Device Research Laboratory

Hall Measurement System Handbook

(System Designed and Revised by Wenyuan Li on Aug.20, 2013)

Written by Wenyuan, Li

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Note: This handbook version is only on the purpose for supporting Mr. Wenyuan Li's application. Some important parts have been through special handling.

This is a handbook for Hall Measurement System designed by Wenyuan, Li on Aug.20, 2013.
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Hall Measurement System

(Designed and Revised by Wenyuan Li on Aug.20, 2013)

● Part 1. Quick Operation Procedure

General

Hall Measurement System can determine accurately the sheet and bulk resistivity, sheet and bulk carrier concentration, and the mobility of carriers in semiconductors. Using Labview, the system is controlled by computer through GPIB card.

The connection block schematic diagram is shown in Fig.1.

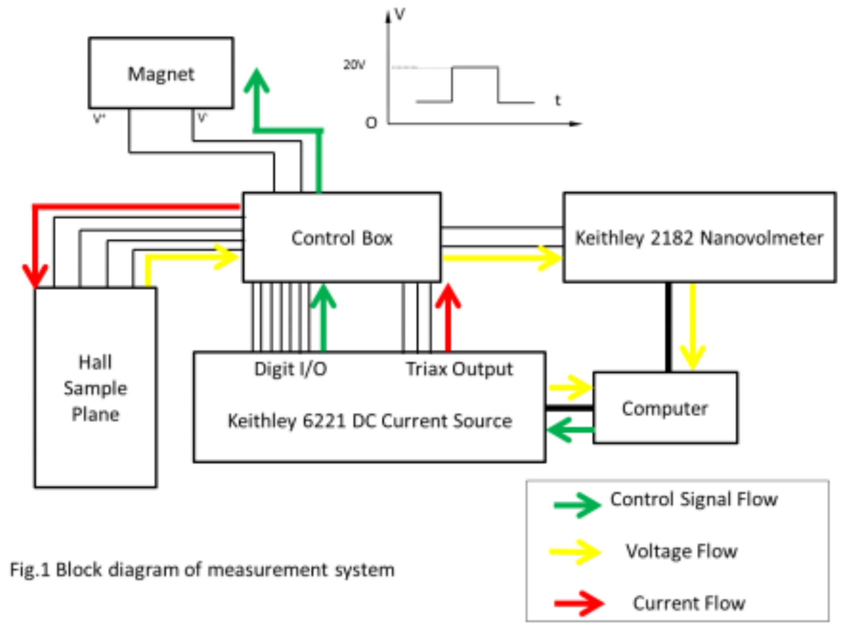

Fig.1 Block diagram of measurement system

Keithley 6221 -- DC Current Source, is programmable and controlled by Labview. Its Triax Output can apply constant current; and its Digit I/O outputs digital signals control relays and change the current direction and test point on the sample.

Keithley 2182 – Nanovolmeter, is used to test the voltage when constant current is applied on the sample and deliver voltage data to computer.

Computer – Using Labview, PC will control the whole measure procedure, monitor the condition of the devices, collect the test data, and calculate the sample parameters.

Magnet – Used to apply magnetic field on sample during the Hall measurements.

Hall Sample Plane – Used to weld the sample on and connect sample to the control box.

Control Box – Change the current direction and voltmeter test pin of the sample according to accepted digital signal.

Operation Procedure

The Hall measurement can be run by program *Hall Measurement Version 5*. Here are the basic steps you need to know when you operate the system.

1. Have your Hall sample ready; the sample should be thin plates with the geometry, as illustrated in Fig.2.

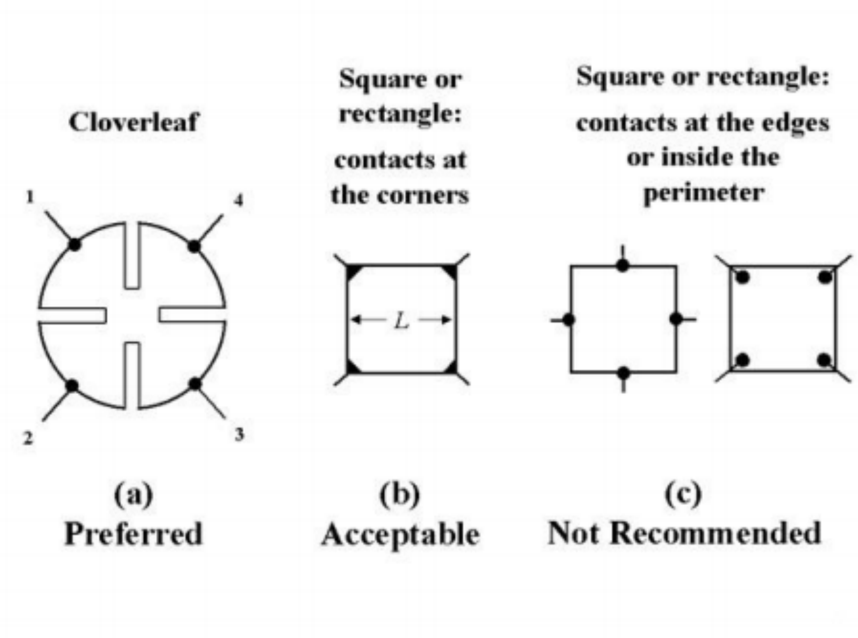

Fig.2 Sample geometries for Van Der Pauw resistivity and Hall effect measurements. The cloverleaf design will have the lowest error due to its smaller effective contact size, but it is more difficult to fabricate than a square or rectangle

2. Measure the resistance between sample pin 1 and pin 3, R_{13}, the allowed maximum DC current is less than $\frac{1}{\sqrt{1000*R_{13}}}$ for not heating up the sample.
3. Measure the sample thickness.
4. Solder the samples to sample plane, in the way shown in Fig.2. Put the sample in the magnetic field in the direction shown in Fig.3(a), while make sure the switch controlling the magnet direction is on the right side, as shown in Fig.3(b). In this way, if the calculated carrier parameters are positive (negative), the sample is p-type (n-type).

Fig.3(a) Fig.3(b)

Fig.3 Sample and magnet direction

5. Follow the steps to connect different parts of the system properly:
   Step 1: Connect the current source: connect the trix output to the box as shown in Fig.4(a); connect the digit I/O to the control box, as shown in Fig.4(b); connect the current source to the computer through GPIB, as shown in Fig.4(c); connect the power cable.

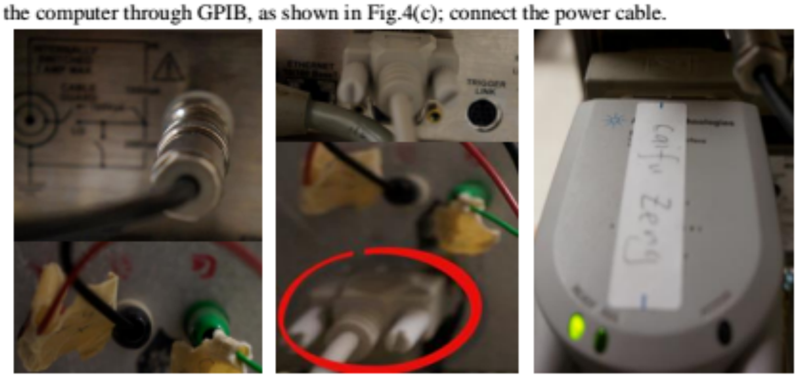

Fig.4(a) Fig.4(b) Fig.4(c)

Step 2: Connect the nanovolmeter: connect the channel line to the converter box, as shown in Fig.4(d); connect the nanovolmeter to the computer through GPIB, as shown in Fig.4(e); connect the power cable.

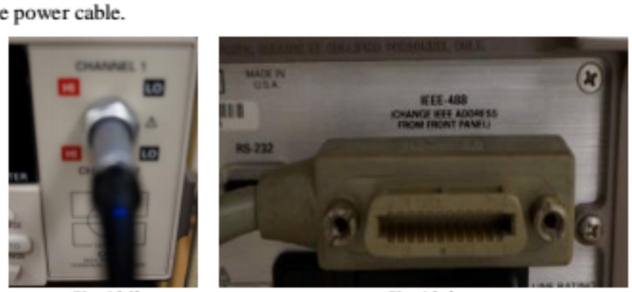

Fig.4(d) Fig.4(e)

Step 3: Connect the control box: connect the hall sample port Sample 1, as shown in Fig.4(f); connect the voltage port to the converter box, as shown in Fig.4(g); connect the box to the amplifier as shown in Fig.4(h); connect the power cable.

Fig.4(f)

Fig.4(g)

Fig.4(h)

Fig.4(i) Front of control box

Fig.4(k) Back of current source

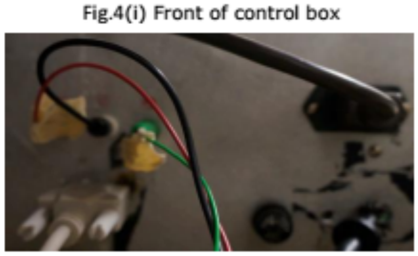

Fig.4(j) Front of control box

Fig.4(l) Back of nanovolmeter

Fig.4 Connection of the hardware

Fig.4(i)-Fig.4(l) show the whole connection configuration of control box and two devices.

6. Ensure the magnet control signal is 20A input in the magnetic field after the amplifier. The calculation for the carrier parameters tacitly approve the magnetic field is on the strength when the current is 20 A, namely 3400 Gauss.

7. Turn on the HARRISON 6823A Power Amplifier, set it to the *volts* and *amplifier* state.

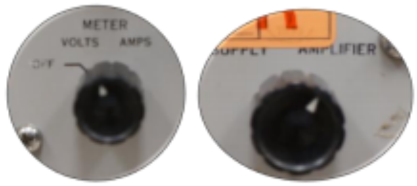

Fig.5 Settings of amplifer

8. Turn on Keithley 6221 Current Source, Keithley 2182 Nanovolmeter, electromagnet power.
9. Run Labview program *Hall Measurement Version 5* or *Hall Measurement Version 6* you will see the screen as shown in Fig.6(a). In version 5, the hall measurements will be taken only in one magnetic field direction, while in version 6, the program allow you to change the magnetic field direction manually which will lead to more accurate consequences. Choose the devices address according to the GPIB Card Controller, and set the two devices parameters for your measurement. The default values are suitable for most measure cases, so don't change them before you make their function clearly. Input the Folder path and Title that you want to record test data and test results. The Description is used to take some details of your test (exp. Sample material, Test Number, or other information). Before you start the program, don't forget to input the thickness of the sample and current sweep parameters in your computer, see Fig.6(b). Get more information in *Software Design Details*.

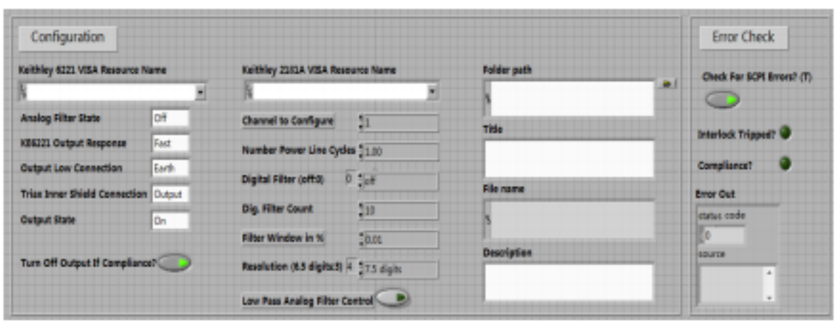

Fig.6(a)

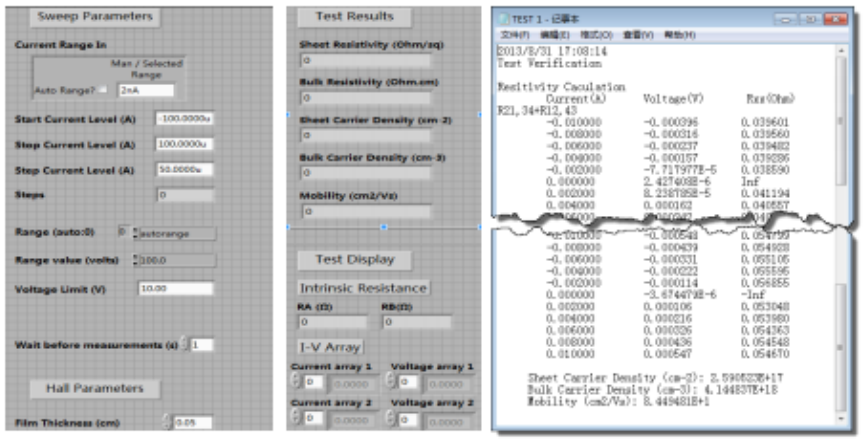

Fig.6(b) Fig.6(c) Fig.6(d)

Fig.6 Brief view of the programing

10. Once all things have been done, click the start button on the toolbar region, then the program will be running. For the version 6, a dialog box will be shown when you start. Click *OK* if you are certain that the magnetic field is in the right direction. Click *Start* if you are sure that the sample top faces the right side of the magnetic field, as shown in Fig.7(a)- Fig.7(b). During the procedure, the programming will pause and tell you to change the magnetic field direction manually. When you have done this, click *Continue* to restart the test, as shown in Fig.7(c). The test data and results will be shown on the right side of the screen, see Fig.6(c); when the programming ends, you can find the test information in the record txt file, see Fig.6(d).

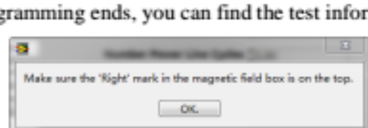

Fig.7(a)

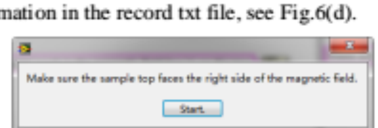

Fig.7(b)

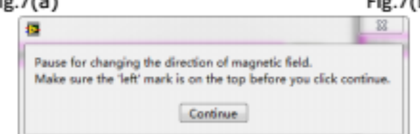

Fig.7(c)

Fig.7 Dialog box in program version 6

11. After you finish the measurement, turn off magnet power, Keithley 6221 Current Source, and Keithley 2182 Nanovolmeter.

Please contact the principal users if you need help or find any strange.

Part 2. System Design Details

Measurement Procedure and Parameters Calculation

Resistivity Measurement

- **Definitions**

We define the following parameters:

ρ=sample resistivity (in Ω·cm)

d=conducting layer thickness (in cm)

I_{12}=positive DC current I injected into contact 1 and taken out of contact 2. Likewise for I_{23}, I_{34}, I_{41}, I_{21}, I_{14}, I_{43}, I_{32} (in amperes, A)

V_{12} = DC voltage measured between contacts 1 and 2 (V_1 - V_2) without applied magnetic field (B = 0). Likewise for V_{23}, V_{34}, V_{41}, V_{21}, V_{14}, V_{43}, V_{32} (in volts, V)

- **Procedure**

- Apply the current I_{21} and measure voltage V_{34}
- Reverse the polarity of the current (I_{12}) and measure V_{43}
- Repeat for the remaining six values (V_{41}, V_{14}, V_{12}, V_{21}, V_{23}, V_{32})

Eight measurements of voltage yield the following eight values of resistance, all of which must be positive:

$$R_{21,34} = V_{34}/I_{21},\ R_{12,43} = V_{43}/I_{12},$$
$$R_{32,41} = V_{41}/I_{32},\ R_{23,14} = V_{14}/I_{23},$$
$$R_{43,12} = V_{12}/I_{43},\ R_{34,21} = V_{21}/I_{34},$$
$$R_{14,23} = V_{23}/I_{14},\ R_{41,32} = V_{32}/I_{41}.$$

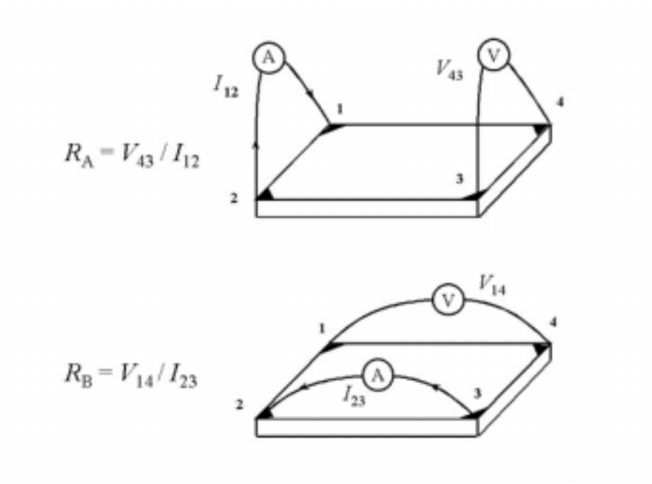

Fig.8 Schematic of a Van Der Pauw configuration used in the determination of the two characteristic resistances R_A and R_B

- **Calculation**

The sheet resistance R_S can be determined from the two characteristic resistances：

$$R_A = (R_{21,34} + R_{12,43} + R_{43,12} + R_{34,21})/4$$
$$R_B = (R_{32,41} + R_{23,14} + R_{14,23} + R_{41,32})/4$$

via the Van Der Pauw equation

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

Fig.9 shows the algorithm for solving Van Der Pauw equation.

If the conducting layer thickness d is known, the bulk resistivity $\rho = R_S{\cdot}d$ can be calculated from R_S.

Algorithm for solving Van Der Pauw Equation

- Set the error limit δ=0.0005(corresponding to the accuracy you want)
- Calculate the initial value of z_i, or $z_0=2\ln(2)/[\pi(R_A+R_B)]$
- Calculate the i^{th} iteration of $y_i=1/\exp(\pi\, z_{i-1}R_A)+1/\exp(\pi\, z_{i-1}R_B)$
- Calculate the i^{th} iteration of z_i where $z_i=z_{i-1}- [(1-y_i)/\pi]/[R_A/\exp(\pi\, z_{i-1}R_A)+ R_B/\exp(\pi\, z_{i-1}R_B)]$

When$(z_i-z_{i-1})/z_i$ is less than δ, stop and calculate the sheet resistance $R_s=1/z_i$.

The resistivity is given by $=R_s d$, where d is the thickness of the conducting layer.

Fig.9 Algorithm for solving Van Der Pauw equation

Hall Measurement

- **Definitions**

For program version 5, we define the following parameters:

$\boldsymbol{I_{13}}$ = DC current injected into contact 1 and taken out of contact 3. Likewise for $\boldsymbol{I_{31}}$, $\boldsymbol{I_{42}}$, and $\boldsymbol{I_{24}}$.

$\boldsymbol{B}$ = constant and uniform magnetic field intensity applied vertical to the sample plane.

$\boldsymbol{V_{24\text{-}on}}$ = Hall voltage measured between contacts 2 and 4 with magnetic field for $\boldsymbol{I_{13}}$. Likewise for $\boldsymbol{V_{42\text{-}on}}$, $\boldsymbol{V_{13\text{-}on}}$, and $\boldsymbol{V_{31\text{-}on}}$.

Similar definitions for $\boldsymbol{V_{24\text{-}off}}$, $\boldsymbol{V_{42\text{-}off}}$, $\boldsymbol{V_{13\text{-}off}}$, and $\boldsymbol{V_{31\text{-}off}}$ when the applied magnetic field $\boldsymbol{B}$ is off.

For program version 6, we define the following parameters:

$\boldsymbol{I_{13}}$ = DC current injected into lead 1 and taken out of lead 3. Likewise for $\boldsymbol{I_{31}}$, $\boldsymbol{I_{42}}$, and $\boldsymbol{I_{24}}$.

$\boldsymbol{B}$ = constant and uniform magnetic field intensity applied vertical to the sample plane. **B** is positive when the 'Right' mark is on the top, and negative when the 'Left' mark is on the top.

$\boldsymbol{V_{24P}}$ = Hall voltage measured between leads 2 and 4 with magnetic field positive for $\boldsymbol{I_{13}}$. Likewise for$\boldsymbol{V_{42P}}$, $\boldsymbol{V_{13P}}$, and $\boldsymbol{V_{31P}}$.

Similar definitions for $\boldsymbol{V_{24N}}$, $\boldsymbol{V_{42N}}$, $\boldsymbol{V_{13N}}$, and $\boldsymbol{V_{31N}}$ apply when the magnetic field $\boldsymbol{B}$ is reversed.