Hall Effect Measurements
Practical Issues

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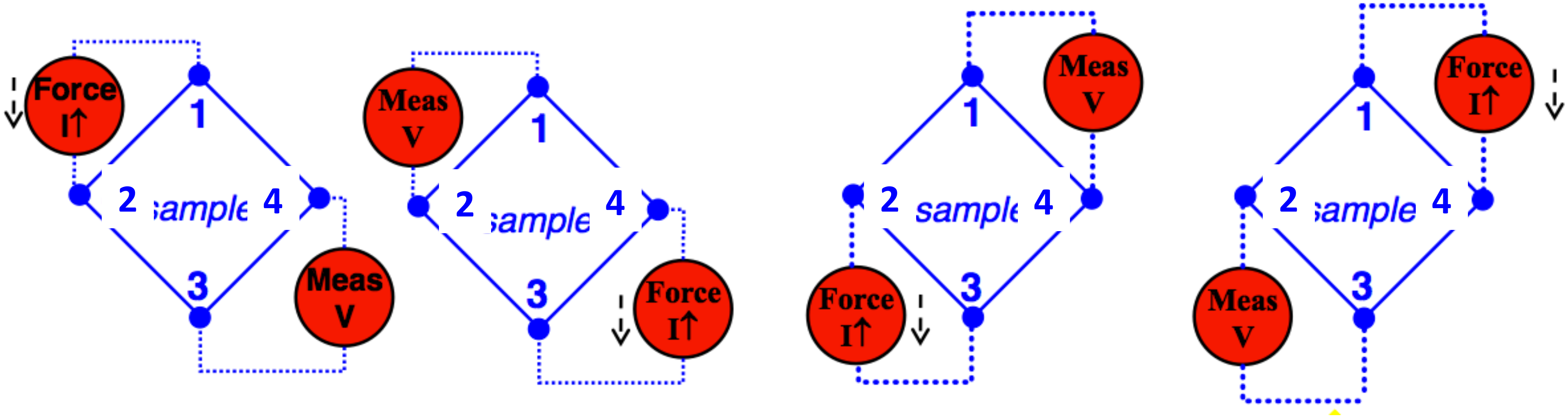
JMR 10/28/14

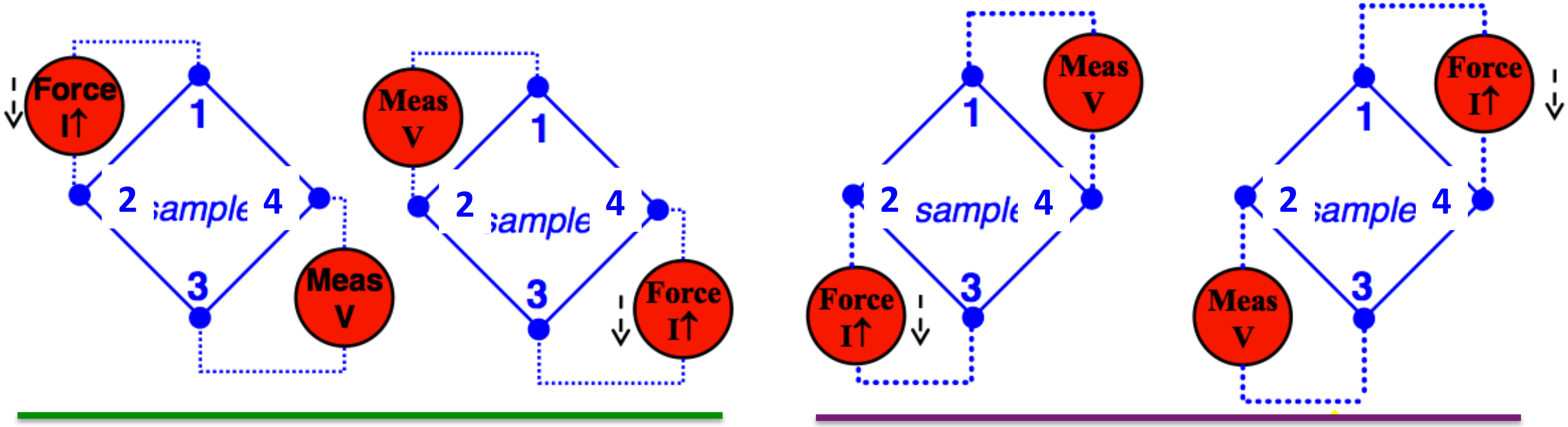
Basics – van der Pauw resistivity



Best results for

- uniform sample
- high symmetry
- point contacts (for blanket coat)
- Ohmic contacts
- low contact resistance

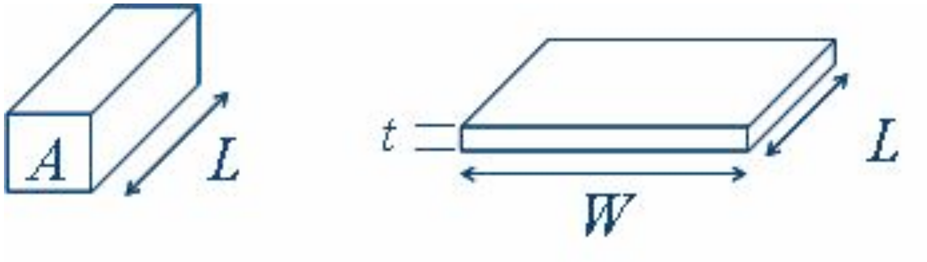
Basics – van der Pauw resistivity



$$e^{-\pi R_A/R_{sheet}} + e^{-\pi R_B/R_{sheet}} = 1$$

$$\rho = R_{sheet} t$$

Aside – sheet resistance

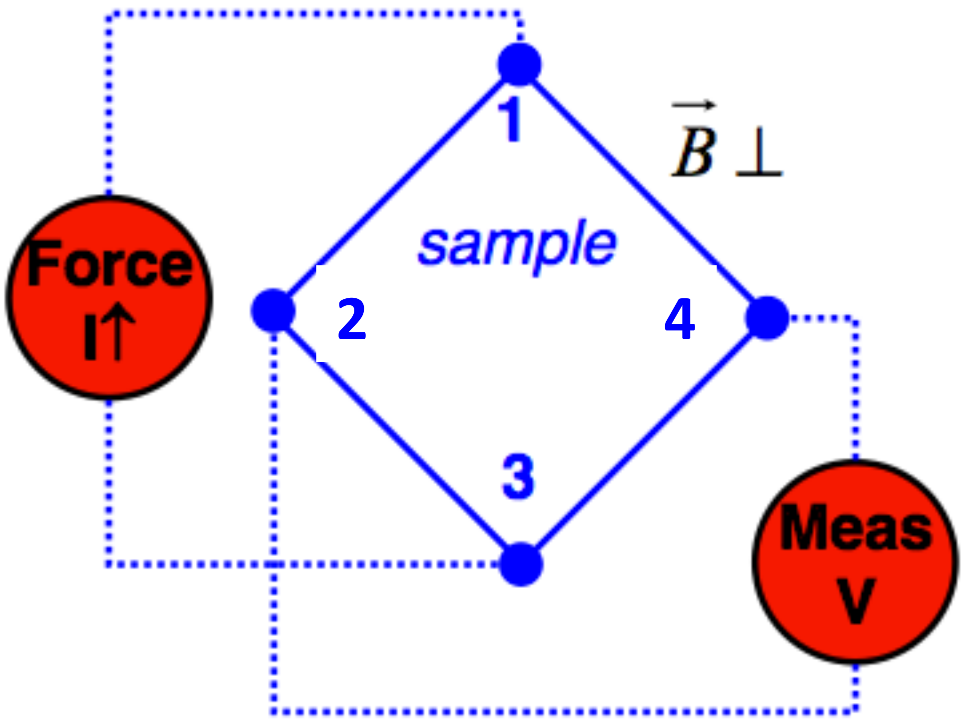


$$R = \rho \frac{L}{Wt} = \frac{\rho}{t}\frac{L}{W} \equiv R_{sheet}\frac{L}{W}$$

$$R_{sheet} = \frac{\rho}{t}$$

Dimensions of Ω, but really Ω cm/cm

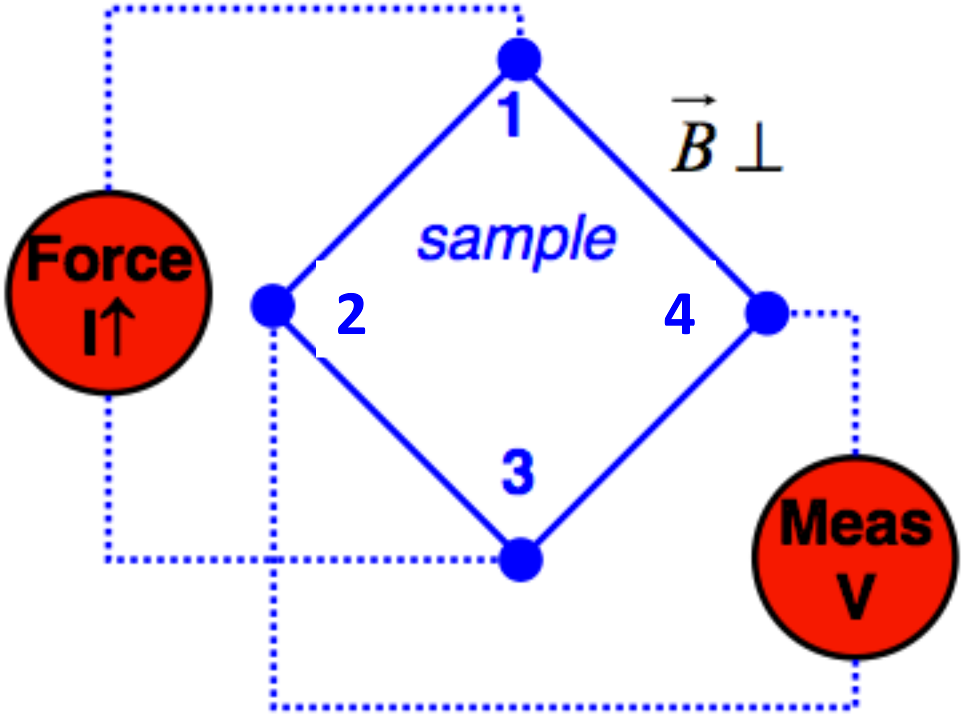
Basics - van der Pauw Hall



Apply I, measure V+, V-
Reverse I, measure V+, V-
Apply I to 2 & 4, repeat
Reverse B field and repeat

TIME to reverse B !
→ Instrument drift
→ Temperature drift
→ Change temperature gradients

Basics - van der Pauw Hall



$$R_H = \frac{r}{q\left(n-p\right)}$$

$$R_{HA} = 10^8 \frac{t}{B}\left[\frac{V_{31,42}^{+/+} - V_{31,42}^{-/+} + V_{31,42}^{-/-} - V_{31,42}^{+/-}}{I_{31}^{+/+} - I_{31}^{-/+} + I_{31}^{-/-} - I_{31}^{+/-}}\right] cm^3 C^{-1}$$

All the other effects ….

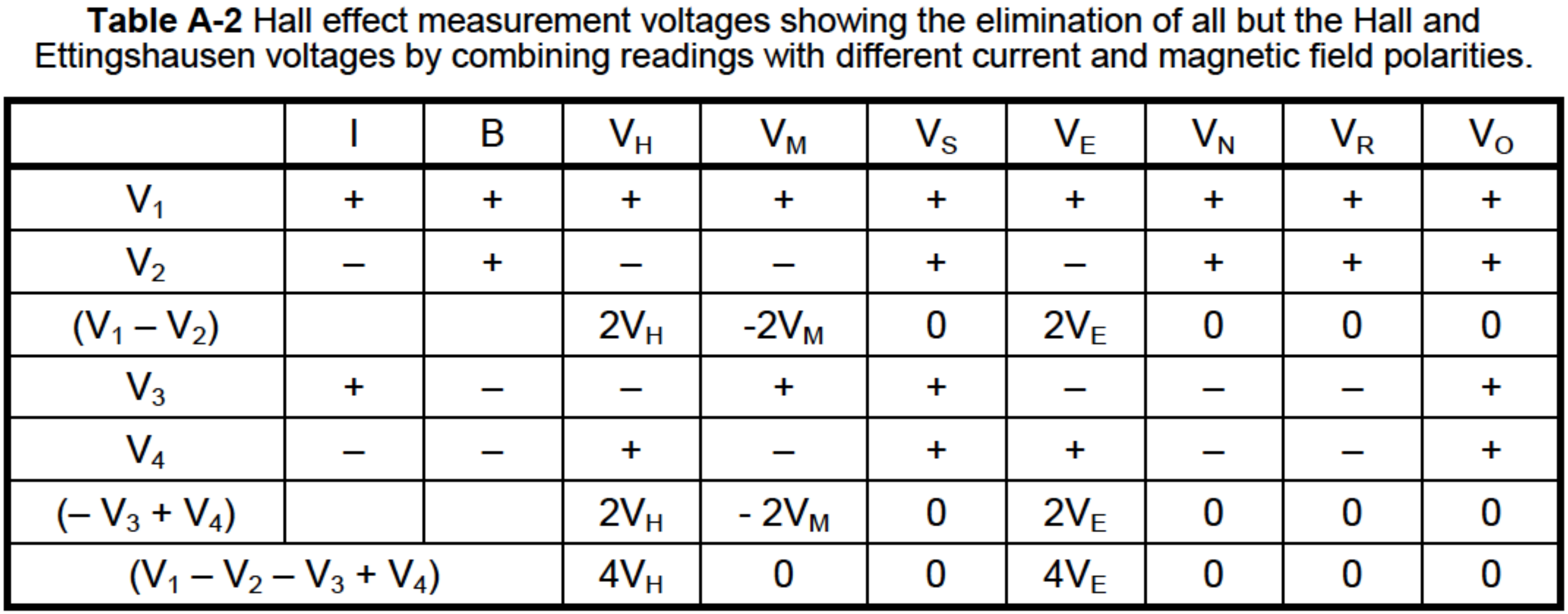


Table A-2 Hall effect measurement voltages showing the elimination of all but the Hall and Ettingshausen voltages by combining readings with different current and magnetic field polarities.

	I	B	V_H	V_M	V_S	V_E	V_N	V_R	V_O
V_1	+	+	+	+	+	+	+	+	+
V_2	–	+	–	–	+	–	+	+	+
$(V_1 – V_2)$			$2V_H$	$-2V_M$	0	$2V_E$	0	0	0
V_3	+	–	–	+	+	–	–	–	+
V_4	–	–	+	–	+	+	–	–	+
$(– V_3 + V_4)$			$2V_H$	$- 2V_M$	0	$2V_E$	0	0	0
$(V_1 – V_2 – V_3 + V_4)$			$4V_H$	0	0	$4V_E$	0	0	0

Vo Voltmeter offset (there is also current meter offset)

Vs   Seebeck voltage due to trans temp gradient

Ve Ettinghausen due to internal Seebeck by ev x B force shunting slow (cool) and fast (hot) electrons to the sides in different numbers

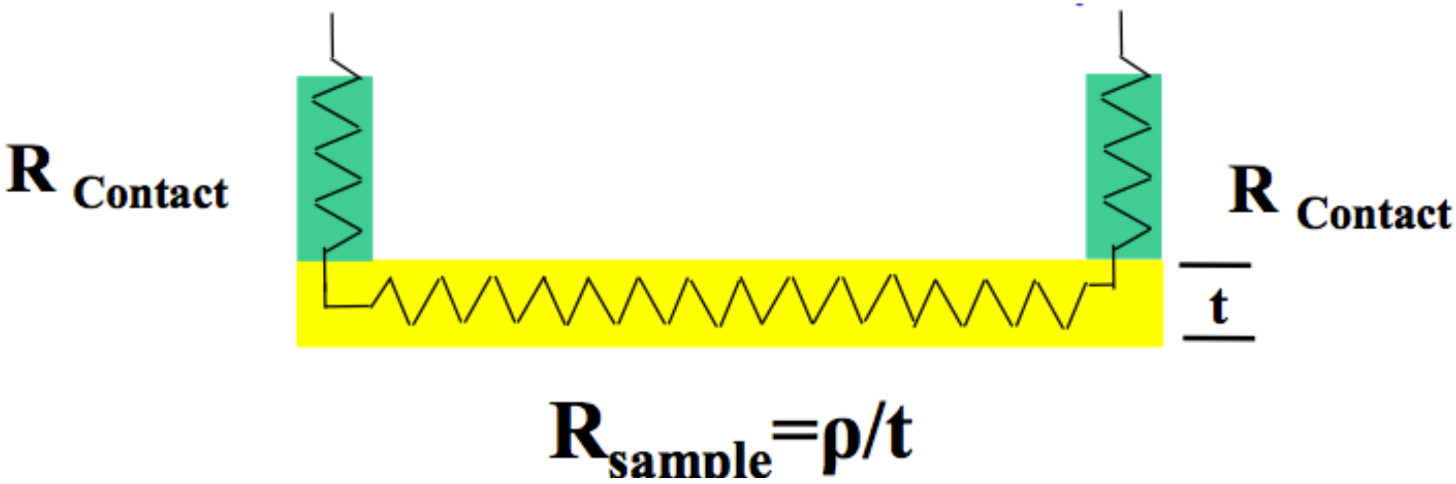
Vn Nernst due to long temp gradient – causes current that generates Hall voltage in B

Vr Righi-Luduc – Ettinghausen of the thermally generated current

Vm misalignment

Resistance ranges

- Total Resistance = Sample R + Contact R
- Sample *R* = ρ/*t* *(square sample);* sample resistivity ρ, thickness *t*. Limits total current. Try to keep power dissipation 1-5 mW
- Contact R at metal semiconductor interface (nominal) GaAs ~ 1000 * R_{sample}; Si: ~ 300 * R_{sample}



Resistance ranges

- Mid range resistance
  100 mΩ to 1 MΩ
  Typically: Nominally doped Si or Ge ($\sim10^{15}$cm^{-3}); Si photvoltaics; pHEMTS; ITO

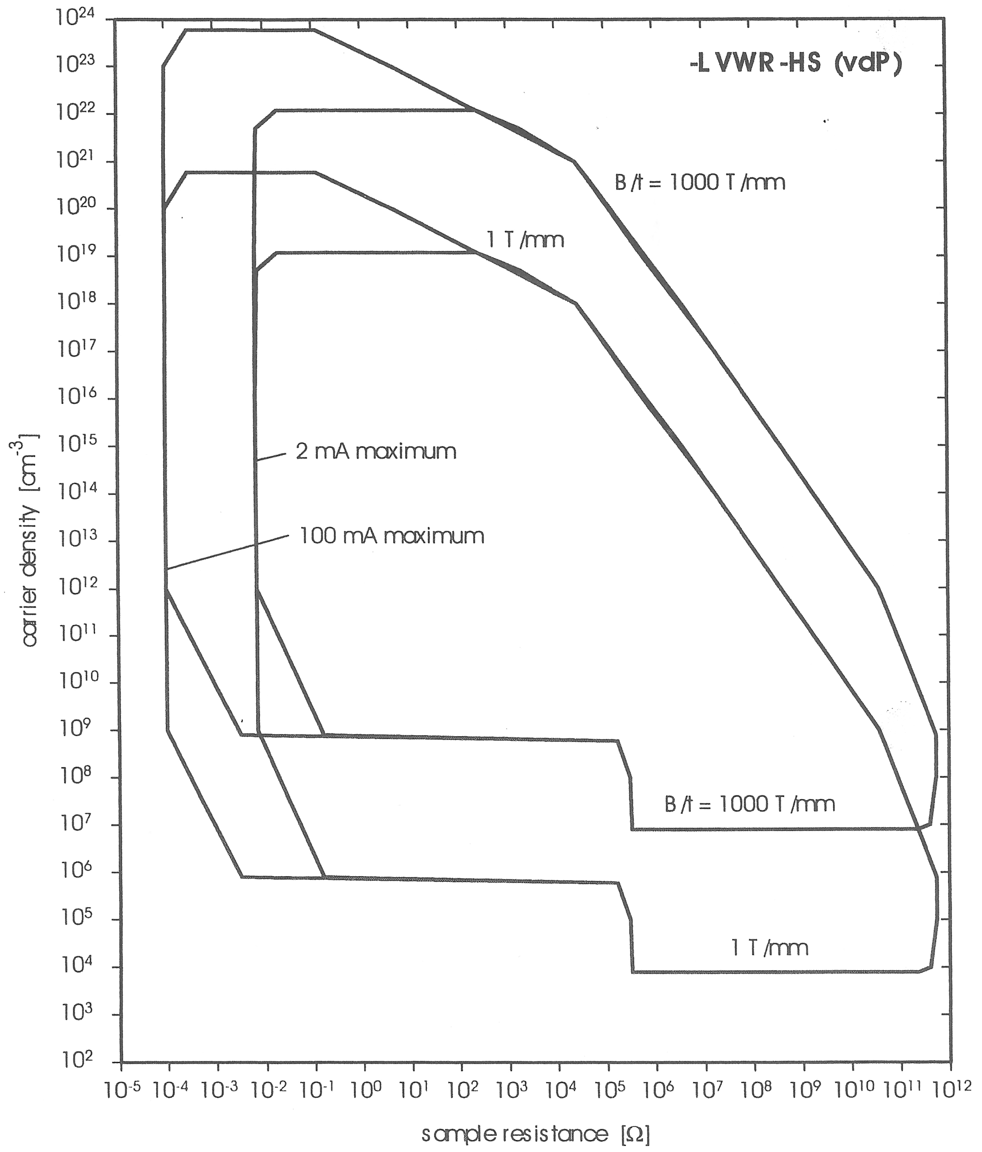


Figure 1-18 Range within which mobility is measured to within an uncertainty of 5% using the -LVWR-HS measuremen configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 29 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) ar sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

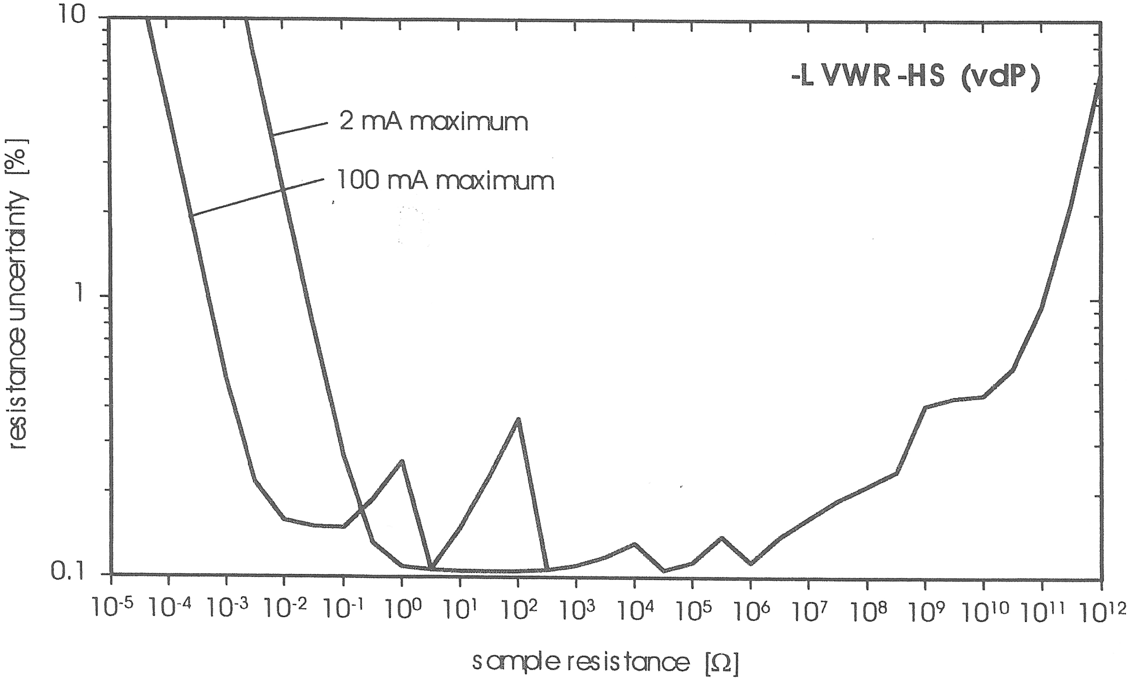


Figure 1-17 Resistance measurement uncertainty using the -LVWR-HS measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

High resistance

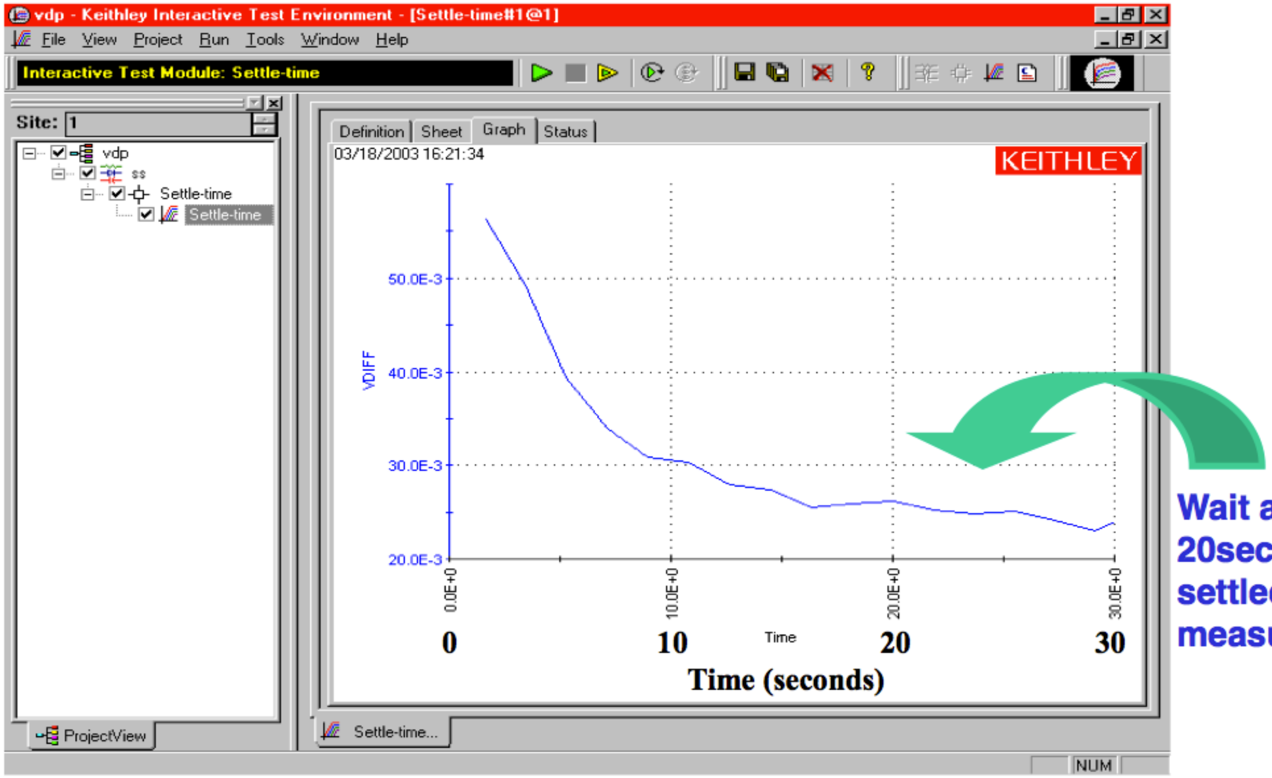
- Electrostatic shielding to minimize electrical interference
  Shield the DUT and all sensitive circuitry
  (there is a metal cover – use it!) Use shielded cabling
  Connect the shield to the low terminal of the system
- Use guarding to reduce the effects of leakage current
  Guarded current source
  Use triax cable instead of coax cable
- Allow sufficient settling time
  Source I and measure V(t) to determine settling time
  A diamond sample can take 10–15 minutes for settling

Thermoelectric effects

- Minimize temperature fluctuations & gradients
  Shield the DUT from air currents
  (there is a metal cover – use it!)
  Keep room temperature constant ☹
  Keep contacts free of oxidation

Settling time

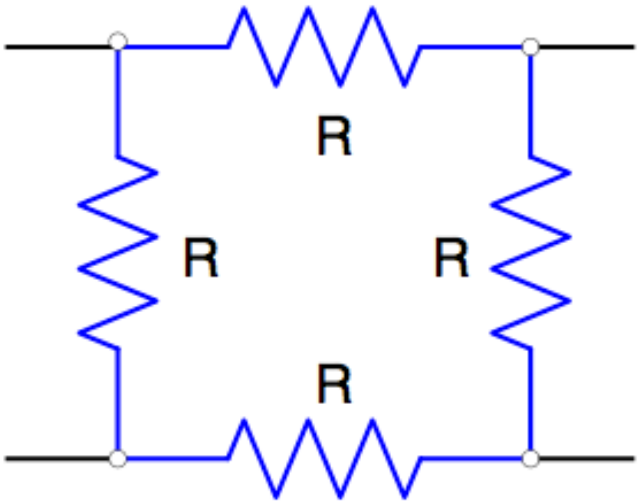
Settling Time of a $10^{12}\Omega$ Resistance Sample



Wait at least 20sec for a settled measurement

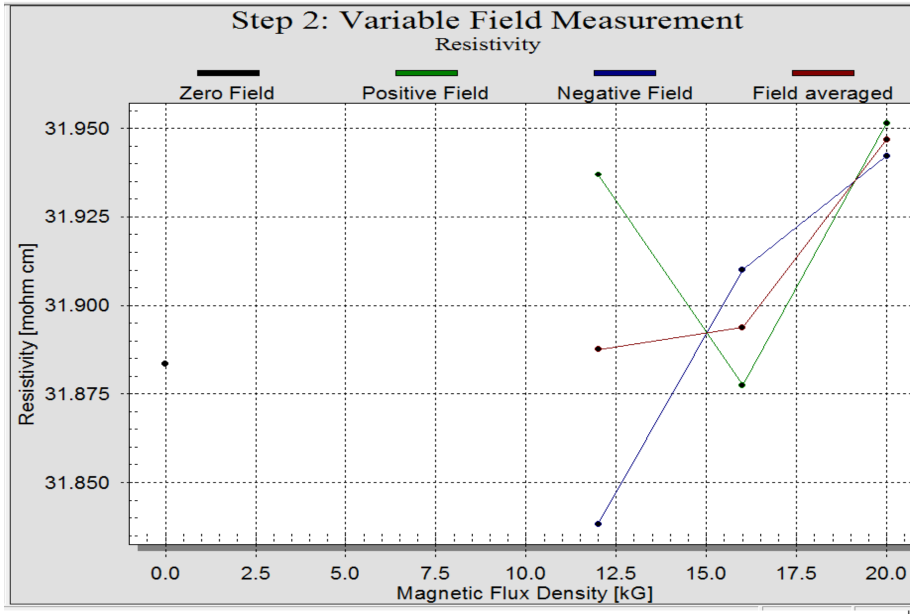
Test and calibrate

- Test structure of four equal resistors similar in magnitude to the resistance of the sample under test



- Have a known good sample (Lakeshore provides these)
- Check the B-field measurement at “0” and other

CATS sample (geometry was cross)



Resistivity ρ (needs *t*)

← variation 1 in 300

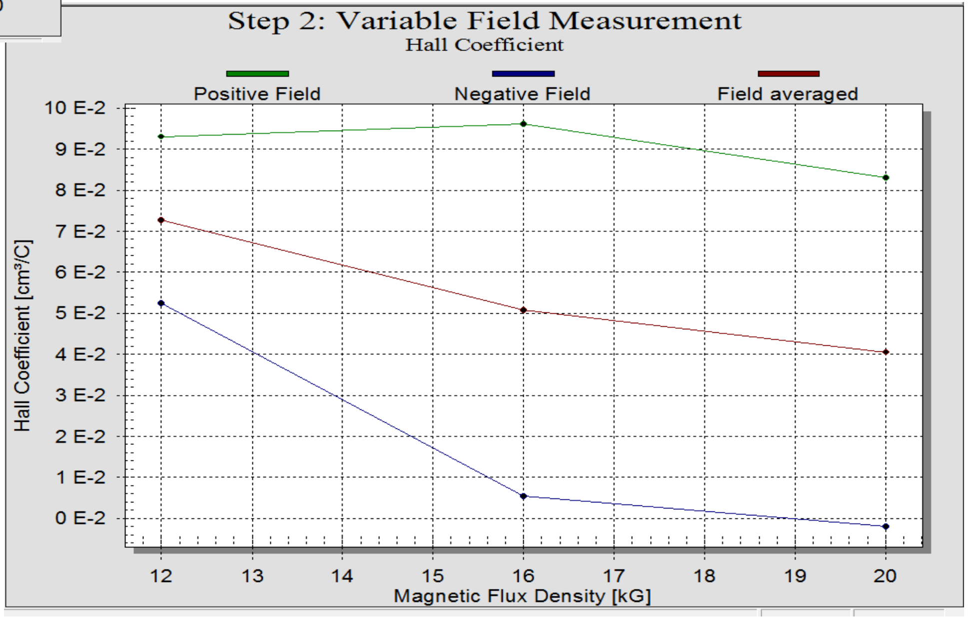
+B/-B < 0.3%

Hall coefficient R_H

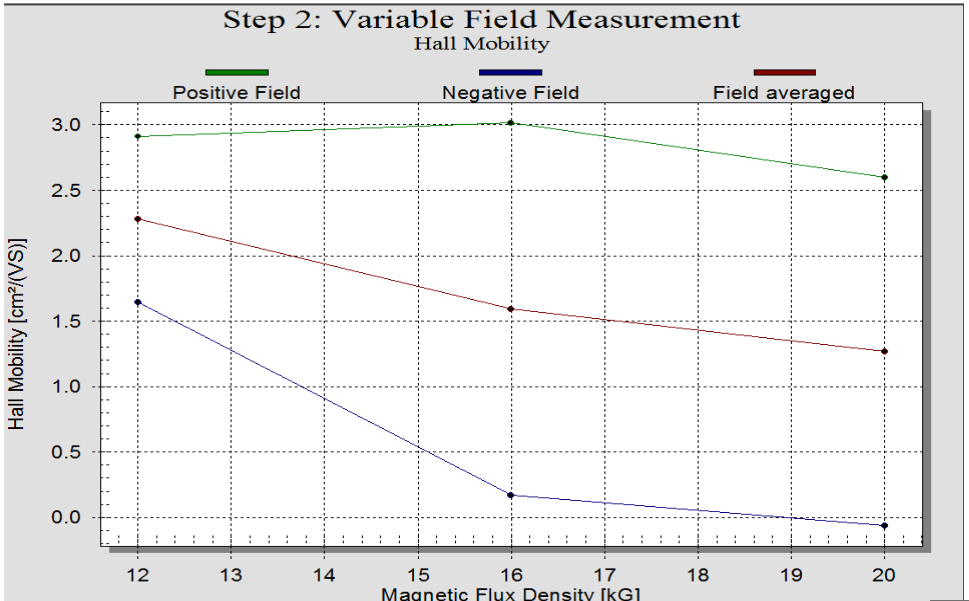
variation 10 in 10 →

+B/-B ≈ 100%

$\langle R_H \rangle = 0.5(R_{HP} + R_{HN})$



CATS sample



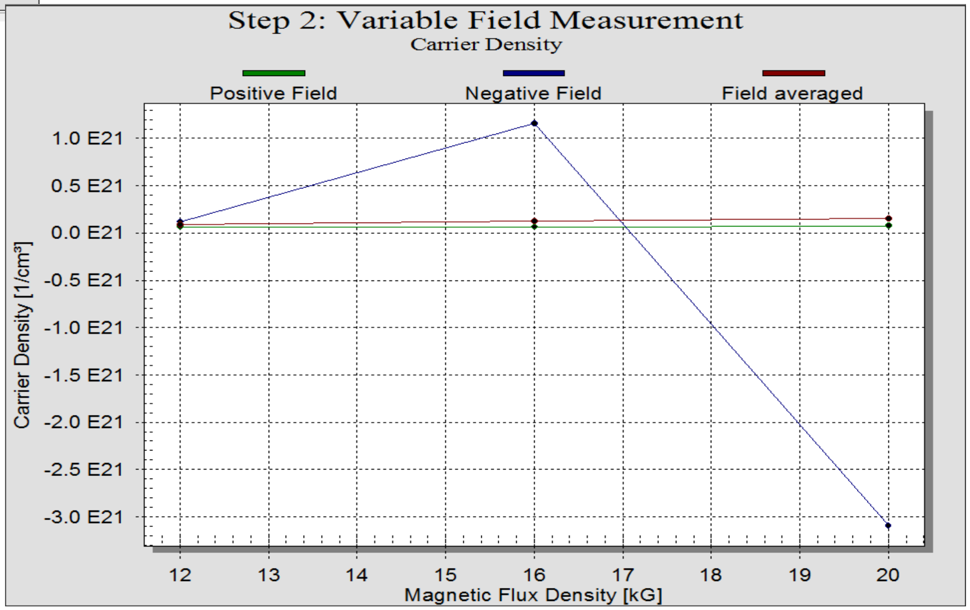
Mobility = R_H/ρ
(no *t* needed)

← variation 100%

Carrier density *n or p*

variation 10 in 10 →
+B/-B ≈ 100%

$<n>^{-1}=n_P^{-1}+n_N^{-1}$



More imperfections

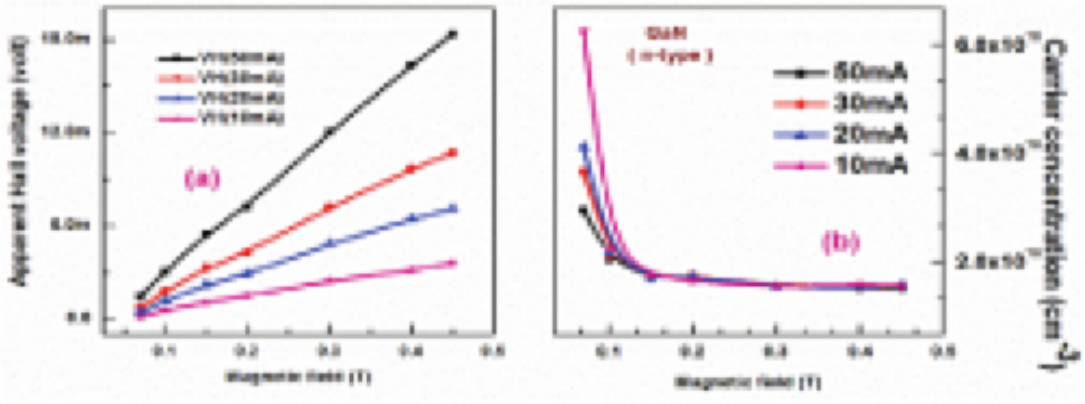


FIG. 4 (a) True Hall voltage plotted as a function of magnetic field, and (b) Carrier concentration extracted from the true Hall voltage at several current values.

$$V_H = \frac{R_H B I}{t}$$

Carrier density *seems* to vary with B – this is because the graph of R_H vs B does not properly intersect the origin – need to use slope, not absolute values (*cf* $V=IR$ that doesn't go through origin)

Importance of homogeneity

Positive Hall coefficients obtained from contact misplacement on evident *n*-type ZnO films and crystals

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J. Mater. Res., Vol. 23, No. 9, Sep 2008

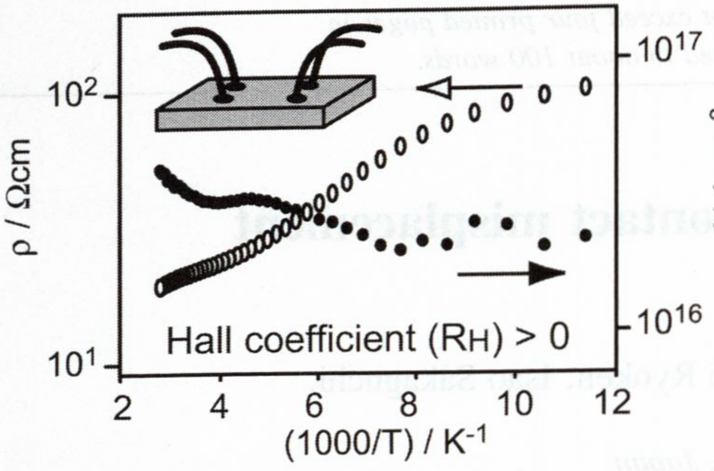

FIG. 1. Electric resistivity and "false hole concentration" in annealed ZnO single crystal.

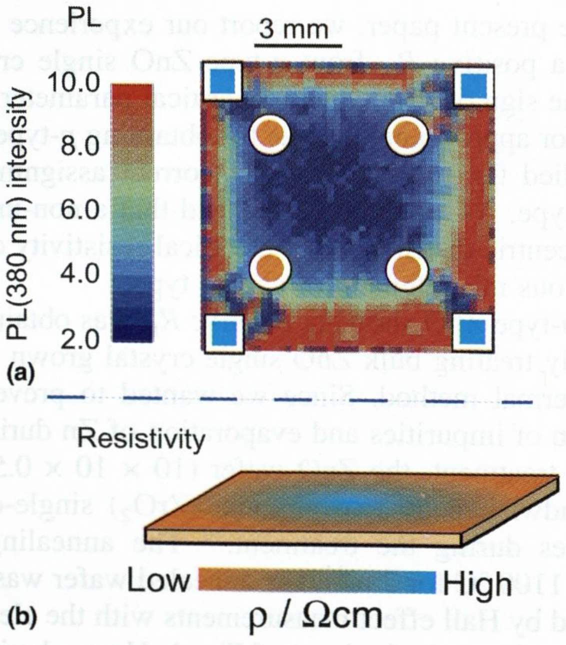

FIG. 2. (a) PL intensity mapping at λ = 380 nm. Orange circles and blue squares indicate position of electrodes for Hall measurements (see text) and (b) speculated resistivity distribution.

Sign reversal due to contact placement in inhomogeneous samples

- ZnO wafer treated by sandwiching between ZrO_2 wafers; inhomogenity clearly visible in PL (speculate Li impurity diffusion inhomogenity)
- Orange contacts $R_H>0$
- Blue contacts $R_H>0$
- $F_{VdP} = 1$! (no anisotropy in resistance measurements in either case)

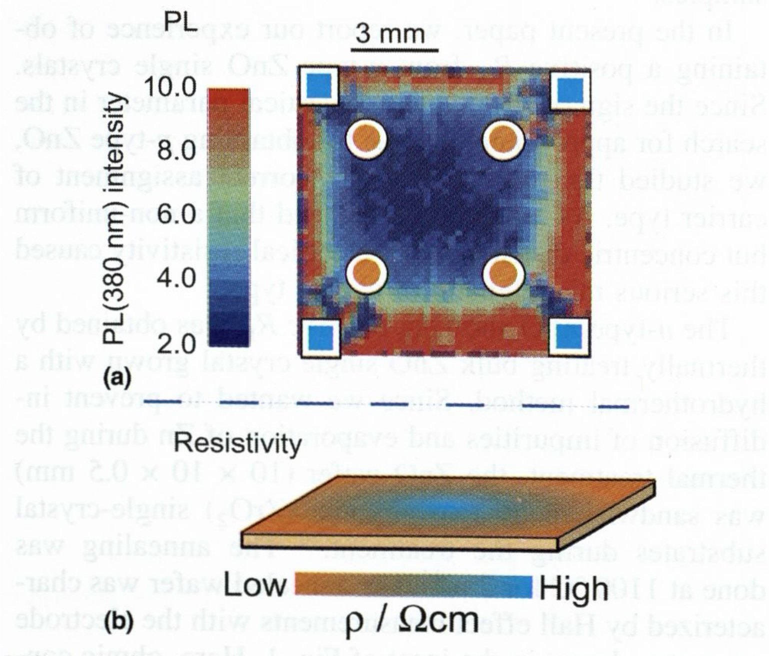

FIG. 2. (a) PL intensity mapping at λ = 380 nm. Orange circles and blue squares indicate position of electrodes for Hall measurements (see text) and (b) speculated resistivity distribution.

n-ZnO:Al films by PLD on sapphire

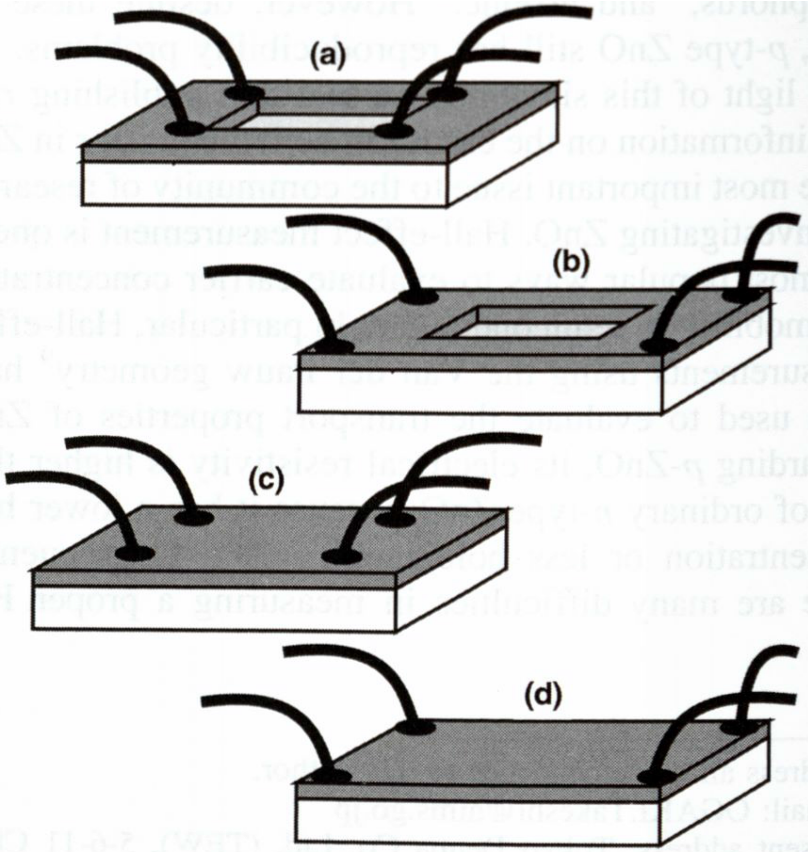

FIG. 3. Structure of ZnO samples to demonstrate Hall measurement for non-uniform samples.

(a) $R_H>0$

(b) $R_H<0$

(c) $R_H<0$

(d) $R_H<0$

- $F_{VdP} = 1$ (isotropic)

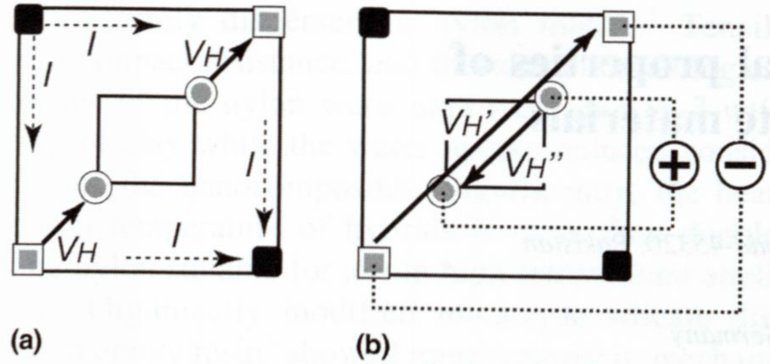

FIG. 4. Dependency of the sign of Hall coefficient on electrode configuration: (a) actual Hall voltage and (b) measured false Hall voltage.