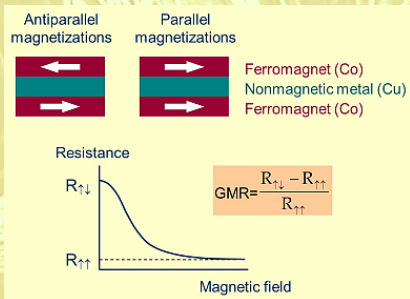


MDG, A. MacDonald, H. Chen, H. Miranda, M.J. Verstraete

## *Spin orbit torques at the Ni-Pt interface*



Refs. 1,2,3

Spin dynamics (LLG):

$$\dot{\mathbf{M}} = -\gamma \mathbf{M} \times \mathbf{H}_{eff} + \alpha \mathbf{M} \times \dot{\mathbf{M}}$$

Spin Transfer Torque (STT): how  $\mathbf{Q}$  influences magnetisation

$$\mathbf{Q} = \mathbf{v} \otimes \mathbf{s}$$

$$\text{Torque: } \mathbf{N}_{st} = - \int_{vol} d^3r \nabla \cdot \mathbf{Q}$$

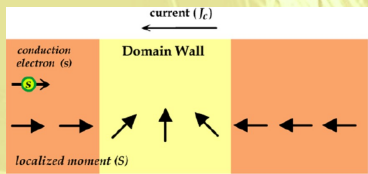
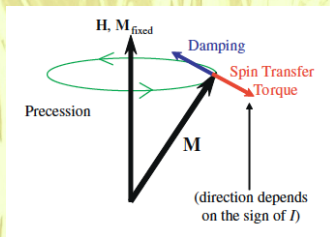


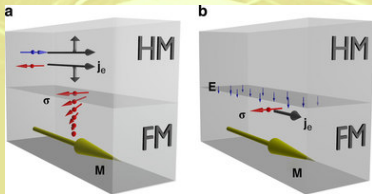
Fig. 1: Spin transfer torque phenomena



$$\dot{\mathbf{M}} = \text{LLG} + \dot{\mathbf{M}}_{SST}$$

Toy model:  $\dot{\mathbf{M}}_{SST} \propto -\mathbf{N}_{st} = -A \hat{x} \cdot (\mathbf{Q}_{in} + \mathbf{Q}_{refl} + \mathbf{Q}_{trans})$

# What happens with SOC?? (Cu→Pt)



- ▶ time reversal symmetry
- ▶ inversion symmetry
- ▶ what happens at the interface?

▶ Rashba:  $(\nabla V \times \vec{p}) \cdot \vec{\sigma}$

▶ Spin Hall Effect:  $\sigma \times I_c$

$\Rightarrow$

$\left\{ \begin{array}{l} \text{In plane} \quad \mathbf{H}_{SOT} \\ \text{Out of plane} \quad \dot{\mathbf{M}}_{SOT} \end{array} \right.$

$SOT \rightarrow SOT$

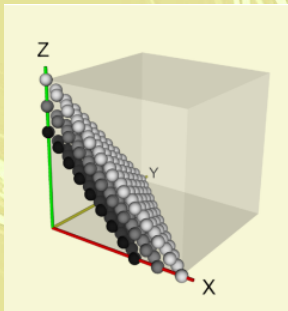
$$\dot{\mathbf{M}} = \text{LLG} + \dot{\mathbf{M}}_{SST} - \gamma \mathbf{M} \times \mathbf{H}_{SOC} + \dot{\mathbf{M}}_{SOT}$$

Ref. 7

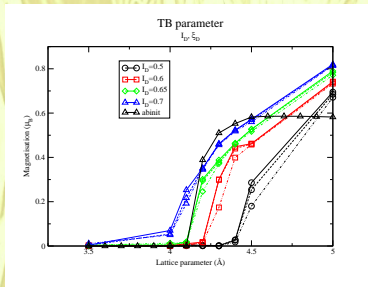
# Micromagnetism: length scales matters!!

$$\mathbf{H}_{\text{eff}} = \underbrace{\mathbf{H}_{\text{ext}}}_{\text{external applied}} + \underbrace{\dots}_{\text{magneto-crystalline anisotropy}} + \underbrace{\dots}_{\text{micro-magnetic exchange}} + \underbrace{\dots}_{\text{magneto-static filed}} + \mathbf{H}_{\text{SOC}}$$

Interface properties:

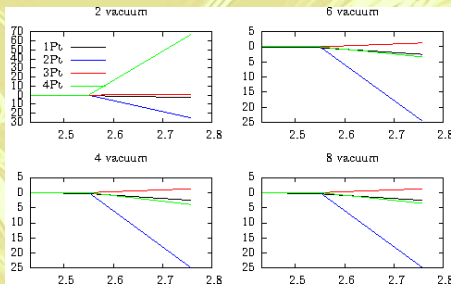


Tight binding and ab-initio:



## "To do" list

1. Influence of the HM on XC field
  - ▶ MCA
  - ▶ AHE density matrix
2. Spin torque calculations
  - ▶ Spin Spiral
  - ▶ Dzyaloshinskii-Moriya interaction
3. Test other HM (eg. Ta)



## Aknoedgments:

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- ▶ Prof. A. MacDonald and Dr. H. Chen (UT Austin)
- ▶ H. Miranda (U Luxemburg)
- ▶ Prof. M. Verstraete (ULg)

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