

SEMI M87-0422

TEST METHOD FOR CONTACTLESS RESISTIVITY MEASUREMENT OF SEMI-INSULATING SEMICONDUCTORS

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1 Purpose

1.1 The purpose of this Test Method is to specify methods for the contactless measurement of the resistivity of semi-insulating samples and wafers.

2 Scope

2.1 This Test Method covers the determination of the electrical resistivity of semi-insulating semiconductors, including GaAs, InP, CdTe, Cd(Zn)Te, SiC, GaN, and AlN, within the resistivity range $1\text{E}5$ to $1\text{E}12\ \Omega\cdot\text{cm}$. It may also be used to characterize other materials exhibiting resistivity in this range, including in particular high resistivity silicon.

2.2 The procedures described in this Standard measure the time constant τ of a network consisting of the resistive sample and the series capacitance of the sample and the capacitive sensor. Alternatively, a plate sensor (PS) (refer to § 6.2) or ring sensor (RS) (refer to § 6.3) may be used. The evaluation is based on the observation of the time-dependent charge transfer after application of a voltage step (time domain [TD] evaluation described in Appendix 1) or on measuring the frequency response of the network (frequency domain [FD] evaluation described in Appendix 2).

2.3 Commercially available measurement system configurations offer the PS combined with TD evaluation and the RS combined with FD and TD evaluation. Topographic evaluation of the sample area is available as well as temperature dependent resistivity measurement to evaluate the activation energy ΔE , needed to normalize measured data to a reference temperature (refer to § 9).

2.4 This Test Method follows the roadmap laid out by SEMI M54 (GaAs) and SEMI M55 (SiC), identifying resistivity as an essential material parameter.

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3 Referenced Standards and Documents

3.1 SEMI Standards and Safety Guidelines

SEMI M54 — Guide for Semi-Insulating (SI) GaAs Material Parameters

SEMI M55 — Specification for Polished Monocrystalline Silicon Carbide Wafers

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology

4.1 Definitions of Equations

4.1.1 $\rho [\Omega \cdot \text{cm}]$ — resistivity of the resistive material under test.

4.1.2 $R_s [\Omega]$ — resistance of a defined, but not mechanically separated portion of the sample under test.

4.1.3 $R [\Omega] = \rho L / A$ — resistance of a specimen of resistive material, where $L [\text{cm}]$ is the length along the current direction and $A [\text{cm}^2]$ the cross section perpendicular to the current direction.

4.1.4 $C_a, C_s [\text{pF}]$ — capacitances of the air gap and of the evaluated portion of sample below the top electrode of the sensor Figure 1 and above the bottom electrode of the sensor Figure 2, respectively.

4.2 ν and $\omega = 2\pi \nu [\text{s}^{-1}]$ — frequency and circular frequency of the voltage applied to the sensor.

4.3 $\epsilon_0 [(Cb/V \times \text{cm})]$ — dielectric constant of vacuum.

4.3.1 $\omega_0 = (R_s C_s)^{-1} [\text{s}^{-1}]$ — characteristic frequency.

4.3.2 $\tau_s = (\omega_0)^{-1} [\text{s}]$ — relaxation time constant.

4.3.3 $\tau = RC [\text{s}]$ — time constant, where C is the total capacitance of the analyzed network.

4.3.4 $T_n = 298 \text{ K } (25^\circ\text{C})$ — temperature used for normalization of resistivity data.

4.4 Symbols

4.4.1 $\Delta E [\text{eV}]$ — activation energy at $T = 0 \text{ K}$.

4.4.2 ϵ — relative dielectric constant of the sample material.

4.4.3 $D [\text{cm}]$ — sensor diameter.

4.4.4 $d_s [\text{cm}]$ — sample thickness.

4.4.5 $Q(t) [\text{Cb}]$ — time-dependent charge on the sensor capacitances $C_a, C_s [\text{pF}]$ after application of the voltage step $U [\text{V}]$.

4.4.6 $T_s [\text{K}]$ — sample temperature.

4.4.7 $U [\text{V}]$ — voltage of the step applied to the sensor.

5 Physical Background

5.1 Conventionally the resistivity ρ is obtained using Ohm's law:

$$V = I R \quad (1)$$

The voltage (V) is applied to an electrically contacted specimen with known dimensions length (L) and cross section (A) and the resulting current (I) along L is measured to yield:

$$\rho = (VA) / (IL) \quad (2)$$

5.2 The noncontacting capacitive methods used in this Standard are based on the property that a network composed of a resistance R_s and a capacitance C_s exhibits a relaxation time constant:

$$\tau_s = R_s C_s \quad (3)$$

or, equivalently, a characteristic circular frequency:

$$\omega_0 = 2\pi \nu_0 = (R_s C_s)^{-1} \quad (4)$$

5.3 Specifically, as described below, the relaxation time constant or characteristic frequency of a network composed of a resistance and two capacitances connected in series is measured.

5.4 Commercial systems for contactless evaluation of resistivity are either based on the evaluation of a time constant (refer to Appendix 1, Method TD) or a characteristic frequency (refer to Appendix 2, Method FD).

6 Sensors

6.1 The network to be analyzed is physically realized by the sample and sensor arrangement. Depending on practical considerations either a PS containing a plate capacitor (refer to Figure 1) or a RS containing a ring capacitor (refer to Figure 2) is used.

NOTE 1: Throughout this Standard plate capacitor refers to 'parallel plate capacitor'.

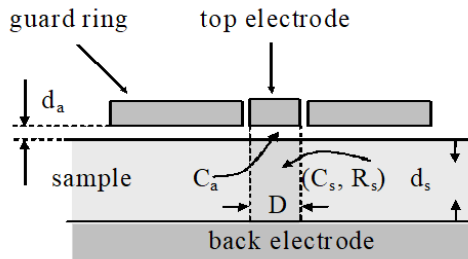


Figure 1
PS Containing a Plate Capacitor

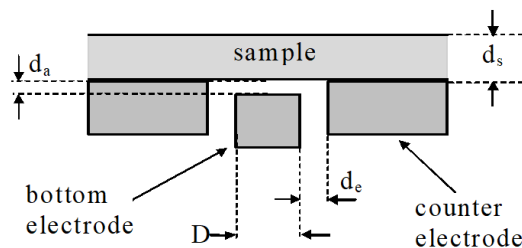


Figure 2
RS Containing a Ring Capacitor

6.2 The PS comprises a top electrode with typically $D = 0.1$ cm diameter and an extended back electrode used to place the sample between these electrodes. An annular guard ring around the top electrode ensures that the electrical field generated by applying a voltage between the electrodes is vertical. The sensor is positioned such that a small air gap d_a (typically $50\ \mu\text{m}$) is obtained between the top electrode and the top surface of the sample. The cylindrical portion of the sample with diameter D underneath the top electrode is analyzed exclusively, because only the charge $Q(t)$ below the top electrode is measured.

6.3 The RS consists of a circular bottom electrode, typically with a diameter $D = 0.6 - 1$ cm, surrounded by a holed counter-electrode, which is formed as an extended plate to deposit the sample. The bottom electrode, centered in the hole of the counter-electrode, defines an annular gap of width d_e . The bottom electrode is recessed with respect to the counter-electrode such that an air gap d_a between the bottom electrode and the bottom sample surface is generated. The circular portion of the sample subject to the electric field above the bottom electrode, with a diameter of about $1.5 D$, is analyzed.

6.4 The network generated by the arrangements described in ¶¶ 6.2 and 6.3, Figures 1 and 2, is shown in Figure 3. Here R_s is the resistance of the sample portion wherein the electric field stimulates the current discharging the dielectric sample capacitance C_s . C_a is the capacitance associated with the air gap. The network analysis by methods TD (refer to Figure 3 [A]) and FD (refer to Figure 3 [B]) is illustrated. A voltage step generator (SG), charge amplifier (CA), floating signal generator (FSG) and signal conditioning circuit (SCC) are required. For details, refer to Appendices 1 and 2.

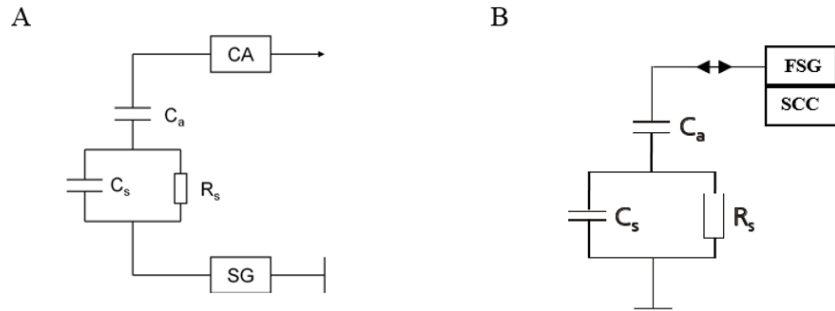


Figure 3
Equivalent Circuit (Network) of the PS and RS Sensors, Analyzed by Methods TD (A) and FD (B)

7 Sample Properties

7.1 The sample requirements are different for the two sensors.

7.2 For analysis with the PS (refer to Figure 1 and ¶ 6.2) the sample must be a slab with a thickness d_s between 0.02 and 0.5 cm (200 to 5000 μm). The sample thickness variation must not exceed 2% across the measurement area D. For automated topographic evaluation of the entire sample area the overall thickness variation must not exceed 100 μm .

7.2.1 The sample must be large enough to cover a circle with diameter 2D. Its maximum lateral size is limited by the dimensions of the tool, usually designed to accommodate wafers up to a specified maximum diameter.

7.2.2 The surface of the sample can be as-sawn, but preferably should be lapped or polished. Due to the vertical orientation of the electric field and the resulting vertical direction of the discharging current, spurious surface conductivity resulting from surface contamination is not critical.

7.3 For use with the RS (refer to Figure 2 and ¶ 6.3), the sample may have arbitrary shape but must have one flat surface covering a circle with diameter 2D, to be placed on top of the RS. Surface contamination resulting in surface conductance may be critical.

8 Anisotropy of Resistivity

8.1 Because the current in the sample is flowing in the directions of the electric field distribution generated by the sensors PS or RS (refer to Figures 1 and 2), the resistivity is measured along these directions. This constraint is inconsequential for crystals with isotropic resistivity such as GaAs or InP. However, hexagonal crystals such as SiC exhibit significant resistivity anisotropy, whence resistivity in this case is described by a second order tensor.

8.2 The electric field direction of the PS (refer to Figure 1) is vertical (perpendicular to the sample surface), whereas the RS (refer to Figure 2) generates a field with components both parallel and perpendicular to the sample surface. The measured resistivity values, therefore, differ according to the resistivity anisotropy of the material.

NOTE 2: For instance, in 6H SiC $\rho [\parallel c] / \rho [\perp c] \approx 4.8$; in 4H SiC $\rho [\parallel c] / \rho [\perp c] \approx 0.8$.

9 Recommended Measurement Procedures

9.1 Commercial tools using TD evaluation are presently available with PS and RS. The system using the PS is designed to generate full wafer resistivity topograms. FD evaluation is offered in combination with RS. Taking into account the respective resistivity measurement ranges (refer to Appendices 1 and 2) and eventual resistivity anisotropy (refer to § 8), FD evaluation is recommended for isotropic material with resistivity up to $1\text{E}9 \Omega \cdot \text{cm}$ (typically GaAs, InP and CdTe), whereas TD evaluation is generally applicable, including in particular high resistivity SiC. For anisotropic material the PS and platelets with their normal parallel to the c-axis are required to obtain $\rho [\parallel c]$.

9.2 Detailed instructions how to initiate, execute and evaluate the computer-controlled measurement is provided by the commercial tools, such that operator action is confined to manually placing and removing the sample, inserting sample identification and measurement definition data, and to starting the automated measurement procedure. As mentioned, no sample preparation other than careful cleaning of the sample surface (in particular dust removal) is required.