Optical Link of the ATLAS Pixel Detector

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Outline

● Introduction
● Proton Irradiation Studies
● Production Status
● Summary
ATLAS Pixel Detector

- Inner most tracking detector
- Pixel size: 50 $\mu$m x 400 $\mu$m
- 100 million channels
- Barrel layers at $r = 5.1-12.3$ cm
- Disks at $z = 50-65$ cm
- Dosage after 10 years:
  - optical link: 17 Mrad or $3.7 \times 10^{14}$ 1-MeV $n_{eq}/cm^2$
ATLAS Pixel Opto-link

VCSEL:  Vertical Cavity Surface Emitting Laser diode
VDC:    VCSEL Driver Circuit
PIN:    PiN diode
DORIC:  Digital Optical Receiver Integrated Circuit
VDC: VCSEL Driver Circuit

- Convert LVDS input signal into single-ended signal appropriate to drive VCSEL diode

- Output (bright) current: 0 to 20 mA
  - controlled by external current $I_{set}$

- Standing (dim) current: ~1 mA
  - improve switching speed

- Rise & fall times: 1 ns nominal for 40 MHz signals

- “On” voltage of VCSEL: up to 2.3 V at 20 mA for 2.5 V supply

- Constant current consumption!

- Use IBM 0.25 μm CMOS

- Use Truelight high-power oxide common cathode VCSEL array
DORIC: Digital Optical Receiver IC

- Decode Bi-Phase Mark encoded (BPM) clock and command signals from PIN diode
- Input signal: 40-1000 µA
- Extract: 40 MHz clock
- Duty cycle: (50 ± 4)%
- Total timing error: < 1 ns
- Bit Error Rate (BER): < 10⁻¹¹ at end of life
- Use IBM 0.25 µm CMOS
- Use Truelight common cathode PIN array (Taiwan)
Opto-board Design/History

- Converts: optical signal ↔ electrical signal
- Contains 7 optical links
- Use BeO for heat management but prototype initially in FR-4 for fast turnaround and cost saving
- 1st BeO vendor:
  - Either under or over filling of vias
  - Use more experienced/expensive vendor
- 2nd BeO vendor:
  - 1st prototype: 1-2 SMD detached from few boards
    - Remove gold under SMD pads
  - 2nd prototype: SMD pads have much better adhesion
    - Remove gold under 80-pin connector pads
    - Order production opto-boards
BeO Opto-board

VCSEL opto-pack
housing

PIN opto-pack

VDC

DORIC

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Optical Power

- Optical power at 10 mA significantly above spec, 500 µW
Minimum PIN Current for No Bit Errors

- minimum PIN current for no bit errors with all links active significantly below spec, 40 µA
PIN Current Threshold vs Dosage

- PIN current thresholds for no bit errors remain constant

Dosage (Mrad) 24 GeV protons @ CERN

Threshold (μA)

Time (h)

spec.
Proton Induced Bit Errors in PIN

- Convert observed bit errors into bit error rate at opto-link location:

- Bit error rate decreases with PIN current as expected
- Bit error rate $\sim 3 \times 10^{-10}$ at 100 $\mu$A (1.4 errors/minute)
  - DORIC spec: $10^{-11}$
Optical Power vs Dosage

- irradiation procedure: ~ 5 Mrad/day (10 hours) with annealing rest of the day
- optical power decreases with dosage as expected
- limited annealing recovers some lost power
- still have good optical power after 30 Mrad

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Opto-Production Challenges

- rigorous QA procedure:
  - 72 hours of burn-in at 50°C
  - 18 hours of 10 thermal cycles between -25°C and 50°C
  - 8 hours of optical and electrical measurements
- use 2 ovens and 2 environmental chambers
- implemented an “early shift” to extend the work day
- aggressive goals:
  - producing 10 boards/week
  - completed production in early October
Initial Production Problem

- initial plan was not to test chips before mounting on opto-board due to high yield during pre-production
- a bunch of produced boards drawing excessive currents
  - thermal image: power to ground shorts
  - test chips before mounting
Opto-board Rework

- recover opto-boards by stacking new chips on top of bad chips
- reworked opto-boards must pass same rigorous QA procedure
  - classified as second class for use as spare
- 18 opto-boards have been recovered
Opto-board Production Status

- relatively smooth production
- yield ~ 93%

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Summary

- opto-boards of ATLAS pixel detector satisfy design spec. and radiation hardness requirement:
  - ✔ low PIN current thresholds for no bit errors
  - ✔ excellent optical power
  - ✔ radiation hard up to ~ 30 Mrad

- simple and modular design allows smooth production
  - ■ production completed in seven months!