In-line Process and Equipment Performance Monitoring using Site Flatness and Raman Mapping

Characterization of Process Footprints

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Topics To Be Discussed

• Necessity of In-Line Monitoring
  – Process Performance (Uniformity & Repeatability)
  – Equipment Performance (Up Time & Reliability)

• Conventional Process Monitoring Values
  – RTO: Oxide Thickness and Uniformity
  – Implant Anneal: Sheet Resistance & SIMS Profiles
  – Silicides: Sheet Resistance
  – Etching: Etch Rate & Profiles
  – CVD: Film Thickness, Dep. Rate, n, k, etc.

• Systems Used in This Study
  – SRTF-302LP: Hot Wall RTP
  – OSP-300: Optical Surface Profilometry
  – MRS-300: Multi-wavelength Raman Spectroscopy

• New Metrology Tools for Hidden Variations
  – Pattern Effect (Blanket Wafer vs. Patterned Wafer)
  – Process Pattern Shift or Drift
  – Global & Local Deformation or Distortion (Elastic vs. Plastic)
  – Bow, Warpage, Site Flatness, Stress, Strain etc.
Process & Metrology Systems Used in This Study

**SRTF-302LP**
- Single Wafer Rapid Thermal Furnace
- RTA under O₂ Controlled Environment (100°C~1100°C)
  - Dual Chamber Configuration
  - No Lamps
  - Low Maintenance
  - High Repeatability
  - High Stability
  - Small Footprint
  - Low Power Consumption
  - Self Contained System
  - No Other Facility Required

**OSP-300**
- Optical Surface Profilometry
- Non-destructive Metrology Tool for Blanket and Patterned Wafers
  - Global Wafer Warpage
  - Global Wafer Distortion
  - Global Wafer Stress
  - Local or Site Flatness
  - Wafer Curvature along Crystal Axes
  - Pattern Overlay
  - Small Foot Print
  - Minimum Facility Requirement

**MRS-300**
- Multi-wavelength Raman Spectroscopy
- Non-destructive Localized Lattice Stress & Strain Evaluation Tool
  - Very High Wavelength Resolution
  - Three Wavelengths: 457.9, 488.0 & 514.5nm
  - Three CCD Cameras
  - Impact of Process Steps on Stress & Strain
  - No Moving Parts in Spectroscope
  - Auto Focus Microscope
  - WaferMasters’ Proprietary Design
Isothermal Process Chamber and Wafer Temperature Profiles

SRTF-302LP

[Diagram of Isothermal Process Chamber]

Aluminum Chamber
Heating Elements
Thermal Insulator
Heat Diffuser
Process Gases

[Graph showing temperature profiles]

Wafer In
Wafer Out

Pattern and Emissivity Insensitive

[Graph showing temperature profiles]

Temperature Controller
TC for Wafer Temp. Monitoring
Data Computer

[Graph showing temperature profiles]
Temperature Sensitivity of Sheet Resistance of Various Silicidies

**Process Capability of SRTF-302LP**

Sheet resistance (Ohm/sq.) vs. Annealing Temperature (°C) for different silicides:
- Ni(10nm)/Si (300s)
- TiN(10nm)/Co(10nm)/Si (120s)
- Ti(35nm)/Si (60s)

Uniformity Change (%) is also plotted on the same graph.
RTO Repeatability: RTP System Dependence

**Single Side Lamp RTP**

- Oxide Thickness (nm)
- Oxide Uniformity (%)

**Double Side Lamp RTP**

- Oxide Thickness (nm)
- Oxide Uniformity (%)

**Hot Wall RTP**

- Oxide Thickness (nm)
- Oxide Uniformity (%)

*Note: Slot Number ranges from 0 to 25.*
In-Line Process and Equipment Performance Monitoring

1. Detect Subtle Differences between Processed Materials
2. Detect and Quantify Process Effect
   • Uniformity, Repeatability, Distribution
3. Utilize Collected Information as Process and Equipment Monitoring and Control Feedback

Strategy for Manufacturing Process and Quality Improvement System Enhancement

- Improvement of Measurement Accuracy & Resolution?
- Changes in Wafer Surface Profile: Bow, Warpage, Distortion, Flatness
- Stress Distribution near Interface: Stress, Crystallinity, Strain, Composition

- Optical Surface Profilometry
- Multi-Wavelength Raman Scattering

WaferMasters Incorporated
OSP-300: Operating Principles

Captured images (reflected, diffracted and scattered images) are transformed into proprietary data set and analyzed to quantify global and local wafer distortion, stress and warpage.

Beam size: \(~0.7\text{mm}\)φ

Image resolution: \(~1\text{arcsec} \ (1/3600 \text{ arcdeg}, \text{ or } 4.85\mu\text{rad})\)

Stage resolution: \(~0.5\mu\text{m}\)
**OSP-300: Measurement Data Display**

<table>
<thead>
<tr>
<th>Vector Plot</th>
<th>Intensity</th>
<th>Height Profile</th>
<th>Beam Position</th>
<th>Curvature</th>
<th>3D Map</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Vector Plot" /></td>
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<td><img src="image6" alt="3D Map" /></td>
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</table>

- **Intensity Mean**
- **Height Mean**
- **Histogram**
- **95% Value**
- **95% Circle**
- **Fitted Curvature**
- **95% Value**
- **Fitted Curvature**
- **Actual Height Range**

**Key Measurements:**
- **Height Range**
- **Contour Interval**
- **Intensity Range**
- **Vector Plot**
- **Intensity**
- **Height Profile**
- **Beam Position**
- **Curvature**
- **3D Map**

**Axes:**
- [110]
- [010]
- [-110]
- [-100]
- [-1-10]

**Note:** Images and diagrams are placeholders for actual content.
OSP-300: Wafer Curvature Estimation

**Measurement Parameters**
- Surface Profile
- Curvature
- Warpage
- Site Flatness
- Distortion
- Stress/Strain
- Process Effect
- Pattern Overlay

**Measurement Capability**
- Blanket Wafers
- Device Wafers
- SOI Wafers
- Bonded Wafers
- Quartz Wafers
- Glass Wafers
- Sapphire Wafers
- Unpolished Wafers

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Vector Plot | Intensity | Height Profile | Beam Position | Curvature | 3D Map
---|---|---|---|---|---

**Graphs**

- **Height vs. Distance from Wafer Center**
  - R = 100m
  - R = 250m
  - R = 500m
  - R = 1000m

**Measurement Parameters**
- Blanket Wafers
- Device Wafers
- SOI Wafers
- Bonded Wafers
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**Vector Plot**

- Intensity
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**Graphs**

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Raman Scattering: Lattice Stress & Strain Characterization

Inelastic Scattering of Photons

Florescence

Electronic States

Virtual States

Anti-Stokes Raman

Rayleigh

Stokes Raman

Ground State

Vibrational States

Mid IR

Bulk Si

Stress: $\sigma_{xx} + \sigma_{yy} = 434 \Delta \omega$ [MPa]

Factors
Peak Shift
Peak Broadening
Asymmetry: $\Gamma_a/\Gamma_b$

Factors

Intensity

Raman Shift

Probability: $<1$ ppm

Stress:
- $3.41\text{eV}$
- $2.71\text{eV}$
- $2.54\text{eV}$
- $2.41\text{eV}$

Penetration Depth

$\delta = 350\text{nm}$

Probing Depth $\delta$: $\sim 1/2$ of Penetration Depth
Raman and Photoluminescence Signals from Bulk Si

Raman Signals from Si

Photoluminescence (PL) from Si

Normalized Raman Intensity

Wavelength (nm) & Photon Energy (eV)

IR

PL Intensity (counts)

Eg of Si

Wavelength (nm) & Photon Energy (eV)
Ge Concentration Maps from Strained Si

Nominal Ge Conc.
5%

15%

25%

514.5nm Excitation
Si-Si in SiGe

Raman Shift (cm$^{-1}$)
Intensity (Counts)

Si
Ge 15%
Ge 20%
Ge 25%
Ge 30%
Raman Characterization: Implant Damages

Asymmetrical broadening with a peak shift to a smaller wavenumber
⇒ deficient recrystallization & poor damage recovery

B : 1keV, $1 \times 10^{15}$ cm$^{-2}$
Ge PAI: 5keV, $1 \times 10^{15}$ cm$^{-2}$
Raman Characterization: Epilayer Quality

Heavily B doped Si Thickness: 775 µm

SiO₂ 300nm
OSP-300 & MRS-300 Application Examples

RTO Film Characterization
## Site Flatness before and after RTO

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### Results:
- **Hot Wall RTA**: No Change
  - Avg. = 5.17nm
  - Unif. = 0.75%
- **Single Side Lamp RTA**: Distortion
  - Avg. = 5.67nm
  - Unif. = 0.49%
- **Double Side Lamp RTA**: Distortion
  - Avg. = 5.63nm
  - Unif. = 0.96%
- **1030°C**
Si Stress Change after RTO at 1030°C
RTP System Dependence

Hot Wall RTP

SiO₂

Si

Compressive

Single Side Lamp RTP

SiO₂

Si

Tensile

Double Side Lamp RTP

SiO₂

Si

Tensile

Avg. = 5.17nm Unif. = 0.75%
Avg. = 5.67nm Unif. = 0.49%
Avg. = 5.63nm Unif. = 0.96%

Raman Shift (cm⁻¹)

FWHM (cm⁻¹)

488.0nm

514.5nm

Stress Free Si

Compressive Stress

Tensile Stress

Prime Si Before RTO
Hot Wall RTP
Single Side Lamp RTP
Double Side Lamp RTP
Effect of Lateral Resolution or Measurement Points

Reality of RTO Process Uniformity

49 points
49 pts
49 pts
49 pts
49 pts
49 pts
625 points
625 pts
625 pts
625 pts
625 pts
625 pts

Single Side Lamp RTP
Double Side Lamp RTP
Hot Wall RTP

V Bare Si 7 Cross
M Bare Si 7 Cross
SRTF Bare Si 7 Cross
V Bare Si 25 Cross
M Bare Si 25 Cross
SRTF Bare Si 25 Cross
RTO Repeatability: RTP System Dependence

Single Side Lamp RTP

Double Side Lamp RTP

Hot Wall RTP

Oxide Thickness (nm)

Oxide Uniformity (%)
Summary

- Introduced Two New Metrology Tools and Their In-Line Process and Equipment Monitoring Applications
- Demonstrated Process Footprint Measurement Sensitivity and Capability of New Metrology Systems
- Proposed New Applications with In Line Monitoring Implementation Examples in Mass Production Environment

Due to the confidentiality agreement with customers, I can only share very limited information at this time.

Product Demos are Welcome.

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