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Progress in the Contactless Capacitive Characterization of Semi-Insulating Substrates

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Outlay

- **Objective**
- **Basics of COntactless REsistivity MApping**
- **Technical Details** - COREMA – WT
  - COREMA – RM
  - COREMA – VT
- **Measurements** - Resistivity topography
  - Contactless mobility
  - Activation energy
- **Summary**

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Objective

To provide innovative analytic tools for

- absolute
- rapid
- laterally resolved
- nondestructive
- precise
- low cost

Evaluation of the electrical properties of compound semiconductor substrates for

- production control
- material development

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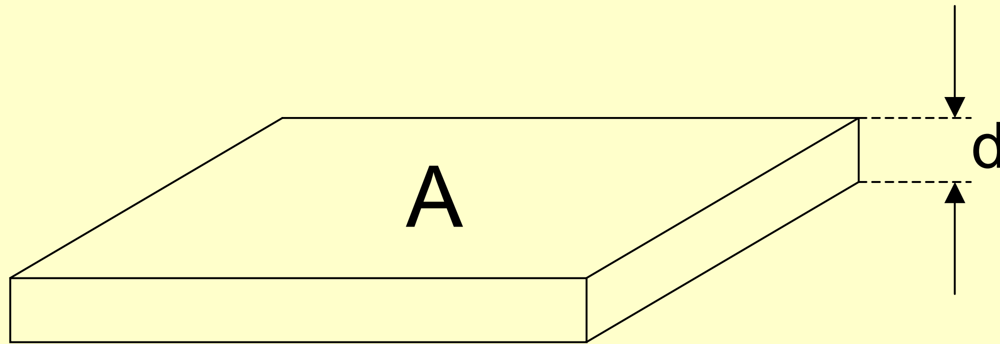
Basics of COntactless REsistivity MApping (I)



Semi-insulating semiconductor

$$R_s = \rho\, d/A$$

$$C_s = \varepsilon\, A/d$$

$$R_s C_s = \rho\, \varepsilon = \tau$$

$$\boxed{\rho = \tau / \varepsilon}$$

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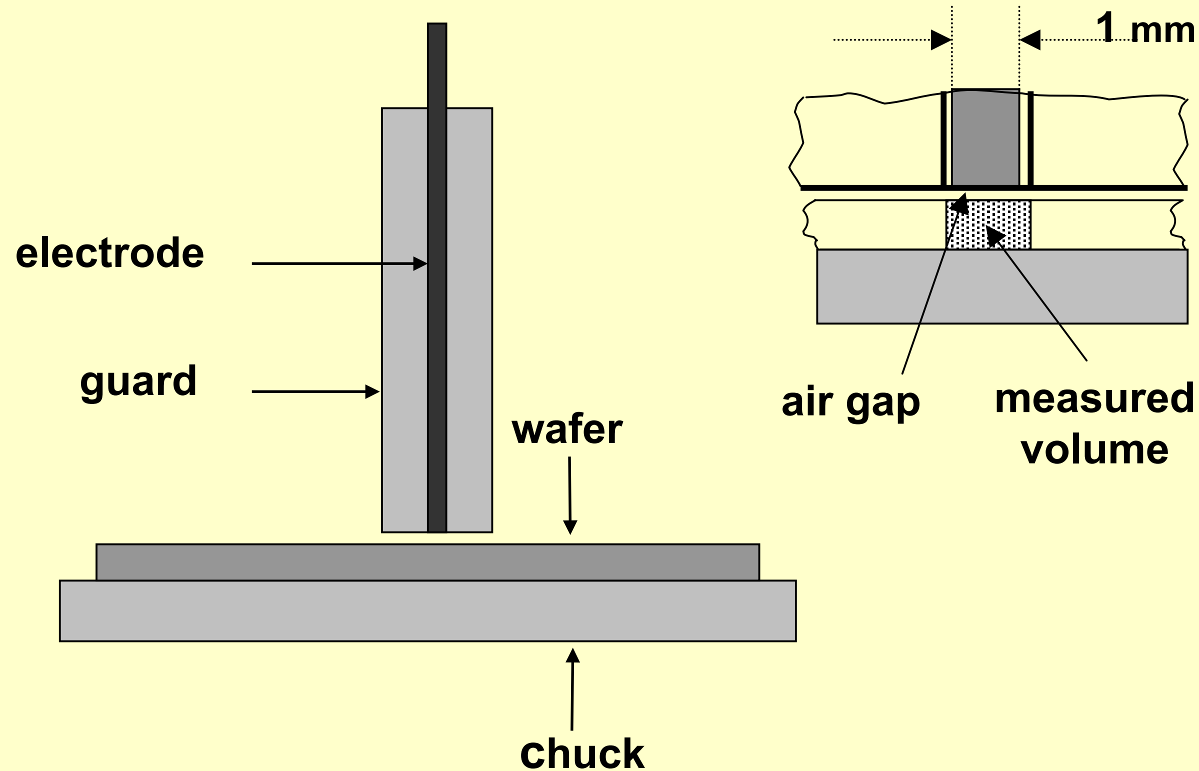
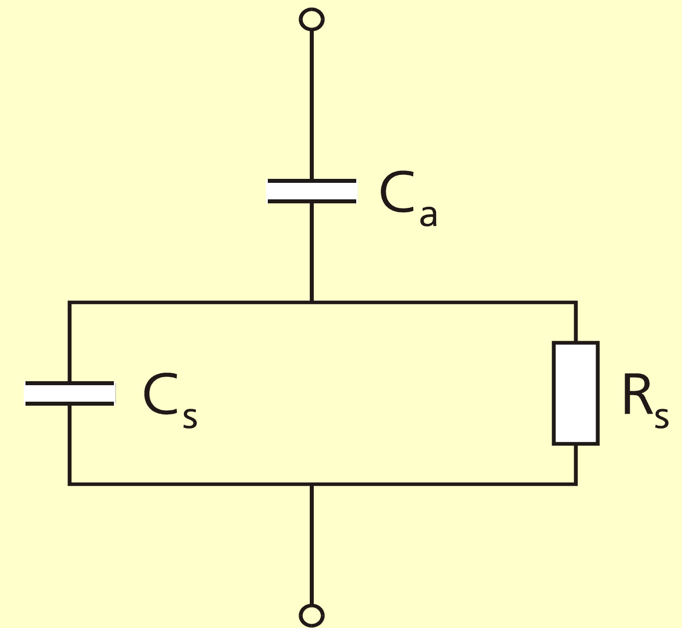
Basics of COntactless REsistivity MApping (II)

Capacitive probe



Equivalent circuit



$$\tau = R_s(C_s + C_a)$$

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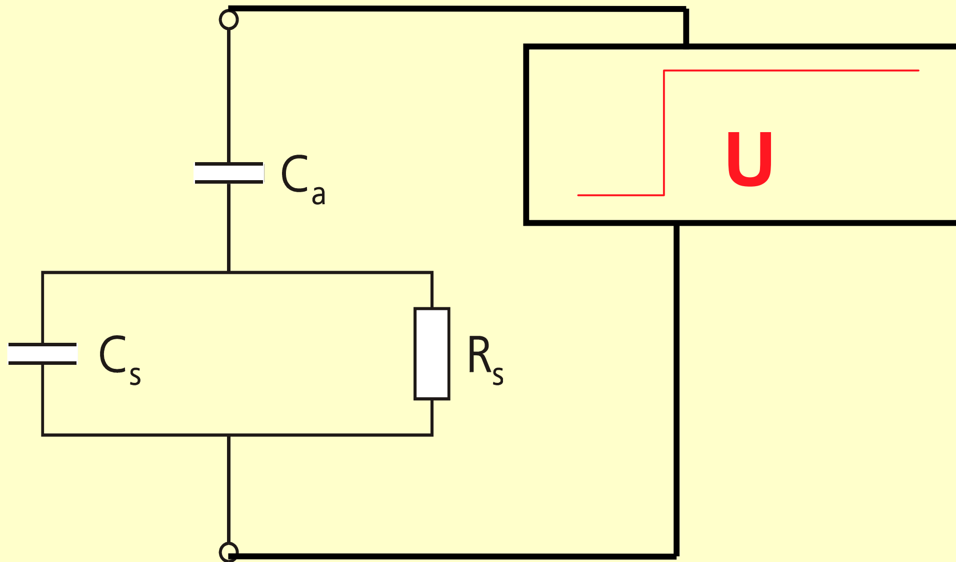
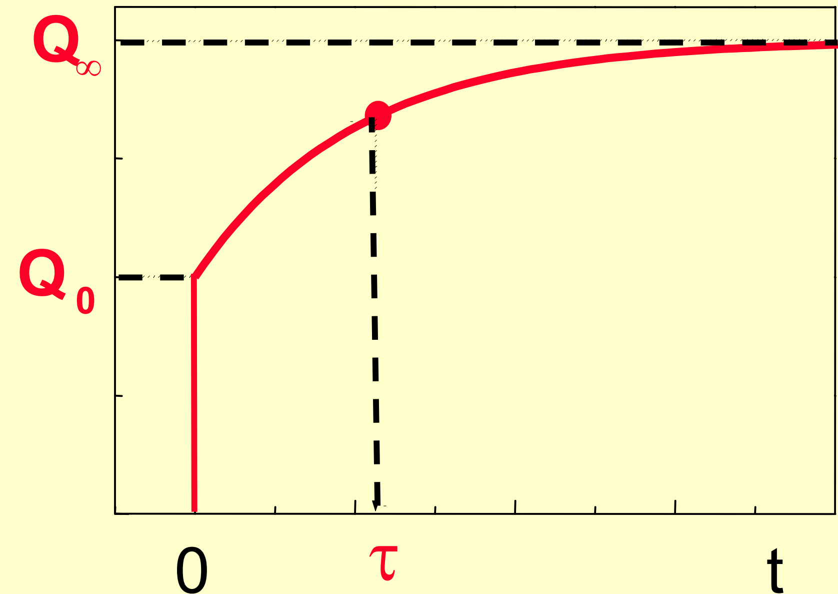
Basics of COntactless REsistivity MApping (III)

Equivalent circuit



$$\tau = R_s(C_s + C_a)$$

Charge transient after voltage step application



$$\rho = Q_0 \, \tau \, (Q_\infty \, \varepsilon \, \varepsilon_0)^{-1}$$

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Basics of COntactless REsistivity MApping (IV)

Evaluation of electrical material properties

Resistivity	$\rho = Q_0 \, \tau \, (Q_\infty \, \varepsilon \, \varepsilon_0)^{-1}$
Mobility	$\mu = 1/B \, [\, \rho(B) \, / \, \rho(0) - 1]^{1/2}$
Activation energy	$E_a = (kT_1T_2)/(T_2 - T_1) * \ln [\rho(T_1) \, / \, \rho(T_2)]$

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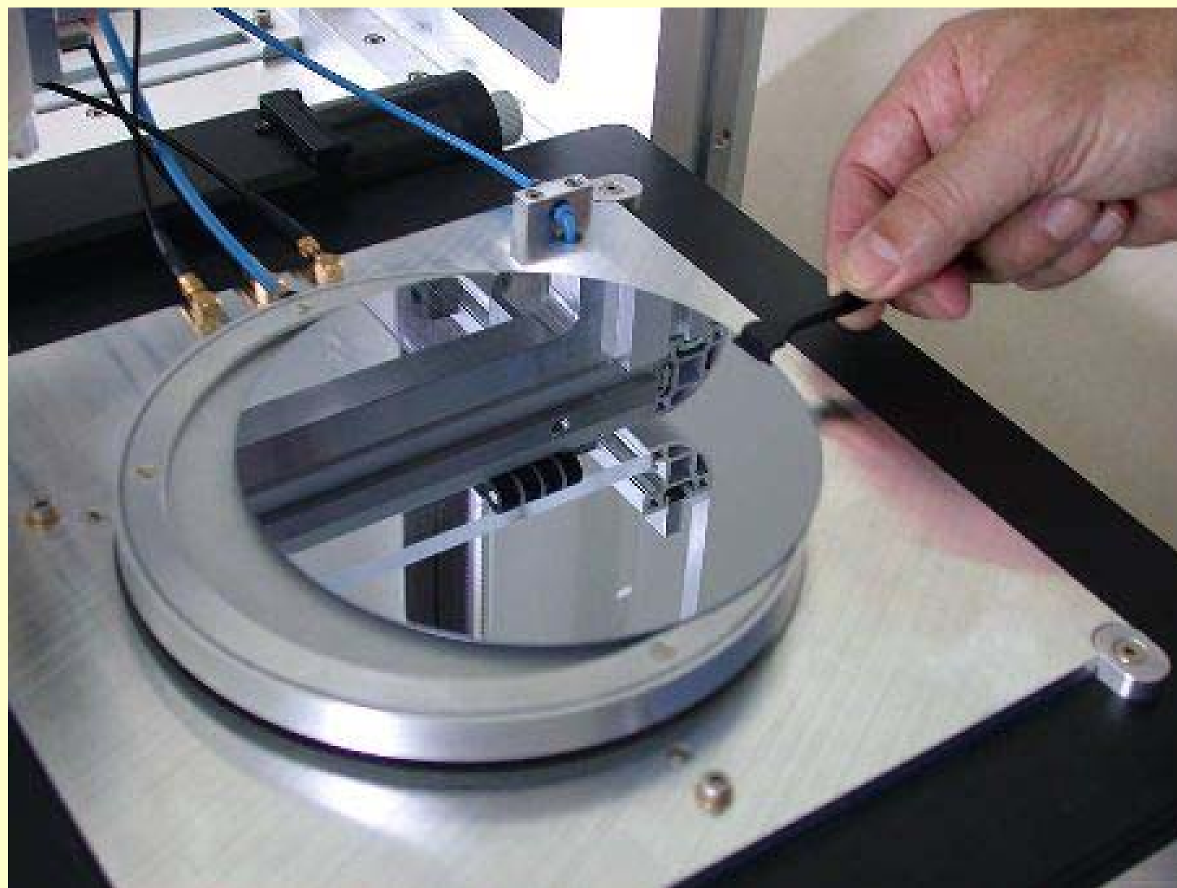
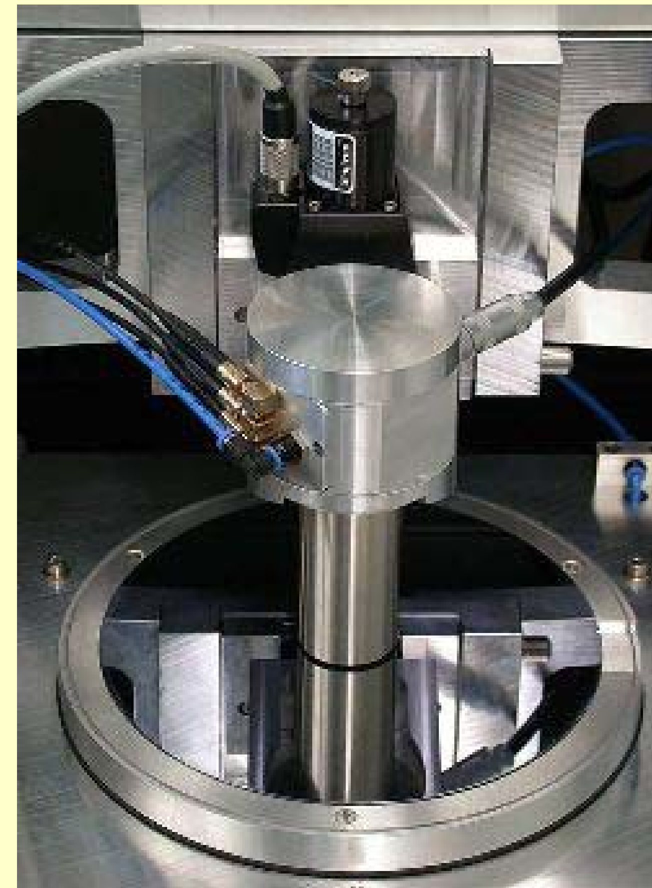
Technical Details (I) CORHEMA - WT

Technical Details (II) COREMA - WT





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Technical Details (III) COREMA - RM

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Technical Details (IV) COREMA - VT

System designed to evaluate resistivity at Variable Temperature

- Temperature range 300 K – 650 K
- Resisitvity range $2 \times 10^{5} – 2 \times 10^{11}$ Ωcm
- High temperature capacitive probe design
- Probe diameter 8 mm
- Sample diameter 10 mm – 100 mm
- Manual loading
- Free choice of measurement position

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Resistivity Topography (I)

GaAs Substrate Production Control

150 mm GaAs wafer

Mean: 3.96x10^{7} Ω cm

Stdv: 4.27 %

Radial variation

Fourfold symmetry

Dislocation network

4.76E7
4.61E7
4.47E7
4.33E7
4.18E7
4.04E7
3.90E7
3.75E7
3.61E7
3.47E7
3.33E7

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Resistivity Topography (II)

SiC Substrate Production Control

2“ SiC Wafer

2.12 x10^{11} - 4.09 x10^{11} Ωcm

Mean: 2.75 x10^{11} Ωcm

Stdv: 14.7%

4.09E11
3.89E11
3.70E11
3.50E11
3.30E11
3.10E11
2.91E11
2.71E11
2.51E11
2.32E11
2.12E11

4.09E+11
3.60E+11
3.10E+11
2.61E+11
2.12E+11

0.0 20.4 40.8 mm

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Resistivity Topography (III)

Exploratory SiC Material Development

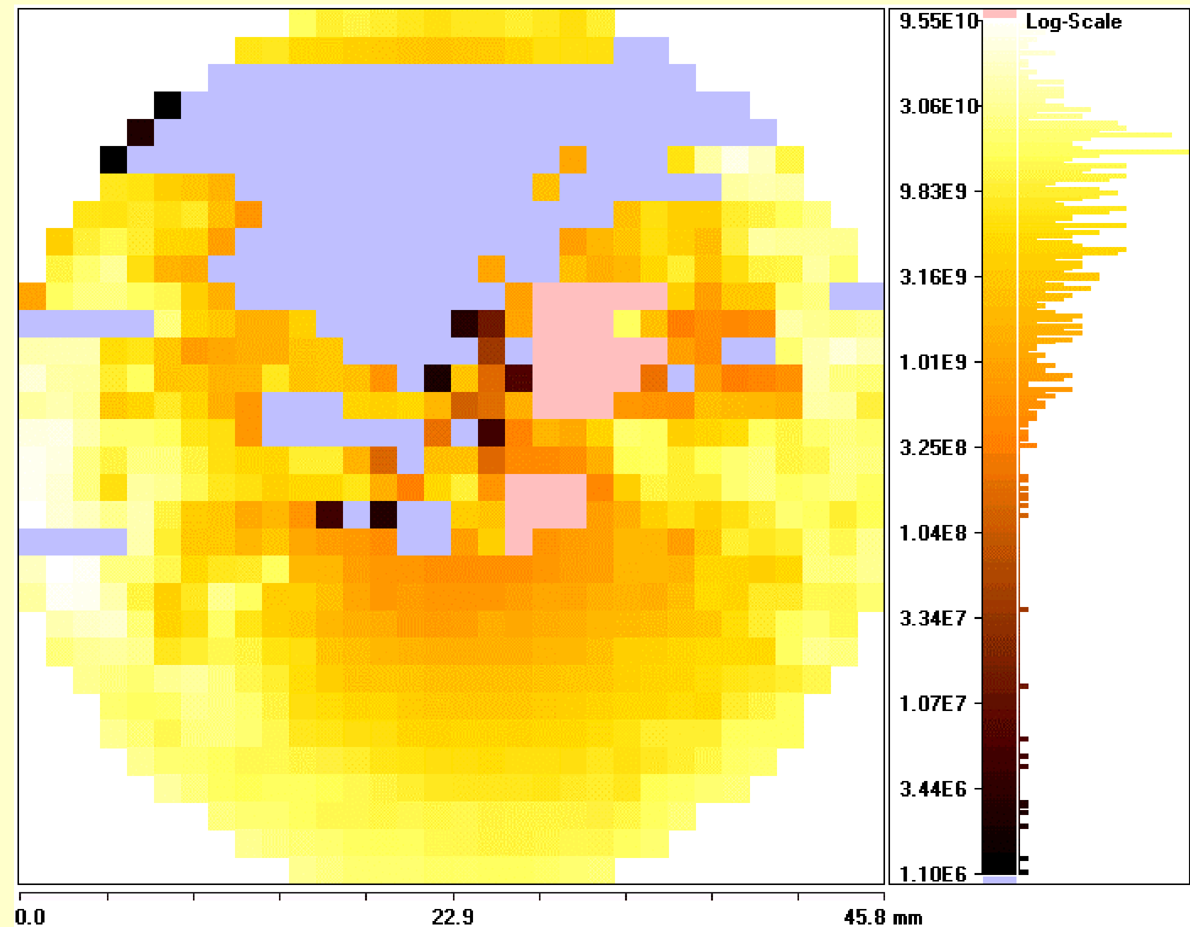
2" SiC wafer

$1.1 \times 10^6 - 1.0 \times 10^{11}$ Ωcm

Blue area below 10^5 Ωcm

Pink area above 10^{12} Ωcm

Rapid order-of-magnitude fluctuations



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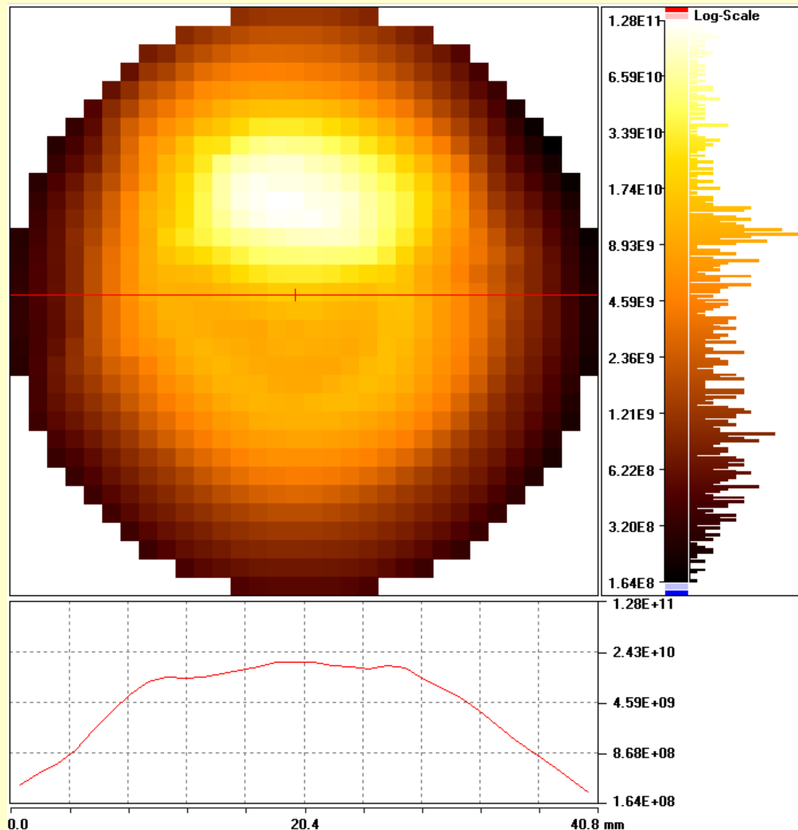
Resistivity Topography (IV)

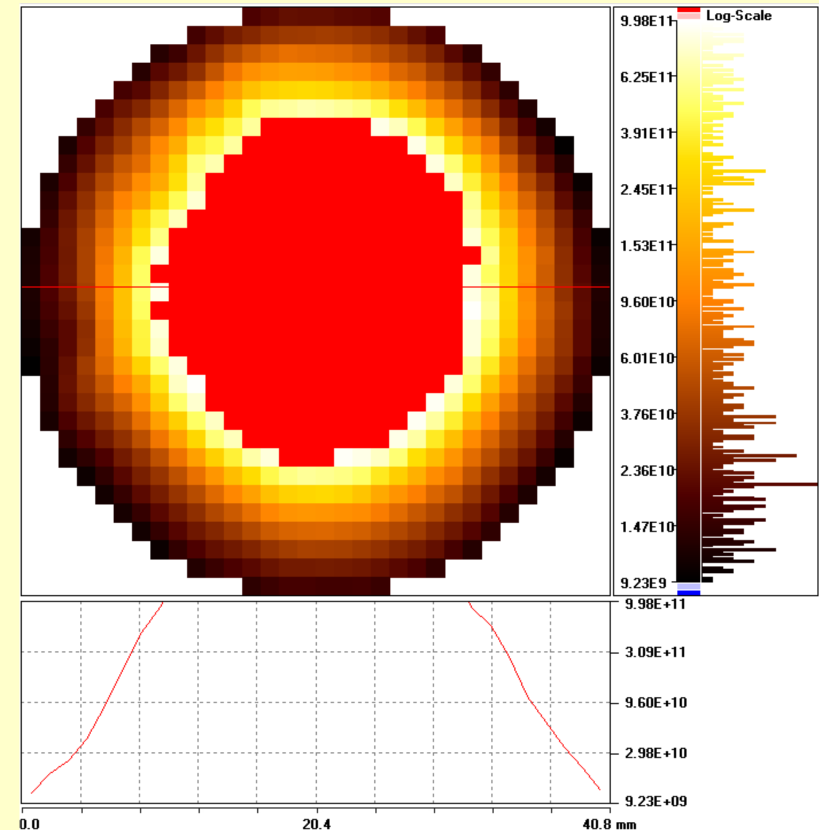
Analysis of Persistent Photoconductivity

Resistivity after 3h storage in darkness



Mean: 1.12 $\times 10^{10}$ Ωcm

Resistivity after 48h storage in darkness



Mean: 1.65 $\times 10^{11}$ Ωcm

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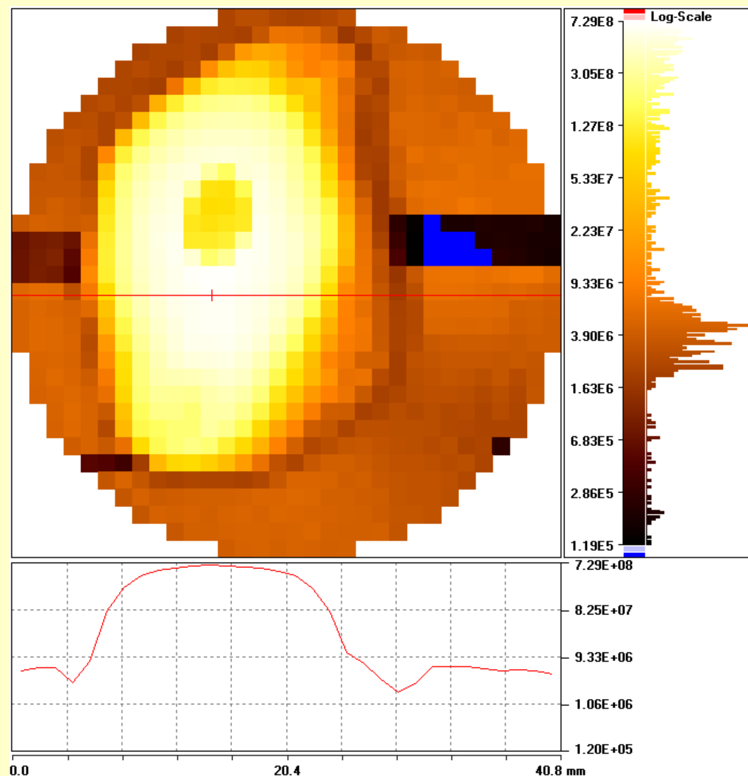
Resistivity Topography (V)

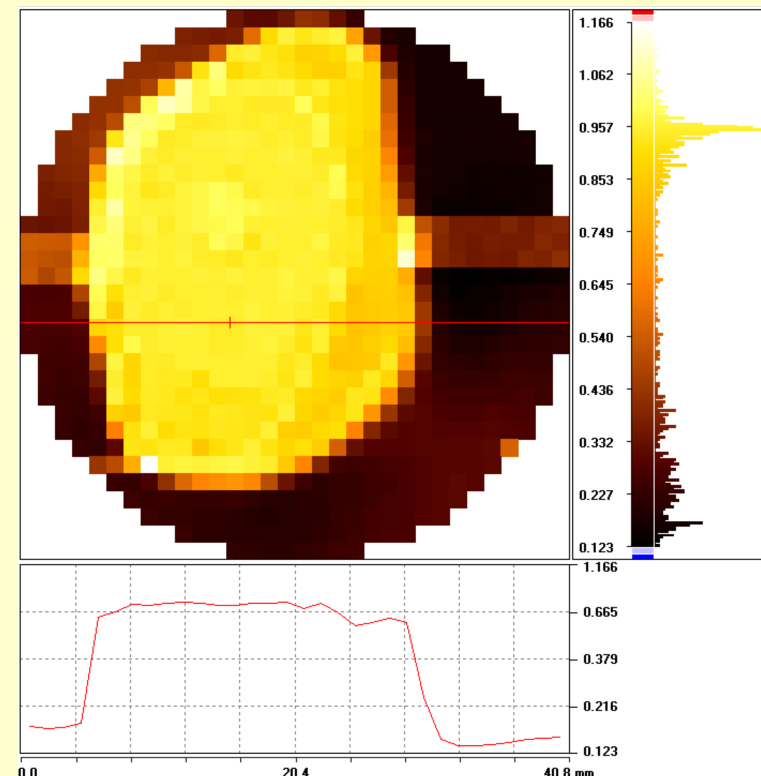
Analysis of locally inhomogeneous Material

Resistivity



Mean: 1.13 x10^8 Ωcm
Stdv: 168 %

Volume



Mean: 62%
Stdv: 54%

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Contactless Mobility Measurement (I)

	CONVENTIONAL HALL	COREMA - RM
Wafer cutting	necessary	nondestructive
Ohmic contacts	needed, critical	obsolete
Sample preparation	~ 15 min	none
Sample insertion and measurement time	~ 10 min	~ 30 s
Repeatability	~ 5%	< 1%
Evaluation of SI material	difficult	easy
Applicability	general	SI material only $\mu > 1000\ cm^2/Vs$
Acceptance	standard method	new method

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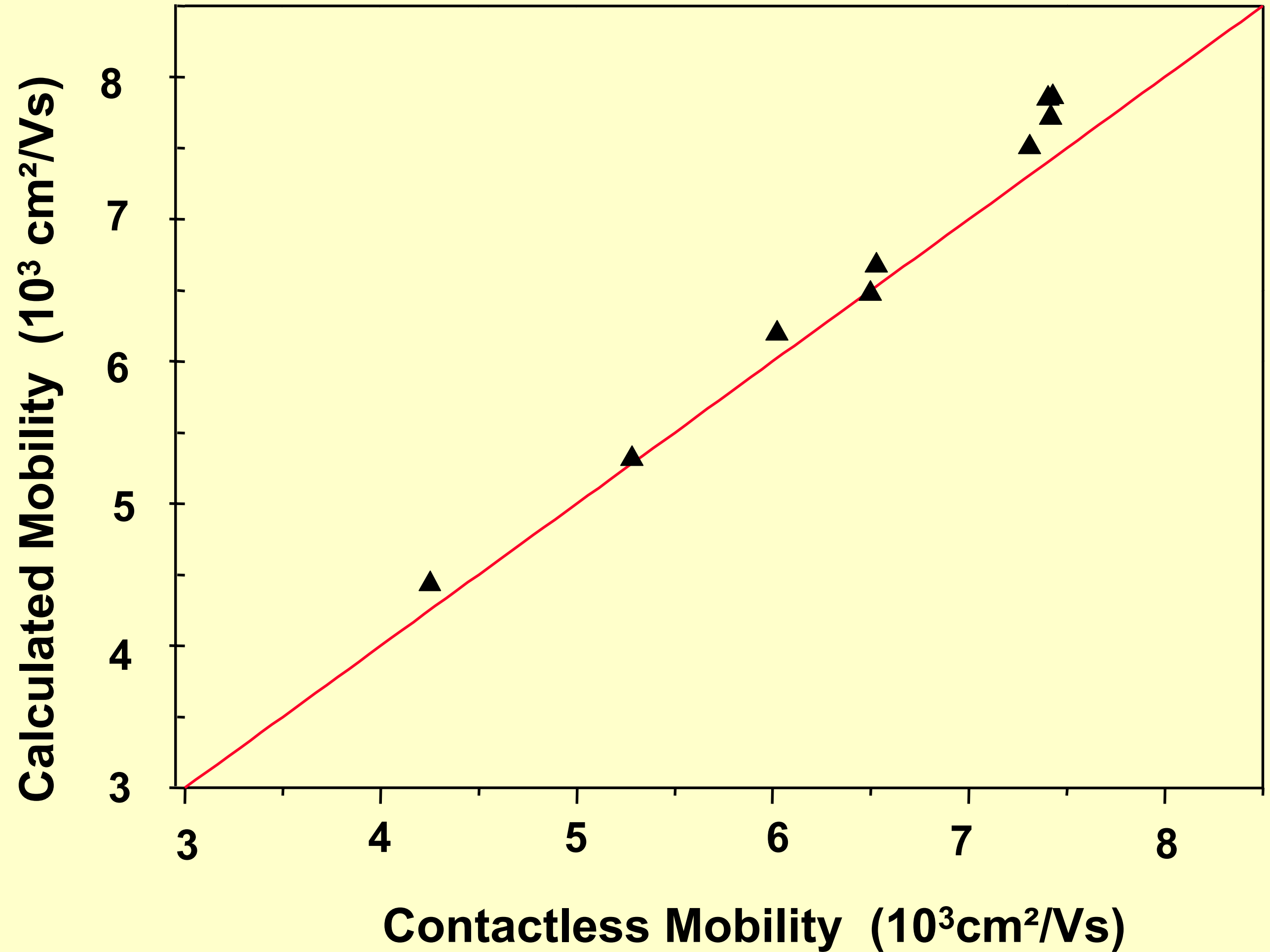
Contactless Mobility Measurement (II)

Verification using GaAs samples with different carbon content

Comparison with ionized impurity scattering theory



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Contactless Mobility Measurement (III)

Verification using GaAs samples with different carbon content

Comparison with Hall data (sample size 27x27 mm^2)

Contactless Mobility (10^3 cm^2/Vs)

Hall Mobility (10^3 cm^2/Vs)

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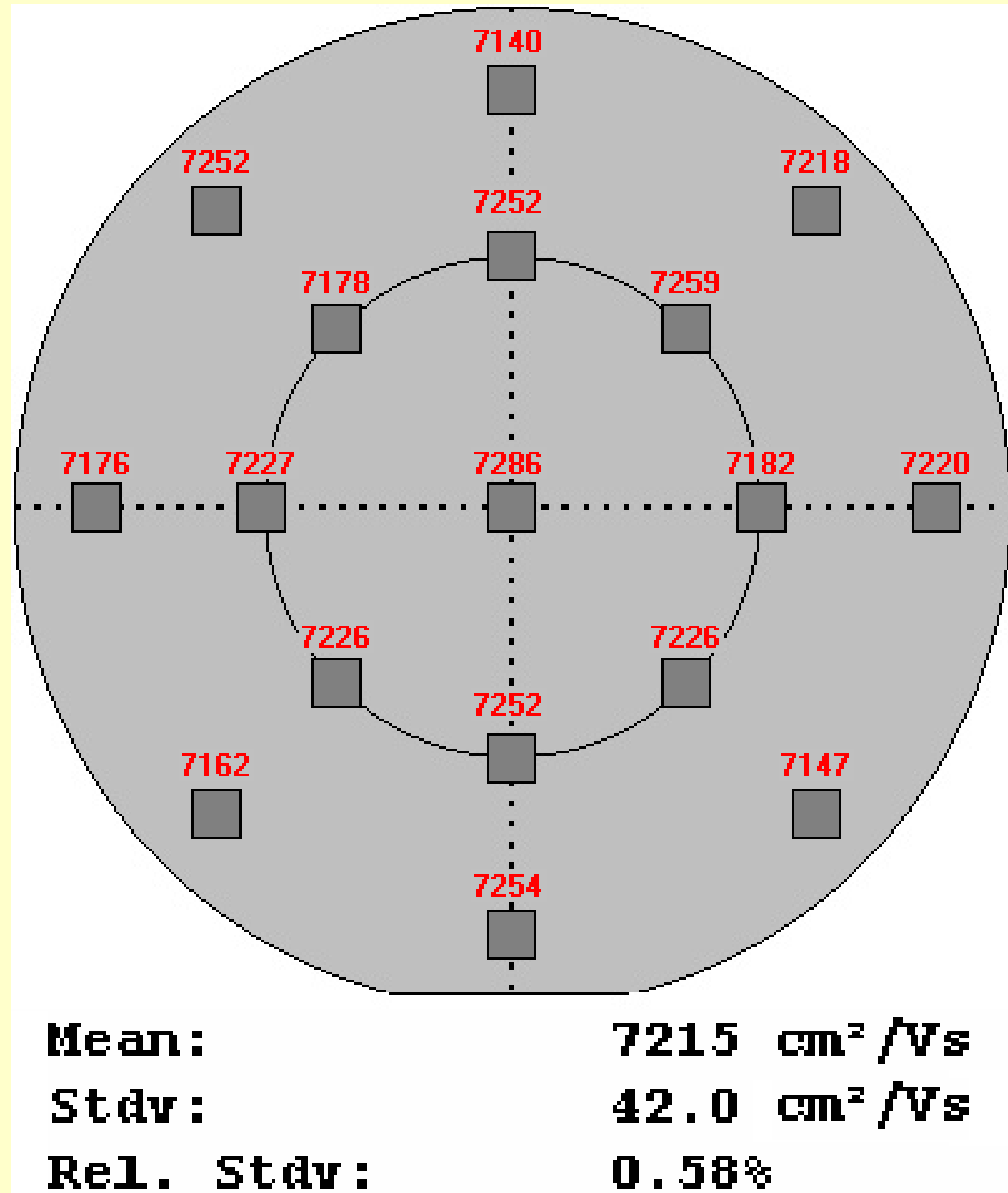
Contactless Mobility Measurement (IV)

Mobility evaluation using a customer specified measurement plan



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High Temperature Resistivity Measurement (I)

2" SiC wafer

Temperature range
40 – 200 ^{0}C

Resistivity range
$3x10^5$ – $1x10^{10}$ Ωcm

Not semi-insulating
at 300 ^{0}C

Temperature (°C)

225 200 175 150 125 100 75 50

Rho (Ohm*cm)

10^{11} 10^{10} 10^9 10^8 10^7 10^6 10^5

s.i. SiC
Activ. Energy: 816 meV

2.0 2.2 2.4 2.6 2.8 3.0 3.2

1/Temperature (1000/K)

$$E_a = (kT_1T_2)/(T_2-T_1) * \ln [\rho(T_1) / \rho(T_2)]$$

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High Temperature Resistivity Measurement (II)

2" SiC wafer

Temperature range
260 – 340 ^{0}C

Resistivity range
5.6 x10^9 – 1.8x10^{11} Ωcm

Semi-insulating at 300 ^{0}C

Temperature (°C)
340 320 300 280 260
10^{12} 10^{11} 10^{10} 10^9 10^8
Rho (Ohm*cm)
s.i. SiC
Activ. Energy: 1330 meV
1.60 1.65 1.70 1.75 1.80 1.85 1.90
1/Temperature (1000/K)

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High Temperature Resistivity Measurement (III)

2" SiC wafer

Temperature range
92 – 256 ^{0}C

Resistivity range
9.0 $\times 10^8$ – 2.3 $\times 10^{10}$ Ωcm

High resistivity, but small activation energy

Exhibits strong persistent photoconductivity

Temperature (°C)
300 270 240 210 180 150 120 90

Rho (Ohm*cm)
10^{12} 10^{11} 10^{10} 10^9 10^8 10^7 10^6 10^5

■ **s.i. SiC**
Activ. Energy: 297 meV

1.8 2.0 2.2 2.4 2.6 2.8
1/Temperature (1000/K)

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Summary

- **Automated resistivity topography is used extensively by industry and academia labs for routine wafer quality control and exploratory material analysis of GaAs, InP, SiC, CdT and GaN wafers.**

- **Mobility evaluation based on contactless magnetoresistance has been developed and commercially introduced for rapid, low-cost quality control of GaAs and InP wafers.**

- **A system measuring resistivity at temperatures up to 350 ^{0}C has been developed. The activation energy of state-of-the-art and exploratory SiC wafers has been obtained.**

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