Radiation-Hardness of VCSEL/PIN

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Outline

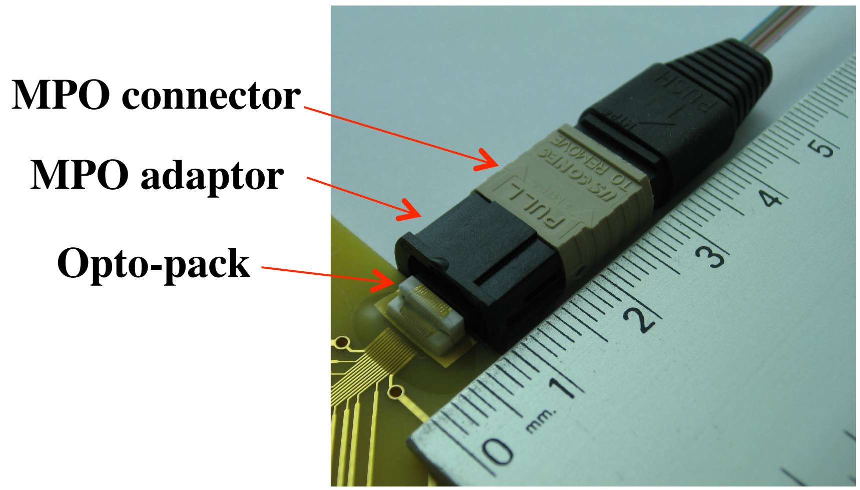
- Introduction
- Radiation hardness of PINs
- Radiation hardness of VCSELs
- Summary

Radiation Dosage at SLHC

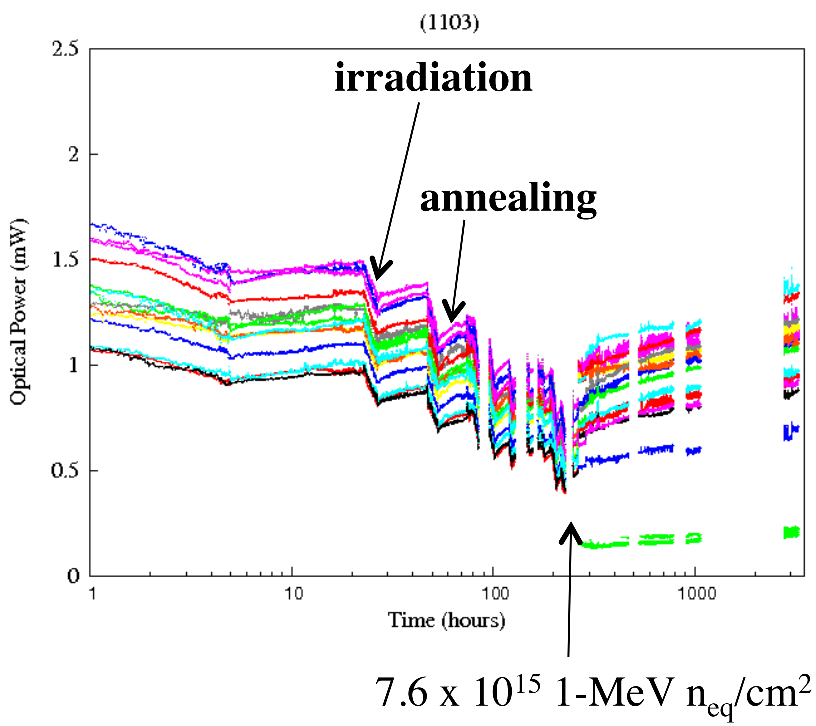
- VCSEL/PIN are used in optical links to transmit/receive light (data)
- VCSEL/PIN of current ATLAS pixel detector are mounted on patch panel (PP0) instead of directly on the FE
  - ⇨ much reduced radiation level
  - ⇨ VCSEL/PIN for pixel detector at SLHC will not be mounted on FE
  - ⇨ expected dosage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

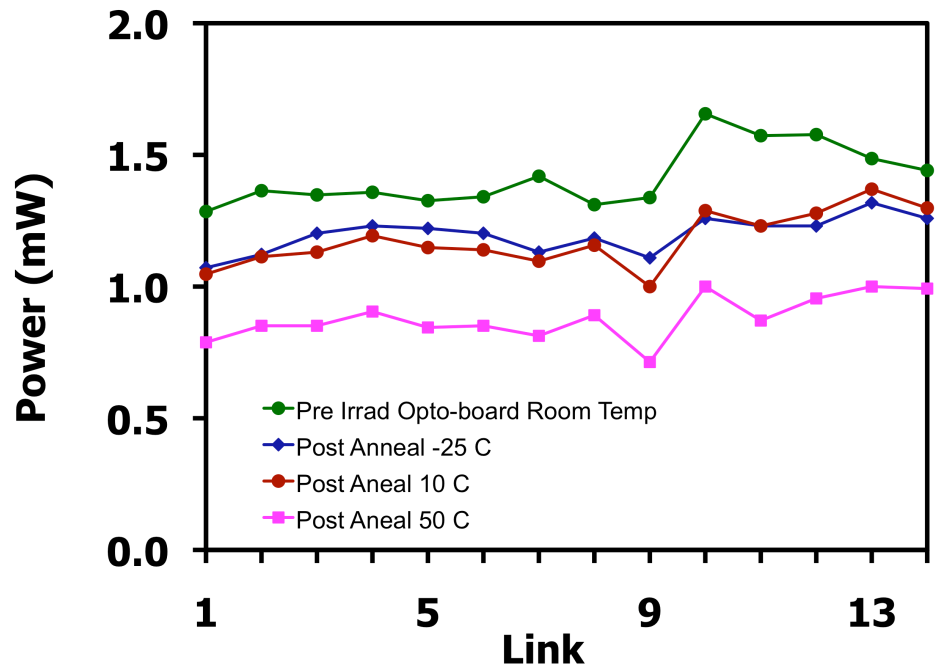
850 nm VCSEL Irradiation

- 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



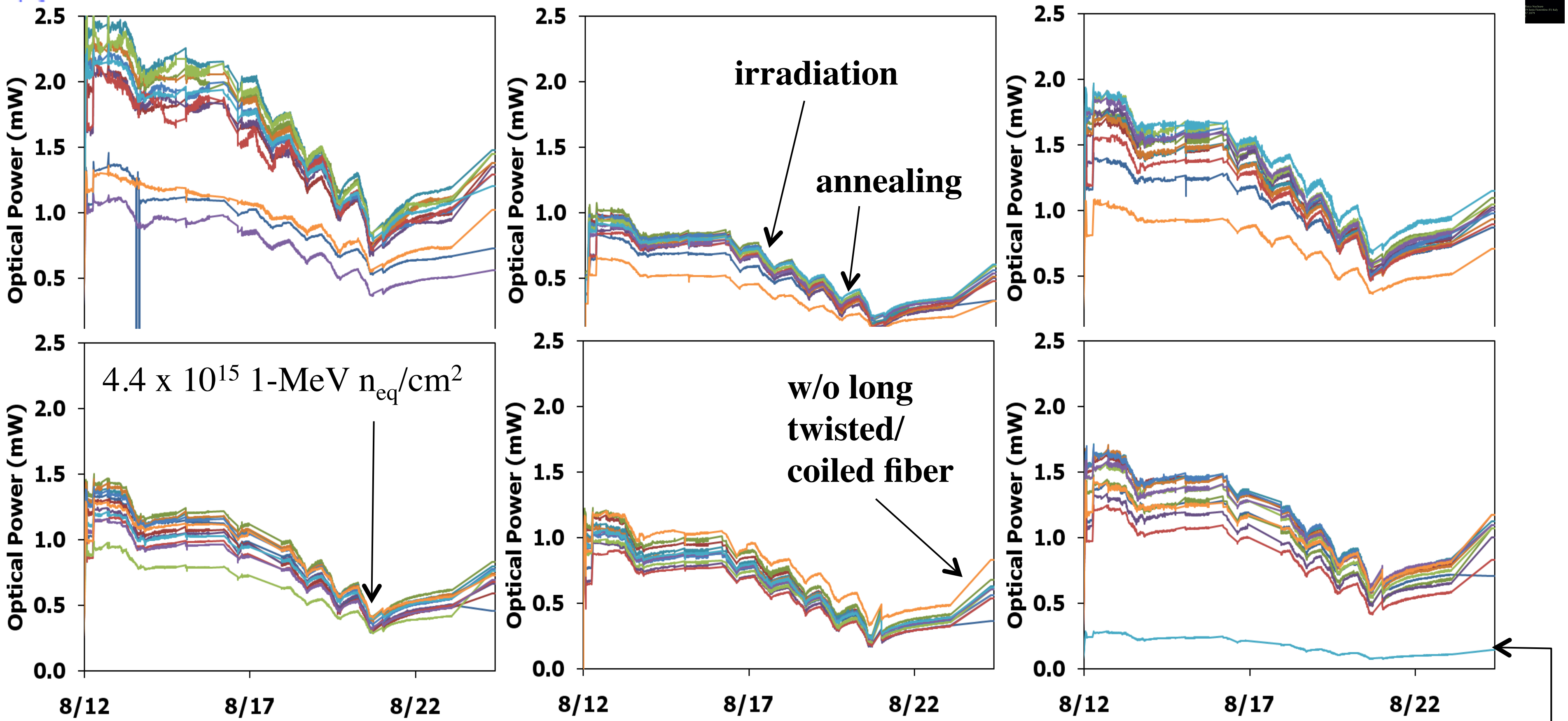
AOC 10 Gb/s VCSEL (2008)





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

AOC 10 Gb/s VCSEL



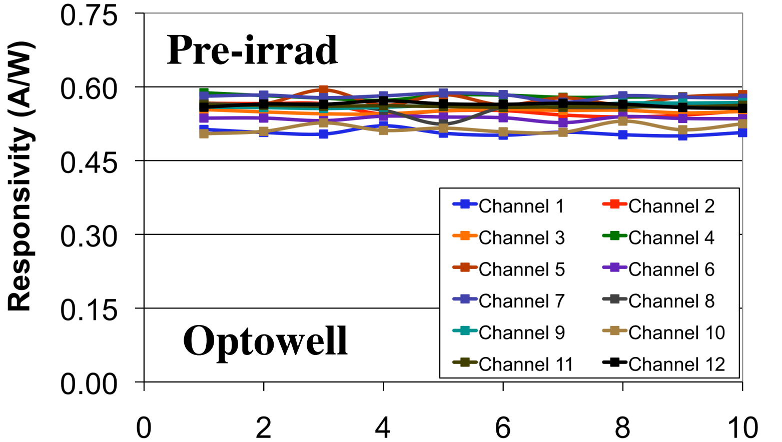
- Good optical power for 6 arrays irradiated
  - await return of arrays to Ohio State for annealing/characterization
  - ⇨ need to irradiate a sample of 20 arrays in 2010

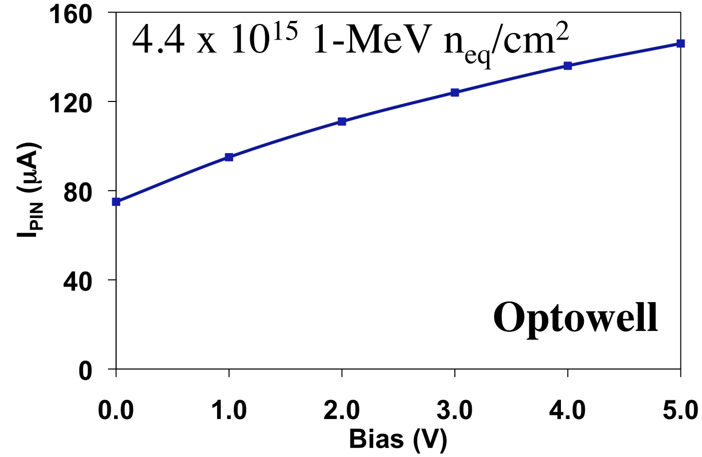
2008 PIN Irradiation

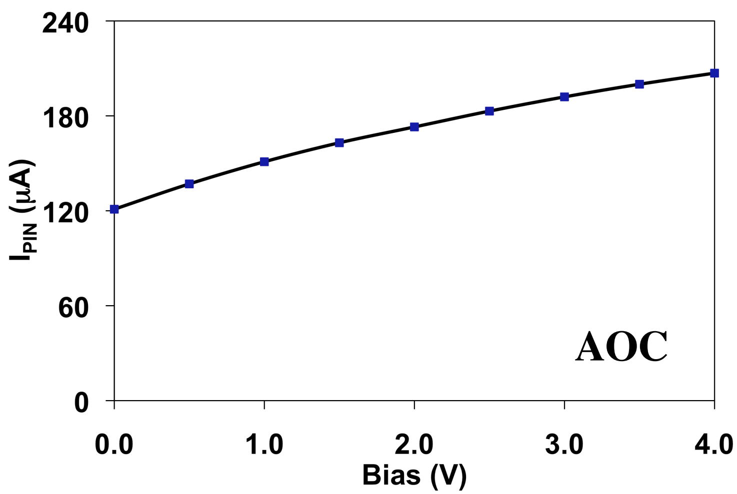
	Gb/s	Responsivity (A/W)	
GaAs (4.4 x 10^{15} 1-MeV n_{eq}/cm^2)		Pre	Post
ULM	4.25	0.50	0.09
AOC	5.0	0.60	0.13
Optowell	3.125	0.60	0.17
Hamamatsu G8921	2.5	0.50	0.28
Si (7.5 x 10^{14} 1-MeV n_{eq}/cm^2)			
Taiwan	1.0	0.55	0.21
Hamamatsu S5973	1.0	0.47	0.31
Hamamatsu S9055	1.5/2.0	0.25	0.20

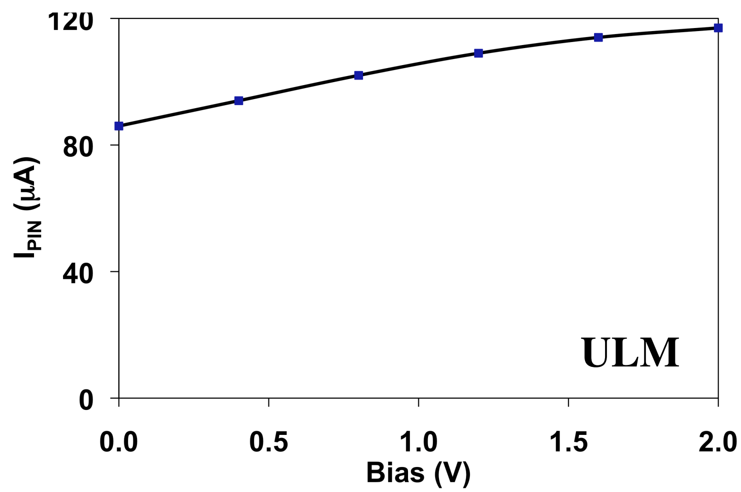
- Irradiated 2 arrays or several single channel devices for each type
- Hamamatsu devices have low bandwidth but more radiation hard
- Irradiated 20 Optowell arrays in 2009

PIN Responsivity vs Bias Voltage



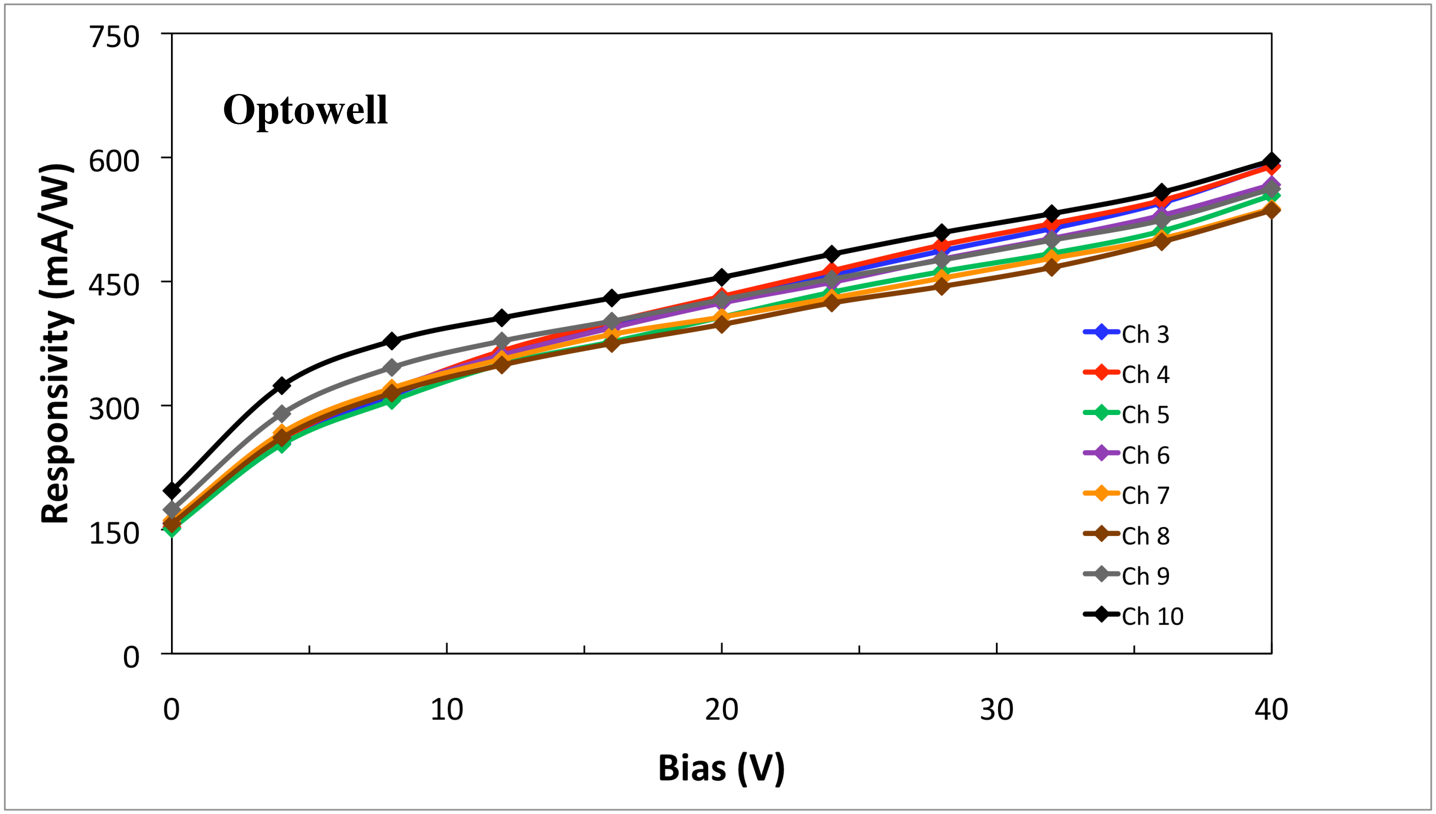






- Responsivity does not depend on bias voltage before irradiation
- Can increase responsivity with higher bias after radiation

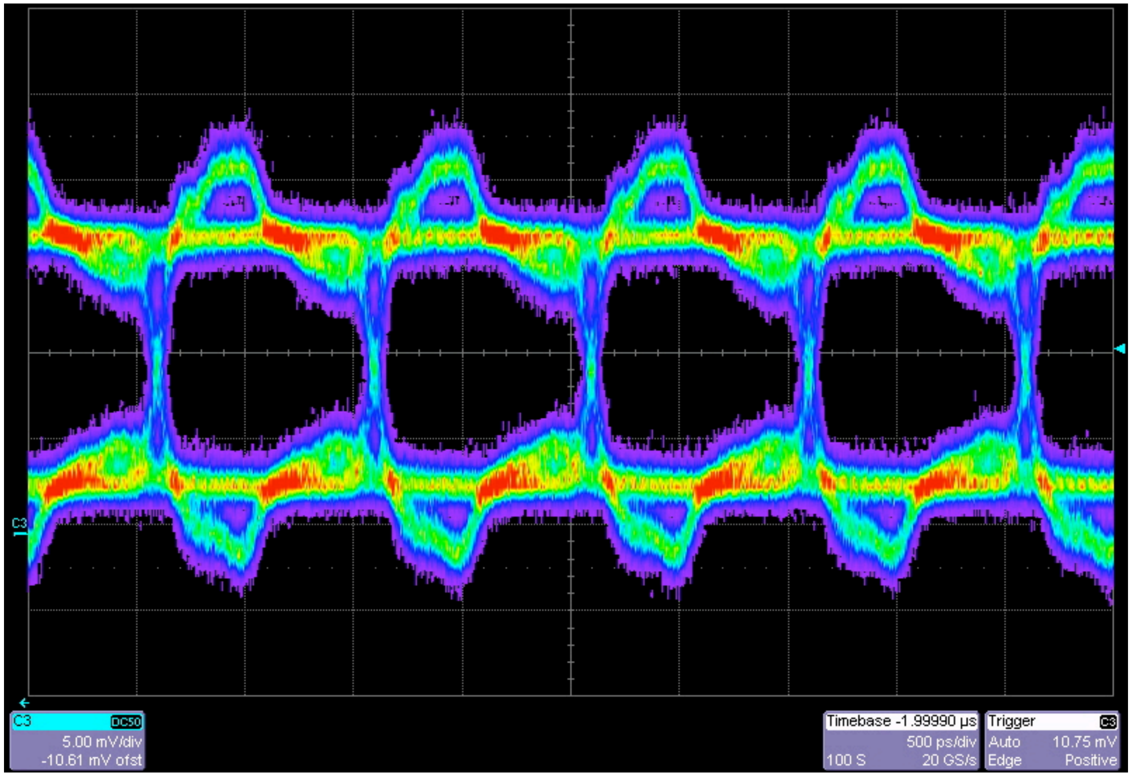
PIN Responsivity vs Bias Voltage



- 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

Optowell

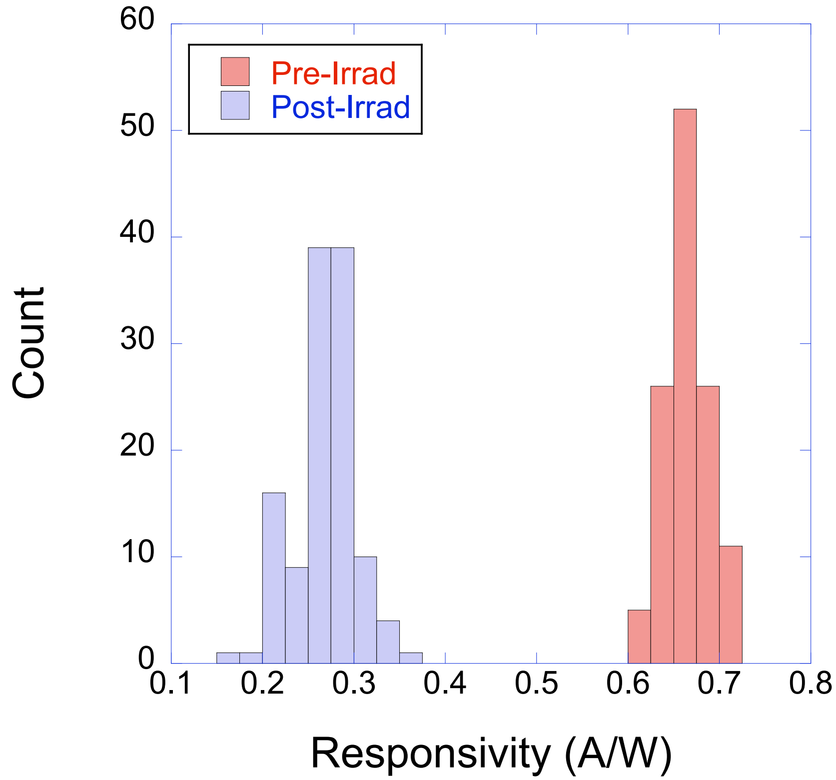


- Test limited to 1 Gb/s @ 40 V due to carry board limitation
- Eye diagram looks reasonable

⇨ need more detailed characterization

Results on Optowell PIN Arrays

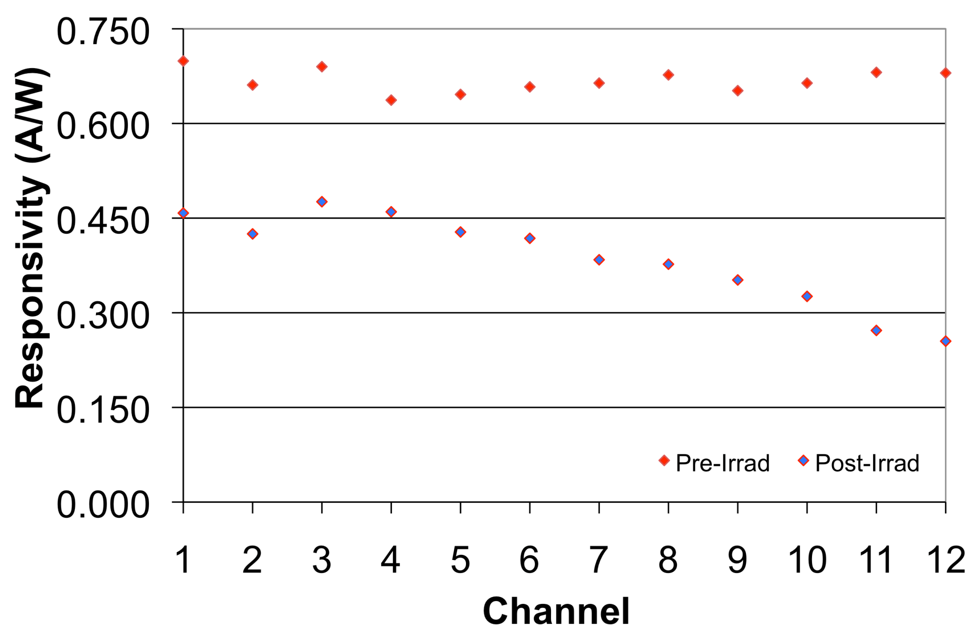
- 20 Optowell PIN arrays irradiated in August 2009
  - ✔ good responsivity after irradiation
  - ◆ average responsivity after irradiation: ~0.3 A/W



8.1×10^{15} 1-MeV n_{eq}/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