Characterization of a BSI sCMOS as a soft X-ray detector

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NAO.CAS
Einstein Probe (EP) satellite

A mission for all-sky monitoring to discover and study high energy transients and variability in the soft X-ray band

Monitoring: 0.5-4 keV soft X-ray
Large Field of View: 3600 sq. deg.
Orbit: 600km
Instruments:
  Wide-field X-ray telescope (WXT)
  Follow-up X-ray telescope (FXT)
Nominal lifetime: 3 +2 years (2022-)
Wide-field X-ray Telescope (WXT)

- **Wide-field X-ray telescope (WXT)**
  - 12 identical modules
  - MPO Lobster-eye optics
  - CMOS detector $\sim 1700 \text{ cm}^2$
  - Field-of-view: 3600 sqr.deg.
  - Spatial resolution: FWHM $\sim 5'$
  - Band pass: 0.5-4keV
  - Effective area: $3 \text{ cm}^2 @ 1 \text{ keV}$

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[WXT module diagram]
## WXT Focal plane detector

### WXT Focal plane detector:

12 modules * 12 cm * 12 cm  
Band pass: 0.5~4 keV

<table>
<thead>
<tr>
<th>Gas detector</th>
<th>MCP</th>
<th>CCD</th>
<th>micro calorimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROSAT RXTE</td>
<td>Einstein Chandra</td>
<td>Chandra XMM-Newton</td>
<td>Suzaku Astro-H</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>20%</td>
<td>No</td>
<td>4% (200eV@5keV)</td>
</tr>
<tr>
<td>Time resolution</td>
<td>us</td>
<td>us</td>
<td>s</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td>-100°C</td>
<td>~ mK</td>
</tr>
<tr>
<td>Advantage &amp; Disadvantage</td>
<td>Low cost, Large area, Ultrathin incident window</td>
<td>High spatial res., Low QE, Good time res.</td>
<td>Good energy res., High QE</td>
</tr>
</tbody>
</table>
CMOS detector

2015: BSI sCMOS (GSENSE400BSI) in China

Number of pixels : 2048×2048
Pixel size : 11µm×11µm
Epitaxial layer thickness : 3.6µm
Frame rate : 48fps@STD

Photograph and physical structure of the GSENSE400BSI.
# Compare CMOS and CCD

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G400 BI sCMOS</th>
<th>E2v CCD4240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>2k * 2k</td>
<td>2k * 2k</td>
</tr>
<tr>
<td>Pixel size</td>
<td>11 µm</td>
<td>13.5 µm</td>
</tr>
<tr>
<td>Fill factor</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Response spectrum</td>
<td>200 – 1100 nm</td>
<td>270-1100 nm</td>
</tr>
<tr>
<td>Full well</td>
<td>&gt; 120 ke- (~2k HG)</td>
<td>100 ke-</td>
</tr>
<tr>
<td>Noise</td>
<td>1.2 e-</td>
<td>3 e-</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>96 dB</td>
<td>90 dB</td>
</tr>
<tr>
<td>Dark current</td>
<td>400 e-/pixel/s @20°</td>
<td>250 e-/pixel/s@20°</td>
</tr>
<tr>
<td></td>
<td>0.03 e-/pixel/s @-50° (@LDC)</td>
<td></td>
</tr>
<tr>
<td>Frame rate</td>
<td>48 fps @STD</td>
<td>~ 5 fps</td>
</tr>
<tr>
<td>PRNU</td>
<td>&lt; 1%</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>&lt;500 mW</td>
<td>~ 5 W</td>
</tr>
</tbody>
</table>
CMOS detector

The image signals from the pixel array are digitized by a low-power ADC array. The digitized image signals are then read out through 8 low-voltage differential signaling (LVDS) channels.

- Integrates all necessary controls, preamplifiers and digitization
- No charge transfer
- high-speed readout -> Virtual cooling
- No deep cooling required

The sCMOS sensor architecture.
CMOS detector

Block diagram of the GSENSE400BSI evaluation system.
X-ray imaging test

A stainless steel diaphragm with an umbrella pattern.

X-ray image captured by the GSENSE400BSI.
CMOS detector

Temperature: -20°C ~ 30°C

- Readout noise
- Dark current
- Energy resolution

A climate chamber.
Readout noise

Readout noise at -20°C.

Readout noise as a function of temperature.
Dark current as a function of temperature.
X-ray spectrum from the $^{55}$Fe source at 20°C (Only single-pixel events).

Energy resolution: 192 eV (3.3%) at 5.9keV.
Low-energy X-rays test

The schematic of the vacuum chamber setup.

Target: Carbon (kα 277eV)

The spectrum from the low-energy X-rays test.
Test with MPO

The corresponding focused image of the point spread function (PSF) of the MPO by integrating the response of the GSENSE400BSI.
Thank you!