Design, Production, and Reliability of the New ATLAS Pixel Opto-Boards

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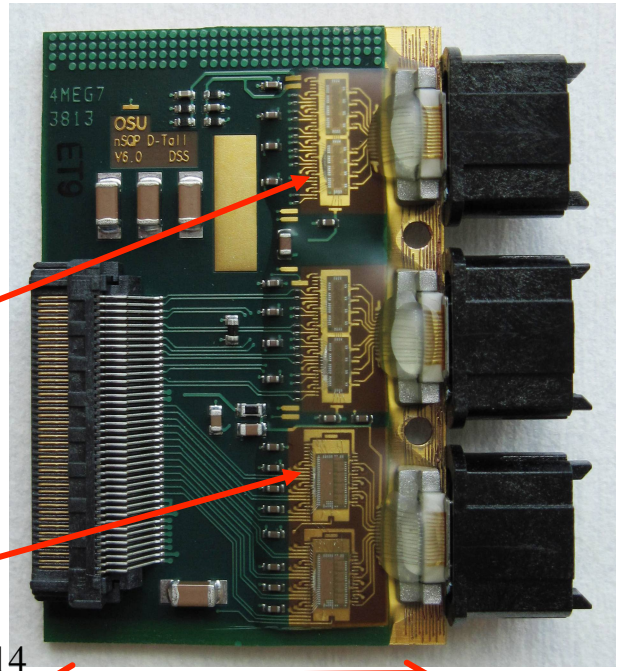
Use of VCSEL Arrays in HEP

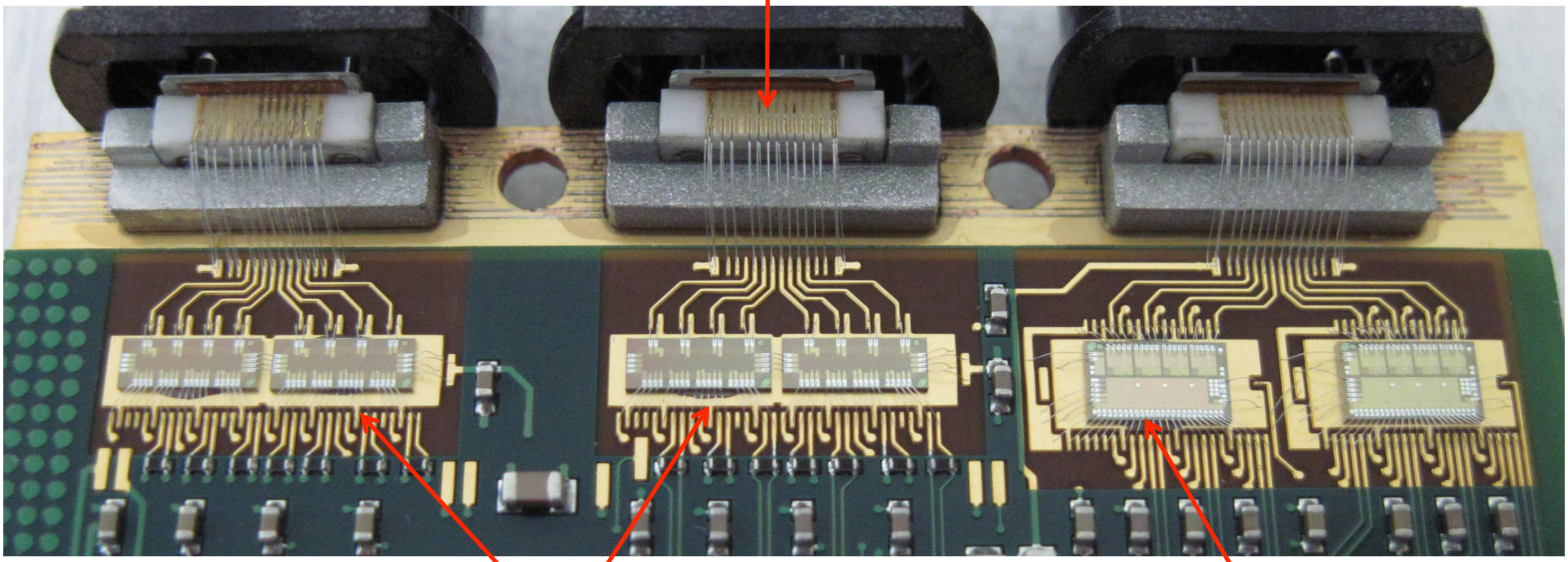
- Widely used in off-detector (no radiation) data transmission
- First on-detector implementation in pixel detector of ATLAS
  - experience has been positive
    - VCSELs used are humidity sensitive but they were installed in very low humidity location
    - modern VCSELs are humidity tolerant
    - opto-links built by OSU have ~0.1% broken links
    - decided to move opto-links to more accessible location
    - ⇨ use arrays for the replacement optical links for current 3-layer pixel detector and the new inner layer (IBL)

Opto-Board Flavors

- 3 opto-board flavors
  - outer 3-layers + disks (nSQP):
    - D opto-board (disk, L1, L2): 7 TTC + 14 data links
    - B opto-board (B-layer): 7 TTC + 14 data links
  - inner layer:
    - IBL opto-board: 8 TTC + 16 data links
- 300 boards needed
  - produced ~400 boards
    or ~8,500 links



Close Up View



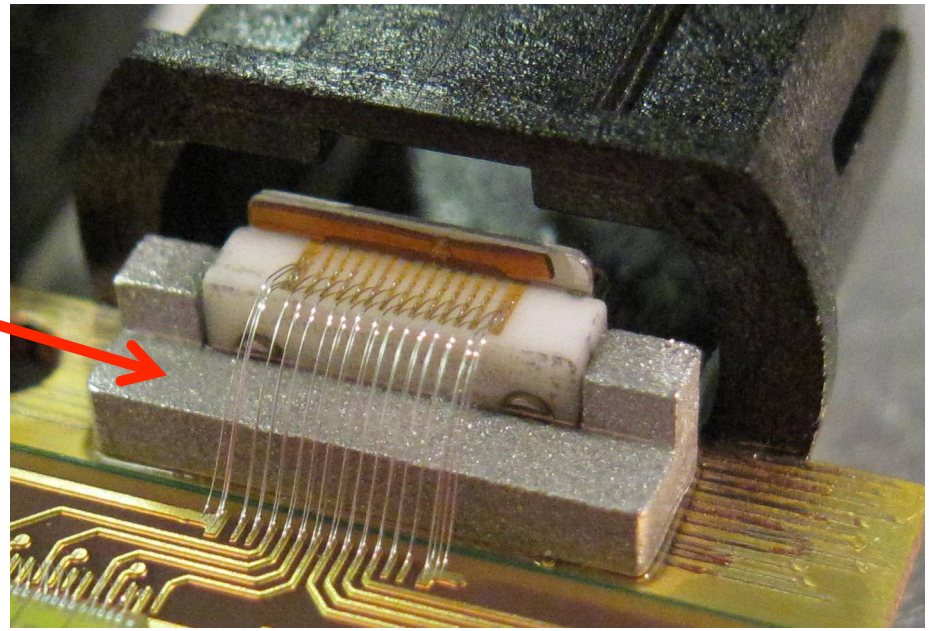
Opto-Board Improvements

- Implemented several improvements based on experience gained from production of 1st generation opto-boards:
  - replace custom optical connector with MPO for easier mating/de-mating
  - mount array on BeO instead of PCB for efficient heat removal
  - connect optical package to opto-board by wire bonding instead of soldering micro-leads to BeO
    - soldering was major challenge in previous opto-board production
      - too much heat cause lead detachments
      - too little heat produces cold solder
    - cold solder is a major cause of opto-link failures
    - opto-boards built by OSU have ~0.1% broken links

Opto-Pack Enforcement

- Several opto-packs detached at various stages of production
  - ⇨ two improvements:
    - scoring of PCB surface to improve adhesion
    - add aluminum brace to greatly increase epoxy contact area
      - ⇨ cannot remove opto-pack without destroying opto-pack

Sandblasted surfaces
to improve adhesion



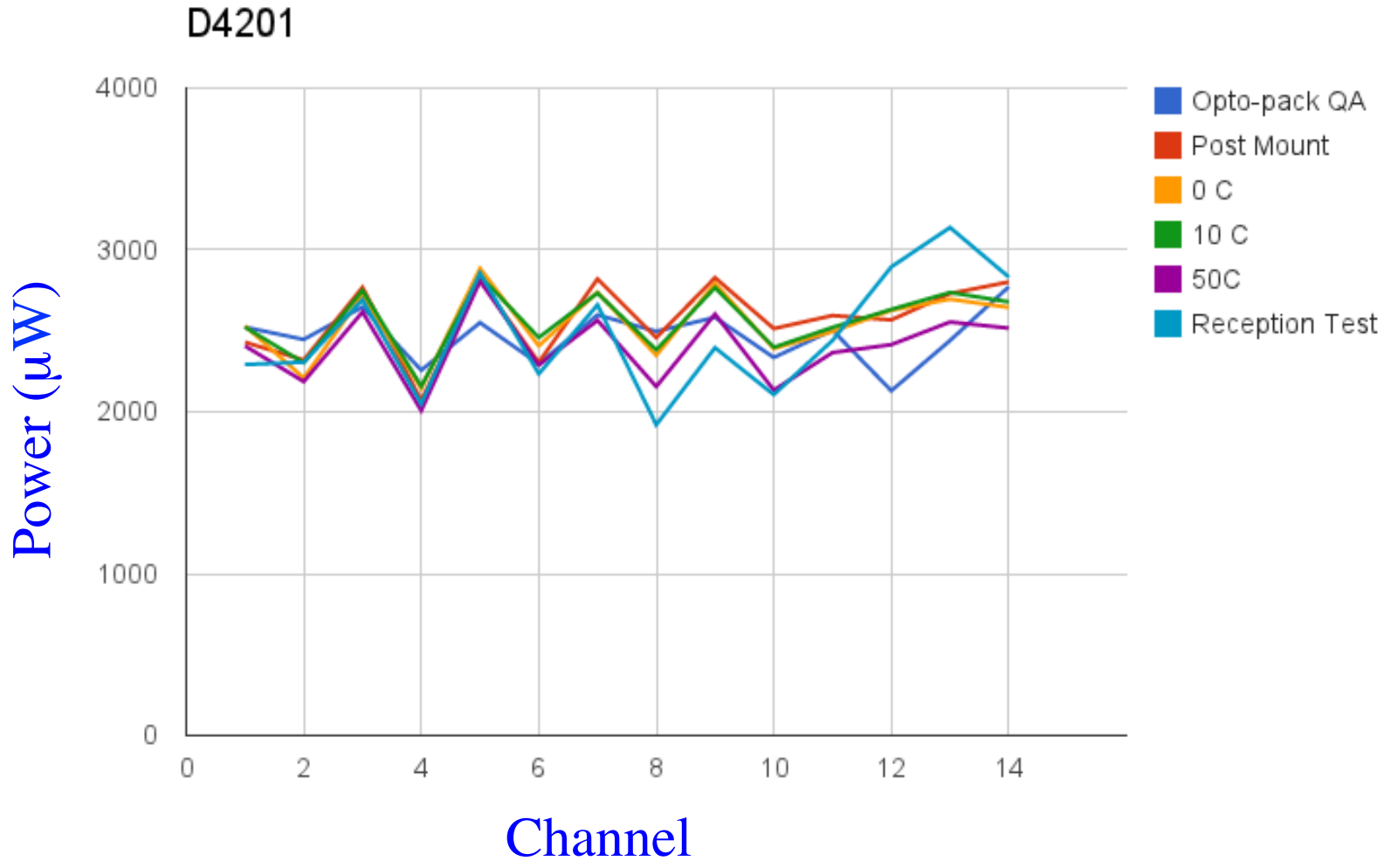
Problematic Epoxy

- Detachment of MPO connectors
  on several boards (< 10) early in the production
- 22 boards used epoxy with different color
  - replace 66 MPO connectors
    - 30 insertion tests performed on 40 connectors before removal
      - 10 insertion tests during QA
      - no connector detached after 40 insertion tests
      - expect no detachment under normal operation
    - 19 boards successfully recovered

Opto-Board Quality Assurance

- perform QA test similar to 1st generation opto-boards to validate constructed boards
  - burn in: 72 hours @ 50°C
  - 10 thermal cycles: 0°C ⇨ +50°C
    - 2 hours per cycle
    - 1 hour soak at 50°C
  - electrical and optical QA

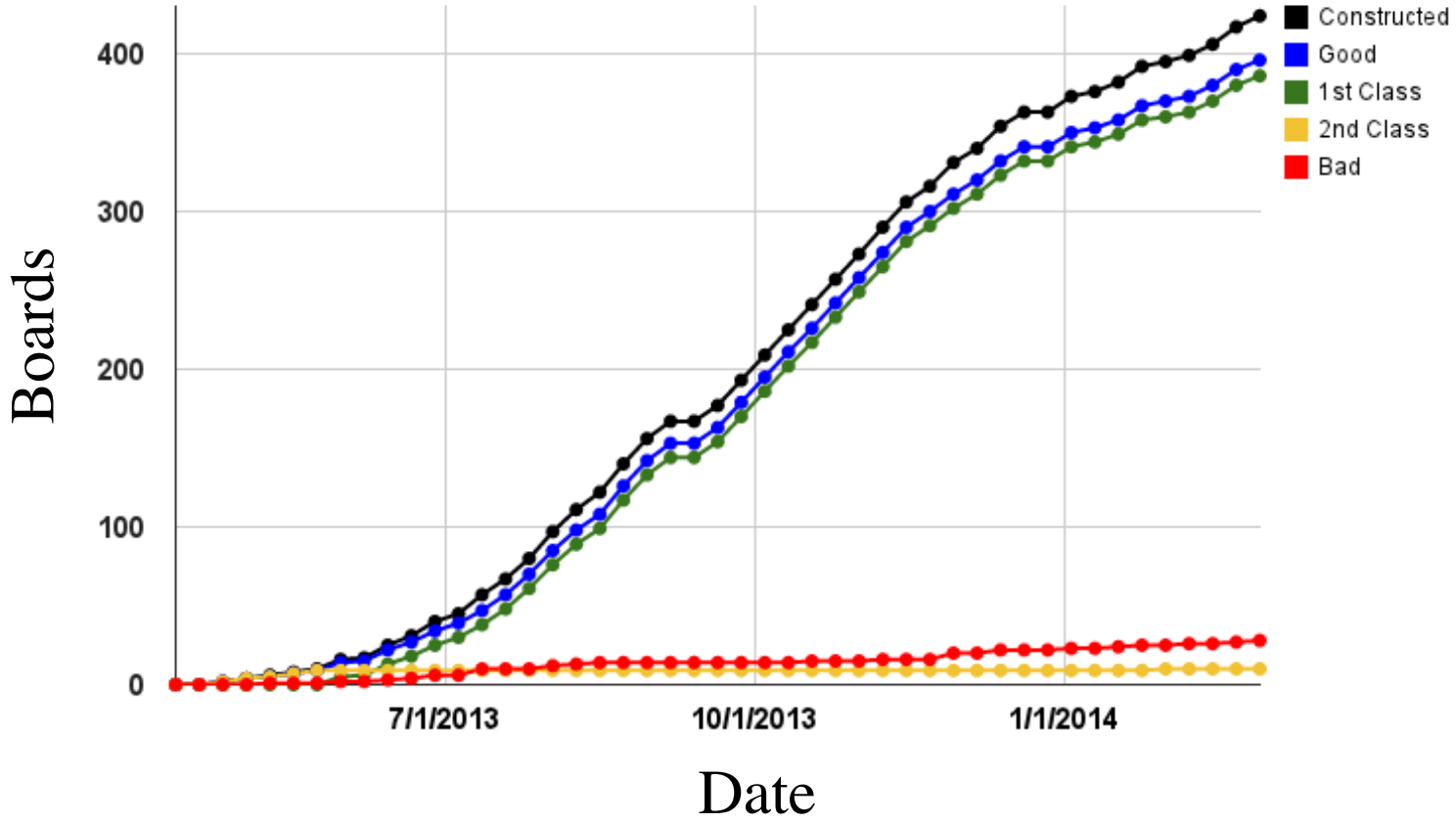
Opto-Board Optical Power



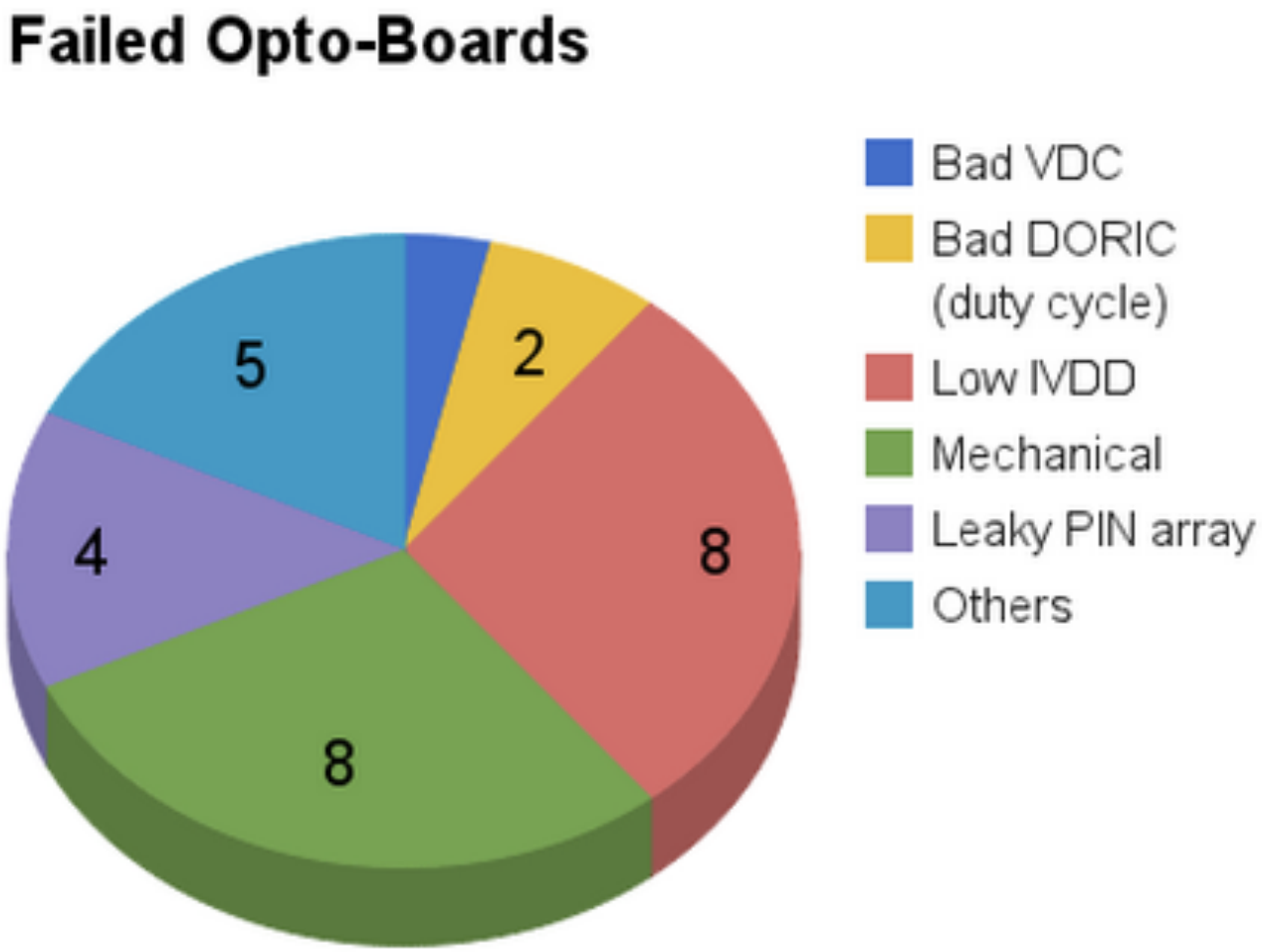
- Excellent optical power!!!

Production Statistics

- Total fabricated: 421
  - Good: 393 (1st class: 383, 2nd class: 10)
  - Bad: 28



Summary of Failed Boards

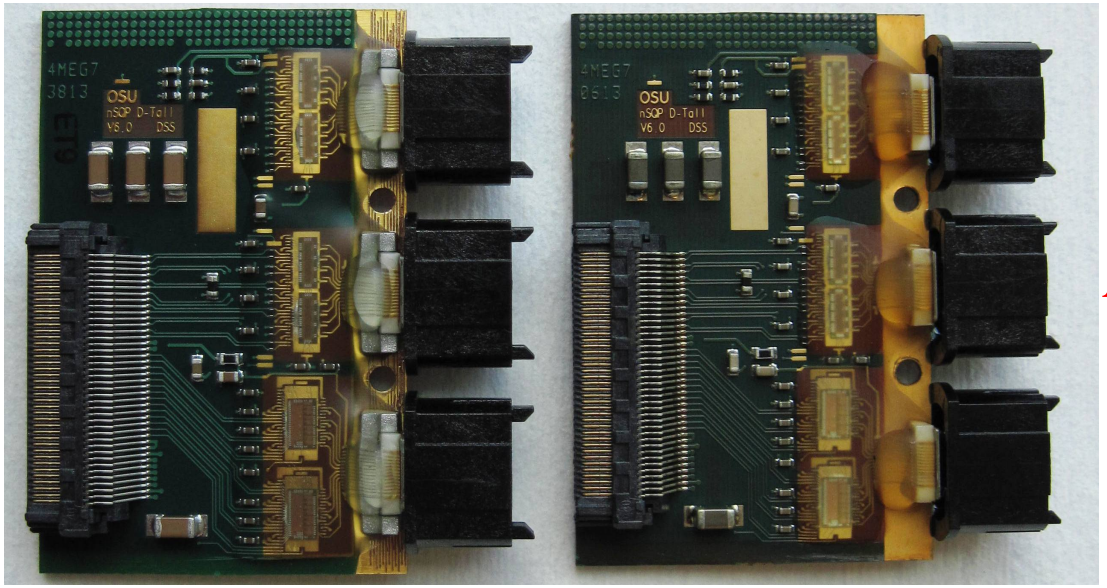


Extended Burn-In

- Several of the 400 boards have problems after burn-in/thermal cycles:
  - 1 VDC: cannot adjust drive current
  - 8 VCSEL arrays have low power
    - 3 failed for thermal cycle outside Finisar spec: -25 C
      - ⇨ thermal cycle: 0-50 C
    - 5 arrays not properly glued to BeO substrate
  - 4 leaky PIN arrays

Accelerated Lifetime Test

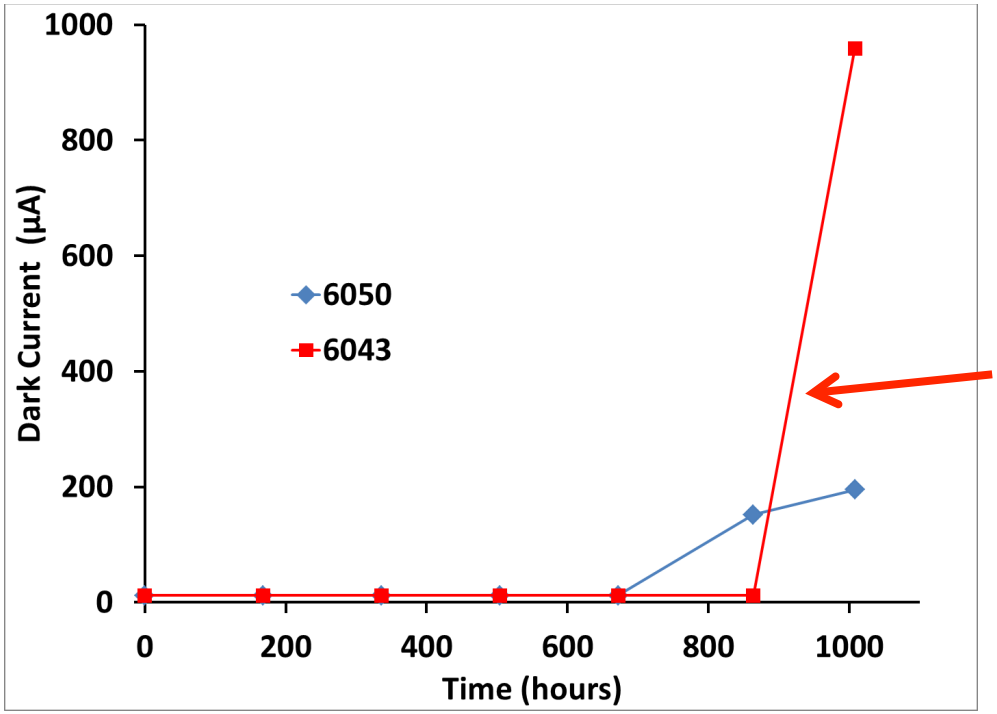
- Industry standard: opto-boards should survive for 1,000 hours at 85°C/85% relative humidity
  - operate each VCSEL channel with 10 mA (pk-pk)
  - perform weekly measurements
    - VCSEL optical power
    - PIN dark current
    - supply current
    - operate with no error in all channels



After 1,500 hours at 85°C/85% RH

Accelerated Lifetime Test-Phase I

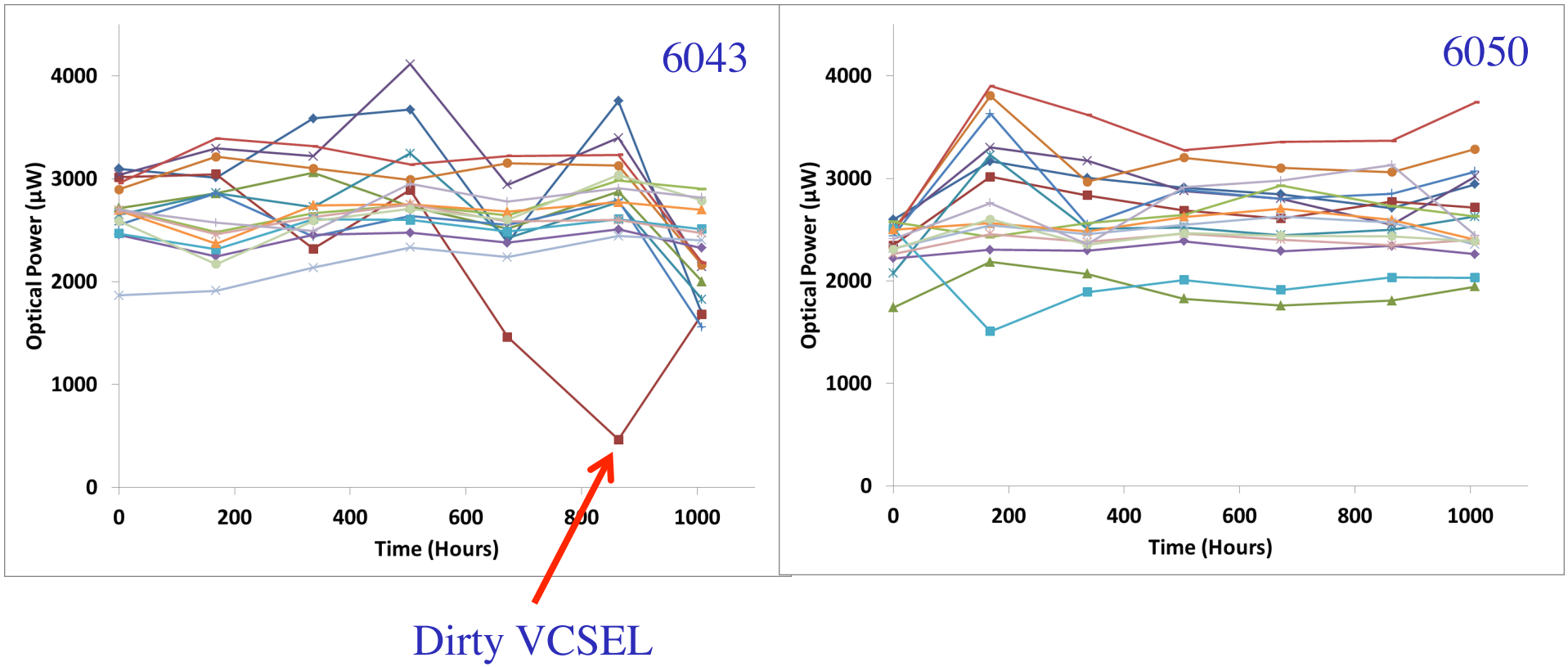
- Started the test with two IBL boards on Feb. 2014
  - All VCSEL channels survived
  - Both PIN arrays became leaky before 1,000 hours
    - PIN biased at 10 V
    - ULM photonics: recommend operate at 5 V even though spec. sheet lists bias as up to 10 V



Spike in dark currents

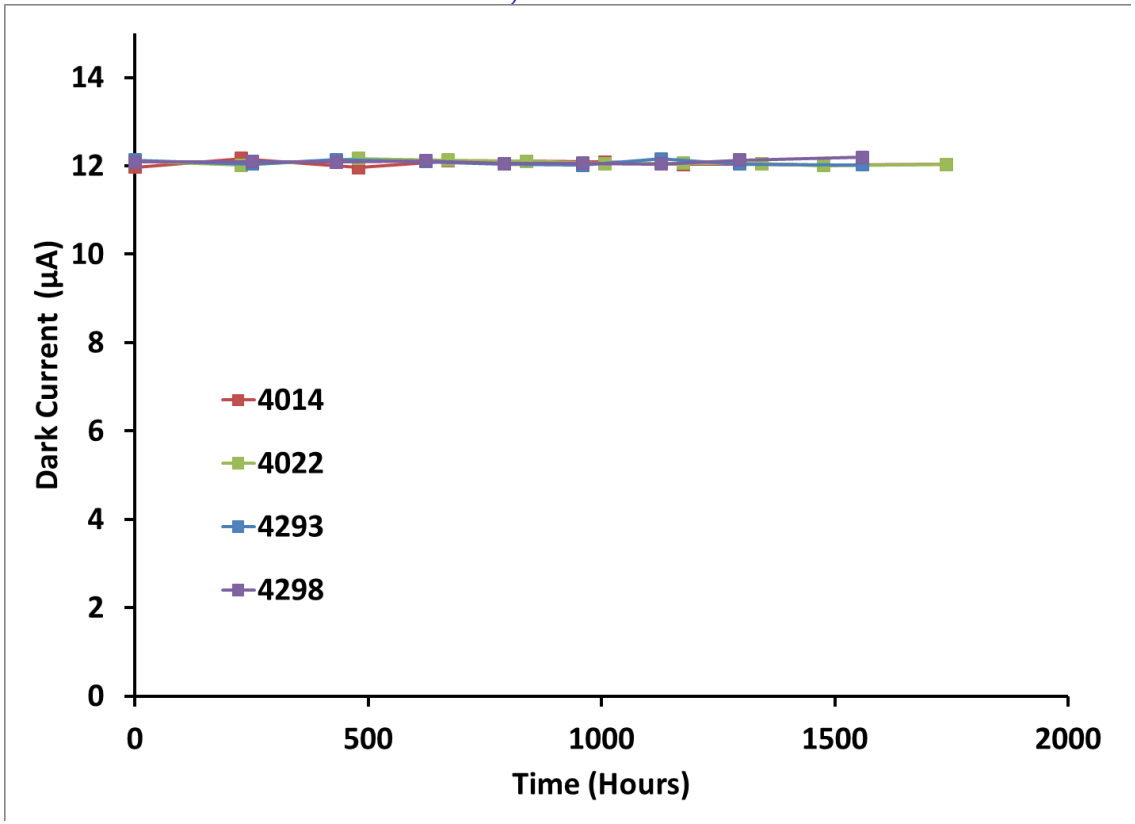
Accelerated Lifetime Test-Phase I

- VCSEL optical power OK up to 1,008 hours in 85ºC/85% RH



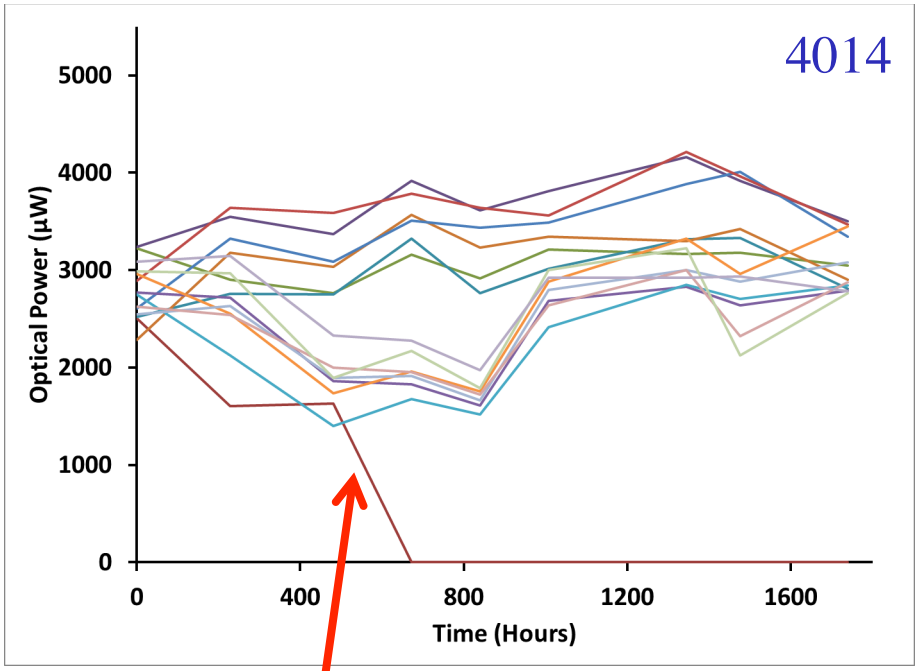
Accelerated Lifetime Test-Phase II

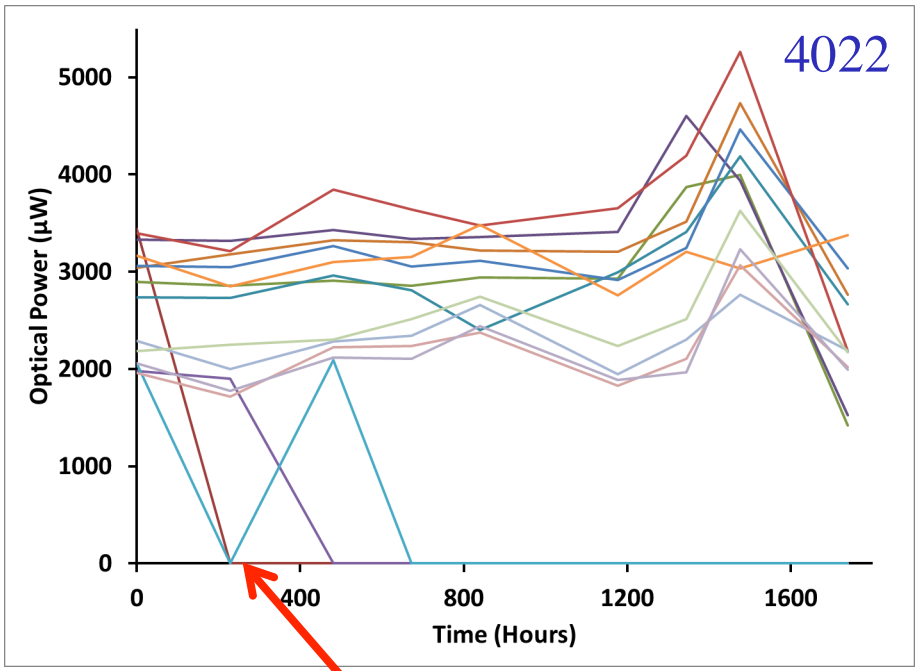
- June/July: started four D opto-boards in 85°C/85% RH
  - 2 boards fabricated in 6/2013: optical power OK after 1,740 hours
  - 2 boards fabricated in 12/2013: optical power OK after 1,560 hours
  - PIN arrays biased at 10 V in ~4 days of burn-in/thermal cycle
    - No leaky PIN arrays for 5 V bias after ~1,650 hours!!



Accelerated Lifetime Test-Phase II

- VCSEL optical power OK up to 1,740 hours in 85ºC/85% RH



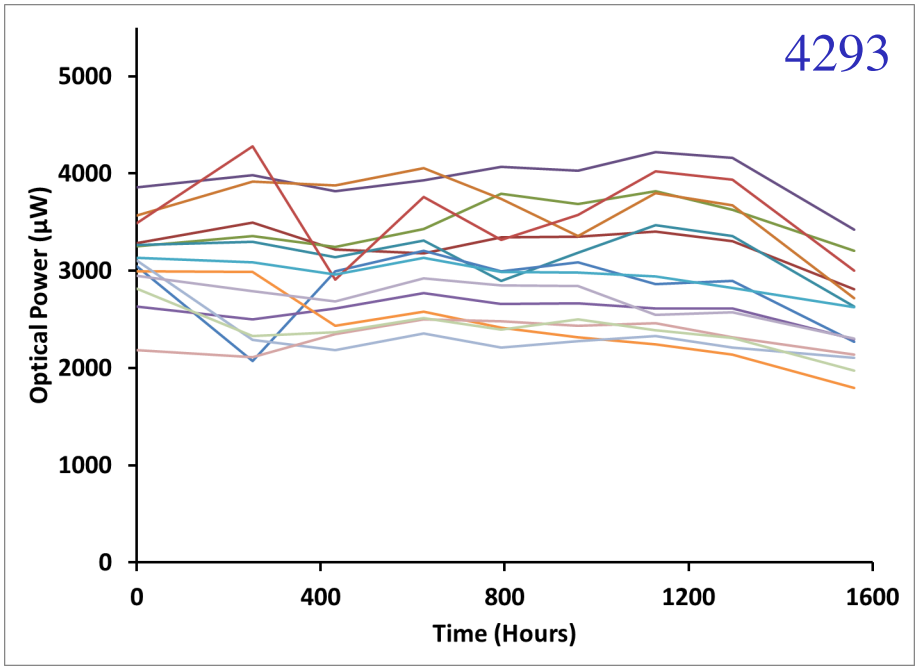


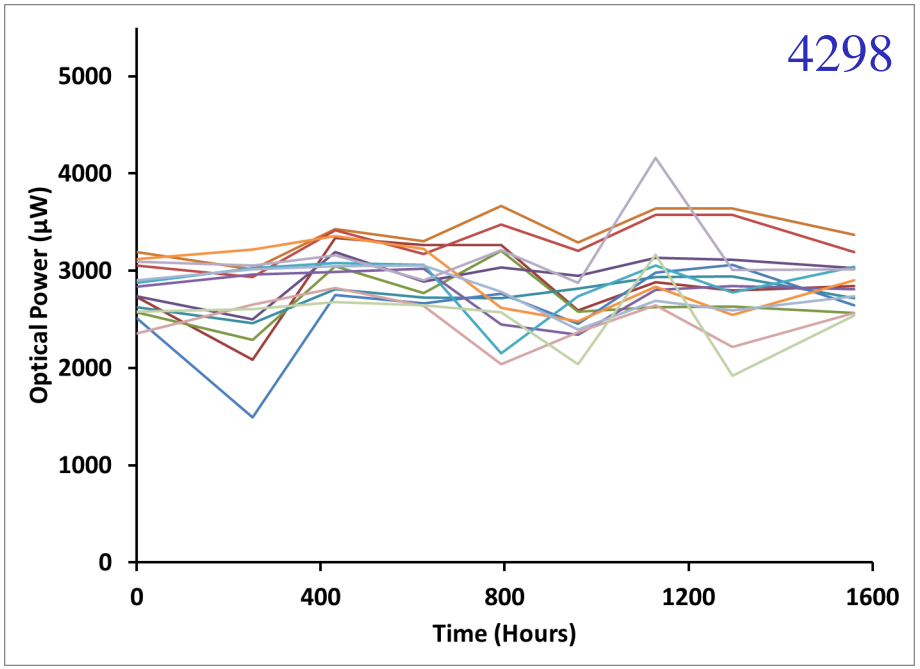
Wirebond broken during cleaning

Board dropped

Accelerated Lifetime Test-Phase II

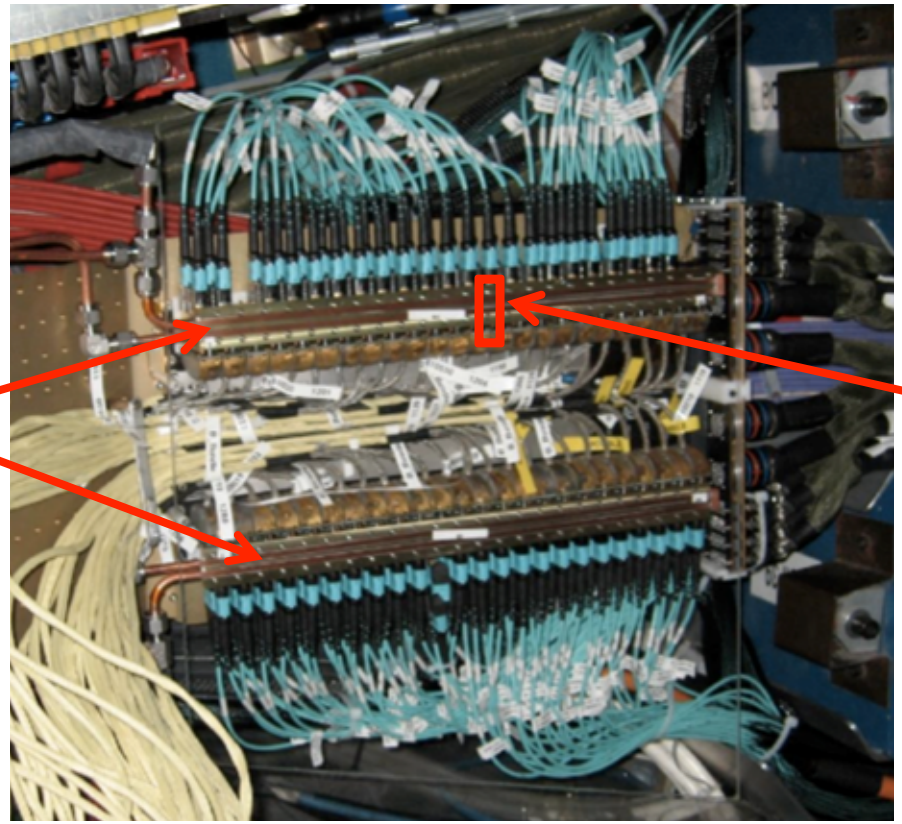
- VCSEL optical power OK up to 1,560 hours in 85ºC/85% RH





Opto-Boards Installation

- Installation successfully completed in June
  - smooth installation process
- No infant mortality after 1 month of operation



Summary

- fabricated 400 opto-boards with many improvements
- opto-boards production was smooth
- opto-boards successfully installed
- production opto-boards passed accelerated lifetime test
  - 10 V bias degrades PIN array lifetime!
- planning to begin long term 50ºC/50% RH study next