

# Spin Hall Magnetoresistance

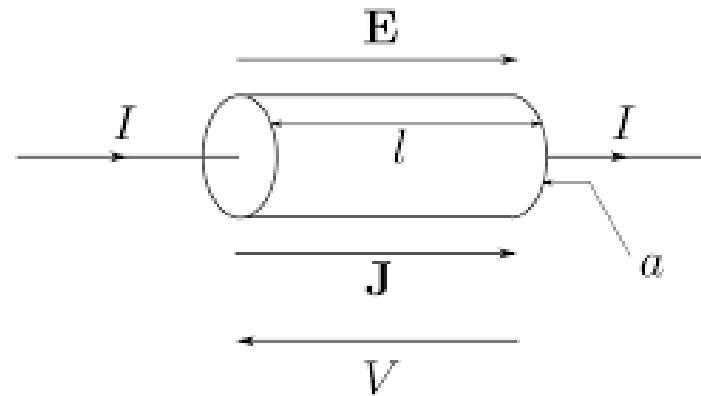
Xiaoshan Xu

2018/04/05

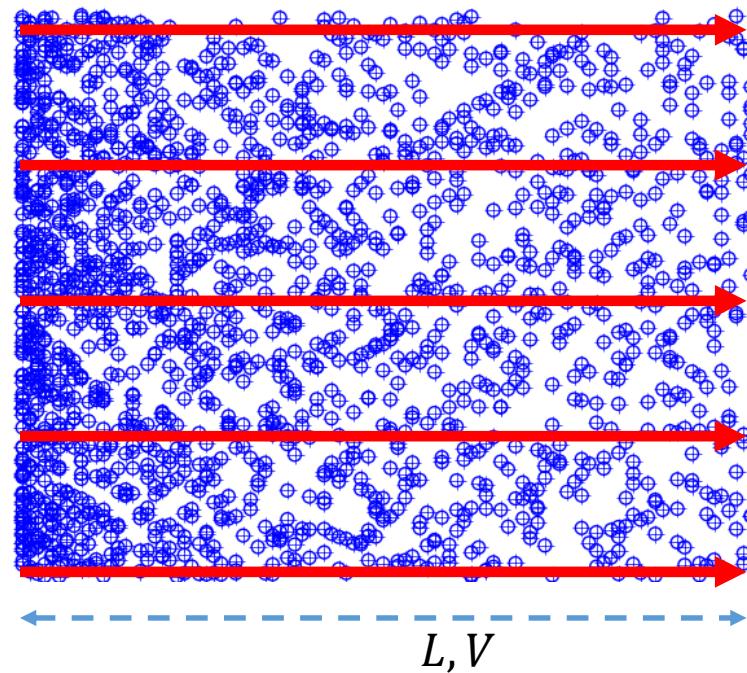
Reference: H. Nakayama et al, PRL 110, 206601 (2013)

# Charge transport

$$\vec{J}^c = e\mu n \vec{E} + eD \nabla n$$



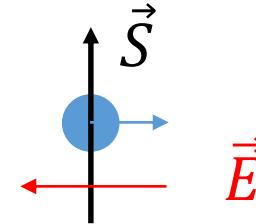
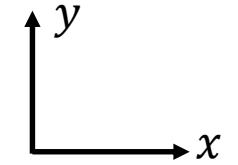
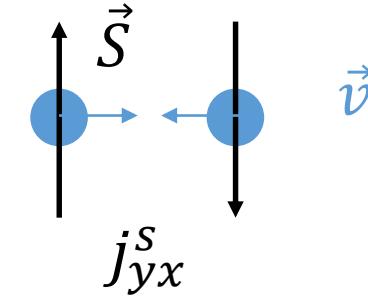
Ohm's law



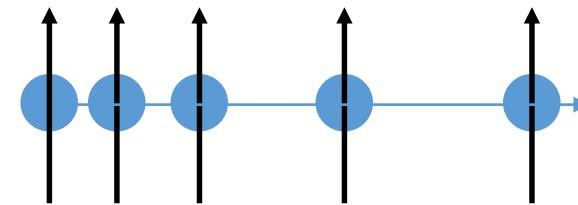
Diffusion

# Spin transport

$$j_{ij}^s = -\hbar \mu n E_i P_j^s + \hbar D \frac{\partial P_j^s}{\partial x_i}$$



**Electric-field generated spin current**



**Diffusion-generated spin current**

# Charge/spin conversion

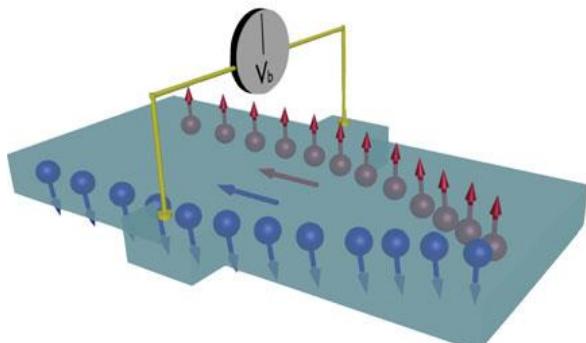
$$\vec{j}^c = e\mu n \vec{E} + eD\nabla n + \textcolor{blue}{e\mu\alpha_{SH}}(\vec{E} \times \vec{P}^s) + \textcolor{green}{e\alpha_{SH}D}(\nabla \times \vec{P}^s) \quad (3)$$

$$j_{ij}^s = -\hbar\mu n E_i P_j^s + \hbar D \frac{\partial P_j^s}{\partial x_i} - \textcolor{red}{\hbar\alpha_{SH}\epsilon_{ijk}(\mu n E_k + D \frac{\partial n}{\partial x_k})}, \quad (4)$$

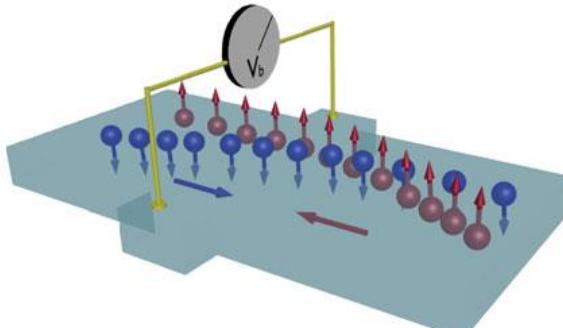


Anomalous Hall effect (AHE)

Spin-Hall effect (SHE)

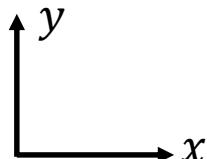


Inverse Spin-Hall effect (ISHE)



# Some schematics of mechanism

- Intrinsic (band structure)



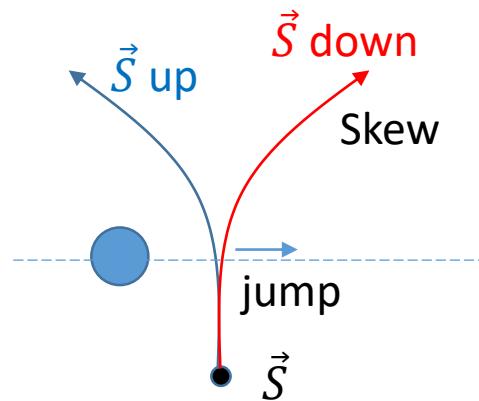
Spin orbit interaction:  
 $\vec{L} \cdot \vec{S} = \xi(\vec{\nu} \times \vec{r}) \cdot \vec{S}$

$\vec{S}$  up: attractive

$\vec{S}$  down: repulsive

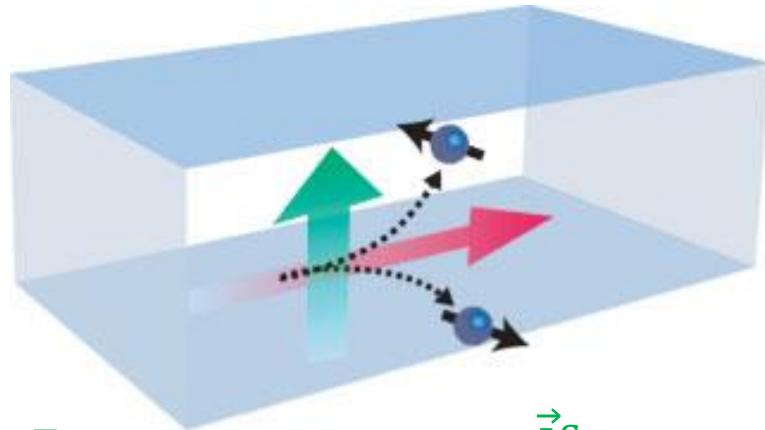
- Skew Scattering

- Side jump



# Pt: non-magnetic, strong spin-orbit coupling

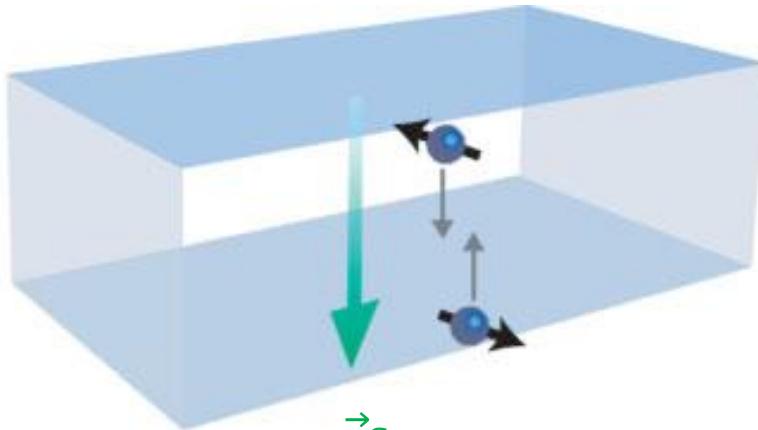
Spin-Hall effect



$$\vec{J}_y^s = \vec{J}_e \times \vec{S}$$

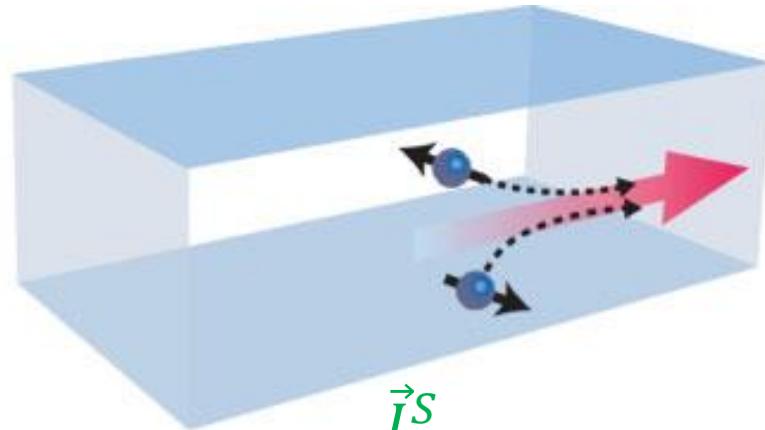
$$\vec{J}_y^s = \vec{J}_e \times \vec{S}$$

Spin current reflection



$$\vec{J}_{y\text{ back}}^s$$

Inverse spin-Hall Effect

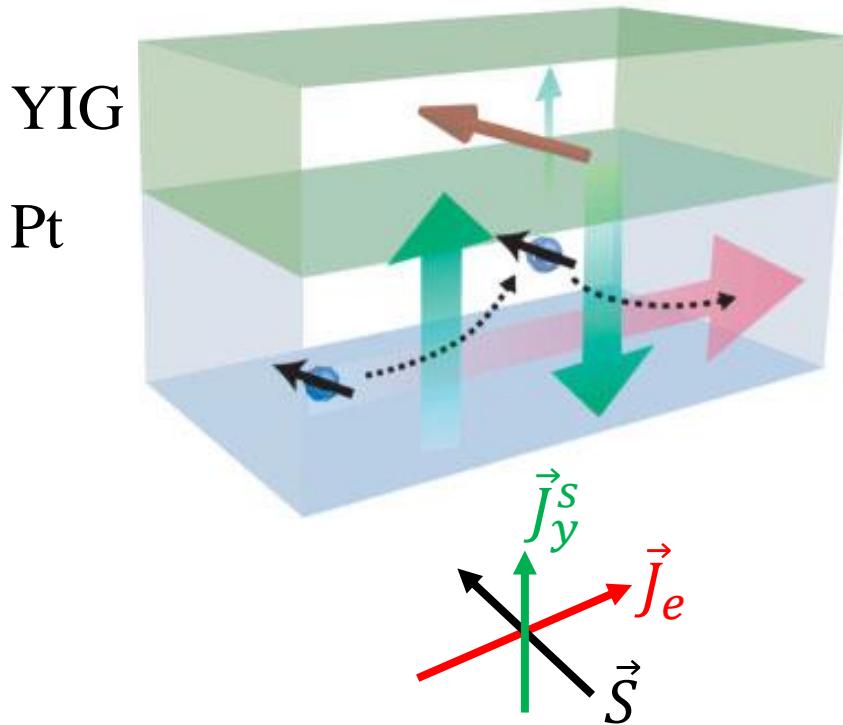


$$\vec{J}_{y\text{ back}}^s = \vec{J}_e' \times \vec{S}$$

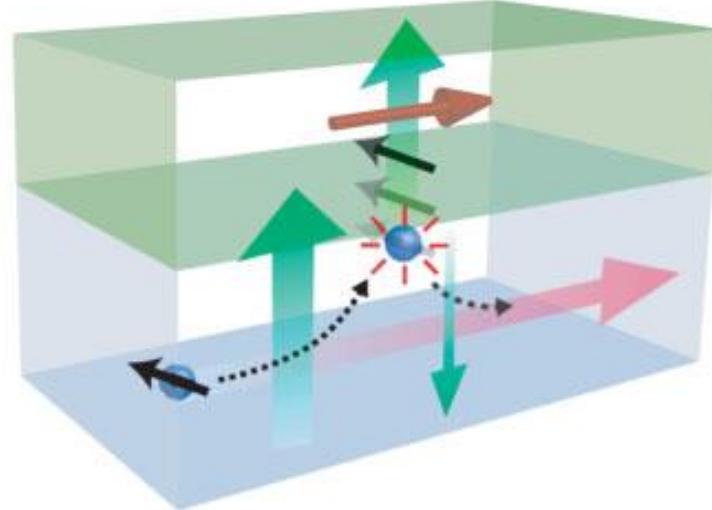
$$\vec{J}_e' = \vec{J}_{y\text{ back}}^s \times \vec{S}$$

Reflection of spin current  
→more charge current  
→smaller resistance

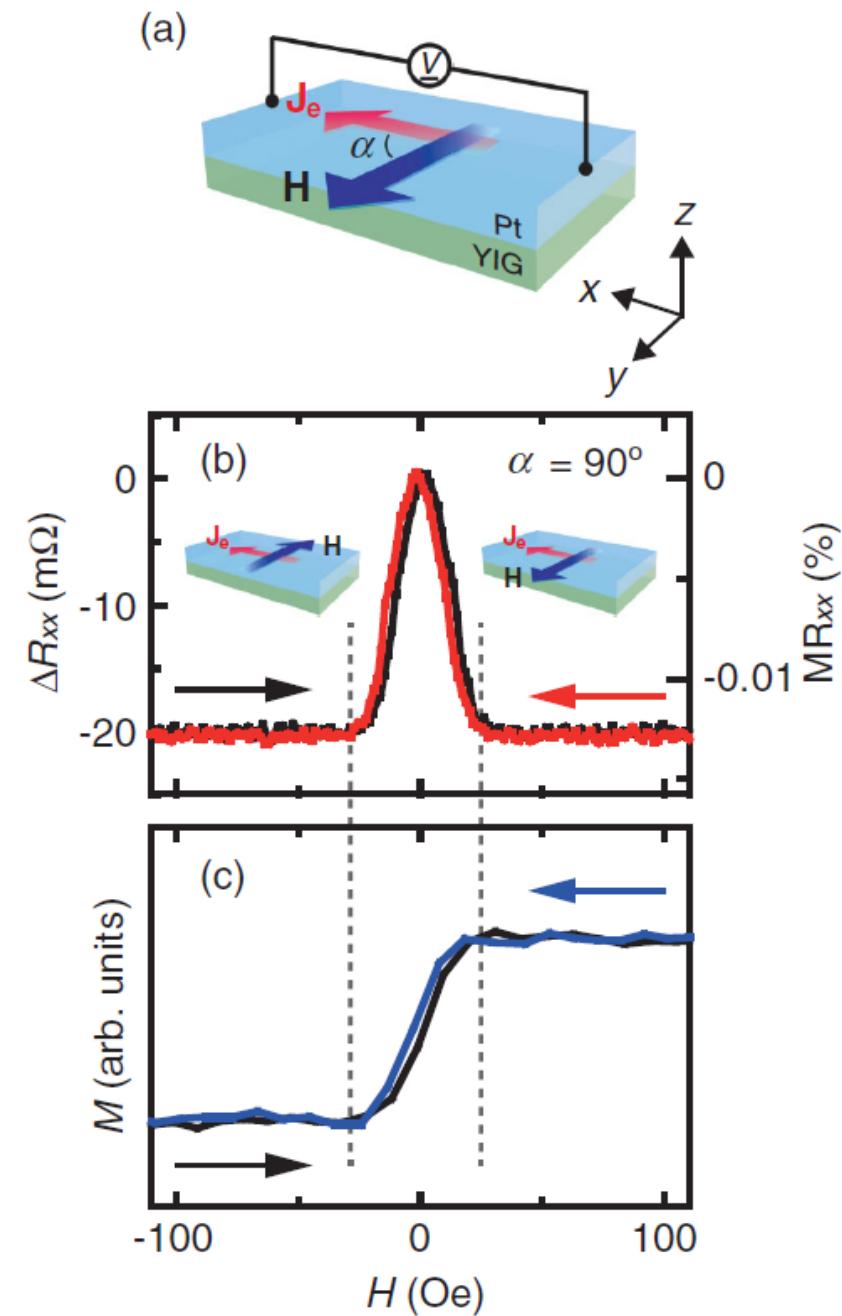
# Spin Hall magnetoresistance



$\vec{M}_{YIG} \parallel \vec{S}, \vec{M}_{YIG} \perp \vec{J}_e$   
Reflection of spin current  
→ inverse spin-Hall effect  
→ more charge current  
→ smaller resistance



$\vec{M}_{YIG} \perp \vec{S}, \vec{M}_{YIG} \parallel \vec{J}_e$   
Absorption of spin current  
→ less charge current  
→ larger resistance



# Conclusion

- Spin-orbit coupling causes spin/charge conversion
- Three effects are derived from the spin-orbit coupling
  - Anomalous Hall effect, Spin-Hall effect, Inverse spin-Hall effect
- Spin-Hall and inverse spin-Hall effect generates spin-Hall magnetoresistance at a Ferromagnetic/Spin-orbit coupled material interface.