Radiation-Hard Optical Link in the ATLAS Pixel Detector

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Outline

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- Summary
ATLAS Pixel Detector

- Inner most tracking detector
- Pixel size: 50 \( \mu \text{m} \times 400 \mu \text{m} \)
- 100 million channels
- Barrel layers at \( r = 5.1, 12.3 \text{ cm} \)
- Disks at \( z = 50, 65 \text{ cm} \)
- Dosage after 10 years:
  - optical link: 30 Mrad or \( 6 \times 10^{14} 1\text{-MeV n}_{eq}/\text{cm}^2 \)
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 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 Truelight common cathode PIN array

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Status of VDC & DORIC

- Original design for ATLAS SemiConductor Tracker (SCT)
  - AMS 0.8 μm BiPolar in radiation tolerant process (4 V)

- DMILL #1-3: Summer 1999 - May 2001
  - 0.8 μm CMOS rad-hard process (3.2 V)
  - VDC & DORIC #3: meet specs
  - severe degradation of circuit performance in April 2001 proton irradiation

- IBM #1-5: Summer 2001 - Dec 2002
  - 0.25 μm CMOS rad-hard process (2.5 V)
  - enclosed layout transistors and guard rings for improved radiation hardness

- IBM 5e: April 2003 engineering run
  - convert 3-layer to 5-layer layout for submission
    with pixel Module Control Chip (MCC) for cost saving
  - this is the production run since chips meet specs
    and sufficient quantity of chips were produced
dim current is $\sim 1$ mA as expected
- bright current measured with 1 $\Box$ in series
- maximum bright current is $\sim 13$ mA
- oxide VCSEL has larger effective resistance than p$^+$ implanted VCSEL
- target is 20 mA but 13 mA is adequate for annealing from irradiation damage
DORIC: PIN Current Thresholds with No Bit Errors

[Graph showing current thresholds for 7 links with points above 40 mA, indicating significantly better performance than the specification of 40 mA.]

thresholds significantly better than spec: 40 mA
Status of BeO Opto-board

- 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 prototype:
  - many open vias due to insufficient gold filling
  - opto-links works after via repairs!
- 2nd BeO prototype:
  - recycled BeO boards
  - many shorts due to over filling
  - use more experienced/expensive vendor
  - produced opto-boards of high quality
BeO Opto-board

housing

opto-pack

VDC

DORIC
Optical Power

- Optical power at 10 mA significantly above spec: 500 mW
Opto-board Status

- 28 boards were delivered
  - ~equal mixture of boards for layers B and 1, 2, disk
  - populated opto-boards have low noise and good optical power
    - no known circuit design errors
  - a few SMD detached from three boards
    - produce 80 B-layer boards with layout changes to improve adhesion
  - expected delivery in September
    - if new boards are satisfactory
      - produce 430 boards for layers 1, 2, and disk
PIN Current Threshold vs Dosage

PIN current thresholds for no bit errors remain constant

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Proton Induced Bit Errors in PIN

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

- bit error rate decreases with increasing PIN current as expected
- bit error rate $\sim 3 \times 10^{-10}$ at 100 $\mu$A (1.4 errors/minute)
- DORIC spec: $10^{-11}$
- irradiation procedure: ~ 5 Mrad/day (10 hours) with the rest of day annealing
- 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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Summary

- **VDC-I5e & DORIC-I5e (IBM 0.25 μm):**
  - radiation hard up to 62 Mrad
  - meet ATLAS pixel specs
  - production is completed

- **BeO opto-board:**
  - several pre-production opto-boards have been fabricated
    - low PIN current thresholds for no bit errors
    - excellent optical power
  - radiation hard up to ~ 30 Mrad
  - modify layout to improve SMD adhesion

- **start opto-link production in September 2004**
  - complete production by September 2005