Non-contact metal layer thickness and sheet resistance measurement on process wafers

Solutions for Semiconductor Industry

Marcus Klein - SURAGUS GmbH
Outline of this Presentation

1. Company
2. Relevance of Conductive Layers and Materials
3. Processes
   • Deposition (CVD, PVD, Plating)
   • Implantation, Doping
   • Etching, Polishing
   • Annealing/Tempering
   • (De)-oxidation
4. Metrology for Conductive Materials
   • Overview
   • Eddy Current Technology
   • Testing Setups
5. Opportunities Provided by Non-contact Eddy Current Testing
   • High Ohm Monitoring
   • Imaging & Near Edge Monitoring
   • Process Wafer Monitoring
6. Tool Implementation Strategies
   • Direct Tool Integration into Layer Modification Tools
   • Fab Central Standalone Testing Tools
7. Summary
SURAGUS GmbH is a German Metrology Specialist

SURface ArGUS = Surface guard

Technology
- Eddy current-based testing solutions (SURAGUS)
- Other integrated metrology (OEM)

Location and Presence
- R&D and manufacturing in Germany (Dresden & Berlin)
- EddyCus systems are present on six continents
- Local representatives and service teams in Korea, China, Taiwan ...

Applications
- Quality assurance of functional thin-films

Values
- ✓ accurate and reliable solutions
- ✓ smart solutions (reverse calibration, automated self-reference, T stabilized)
- ✓ high technical flexibility (gap sizes, sensor setups, traverse and fixed)
- ✓ excellent service (close contact / short response times)
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Conductive Coatings are Applied for Various Reasons

Layers can achieve a superior and competitive set of characteristics

Physical Characteristics
- Electrical properties
- Mechanical properties
- Chemical properties
- Optical properties
- Geometrical (Surface) Properties
- Etc.

Soft characteristics
- Stable over time

Financial Characteristics
- Cost per performance
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Modification of Conductive Layers has a Wide Range of Applications

Processes for conductive monitoring

- Deposition (CVD, PVD, plating...)
- Implantation / Doping
- Etching
- Polishing
- Annealing/Tempering
- (De)-oxidation

Negative layer modification assessment

- Cleaning
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Metrology for Conductive Layers

Commonly applied testing technologies on conductive coatings

- TEM and SEM
- High magnification optical microscopes
- Optical spectrometer (reflectance, ...)
- Raman
- Ellipsometry
- 4PP / Eddy Current
- Van der Pauw / Hall effect
- Radiological Testing
- Others
Metrology for Conductive Layers

Commonly applied testing technologies on conductive coatings

- TEM and SEM
- High magnification optical microscopes
- Optical spectrometer (reflectance, ...)
- Raman
- Ellipsometry
- 4PP / Eddy Current ➔ Electrical properties are typically tested using an electrical testing method
- Van der Pauw / Hall effect
- Radiological Testing
- Others
Comparison of electrical testing methods

4-point-probe testing

- Contact / Contact quality influences measurement
- Single point and mapping solutions
- Possible damage to sensitive layers
- Single point sheet resistance testing only
- Wearing of probe with time
- No measurement of encapsulated films

Non-contact eddy current testing by EddyCus

- Non-contact & real-time, no wearing
- High accuracy without influence of contact resistance
- No harm or artifacts to sensitive films
- High resolution mapping & Inline measurement for process control
- Encapsulated films & multilayer systems
- Best usage for touch-sensitive layers

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<td>82.500</td>
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The correlation of the results is shown in the below image.
How Eddy Current Works

I. A primary magnetic field is created when alternating current is injected into an induction coil

II. Eddy Currents are generated when the coil is placed over a conductive sample

III. The characteristics of the Eddy Currents are determined by material characteristics

IV. The Eddy Currents generate a secondary magnetic field opposed towards the primary field

V. The impedance of the coil is affected by material differences that influence conductivity

VI. This influence is measured by a pick up coil

+ High sample rate
+ High sensitivity
+ Non-contact solutions
  – Limited to conductive materials
How does eddy current testing work?

Setup for layer characterization

- Frontside reflection mode
- Backside reflection mode
- Transmission
Sheet Resistance and Metal Thicknesses do Correlate

Sheet resistance and layer thickness correlation for thick layers

Cross-section area $A$

$R \sim \frac{l}{A}$. It can be written as

$$R = \rho \frac{l}{A} = \frac{1}{\sigma} \frac{l}{A}$$

$\rho$ is the specific resistance, whereas $\sigma$ describes the specific conductivity of the material.

$$\sigma = \frac{1}{\rho} \quad \text{Unit [S] (Siemens)}$$

Sheet resistance $R_n$ or $R_s$ is derived by assuming that the film width equals the film length ($w = l$)

$$R = \frac{\rho}{t} \cdot \frac{l}{w} \equiv R_s \frac{l}{w}$$

The unit of $R$ is $\Omega$
The unit of $R_s$ is $\Omega$ ($\Omega/\square$ is typically used in order to distinguish between resistance)
Capabilities of eddy current monitoring

- Metal layer thickness measurement from 2 nm – 2 mm
- Sheet resistivity measurement from 0.1 mOhm/sq to 1,000 Ohm/sq (upto 100k Ohm/sq)
- Imaging solutions
- Defectoscopy
- Permittivity testing (high k materials)
- Combined solutions (eg. optical and electrical testing)
Introducing Four General Testing Setups

Non-contact single point measurement

1.35

Non-contact imaging solutions

Inline / Tool integrated

Portable Testing

Metallization on wafer

Line Profile

Layer Thickness [nm]

Distance [mm]
Sheet Resistance Images – GaAs Wafer

Image exposes homogeneity

Sheet resistance imaging [ohm/sq] on 4 inch wafer with 1 mm measurement pitch
Layer Thickness Imaging

Copper layer
Sheet Resistance Mapping – Doped Si Wafer

Wafer Substrates
Sheet Resistance Mapping - Poly-Si Wafer

Wafer Substrates
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Opportunities Provided by Non-contact Eddy Current Testing I

High Ohm Monitoring

Situation

• 4PP testing required appropriate surfaces quality for establishing electrical contact

• Limitations in high ohmic range → not reliable testing possible

Opportunity

• Incoming wafer inspection for high ohmic wafer
High Resistivity Measurements

Example 1 – Five Point Measurement on 8inch Wafer

Theoretical value: \[ R = \frac{\rho}{d} = \frac{100 \times 10^{-2}}{739.4 \times 10^{-6}} = 1.352 \, \Omega/\square = 1.35 \, k\Omega/\square \]

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</table>
**Example 2 – Five Point Measurement on 8inch Wafer**

**Theoretical value:**

\[ R_\square = \frac{\rho}{d} = \frac{1,000 \cdot 10^{-2}}{734 \cdot 10^{-6}} = 13,624 \, \Omega/\square = 13.6 \, k\Omega/\square \]

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High Resistivity Measurements

Example 3 – Five Point Measurement on 8inch Wafer

Theoretical value:

\[ R_n = \frac{\rho}{d} = \frac{5,000 \cdot 10^{-2}}{647.5 \cdot 10^{-6}} = 77,220 \, \Omega/\square = 77.2 \, k\Omega/\square \]

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Opportunities Provided by Non-contact Eddy Current Testing - II

Imaging & Near Edge Characterization

Situation

• Electrical near edge characterization is challenging with currently available conventional solutions
• 4PP and Eddy Current Testing need to cope with edge effects
• EddyCus System provided edge effect compensation algorithms

Opportunity

• QA and process control for process monitoring of edge zones
Sheet Resistance Mapping – Metal Oxide with Oxide Gradient

Line profile analysis exposed homogeneity in all directions

Sheet resistance imaging [ohm/sq] on 50 x 50 mm with 1 mm measurement pitch (2500 measurement points)
Doping Efficiency Imaging

Doped Graphene

- Half of the wafer was intensively doped
Near Edge Characterization

Metalization Thickness Measurement with Near Edge Characterization
Metalization Thickness Measurement with Near Edge Characterization
Metalization Thickness Measurement with Near Edge Characterization
Defectoscopy

Automated defect detection
Opportunities Provided by Non-contact Eddy Current Testing - III

Process Wafer Monitoring

Situation
- 4PP contact testing is typically applied on test wafer
- Indirect measurement based on the assumption of constant processes without any randomness
- Testing wafer block tool capacity and create costs

Opportunity
- Full confidence in wafer integrity by non-contact testing on process wafers
- Reduce amount of test wafer
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Tool Implementation Strategies

Direct Tool Integration into Layer Modification Tools

Setup
- Sensor integration into processing tools

Advantage
- Fast process feedback
- Process control
- Low hardware costs
- No additional floor space

Drawback
- Many integration projects
Tool Implementation Strategies

Fab Central Standalone Testing Tools

Setup
- Central tools providing testing for various processes

Advantage
- No sensor integration required.

Disadvantage
- Higher investment costs
- Additional floor space
- Significant delay between process and measurement
Tool Implementation Strategies

Fab Central Standalone Testing Tools

Setup

• Sorting Setup
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Fax: +49 351 - 32 111 509
Take Home Messages

- **Process Monitoring and QA**
  - Deposition (CVD, PVD, Plating)
  - Implantation, Doping
  - Etching, Polishing
  - Annealing/Tempering
  - (De)-oxidation

- **Metrology for Conductive Materials**
  - Contact and non-contact testing

- **High performance by Eddy Current Testing**
  - Large measurement range
  - High resistive testing
  - High sample rates

- **Testing Setups**
  - Single Point
  - Mapping / Imaging
  - Tool integrated
  - Portable testing

- **Electrical testing solution enable the measurement of**
  - Sheet resistance, metal thickness, defect monitoring

- **Opportunities by Non-contact Eddy Current Testing**
  - High Ohm Monitoring
  - Imaging & Near Edge Monitoring
  - Non-contact measurement on process wafer

- **Tool Implementation Strategies**
  - Direct Tool Integration into Layer Modification Tools
  - Fab Central Standalone Testing Tools

- **LayTec SURAGUS Group**
  - Strong partners for electrical and optical testing solutions

- **Smart solutions**
  - Temperature corrected
  - Anisotropy testing
  - Multilayer film testing
  - Structured film testing
  - Smart calibration
For questions and requests please feel free to contact us...

Contact us for
- Discussion of testing tasks
- Demo measurements
- System suggestion

Contact in Germany

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