Progress on X-ray Imagers at MIT

Mark Bautz
MIT Kavli Institute for Astrophysics & Space Research
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Overview

- Near term: Directly-deposited blocking filters
- Far term: 3-D Active Pixel X-ray Sensors
- Mid term: Advanced CCDs
Deposited Filters: Objectives

- Avoid fragile optical/UV blocking filters, associated support hardware (e.g. vacuum doors), risk & I&T expense.
- Improve instrument performance
Status: 1\textsuperscript{st} Coated Bl CCD under test

- Chip-level coating process characterized in depth
- 1\textsuperscript{st} test device: engineering grade with prior MBE Bl treatment
- OBF: 220nm Al over 140nm ‘buffer’ layer
  - Buffer reduces OBF-induced dark current
- Characterization in progress
  - Soft X-ray QE confirms Al thickness
- Next:
  - Thinner buffer layer on higher-quality device
Beyond CCDs: Active Pixel Sensors (APS)

• Faster readout $\rightarrow$ better QE, count-rate, timing
  * Speed comes from parallelism & technology
  * Parallelism comes from CMOS compatibility

• “No” charge transfer $\rightarrow$ better radiation tolerance

• Integrated signal/data processing
  * Allows Gpix focal planes at kHz rates
  * Allows for on-chip intelligence (e.g., event detection)
Challenges for APS in X-ray Astronomy

• Challenge for monolithic architectures: detection efficiency
  * Difficult to deplete ~100+ μm
  * May be difficult to tile large focal planes

• Challenge for hybrid architectures: noise
  * Interlayer connection has large capacitance → lower responsivity, higher noise (referred to input)

• Challenge for both: demonstrate proper BI treatment

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MIT/Lincoln 3D X-ray Sensor (APS2)

Readout ‘tier’:
* FDSOI CMOS
* 350nm/3.3V

Inter-wafer connection:
* Tungsten Via
* Low-T oxide bond

Detector ‘tier’:
* Bulk photodiode array
* 3 kΩ-cm n-substrate
* Thinned (50 mm)
* Back-illuminated

Test Array: 256 x 256, 24 μm pixels

V. Suntharalingam, MIT/LL

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X-ray Performance at 5.9 keV

MIT/LL 3-D X-ray Active Pixel Sensor APS2

- T = 60°C, 325 kHz, off-chip CDS, single pixel, 5.9 keV
- Noise: 13 e⁻, 10 samples
- Responsivity: 4.6 μV/e⁻

Prigozhin et al. (2009)

181 eV FWHM
Next Generation Sensor APS3

Goals:

* Reduce noise through improved responsivity, lower transistor noise
* Reduce inter-pixel coupling through better layout
* Demonstrate high-quality back-illumination (good soft X-ray response)
APS3 pixel with CCD-like output

Red:
In Detector Tier

Blue:
In Readout Tier
APS3 CMOS Readout Tier

200mm-diameter wafer (45 die)  Shared, 22 mm die; 2 APS3 readouts
APS3 Status

• Expected performance:
  ~ <5 e^- noise; 50-100µm depletion, back-illumination

• Status:
  * Tier-2 complete; Tier-1 in fabrication
  * Front-illuminated devices within ~ 6 months
Progress in CCD Technology: a middle way

- CCD technology has advanced since Suzaku:
  * Much faster readout at a given noise level
  * Much lower power
  * More flexible architecture for larger focal planes and better radiation tolerance
- These advances can meet near-term technology development needs, e.g., for:
  * Faster, low-power XGS readouts for AXSIO
  * Large-area, wide-field detectors for Explorers
Advanced CCD Technology from MIT Lincoln Laboratory

1. 10x faster low-noise output amplifiers

- ACIS/Suzaku
  1-stage MOSFET
  2 e⁻ RMS @ 100 kHz

- Current MIT/LL
  2-stage pJFET
  2 e⁻ RMS @ ~2 MHz

B. Burke, MIT/LL
2. Low-power, high-speed charge transfer transfer

Single-layer, non-overlapping transfer electrodes:

- Enabled by advances in photolithography
- ~3V clock amplitude (cf 8-10V for ACIS/Suzaku)
- 5-10x lower power enables high-speed readout
- Excellent charge transfer efficiency
3. Modular, multiplexed CCD architecture

Developed for Pan-STARRS (Tonry, Burke+, 2008)
- Allows large (5 x 5 cm) detectors w/ multiple CCDs (cells) on one chip
- Multiple parallel outputs for higher speed readout
- Four-side abuttable to tile very large focal planes
- Small cells minimize transfer distance, improve radiation tolerance
- Modular: cells can be assembled in multiple configurations
Modular and ACIS/Suzaku CCDs

Pan-STARRS modular CCD

5 x 5 cm
8 x 8 cells

ACIS-I Focal Plane

5 x 5 cm active
+ 5 x 3 cm inactive
Modular 3-D Advanced CCD Now in Fabrication at MIT/Lincoln

Test Device Configuration

Detector Tier

Readout Tier

Die Layouts

Detector Tier

Readout Tier

2 x 2 independent CCD cells, each with:

- 512 x 512 pixels, 4.8 μm square
- High-speed low-noise amplifiers
- High-speed, low-power transfer gates

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Modular Architecture Supports Multiple Applications

For X-ray Grating Spectrometer

- Single CCD cell module design serves multiple applications
- Cell array tailored for each application
- Reduces design cost and risk, increases TRL

For Wide-field Explorer
Modular Architecture Supports Multiple Applications

X-ray Grating Spectrometer Detector

- 4 x 16 independent CCD cells; 10 x 40 mm
- 15 Hz frame rate meets AXSIO requirement
- Power consumption 20% of Suzaku-based AXSIO XGS
- Electronics mass 25% of Suzaku-based AXSIO XGS
- Radiation tolerance 10x better than ACIS
Summary

• CCD technology continues to progress
• This progress offers important benefits to X-ray astronomy:
  * Achieves performance requirements
  * Reduces power & mass, increases reliability
• Effective technology development planning must allow for unplanned technical progress