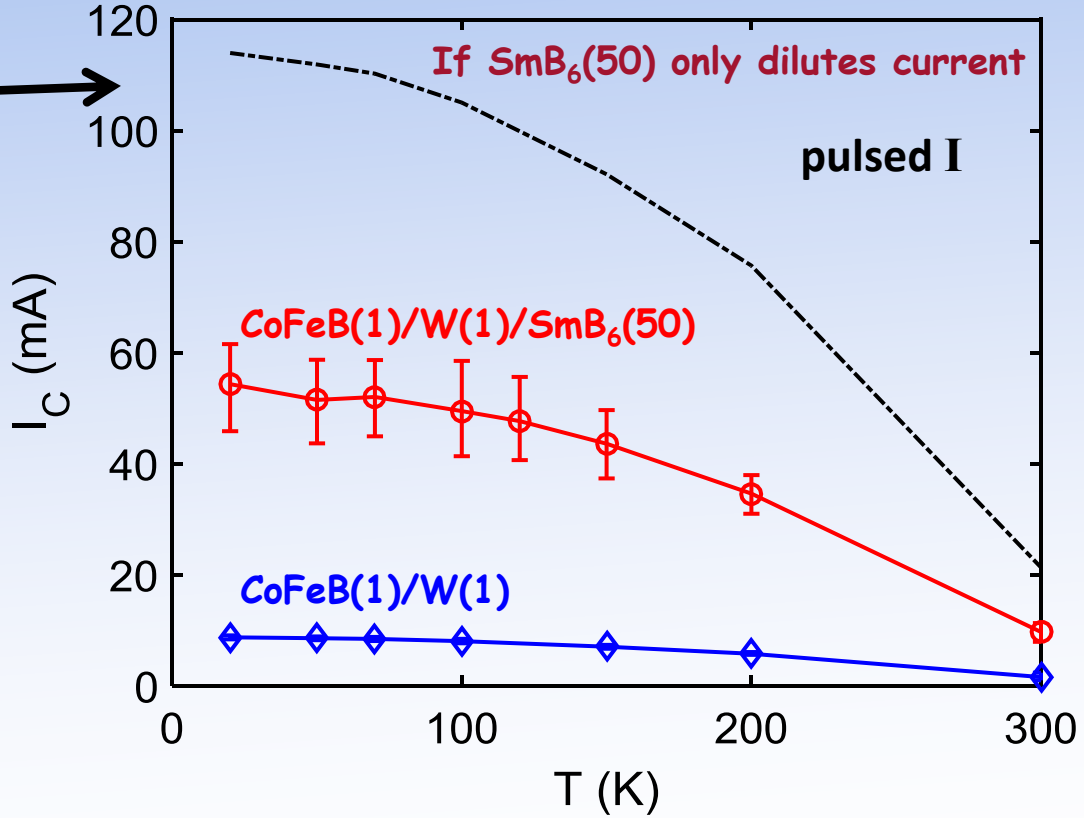
Current should increase 13x

Spin current switching assisted by SmB_6



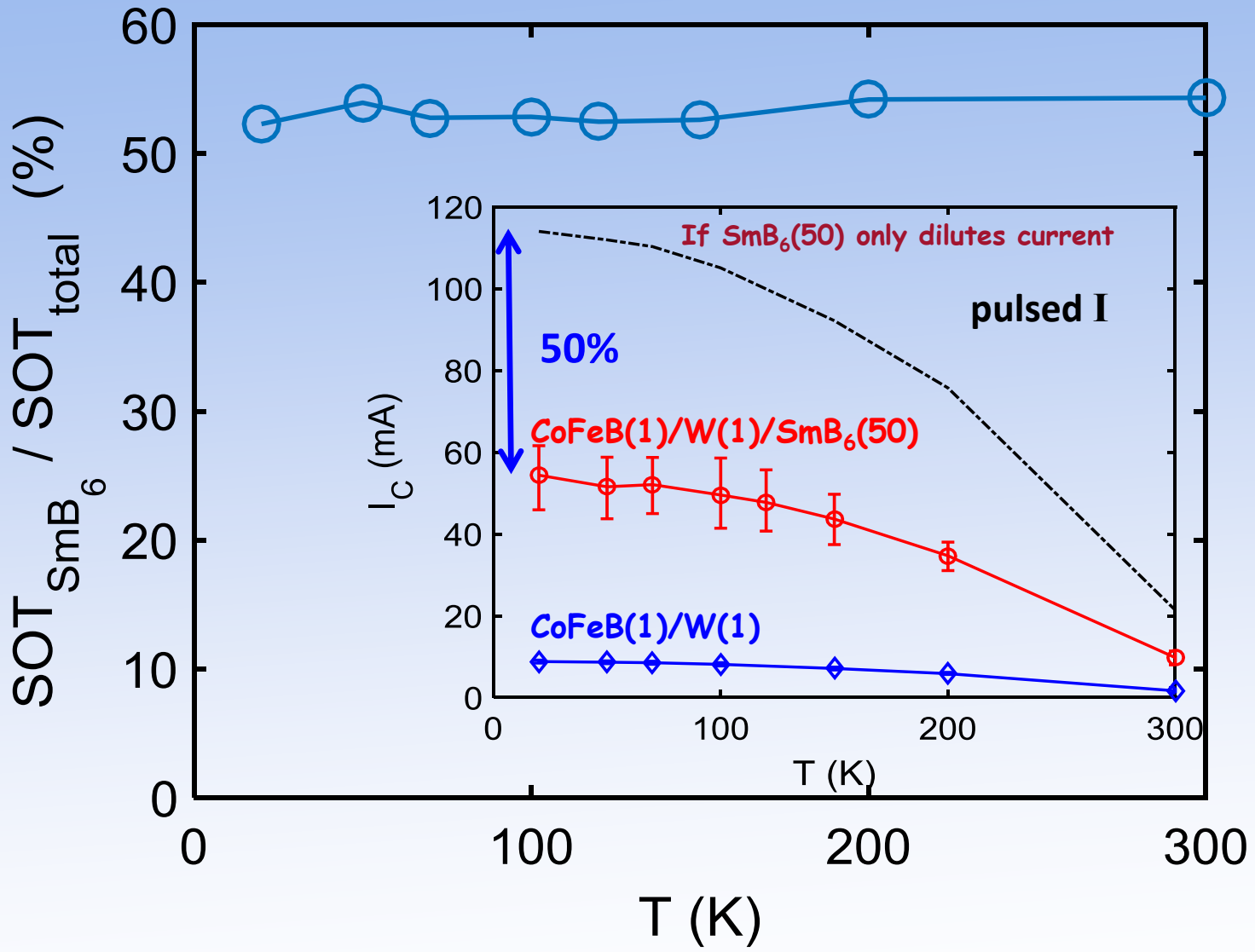
I_C should increase by 13x

but only 5x



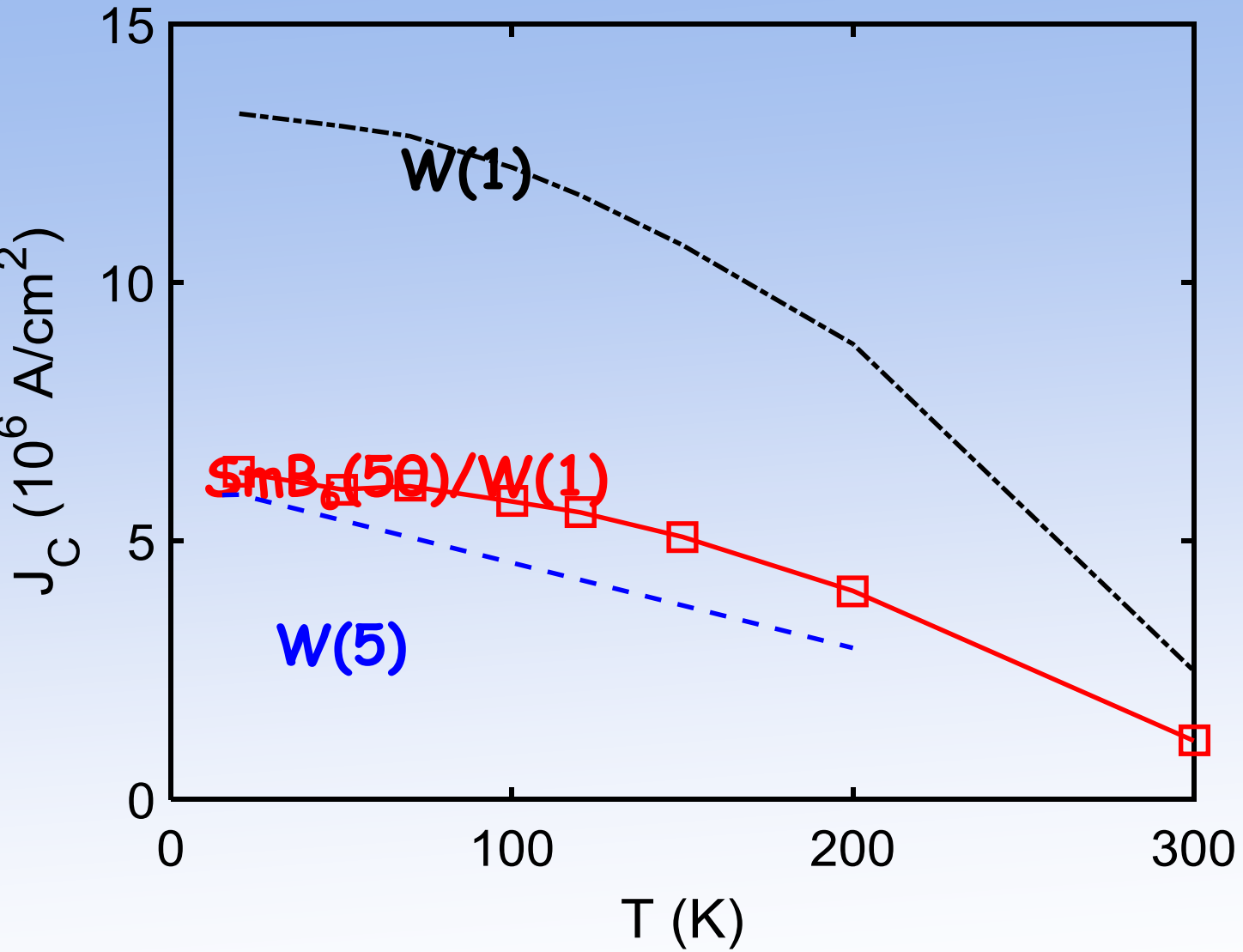
SmB_6 reduces current for switching PMA layer

SOT contribution by SmB_6



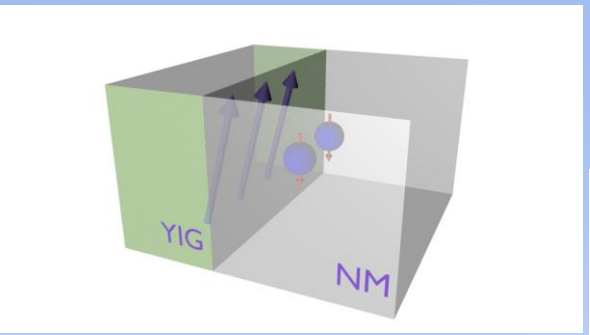
SmB_6 contributes 50% of SOT

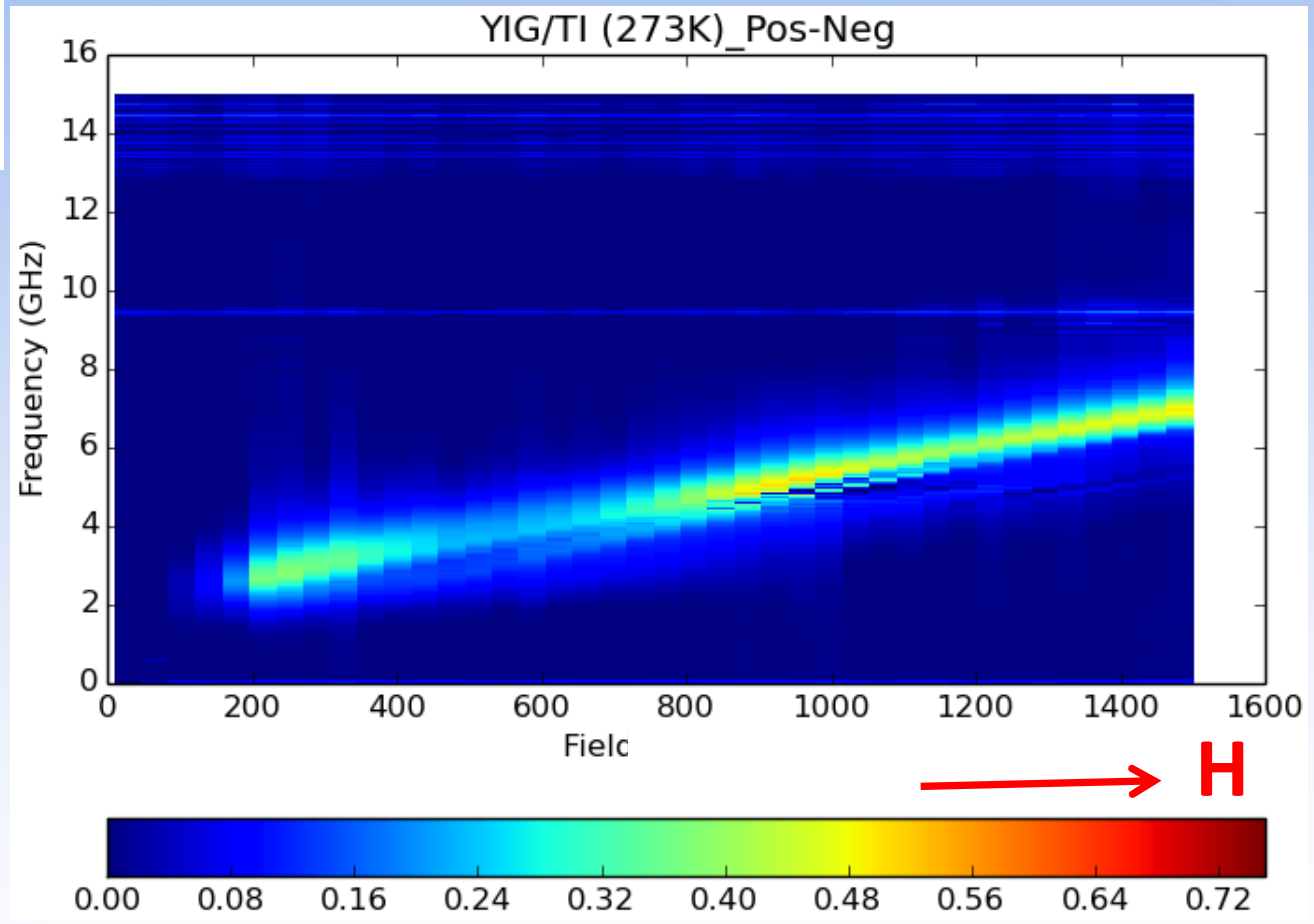
J_c through W



SmB$_6$ (50)/W(1) is comparable to W(5)

Spin pumping from YIG into SmB_6 at 273 K





(Minzhong Wu)

Conclusions

- Epitaxial (100)SmB_6/(100)Si thin film by sputtering.
- Low temperature resistivity plateau with constant gap persists.
- $G_{\square} \propto t$, *3d* conduction, No evidence of surface conduction.

BUT

- SmB_6 assisted SOT switching of PMA layers
- SmB_6 is comparable to W for SOT switching
- Spin pumping in SmB_6/YIG (M. Z. Wu)

SmB_6 is novel after all