Electrical Characterization of Semiconductor Nanostructures for Spintronics Applications

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Major : Computer Engineering

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Funded By : Defense Advanced Research Projects Agency (DARPA)

Semiconductors

- SC resistivity between that of conductors and insulators
- Resistivity can be tailored over many orders of magnitude by *Doping*

Conductors
$\rho \sim 1\ \mu\Omega\text{-cm}$ ← higher doping — Semiconductors — lower doping → Insulators
$\rho \sim \infty$

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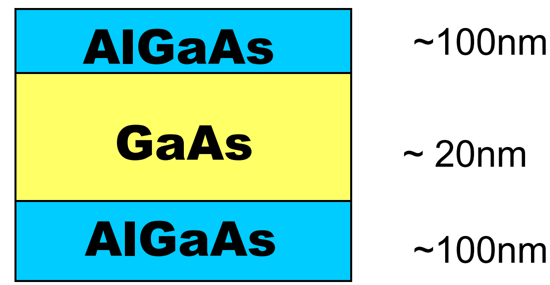
Nanostructures

- Dimension(s) <100nm



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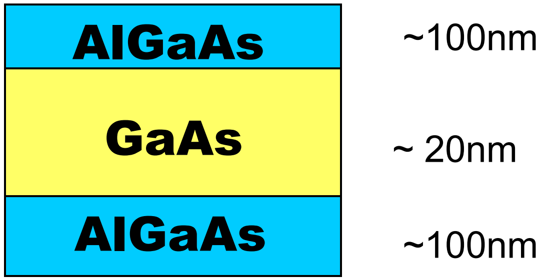
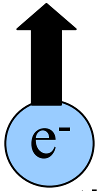


Spintronics

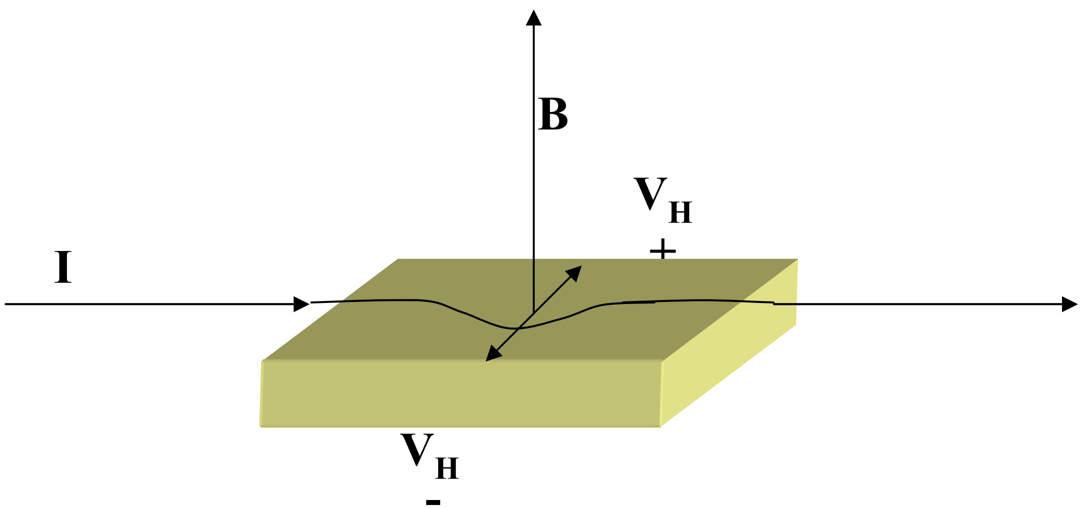


- Concerned with the generation, manipulation, and detection of spin polarization
- Technological example: HD read heads- “Spin Valve”
- Semiconductor Spintronics : No real world devices yet

  How spin behaves in semiconductor material is currently being studied

Project Objectives

- Characterize electrical properties of semiconductor structures using the *Hall Effect*



$n_s = IB/(qV_H)$

n_s = Sheet Density
I = Current
B = Magnetic Field
q = Charge
V_H = Hall Voltage

$\mu = 1/(n_s e R_s)$

R_s = Sheet Resistance
n_s = Sheet Density
e = Electron Charge
μ = Mobility

- Upgrade the PPMS (Physical Properties Measurement System) to allow van der Pauw measurements

- Measure samples grown by MBE

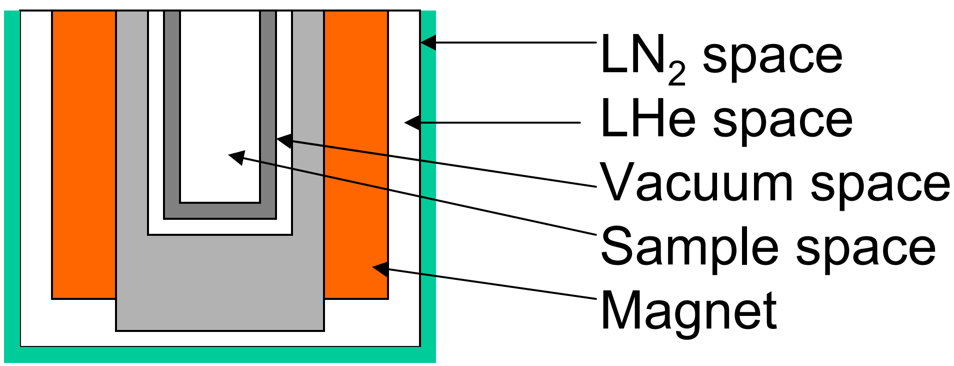
System

Current Source/DMM
Control Computer
- LabView for instrumentation control and data analysis

PPMS Electronics
- Temperature control
- Magnetic field control

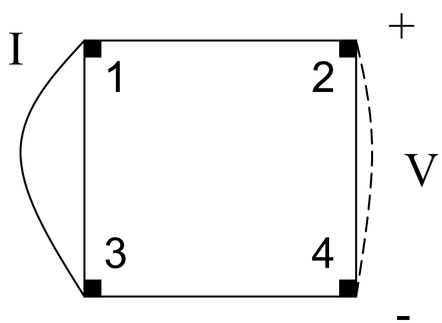
Cryostat

Cryostat

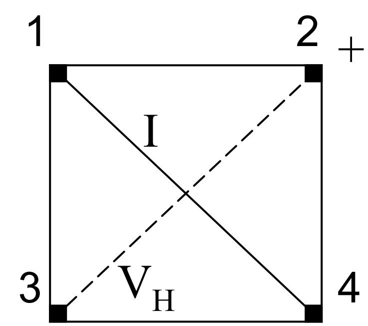


Sample Puck

Resistivity



Hall



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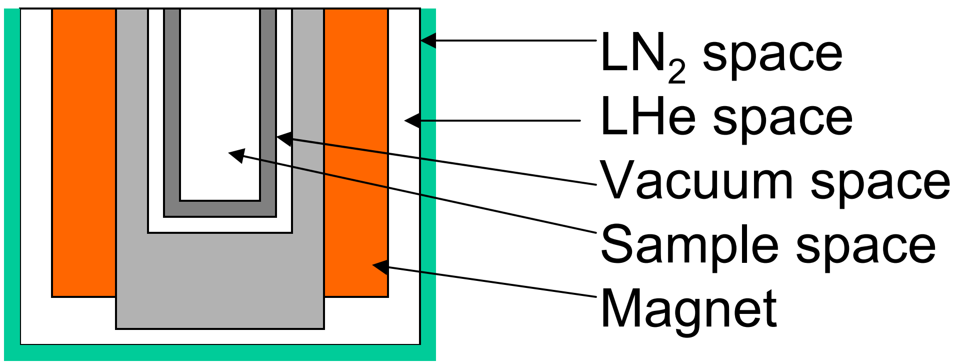

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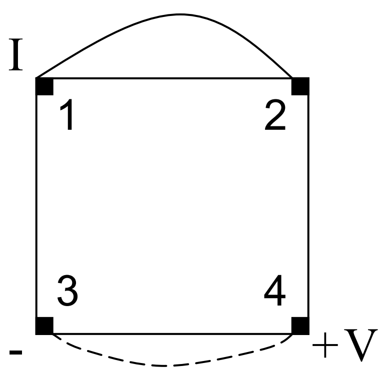
Resistivity



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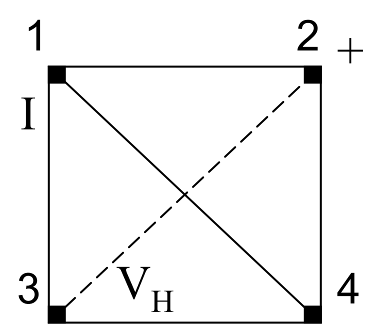

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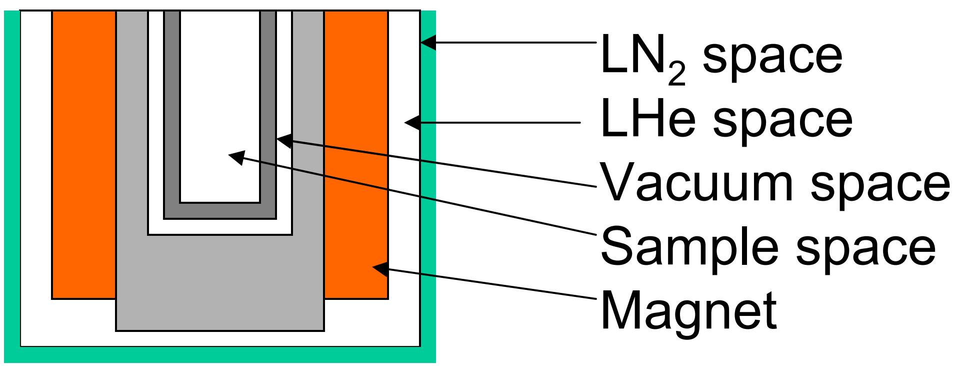

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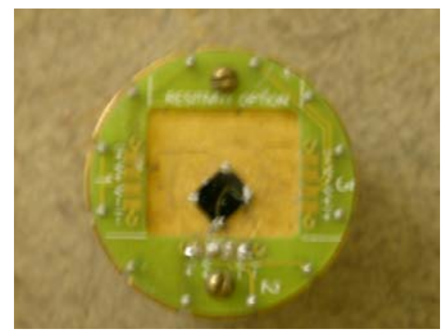
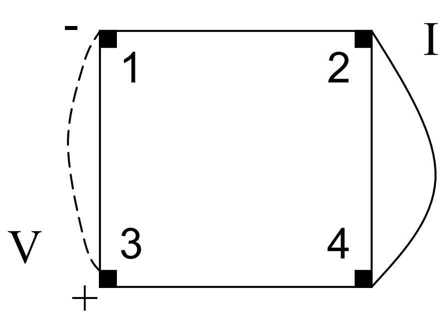


Resistivity



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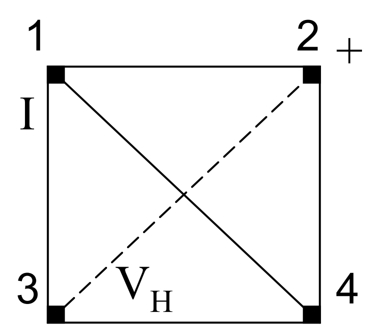

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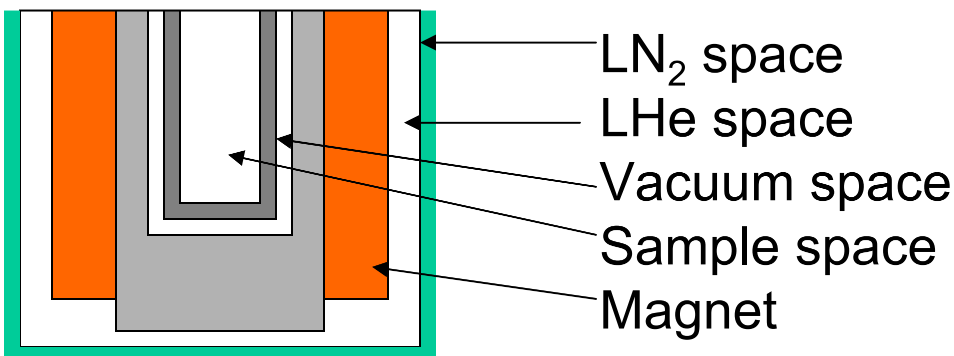

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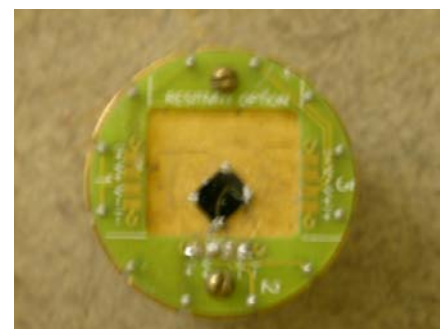

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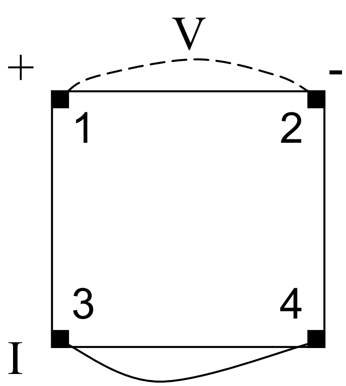

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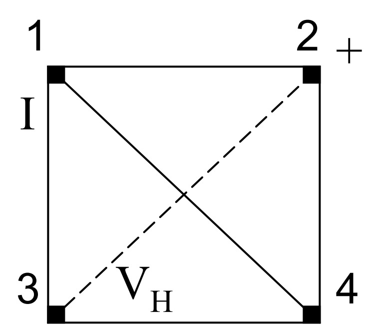

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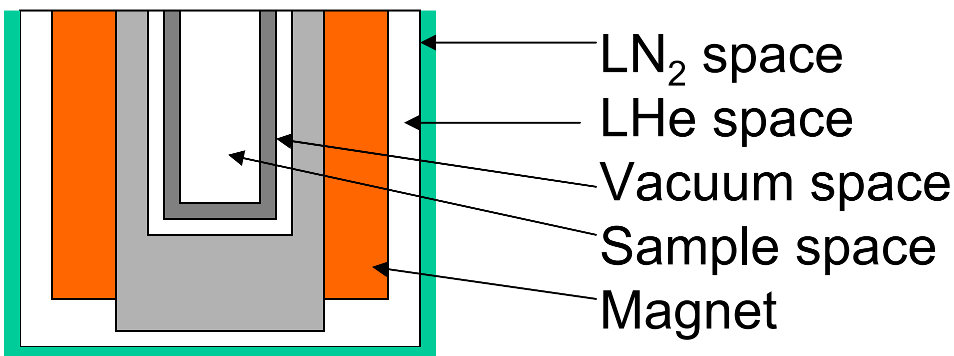
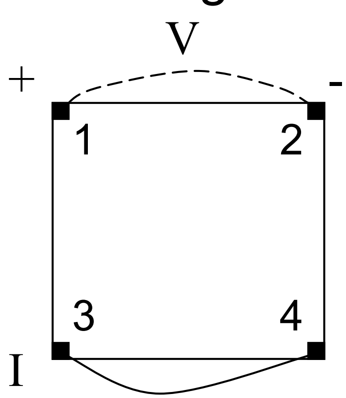
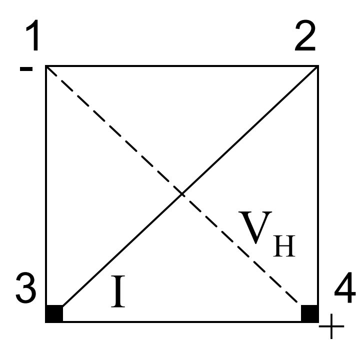


Sample Puck

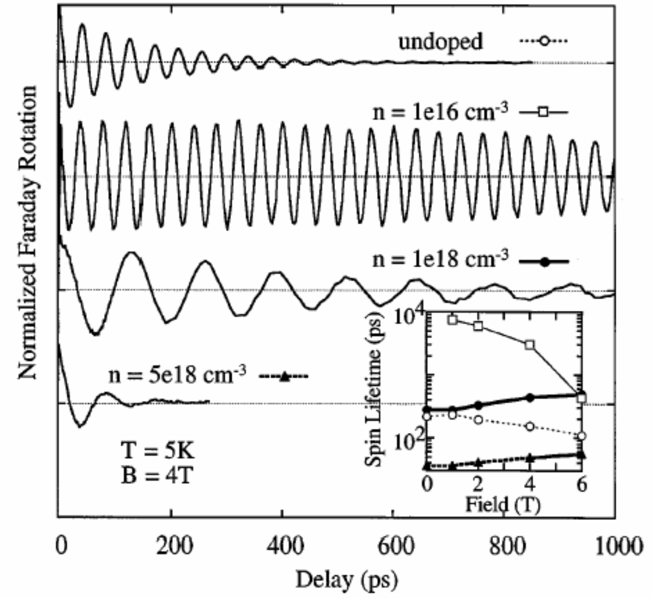
<u>Resistivity</u>



<u>Hall</u>

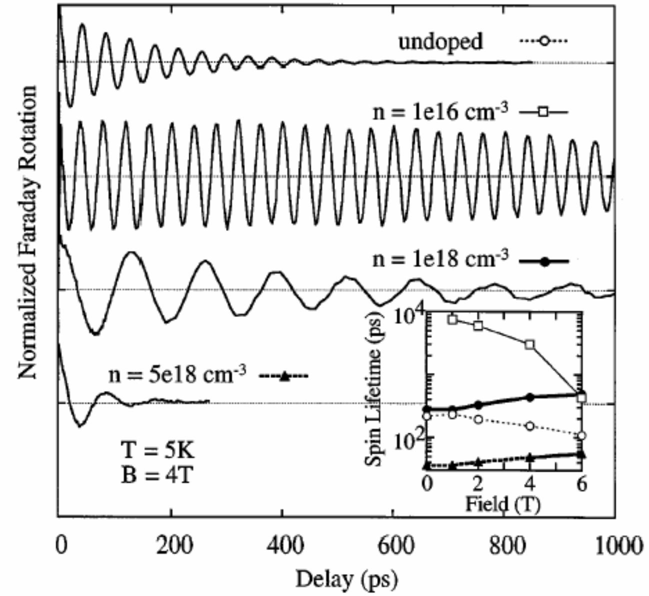


Sheet resistivity, sheet density, mobility



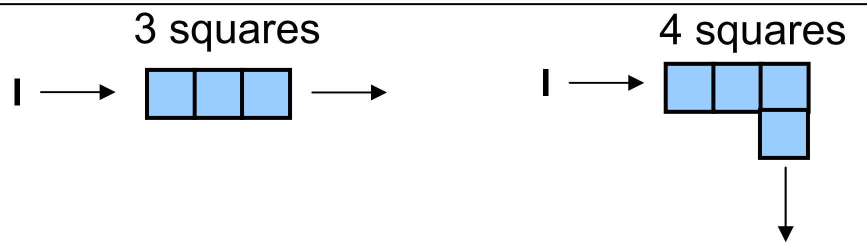
Spin lifetime depends strongly on carrier concentration

Sheet resistivity, sheet density, mobility



Spin lifetime depends strongly on carrier concentration

- Sheet Resistivity (Ohms/square)



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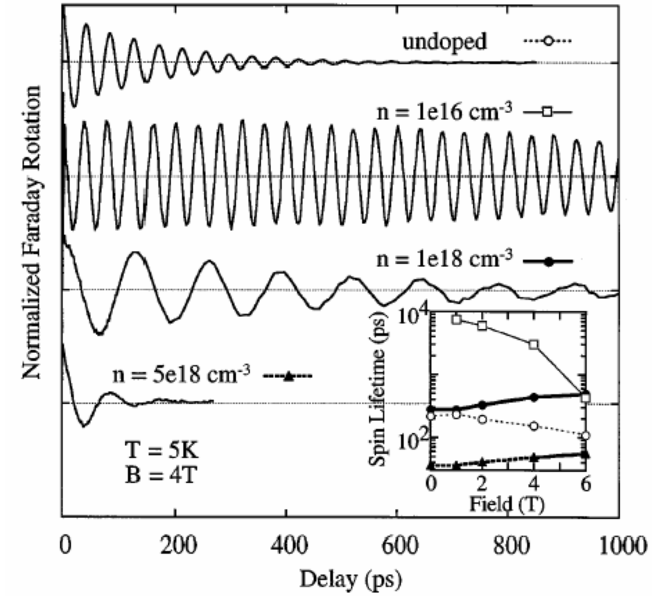
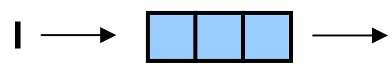


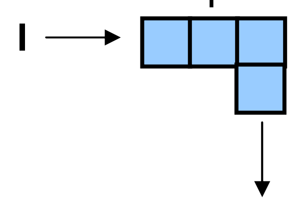
Spin lifetime depends strongly on carrier concentration

- Sheet Resistivity (Ohms/square)

3 squares

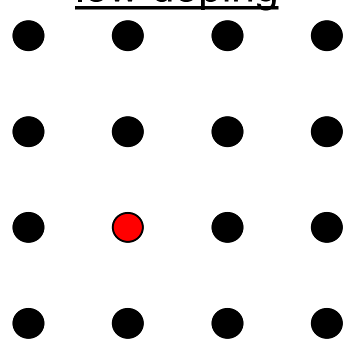


4 squares

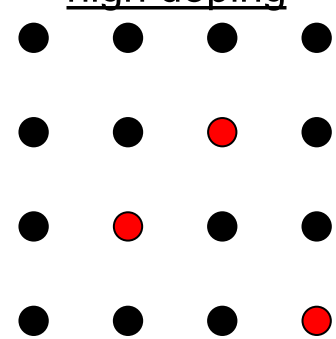


- Sheet Density (number/cm^2)

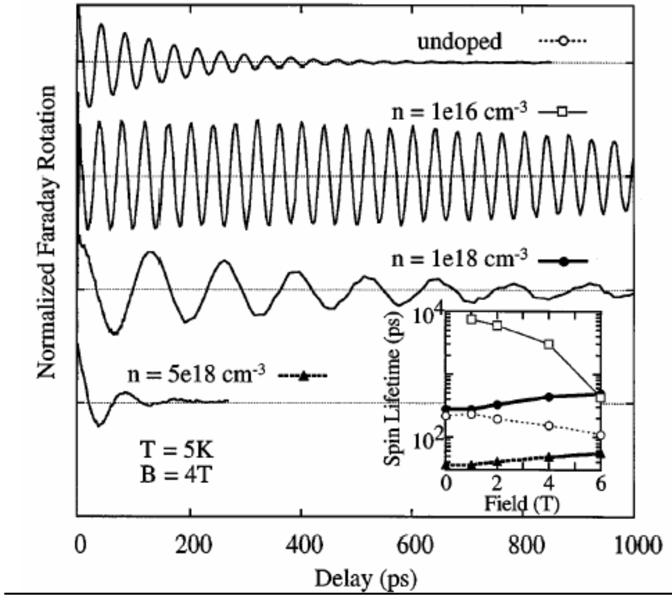
low doping



high doping



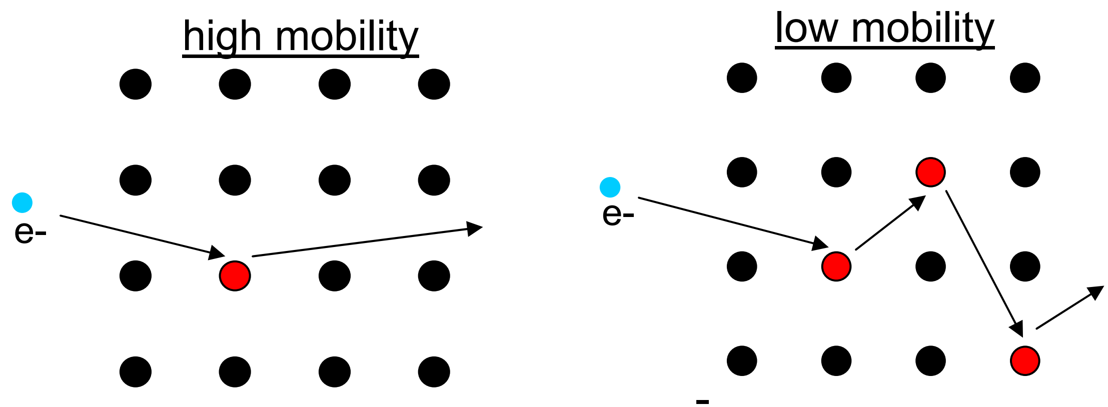
Sheet resistivity, sheet density, mobility



Spin lifetime depends strongly on carrier concentration

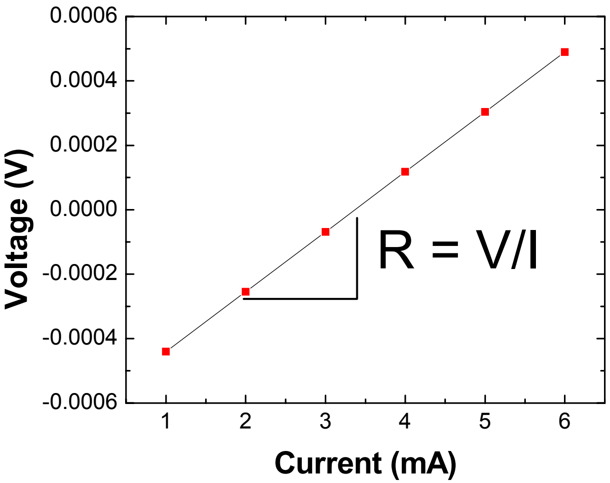
- Sheet Resistivity (Ohms/square)

- Sheet Density (number/cm^2)
- Mobility (cm^2/V-s)



Calculating R_s, n_s, μ

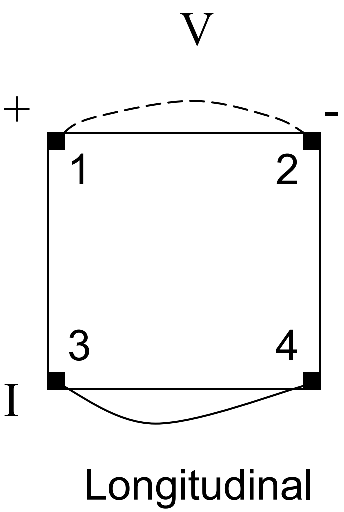
I-V meas. → determine R → Calculate R_s



$R_A = (R_{12} + R_{34})/2$ $R_B = (R_{13} + R2_4)/2$

$$\exp(-\pi\, R_A/R_S) + \exp(-\pi\, R_B/R_S) = 1$$

Calculate R_s



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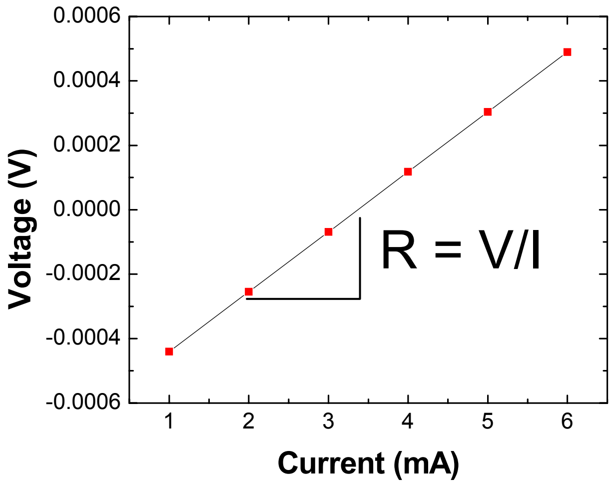

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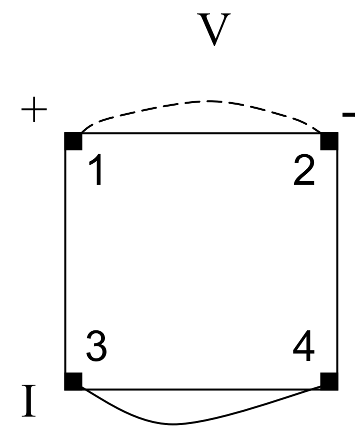
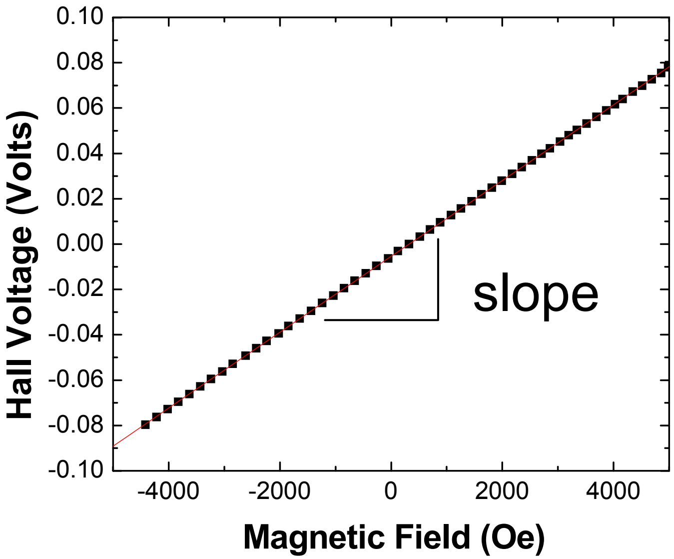


Longitudinal

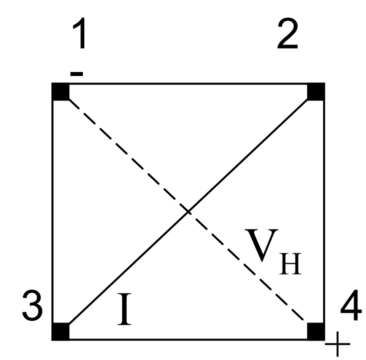
Hall measurement



$n_s = (I/q)*(B/V_H)$

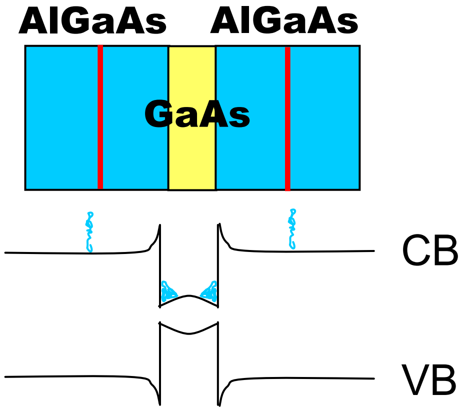
$= (I/q)*(1/\text{slope})$

$\mu = 1/(n_s e R_s)$

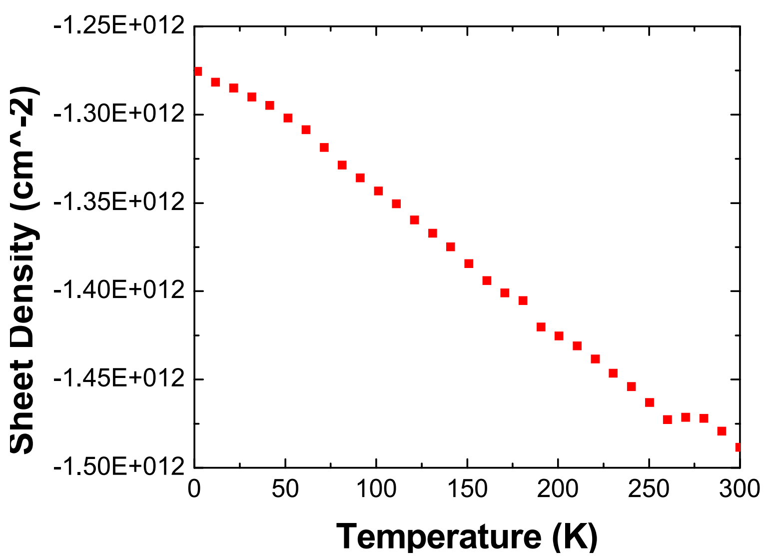


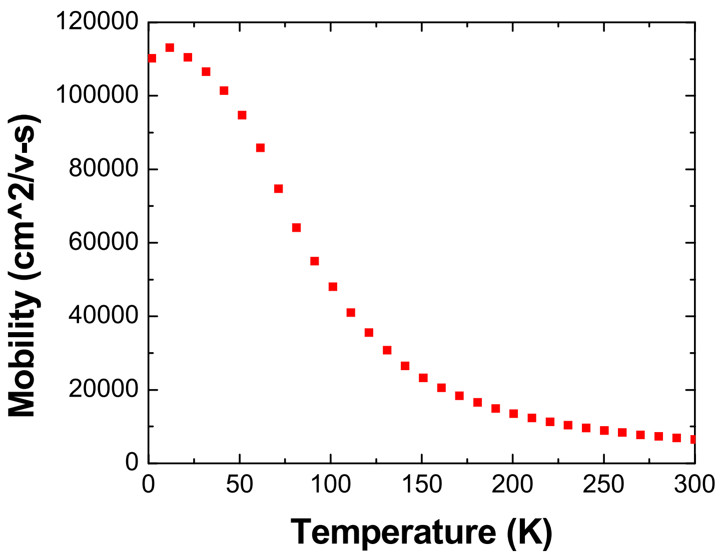
Transverse

Sheet resistivity, density, mobility vs. temperature



"multi-2DEG sample"





- Sheet Density

  Generally increases with temp.

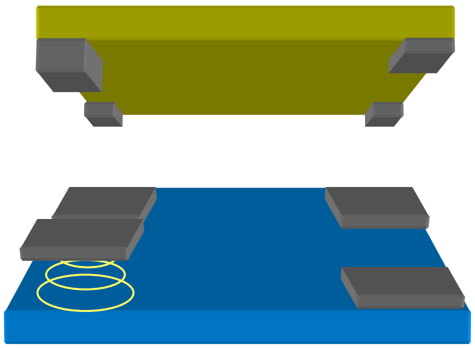
- Mobility

  Strong function of impurities and temperature (phonons)

Remaining Tasks

- Sample puck modifications

  Faster/Easier

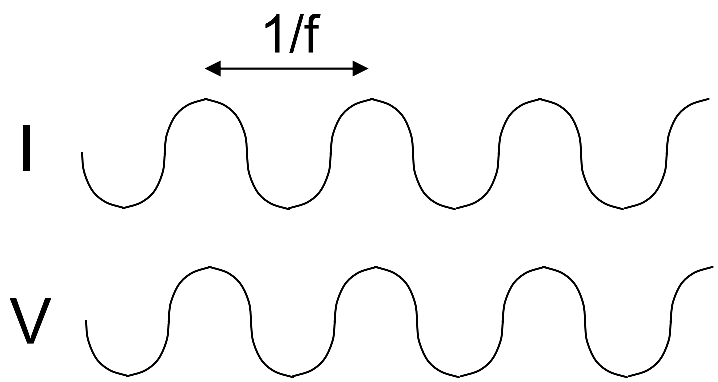


- AC/Lockin measurement

  Alternating current

  More data

  Signal/Noise



- Measure magnetic samples

  Anomalous Hall Effect

  "hysteresis"