Ultrafast manipulation of Heisenberg exchange and Dzyaloshinskii Moriya interactions in antiferromagnetic insulators

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Spintronics

Study and use the intrinsic spin of the electrons, in addition to their charge, to build devices. Example: Magnetoresistive random access memory.

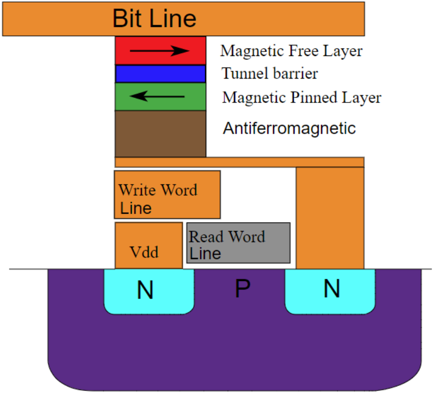

Figure: Source: Wikipedia

Antiferromagnetic Spintronics

The development of information technology demands devices with high storage density, high energy efficiency and high write-read speeds. Antiferromagnets have appear as a natural alternative to ferromagnets due to some advantages:

- Robustness against magnetic disturbances.
- No hysteresis loss.
- Produce no stray fields.
- Ultrafast dynamics (femtosecond).

Antiferromagnetic Spintronics

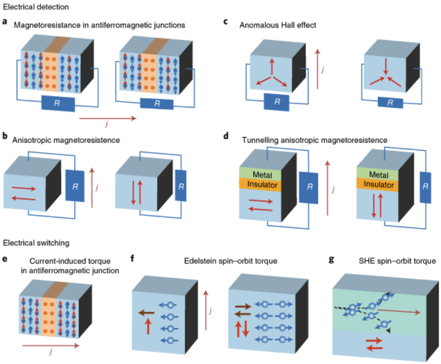

Figure: Source: Nature, Spin transport and spin torque in antiferromagnetic devices

Manipulation of the spin state

Heisenberg model

$$\hat{H} = \sum_{\langle i,j \rangle} J \boldsymbol{S}_i \boldsymbol{S}_j$$

In antiferromagnets $J > 0$ ($J < 0$ for ferromagnets). Mentink, J. H. et al. showed that it is possible to manipulate the exchange constant by applying a laser field. $J = J_0 + \Delta J$.

Manipulation of the spin state

Heisenberg model with DMI

$$\hat{H} = \sum_{\langle i,j \rangle} J \boldsymbol{S}_i \boldsymbol{S}_j + \sum_{\langle i,j \rangle} \vec{D}_{ij} \boldsymbol{S}_i \times \boldsymbol{S}_j$$

Under some circumstances this Hamiltonian describes a canted antiferromagnet.

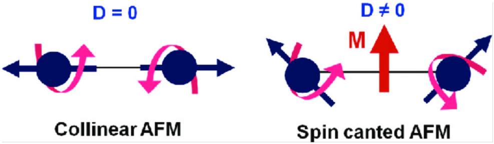

Figure:
Source: Nanoscale

Manipulation of the spin state

If we can manipulate J and D we can control the canting angle.

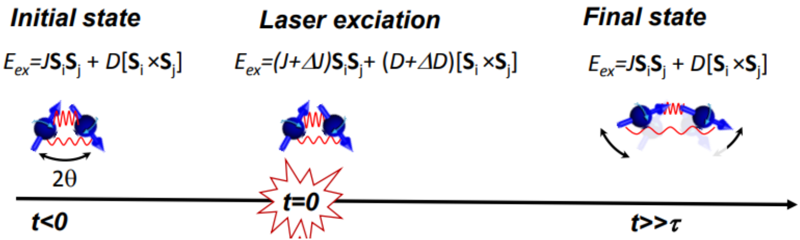

Figure: Source: Kimmel presentation

Manipulation of the spin state

We need $\frac{J}{D} \neq \frac{J+\Delta J}{D+\Delta D}$.

However, $\frac{J}{D} = \frac{J+\Delta J}{D+\Delta D}$.

Manipulation of the spin state

Kane-Mele-Hubbard model

$$\hat{H}_{\mathrm{KMH}} = -t_1 \sum_{\langle ij \rangle \sigma} \hat{c}^{\dagger}_{i\sigma} \hat{c}_{j\sigma} + i\Delta \sum_{\langle\langle ij \rangle\rangle \sigma\sigma'} \hat{c}^{\dagger}_{i\sigma} \nu_{ij} \sigma^{z}_{\sigma\sigma'} \hat{c}_{j\sigma'} + \mathrm{U}\hat{D}$$

It leads to a spin Hamiltonian:

$$\hat{H}^{\mathrm{eff}}_{\mathrm{KMH}} = \sum_{\langle i,j \rangle} J_{ij} \boldsymbol{S}_i \boldsymbol{S}_j + \sum_{\langle\langle i,j \rangle\rangle} \boldsymbol{S}_i \boldsymbol{\Gamma}_{ij} \boldsymbol{S}_j$$

Manipulation of the spin state

Modified Kane-Mele-Hubbard model

$$\hat{H} = -t_1 \sum_{\langle i,j \rangle,\sigma} \hat{c}^\dagger_{i\sigma} \hat{c}_{j\sigma} + \sum_{\langle\langle i,j \rangle\rangle,\sigma} (t_2 + i\Delta\nu_{ij}\sigma^z_{\sigma,\sigma})\hat{c}^\dagger_{i\sigma}\hat{c}_{j\sigma} + \mathrm{U}\hat{D}$$

It leads to a spin Hamiltonian:

$$\hat{H}_{\text{eff}}(t) = \sum_{\langle i,j \rangle} J_{1,ij} \boldsymbol{S}_i \boldsymbol{S}_j + \sum_{\langle\langle i,j \rangle\rangle} \{ J_{2,ij} \boldsymbol{S}_i \boldsymbol{S}_j + \boldsymbol{D}_{2,ij} \boldsymbol{S}_i \times \boldsymbol{S}_j + \boldsymbol{S}_i \boldsymbol{\Gamma}_{ij} \boldsymbol{S}_j \}$$

What we wanted, in this case if we apply light $\frac{J}{D} \neq \frac{J+\Delta J}{D+\Delta D}$.

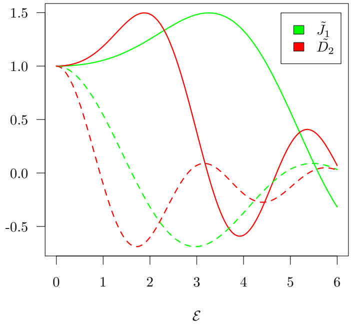

Figure: $\frac{J_1}{J_1^0}$ and $\frac{D_{2,ij}}{D_{2,ij}^0}$ are plotted as function of $\mathcal{E}$. Similar results are obtained in [1] for J_1. Solid lines are for $\omega = 4$ and dashed lines are for $\omega = 14$.

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[1] Mentink, J. H. *et al.* Ultrafast and reversible control of the exchange interaction in Mott insulators. *Nature Communications.* arXiv: arXiv:1407.4761v1 (2015).

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