Radiation-Hardness of VCSEL/PIN

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Outline

- Introduction
- Radiation hardness of PINs
- Radiation hardness of VCSELs
- Summary
Radiation Dosage at SLHC

- VCSEL/PIN are used in optical links to transmit/receive light (data)
- VCSEL/PIN of current ATLAS pixel detector are mounted on patch panel (PP0) instead of directly on the FE
  - much reduced radiation level
  - VCSEL/PIN for pixel detector at SLHC will not be mounted on FE
  - expected dosage at $r = 37 \text{ cm}$ for $3,000 \text{ fb}^{-1}$ with 50% safety factor:
    - silicon: $7.2 \times 10^{14} \text{ 1-MeV } n_{eq}/\text{cm}^2$
    - GaAs: $2.8 \times 10^{15} \text{ 1-MeV } n_{eq}/\text{cm}^2$
    - assuming radiation damage scales with Non-Ionizing Energy Loss (NIEL)
850 nm VCSEL Irradiation

- 2006-7:
  - ~2 VCSEL arrays were irradiated to SLHC dosage
  - AOC 2.5 Gb/s (obsolete), 5 Gb/s, 10 Gb/s
  - ULM 5 Gb/s, 10 Gb/s
  - Optowell 2.5 Gb/s
  - insufficient time for annealing during irradiation

- 2008:
  - ~2 VCSEL arrays
  - AOC 5 Gb/s, 10 Gb/s
  - Optowell 2.5 Gb/s

- 2009:
  - AOC 10 Gb/s
  - goal: 20 arrays
  - actual: 6 arrays due to manufacturer problem
7.6 x 10^{15} 1-\text{MeV} n_{eq}/\text{cm}^2

- optical power recovery by annealing is slow
- almost recover the initial power after extended annealing
- VCSEL produces more power at lower temperature

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Good optical power for 6 arrays irradiated
- await return of arrays to Ohio State for annealing/characterization
- need to irradiate a sample of 20 arrays in 2010

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145 μW

4.4 x 10^{15} 1-MeV n_{eq}/cm^2
## 2008 PIN Irradiation

<table>
<thead>
<tr>
<th>Material</th>
<th>Gb/s</th>
<th>Responsivity (A/W)</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs (4.4 x 10^{15} 1-MeV n_{eq}/cm^2)</td>
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<tr>
<td>ULM</td>
<td>4.25</td>
<td>0.50</td>
<td>0.09</td>
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<tr>
<td>AOC</td>
<td>5.0</td>
<td>0.60</td>
<td>0.13</td>
<td></td>
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<tr>
<td>Optowell</td>
<td>3.125</td>
<td>0.60</td>
<td>0.17</td>
<td></td>
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<tr>
<td>Hamamatsu G8921</td>
<td>2.5</td>
<td>0.50</td>
<td>0.28</td>
<td></td>
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<tr>
<td>Si (7.5 x 10^{14} 1-MeV n_{eq}/cm^2)</td>
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<td></td>
<td></td>
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<tr>
<td>Taiwan</td>
<td>1.0</td>
<td>0.55</td>
<td>0.21</td>
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<tr>
<td>Hamamatsu S5973</td>
<td>1.0</td>
<td>0.47</td>
<td>0.31</td>
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<tr>
<td>Hamamatsu S9055</td>
<td>1.5/2.0</td>
<td>0.25</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

- Irradiated 2 arrays or several single channel devices for each type
- Hamamatsu devices have low bandwidth but more radiation hard
- Irradiated 20 Optowell arrays in 2009

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Responsivity does not depend on bias voltage before irradiation
- Can increase responsivity with higher bias after radiation

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4.4 x 10^{15} \text{1-MeV n_{eq}/cm}^2
PIN Responsivity vs Bias Voltage

- can fully recover pre-irradiation responsivity with high bias voltage
- need to look at pulse shape at high bias voltage
Eye Diagram at High Bias Voltage

● Test limited to 1 Gb/s @ 40 V due to carry board limitation
● Eye diagram looks reasonable
⇒ need more detailed characterization

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Results on Optowell PIN Arrays

- 20 Optowell PIN arrays irradiated in August 2009
  - good responsivity after irradiation
  - average responsivity after irradiation: \sim 0.3 \text{ A/W}

8.1 \times 10^{15} \text{ 1-MeV } n_{\text{eq}}/\text{cm}^2
Results on Optowell PIN Arrays

- above result is for 10 out of 20 Optowell arrays irradiated in 2009
  - analysis complicated by beam misalignment
    - need more detailed study, including eye diagram after cooldown
- AOC plans to release high-speed PIN arrays in 2010
  - plan to irradiate a sample of 20 arrays
Summary

● AOC 10 Gb/s arrays have good optical power after irradiation
  ◆ VCSEL produces more power at room temperature or lower
  ◆ Need to repeat irradiation with large sample in 2010
● Hamamatsu PINs are slow but more radiation hard
● Optowell PIN arrays have good responsivity after irradiation
  ◆ Can increase responsivity with higher bias voltage after radiation
● Will irradiate a large sample of AOC PIN arrays in 2010