LASER SYSTEM FOR SINGLE EVENT EFFECTS (SEE) TESTING

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Outline

- Introduction
  - What is a Single event effect (SEE)
  - How SEE testing is done
  - Advantage and limitation of pulsed laser testing system

- ASP 2\textsuperscript{nd} generation laser system for SEE testing
  - Basics of laser-matter interaction
  - Femtosecond laser
  - Imaging system
  - Positioning system

- Conclusion
What is a SEE?

- Electrical disturbance in a microelectronic circuit caused by the passage of a single energetic particle, heavy ions, protons or neutrons through semiconductor material.

- A circuit functional error or a circuit failure either temporarily or permanently could take place if the single energetic particle induces sufficient plasma density reaching critical charge criteria and the induced charges (electron-hole pairs) are collected at a sensitive node.

*Sensitive node: a node in a circuit whose electrical potential can be modified by internal injection or collection of electrical charges.
Types of SEE:

- Non-destructive/Soft Errors: SEU, SET, SEL
- Destructive/Hard Errors: SEL, SEGR, SEB

**SET** (Single Event Transient)
**SEU** (Single Event Upset), a transient effect, affecting mainly memories
**SEL** (Single Event Latch-up), can destroy the component, affecting mainly CMOS
**SEGR** (Single Event Gate Rupture), potentially destructive, affecting mainly submicron structure
**SEB** (Single Event Burnout), has destructive impact, affecting mainly power MOSFET
What is SEE testing?

- Exposure of a microelectronic circuit (DUT: device under test) to a beam with known characteristics and observation of the circuit response

How SEE testing is done?

- Radiation method (simulate the space environment with particle accelerator)
- Ultrashort pulsed laser method
- Short pulsed X-ray method
DUT strike

*SPA: single photon absorption
TPA: Two photon absorption

SPA or TPA depending on laser wavelength selection
Advantages and limitations of laser testing

Advantages

- Providing detailed **spatial** (mapping) and **temporal** information (SPA, and TPA)
- Possibility of splitting beam into parallel for multi sensitive nodes testing
- No radiation damage
- Fast and low cost

Limitations

- No absolute measure of SEE threshold
- No direct measure of asymptotic cross-section
- Inability to penetrate metal
Basics of laser-matter interaction

\[
\frac{dI(r, z)}{dz} = -\alpha(\lambda)I(r, z) - \sigma_{ex}N I(r, z)
- \beta_2(\lambda)I(r, z)^2
\]

\[
\frac{d\Phi(r, z)}{dz} = \beta_1 I(r, z) - \gamma_1 N(r, z)
\]

\[
\frac{dN(r, z)}{dt} = \frac{\alpha(\lambda)I(r, z)}{\hbar\omega} + \frac{\beta_2(\lambda)I^2(r, z)}{2\hbar\omega}
\]

\(I(r,z)\): laser intensity
\(\Phi(r,z)\): phase
\(r,z\): radial and penetration positions
\(\sigma_{ex}\): free electron absorption cross-section
\(\gamma_1\): refraction factor due to free electron
\(\alpha(\lambda)\): SPA coefficient
\(\beta_2(\lambda)\): TPA coefficient (~1 cm/GW)
\(N\): plasma density
\(\omega\): laser frequency
Plasma lifetime in silicon: ~ 10s ns
Absorption Coefficient of Silicon
Penetration depth in silicon
<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Absorption coefficient (/cm)</th>
<th>Absorption depth (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>530</td>
<td>7.85E+03</td>
<td>1.27</td>
</tr>
<tr>
<td>800</td>
<td>8.5E+02</td>
<td>11.8</td>
</tr>
<tr>
<td>1030</td>
<td>30.2</td>
<td>331</td>
</tr>
<tr>
<td>1060</td>
<td>11.1</td>
<td>901</td>
</tr>
<tr>
<td>1240 (TPA)</td>
<td>2.4E-03</td>
<td>4.17E+06</td>
</tr>
</tbody>
</table>
Two-photon absorption

- Nonlinear process
  - Several orders of magnitude weaker than single-photon absorption (because it depends on the probability of simultaneously absorbing two photons at the same time).
  - Strength of absorption depending on the square of the laser intensity (therefore, ultrashort pulse laser is required).

- Photon energy
  - Single-photon absorption: photons with energies exceeding the band-gap
  - Two-photon absorption: smaller than band-gap and higher than half the band-gap (silicon band-gap: ~1.1 eV / ~ 1127 nm). For TPA to take place in silicon, a femtosecond laser with wavelength greater than ~1127 nm is thus required.
Advantage of TPA

- **Penetration depth**
  - No limit for TPA, capable of 3D mapping, back-side irradiation of circuits and devices built on silicon wafers; avoid interference from metal overlayers
  - ~1 \( \mu \)m Up to ~1 mm for SPA depending on wavelength

- **Interaction zone**
  - Deposited energy well confined in the focal zone for TPA due to the nonlinear absorption
  - Linear absorption taking place along the laser path in silicon for single photon absorption

**Disadvantage of TPA**
- Reduced resolution for the microscope system
- High cost for the ultrashort laser system
Applications of SPA and TPA

- SPA: can be used for font-side and back-side irradiations, but it is limited in the penetration depth (~1 µm to ~1 mm).

- TPA: used for 3D mapping, back-side irradiation, theoretically can be focused to any depth. Mostly used for the situations that SPA cannot fulfill and high-density circuits and flip-chip configuration.
2\textsuperscript{nd} generation SEE testing platform

- 1. Laser system with external power control and monitoring for irradiation
- 2. Telecentric Kohler-type illuminator for high-contrast shadow-free imaging
- 3. Imaging system (>1.5 Megapixel) for front side and back side irradiation
- 4. High resolution positioning subsystem based on a motorized xyz stage. Auto-focusing system could be incorporated if needed.
## ASP laser system characteristics

<table>
<thead>
<tr>
<th>ASP laser system</th>
<th>Femto</th>
<th>Femto OPA for TPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>1030 nm</td>
<td>630-2600 nm</td>
</tr>
<tr>
<td>Max power</td>
<td>5 W</td>
<td>6 W</td>
</tr>
<tr>
<td>Rep. rate</td>
<td>Single shot ~ 1 MHz</td>
<td>Single shot ~ 100 kHz</td>
</tr>
<tr>
<td>Max pulse energy</td>
<td>60 μJ</td>
<td>&gt; 200 nJ @ 1240 nm @ 1 kHz</td>
</tr>
<tr>
<td>Pulse width</td>
<td>&lt; 400 fs</td>
<td>150 ~ 250 fs</td>
</tr>
<tr>
<td>External triggering for synchronization</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Beam quality</td>
<td>$M^2 &lt; 1.2$, TEM$_{00}$</td>
<td></td>
</tr>
<tr>
<td>Energy contrast</td>
<td>23 dB</td>
<td></td>
</tr>
<tr>
<td>Shot to shot instability</td>
<td>&lt; 2%</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Output polarization</td>
<td>H</td>
<td>630-1030 nm (H)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1030-2600 nm (V)</td>
</tr>
</tbody>
</table>

*For most SEE laser tests, the pulse energy on the DUT is varied from 10 pJ to 1 μJ.*
Positioning stages (example)

<table>
<thead>
<tr>
<th>Item #</th>
<th>LNR50S</th>
<th>LNR50SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Range</td>
<td>50 mm (1.97&quot;)</td>
<td></td>
</tr>
<tr>
<td>Velocity (Max)</td>
<td>20 mm/s</td>
<td></td>
</tr>
<tr>
<td>Min Achievable Incremental Move</td>
<td>0.05 µm</td>
<td>0.3 µm</td>
</tr>
<tr>
<td>Bidirectional Repeatability</td>
<td>0.5 µm</td>
<td>0.3 µm</td>
</tr>
<tr>
<td>Backlash</td>
<td>&lt;6 µm</td>
<td></td>
</tr>
<tr>
<td>Horizontal Load Capacity (Max)</td>
<td>66 lbs (30 kg)</td>
<td></td>
</tr>
<tr>
<td>Vertical Load Capacity (Max)</td>
<td>22 lbs (10 kg)</td>
<td></td>
</tr>
<tr>
<td>Included Actuator</td>
<td>DRV014 Stepper Motor</td>
<td></td>
</tr>
<tr>
<td>Cable Length</td>
<td>500 mm (1.64 ft)</td>
<td></td>
</tr>
<tr>
<td>Recommended Controller</td>
<td>APT™ Stepper Motor Controllers</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- Laser system for both SPA and TPA
- Real-time energy monitoring
- High resolution CCD (color and SWIR) for front and back side irradiation
- Kohler-type illumination for better imaging