“Scribing-Cleaving-Passivation” for High Energy Physics Silicon Sensors

Marc Christophersen¹, Bernard F. Phlips¹, Vitaliy Fadeyev², Scott Ely², Hartmut F.-W. Sadrozinski²

(1) Code 7654, U.S. Naval Research Laboratory
(2) Santa Cruz Institute for Particle Physics (SCIPP), UCSC

Contact: marc.christophersen@nrl.navy.mil
+1-202-404-2448
Outline

• Slim Edges – Motivation and Approach

• “SCP” Process

• Different Scribing Methods and Damage Removal
  - Diamond-Scribing
  - Laser-Scribing
  - Etch-Scribing

• Surface Termination and Leakage Currents

• “Towards an Automated SCP Process”

• SCP Activities within RD50

• Conclusions and Outlook
Motivation – Slim Edges

If you obtain
1. minimal damage at edge and
2. “right” sidewall surface charge
one can make slim edges with post processing.

Slim edges offer:
• better tiling of sensors
• reduced inactive area
Motivation – Slim Edges

optical micrograph, bird’s-eye view
SCP Process

S

finished die

laser-, diamond or DRIE-scribing

C

cleaving

P

annealing and testing

sidewall passivation
Using a pad diode from HPK test structure meant to provide control over key sensor parameters for ATLAS07 sensors.
- It features a classic HPK single-guard ring design.
- Simple DC-coupled n-on-p pad. \( V_{\text{depl}} \approx 180 \text{ V} \). Thickness 320 \( \mu \text{m} \).
**Slim-Edge Sensor**

- Using a pad diode from HPK test structure meant to provide control over key sensor parameters for ATLAS07 sensors.
- It features a classic HPK single-guard ring design.
- Simple DC-coupled n-on-p pad. $V_{\text{depl}} \sim 180$ V. Thickness 320 µm.
Dicing Technologies

1. Mechanical Blade Dicing
2. Dicing Before Grinding
3. Mechanical Scribe-and-Break
4. Laser Scribe-and-Break
5. Laser Full-Cut Dicing
6. Stealth Dicing
7. Plasma Dicing
1. Mechanical Blade Dicing
2. Dicing Before Grinding
3. Mechanical Scribe-and-Break
4. Laser Scribe-and-Break
5. Laser Full-Cut Dicing
6. Stealth Dicing
7. Plasma Dicing

- 100 μm wide damaged silicon region
- micro-cracks, dislocations, etc.
1. Mechanical Blade Dicing
2. Dicing Before Grinding
3. Mechanical Scribe-and-Break
4. Laser Scribe-and-Break
5. Laser Full-Cut Dicing
6. Stealth Dicing
7. Plasma Dicing

We have not tried this technique. Furthermore, not applicable for double-sided processing.
1. Mechanical Blade Dicing
2. Dicing Before Grinding
3. **Mechanical Scribe-and-Break**
4. Laser Scribe-and-Break
5. Laser Full-Cut Dicing
6. Stealth Dicing
7. Plasma Dicing

\[
\text{Laser-Cutting-and-Break} \quad \quad \text{Etch-Scribing-and-Break}
\]
Use of automated scribe-and-cleave systems:

- Loomis Inc. - LSD-110
- Dynatex GST-150 (test done at Caltech’s KNI)
- tested: diamond scribing, laser-scribing, and etch-scribing
Edge Emitting Laser (EDL)

Application of scribing and cleaving for III-V compounds:
• to create reflection mirrors on two sides of the cavity
• substrate is thinned down (~100 µm) before cleaving
• after cleaving, protective coating is deposited on both facets to improve lifetime
• cleaving III-V is easy due to Wurtzite crystal structure
• reported yields for dicing GaAs and LED sapphire using diamond-scribe and break: 90–98 %.
Cleaving Silicon

Scribing and cleaving for silicon:
- “ancient technology” – dates back to around 1955.
- By 1983, fully automated in-line blade sawing systems were introduced (higher yield and fully automated).
- Crack naturally propagates also along <110> directions.
- Crack propagation can deflect out of the {110} planes onto the {111} planes.
Diamond-Scribe-and-Cleave

Diamond scribed done with Loomis Inc., LSD-110 and Dynatex GST-150 (test done at Caltech’s KNI).

SEM micrographs, cross-sections

damage from diamond scribing in top passivation layer
“Variations on the Theme”

This is an optional step for the SCP process. A gaseous Xenon Difluoride (XeF₂) etch step can remove scribing damage.
• XeF$_2$ etch clearly reduced the diamond scribe damage.
• XeF$_2$ removes sharp corners, making the diode suitable for high-voltage
Diamond-Scribe-and-Cleave

• XeF$_2$ removes sharp corners, making the diode suitable for high-voltage
Die Strength Enhancement (DSE)

Die strength enhancement (DSE) effort dates back to mechanical grinding for wafer thinning (two-step process including coarse and fine grinding).

Several sidewall treatments using plasma or gaseous Si etching have been used for DSE.


\[ \sigma_{\text{stress}} = \frac{3FL}{2bh^2} \]
• XeF$_2$ etch clearly reduced the laser scribe damage.
SEM micrograph, **no XeF_2 etched sidewall**  

SEM micrograph, **with XeF_2 etched sidewall**

- XeF_2 etch clearly reduced the laser damage at the edge.
- Some roughness remains after XeF_2 etch.
XeF₂ Etch-Scribing

Si SSD with 900 μm dead edge

Cut within 50 μm of Guard Ring

Guard Ring Cut (!) 0 μm to Guard Ring

XeF₂ scribing + Nitride PECVD

with guard ring

without guard ring
Use of automated scribe-and-cleave systems:
• Loomis Inc. - LSD-110
• Dynatex GST-150 (test done at Caltech’s KNI)

Neither system could break the XeF$_2$ etch-scribing sensors.
Stress Concentration Factor

stress concentration factor: \( k = 2(d/r_t)^{1/2} \)

- narrow trench
- deep trench

\( r_t \)

\( d \)

easier cleaving
DRIE Etch-Scribing

- DRIE etching is well-established and controlled process.
DRIE Etch-Scribing

SEM micrographs, cross-sections

- XeF$_2$ etch completely removes scribe line.
1. litho step
2. open oxide with Vapox III Etch (wet etch)
3. DRIE etch
4. laser-scribing
5. cleaving using tweezers
6. XeF₂ sidewall etch (5 cycles)
7. H-termination of sidewall (wet etch)
8. ALD deposition, SiO₂ and Al₂O₃
9. Anneal @ 400 degree C for 10 min

- This could be done in an fully automated process (**tests ongoing**).
- low leakage current and break-down voltage > 1,000 V.
DRIE Etch-Scribing – All Four Sides

- HPK N-Type
- GLAST Baby

- Test DRIE-scribed sensor w/ automated systems

- Optical micrograph, top-view

- Damage from tweezers cleaving
Plasma Dicing

- Plasma dicing is a “DRIE-like” etch process
- Through silicon etch
- Low damage sidewall

Problems with blade dicing:
- Mechanical forces and vibration can cause die crack and chip-outs for thinned wafers
- Damage to low-k dielectrics
- Weak die strength (see special slide)
Effect of Surface Termination – N-Type Si

- Silicon sidewall was H-terminated before depositions.
- The type of passivation material strongly influences the leakage current.
- ALD (Atomic Layer Deposition) nano-stack can be fully automated.
Effect of Surface Termination – P-Type Si

• The type of passivation material strongly influences the leakage current.
• Type of silicon termination influences ALD reactions.
• Still working on ideal surface termination for p-type Si.
### RD50 Activity Matrix

<table>
<thead>
<tr>
<th>Institute</th>
<th>Contact Person</th>
<th>Sensors</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNM Barcelona</td>
<td>G. Pellegrini</td>
<td>3D diodes, strips, pixels</td>
<td>2\textsuperscript{nd} round of tests (FEI3 and FEI4 pixel)</td>
</tr>
<tr>
<td>FBK Trento</td>
<td>G.-F. Dalla Betta</td>
<td>3D diodes, strips</td>
<td>2\textsuperscript{nd} round of tests ongoing</td>
</tr>
<tr>
<td>MPI Muenchen</td>
<td>A. Macchiolo</td>
<td>P-type planar pixels</td>
<td>In progress</td>
</tr>
<tr>
<td>UNFN Bari</td>
<td>D. Creanza</td>
<td>N-type “SMART” detectors</td>
<td>In progress, first devices sent for experimentation</td>
</tr>
<tr>
<td>Ljubljana U.</td>
<td>G. Kramberger</td>
<td>P- and N- type</td>
<td>Devices sent for experimentation</td>
</tr>
<tr>
<td>Glasgow U.</td>
<td>R. Bates</td>
<td>P- and N- type</td>
<td>Used in precision X-ray scan</td>
</tr>
<tr>
<td>TU Dortmund</td>
<td>T. Wittig</td>
<td>IBL-style n-on-n sensors</td>
<td>Initial tests done, Iterations with IBL sensors</td>
</tr>
</tbody>
</table>

**Ongoing Activities within RD50 Collaboration**
3D FEI3 Sensor from CNM

optical micrograph, top-view

SCP edge distance to guard is \( \sim 58 \, \mu\text{m} \).

3D sensor w/ very low depletion voltage

3D sensor from CNM
Thanks to Giulio Pellegrini and Sebastian Grinstein

Scribing-Cleaving-Passivation for HEP Si Sensors
The leakage current for n- and p-type Si diodes strongly depends on the sidewall quality, is a function of the damage on the sidewall, cut distance to the guard ring, and sidewall passivation.

Etch-scribing (shallow plasma etch step) shows very low leakage currents.

Similar singulation techniques are commonly used for commercial thin wafer dicing.

A post-cleaving etch can be used as post-cleaving step to remove sidewall damage, improving the leakage current by removing scribe damage.

Several ongoing joint projects within RD50 collaboration.

We have a clear path towards wafer-scale and fully automated process.

Radiation hardness tests are ongoing.

Fully automated process sequence – ongoing.

We will continue to work with RD50 on common projects.

Pico-sec laser-machining for SCP.
Acknowledgements

We would like to thank the Institute for Nanoscience (NSI) at the Naval Research Laboratory (NRL) and the NSI staff members.

This work was funded in part by the Office of Navy Research (ONR).
Back-Up Slides
Vertex 2012                         Scribing-Cleaving-Passivation for HEP Si Sensors

![Graph showing the relationship between current and minimum distance to bias ring](image)

- **Current [µA]**
  - 0.05
  - 0.1
  - 0.15
  - 0.2
  - 0.25
  - 0.3

- **Min. Distance to Bias Ring [µm]**
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90
  - 100
  - 110

- **Labels:**
  - **guard ring**
  - **SiO₂**
  - **Si₃N₄**

Scribing-Cleaving-Passivation for HEP Si Sensors
Dortmund N-on-N

- easy cleaving
- no tilted sidewall
- cleavage plane follows scribe line
- distance to guard ~ 60 μm

Sensors from U. of Dortmund

top view optical micrographs

Scribing-Cleaving-Passivation for HEP Si Sensors
Dortmund N-on-N

- no tilted sidewall
- cleavage plane follows scribe line

Sensors from U. of Dortmund