



# Radiation-Hardness of VCSEL/PIN

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November 6, 2009



# Outline

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



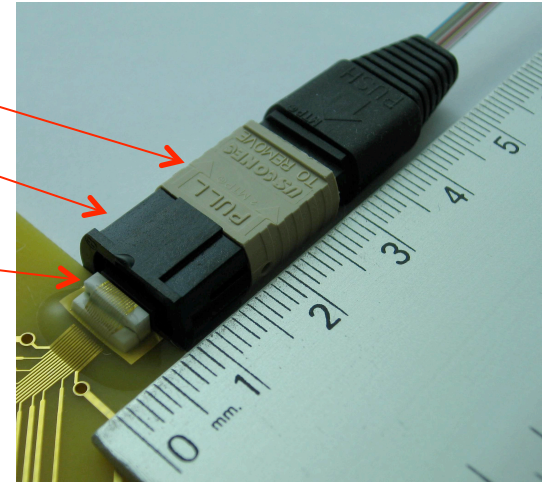
# 850 nm VCSEL Irradiation

- 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**

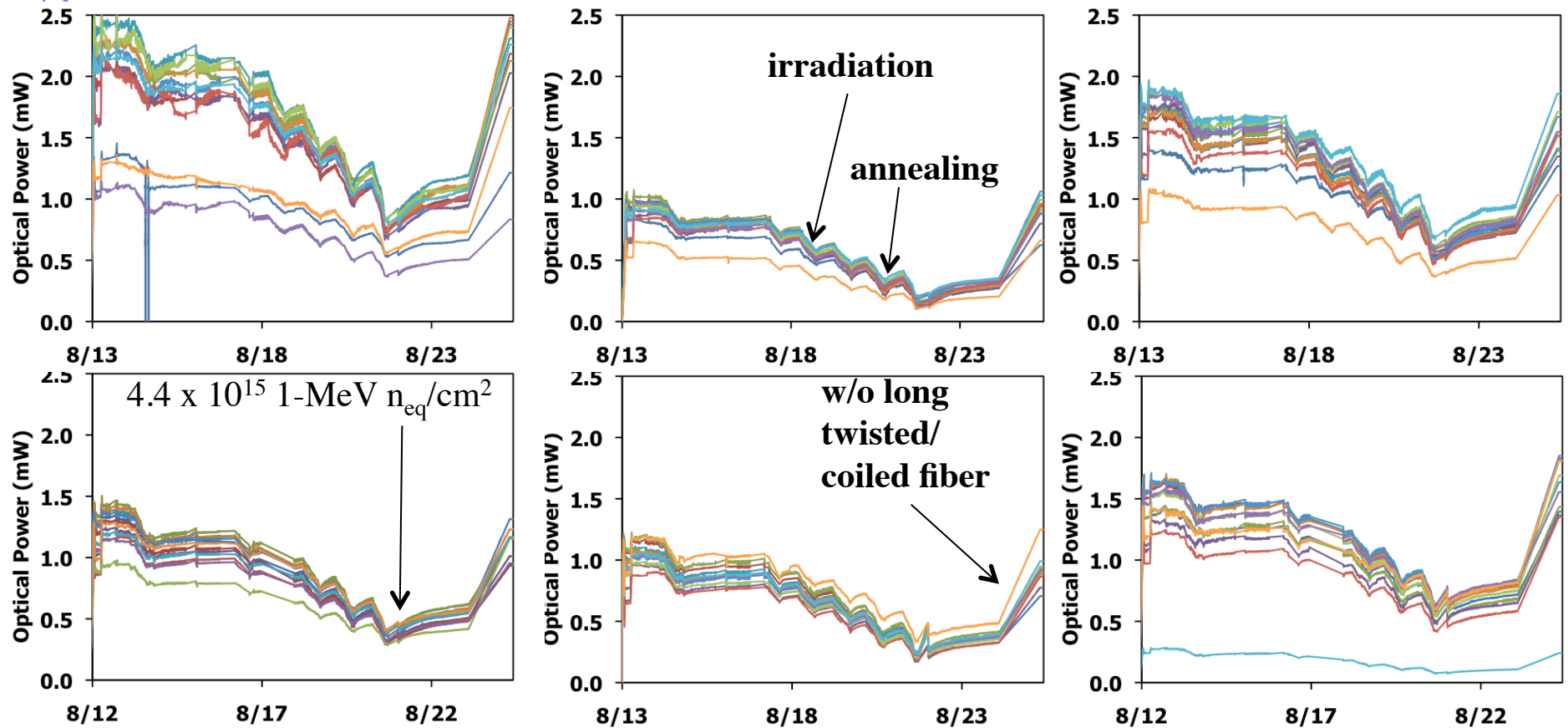
**MPO adaptor**

**Opto-pack**





# AOC 10 Gb/s VCSEL



- Good optical power for 6 arrays irradiated
  - ◆ will start annealing next week at Ohio State to regain some power
  - ⇒ need to irradiate a sample of 20 arrays in 2010



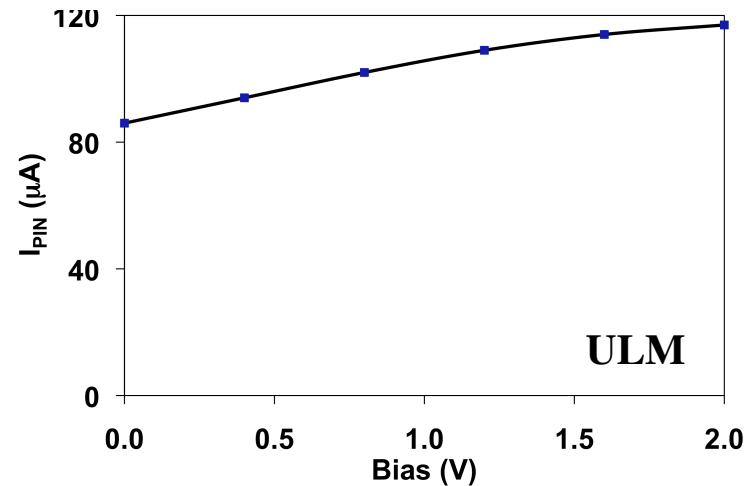
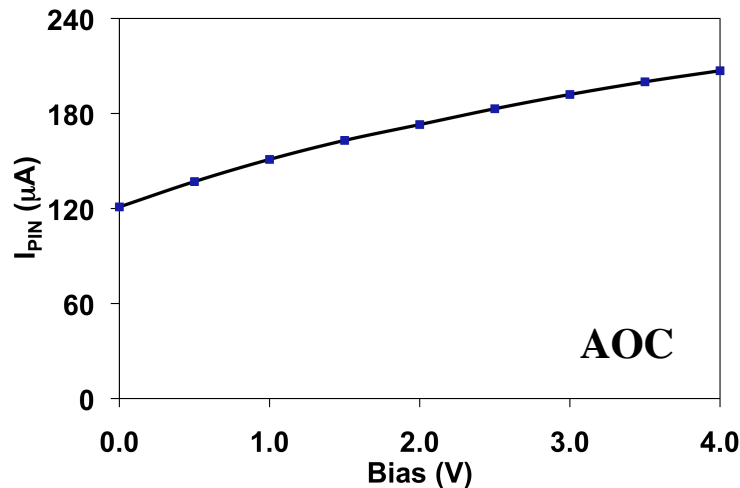
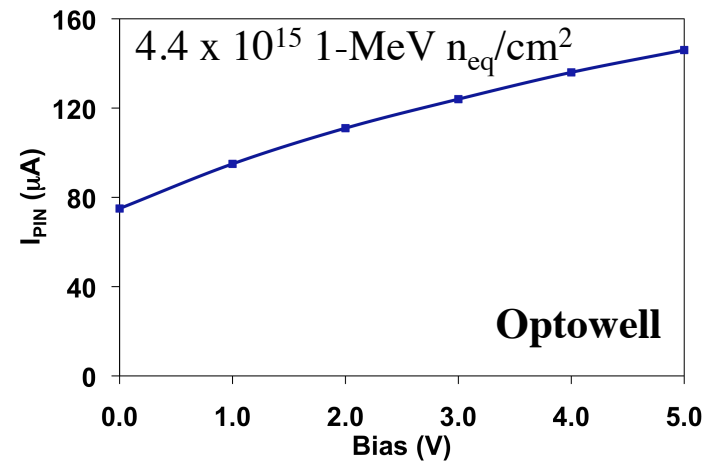
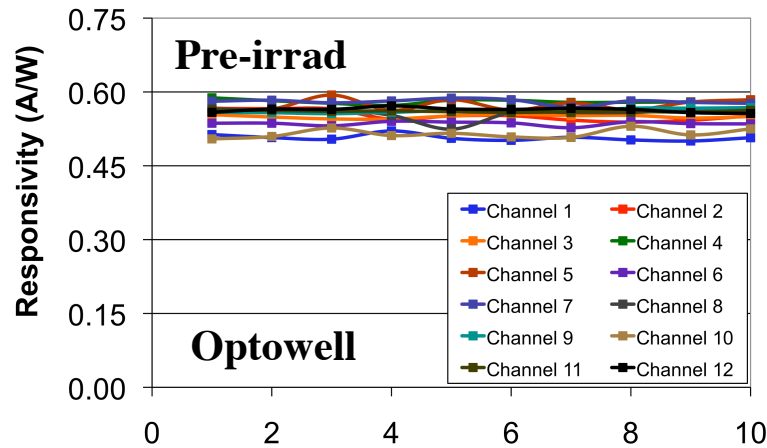
# 2008 PIN Irradiation

	Gb/s	Responsivity (A/W)	
		Pre	Post
GaAs ( $4.4 \times 10^{15}$ 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 ( $7.5 \times 10^{14}$ 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



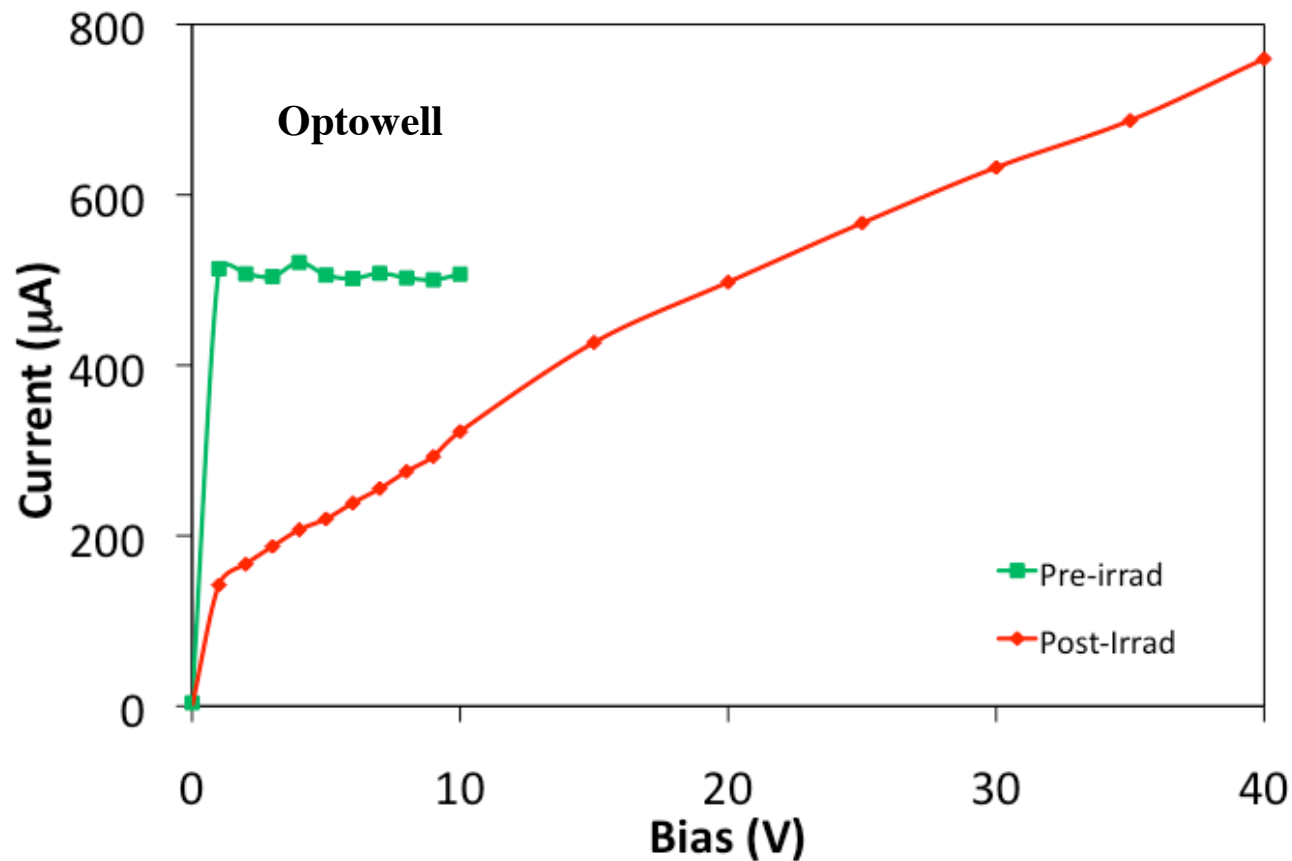
# PIN Responsivity vs Bias Voltage



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



# PIN Responsivity vs Bias Voltage

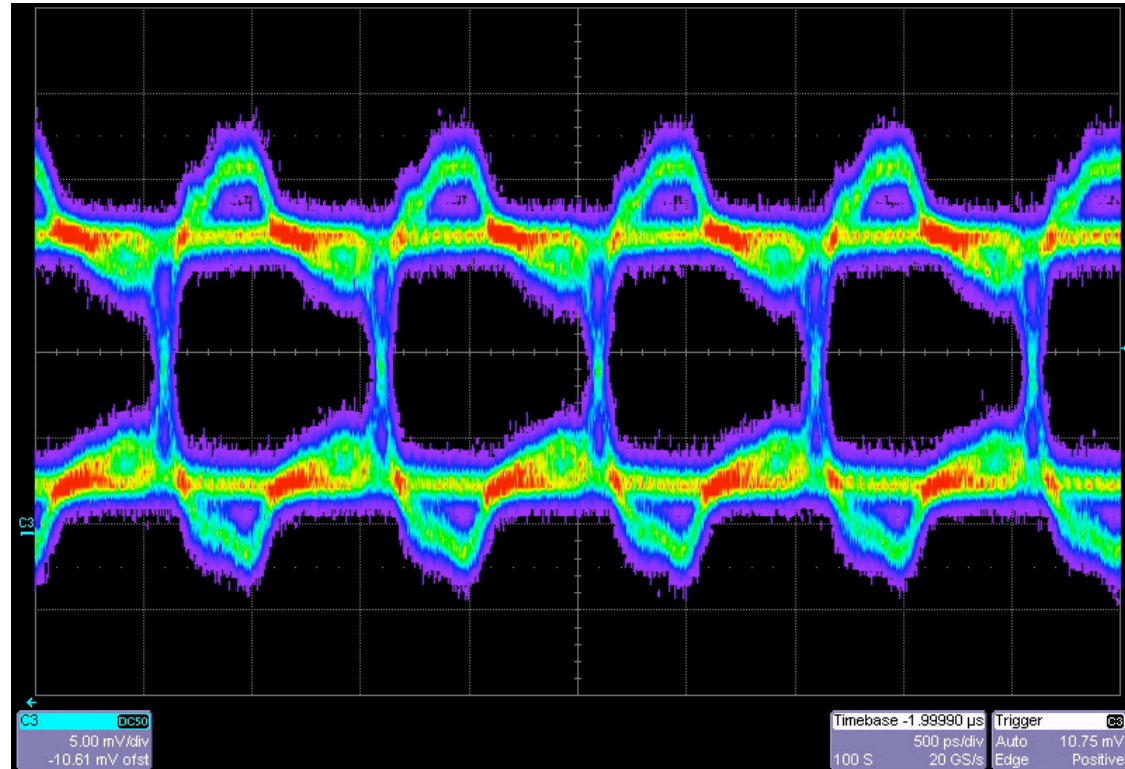


- can fully recover pre-irradiation responsivity with high bias voltage
- ⇒ need to look at pulse shape at high bias voltage



# Eye Diagram at High Bias Voltage

Optowell



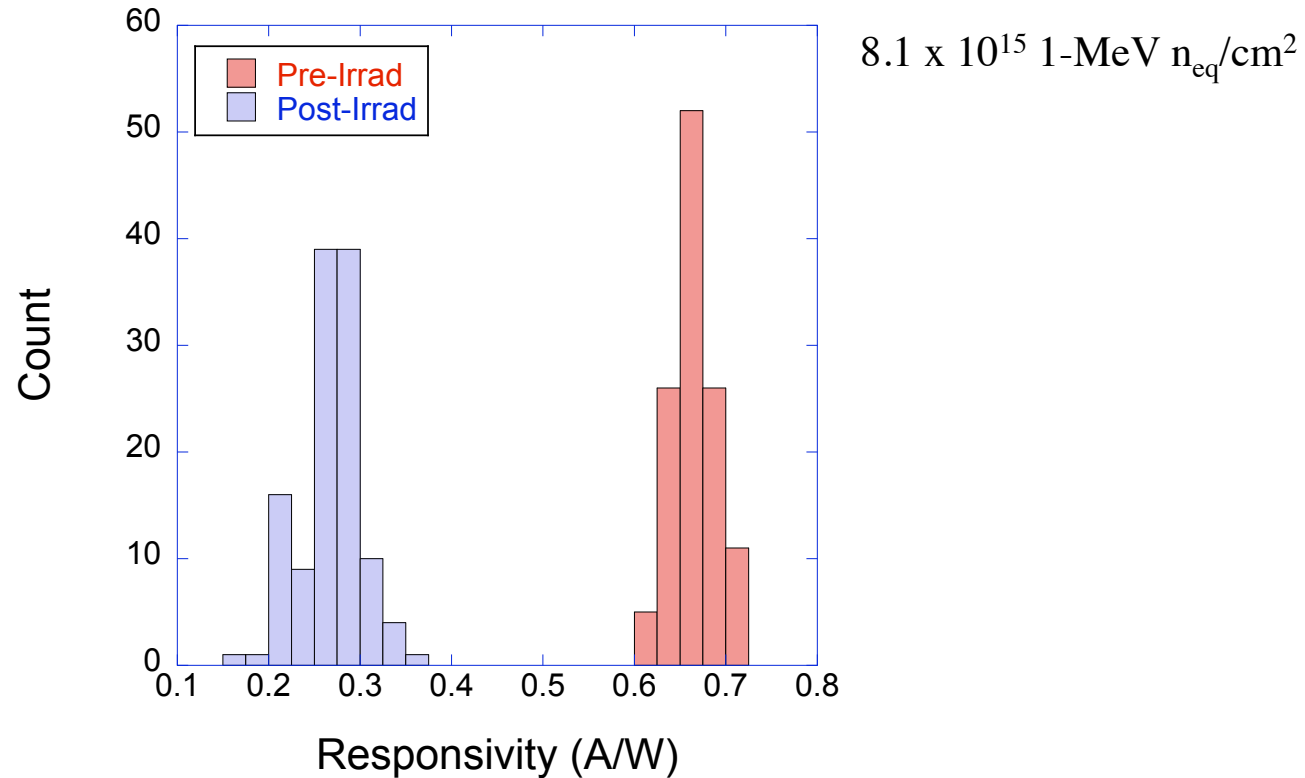
- Test limited to 1 Gb/s @ 40 V due to carry board limitation
- Eye diagram looks reasonable
- ⇒ Need trans-impedance amplifier (TIA) from Siegen for detailed characterization





# Results on Optowell PIN Arrays

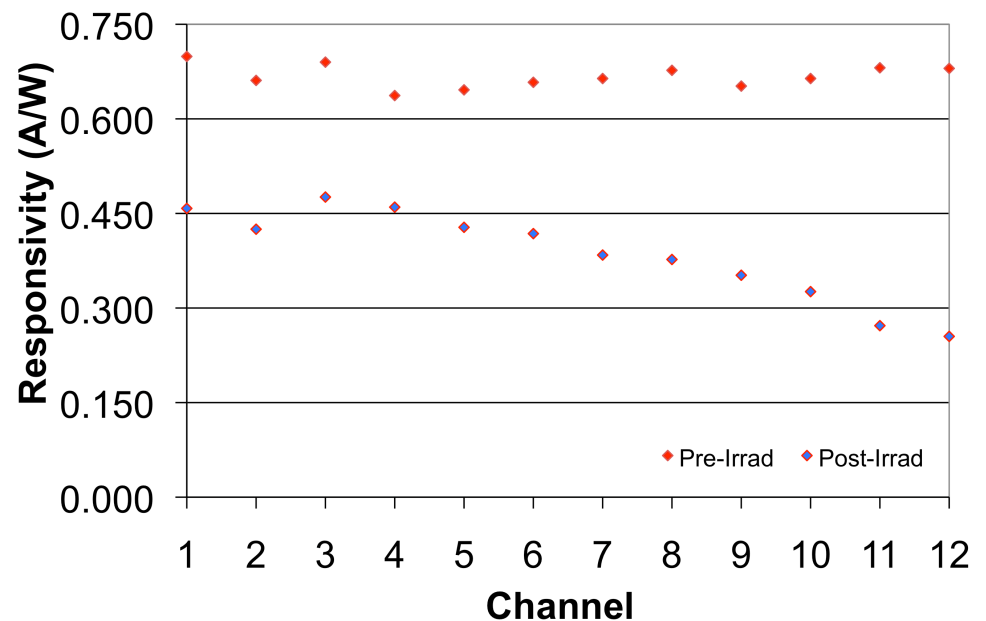
- 20 Optowell PIN arrays irradiated in August 2009
  - ✓ good responsivity after irradiation
  - ◆ average responsivity after irradiation:  $\sim 0.3$  A/W





# 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