Four Point Resistivity Probe Operation

Probe base:	Kulicke and Soffa Industries, Inc. Model 3007 Resistivity Probe Base
Electronic Circuitry:	Keithley Model 530 Type-All System, containing: Keithley Model 225 Current Source and Keithley Model 160 Digital Multimeter

For the Micro-Electronics Laboratory
At
University of Notre Dame
Department of Electrical Engineering

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http://www.nd.edu/~ee/ndnf/

or contact Keith Darr for a copy of this manual.

Purpose

A Kulicke and Soffa Industries, Inc. Model 3007 four-point in-line probe is used in conjunction with a Keithley model 530 Type-All system to make applicable characterization measurements. The Keithley model 530 Type-All system is an electronic system designed for measurement of resistivity and determination of conductivity type of a semiconductor. The Keithley system contains a precision current source, digital microvoltmeter, in conjunction circuitry needed for resistivity and typing determinations.

Reference Documents

Keithley model 530 instruction manual, Keithley model 225 current source instruction manual, Keithley model 160 digital multimeter instruction manual, and Kulicke and Soffa Industries, Inc. model 3007 resistivity probe base instruction manual, additional documentation has been cited at the end of this procedure.

Additional Equipment Required

none

Materials Required

Semiconductor sample of a known geometric dimensions, which meet the requirements defined in this procedural document.

Protective Equipment Required

Latex Gloves
Safety glasses

Engineering and/or Administrative Controls

Only authorized users may operate this piece of equipment

Training

To obtain training on this machine, please contact Keith Darr (office 221, phone 1-5497, email kdarr@nd.edu)

Problems

For problems, clarification of procedures, or general information pertaining to this machine please contact one of the following personnel.

Keith Darr	**631-5497**	**Kdarr@nd.edu**
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Mark Richmond	**631-6478**	**Richmond.7@nd.edu**

In Case of Emergency, Please Contact Notre Dame Security at

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Table of Contents

Page Contents

4	**Authorized Users List**
5	**Standby Conditions** **Sample requirements**
6	**Equipment Setup and**
7	**Connection Check** **Resistivity Measurement**
8	**Resistivity Measurement** **Conductivity Type Procedure**
9	**Slice Resistance (ρ) Calculation**
10	**Sheet Resistance (R_s) Calculation**
11	**Formulas and variables**
12	**Referenced Works**

Authorized Users List

Name	Email	Advisor	Date

Standby Conditions

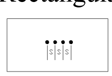
1. The 163 digital voltmeter
    1. In the 100 mV position.
    2. The LO and the HI banana plugs should have a shorting device connected to the respective plugs on the 530 Type-All system and the voltmeter.
2. The 530 Type-All system
    1. Function set to standby
    2. Power switch off
    3. Probe set to A
    4. Current shunt set to 1K
3. The 225 current source
    1. Power switch turned off
    2. Voltage compliance set to 50
    3. Output selector set to either of the standby positions
    4. Decade switched set to 1-0-0
    5. Range set to left most mA position
    6. Filter off

Sample requirements

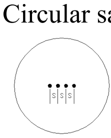
1. The sample under test must meet the following requirements to be tested using the four point probe.
    a. The sample under test must be on top of an insulating layer, unless the thickness (t) of the sample under test is greater than 5 times the probe tip spacing (5*s).
        i. This is a thickness (**t**) value greater than 250 mil (0.635 cm) thick when using a probe tip spacing of 50 mil (0.127 cm), as in the case of this piece of equipment.
            1. If the thickness (**t**) of the sample is greater than 5 times the probe tip spacing (**s**), the sample is viewed as being infinitely thick to the four point probe and no thickness correction factor **F(t/s)** will be needed for sheet and slice resistivity calculations.
        ii. The sample may be a a bare semiconductor sample or a relatively thin layer in respect to the probe tip spacing (**t**)<<(**s**), such as an implanted or diffused layer, if that layer is of different majority carrier that that of the underling layer. For example, if the sample is a P-type layer on top of an N-type layer, or an N-type layer on top of a P-type layer.
    b. Sizing requirements:
        i. If the sample is round:
            1. The sample diameter must be greater than 150 mil (0.381 cm) = (3*s), so to accommodate all four probe points.
        ii. If the sample is rectangular:
            1. Sample length must be greater than 150 mil (0.381 cm) = (3*s), so to accommodate all four probe points.
        iii. Geometric correction factors have only been included to compensate for round and rectangular samples.
            1. Corrections factors are needed to accurately calculated sheet and slice resistance of thin and of relatively small sized samples. This is due to current source imaging that is created when the electron field comes into contact with an electrical boundary.

Equipment Setup

1. Check the logbook to make sure the last user has logged out.
    1. Read the log book comments of previous users to verify the machine condition.
2. Log in to the log book.
3. Ensure that the four point probe station is setup to the following stand by condition:
    1. The 163 digital voltmeter
        1. In the 100 mV position.
        2. The LO and the HI banana plugs should have a shorting device connected to their respective plugs on both the 530 Type-All system and the voltmeter.
    2. The 530 Type-All system
        1. Function set to standby
        2. Power switch off
        3. Probe set to the A position
        4. Current shunt resistor set to 1K Ω
    3. The 225 current source
        1. Power switch turned off
        2. Voltage compliance set to 50 volts
        3. Output selector set to either of the standby positions
        4. Decade switched set to 1-0-0
        5. Range set to left most mA position
        6. Filter off
4. Turn on the 225 current source, 163 DMM, and the 530 Type-All system.
    1. Allow 30 minutes for warm up.
        1. If the sample dimensions are not know, it is recommended to measure the dimensions of your sample during this warm up time.
            1. Sample thickness (in cm, 1 mil = 0.00254 cm)
                1. 5 mil = 0.0127 cm
                2. 10 mil = 0.0254 cm
                3. 20 mil = 0.0508 cm
                4. 30 mil = 0.0762 cm
            2. Sample
                1. Diameter (if round, in cm)
                    1. 2 inches = 5.08 cm
                    2. 3 inches = 7.62 cm
                    3. 4 inches = 10.16 cm
                2. Length and Width (if rectangular, in cm)
5. Place the test sample on the glass plate and center the sample under the probe head.
    1. Rectangular samples should be tested with the length parallel to the probe tips.

    2. Circular samples should be tested with the probe tips centered on the sample.

6. Lower the probe head by moving the chrome handle down. Once at the bottom of the handle travel, slide the handle to the left so to lock it in the lowered position.

Connection Check:

1. Verify that the current source has a value of 1.00 mA selected.
2. Switch the output selector on the current source to the “+” position.
3. Verify on the 530 Type-All system that the 1K Ω current shunt resistor is selected.
4. Apply the current to the sample by switching the Type-All system function selector to the current position.

   NOTE:

   At times the limit light on the current source will be lit. This is an indication that the probes have not made proper contact with the sample.

   If this occurs, place the Type-All system and the current source back into their standby conditions and then release the locked chrome handle holding the probe against the sample.

   Reposition the sample, then lower and secure the chrome handle so to remake contact to the sample.

   If the limit light is still lit after 3 reposition attempts, contact lab staff.

5. Read and record the voltage displayed on the voltmeter.
   1. Divide this voltage by the current value. This resistance value should match the value of the current shunt resistor.
      1. If the calculated value is equal to the current shunt resistor value, then the current source is outputting the correct current value.
   2. If the calculated value does not match the current shunt resistor value, there is likely a problem with the four point probe and lab staff should be contacted.

Resistivity Measurement:

Maintaining the conditions as described above, the sample resistivity (**V/I**) can be easily determined. This value, in ohms, is the resistivity of the sample at the point where the four point probe has been connected to the sample under test. This value is a function of the position of the contacts on the sample surface and will differ if the operator were to test the sample at different points across the surface of the sample.

This resistivity measurement (**V/I**), also referred to as the spreading resistance ($\mathbf{R_{sp}}$), should not be confused with other sample properties such as the sheet resistance ($\mathbf{R_s}$) or the slice resistance (**ρ**). The technique for calculating the sheet resistance ($\mathbf{R_s}$) and the slice resistance (**ρ**) are described latter in this procedure.

Resistivity Measurement:

1. Set the 530 Type-All system to the (**V_{fwd}**) function.
    1. Ensure that the output selector, on the current source, is in the "+" position.
    2. Verify that the voltmeter is in the 100 mV position and that the current source is set to output a value of 1.00 mA (left most mA position).
2. Record the value displayed on the voltmeter as (**V_{fwd}**).
3. Divide this value by the selected "+"current setting (**I_+**) to obtain the forward resistance (**R_{fwd}**).
4. Change the 530 Type-All system to the (**V_{rev}**) function.
5. Change the output selector on the current source, to the "**-**" position.
6. Record the reading on the voltmeter as (**V_{rev}**).
7. Divide this value by the selected "**-**" current setting (**I_-**) to obtain the reverse resistance (**R_{rev}**).
8. The two readings, (**R_{fwd}**) and (**R_{rev}**), should be within 10% of each other.
    1. If the readings are different by a large value this is likely due to probe rectification.
        1. One may achieve a more ohmic contact by repositioning the sample in respect to the probe head. This should be accomplished by placing the Type-All system and current source back into standby, releasing the probe head, slightly reposition the sample, and remaking contact by lowering and locking the chrome handle.
            1. In doing so, the operator must perform the contact verification steps prior to re-measurement of the (**V_{fwd}**) and (**V_{rev}**) values.
            2. If the operator is unable to obtain resistance values that are within 10% of one another after multiple repositioning attempts, contact lab staff.
9. Calculate the mean resistance, $(V/I)=[(R_{rev})+(R_{fwd})]\ /2$, and record this value as the spreading resistance (**R_{sp}**).
    1. This value will be used to calculate the sheet resistance (**R_s**) and the slice resistance (**ρ**).

Conductivity Type Procedure:

The four point probe can be used to determine the sample conductivity type through use of the AC signal rectification. Another method is available to determine sample conductivity type when using the Type-All system. This method, known as the thermoelectric mode or as the hot and cold probe method, generates a voltage by means of the Seebeck effect to determine the carrier type.

1. Set up the sample in the same manner as described in the contact verification procedure.
2. Set the 530 Type-All system to the type (**Rect**) function.
    1. If the voltmeter indicates a value greater than 0.5 mV, then the majority carrier type can be determined by the polarity indicated on the voltmeter.
        1. Positive polarity = P type
        2. Negative polarity = N type
3. If the reading is less than 0.5 mV then switch to the thermoelectric mode by selecting type (**Therm**) function.
    1. If the voltmeter indicates a value greater than 0.5 mV, then the majority carrier type can be determined by the polarity indicated on the voltmeter.
        1. Positive polarity = P type
        2. Negative polarity = N type
4. If either of the two methods do not have desirable results.
    1. One may place the Type-All system into the standby position, release and reposition the sample in respect to the probe head, remake contact, and then perform the contact verification steps and the resistivity tests once more.
5. If the probe connection has been maintained and all tests have been completed, return the Type-All system and the current source to the standby condition.
6. Release and remove the sample from the four point probe station.
7. Turn off the current source, voltmeter, and the Type-All system power.
8. Complete the calculations of the sheet resistance (**R_s**) and the slice resistance (**ρ**), which are explained in the following sections.
9. Clean up the work area, enter needed comments in the log book, and sign out of the log book.

Calculation of the sheet resistance (R_s) and the slice resistivity (ρ)

Slice Resistivity (ρ)

Slice resistance (**ρ**), expressed in units Ω-cm, should be calculate before sheet resistance (**R_s**) except for situations where a rectangular sample is being tested. In that application, the sheet resistance (**R_s**) will be calculated first and the slice resistance (**ρ**) will then be calculated as a function of the sheet resistance (**R_s**).

$\rho = F * R_{sp}$	Ω-cm	Slice resistivity formula used for circular samples
$\rho = (R_s) * t$	Ω-cm	Slice resistivity formula used for rectangular samples
$R_{sp} = (V/I)$	Ω	The spreading resistance
$F = F_2 * F(t/s) * t$	none	Geometric correction factor derived from table 1 for round samples
t	cm	Thickness of the sample, expressed in cm
s	cm	Probe tip spacing, expressed in cm (**s**) = 50mil = 0.127 cm
d	cm	Sample diameter, expressed in cm

Table 1

F(t/s) Thickness correction factor as a function of the ratio of thickness to probe tip spacing

If (t/s)<0.5 then F(t/s) = 1

(t/s)	F(t/s)
0.5	0.997
0.6	0.992
0.7	0.982
0.8	0.966
0.9	0.944
1.0	0.921
1.1	0.864
1.2	0.803
1.3	0.742
1.4	0.685
1.5	0.634
1.6	0.587
1.7	0.546
1.8	0.510
1.9	0.477
2.0	0.448
2.1	0.422
2.2	0.399
2.3	0.378
2.4	0.359
2.5	0.342

F_2 Correction factor as a function of the ratio of probe tip spacing to sample diameter

(s/d)	F_2
0.000	4.532
0.005	4.531
0.010	4.528
0.015	4.524
0.020	4.517
0.025	4.508
0.030	4.497
0.035	4.485
0.040	4.470
0.045	4.454
0.050	4.436
0.055	4.417
0.060	4.395
0.065	4.372
0.070	4.348
0.075	4.322
0.080	4.294
0.085	4.265
0.090	4.235
0.095	4.204
0.100	4.171

Values that fall in between displayed values can more correctly approximated via the following method:

If (s/d) = 0.053

(s/d)	F_2
0.050	4.436
0.055	4.417

F_2 = [(0.050 - 0.055) / (4.436 - 4.417)] * (0.050 - 0.053) + 4.436 = 4.437689

Sheet Resistance (R_s)

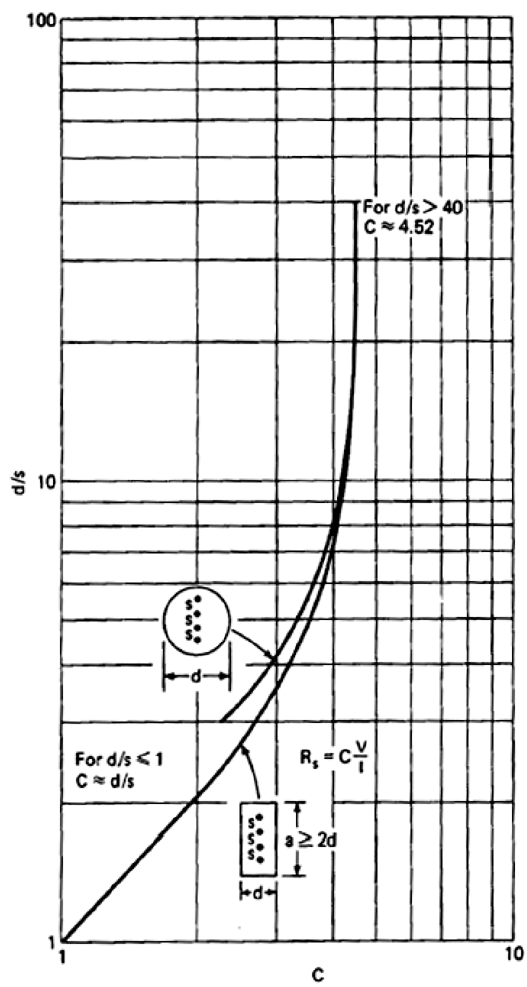
Sheet resistance (**R_s**) can be simply calculated as a function of the slice resistance (**ρ**) and the sample thickness (**t**). However when testing rectangular samples, this procedure requires that the sheet resistance (**R_s**) be found before the slice resistance (**ρ**), which will then become a function of the sheet resistance (**R_s**) and sample thickness (**t**).

$R_s = \rho / t$	Ω/sq	Sheet resistance (**R_s**) as a function of slice resistance (**ρ**) an sample thickness.
t	cm	Thickness of the sample, expressed in cm.
C	none	Sheet resistance correction factor (**R_s**),for circular and rectangular samples as derived from chart 1.
$R_s = C * (V/I)$	Ω/sq	Sheet resistance (**R_s**), for circular and rectangular samples. C is found directly from chart 1
l	cm	Length of a rectangular sample, in cm
w	cm	Width of a rectangular sample, in cm
$R_s = C * (V/I)$	Ω/sq	Sheet resistance (**R_s**) of a rectangular sample when (a<2d) where a = length and d = width, as in chart 1 (see note)

Chart 1

Used to calculate sheet resistance (**R_s**) for circular and rectangular samples.

Note: When a rectangular sample is under test and the length (a) is less than 2 times the width (d), (a<2d), the sample approaches a circle in dimension. Therefore, the correction factor can be closely approximated by an estimation of the values that are between the curve for a circular sample and the defined rectangular sample in chart 1.



Sheet resistance correction factors for circular and rectangular samples. F.M. Smits, "Measurements of Sheet Resistivity with Four-Point Probe," *Bell Syst. Tech J.*, (3), 711-718, May 1958. (Courtesy of AT&T Bell Laboratories.)

Appendix

Formulas and variables:	Units	Description
(t)	cm	Sample thickness, expressed in cm
(s) = 50mil = 0.127 cm	mil / cm	Probe tip spacing constant for this four point probe configuration
(I_-)	mA	Reverse current
(I_+)	mA	Forward current
(V_{fwd})	mV	Forward voltage
(V_{rev})	mV	Reverse voltage
(R_{fwd}) = (V_{fwd}) / (I_+)	Ω	Forward resistance
(R_{rev}) = (V_{rev}) / (I_-)	Ω	Reverse resistance
(V/I) = [(R_{rev}) +(R_{fwd})] / 2	Ω	The average resistance as a function of the forward resistance (R_{fwd}), reverse resistance (R_{rev})
R_{sp} = (V/I)	Ω	The spreading resistance (R_{sp})
(t/s)	cm	Ratio of the sample thickness (t) in cm, to the probe tip spacing (s) in cm. Probe tip spacing (s) = 50mil = 0.127 cm in this application
(d/s)	cm	Ratio of the sample diameter (d) if round, or the width (d, as used in chart 1) if rectangular, to the probe tip spacing in cm. (s) = 0.127 cm in this application. C is found directly from chart 1
C	none	Sheet resistance correction factor for circular and rectangular samples
$\rho = R_s * t$	Ω-cm	Slice resistance
$\rho = F * R_{sp}$	Ω-cm	Slice resistance as a function of the geometric correction factor (F) and the spreading resistance (R_{sp})
$F = F_2 * F(t/s) * t$	none	Geometric correction factor derived for round samples used to find slice resistance (ρ)
F_2	none	Correction factor used to calculate slice resistance (ρ) as a function of the ratio of probe tip spacing to sample diameter. derived from table 1
F(t/s)	none	Thickness correction factor as a function of the ratio of thickness to probe tip spacing. Derived from table 1. Used to calculate slice resistance (ρ)
$R_s = \rho / t$	Ω/sq	Sheet resistance (R_s) as a function of slice resistance (ρ) and sample thickness in cm
$R_s = C * (V/I)$	Ω/sq	Sheet resistance (R_s) with a correction factor C derived from chart 1
l	cm	Length of a rectangular sample, in cm
w	cm	Width of a rectangular sample, in cm
1 mil = 0.00254 cm	mil / cm	Conversion factor between mil and cm measurement units

Referenced Works

Thickness correction factor for a four point probe on an infinitely large sample horizontally. Data from L. B. Valdes, "Resistivity Measurements on Germanium for Transistors," *Proc*. IRE, **42**,(2),420-427, Feb. 1954 © 1954 IEEE.

ASTM F-84-99 "Standard Test Methods for Resistivity of Semiconductor Materials"

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