APPLICATION OF CMOS IN SPACE DEBRIS MEASUREMENT

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Requirement of photon detector for SD
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Requirement of Photon Detector for SD

Pursuit of information acquisition for space debris
- Sensitivity
- Resolution (Temporal & Spatial)
- Dynamic range

Requirement of Detector
- High efficiency
- Low noise
- Fast read speed
- Small pixel size
- High full depth
- Linearity
- ...

...
CMOS vs CCD

- CMOS\((\text{parallel})\)
- CCD\((\text{serial})\)

Parallel pattern means high read speed, but takes the risk of high noise at the same time.

In scientific market, CMOS performance has generally been worse than CCDs due to a reputation of unacceptably high read noise and dark current, lower fill factors, and greater non-uniformity.

sCMOS has been designed to overcome the drawbacks of traditional CMOS, and it is comparable to CCD in scientific market.
**SCMOS (Andor Neo sCMOS) vs CCD**

- QE
- Pixel size & Full depth
- Fill factor
- Cross-talk
- Read speed & noise
- PRNU (Pixel Response Non-Uniformity)
- Linearity
- Shutter
- Dark current
QE of sCMOS is lower than type value of Back-illuminated CCD, and is higher than that of Front-illuminated CCD.
Pixel size & Full Depth

Pixel size of sCMOS is 6.5μm × 6.5μm, much smaller than type size (12μm, 13.5μm) of CCD, which means higher spatial resolution. Small size is company with lower full depth at some extent, which would limit the measurement of bright signal.
**Fill Factor**

- Lower fill factor is the inevitable drawback of sCMOS due to its architecture.
- sCMOS utilizes micro lens to improve fill factor.

Fill factor of sCMOS is more than 90%, but still worse than CCD (nearly 100%).
Cross-talk of sCMOS is not just electrical effect as CCD.

When the incident ray is off-axis, the cross-talk would occur by the effect of micro-lens.

Cross-talk could be optimized by optic design, such as air gap, light guide, metal-mirror and so on. But it could not be eliminated.

The Cross-talk effect would limit the off-axis angle of ML, and focal ratio (not too fast).
**Read Speed & Noise**

**CCD**
- Read speed and noise is a compromise pair for normal CCD
- For EMCCD, both fast read speed and low read noise could be reached, but introduce additional noise source (multiplicative noise)

**sCMOS**
- Parallel architecture means fast speed
- Due to improvement of lithography and process control in fabrication, sCMOS could reach low read noise (**high sensitivity**) with fast speed (**high temporal resolution**) at the same time.
- sCMOS has a **high dynamic range** because of low read noise, although the full depth is lower
PRNU (Pixel Response Non-Uniformity)

- Serial architecture means difficult to overcome non-uniformity,
- Thanks to lithography and process control in fabrication, sCMOS could reach 1% uniformity (the data is acquired by observation), which is comparable to CCD.
The linearity of sCMOS is a little superior to CCD
SHUTTER

- CCD(mechanical)
  - Shutter effect
  - High malfunction rate

- sCMOS(electronic)
  - No shutter effect
  - Low malfunction rate
  - Difficult to suitable for large image area
**Dark Current**

- sCMOS could be cooled to -40°C
- The dark current could reach 0.03 e-/pixel/sec, which is comparable to CCD
Observation result of sCMOS

- Telescope: 25cm, f3.6
- Photometric accuracy: 1.7\%(11 \text{ mag})
- Acquired SD’s images by high frame rate and high spatial resolution
### CONCLUSION

By sCMOS, we could acquire **high temporal and spatial resolution**, with **photometric accuracy** comparable to CCD. It would be widely applied in space debris measurement in the near future.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance</th>
<th>VS CCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantum efficiency(QE)</td>
<td>57%@570nm</td>
<td>lower than back illuminated CCD</td>
</tr>
<tr>
<td>image area</td>
<td>16.6mm × 14mm</td>
<td>comparable to CCD</td>
</tr>
<tr>
<td>pixel size</td>
<td>6.5μm</td>
<td>smaller than CCD</td>
</tr>
<tr>
<td>fill factor</td>
<td>&gt;90%</td>
<td>less than CCD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(usually 100%)</td>
</tr>
<tr>
<td>read noise</td>
<td>1e-@100Mhz 1.4 e-@280Mhz</td>
<td>less than normal CCD, comparable to EMCCD</td>
</tr>
<tr>
<td>read speed</td>
<td>100/280Mhz</td>
<td>much faster than CCD</td>
</tr>
<tr>
<td>full well</td>
<td>29400e-</td>
<td>less than CCD</td>
</tr>
<tr>
<td>dark current</td>
<td>0.03e-/pixel/sec(-40°C)</td>
<td>lower than normal CCD, comparable to EMCCD</td>
</tr>
<tr>
<td>photo response non uniformity</td>
<td>1%</td>
<td>comparable to CCD</td>
</tr>
<tr>
<td>linearity</td>
<td>99.9%</td>
<td>a little superior to CCD</td>
</tr>
<tr>
<td>shutter</td>
<td>electronic</td>
<td>eliminate the shutter effect and reduce the malfunction rate of CCD(mechanical)</td>
</tr>
</tbody>
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REFERENCE


- Optical Crosstalk in CMOS Image Sensors, Chris Fesenmaier and Benjamin Sheahan, Psych 221 - Winter 2006-2007
Thank You!