Hall Effect Measurement

Anil Dhote

NUFAB
NORTHWESTERN UNIVERSITY
MICRO/NANO FABRICATION FACILITY

NUFAB_Cook

Photolithography
Mask Aligner - MA/BA6
Mask Aligner - Q-4000
Lithography hood
Baking Plates
Optical Microscope

Thin Film Deposition
ALD - Savannah S100
E-Beam Evaporator - Auto 306
E-Beam Evaporator - Auto 500
Sputter-AJA-Nb Deposition system

Characterization
Hall Effect Measurements System - HMS 8404
Thin Film Analyzer- Filmetrics F20
Metricon 2010 Prism Coupler

Etching
RIE 10NR - Samco

Materials Processing
RTP - AS-Micro

Packaging
Wafer Dicing System - ADT 7122
Wire Bonder-Wedge - West Bond

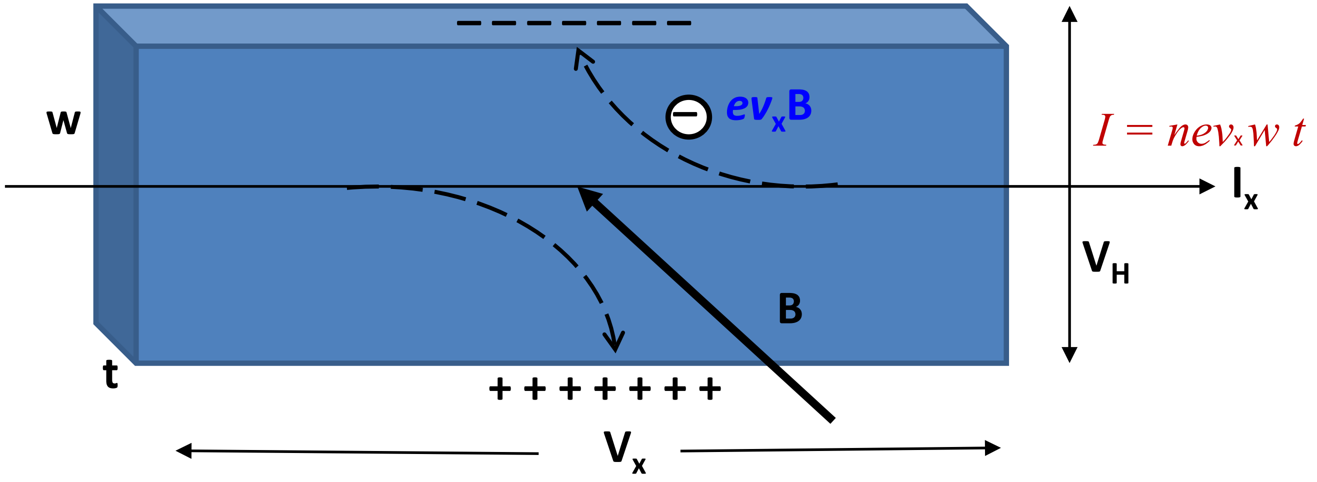
The cleanroom complex in Cook Hall provides *microfabrication and thin film processing* capabilities.

Facility includes class 100, 1000 space (1800 SqFt)

Hall Effect

Edwin Hall, 1879

When the combination of a magnetic field and a flowing current in a material produces a new voltage (Hall voltage), it is called the Hall effect.



The Lorentz force on the charges ev_xB pushes the carriers along the curved lines
(v_x is the velocity of the carriers)

The charges build up on the edges of the material and creates the Hall voltage across the width of the material.

When the force from the Hall voltage exactly balances the Lorentz force, no more carriers hit the edge of the material.
(The force from the Hall voltage is eV_H /w)

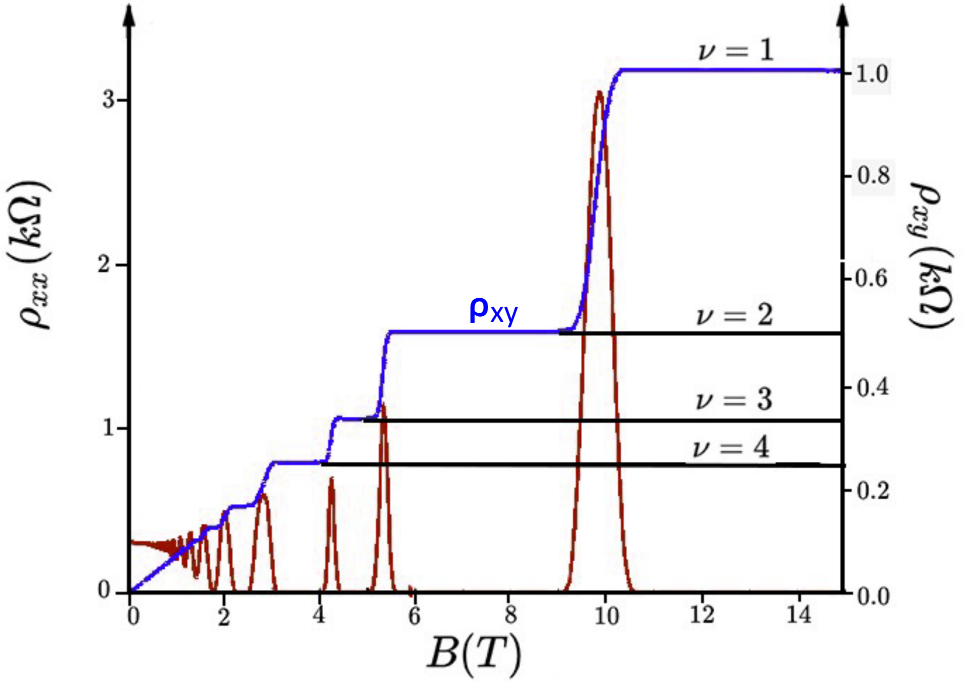
$$V_H = IB / tne$$

(*n* carrier density)

The Hall voltage can be either positive or negative. Hall voltage is negative, the carriers are electrons. Hall voltage is positive, the carriers are holes.

Quantum Hall Effect

Hall Resistance **exhibits steps that take on the quantized values**



Longitudinal ρ_{xx} and transverse (Hall) ρ_{xy} resistivity, of a two-dimensional electron system as a function of magnetic field

Image: Alba Cazorla, Creative Commons Attribution-Share Alike 4.0 International

The quantum Hall effect (QHE) is a quantization of Hall resistance, exhibited by two-dimensional electron systems (low T/strong B), that is defined by the electron charge e and Planck's constant h

Hall resistivity $\rho_{xy} = h/ \nu e^2$ (ν -integer or fraction)

ν = n / G = *density of electrons / Total number of Landau states*

……*(simply number of occupied Landau levels)*

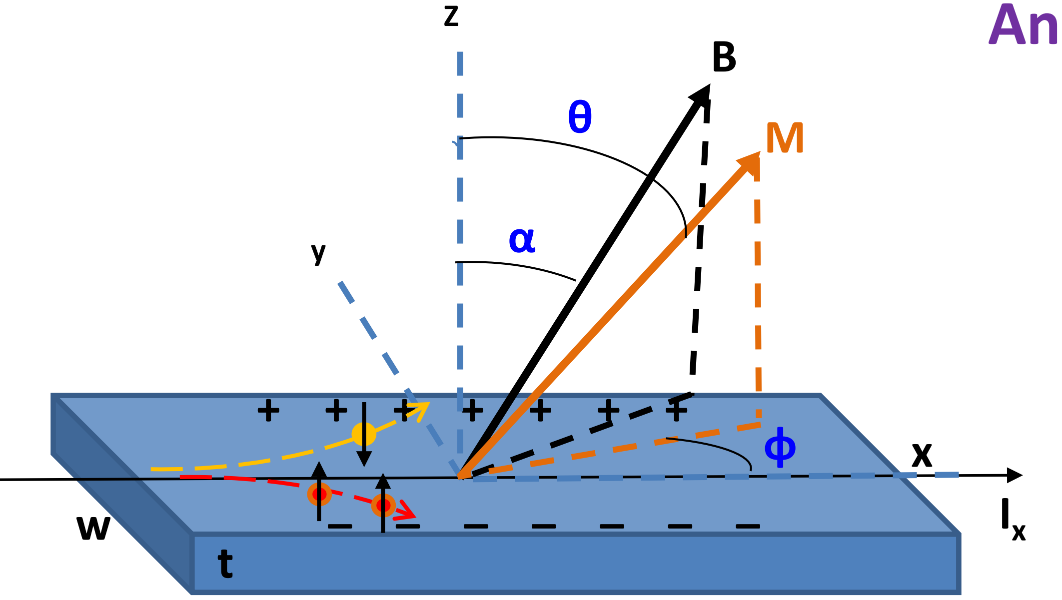
B ↑ *G* ↑ *ν* ↓

The electron population distribution in these quantized orbits results in a quantization of the electrical resistance

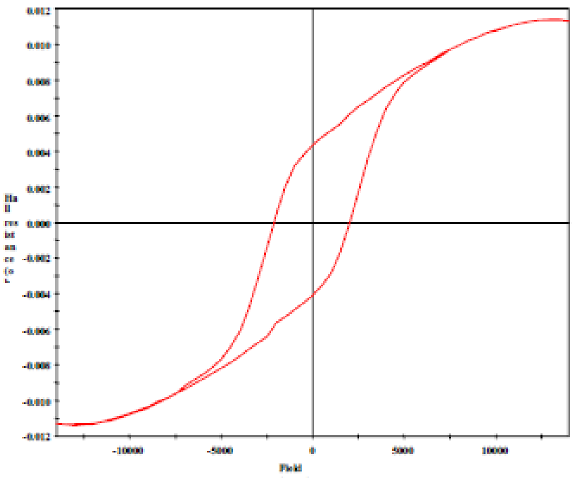
ρ_{xy} is integer or fractional multiples of h/ e^2 to nearly one part in a billion.
This effect is used to represent a resistance standard
$R_K = h/e^2 = 25812.80745...\ \Omega$

Integer quantum Hall effect was reported in graphene, gallium arsenide heterostructures and in magnesium zinc oxide $ZnO–Mg_xZn_{1-x}O$

Anomalous Hall Effect



α, the angle between the applied field and the normal to the sample,
θ, the angle between the magnetization and the normal
ϕ, the angle between the current and the in plane component of the magnetization.



Hysteresis

In addition to the ordinary Hall effect (OHE) in semiconductors and metals, there is an additional voltage proportional to the magnetization (in magnetic materials) called the anomalous Hall effect (AHE).

In a Hall effect measurement there are three Hall voltage (V_H) components

$$V_H = (R_H I/t)B\cos(\alpha) + \boxed{(\mu_o R_s I/t)M\cos(\theta)} + (kI/t)M^2\sin^2(\theta)\sin(2\phi)$$

Ordinary Hall effect (**OHE**) due to Lorentz force acting on conduction electrons.
Depends on **Bz** field, and produces an electric field perpendicular to **Bz** and the current.
Affect all conduction electrons (spin- polarized + spin- unpolarized

Anomalous Hall effect (**AHE**) due to magnetic moments of localized electrons/magnetization M.
Depends on the **Mz**, and produces an electric field perpendicular to **Mz** and the current.
Affect all conduction electrons (spin- polarized + spin-unpolarized

Planar Hall effect (**PHE**), or anisotropic magneto-resistance due to magnetic moments of localized electrons/magnetization M.
The PHE is proportional to the square of the planar component of **M**, and produces an electric field parallel and perpendicular to the current.
Affect only spin-polarized conduction electrons

-Measure the magnetic hysteresis loops of perpendicular magnetic recording media (PMRM), ferromagnetic/semiconductor heterostructures (spintronic devices), and diluted-magnetic-semiconductors

Hall Effect Measurement System

HMS 8404

Variable Temperature Hall Effect Measurement : Direct and Derived Measurements as a Function of Field and Temperature:

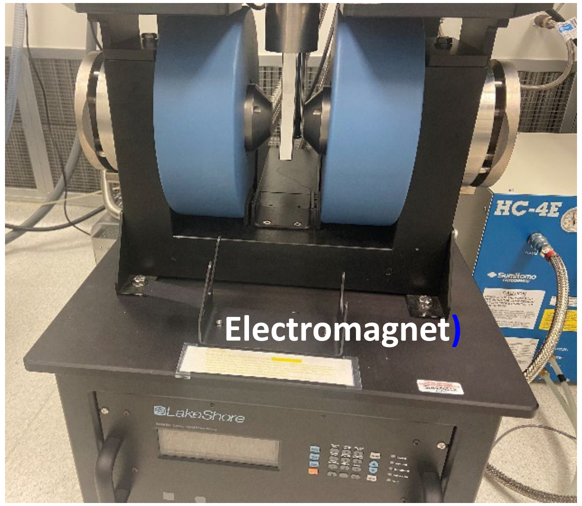
Hall voltage
Resistivity
IV Curves

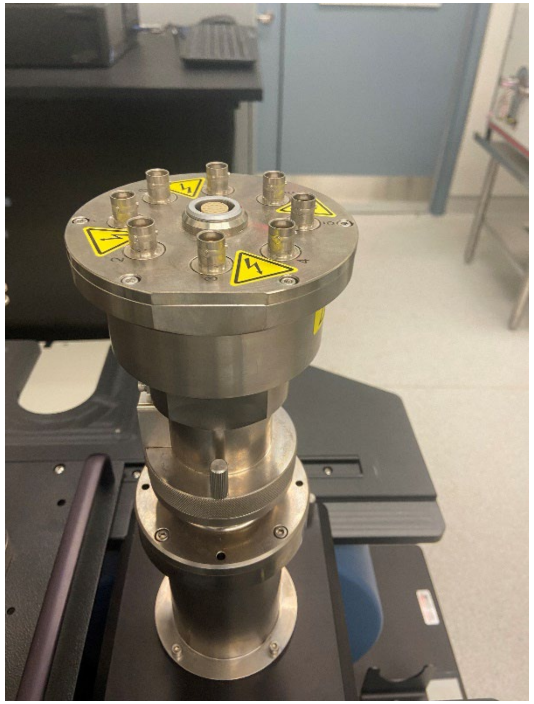
Hall coefficient
Carrier type
Carrier concentration / density
Hall mobility
Magneto-resistance

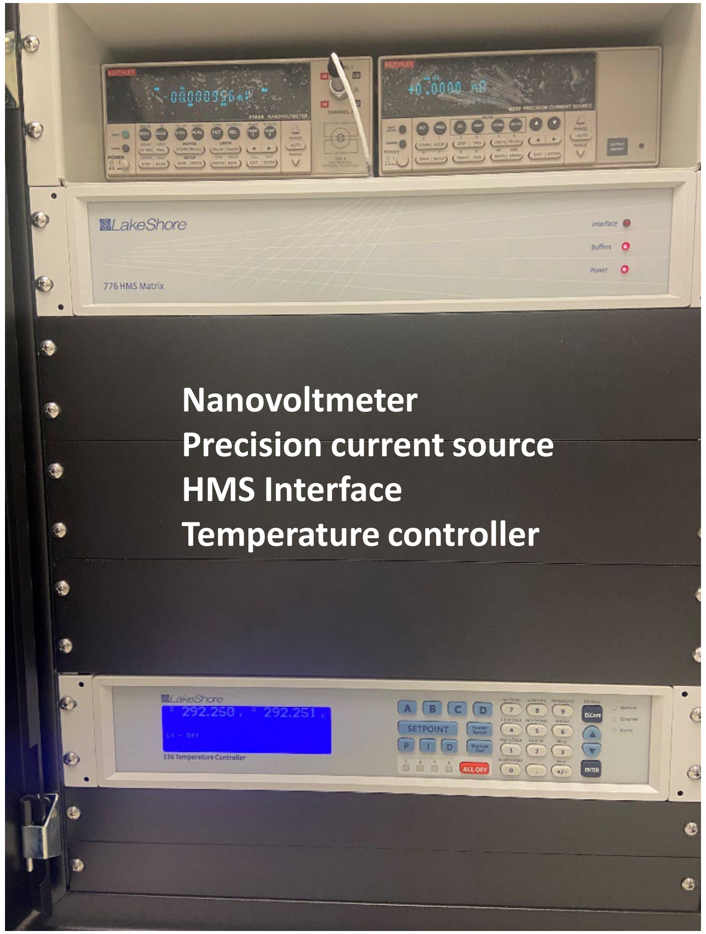
Features

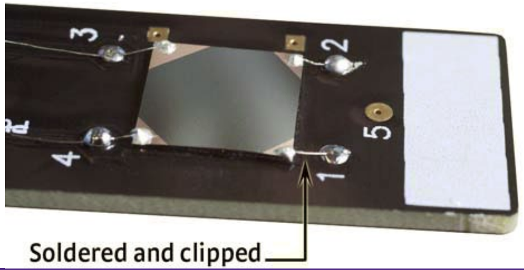
- Mobilities from 1 to 10^6 cm^2/V s
- Resistances from 0.5 mΩ to 10 MΩ
- Closed cycle Refrigerator (CCR)
- Temperatures from 15K to 400K
- DC Fields ` 1 T (Low Temperature, RT)
- Sample Rotation Option (0-360 ° sample orientation)
- Integrated software: define samples and create measurement profiles from the Windows® menu-driven interface

Measurement Accessory









Sample mount card

Hall Measurement Applications

HMS 8404

Measurements can be applied to Materials:

Transparent Conducting Oxides

III-V Semiconductors

II-VI Semiconductors

Elemental Semiconductors

Dilute Magnetic Semiconductors

Other Conducting Materials

High Temperature Superconductors

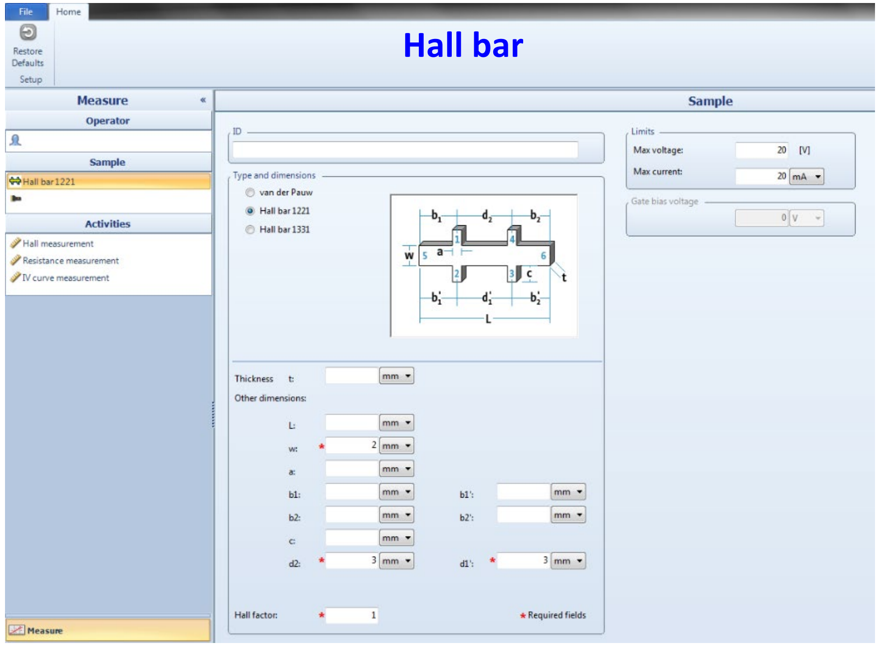
Organic electronics

Solar cells

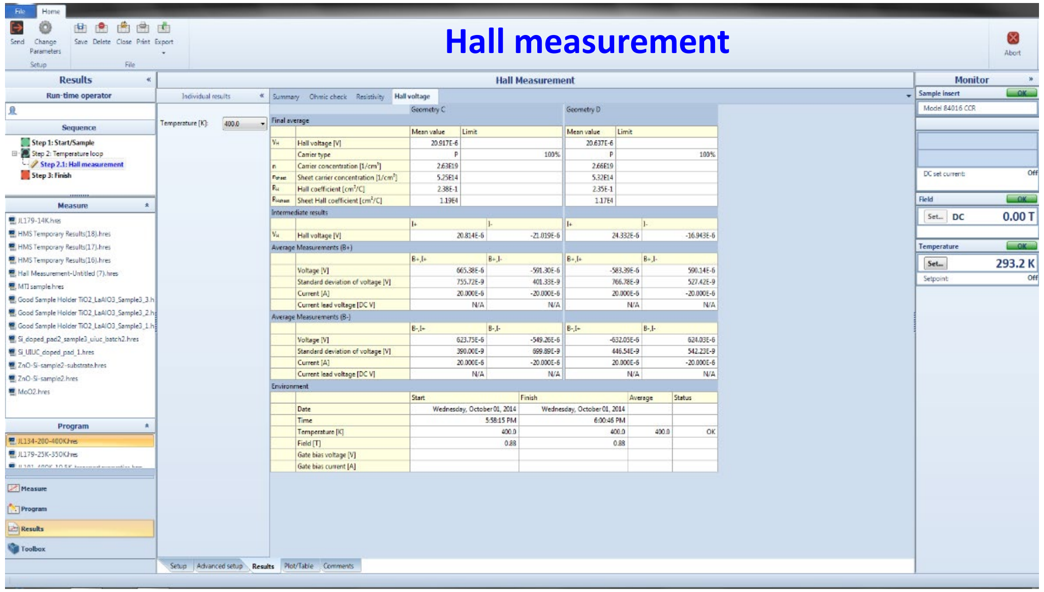
Measurement Setup

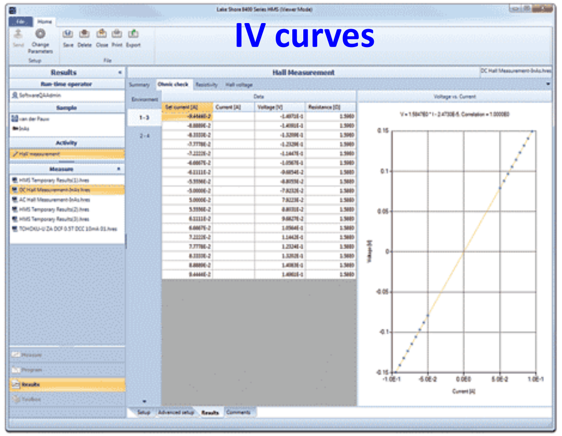
Steps include checking the quality of sample contacts, measuring the resistivity of sample and the Hall voltage

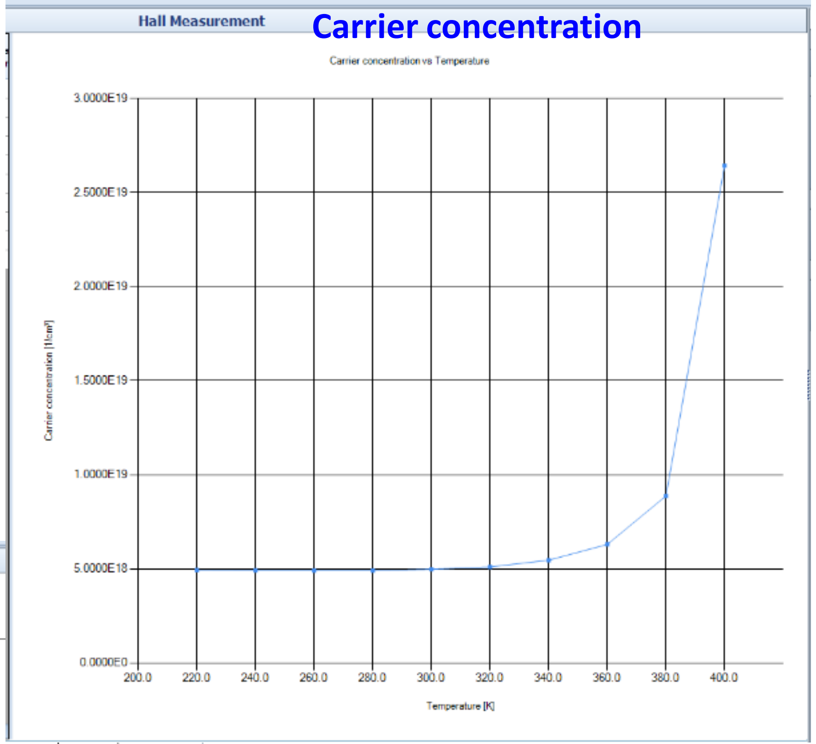
User interface / Hall measurements

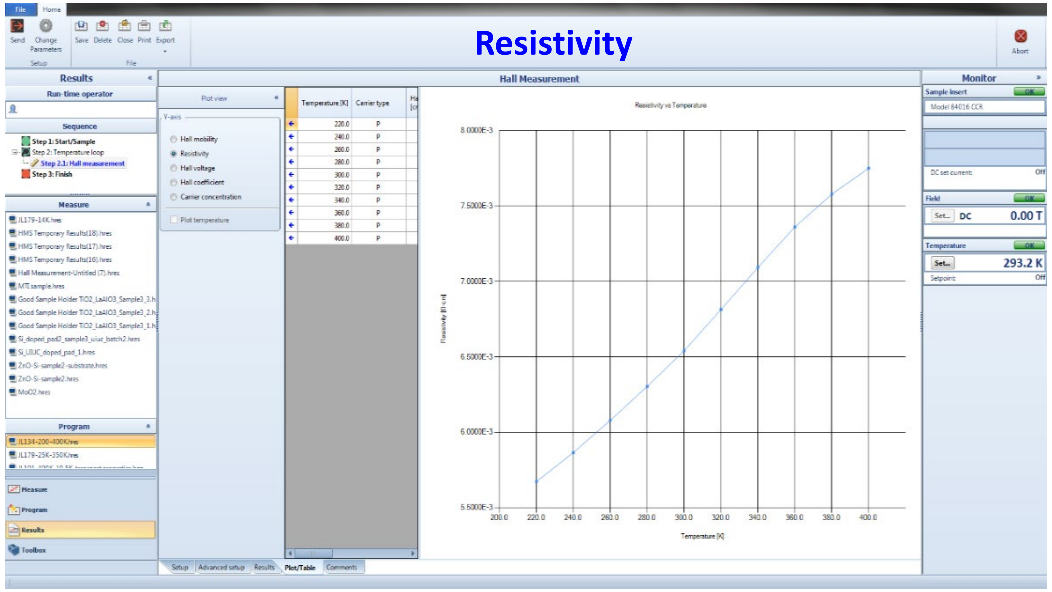


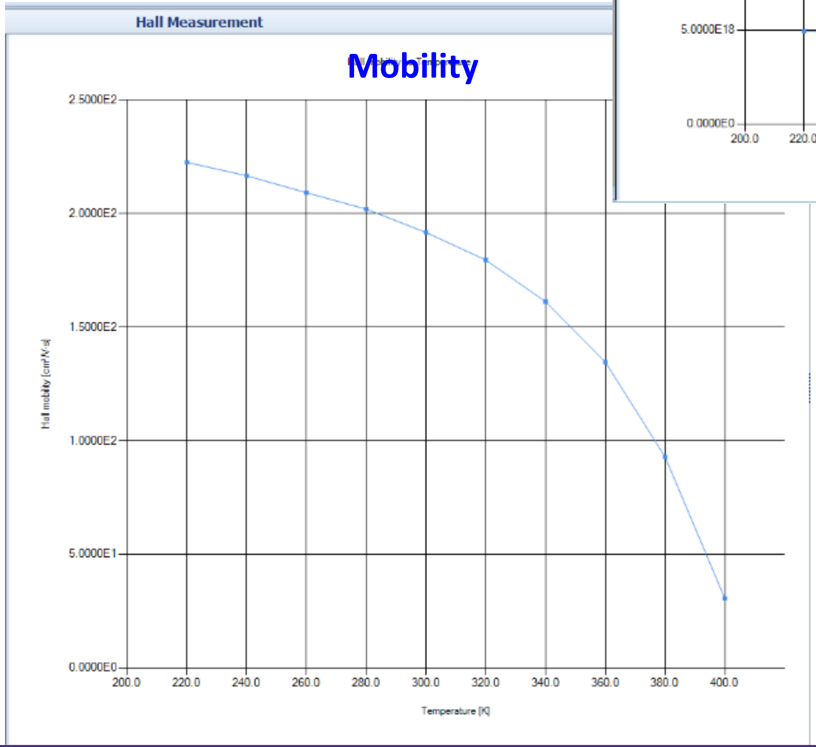
Results Transport properties



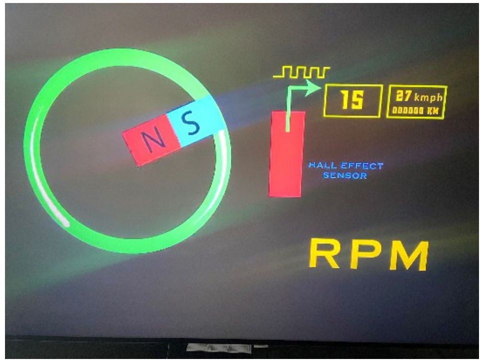


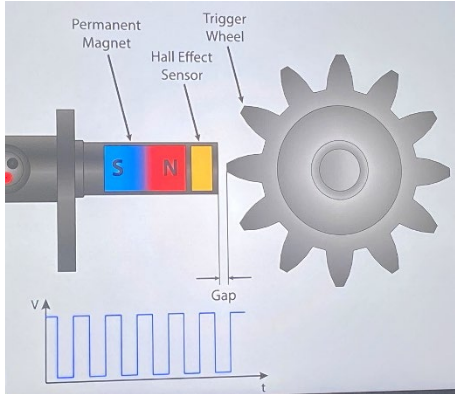






Hall Effect Sensors





Proximity sensing

DC transformers / current sensing

Automotive: fuel-level indicator, speed, tachometers and anti-lock braking systems

Hall Probe

Keyboard switches for high-reliability applications (aerospace and military)

Biological and chemical Hall sensors
(detection of biomolecule labeled with MNP)

Thank You