



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 of current 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 $3,000 \text{ fb}^{-1}$ with 50% safety factor:
 - ◆ silicon: 7.2×10^{14} 1-MeV $n_{\text{eq}}/\text{cm}^2$
 - ◆ GaAs: 2.8×10^{15} 1-MeV $n_{\text{eq}}/\text{cm}^2$
 - ◆ assuming radiation damage scales with Non-Ionizing Energy Loss (NIEL)



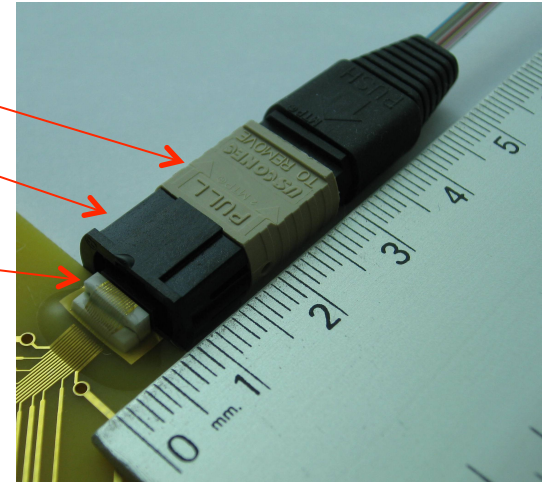
850 nm VCSEL Irradiation

- 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

MPO connector

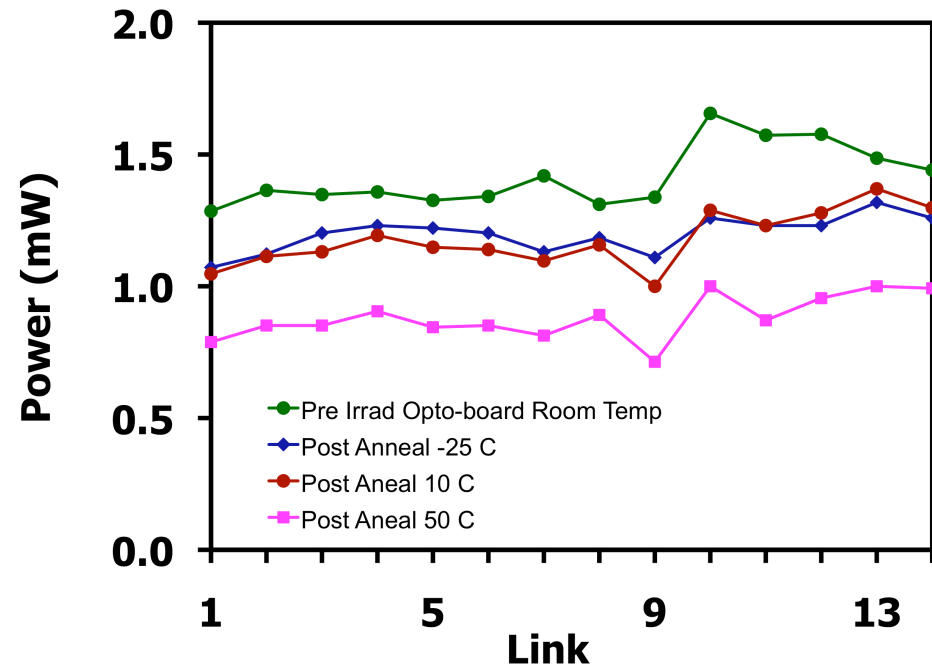
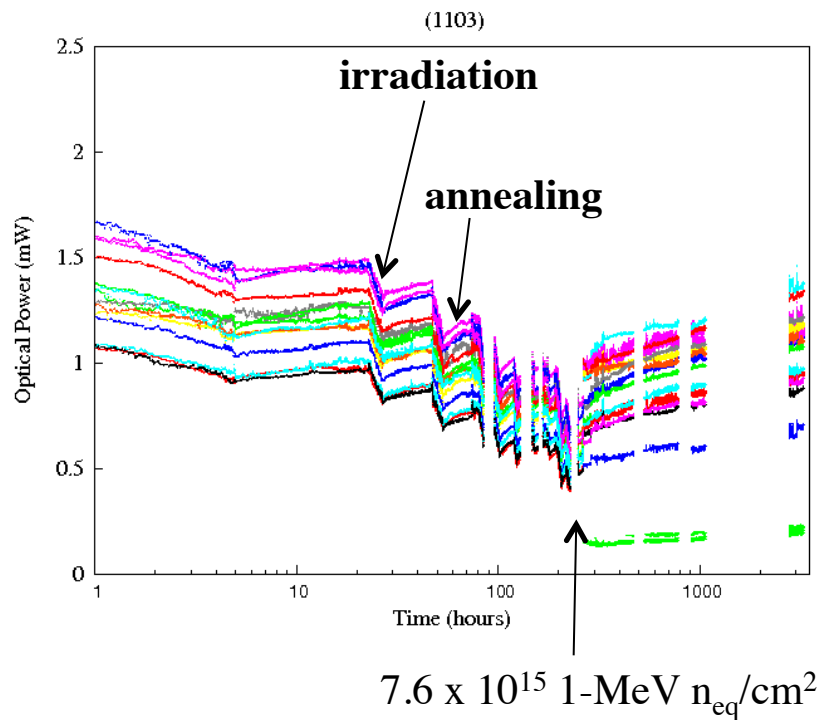
MPO adaptor

Opto-pack





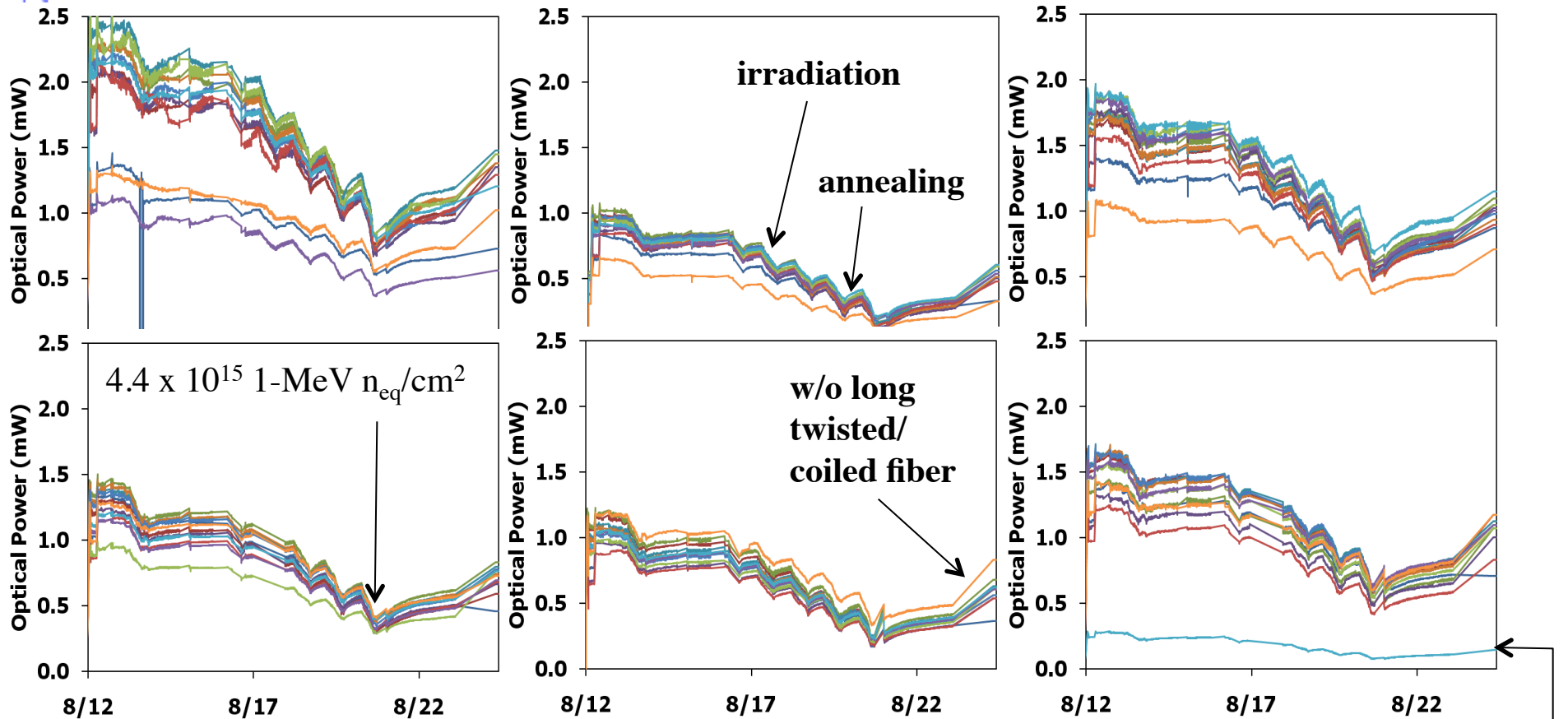
AOC 10 Gb/s VCSEL (2008)



- 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



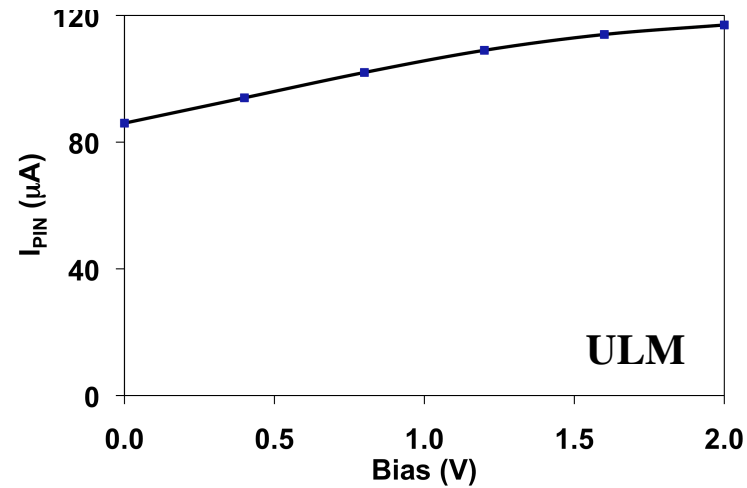
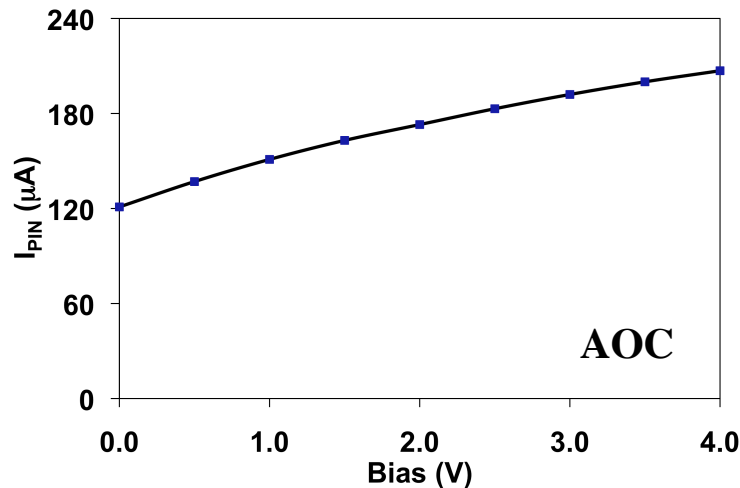
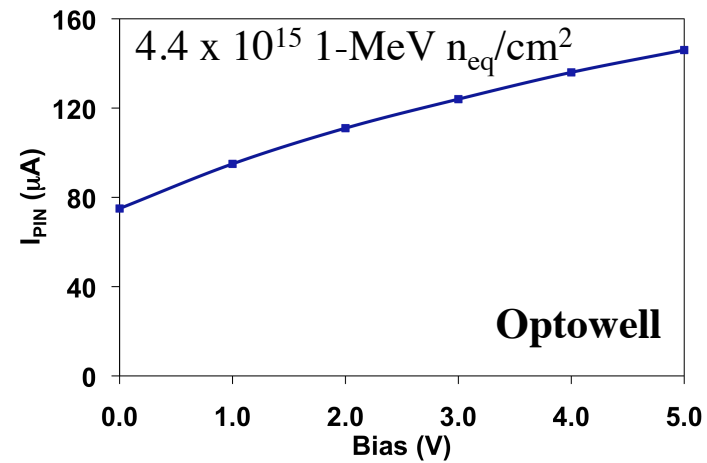
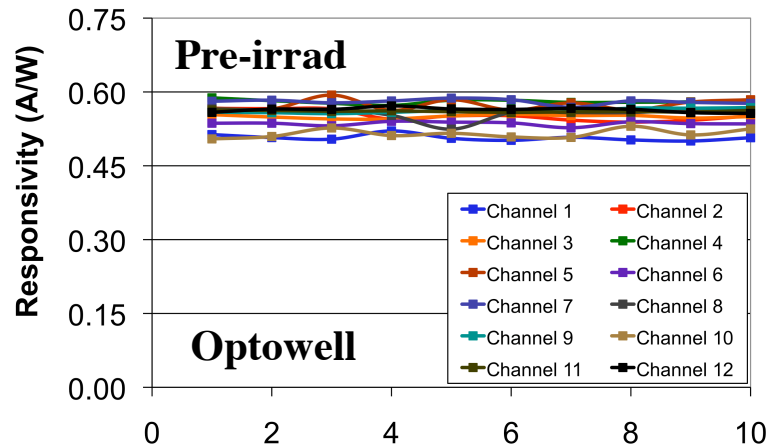
2008 PIN Irradiation

	Gb/s	Responsivity (A/W)	
		Pre	Post
GaAs (4.4×10^{15} 1-MeV n_{eq}/cm^2)			
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 (7.5×10^{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



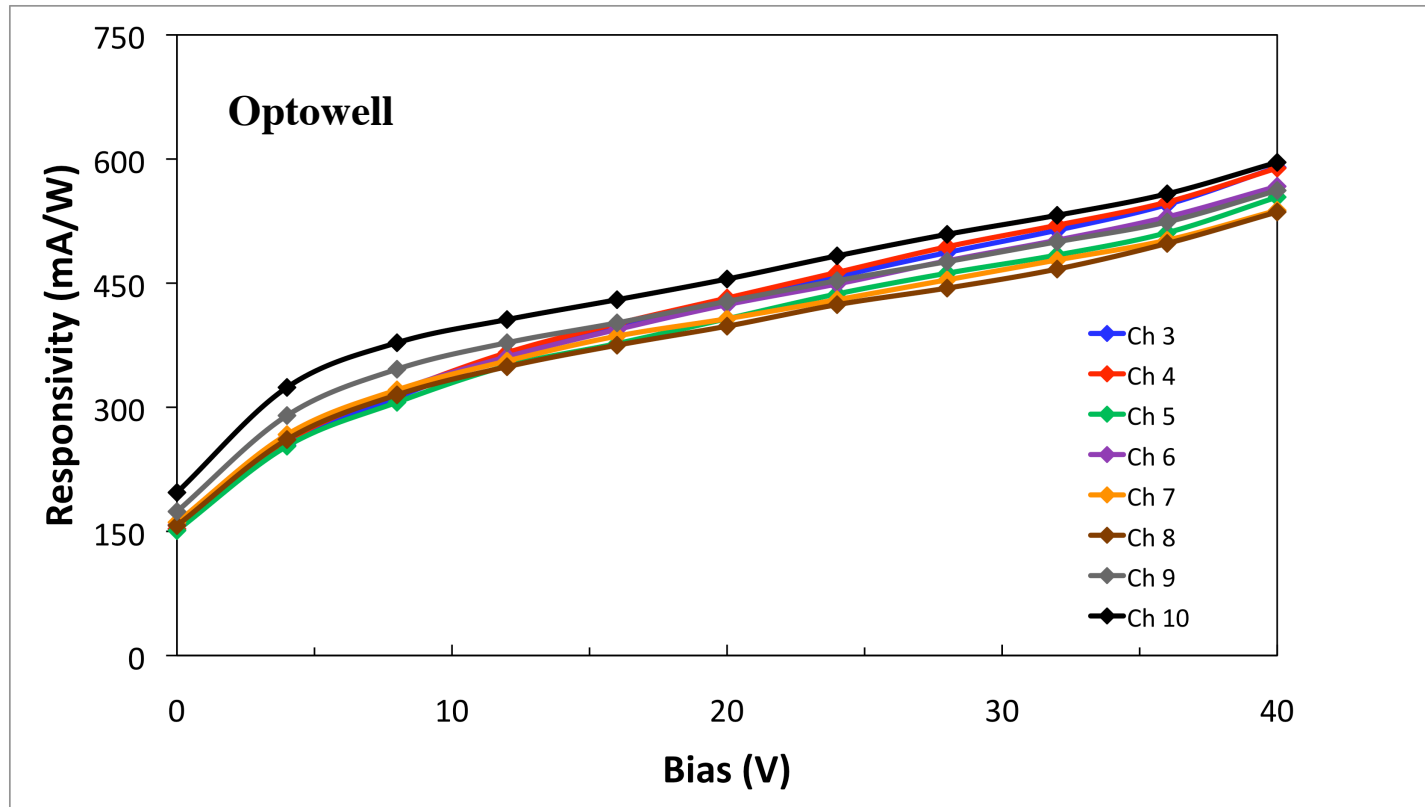
PIN Responsivity vs Bias Voltage



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



PIN Responsivity vs Bias Voltage

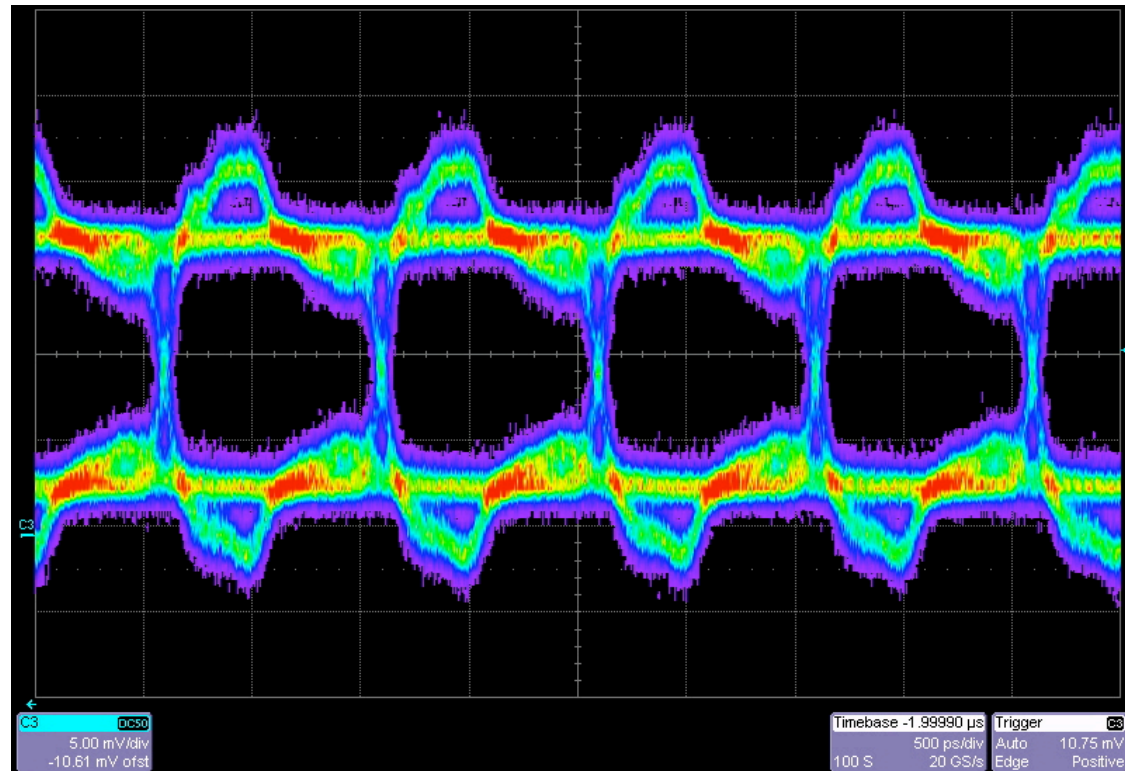


- can fully recover pre-irradiation responsivity with high bias voltage
- ⇒ need to look at pulse shape at high bias voltage



Eye Diagram at High Bias Voltage

Optowell

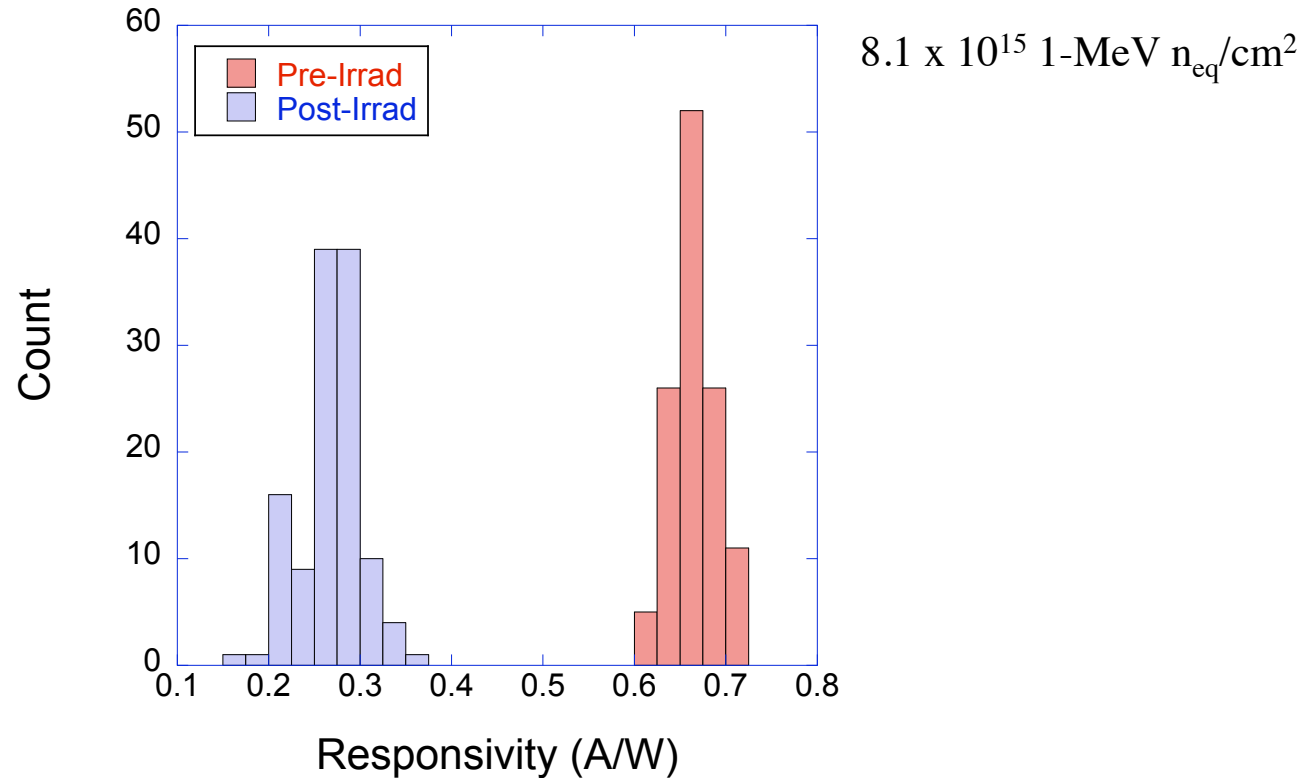


- Test limited to 1 Gb/s @ 40 V due to carry board limitation
- Eye diagram looks reasonable
- ⇒ need more detailed characterization



Results on Optowell PIN Arrays

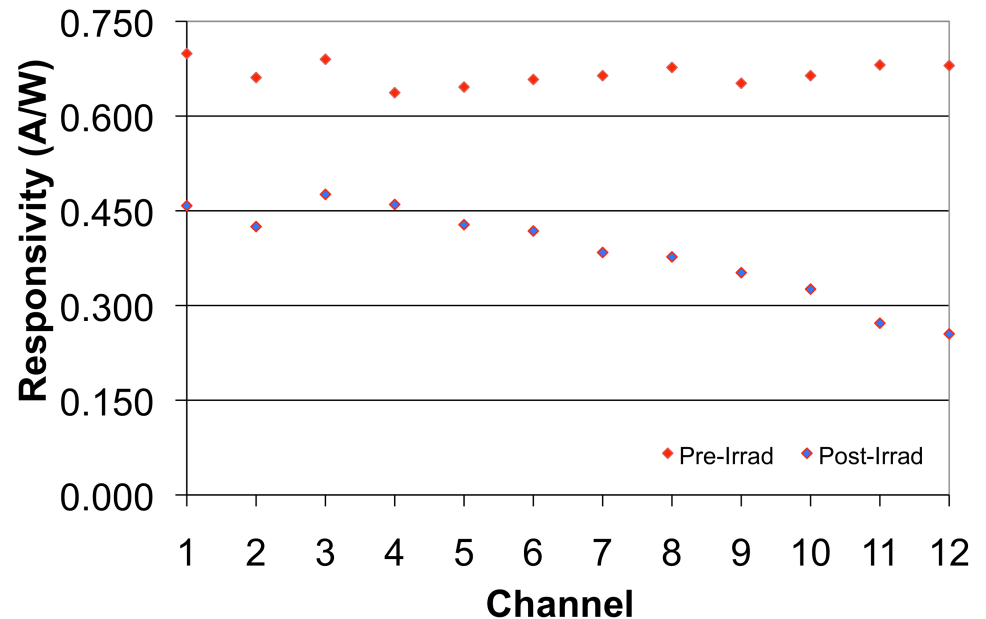
- 20 Optowell PIN arrays irradiated in August 2009
- ✓ good responsivity after irradiation
- ◆ average responsivity after irradiation: ~ 0.3 A/W





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