Radiation-Hard Optical Link in the ATLAS Pixel Detector

K.K. Gan
The Ohio State University

May 24, 2004

The Ohio State University

A. Ciliox, M. Holder, S. Nderitu, M. Ziolkowski
Universitaet Siegen, Germany
Outline

- Introduction
- Results on IBM 0.25 μm Chips
- Results on Proton Irradiations
- Summary
ATLAS Pixel Detector

- Inner most tracking detector
- Pixel size: 50 μm x 400 μm
- 100 million channels
- Barrel layers at $r = 5.1, 12.3$ cm
- Disks at $z = 50, 65$ cm
- Dosage after 10 years:
  - optical link: $30 \text{ Mrad}$ or $6 \times 10^{14}$ $1$-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 $I_{\text{set}}$
- Standing (dim) current: $\sim 1$ mA to improve switching speed
- Rise & fall times: 1 ns nominal for 80 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: 40-600 mA
- 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
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
VDC-I5e: Bright and Dim Currents vs. $I_{set}$

- dim current is $\sim 1$ mA as expected
- bright current measured with 1 W 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
VDC-I5e: Clock Rise/Fall Time

- fall time < 1 ns
- rise time > 1 ns
- measured with 44-pin package
- faster rise time on opto-board
- no degradation up to 62 Mrad
DORIC: PIN Current Thresholds with No Bit Errors

 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
optical power at 10 mA significantly above spec: 500 mW
Proton Irradiation at CERN

- use 24 GeV protons at T7 to verify radiation hardness of opto-links
- monitor performance of opto-links in real time
- cold box: irradiate 4 VDC-I5e and 4 DORIC-I5e with no optical components
- shuttle: irradiate 4 opto-boards
  - opto-boards can be moved in and out of beam remotely for VCSEL annealing
Shuttle Test System

opto-board test system  20 m fibers/wires spool  opto-boards

shuttle test electronics at OSU prior to shipping to CERN
PIN current thresholds for no bit errors remain constant
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 ~ $3 \times 10^{-10}$ at 100 $\mu$A (1.4 errors/minute)
- DORIC spec: $10^{-11}$
irradiation procedure: ~ 5 Mrad/day (6 hours) with the rest of day annealing
optical power decreases with dosage as expected
annealing at ~ 13 mA recovers some lost power
optical power satisfies spec after extended annealing at home institutions
Summary

- VDC-I5e & DORIC-I5e (IBM 0.25 μm):
  - radiation hard 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

- VCSEL lost significant fraction of optical power after irradiation
  - power satisfies spec after extended annealing at home institutions

- start opto-link production in July 2004