Sensor developments themes at e2v

Paul Jorden

13 Oct 2009

Detectors for Astronomy 2009, Garching

Contents

Main themes covered today

- L3 (electron-multiplying) sensors
- High-rho sensors
- CMOS/APS
- Other new CCDs

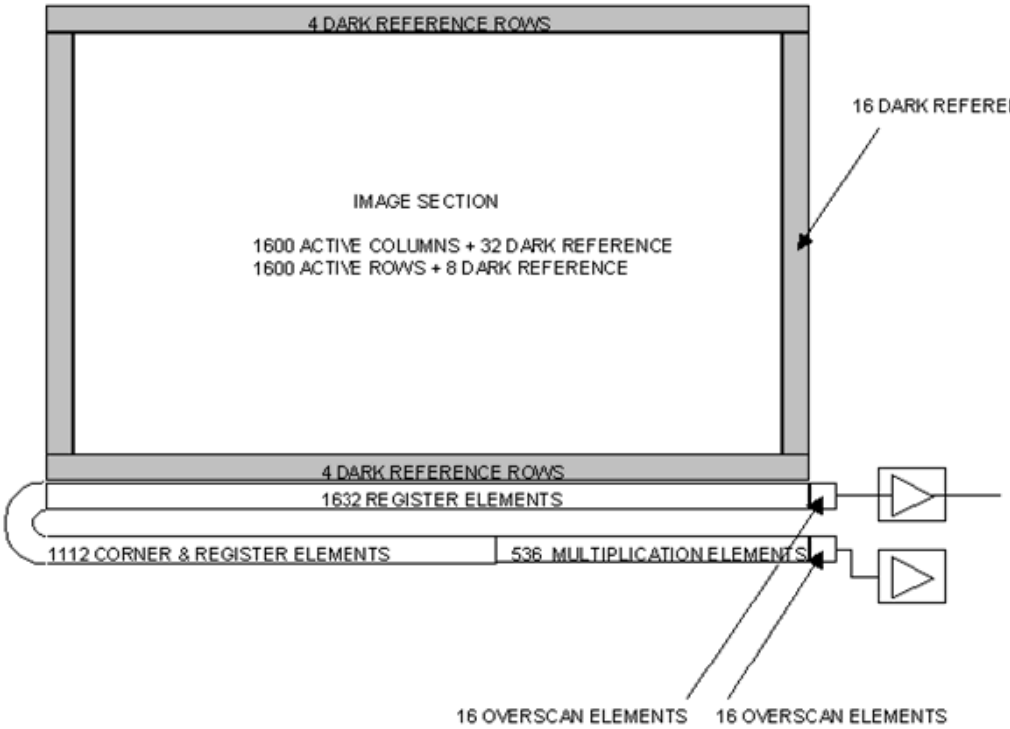
- **L3Vison (electron-multiplying; EMCCD) sensors**
- High-rho sensors
- CMOS/APS
- Other new CCDs

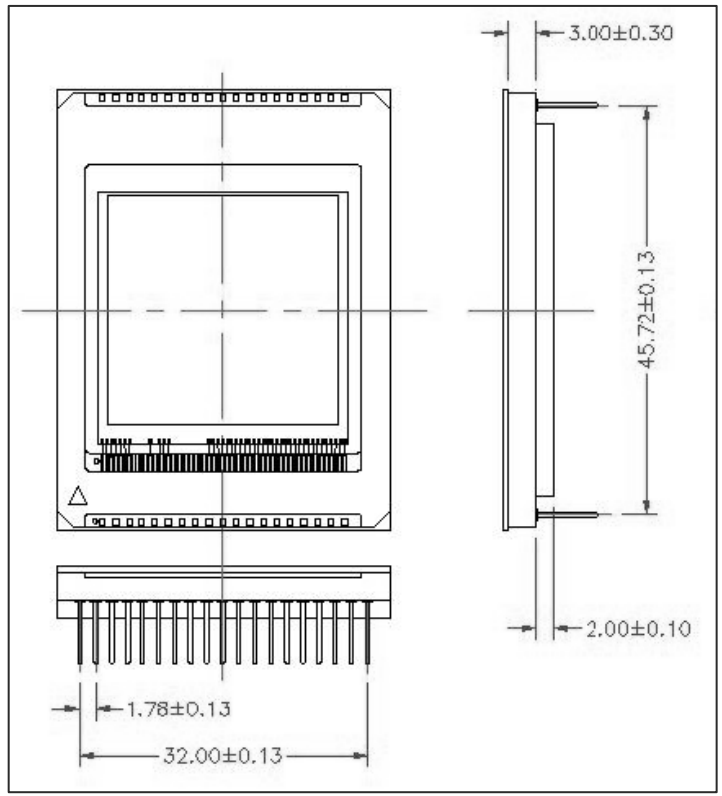
Large format scientific sensor

- Format: 1632 X 1608; Full Frame architecture
- Image size: 26 X 26 mm
- Pixels: 16 X 16 µm
- Pixel rate; 3-20 MHz (depends on output, and required settling time)
- Number of outputs: Two: one EM-type; one normal low noise
- QE: backthinned for high QE
- Ceramic package

Designed for scientific use.
Limited availability.

L3 (electron-multiplying) sensors- 1b
New devices: CCD207-40





L3 (electron-multiplying) sensors- 2
New devices: CCD251

A new sensor in the L3 (EMCCD) family- Samples (backthinned) due Dec-2009

➲Format:	1024 X 1024; FT architecture
➲Image size:	8 X 8 mm
➲Pixels:	8 X 8 µm
➲Pixel rate;	>30 MHz
➲Number of outputs:	one, EM-type; sub-electron noise
➲QE:	backthinned for high QE
➲Frame rate:	35 fps
➲Ceramic package	

Some performance improvements designed (ageing etc)

Designed for scientific & camera use.

L3 (electron-multiplying) sensors- 3
New devices CCDxxx (planned)

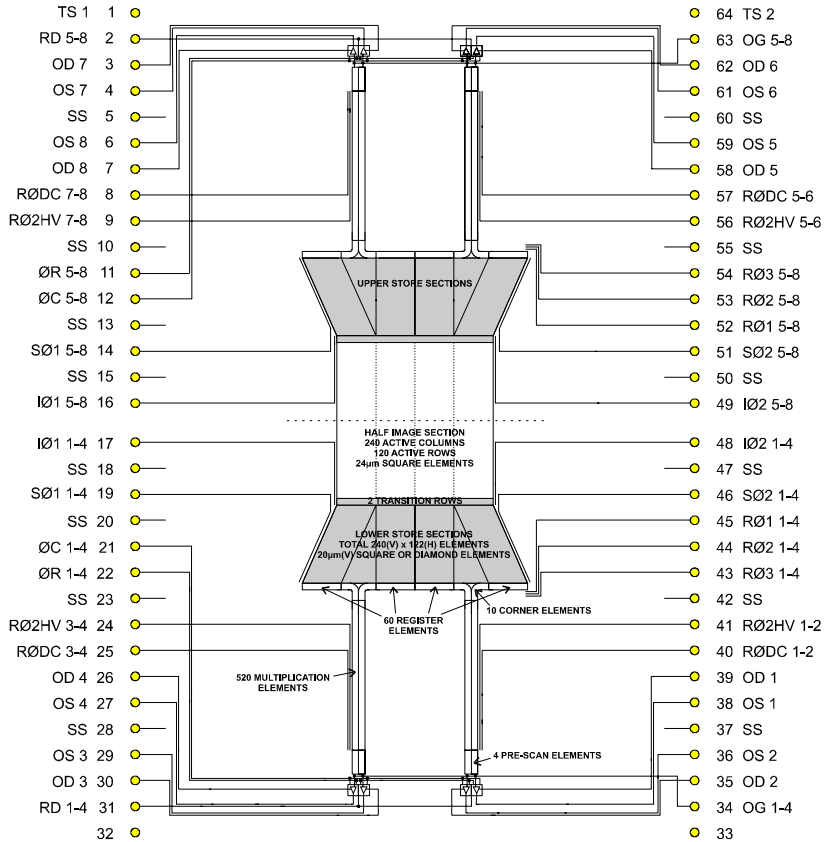
Large-format, multi-output scientific L3 sensor
New custom design; projected start due ~ 2Q 2010

➲Format:	2048 X 2048 (TBC); FT architecture
➲Image size:	30.7 X 30.7 mm
➲Pixels:	15 X 15 µm
➲Pixel rate;	15 MHz (TBC)
➲Outputs:	two L3 gain, plus two normal low noise (TBC)
➲Frame rate:	6 fps, from L3 outputs
➲QE	Backthinned for high QE; deep depletion TBC
➲Buttable package	TBC

“Stitchable” design; other formats possible

L3 (electron-multiplying) sensors- 4
CCD220

- 240 x 240 pixels; split FT format
- 24 X 24 µm pixels; 5.8 X 5.8 mm image
- 100% fill factor
- Back-illuminated for high QE
- Deep depletion (red) variant
- High frame rates (1000 fps nominal)
- 8 L3Vision™ outputs; sub-electron noise
- Integral Compact Peltier package



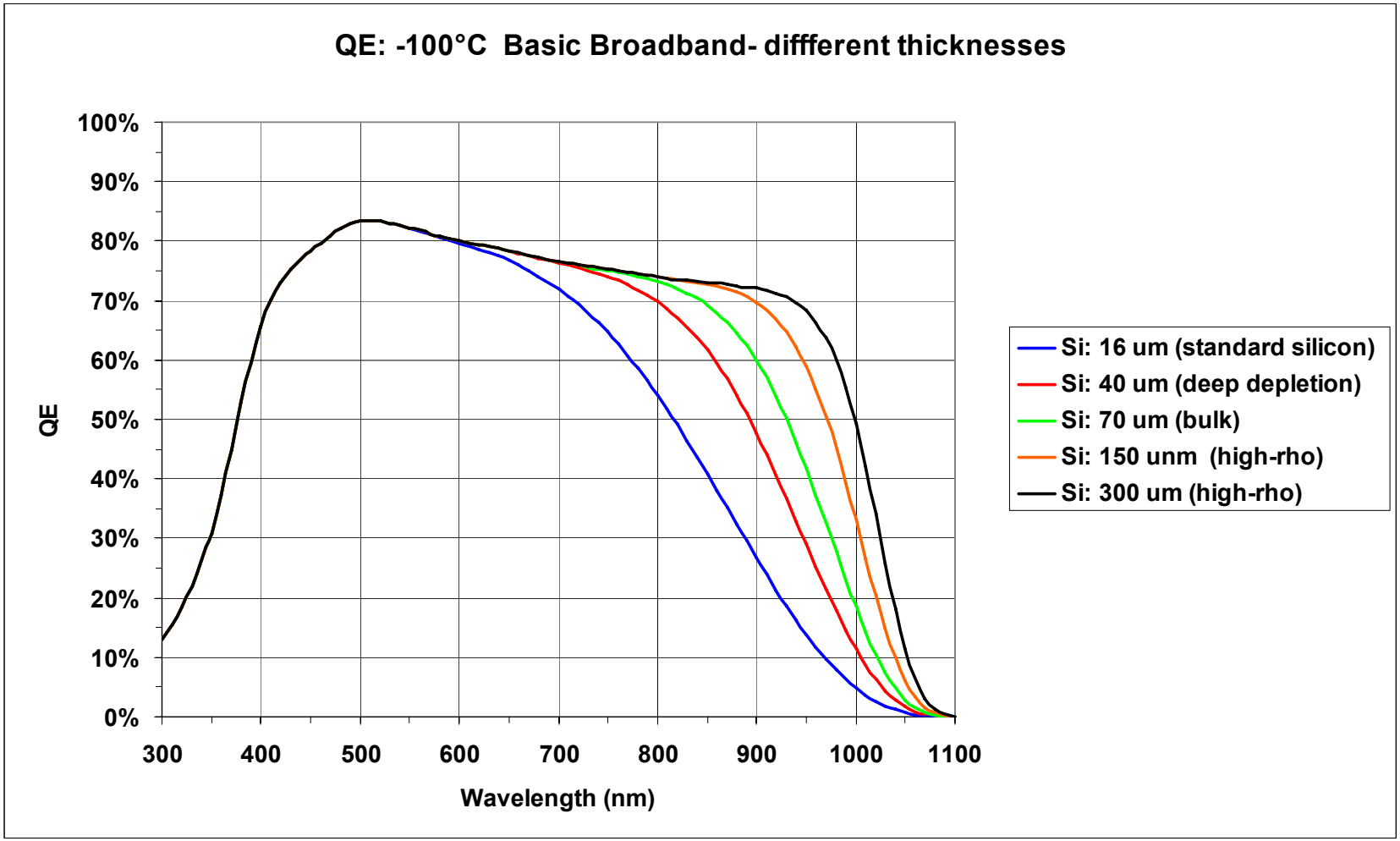
ESO/ Opticon project: See Feautrier & Downing talks (Wed am)

New Product development
L3C216 (L3 EM camera)

- New L3 camera with 768 pixels per line in 2/3” format to allow use of smaller lenses.
- 9.0 X 6.6 mm image
- CameraLink interface
- Backthinned CCD
- Manual or automated gain control with flexible user defined settings
- 525 line or 625 line formats
- Provides real time images down to overcast starlight outperforming intensified camera.

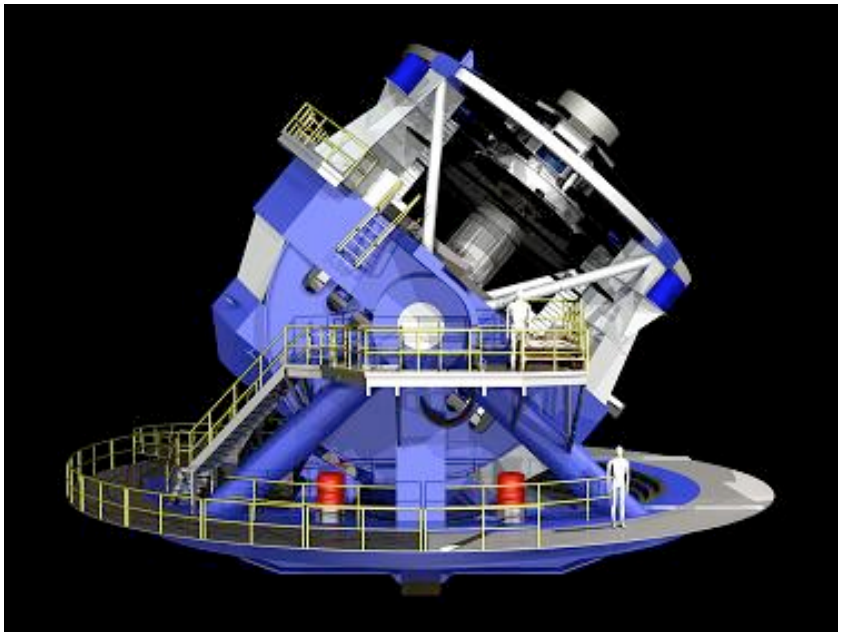
- L3 (electron-multiplying) sensors
- **High-rho sensors**
- CMOS/APS
- Other new CCDs

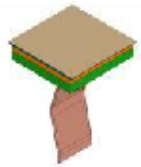
High-rho sensors- 1
Introduction



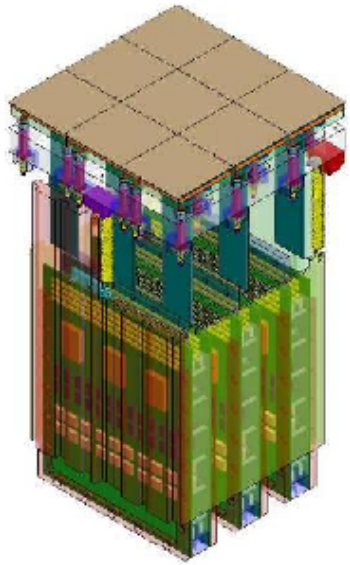
High-rho sensors- 2
LSST system

e2v



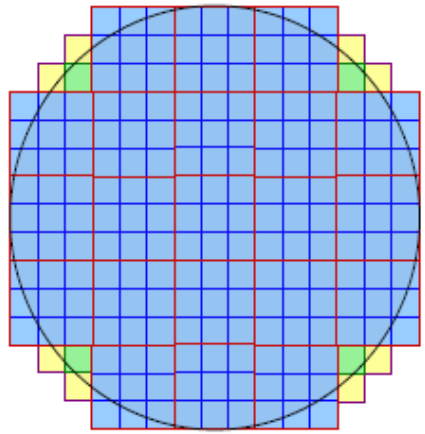


4K x 4K pixels on 10μm centers
16 readouts/sensor
330 nm to 1070 nm response
1 second read time



9 CCD's assembled into one raft
21 rafts in the camera

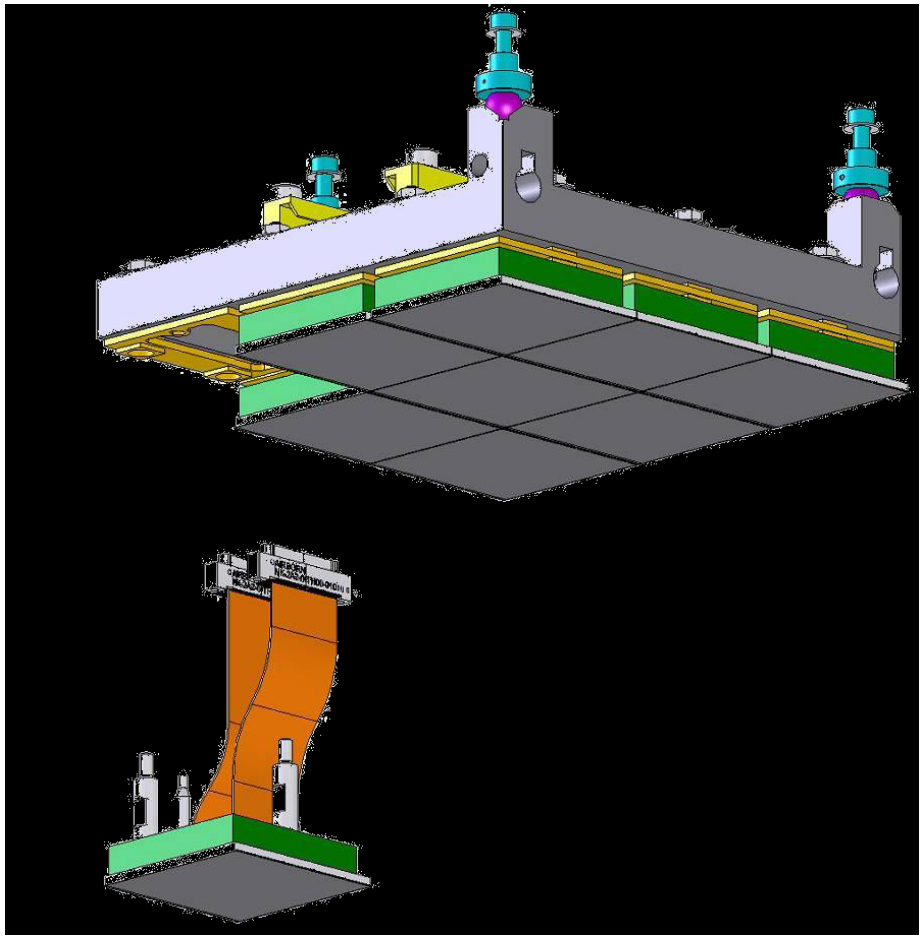
The 63cm diameter focal plane has 189 CCD's arranged on 21 modular rafts

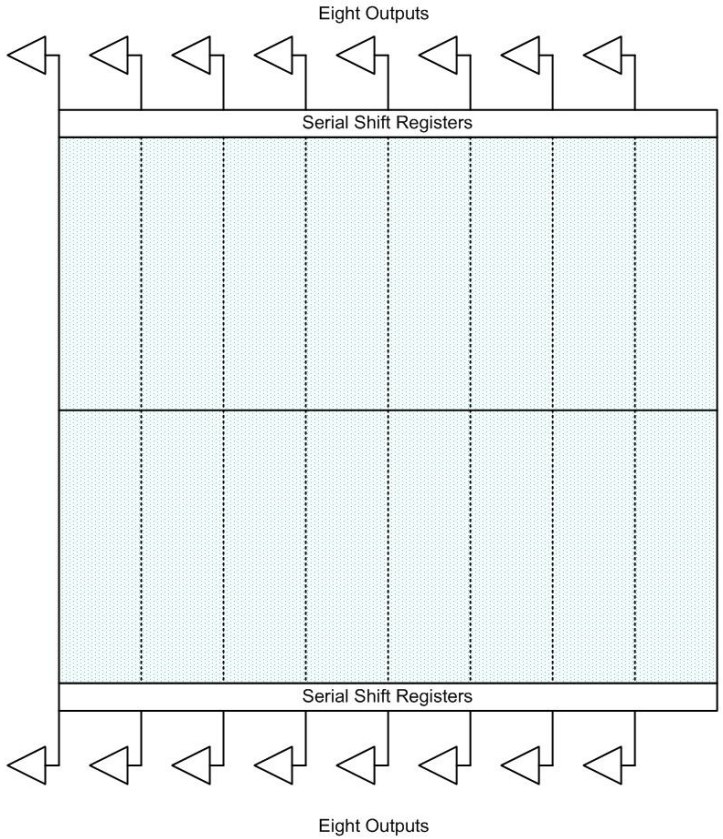


Acknowledgements to LSST

From AAS Jan 2008

High-rho sensors- 2
LSST CCD concepts





High-rho sensors- 2
LSST CCD outline

e2v

Sensor

4K x 4K CCD sensors

2 contiguous imaging areas 2K x 4K

2 sec readout at 500 kHz → ~1M pixels per output

Fill factor must approach unity, which favors a fairly large area footprint of ~16 cm^2

500 pixels/segment for blooming control of bright stars

Required flatness across sensor: 5 microns

Key parameters

10 X 10 µm pixel size

16 parallel outputs for short read-time

Backthinned for UV to NIR response

100 µm thick for high red response and maintain good PSF

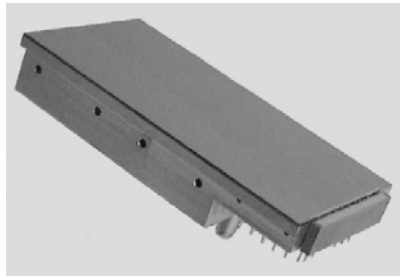
Backside bias with high resistivity silicon

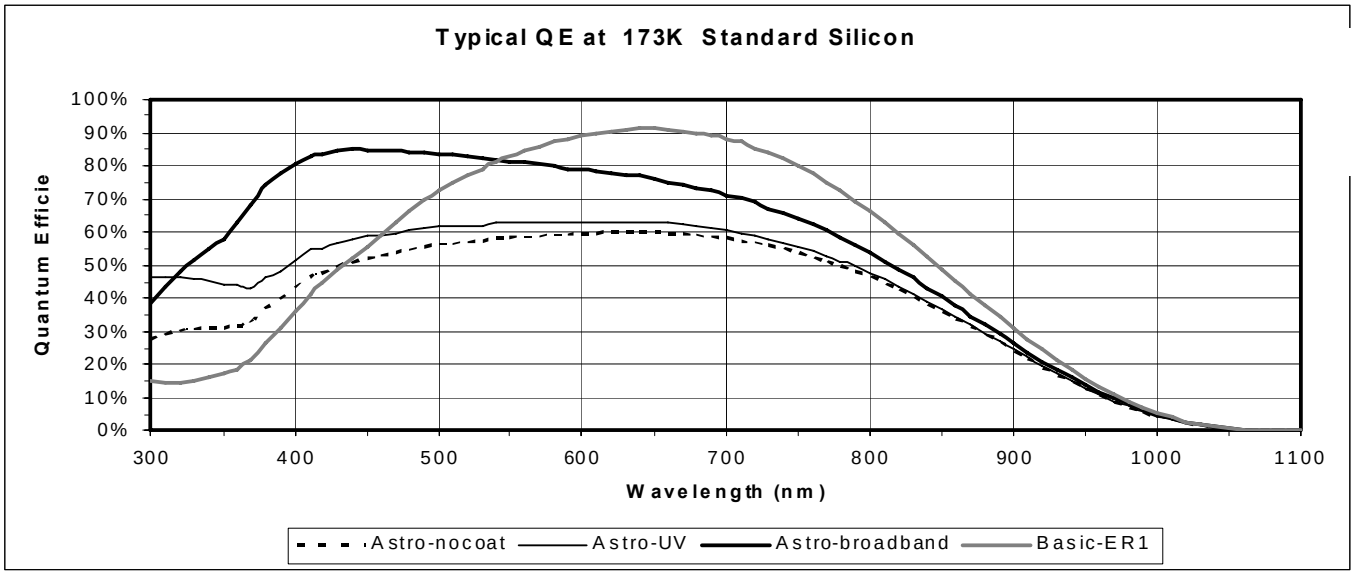
4-side butting with minimal gap- custom package development

Demanding flatness and precision height specification

[F/1.2 across 3.5 deg FOV]

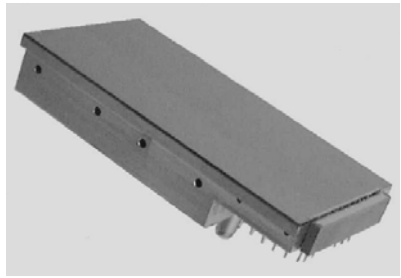
High-rho sensors- 3
Bulk CCDs

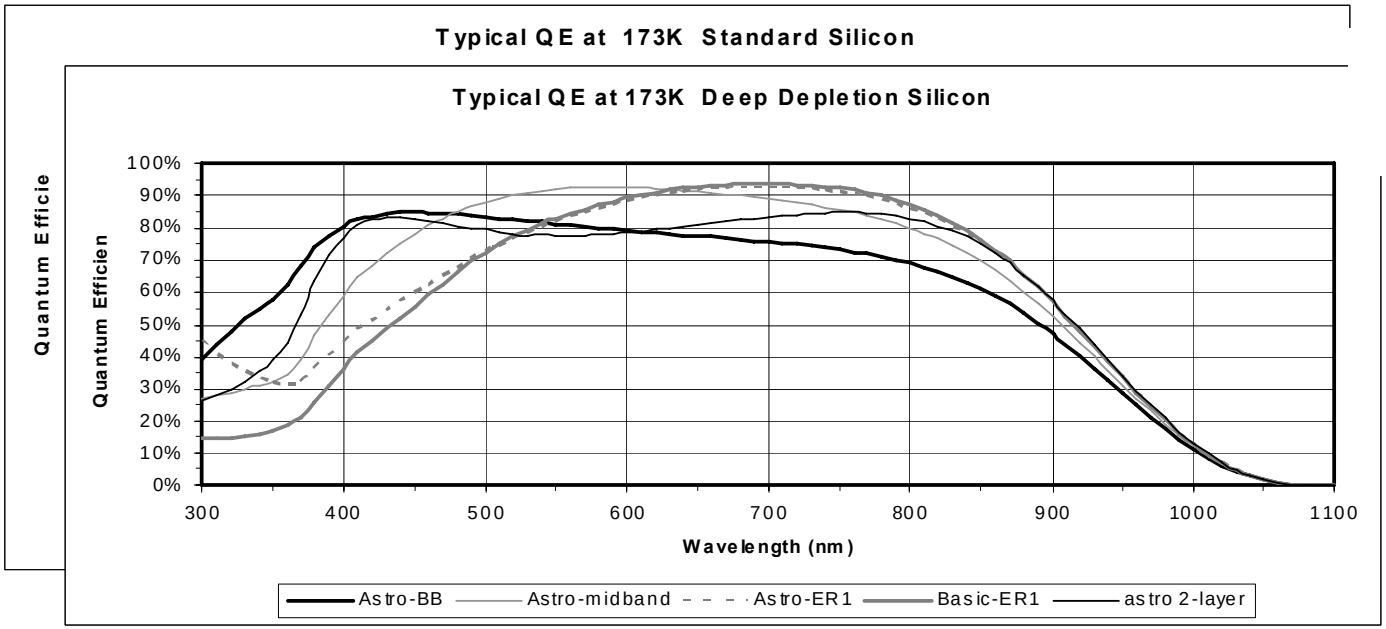




100 ohm-cm; 16 µm thick

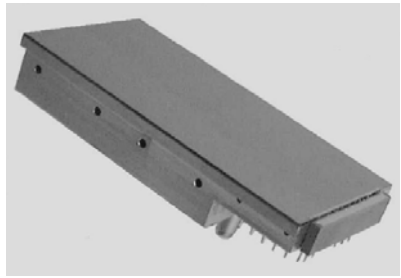
High-rho sensors- 3
Bulk CCDs





1500 ohm-cm; 40 µm thick

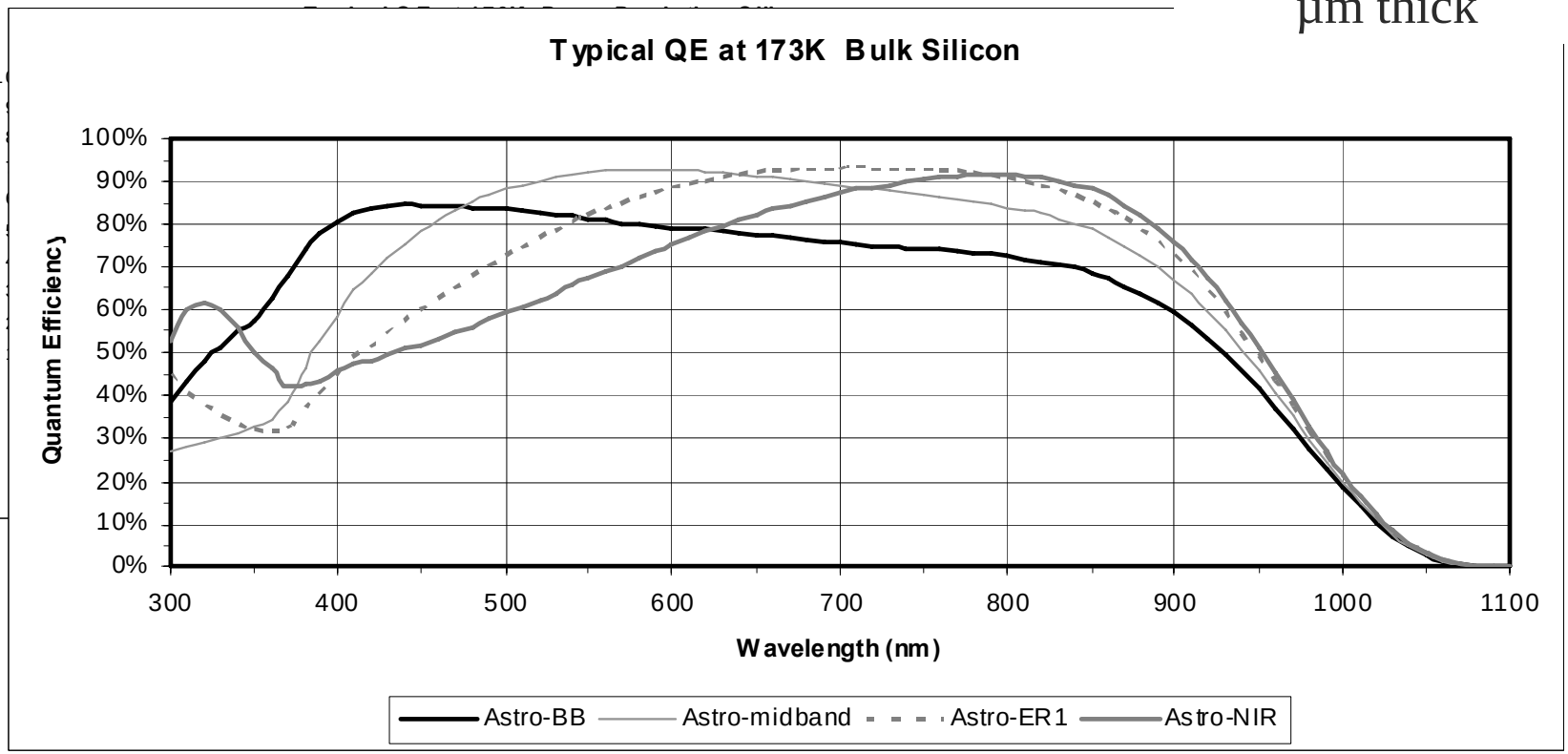
High-rho sensors- 3
Bulk CCDs



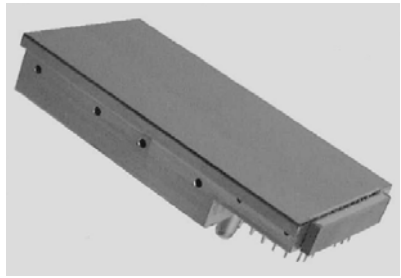
Same design; same operation; more red QE.

(See also Downing et al; wed pm)

3000 ohm-cm; 70 µm thick

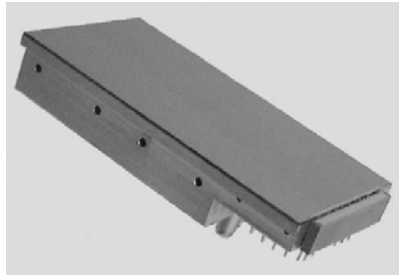


High-rho sensors- 4



- Previous generations of device demonstrated high-rho QE and low noise.
- New design of a true scientific sensor, with the same noise as other standard CCDs
- A new family of “high-rho” sensors: **CCD261**
- Enhanced red sensitivity; substrate bias to backside
- 2k4k first device: samples due- end 2009

High-rho sensors- 4
CCD261-84

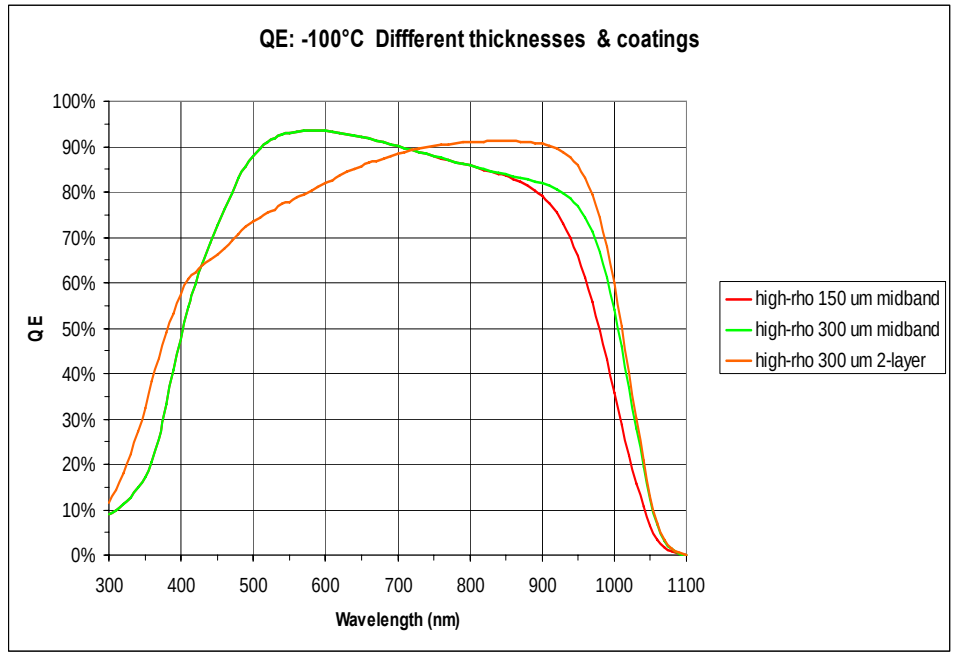


Number of pixels	2048(H) x 4104(V)
Pixel size	15 µm square
Image area	30.7 mm x 61.6 mm
Outputs	2
Package size	31.9 mm x 66.6 mm
Package format	Invar metal package with PGA connector
Focal plane height, above base	14.0 mm
Connectors	40-pin PGA
Flatness	20 µm p-v
Amplifier responsivity	6 µV/e^-
Readout noise	2 e^- at 20 kHz
Maximum data rate	~1 MHz
Image pixel charge storage	230,000 e^-
Dark signal	0.01 e^-/pixel/hour (at 153K)

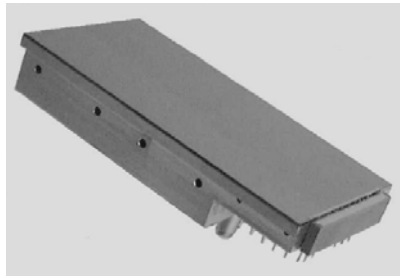
A new family of “high-rho” sensors

2k4k first device

Enhanced red sensitivity; substrate bias to backside

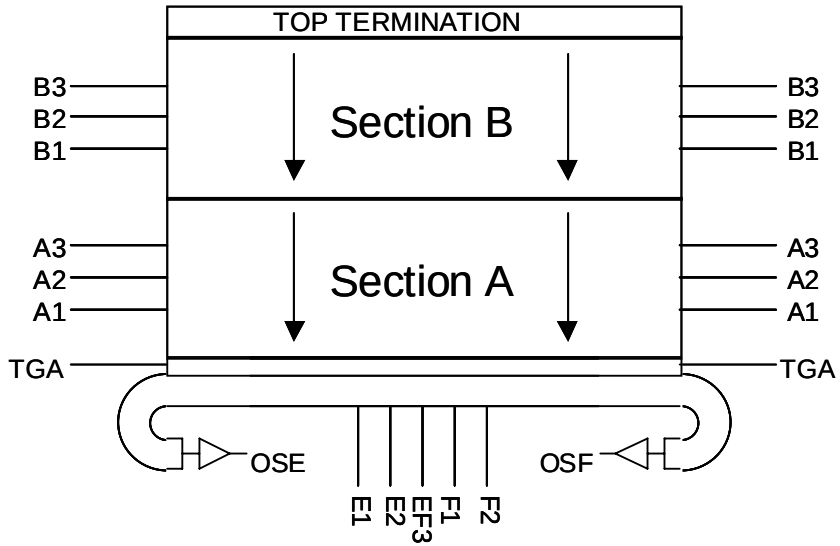


High-rho sensors- 4
CCD261-84

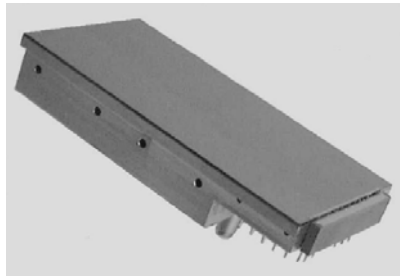


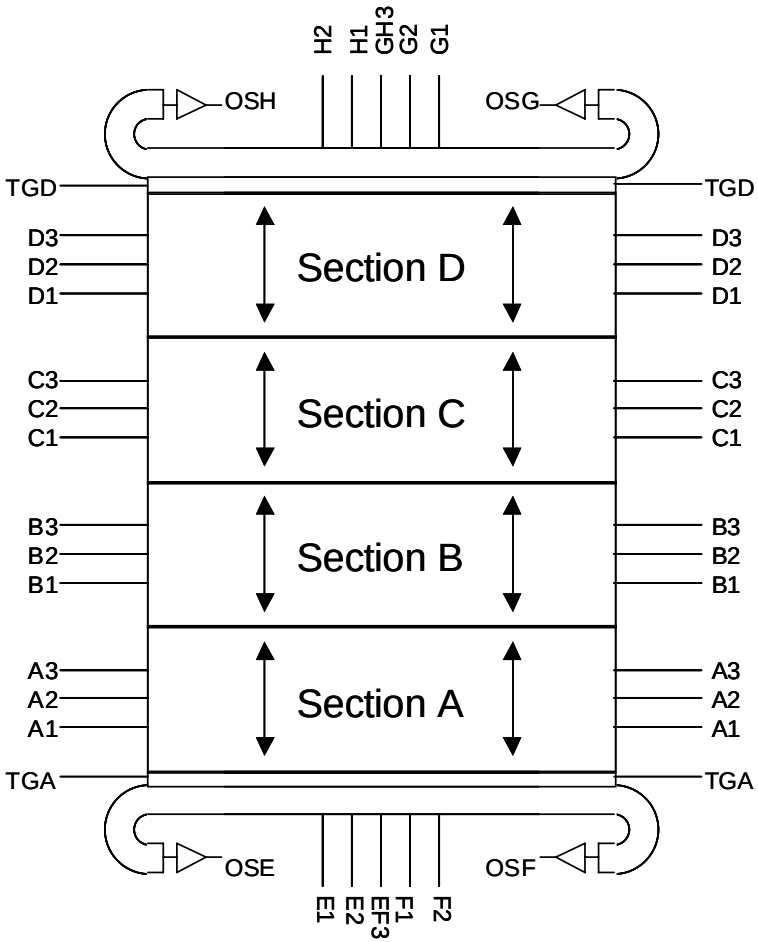
Functions (pins)	
BSS	Back-side bias
B3	Image phase
B1	Image phase
B2	Image phase
A3	Image phase
A1	Image phase
A2	Image phase
TGA	Transfer gate
ØRE	Reset clock
RDE	Reset drain
LSS	Local Vss
OSE	Output source
ODE	Output drain
OGE	Output gate
SWE	Summing well
GD	Guard drain
E2	Serial clock
E1	Serial clock
EF3	Serial clock
F2	Serial clock
F1	Serial clock
SWF	Summing well
OGF	Output gate
ODF	Output drain
OSF	Output source
RDF	Reset drain
ØRF	Reset clock

Similar format, same package style, same connector, and similar pin function as the CCD44-82



High-rho sensors- 4
CCD261





"Stitchable" building blocks

Other formats planned:

4-output variants

4k X 4K formats

FT variants

Other sizes

CCD260 variant:

Larger charge capacity; lower responsivity (3 µV/e-)

- L3 (electron-multiplying) sensors
- High-rho sensors
- **CMOS/APS**
- Other new CCDs

CMOS/APS

e2v BI CMOS

CMOS (APS) sensors

		Main application
➲ Ev76c454	860 X 640	[Industrial]
➲ Ev76c560	1280 X 1024	[Industrial]
➲ Hyperspectral demo	1024 X 256 pixels	[Space]
➲ Cobra-2M	2Mpix; space qualified; designed for BI	
➲ High frame rate, low noise sensor (in development)		[Scientific]

CMOS/APS- 1

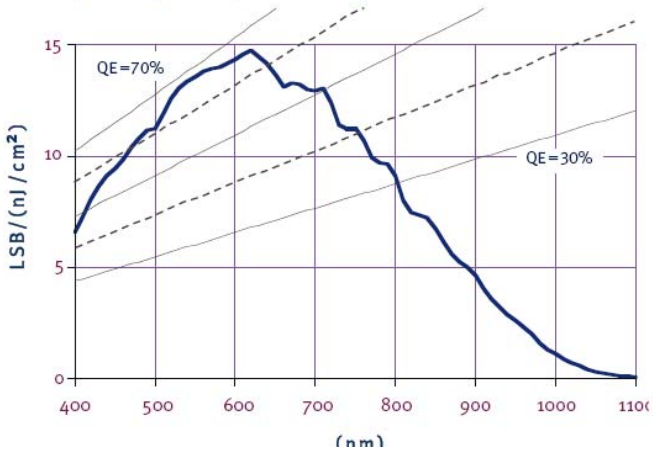
ev76c454

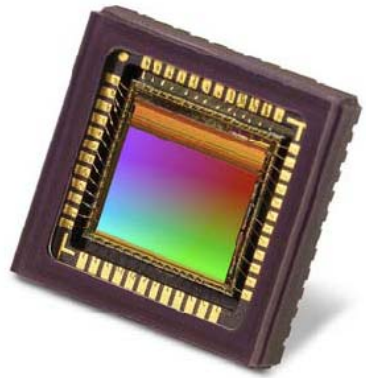
Typical Performances

Electro-optical performances

Sensor characteristics		
Resolution	pixels	838 (H) x 640 (V)
Image size	inches	1/2.9
Pixel size (square)	µm	5.8 x 5.8
Aspect ratio		4 / 3
Max frame rate	fps	60 @ Full format 80 @ VGA format
Pixel rate	Mpixels / s	48
Pixel performance		
Bit depth	bits	8
Dynamic range	dB	›52 (linear) ›100 (HDR mode)
SNR max	dB	›40
Responsivity	LSB_8 (nJ/cm²)	15
Mechanical & electrical interface		
Power supplies	V	3.3 & 1.8
Power consumption Functional Standby	mW µW	80 40

Spectral response & Quantum efficiency Gain = 1





Key Features

- High QE, low light CMOS sensor
- Global shutter
- 860 x 640 pixels @ 60 fps
- 5.8 µm square pixels with Micro-lens
- Wide dynamic range (120 dB)
- Power supplies 3.3V & 1.8V
- Low power consumption
- Output format 8 bits parallel
- Operating temperature [-30° to +65°C]
- Package: µCLCC48 10 x 10 mm

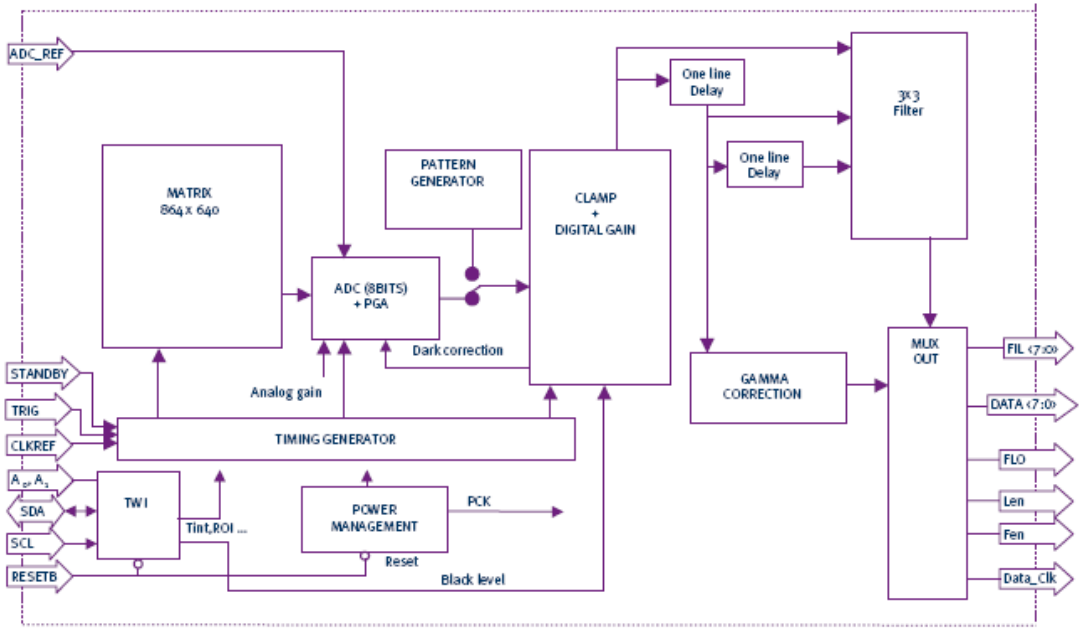
Applications

- Surveillance IP/CCTV cameras
- Industrial machine vision
- Biometric/medical imaging
- Automotive vision

CMOS/APS- 1
ev76c454

Sensor architecture

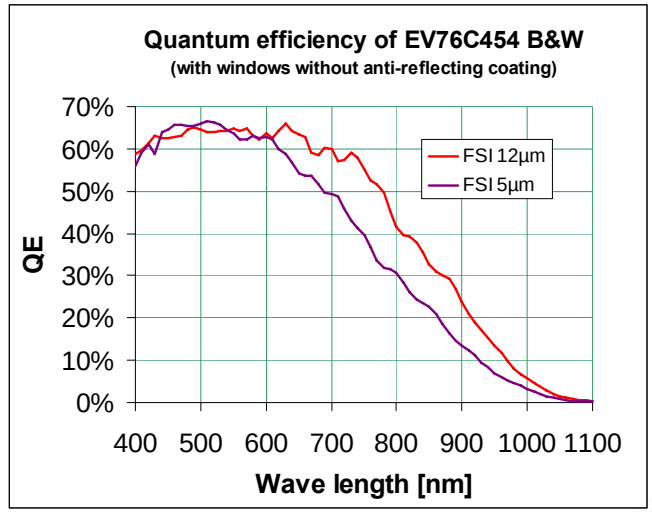
Block diagram



Samples/ demo-kit available

Designed for backside illumination

Thicker variants for higher QE



CMOS/APS- 2
ev76c560

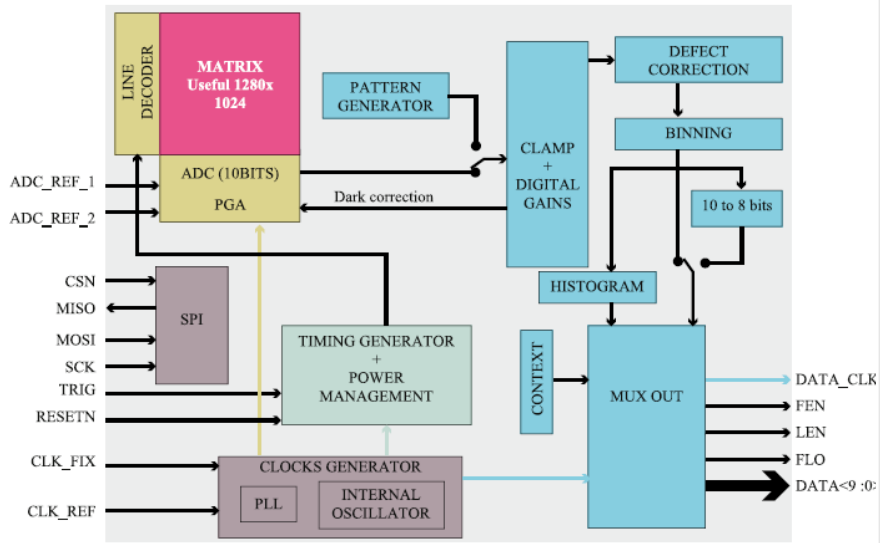
Key Features

- 1.3 Million pixels (1280 x 1024), 5.3µm Square pixels with micro-lens
- High speed: 60 fps at full resolution, low light CMOS sensor
- Global shutter for sharp images of fast moving objects
- Rolling shutter allowing true CDS and global reset for best SNR
- Multiple simutaneous regions of interest [4 separate windows]
- Linear dynamic range 62dB @ 25°C with possible HDR modes
- Low power consumption
- Output format 10 bits parallel plus synchronisation
- Operating temperature [-30° to +65°C]
- Package : CLCC 48 12.7x12.7mm
- SPI control

Typical Applications

- Intelligent cameras
- CCTV/IP surveillance cameras
- Industrial machine vision
- Barcode reading/scanners
- Biometric and medical imaging
- Automotive vision
- HD camcorders

Sensor block diagram



- Electronic rolling shutter and electronic global shutter
- High-readout speed of 60 fps in full resolution.
- Multi ROI and histogram output embedded on-chip
- Very low power consumption (battery powered use)

CMOS/APS- 2
ev76c560

e2v

Sensor characteristics

Sensor Characteristics		
Resolution	pixels	1280 (H) x 1024 (V)
Image size	inches	1/1.8
Pixel size (square)	µm	5.3 x 5.3
Aspect ratio		5 / 4
Max frame rate	fps	60 @ Full format ›100 @ VGA format
Pixel rate	Mpixels /s	90 to 120

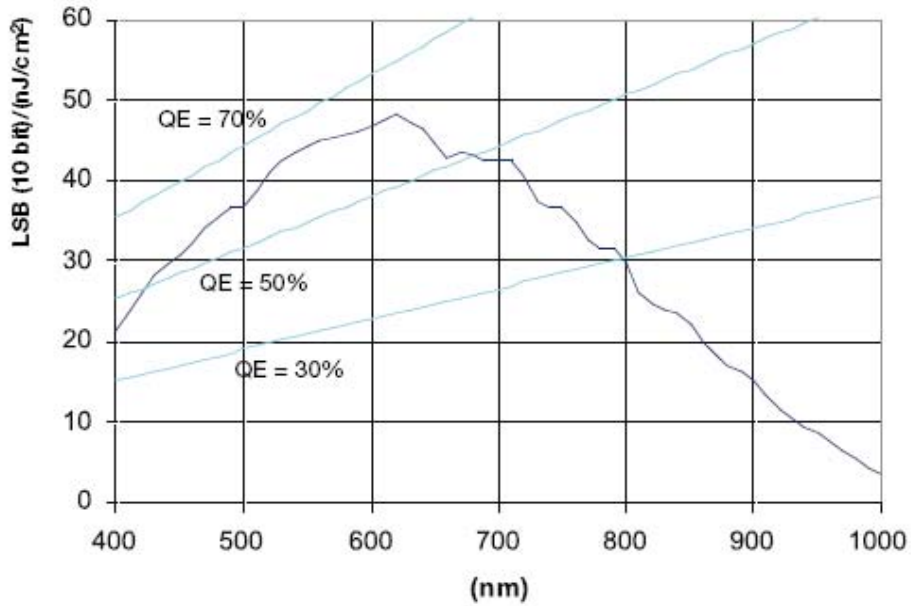
Pixel performance		
Bit depth	bits	10
Dynamic range	dB	66 (linear) ›100 (HDR mode)
SNR max	dB	42
Responsivity	LSB10/(nJ/cm²)	48

First samples: 6.5 e- rms noise

Samples made

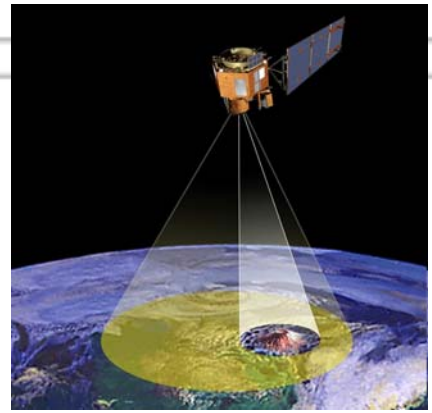
Designed for backside illumination

Spectral response & Quantum efficiency

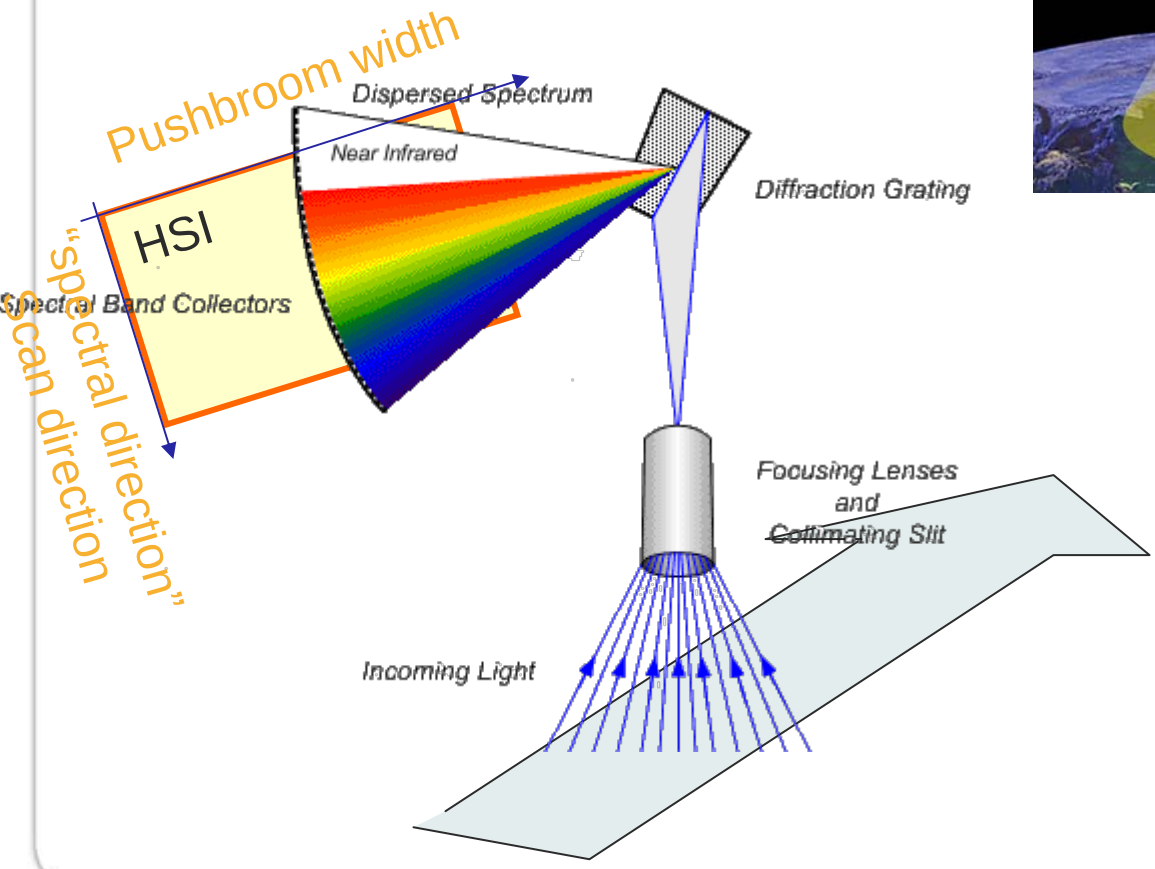


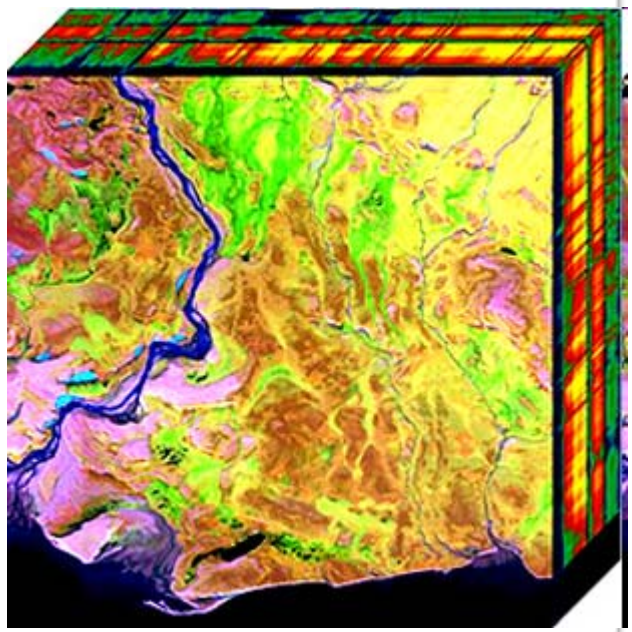
CMOS/APS- 3

Hyperspectral Imager (for space)



Hyper spectral imaging





CMOS/APS- 3
Hyperspectral Imager

Device designed to achieve the difficult combination of:

→fully pipelined synchronous shutter

→ in a standard CMOS technology, yet
-with high resistivity thick epi
-with maximum QE in backside illumination.

→ CDS operation.

→ Programmable sensitivity row by row

Hyperspectral imaging (HSI), benefits from CMOS:

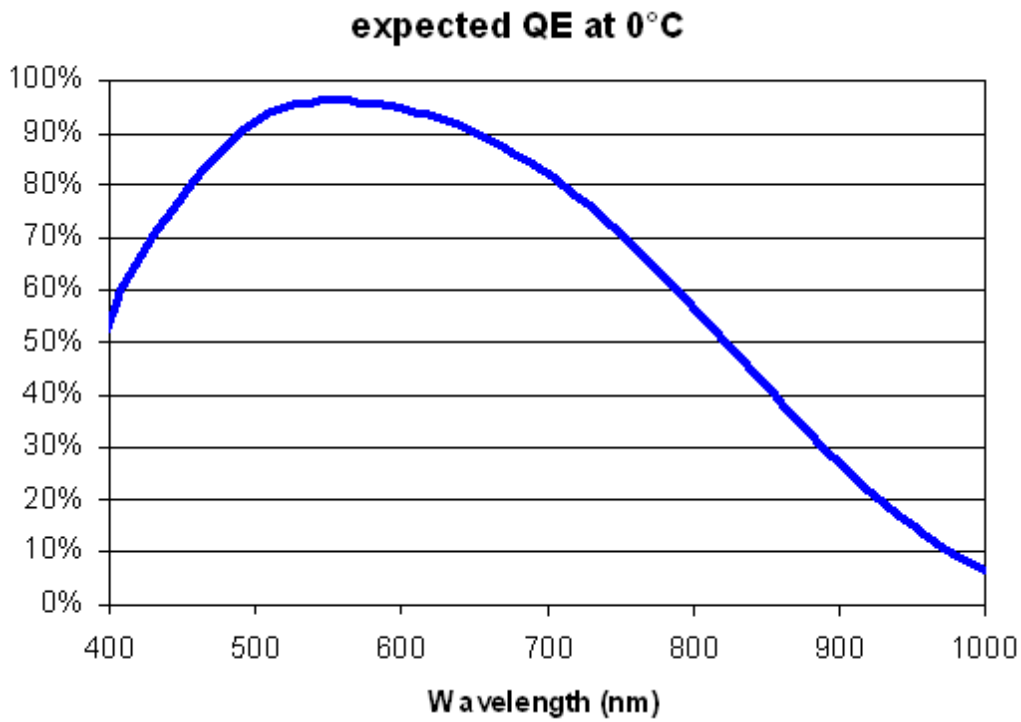
- ➲Very large difference in intensity between the weakest and brightest spectral lines
- ➲The use of CMOS technology removes the frame-shift smear that can produce significant crosstalk
- ➲optimum performance from all spectral lines by flexible integration time and programmable sensitivity.
- ➲High frame rate and random access to lines of interest
- ➲BSI compatible, radiation tolerance etc.

CMOS/APS- 3
Hyperspectral Imager- key specifications

Resolution	1024 x 256 (n*512 x 256)
Pixel pitch	24µm
Number of spectral bands	256
Readout speed	250 frames per second
ROI, windowing	Random access in Y-direction (spectral direction) only
Full Well charge for 1% linearity	100ke- and 300ke- (programmable)
Line-by-line programmable charge conversion factor	12fF or 13 µV/e^- 36fF or 4 µV/e^-
Total noise	<50 e^-_{RMS} in basic mode without CDS <20 e^-_{RMS} with CDS
QE	>90% in VIS(+NIR)

CMOS/APS- 3
HSI predicted QE

For 12µm thick Si
Without Mirror



APS devices operate at 2 or 3V

Depletion depth is small

100 ohm-cm → 5 µm

500 ohm-cm → 12 µm

[Needs high resistivity for good red QE and good blue PSF]

CMOS/APS- 3
HSI demo chip status

The design is complete-

- Multiple operation modes are possible and are being explored:
  - Rolling or pipelined synchronous shutter
  - CDS operation or double sampling or direct readout
  - NDR modes, even only for specific lines, and other HDR modes
  - Spectral line-wise sensitivity programming and random access

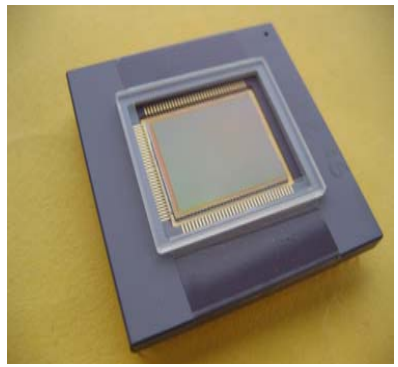
- Photodiode and CMOS technology
  - PIN diode in BSI: highest possible VIS+NIR QE
  - Migrate to buried/pinned photodiode:
    - fully depletable (CDS in all operation modes)
    - low dark current as shielded from interface generation centers.

Manufacture about to start

CMOS/APS- 4
CMOS space demonstrator (Cobra-2M)

Demonstrator devices (made in 2008) for a geostationary ocean imager using a 2M pixel CMOS sensor for Astrium. These devices are now available both as demonstrators and fully qualified FM devices.

➲Number of pixels	1415(H) x 1430(V)
➲Pixel Size	14.81 µm x 11.53 µm
➲Image area	20.96 mm x 16.49 mm
➲Optical Fill factor	65%
➲Conversion gain	4.75 µV/e
➲Dynamic range	0.98V
➲Data rate	10 MHz
➲Connectors	Pin Grid Array (PGA)
➲Power consumption	50mW



CMOS/APS- 5

Wavefront sensor concept

e2v

➲Overview of main requirements

- ➲Format: >1024 X 1024 pixels
- ➲Pixels: 24 X 24 µm nominal
- ➲Frame rate: 700 fps nominal
- ➲Readout noise: < 3 e- rms
- ➲QE: 90% at 590 nm
- ➲Low dark current
- ➲Good PSF
- ➲Good pixel non-uniformity and cosmetics
- ➲Integral Peltier-cooled package (desirable)

Only an Active pixel sensor (APS) can meet this format/frame-rate requirement
Backthinned for high QE, very low readout noise

The APS sensor should achieve the speed (700 fps) and low noise (<3 e-) from such a large area

CMOS/APS- 5
WFS demo device photos

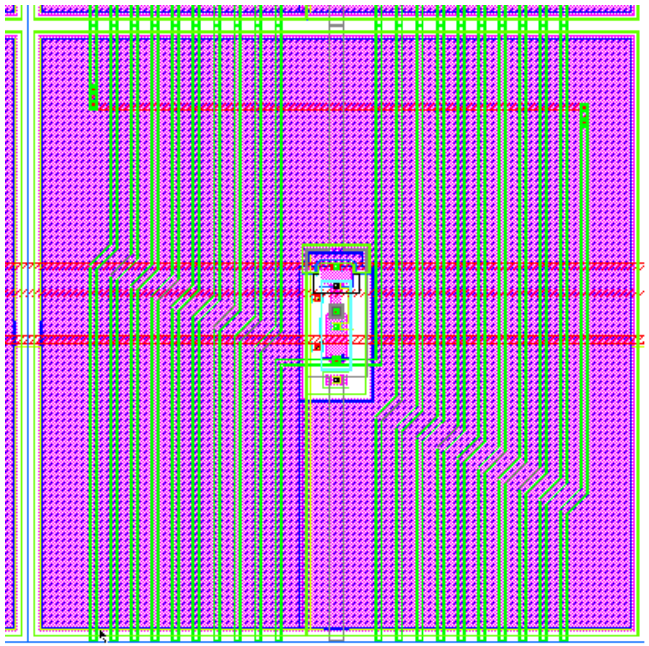
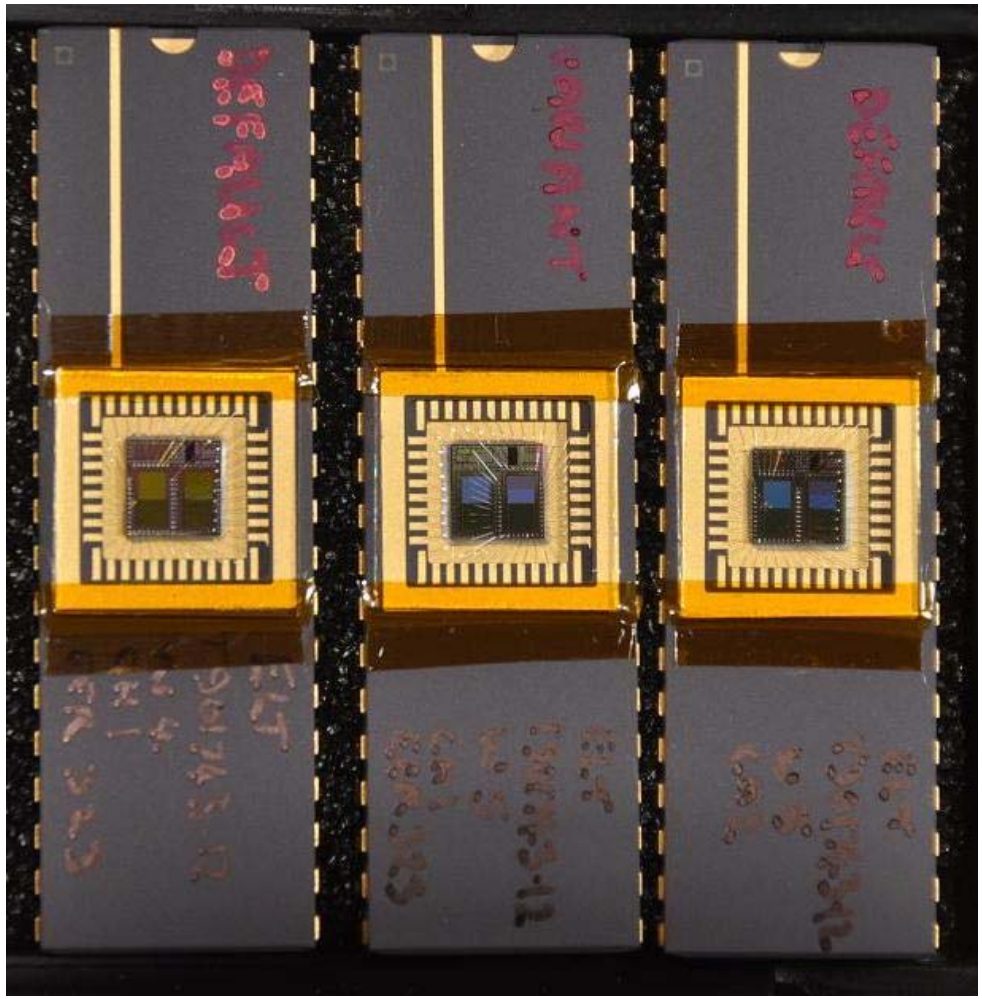


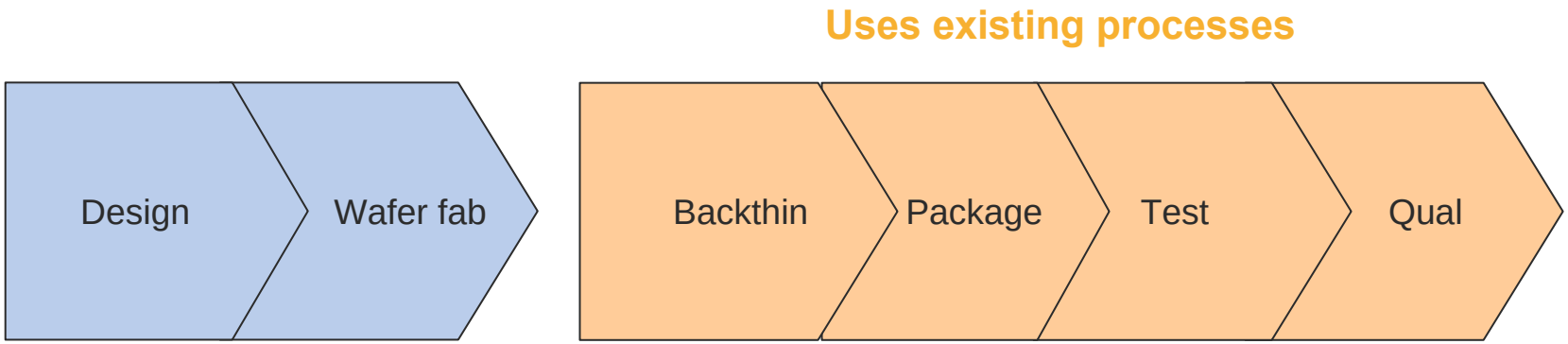
Illustration of one 24 X 24 µm pixel



CMOS development (for space/astronomy)

➲e2v is well established as the leading supplier of CCDs for space , astronomy, and scientific applications.

➲Most of the main process steps are identical for space CMOS and CCD manufacture



➲Wafer fab is outsourced. Design expertise is established (and rapidly developing)- with a team of over 20 designers at e2v

CMOS development

- e2v has very extensive IP already developed in CMOS imaging
- Expertise includes
  - 3T : rolling shutter
  - 4T : low noise-rolling shutter
  - 5T : global shutter (99.7% efficiency) with ROI capability
  - from 2.2 µm (Telecom) to 19 µm (Medical)
- Initial focus has been on dental and industrial now moving to Space
- Devices from 3 foundries have been backthinned results all look good
- Significant benefit from volume requirements for dental & industrial imaging
- Several space CMOS programmes in progress; more planned.
- Multiple development strands: (backthinning; space qualification, low noise,..)

CMOS Backthinning

➲ wafers have been thinned from three foundries. All behave as expected. epi starting thickness (thinner) gave lower QE than CCDs.

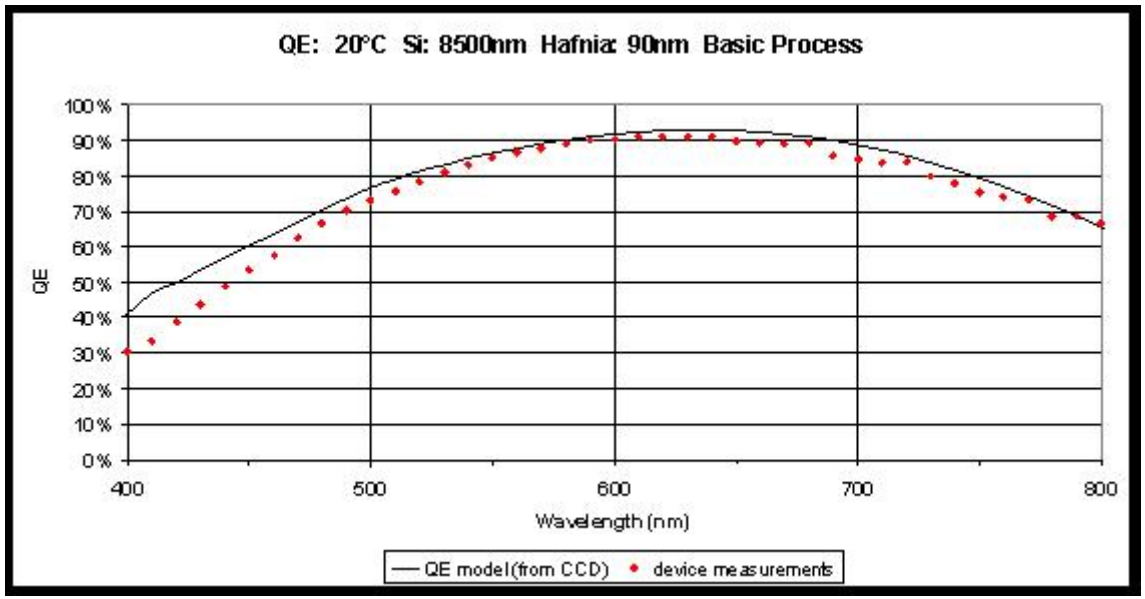
➲ Further work is in progress using epi of different starting thickness (12µm)

➲ Backthinned demonstrators are available of the ‘Jade’ sensor

➲ Next step is to space qualify a backthinned CMOS sensor

➲ Initial results from a non-optimised device are shown on the next slide (made on standard epi)

CMOS/APS
ev76c454 backthinned results



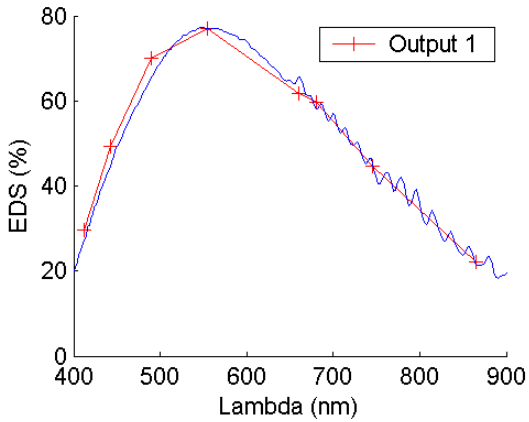
2009 data-

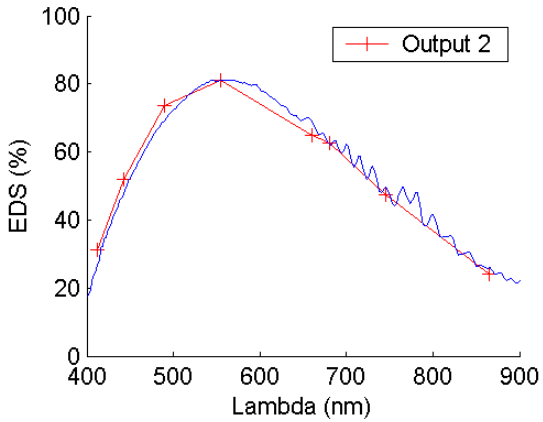
Predicted and measured spectral response

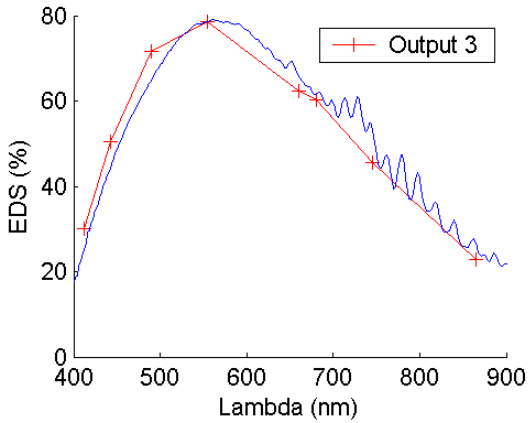
Device backthinnned with ‘basic’ process; designed for ‘red’ wavelength use

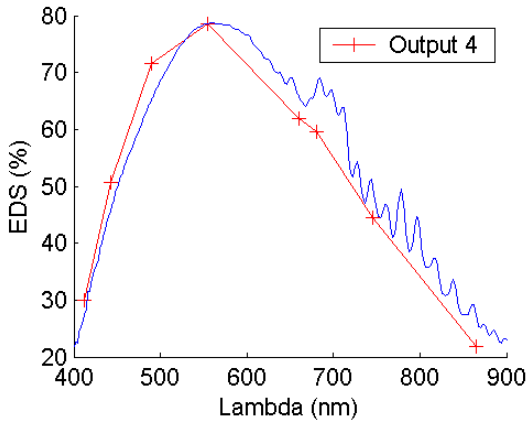
8.5 µm thick silicon

CMOS Backthinning results (Cobra2M)









Acknowledgements to Astrium for measurements

Recent (Sept-2009) data shows good 320 nm QE:

26% QE at 320 nm from non-optimised, uncoated device.

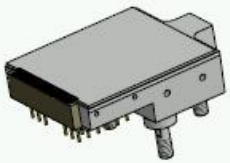
Response comparable to CCD (as expected)

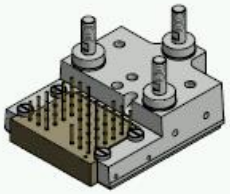
- L3 (electron-multiplying) sensors
- High-rho sensors
- CMOS/APS
- **Other new CCDs**

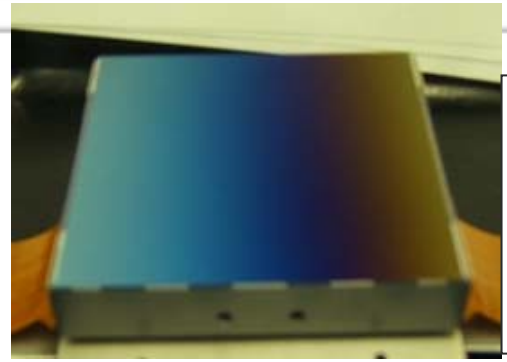
Other new CCDs-
a progression of sizes

CCD44-42

2048 X 2048



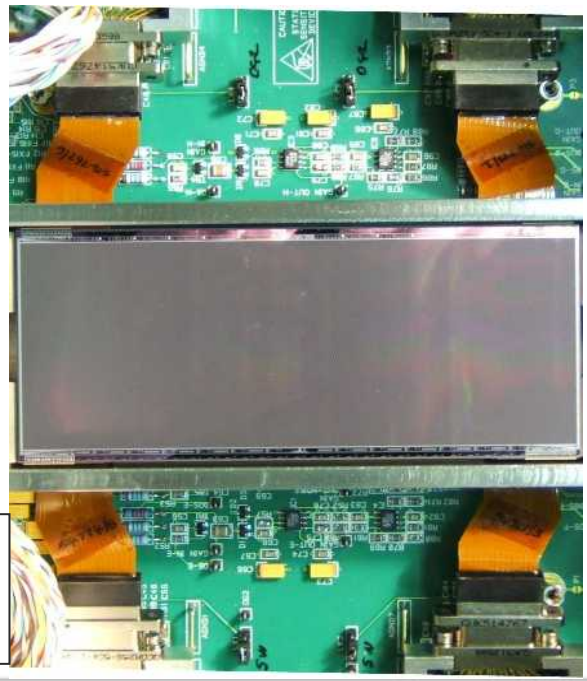


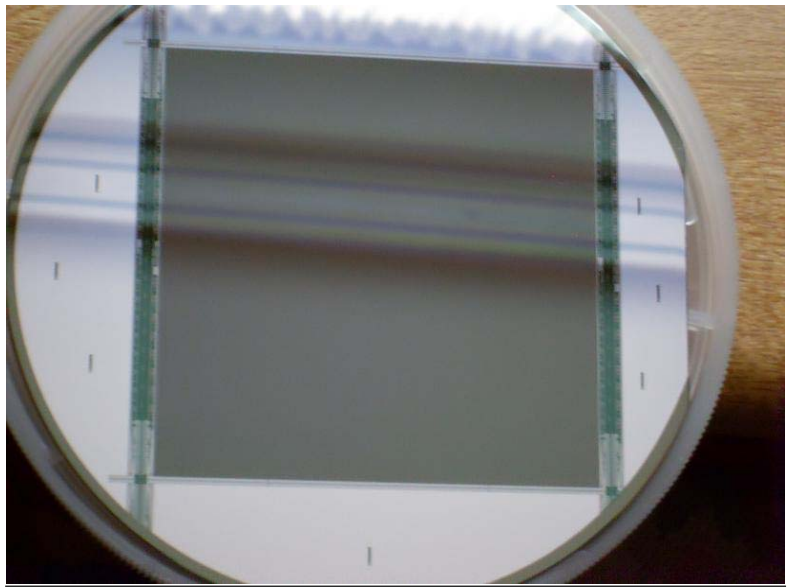


CCD231-84

4096 X 4096

(MUSE)





CCD231-68

8192 X 3072

CCD231-C6 6144 X 6144

The end

➲Thank you for your attention

Thanks to many others for providing material used here-

LSST, Caeleste, Astrium,

Peter Pool, Paul Jerram, Andrew Pike, and colleagues at e2v

Paul.Jorden@e2v.com