Radiation Hardness of VCSEL and PIN Arrays

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Outline

- Radiation damage in VCSEL and PIN
- Results on PIN with protons/pions irradiation
- Results on VCSEL with protons/pions irradiation
- Summary
Radiation Damage in VCSEL/PIN

- optical links use VCSEL and PIN:
  - Vertical-Cavity Surface-Emitting Laser to convert electrical signal into optical signal
  - PIN diode to convert optical signal back into electrical signal

- main effect of radiation:
  - bulk damage, i.e. displacement of atoms

- high speed VCSEL/PIN are fabricated using GaAs instead of silicon

- VCSEL/PIN in collider experiments are exposed to mixture of particle species
  - use NIEL hypothesis to estimate fluence:
    - damage is proportional to non ionizing energy loss
Fluence at High Luminosity-LHC

- Expected fluence for 3,000 fb$^{-1}$ at radius of 37 cm
  - $2.8 \times 10^{15}$ 1-MeV $n_{eq}/\text{cm}^2$
  - $5.4 \times 10^{14} \ p/\text{cm}^2$ for 24 GeV protons

- Study degradation with 24 GeV protons and 300 MeV/c pions
  - NIEL hypothesis: 300 MeV pion is 1.5 more damaging
VCSEL/PIN Irradiation

Study radiation hardness of VCSEL/PIN arrays since 2006:
- vendors: AOC, Optowell, ULM, Hamamatsu
- speed: up to 10 Gb/s
- results: identified following devices for irradiation with 20 arrays
  - Optowell 3.125 Gb/s PIN arrays (2009): large leakage current
  - ULM 4.25 Gb/s PIN arrays (2010): see next slides
  - AOC 10 Gb/s VCSEL (2010): see next slides
Irradiation of PIN with Protons

20 ULM 12-channel PIN arrays (4.25 Gb/s) were irradiated to a dose of $1.0 \times 10^{15} \text{p/cm}^2$ (24 GeV/c).

- decrease in PIN responsivity is modest
Irradiation of PIN with Pions

- 2 ULM 12-channel PIN arrays (4.25 Gb/s) were irradiated to a dose of $4.3 \times 10^{14}$ π/cm$^2$ (300 MeV/c).
- Decrease in PIN responsitivity is small.

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<tr>
<th>Channel</th>
<th>Dose</th>
<th>I/I$_0$</th>
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<tr>
<td>Entries</td>
<td>I/I$_0$</td>
<td>Channel</td>
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Test of NIEL Hypothesis

- NIEL hypothesis:
  - damage is proportional to the non ionizing energy loss
  - 300 MeV pion is 1.5 more damaging than 24 GeV protons
  - decrease in PIN responsivity with $4.3 \times 10^{14} \pi/cm^2$: 81%
  - decrease in PIN responsivity with $6.6 \times 10^{14} p/cm^2$: 78%
  - consistent with NIEL hypothesis
Resposivity vs Voltage

- Before irradiation: reach responsivity plateau at relatively low voltage
- After irradiation: can partially recover responsivity with higher voltage
  - need to verify the high-speed operation
Proton Irradiation of VCSEL

- 12 AOC arrays (10 Gb/s) irradiated to $8.0 \times 10^{14} \text{ p/cm}^2$ (24 GeV/c)
  - alternate between irradiation and annealing (biased/no radiation)
  - decrease in optical power is modest
  - annealing in progress
    ⇒ will recover most lost optical power
Radiation Effect on Threshold Current

- Radiation damage increases current threshold for lasing
- Decrease optical power at same drive current

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Annealing of Radiation Damage

- Radiation damage can be annealed by drive current in VCSEL
  - decrease in threshold current
  - increase in optical power at same drive current
Pion Irradiation of VCSEL

One AOC 10 Gb/s VCSEL array was irradiated:

- dose: $4.1 \times 10^{14} \pi/\text{cm}^2$ (300 MeV/c)
- continuous irradiation with no dedicated annealing period due to limited time slot
- decrease in optical power is modest
Test of NIEL Hypothesis

- NIEL hypothesis:
  - damage is proportional to the non ionizing energy loss
  - 300 MeV pion is 1.5 more damaging than 24 GeV protons
  - damage with $4.1 \times 10^{14} \pi/\text{cm}^2$ is equivalent to $6.4 \times 10^{14} p/\text{cm}^2$?
  - need to repeat proton irradiation with no dedicated annealing
    - difficult to receive the exact required dose in 47 hours

6.4 x $10^{14}$ p/cm²
Plan for VCSEL/PIN Array Irradiation

- **AOC 10 Gb/s VCSEL arrays:**
  - NIEL study: need to perform proton irradiation with no dedicated annealing
  - Need to repeat proton irradiation with higher statistics
    - Half of arrays produced no light before irradiation last summer
    - AOC claimed due to material from sticky membrane

- **ULM 10 Gb/s PIN arrays:**
  - Will test two of these newly available arrays to start
Summary

- ULM PIN arrays: modest decrease in responsivity after irradiation
  - damage from pion/proton consistent with NIEL hypothesis
- AOC VCSEL arrays: modest decrease in opto-power after irradiation
- more irradiation of 10 Gb/s PIN/VCSEL arrays this summer
  - attempting proton irradiation of VCSEL arrays with precise dosage and no dedicated annealing to test NIEL hypothesis