Spin Hall Effect and Experimental Observation

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Introduction

1. Hall Effect and Anomalous Hall Effect

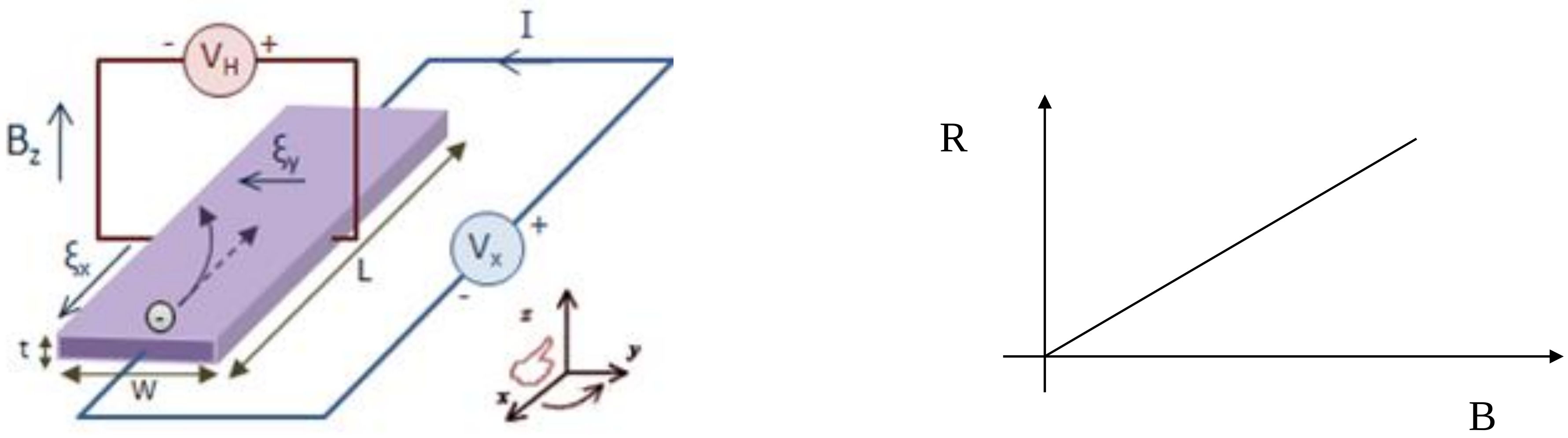


Fig1: Hall Effect

Introduction

1. Hall Effect and Anomalous Hall Effect

In ferromagnetic materials or paramagnetic materials in a magnetic field, the Hall resistivity includes an additional contribution: the anomalous Hall effect

Depend on the magnetization of the material
Often much larger than the ordinary Hall effect

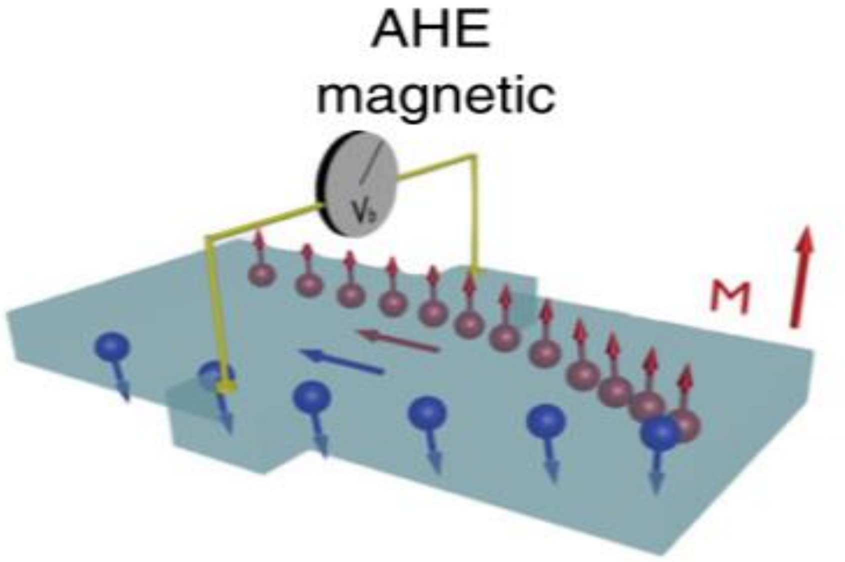
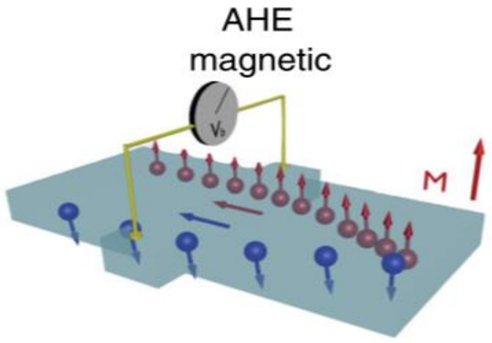


Fig2: Anomalous Hall Effect

Introduction



2. Mott scattering:

A. An unpolarized beam of electrons is scattered from heavy nuclei in a target.
B. Because of the relativistic spin-orbit coupling, large angle (~90°) scattering from the first target produces a polarized beam with the spin polarization transverse to the scattering plane.
C. Scattering of these polarized electrons from the second target results, again due to the spin-orbit coupling, in a left-right scattering asymmetry that is proportional to the polarization induced by the first scattering

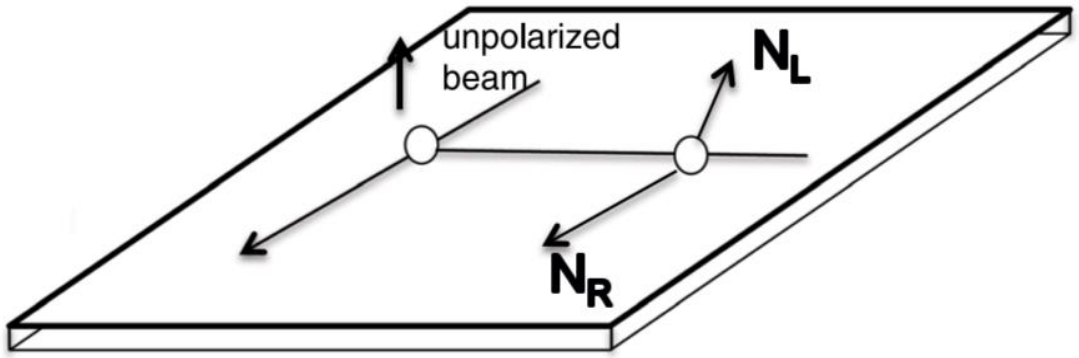


Fig3: Mott double-scattering proposal

Introduction

3. Spin Hall Effect and Inverse Spin Hall Effect

A. The same number of spin-up and spin-down electrons, thus no transverse charge imbalance
B. Mott scattering of electron beams from heavy nuclei in a vacuum chamber can be regarded as the SHE in a non-solid-state environment

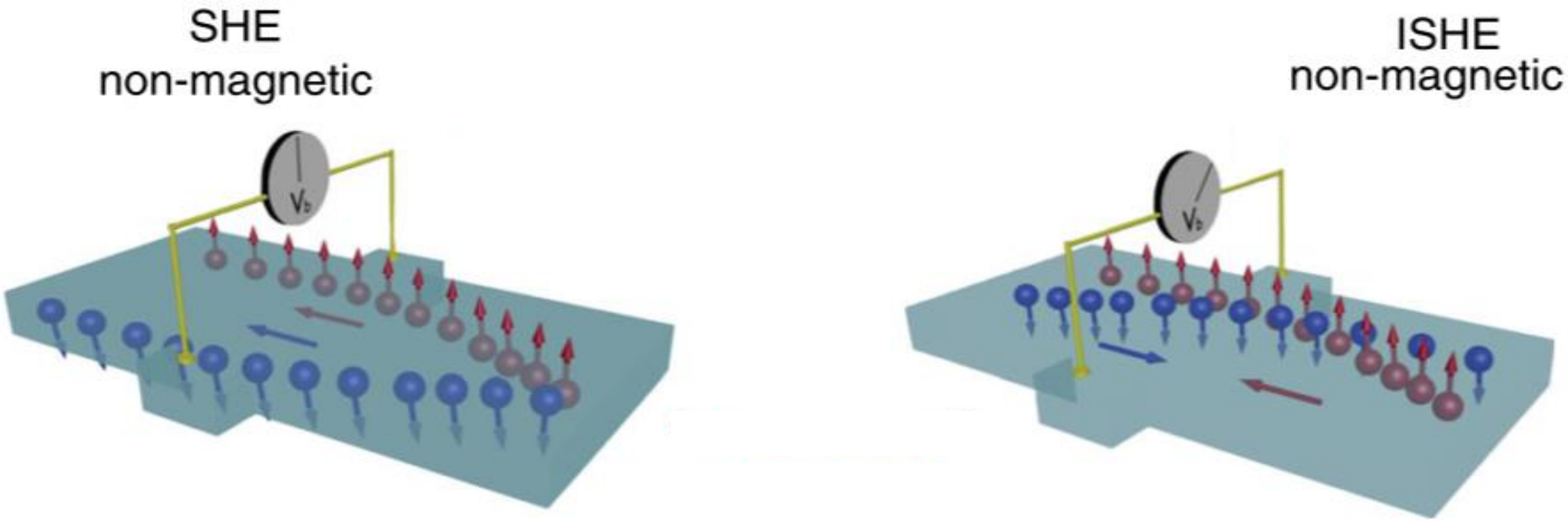


Fig4: Spin Hall Effect and Inverse Spin Hall Effect

Introduction

3. Spin Hall Effect and Inverse Spin Hall Effect

The spin current is determined by the local gradient of the spin dependent chemical potentials which vanishes on the length scale given by the spin lifetime. As long as the connecting wire is longer than the characteristic spin-conserving length scale, there is no difference between a closed and an open spin-current circuit

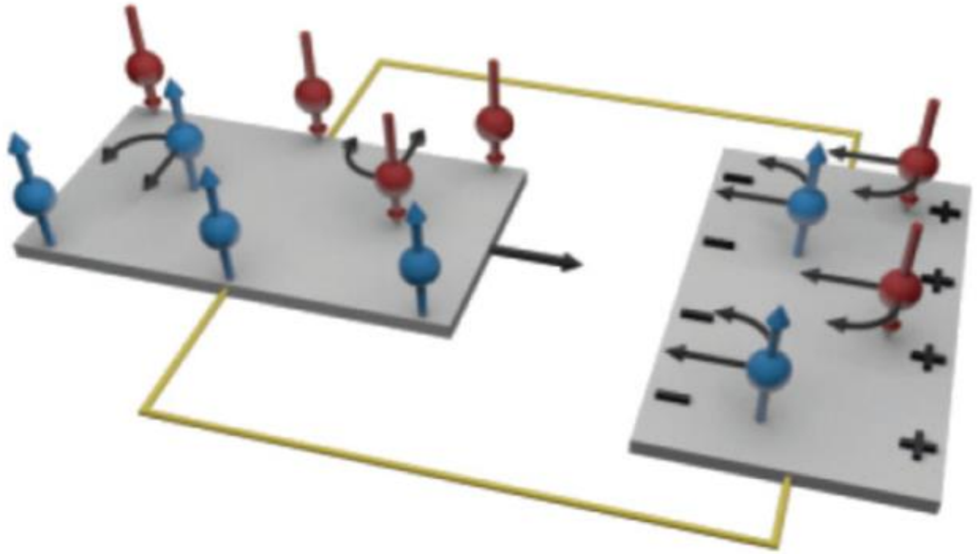


Fig5: SHE and ISHE wired as proposed by Hirsch (1999)

Experiments

Observation of the Spin Hall Effect in Semiconductors

Y. K. Kato, R. C. Myers, A. C. Gossard, D. D. Awschalom*

Electrically induced electron-spin polarization near the edges of a semiconductor channel was detected and imaged with the use of Kerr rotation microscopy. The polarization is out-of-plane and has opposite sign for the two edges, consistent with the predictions of the spin Hall effect. Measurements of unstrained gallium arsenide and strained indium gallium arsenide samples reveal that strain modifies spin accumulation at zero magnetic field. A weak dependence on crystal orientation for the strained samples suggests that the mechanism is the extrinsic spin Hall effect.

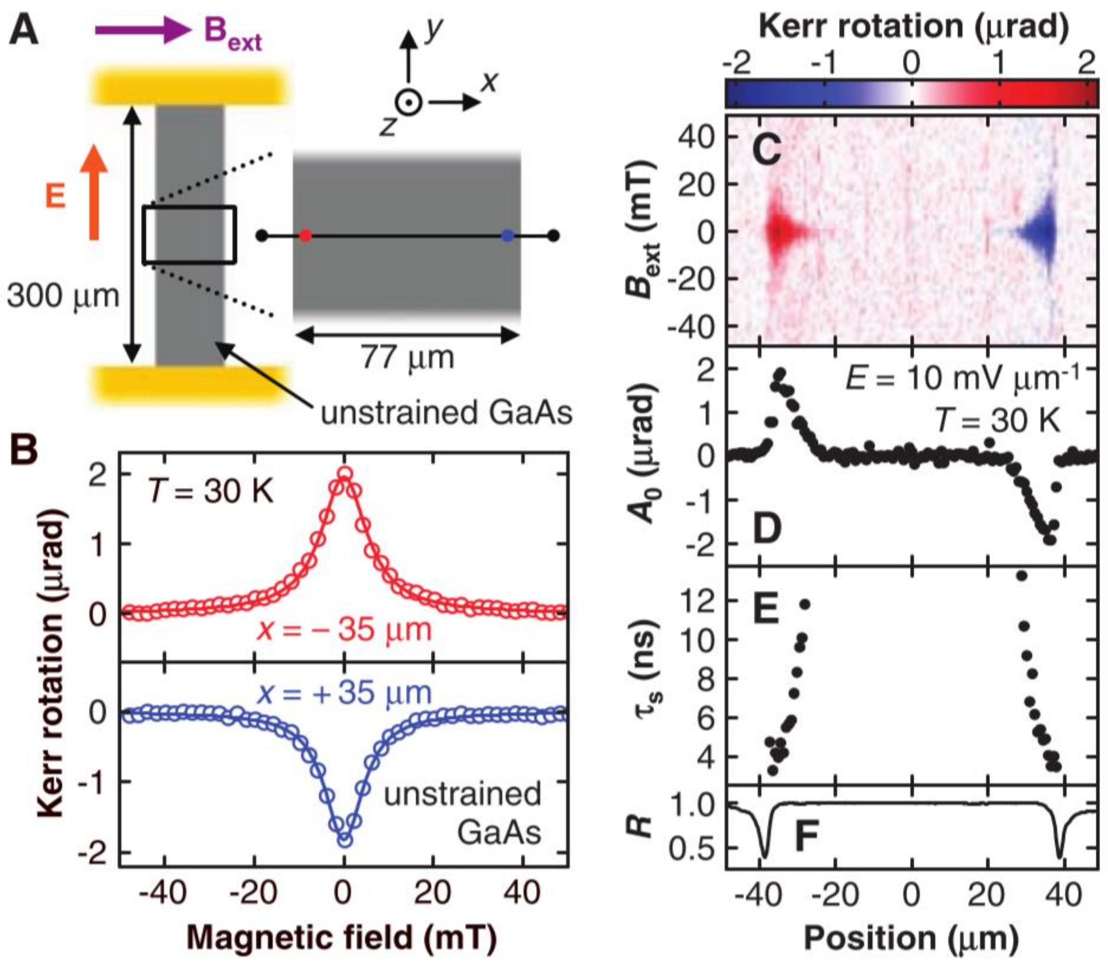
Science 306 , 1910 (2004)

Optical detection of the spin Hall effect in thin films of the semiconductor GaAs and InGaAs.

Scanning Kerr rotation measurements show the presence of electron spin accumulation at the edges of the samples, consistent with the prediction of a spin current transverse to the applied electric field.

We investigated the effect in both unstrained and strained samples and found that an applied in-plane magnetic field can play a critical role in the appearance of the spin accumulation.

Experiments



B: The Hanle effect: spin precession

$Fit\ \frac{A_0}{(\omega_L \tau_s)^2+1}$

ω_L: $electron\ Larmor\ precession\ frequency$

τ_s: $electron\ spin\ lifetime$

A_0: $the\ peak\ KR$

Experiments

Direct electronic measurement of the spin Hall effect

S. O. Valenzuela[1]† & M. Tinkham[1]

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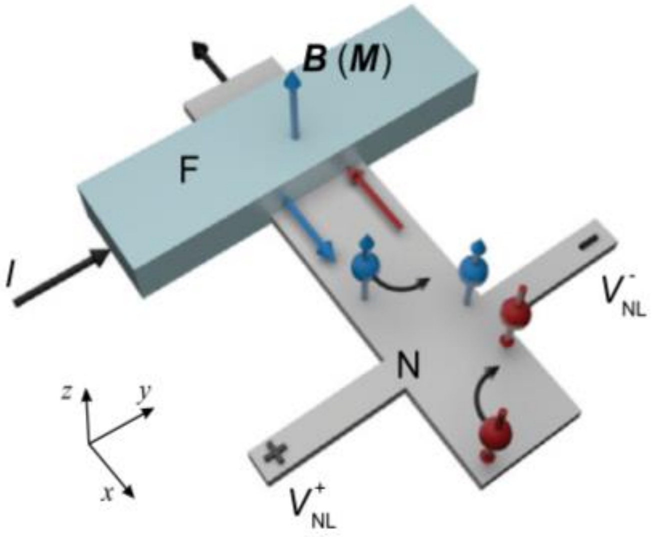
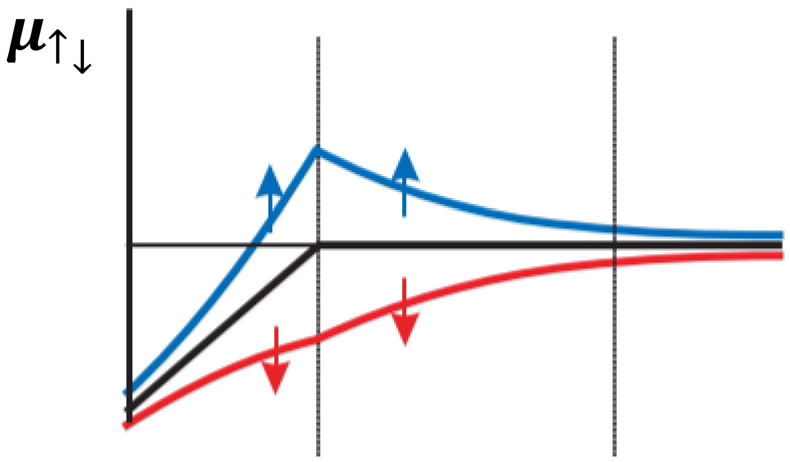
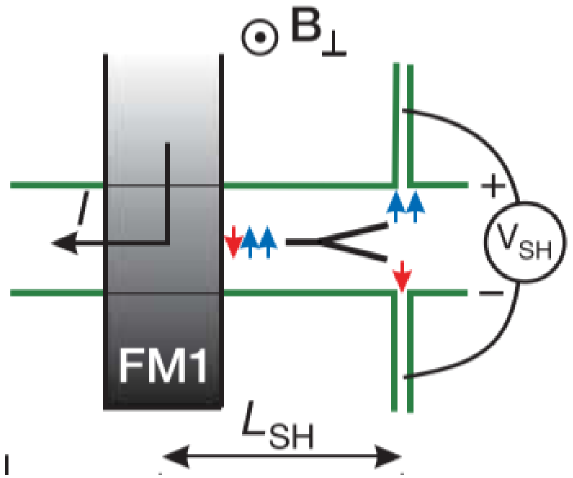
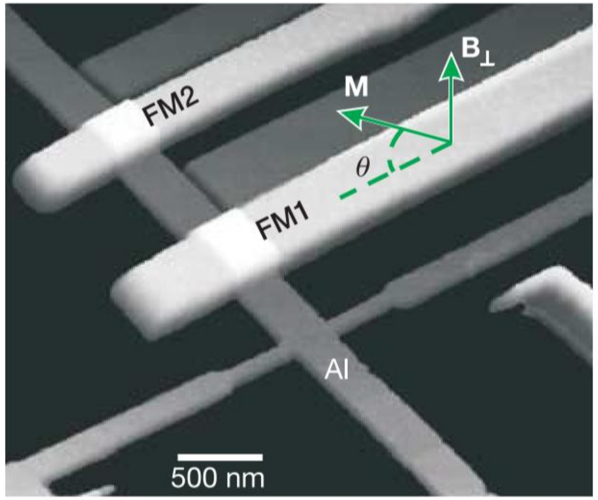




Experiments





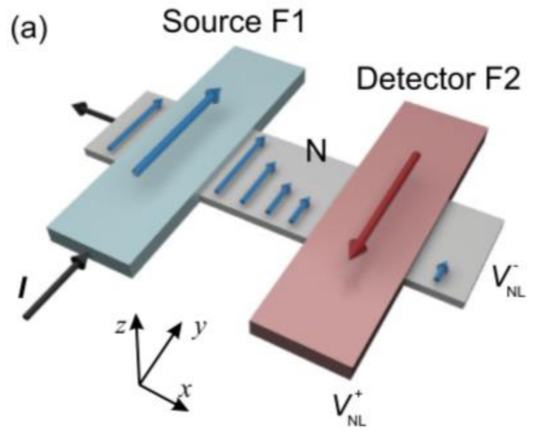
V_{SH} are expected to be proportional to P and to decay with spin diffusion length λ_{sf}

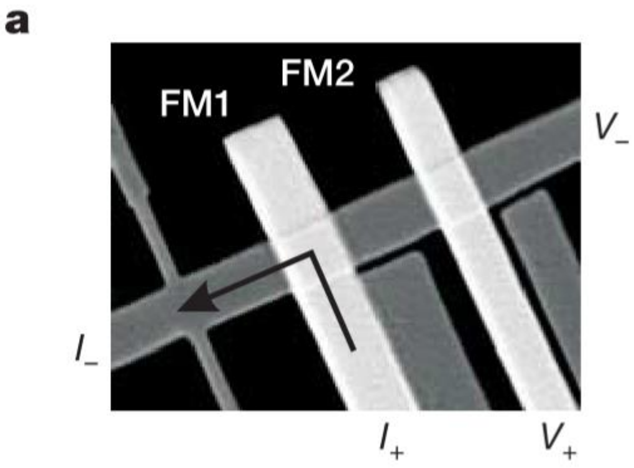
$$V_{SH} \propto \vec{\sigma} \times \overrightarrow{E^{\sigma}} \propto sin\theta, \overrightarrow{E^{\sigma}} = -\nabla\mu^{\sigma}(r)$$

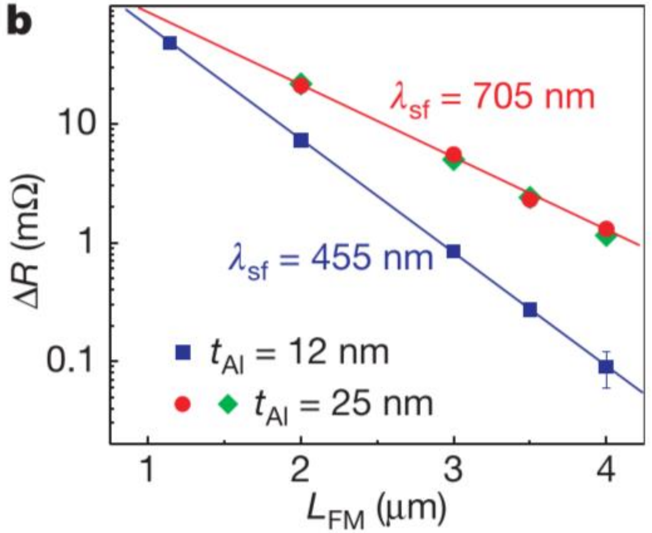
P: The spin polarization of the electrons injected by FM1; depends on the effective tunnel conductance for spin-up and spin-down electrons, respectively $G\uparrow$ and $G\downarrow$, and can be written as：

$$P = \frac{G\uparrow - G\downarrow}{G\uparrow + G\downarrow}$$

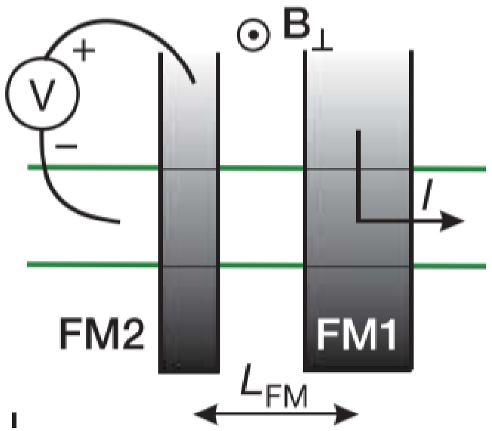
Experiments







P=0.28



Obtain P and λ_{sf}:

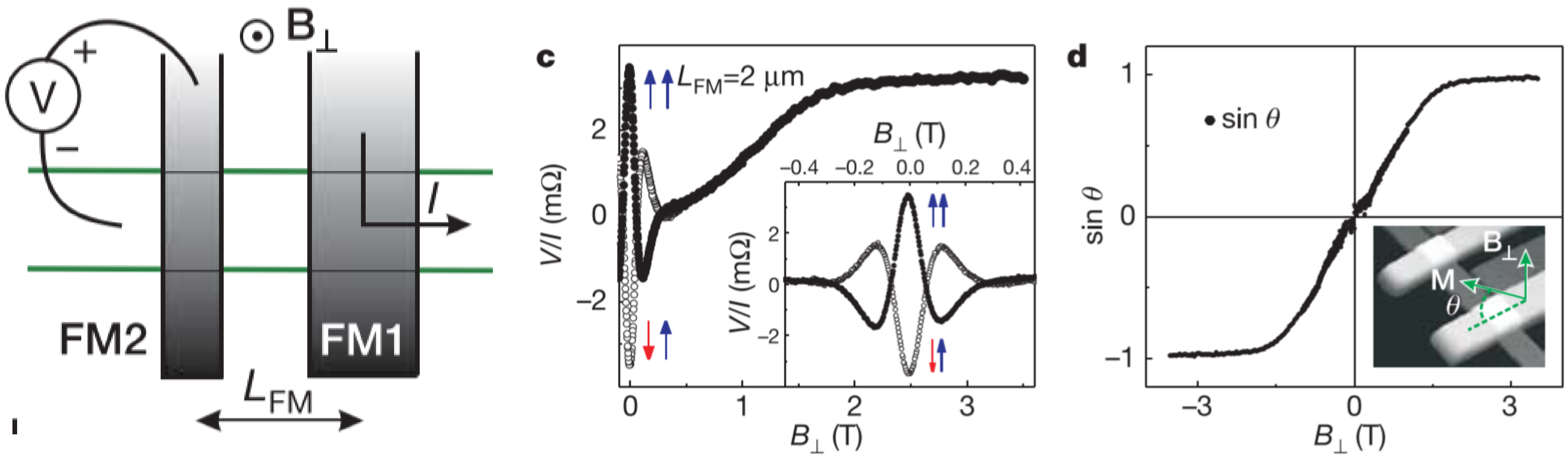
$$\Delta R = \frac{\Delta V}{I} = \frac{P^2 \lambda_{sf}}{\sigma_c A} \exp\left(-\frac{L_{FM}}{\lambda_{sf}}\right)$$

ΔV is the difference in the output voltage between parallel and antiparallel magnetization configurations of the FM electrodes at zero magnetic field

σ_c: Charge conductivity;

A: Cross-section area.

Experiments

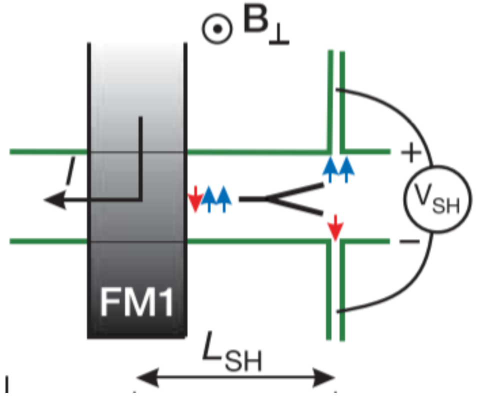


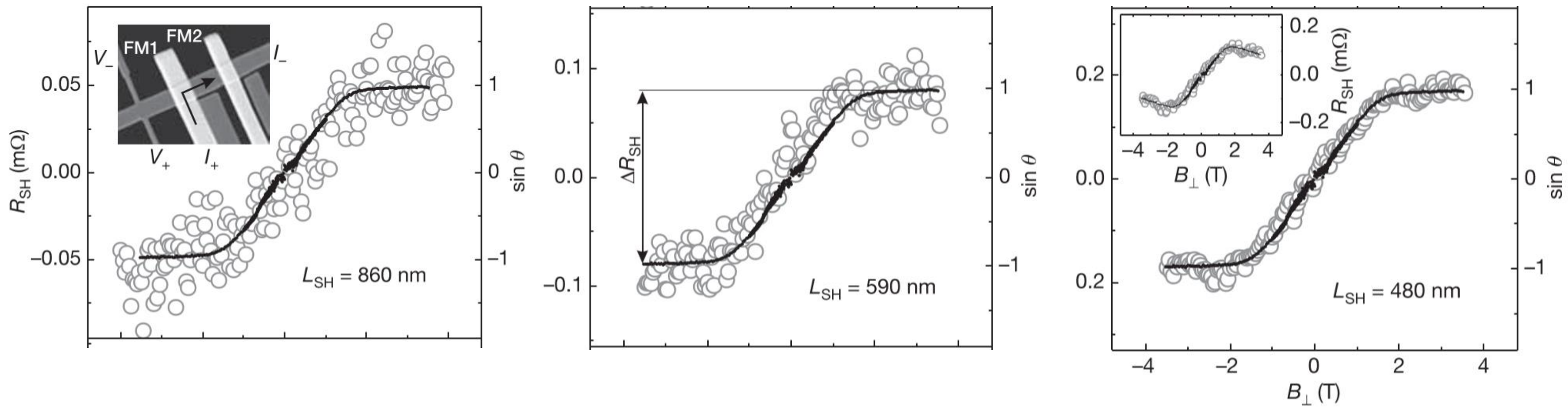
Small B: the measurements show the Hanle effect associated with precessing spins.

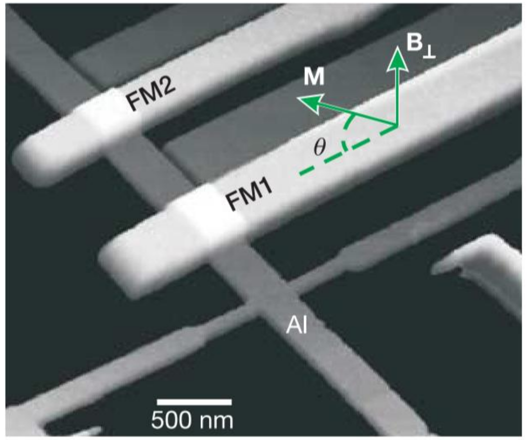
As B increases, the magnetizations tilt out of plane.
For large enough B, they orient completely along the field and the measurements saturate to a positive constant value.

Calculate θ: At B=0, $V_{\pm} \propto \pm f(B)\cos^2\theta + \sin^2\theta$, thus $V_+ + V_- \propto 2\sin^2\theta$
At $B{\sim}1.55T\ sin\theta\ {\sim}1$

Experiments







$V_{SH} \propto \vec{\sigma} \times \overrightarrow{E^{\sigma}} \propto sin\theta$

$V_{SH} \propto sin\theta$ and decay with L_{SH}

Summary

1. Brief introduction to Spin Hall Effect and Inverse Spin Hall Effect
2. Optical detection of the spin Hall effect
3. Electronic measurement of the spin Hall effect

Thanks!

Reference

[1]. Jairo Sinova, Sergio O. Valenzuela, J. Wunderlich, etal. Spin Hall Effect. REVIEWS OF MODERN PHYSICS, 2015, 87(4): 1213-1247