Comprehensive Characterization of \( B^+ \) Implanted Silicon after Rapid Thermal Annealing

Woo Sik Yoo, Jung Gon Kim, Toshikazu Ishigaki and Kitaek Kang

WaferMasters, Inc.
Dublin, CA
USA
Outline

- Objectives: Visualization of Invisible Si Material Properties
  - Surface
  - Interface
  - Bulk
  - Defects
  - Charge Distribution
  - Stress/Strain
  - Band Bending

- Experiment:
  - Implanted Wafers
    - \(^{11}\text{B}^+\) 1keV 1x10\(^{15}\) atoms/cm\(^2\)
  - RTA System (Hot Wall System)
    - Resistively heated single wafer rapid thermal furnace (SRTF)
  - Annealing Conditions
    - Temperature: 850\(^\circ\)C~1050\(^\circ\)C
    - Time
      - 30s~180s (Residence time in SRTF)
      - 1s~150s (Equivalent soak time in lamp-based RTP)
    - Atmosphere: 1 atm, N\(_2\)
  - Multiwavelength Room Temp. Photoluminescence (RTPL)

- Results and Discussions
- Prospects
Band Structure of Semiconductors

Conduction Band

Valence Band

Interatomic Distance

Energy

Excitation

Conduction Band

Valence Band

Luminescence

PL, EL, CL, TL

X-ray

Waterfalls are often formed where hard rock lies on top of softer rock.
Excitation Source
PL: Light (Photon)
EL: Current
CL: Electron
TL: Heat

Conduction Band
Valence Band
Bandgap

Excited States
Relaxation
Localized Defects (Surface/Interface, Passivation Problems)
Point Defects
Minority Carrier Lifetime
Carrier Mobility
Local Band Bending
Impurity Levels
Midgap Levels
Luminescence (Potential Energy, Water Fall)
Leakage through Ground (Traps, Impurities, Defects)
Potential Island (Ions)

Detailed Information Needed for Proper Interpretation
PL Mapping Examples (SiO$_2$/Si)

SiO$_2$/Si Interface Quality Monitoring

Wafer A  Wafer B  Wafer C  Wafer D
Multiwavelength Photoluminescence Spectroscopy: The most direct way to measure band-gap energies, dopant activation, electrically active defects, plasma induced damage (PID), dielectrics/Si interface quality, metal contamination which affect minority carrier lifetime and electron mobility characteristics of the semiconductor.

MPL-300: Multiwavelength Photoluminescence

Photoluminescence
Single Wafer Rapid Thermal Furnace (SRTF)

**Hot Wall RTA Process Chamber**

- Aluminum Chamber
- Thermal Insulator
- Heat Diffuser
- Process Gases
- Heating Elements

**Wafer Temperature Profile**

- Wafer In
- Wafer Out

**Temperature Controller**

- TC for Wafer Temp. Monitoring
- Zone 1 Power
- Zone 2 Power
- Zone 3 Power

**Computer**

**Data**

**Time (s)**

0 60 120 180 240 300

**Wafer Temperature (°C)**

0 200 400 600 800 1000 1200

Wafer Temperature Profile
Boron Diffusion from Limited Source after RTA

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**Graph:**

- Title: B⁺ 1 keV 1E15
- Axes:
  - Y-axis: B Concentration (atms/cm³)
  - X-axis: Depth (nm)
- Legend:
  - As implanted
  - 1050°C 35s 202.66 ohm/sq.
  - 1050°C 60s 173.41 ohm/sq.
  - 1000°C 35s 344.41 ohm/sq.
  - 1000°C 60s 240.80 ohm/sq.
  - 1000°C 100s 200.19 ohm/sq.
  - 1000°C 140s 186.34 ohm/sq.
  - 950°C 35s 657.39 ohm/sq.
  - 950°C 60s 445.57 ohm/sq.
  - 950°C 100s 332.76 ohm/sq.
  - 950°C 140s 278.23 ohm/sq.
  - 950°C 180s 247.21 ohm/sq.
  - 900°C 60s 729.40 ohm/sq.
  - 900°C 100s 612.17 ohm/sq.
  - 900°C 140s 494.61 ohm/sq.
  - 900°C 180s 463.71 ohm/sq.
  - 850°C 100s 986.62 ohm/sq.
  - 850°C 140s 877.32 ohm/sq.
  - 850°C 180s 816.65 ohm/sq.

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**Note:**

- **SRTF Anneal**
- Variations in temperature and time impact the boron diffusion, as shown in the graph.
Stress Induced Property Change

(a) As Received
Free Standing in Container
(b) Stressed for 3 days
Tightly Closed Lid with Washer

(c) RTPL Mapping & Line Scan Direction
Si Wafer
Diameter: 50 mm
Edge Exclusion: 3 mm
Intervals: 500 μm in X and Y Directions
Measurement Points: >6000 Points
Excitation Wavelength: 830 nm
Exposure Time: 500 ms/point

RTPL Line Scan (51 Points)

Intensity (x10^3 Counts)
Distance from Y-axis (mm)

Stress Induced PL intensity variations

As Received
Stressed for 3 days without additional washer
Stressed for 3 days with additional washer
Stress Induced Property Change

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Stress induced PL intensity variations

As Received

Stressed for 3 days without additional washer

Stressed for 3 days with additional washer
Stress Induced Property Change
650nm/827nm PL Mapping Results

Slot 01: Reference Si
Slot 02: DOP Vapor 7 Days
Slot 03: DOP Vapor 7 Days
Slot 04: DOP Vapor 14 Days
Slot 05: DOP Vapor 14 Days
Slot 06: DOP Liquid
Slot 07: DOP Liquid
Slot 08: XRR + XRF
Slot 09: XPS
Slot 10: WDXRF
650nm Excitation PL Area Mapping

Slot 08: XRR+XRF
Slot 09: XPS

10mm x 10mm in 100um intervals

Slot 01: Reference Si
Slot 02: DOP Vapor 7 Days
Slot 03: DOP Vapor 7 Days
Slot 04: DOP Vapor 14 Days
Slot 05: DOP Vapor 14 Days
Slot 06: DOP Liquid
Slot 07: DOP Liquid
Slot 08: XRR + XRF
Slot 09: XPS
Slot 10: WDXRF
PL Wafer Mapping Results

827nm Excitation RTPL Maps

Exposure: 250 ms

Batch A
Old Wafers

Batch B
Old Wafers

Batch C
New Wafers

Intensity (Counts)

<table>
<thead>
<tr>
<th>Slot 03</th>
<th>Slot 08</th>
<th>Slot 15</th>
<th>Slot 20</th>
<th>Slot 22</th>
</tr>
</thead>
</table>

PL Spectrum under 827nm Excitation:
Wafer Center

Intensity (Counts)

![Graph for PL Spectrum]
Photoluminescence (PL) vs. Surface Photovoltaic (SPV)

**SPV:** Poor Sensitivity, Poor Repeatability, Poor Spatial Resolution (~10mm), Mainly for Blanket Wafer Applications.
Rs and PL Spectra from Implanted Si after RTA

Brightness: Overall Ariel Intensity
Spectra: Intensity Distribution in Wavelength Domain
Multiwavelength PL Mapping Results after Non-contact Corona-based C-V and I-V Measurements

C-V and I-V Measurement Signatures

Evidence for Destructive Characterization
Multiwavelength PL Mapping Results after C-V and I-V Measurements

Front Side Measurement

Backside Measurement

No electrical (C-V and SILC) measurements from backside

PL Intensity (x1000 Counts)

Distance from Wafer Center (mm)

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Multiwavelength PL Mapping Results after UV-Based Film Thickness Measurements

<table>
<thead>
<tr>
<th>Additional UV+VIS+NIR Radiation Experiment</th>
<th>As Deposited SiO₂/Si</th>
<th>UV+VIS+NIR Radiation</th>
<th>UV Line Scan VIS+NIR Line Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>No UV Radiation</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- **827nm Excited Room Temp. PL Intensity 2D Map**

- **827nm Excited Room Temp. PL Intensity 3D Map**

**Forming Gas Anneal at 400°C for 5 min**

- **300mm dia.**
- **60mm dia.**
- **60mm dia.**

**WaferMasters Incorporated**
PL Intensity Change at Various Stages

827nm Excitation

As Deposited

800°C FGA

400°C FGA

UV Rad. VIS+NIR Rad.

UV Rad. VIS+NIR Rad.

FGA at 400°C 5 min

FGA at 800°C 5 min

PL Intensity Change at Various Stages

UV Rad.

Tutorial: UV Induced Electron Accumulation → Localized Band Bending

SiO₂

Si

O₂ Molecular Dissociation

Si VB → SiO₂ CB Transition

Si CB → SiO₂ CB Transition

Optical Si-Si Bond Breaking, Photogeneration of Electron-Hole Pairs in Si

Deuterium Lamp

Multi-Photon Excitation

8.9 eV

1.1 eV

3.2 eV

4.3 eV

4.6 eV

E_v

E_c

E_\text{vac}

1.0 eV
Properties of Native Oxide/Si Interface after Electrical Breakdown

(a) HVDC Arc
2000V DC, ~1000 ms

(b) Piezo Ignition Arc
~4000V Pulse, ~1 ms