RESISTIVITY MEASUREMENT AND CONDUCTIVITY TYPE DETERMINATION FOR SEMICONDUCTING MATERIALS USING A FOUR-POINT PROBE

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1. Introduction

Resistivity and conductivity type, fundamental properties of semiconductors, are critical parameters in both materials research and wafer fabrication. A 4-point collinear probe and the appropriate test equipment can be used to determine both resistivity and conductivity type. Using 4 probes eliminates errors due to the probe resistance, the spreading resistance under each probe, and the contact resistance between probe and the semiconductor material.

2. The four-point collinear probe method for measuring resistivity (Fig. 1a)

The two outer probes source current, while the two inner probes sense the resulting voltage drop across the sample. The volume resistivity is calculated: $\rho = \frac{\pi}{ln2} \times \frac{V}{I} \times t \times k$ where: ρ = volume resistivity (Ω/cm), V = the measured voltage (V), I = the source current (A), t = the sample thickness (cm), k = a correction factor based on the ratio of the probe spacing to wafer diameter and on the ratio of wafer thickness to probe spacing [1].

3. Measuring high resistance semiconductor materials (Fig. 1b)

Measuring the resistivity of high resistance samples often requires using four isolated probes and the van der Pauw measurement technique. However, if the four-point probe head has very good isolation between the probes, then these measurements may be achievable. This measurement also requires sourcing current with high output impedance and making differential voltage measurements [1]. The system for high resistance measurement includes two electrometers (Model Keithley 6514s), a differential nanovoltmeter (Model 2182A) and a current source (Model Keithley 6221) [2]. In this circuit, the electrometers are used as unity-gain buffers.

4. Determining conductivity type by thermoelectric voltage method (Fig. 1c)

With this method, an AC current flows between probes 1 and 2 and causes joule heating. The Seebeck voltage is generated between probes 3 and 4 by the diffusion of thermally generated carriers from the hot region of the material to the cold region. This diffusion creates a non-equilibrium carrier concentration in the cold region, which generates an electric field, opposing further diffusion. This diffusion of carriers from the hot probe to the cold probe continues until the generated electric field is sufficient to overcome the tendency of the carriers to diffuse. For example, in p-type material, the thermally generated holes diffuse to the cold probe, building up a positive space charge, which prevents further diffusion. As a result, the cold probe is more positive than the hot probe [1].

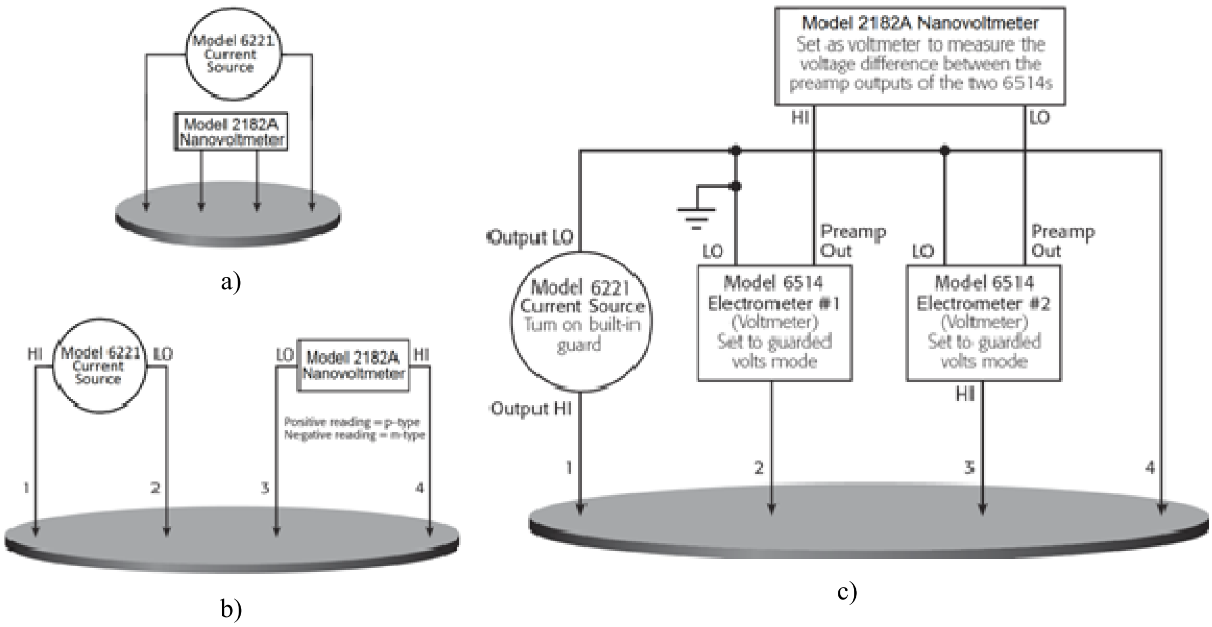

Fig.1: *Four-point collinear probe method for measuring* [1, 2]*:*
a) low resistivity, b) high resistivity, c) conductivity type

5. Complete measuring system

We have integrated all this methods to one complete measuring system controlled via universal designed software (Fig. 2). The mechanical part is based on four-point holder with collinear or quadratic probe. The probe spacing are 1,06 and 1,57 mm for linear and 0,7 mm for quadratic probes. With this system we can reliably measure parameters of samples in formats from 5x5 to 100x100 mm. Because the probe spacing is very low, we are able to measure large samples relatively close to edges as well as the homogeneity of the sheet resistivity through the area of whole sample. The software was designed in Agilent VEE version 9.2 [3] to measure materials of low and high resistivity. This program includes also the subprograms for calculating of correction factors for different sample configurations.. To increase final accuracy of the measurement we always averaged couple of results from positive and negative current flow. Since the joule heating is different for each type of measured materials, our method is designed to maximize the heating power as a first step of determining the conductivity type. The input current grows logarithmically from minimal (1 nA) to maximal floating current (the maximal current value can be read from status buffer of current source 6221) which is held for 30 seconds. Finally, the Seebeck voltage is read out after 3 seconds delay at zero current and the type of conductivity is determined. For further direction of our research also the time dependences of Seebeck voltage are collected for estimation of the thermal conductivity coefficients. For software optimization we have measured cooling rate after joule heating using thermometric system FLIR [4]. For instance in case of Si substrates (ρ = 1,5 Ω/cm) we found the maximal temperature about 51 °C and temperature gradient between hot (3) and cold probe (4) in range 0,1 – 0,15 °C (Fig. 3).

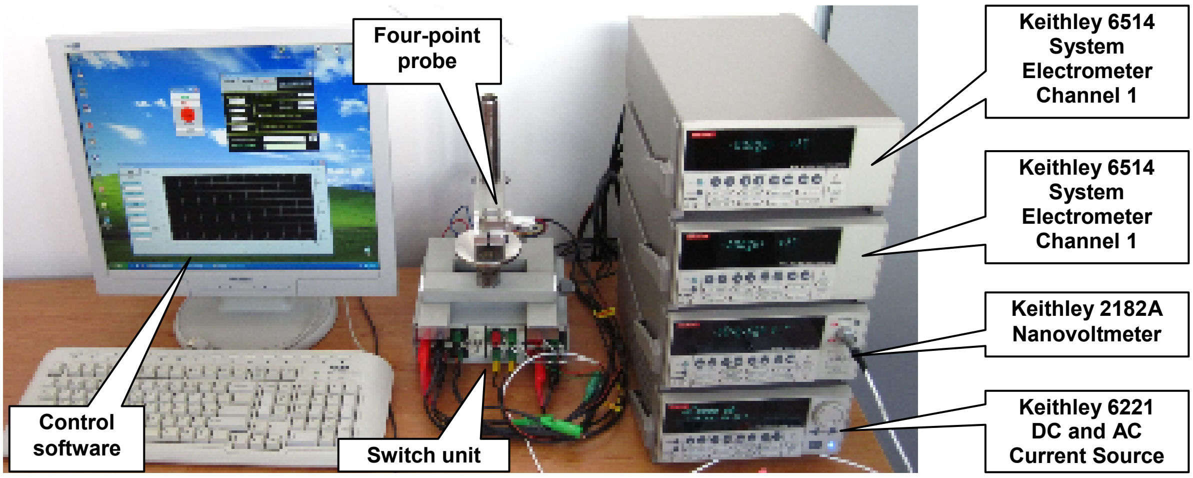

Fig.2: *Complete measuring system*

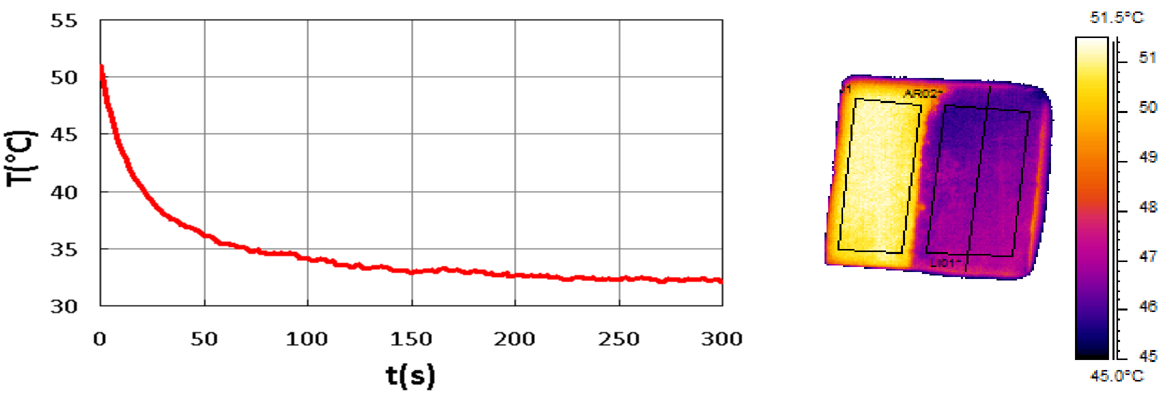

Fig.3: *Thermometric measurements: left) time dependence, right) temperature gradient*

In Tab. 1 you can see some experimental results measured with our complex measurements system.

Tab. 1: *Experimental results*

Sample	Compliance (V)	I_{max} (mA)	U_{seeb} (mV)	ρ (Ω/cm)	Type
Si - P1	100	39,81	2,491	31,18	P-typ
Si - P2	100	39,81	2,398	28,26	P-typ
Si - P3	100	39,81	2,356	30,61	P-typ
Si - P4	100	25,12	1,173	34,17	P-typ
Si - P5	100	19,95	0,938	34,27	P-typ
Si - N1	100	25,12	-2,398	15,19	N-typ
Si - N2	100	25,12	-2,468	10,28	N-typ
Si - N3	100	25,12	-2,26	15,49	N-typ
Si - N4	100	39,81	-4,395	13,54	N-typ
Si - N5	100	31,62	-3,134	13,44	N-typ
ZnO:Al 17	100	100	-0,022	0,035	N-typ
ZnO:Al 52	100	79,43	-0,016	0,048	N-typ
ZnO:N	100	0,316	0,126	4,96	P-typ
ZnO:Sc 01/17/100	100	2,512	-0,441	0,77	N-typ
ZnO:Sc 01/17/140	100	19,95	-0,014	0,17	N-typ

6. Conclusion

We built and programmed complex 4-point probe system for semiconductor materials testing. Resistivity measurements were plenty time tested and they approve good reliability in both, high and low resistivity measurements. Determination of conductivity is still in evolution, we want to expand the final system with quick temperature conductivity screening.

Acknowledgement

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References:

[1] Keithley Instruments, Inc., Measuring the Resistivity and Determining the Conductivity Type of Semiconductor Materials Using a Four-Point Collinear Probe and the Model 6221 DC and AC Current Source, Cleveland, USA, (2005).

[2] Keithley, Inc., Operation manuals, http://www.keithley.com/, (2006).

[3] Agilent Technologies, Inc., Agilent VEE Pro 9.2, www.agilent.com, (2010).

[4] Flir Systems, Inc., Thermacam PM 595 – High Performance Handheld Infrared Camera, http://www.flir.com, Boston, USA, (1999).