e2v CCD and CMOS sensors and systems designed for astronomical applications

Paul Jorden, Paul Jerram, Doug Jordan, Jérôme Pratlong, Mark Robbins

e2v

SPIE, Edinburgh, 26 June 2016, Conf. 9915-3

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An update of recent sensors and systems

e2v designs and manufactures an increasing suite of CMOS imagers for high performance use

1. CMOS Sensors achieve maturity
   • Custom Backthinned CMOS sensors for ground-based astronomy
     • Custom CMOS sensors for space use
       • Standard CMOS sensors
       • CMOS developments

2. EM CCDs
   • Standard L3|Vision sensors
   • Custom sensors for astronomy & science

3. Precision System assemblies
   • The WUVS space sensor system
     • KMTNet focal planes
     • The J-PAS OAJ Cryocam system

4. Summary
CMOS detectors-1

CIS113 (Vega)

Developed for the TAOS-II project. Development complete; production of 40-off in progress

Number of pixels | 1920 (H) × 4608 (V)
---|---
Pixel size | 16.0 μm square
Image area | 73.73m × 30.72 mm
Output ports | 8 (REF and SIG each)
Package size | 82.39 mm × 31.7 mm
Package format | 76 pin ceramic PGA attached to invar block
Focal plane height | 14.0 mm
Flatness | < 30 μm (peak - valley)
Conversion gain | 75 μV/e-
Readout noise | 3 e− at 2 MP/s per ch.
Maximum pixel rate | 2 MP/s per channel
Maximum charge | 22,000 e− per pixel
Dark signal | 70 e−/pixel/s (at 21 °C)
Frame rate | 2 fps (full frame mode)
20 fps (multiple ROI’s)

Paper by Jérôme Pratlong, 9915, Tues am, S8
CMOS detectors-2

CIS112 (NGSD)

Developed for Adaptive Optics on large telescopes.

- High frame rate and very low noise
- Backthinned and red sensitive
- Precursor of 1600 X 1600 sensor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pixels</td>
<td>880 X 840</td>
</tr>
<tr>
<td>Pixel size</td>
<td>24.0 µm square</td>
</tr>
<tr>
<td>Image area</td>
<td>21.12 mm × 20.16 mm</td>
</tr>
<tr>
<td>Output</td>
<td>Digital; multiple parallel ADCs</td>
</tr>
<tr>
<td>Package format</td>
<td>Ceramic PGA</td>
</tr>
<tr>
<td>Readout noise</td>
<td>&lt; 3 e⁻</td>
</tr>
<tr>
<td>Variants</td>
<td>&gt; 85% at 589 nm</td>
</tr>
<tr>
<td>Maximum charge per pixel</td>
<td>4,000 e⁻</td>
</tr>
<tr>
<td>Frame rate</td>
<td>&gt; 700 fps</td>
</tr>
</tbody>
</table>

See paper by Mark Downing, 9915, Tues am, S8
CMOS detectors-3

Onyx EV76C664

- **Standard product with low noise**
- **Fully digital sensor with multiple modes**
- **Frontside illuminated with micro-lens**

**Key Features**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pixels</td>
<td>1280 X 1024 (1.3 Megapixel)</td>
</tr>
<tr>
<td>Pixel size</td>
<td>10.0 µm square</td>
</tr>
<tr>
<td>Shutter modes</td>
<td>Global and Rolling</td>
</tr>
<tr>
<td>Output</td>
<td>8, 10, 12, 14 bit LVDS</td>
</tr>
<tr>
<td>Package format</td>
<td>Ceramic 67-pin PGA</td>
</tr>
<tr>
<td>Readout noise</td>
<td>6 e⁻ (min, depending on mode)</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>Monochrome or sparse colour (with microlens)</td>
</tr>
<tr>
<td>Maximum charge</td>
<td>16,000 e⁻ per pixel</td>
</tr>
</tbody>
</table>

See e2v.com for datasheet
CMOS detectors-4
CIS115 (Sirius)

- Backthinned sensor with low read-noise
- Designed for space applications
- Planned for JANUS (Juice) ESA mission
- Being qualified for space use by end-2016
- Samples available; FMs to follow

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pixels</td>
<td>1504(H) × 2000(V)</td>
</tr>
<tr>
<td>Pixel size</td>
<td>7.0 µm square</td>
</tr>
<tr>
<td>Number of output ports (reset and signal pins)</td>
<td>4 pairs of analogue outputs</td>
</tr>
<tr>
<td>Package size</td>
<td>48.26 mm square</td>
</tr>
<tr>
<td>Package format</td>
<td>140 pin ceramic PGA</td>
</tr>
<tr>
<td>Flatness</td>
<td>&lt; 10 µm (peak to valley)</td>
</tr>
<tr>
<td>Conversion gain</td>
<td>35 µV/e−</td>
</tr>
<tr>
<td>Readout noise</td>
<td>7 e− (Rolling shutter)</td>
</tr>
<tr>
<td>Maximum pixel data rate</td>
<td>8 MP/s per channel</td>
</tr>
<tr>
<td>Maximum charge per pixel</td>
<td>55,000 e−</td>
</tr>
<tr>
<td>Frame rate</td>
<td>Up to 10 Hz</td>
</tr>
<tr>
<td>Minimum time to read one line at 6·2 MP/s</td>
<td>66.25 µs</td>
</tr>
<tr>
<td>Frame rate at full resolution</td>
<td>Up to 7.5 fps</td>
</tr>
</tbody>
</table>
CMOS detectors-5

**TDI CMOS development**

Time-Delay-Integrate used for scanning space applications; eg GAIA uses TDI CCDs

- TDI CMOS offers digital architecture & low power
- Most promising technique is a CCD-like structure-
- Charge summation along track
- Good CTE after irradiation is important
- Small test devices made & tested
- Full sized device planned

See paper by F Mayer, IISW 2015 on e2v.com
**CMOS detectors-6**

**CIS111 (MTG FCI)**

- Example of imager used for earth observation-
- Offers higher frame rate and lower crosstalk than an equivalent CCD
- CIS111 to be used on Meteosat Third Generation Flexible Combined Imager
- 5 independent imager blocks with in-package filters
- Rhombus shaped pixels in outer blocks
- Optimised for good transfer through large pixels and low lag

**CIS111 architecture**
Custom test vehicle with 250 um square pixels
- Each pixel has 8 photodiodes with a common sense node
- Aims to optimise lag and Charge-Voltage-Factor
- 2.5 Me- peak signal; 84 dB dynamic range
- Designed for backthinning
- Test devices have been characterised
We illustrate selected EMCCDs
Internal electron gain allows sub-electron read-noise
Combined with backthinned spectral response for very high sensitivity
Several formats and sizes available

Standard (non EMCCDs) are not discussed in the presentation- since many are visible on e2v.com and have been discuss previously

2. EM CCDs
   • Standard L3Vision sensors
   • Custom sensors for astronomy & science
CCD sensors-1

CCD201

- Standard product
- 1024 X 1024 pixels; 13 µm pixels
- Larger format than CCD97 (512 X 512 pixels)
- Widely used for commercial applications
- Also useful for astronomy at low signal levels
- Sub-electron read noise
- Backthinned for high spectral response
- Inverted mode dark current

- Under evaluation for space use (NASA WFIRST Coronagraph)


See poster by Nathan Bush, 9904, Tues pm
CCD sensors-2

CCD282

- Largest EMCCD manufactured to date
- 4096 X 4096 pixel image area
- Split frame-transfer read-out with 8 outputs
- > 4 frames per second
- Sub-electron read-noise
- Backthinned for high Quantum Efficiency
- Very low levels of clock-induced charge
- Non-inverted operation at cryogenic temperatures
- Development is complete; sensors have been delivered

CCD sensors-3

CCD351

- Standard product, for commercial use
- L3Vision technology for sub-electron read-noise
- Video rate readout
- Backthinned spectral response
- In standard production

Typical Performance

<table>
<thead>
<tr>
<th>Image section</th>
<th>1024 x 1024</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>10 µm × 10 µm</td>
</tr>
<tr>
<td>Active image area</td>
<td>10.24 × 10.24 mm</td>
</tr>
<tr>
<td>Package size</td>
<td>22.86 × 28.00 mm</td>
</tr>
<tr>
<td>Amplifier responsiveness</td>
<td>3.5 µV/e–</td>
</tr>
<tr>
<td>Readout noise</td>
<td>&lt; 1 e– (with EM gain)</td>
</tr>
<tr>
<td>Multiplication gain</td>
<td>100-1000 typical</td>
</tr>
<tr>
<td>Output data rate</td>
<td>37 MHz</td>
</tr>
<tr>
<td>Pixel charge storage</td>
<td>35 ke-/pixel</td>
</tr>
<tr>
<td>Dark signal (18°C)</td>
<td>100 e-/pixel/s</td>
</tr>
</tbody>
</table>

Package illustration (not final)
e2v develops sub-systems to complement its supply of sensors.

- Bespoke systems are optimised for each application and use common modules where appropriate.
- Performance of sensors combined with system can be guaranteed.

3. Precision System assemblies

- The WUVS space sensor system
  - KMTNet focal planes
- The J-PAS OAJ Cryocam system
World Space Observatory UV Spectrograph

- 115-310 nm range covered by three sensor channels
- Custom sealed vacuum cryostat enclosures for 9 year life
- with flight electronics (associated with RAL Space)
- UV optimised custom CCD272 operated at -100°C
- Components maintain alignment after shock & vibration of launch
- Design and manufacture underway
Precision System Assemblies-2
WUVS

Triple detector unit detector layout with camera electronics units

See Poster by Vladimir Panchuk, 9905, Sun pm
Korea Micro-lensing Telescope Network
3 telescopes each with its own camera; 350 mm focal plane; 340 MegaPixel each
Each camera had four CCD290 science sensors and four guide sensors; < 30 µm flatness
Focal planes are complete (e2v), operational and installed in cameras (by Ohio State University)

See Poster by Dae-Sik Moon, 9906, Mon pm. Also see previous paper Jorden et al, SPIE 2014
A 1.2 Gigapixel cryocam for use on the 2.5m OAJ telescope for the J-PAS survey. e2v has just completed this important commercially-supplied astronomical camera.
## Table of key features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 mm focal plane diameter</td>
<td>-100°C operating temperature</td>
</tr>
<tr>
<td></td>
<td>Stable to +/- 0.5°C</td>
</tr>
<tr>
<td>27 µm peak-valley flatness</td>
<td>Measured at -100°C</td>
</tr>
<tr>
<td></td>
<td>Stable against flexure</td>
</tr>
<tr>
<td>14 science CCD290-99 sensors:</td>
<td>1.2 Gig pixels</td>
</tr>
<tr>
<td></td>
<td>9K X 9K sensors</td>
</tr>
<tr>
<td>8 wavefront sensors:</td>
<td>CCD44-82 FT</td>
</tr>
<tr>
<td></td>
<td>Custom packages</td>
</tr>
<tr>
<td>4 guide sensors:</td>
<td>CCD47-20 FT</td>
</tr>
<tr>
<td></td>
<td>Custom packages</td>
</tr>
<tr>
<td>Integrated electronics</td>
<td>224 science channels</td>
</tr>
<tr>
<td></td>
<td>&lt; 5 e- read-noise at 400 kHz</td>
</tr>
<tr>
<td>Modular CCD drive units</td>
<td>Synchronized readout of science CCDs</td>
</tr>
<tr>
<td>Complete LN2 cooling system</td>
<td>Integrated vacuum system</td>
</tr>
<tr>
<td></td>
<td>Post-delivery support</td>
</tr>
<tr>
<td>Cold light baffle</td>
<td>High Quantum Efficiency</td>
</tr>
<tr>
<td></td>
<td>minimum reflection AR coat</td>
</tr>
</tbody>
</table>

See paper by Mark Robbins, 9908, Tues 28 June 2016, am, S8

And K Taylor et al, JPCAM, JAI vol 3, 2014
Summary

And some closing remarks

This paper is an update of e2v technology developments and products since:


• An increasing number of sensors are being developed using CMOS architectures
  Many of these are backthinned and offer low read-noise (comparable to CCDs)

• CCDs continue to be used in larger quantities and with greater heritage
  CCDs offer better red response in general (thicker silicon)

• e2v offers custom system solutions including cryogenic cameras and electronic modules to complement its supply of sensors- and with guaranteed performance

Thank you for your attention
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