Hall Effect Measurement

Anil Dhote







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



NUFAB_Cook

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

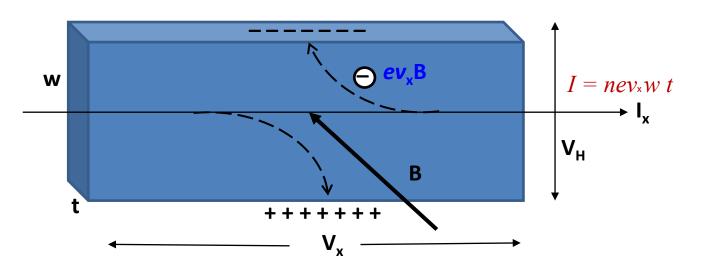
Facility includes class 100, 1000 space (1800 SqFt)





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 $ev_x B$ 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 $eV_{\rm H}/w$)

V_H = **IB** / **tne** (*n* carrier density)

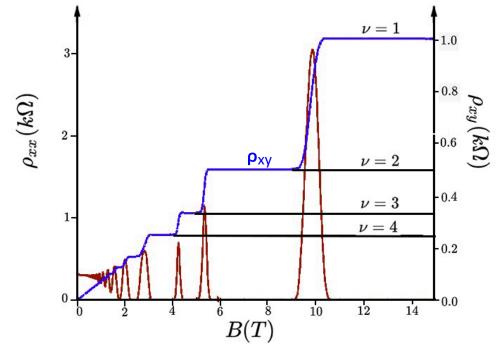
The Hall voltage can be either positive or negative. Hall voltage is negative, the carriers are electrons. Hall voltage is positive, the carriers are holes.





Quantum Hall Effect

Hall Resistance exhibits steps that take on the quantized values



Longitudinal ρ_{xx} and transverse (Hall) ρ_{xy} resistivity, of a twodimensional electron system as a function of magnetic field Image: Alba Cazorla, <u>Creative Commons Attribution-Share Alike 4.0 International</u> 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 $\rho_{XY} = h/v e^2$ (*v*-integer or fraction)

v = n / G = density of electrons / Total number of Landau states

.....(simply number of occupied Landau levels)

 $B \uparrow G \uparrow v \downarrow$

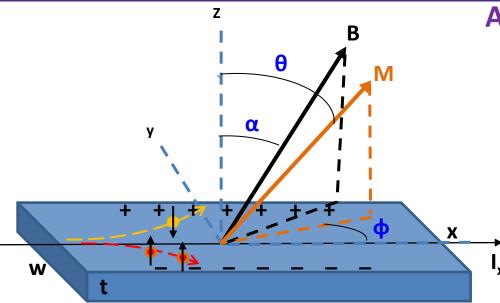
The electron population distribution in these quantized orbits results in a quantization of the electrical resistance

 $ρ_{XY}$ 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 $R_{\kappa} = h/e^2 = 25812.80745... \Omega$

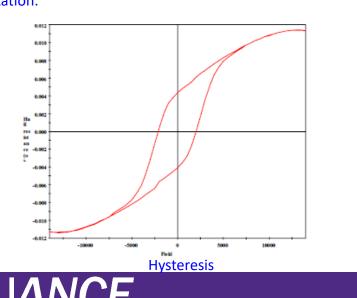
Integer quantum Hall effect was reported in graphene, gallium arsenide heterostructures and in magnesium zinc oxide $ZnO-Mg_{x}Zn_{1-x}O$







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.



Nanoscale Characterization Experimental Cente

Anomalous Hall Effect

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

$V_{\rm H} = (R_{\rm H} I/t) B\cos(\alpha) + (\mu_{\rm o} R_{\rm s} I/t) M\cos(\theta) + (kI/t) M^2 \sin^2(\theta) \sin(2\phi)$

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 + spinunpolarized 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 magnetoresistance due to magnetic of localized moments electrons/magnetization M. The PHE is proportional to the square of the planar component Μ, of 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



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 10⁶ cm²/V s
- Resistances from 0.5 m Ω to 10 M Ω
- 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





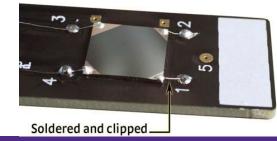






Measurement Accessory

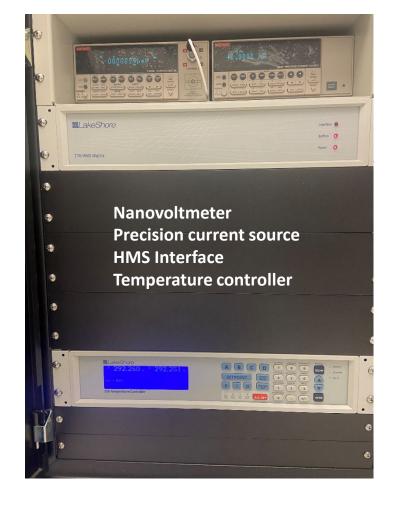




Sample mount card







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

E Harrie		Line Start RAX Series HV/S									
Start Stop Restart Execute Setup	Ribbon Setup file indicator										
Measure «		Hall Neasurement	Monitor *								
Operator	Generation			Sample insert							
R SoftwareQAAdmin	Z Ohmic check	V Measure resistivity	Z Measure Hall voltage	Model 84000 Standard Insert							
Sample	Pesstance ressumment method Sundard tesistance High resistance Contact sequence	Resistance messurement method Standard resistance High resistance Lownesstance	Well measurement method @ DCfield Hell measurement C ACfield Hell measurement Resistance measurement method	DC voltage							
Activities	8 14,24,0%	Excitation current	@ Standard resistance	DC set current: 0							
	ONNH-	Manual DV gA +	O High resistance	Gate bias voltage							
Î	C Custom	O ris i fabr	C Low resistance	Set_ 0.0000E0 V							
1	Min carrent 1 mA +	7 Current reversal	Excitation field Magnitude: 0.3 T •	East bias current -1.3760E-12							
Second level	Nax ourrent 20 mA +			Set_ DC							
navigation		Serveral Sample geometry Geometry averaged *	Field reversal	Jac De							
stage	Spacing Bisearspacing	we de deserts	Excition current Winual 200 pA	Temperature OK							
stage	Number of points 30 C Log spacing Points per decade 30	Avessge court 20	👩 Ivs. TTable	296.0 K							
			Current revenal	+							
First level		Manual resistivity	Gereni								
navigation		Manual residivity	Sample geometry: Gesmetry interaged •	Monitor							
stage			Average count 30	pane							
Messare	1										
Program	1	Workspace	1								
Results	Charles	har									
Tealbox	Status	sbar									

User interface / Hall measurements

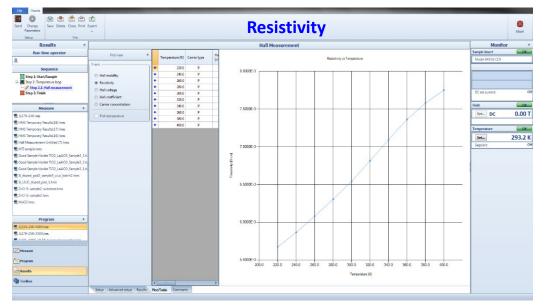








Send Change Save Delete Close Print Parameters Setup File	Export			ŀ	Iall	me	as	ure	em	ien	t		Abo
Results *					н	all Measurem	ent					Moni	tor
Run-time operator	Individual results	* Sum	many Ohmic check Resistivity Hal	voltage								 Sample Insert 	
				Geometry C			Geometry D					Model 84016 CCR	
Sequence	Temperature (K) 400	400.0 - Final average											_
				Mean value	Limit		Mean value						
Step 1: Start/Sample		Vie	Hall voltage [V]	20.917E-6	-		20.63						
Step 2: Temperature loop			Carrier type Carrier concentration [1/cm ⁷]	2.63E19		100%	26	P		100%			
Step 3: Finish		n Febre		5.25E14				2614				DC set current:	
-		P ₁₄	Hall coefficient [cm ² /C]	2.38E-1				58-1					
.1930.093			 Sheet Hall coefficient [cm²/C] 	1.1954				1764				Field	
Measure *			mediate results	1.1904									
J1179-14Khis				l+	ŀ		l+	. It	ŀ.			Set DC	0.
HMS Temporary Results(18).hres		Via	Hall voltage [V]	-	20.814E-6	-21.0195-6	-	24.332E-6		-16.9435-6			
HMS Temporary Results(17).hres		Avera	age Measurements (B+)									Temperature	
HMS Temporary Results(16).hres				8+,I+	8+,1-	8	B+,I+	1	8+,1-			Set.	29
Hall Measurement-Untitled (7).hres			Voltage [V]		665.38E-6	-591.30E-6		-583.39E-6		590.14E-6		Contractor	29
MTI sample hres			Standard deviation of voltage [V]		755.726-9	401.33E-9		766.78E-9		527.425-9		Setpoint	
Good Sample Holder TiO2_LaA(O3_Sample3_3.h			Current [A]		8-3000.02	-20.800E-6		20.000E-5		-20.0002-5			
Good Sample Holder TiO2_LaA(O3_Sample3_2.h			Current lead voltage [DC V]		N/A	N/A		N/A		N/A			
Good Sample Holder TiO2 LaAO3 Sample3 1.h		Avera	age Measurements (8-)	1	10				_				
Si doped pad2 sample3 uiuc batch2 hres				8-,I+	8-,I-	-549.262-6	B-,I+	-632.05E-5	8-,1-	621,032-6			
			Voltage [V] Standard deviation of voltage [V]		523.73E-6 390.00E-9	-549.201-0		446,54E-9		542,23E-9			
S_UIUC_doped_pad_1.hres			Current IA1		20.000E-6	-20.000E-6		440.54E-9 20.000E-6		-20.0005-6			
ZnO-Si-sample2-substrate.hres			Current lead voltage [DC V]		N/A	120.000-6 N/A		20.000Er6		120.000016 N/A			
ZnO-Si-sample2.hres		Fruit	onment	1	10.4			16.4		100			
MoO2.hves		Contra Co		Start		Finish		Aver	-	Status			
			Date	Wednesd	iay, October 01.	2014 Wedne	sday, October	01, 2014					
			Time		5.58-15	5 PM	60	00:45 PM					
riogram			Temperature [K]			0.004		400.0	400.0	OK			
JL134-210-400K/ms			Field (T)	1		88.0		0.88					
JL179-25K-350KJves			Gate bias voltage [V]										
F181 APPE 10 FF International States			Gate bias current [A]										
Measure													
Measure													
Program													
Results													
Toolbox													
	Seture Articany end cal	Danite I	Not/Table Comments										





Results

Run-time operator

Sample

Activity

Measure mporary Results(1)-hve

Amporary Results(2) Invest

2.5000E2

2.0000E2-

1.5000E2-

1.0000E2-

5.0000E1

0.0000E0-

200.0

Temperature [K]

oblity

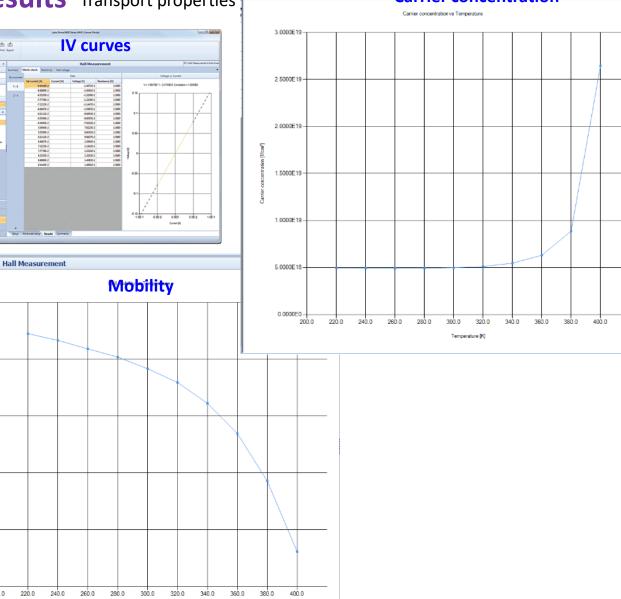
Hall

1-3

2-4

Setup Advanced setup Results



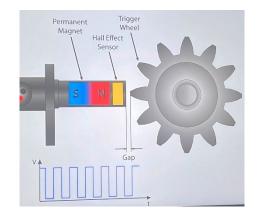






Hall Effect Sensors





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



