International Journal of Scientific & Engineering Research Volume 2, Issue 10, October-2011
ISSN 2229-5518

An Innovative Method of Measuring Semiconductors Resistivity Using Van der Pauw Technique

Amir J. Majid

Abstract— Van der Pauw technique for measuring semiconductors resistivity is adopted to remove contacts and isolation effects on high resistance materials. An innovative digital method is proposed using, analog-to-digital (ADC) and digital-to-analog (DAC) circuits to reduce voltage coefficient, temperature coefficient and geometrical errors. With the aid of an N-bit timer and N-bit ADC and DAC, a set of 2^N values of different values of current sources are applied and consequent voltage measurements are used in the calculation of resistivity. Consequently, a more accurate average is obtained with less voltage coefficient and temperature effects. This can be implemented by the use of embedded computers and microcontrollers.

Index Terms— resistivity, measurement, Van der Pauw, semiconductors, contacts, voltage coefficient, microcontrollers

◆

1. INTRODUCTION

Semiconductors have high resistivity in the mega-ohm range and special methods are required to avoid contact and isolation resistances, leakage currents as well as voltage, temperature and bandwidth effects. The four-point method and Van der Pauw techniques are normally used for the resistivity measurement to avoid most of these erroneous effects. A more innovative method is needed, in which not analog measurement, but rather digital arrangement is used with the aid of embedded microcomputers.

1.1 Semiconductor Resistivity

Certain conductor materials, such as silicon, may have high resistivity. Several factors can complicate measuring the resistivity of these materials, including problems in making good contact with the material. Special probes have been designed for making resistivity measurements on semiconductor wafers and bars. These probes typically use a hard metal such as tungsten, which is ground to a sharp point . Contact resistance is a very high in these cases, thus either a four-point probe or four isolated probes should be used. While two contacts supply a constant current, the other two contacts are used to measure the voltage drop across a portion of the sample, as depicted in Fig. 1. The resistivity can be calculated by applying geometrical factors in the computation of sample resistance.

These measurements may seem straightforward, but certain precaution should be observed, such as good shielding of the contacts and electrical leads is in order to avoid any diode action pickups.

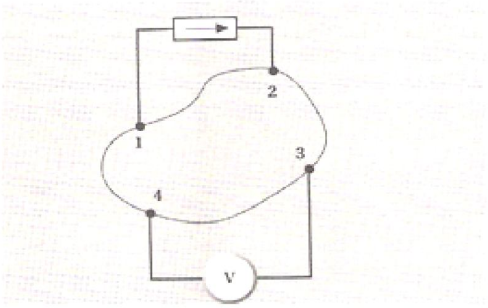


Fig. 1. Basic resistivity measurement of an arbitrary sample, in which current is sourced through two contacts, and voltage is measured across the other two contacts.

1.2 Four-Point Resistivity Method

Amir J. Majid, College of Engineering, Ajman University of Science & Technology, Fujairah, UAE.

The four-point collinear probe resistivity measurement technique, [1], [2], [3], [4] involves bringing four equally spaced probes in contact with the material of unknown resistance, such as a semiconductor wafer. The probe array is placed in the center of the material as shown in Fig. 2. A known current source is passed through the two outside probes and the voltage is sensed at the two inside probes. The resistivity ρ is then calculated as:

(1)

where: V = the measured voltage (volts)
I = the source current (amps)
t = the wafer thickness (cm)
k = a correction factor depending on the ratio of the probe to wafer diameter and on the ration of wafer thickness to probe separation.

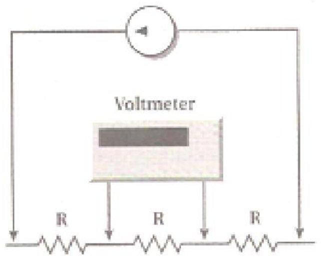


Fig. 2. The four-point resistivity measurement eliminates the effect of probe resistances.

1.3 Van der Pauw Technique

This technique [5], [6], [7], utilizes a constant current method, and is particularly useful for measuring very small samples because the dimensions of the sample and the spacing of the contacts are unimportant. This technique uses four isolated contacts on the boundary of a flat, arbitrary shaped sample. A total of eight measurements are made around the sample, as illustrated in Fig. 3

Two values of resistivity, ρ_A and ρ_B, are then computed as follows [7]:

– (2a)

– (2b)

where: ρ_A and ρ_B are the resistivity in ohm-cm
t_s is the sample thickness in cm
V_1-V_8 represents the voltage measurements by the voltmeter
I is the current through the sample in amperes,
f_A and f_B are geometrical factors based on sample symmetry, and are related to the two resistance ratios Q_A and Q_B as shown in the following equations:

(3a)

(3b)

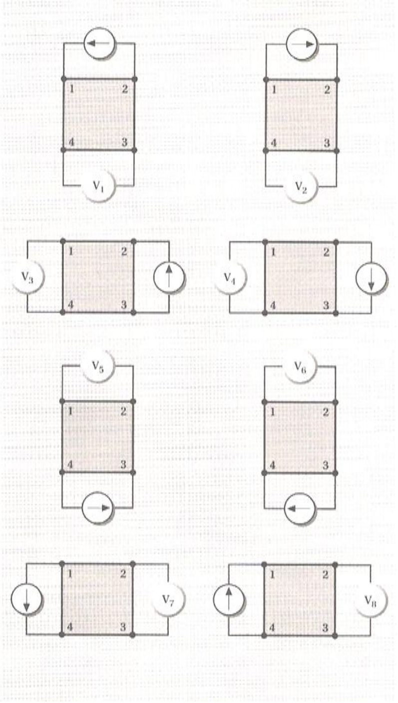


Fig. 3. Van der Pauw technique, in which eight different measurements are conducted.

Q and f are related as follows:

(4)

It is noted that f_A and f_B =1 for perfect symmetry. It is assumed that if ρ_A and ρ_B are not within 10% of one another, the sample is not sufficiently uniform to determine resistivity accurately. Finally, the average of ρ_A and ρ_B is used.

1.4 Practical Measurement Considerations

The current source is not completely isolated from earth ground, so as the sample resistance increases, it becomes increasingly necessary to use a differential electrometer. The problem exists because the sample may have a very high resistance of 100 MΩ or higher, which is of the same order of magnitude as the isolation of the electrometer voltmeter. Considering the current flow in Fig. 4, the voltage drop will cause erroneous result. Thus, a differential electrometer eliminates this problem, as shown in Figure 4. The voltmeter will then read the difference between the two buffer outputs. The unity gain buffers have very high input resistances, so little common-mode current will flow improving the calculations. To avoid leakage current, either isolated or guarded probes are used to make contact with the sample. The current source should be in the guarded mode.

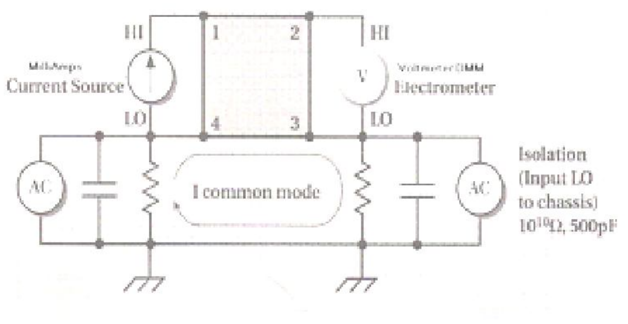


Fig. 4. Practical setup used for sample resistivity measurement, to reduce leakage current..

2 EFFECTS IN VAN DER PAUW TECHNIQUE

2.1 Voltage Coefficients

Very high ohmic value resistors may exhibit a significant change in resistance with a change in applied voltage. This effect is known as the voltage coefficient. The voltage coefficient is the percent change in resistance per unit change in applied voltage and is defined as :

Voltage Coefficient

(5)

Alternately, the voltage coefficient may be expressed in ppm as follows:

Voltage Coefficient

(6)

where: R_1 = resistance calculated with first applied voltage (V_1)
R_2 = resistance calculated with second applied voltage ($V2$), with $V2 > V1$

A typical voltage coefficient for a 10GΩ can be about -0.008% / V or -80ppm / V. Thus, if a high resistance is required in a measurement circuit, the error analysis must account for the error due to the voltage coefficient of the resistor, in addition to all other time and temperature error factors. To minimize noise and leakage resistance, the resistor should be placed in a shielded, guarded test fixture.

2.2 Bandwidth Effect

It's known that source resistors impose Johnson noise in the form of voltage and current noised embedded in source currents and voltages. These noises depend on resistor values as well as temperature and bandwidth. Since Johnson noise is uniformly distributed over a wide frequency range, reducing the noise bandwidth effectively decreases the noise in the measurement. In high-resistance circuits, the noise bandwidth is often limited by the time constant of the source resistance and input capacitance. In this case, noise bandwidth can be approximated using a simple first order system with one dominate time constant:

(7)

Where R_{in} is the source resistance in parallel with the input resistance of the measuring device, and C_{in} is the sum of all capacitances shunting the input to the instrument, as well as cable capacitance.

2.3 Geometrical and Shapes Consideration

Resistivity is determined by measuring resistance, then converting to surface or volume resistivity [8], [9], by taking geometrical considerations into account. Here, we need to differentiate between volume and surface resistivity. Volume resistivity is a measure of the leakage current directly through a material, having a certain thickness and geometry, as depicted in the following Fig. 5

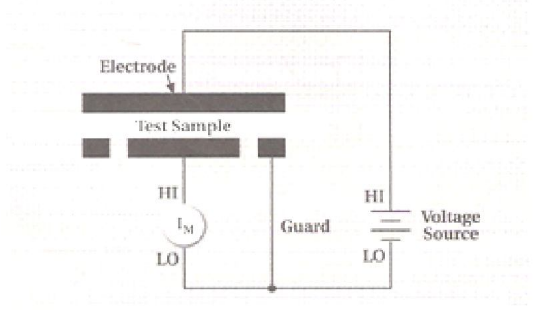


Fig. 5. Sample volume resistivity measurement

Volume or bulk sample resistivity is defined as:

— (8)

where ρ = volume resistivity in ohm-cm
K_V = test cell constant for volume resistivity based on cell geometry in cm^2

t = sample thickness in cm

Surface resistivity on the other hand, is expressed in ohm or ohm per square. Fig. 6 depicts the measurement arrangement for surface resistivity measurement

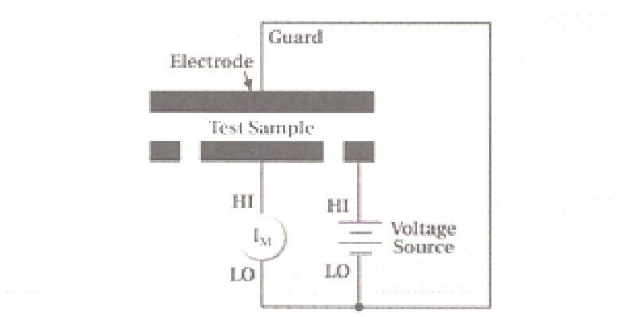


Fig. 6. Surface resistivity measurement set-up.

The surface resistivity is calculated as

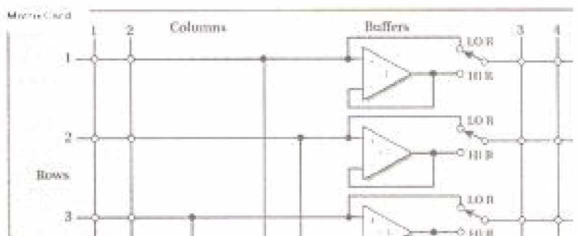
(9)

Where K_S = test cell constant for surface resistivity based on cell geometry.

3. PRACTICAL IMPLEMENTATION OF VAN DER PAUW TECHNIQUE

Van der Pauw technique is used on samples that are flat, homogenous in thickness and arbitrary shaped, and that do not contain any isolated holes as show in Fig. 7, where small contacts are placed on the periphery of the sample.

A total of eight measurements are made around the sample. These readings are combined mathematically to determine the average resistivity of the sample, according to the following formulae:



3.1 Switching Circuit

Fig. 8 shows a system that can be used to determine the resistivity of conductors using the Van der Pauw technique. It includes a source current to supply the current through the sample, as well as a voltmeter for measuring resulting voltage drops. A switching matrix is used to switch the voltmeter and current source among the four sample terminals. Connection to the sample is made with un-tinned copper wire to minimize thermoelectric EMF's.

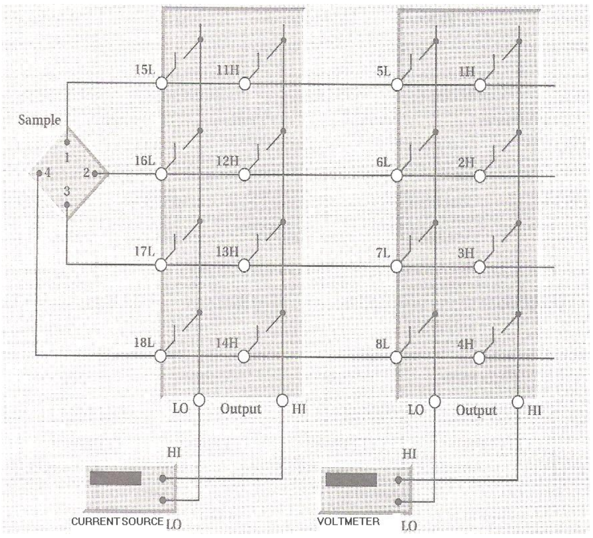


Fig. 8. Switching circuit used to switch source currents and consequent voltage drop measurements.

For example, to source current between terminals 3 and 4, channels 7L and 4H are closed, then the voltage drop between terminals 1 and 2, are measured by closing channels 15L and 12H.

3.2 Digital Measurement

So far, analog current source is used in the Van der Pauw technique for sample resistivity measurement. The measured voltage drop is measured with an analog voltmeter. In this arrangement, only one value of current source and measured voltage drop is used. Alternatively, a set of current source values can be used over a large range of digital *binary* values, in order to reduce the effect of voltage coefficient errors as well to obtain a better average value. This digital range is formed from digital devices and circuits such as timers, decoders and multiplexers. With this arrangement, Fig. 8 can be reduced to a simpler and more efficient tool to be used in the measurement, with no need for the switching mechanism. Bandwidth, time rise and Johnson noise effects in (7) are eliminated.

4. DIGITAL VAN DER PAUW TECHNIQUE

An innovative method in utilizing Van der Pauw technique is proposed here to reduce erroneous effects of voltage and temperature coefficients, as well as bandwidth, time rise and noise effects. This is accomplished by the recent extensive usage of embedded microprocessors and microcontrollers.

4.1 ADC and DAC

In order to implement the digital form of Van der Pauw technique, analog-to-digital converter (ADC) and digital-to-analog converter (DAC), [10], [11], [12], are used. The analog value is calibrated and referenced with a N-bits DAC. Thus, 2^N values of source current can be inputted ranging from binary 0 to N-bits 1. These values can be initiated with an N-bit timer (oscillator) and DAC and ADC devices, as depicted in Fig. 9. The analog output voltage drop can in the same way be measured with an N-bit ADC, and thus 2^N sets of calculations are conducted digitally.

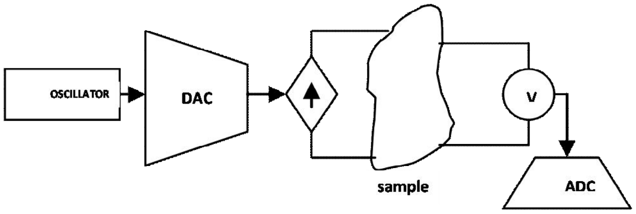


Fig. 9. Digital Van der Pauw method in which digital current s values are converted to analog before applying on sample.

As an example, an 8-bit timer and DAC, is used to generate a range of 256 binary values ranging from hexadecimal *00H* to *FFH*, which are calibrated to generate a referenced analog input current source, needed for the measurement. This range can be sequentially generated for repeated measurements and computations. Thus different referenced values of source currents are used to reduce the erroneous effects of voltage coefficients, temperature and bandwidth. It is also assumed that a better average is obtained.

The measured voltage drops can further be converted to digital with an 8-bit ADC, for ease of measurement and accurate computations.

4.2 Microcontroller and embedded microprocessors

Due to the vast usage of embedded microprocessors, the same ADC and DAC arrangement can be carried out using a microcontroller, [13], with output ports configured to source currents and input ports to measure voltage drops. The microcontroller can be programmed to do all calculations required in the Van der Pauw technique as depicted in Fig. 10.

An example of using microcontrollers, is illustrated with one port (A) is used to output and source current to the sample. A build-in DAC converts 256 digital values of referenced current to analog values, as shown in Fig. 10. The measured referenced analog voltage is feedback to a second port (B) after being converted to a digital value with an ADC. A program written in Basic, C, C++ or Assembly will compute the resistivity according to Van der Pauw technique. It is noted that the same port can be used for outputting and inputting values by configuring the ports in the source program.

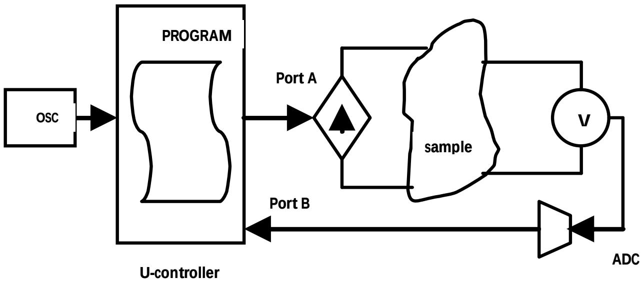


Fig. 10. Embedded microcomputer or microcomputer used in the implementation of Van der Pauw technique.

This arrangement is a replica for using micrometers such as Pico-ammeters and Nano-voltmeters It is to be noted that this arrangement is more compact and portable, making it suitable for small and minute samples. The sequence of measurements and computations can be also programmed by the source program, as well as saved by the build-in memory, for further references.

5. CONCLUSION

An innovative method of measuring high resistance materials, such as silicon, is proposed in which a range of digital or binary values of source currents are applied on two contacts of the sample and the voltage drop across other two contacts are measured. This is implemented using either an N-bit DAC/ADC or microcontrollers.

Voltage coefficient errors are eliminated due to averaging many comparable values covering a wide range of voltages, and thus reaching a better averaged value and a near zero standard of deviation. Erroneous computations due to temperature coefficients are also eliminated, due to the relation between voltage drops and temperature coefficients.

Bandwidth, Johnson noise and time rise effects are also reduced, by eliminating the mechanical switching action of currents and voltages in Van der Pauw technique.

REFERENCES

[1] RA. *Witte, Electronic Test Instruments (Analog and Digital Measurements);* PP. 70-72, Prentice Hall, 2nd Edition, 2202
[2] DA. Bell, *Electronic Instrumentation and Measurements*, PP. 163-184, DHI, 2nd Edition, 1997
[3] “Two-point and Four-point Method for Measuring Small Resistances”, http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p025.shtml?from=Home
[4] “Four-technical Sensing”, http://en.wikipedia.org/wiki/Four-terminal-sensing
[5] M.S. Daluz, “The Van der Pauw Method of Measurements in High-TC Superconductors”, Materials Science-Polans, Vol. 27, No. 2, 2009
[6] “Van der Pauw Methos”, http://en.wikipedia.org/wiki/Van_der_Pauw_method
[7] Keithley; *Low Level Measurements*, PP. 4.18-4.49 & 3.16-3.24, Keithley 5th Edition,
[8] M..S. Da Luz, “The Van der Pauw Method of Measurements”, Materials Science – Poland, Vol. 27, No. 2, 2009
[9] P.G. Muzykov, “A Method of Measuring Specific Resistivity and Hall Effects of Discs of Arbitrary Shape”, Journal of Electronic Materials: High resistivity measurement of Sic wafers using different techniques
[10] JJ. Carr, *Elements of Electronic Instrumentation and Measurements*, PP.142-148 & 571-576 & 392-401, Prentice Hall, 3rd Edition, 1996
[11] A. Majid, “MEMS AD/DA Converters”, ICM2006 18th international conference on microelectronics, 16-19 December 2006, KFUPM, Dhahran, KSA
[12] A. Majid, “Electrostatic and Electromagnetic Fields Actuators for MEMS AD/DA Convertors”; Arabian Journal for Science and Engineering, KSA, May 2007.
[13] A. Majid, “Resistivity Measurements of Conductors and Semiconductors of Different Geometrical Shapes Using Van der Pauw Technique”, IJSER, submitted for publication.