Modern CMOS Image Sensors for Scientific and Industrial Camera Applications

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Overview

- parameters of scientific image sensors to be improved...
- high speed CMOS image sensor
  - characteristics, camera, applications
- scientific CMOS (sCMOS) image sensor
  - characteristics, camera, applications
- summary

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Parameters of scientific image sensors to be improved...

- higher resolution for larger field of view
- faster frame rate at higher resolution
- higher sensitivity and lower readout noise at low light levels
- higher dynamic to detect the whole range from weak to bright illumination in one image
- robust and reliable recording performance (no significant degradation over time)
- image quality
- image data transfer (time)
- image data processing and storage

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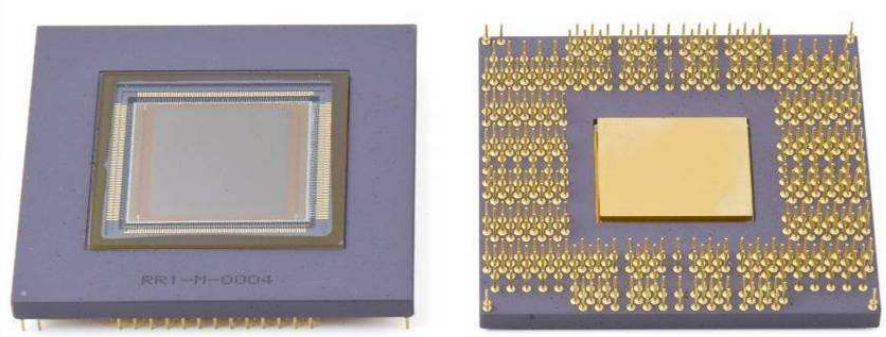
Highspeed CMOS Image Sensor

CMOS Image Sensor - Characteristics



- 2016 x 2016 pixel
- 1279 frames/s (full frame)
- 4502 frames/s @ 1008 x 1000 pixel
- 11.3 bit dynamic
- quantum efficiency ≈ 48 %
- 31.2 mm diagonal (11µm pixel pitch)

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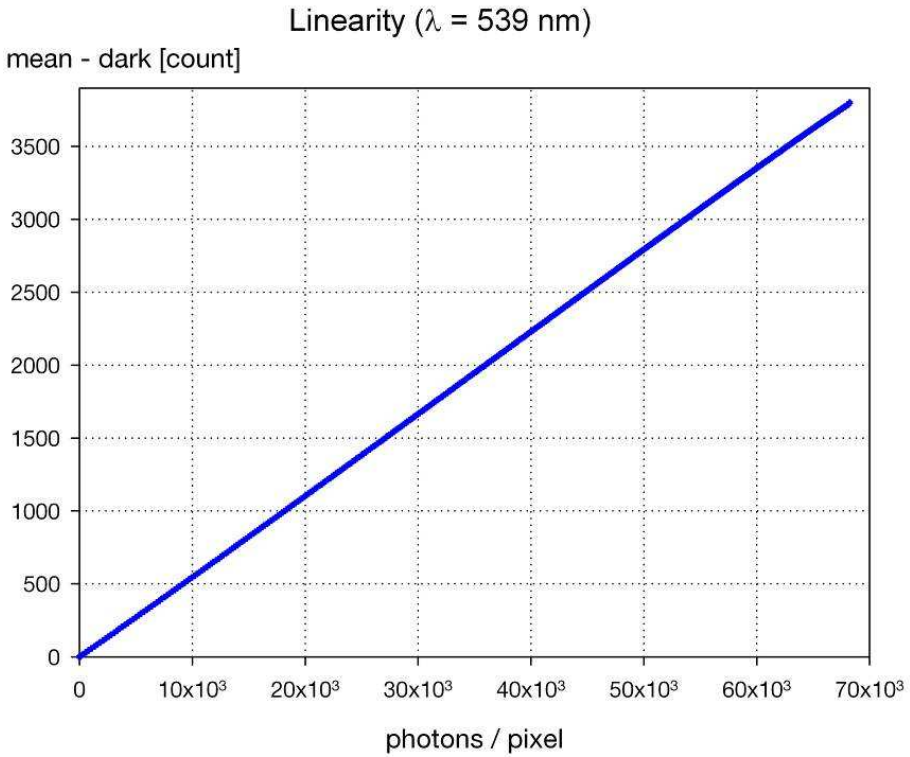
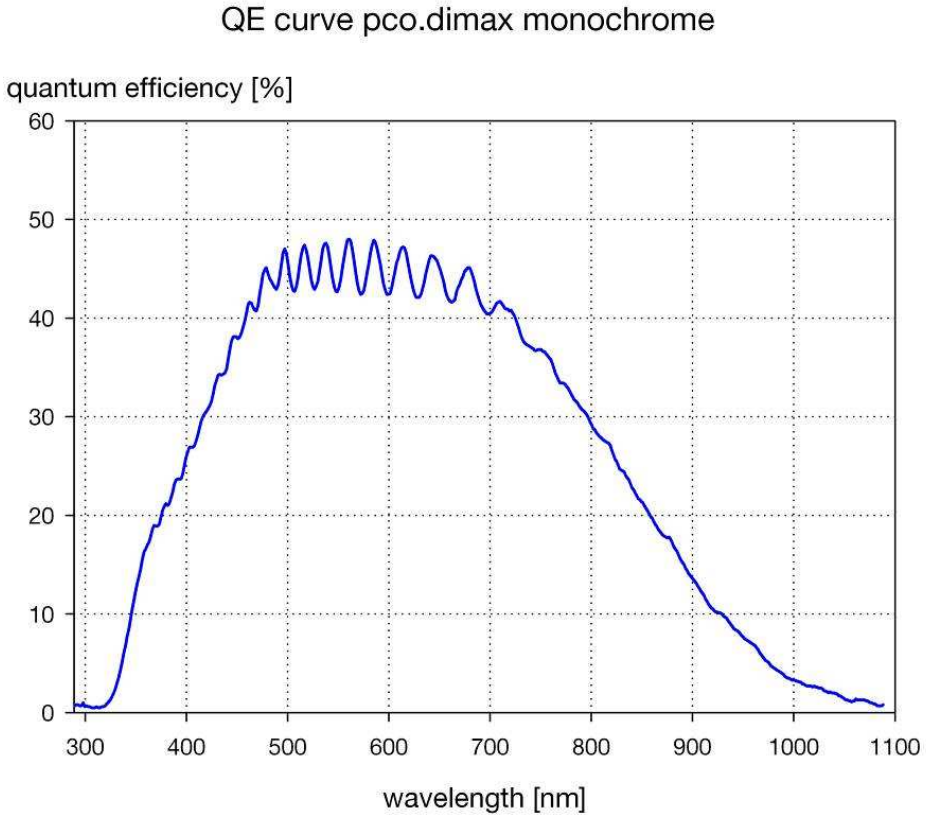
Highspeed CMOS Image Sensor

pco.dimax - EMVA1288 Performance Data

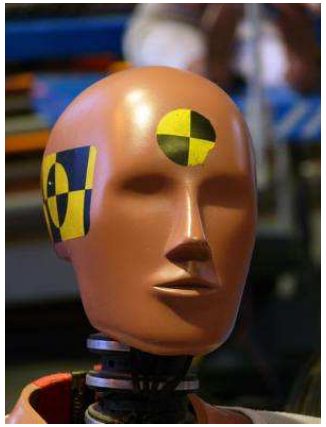




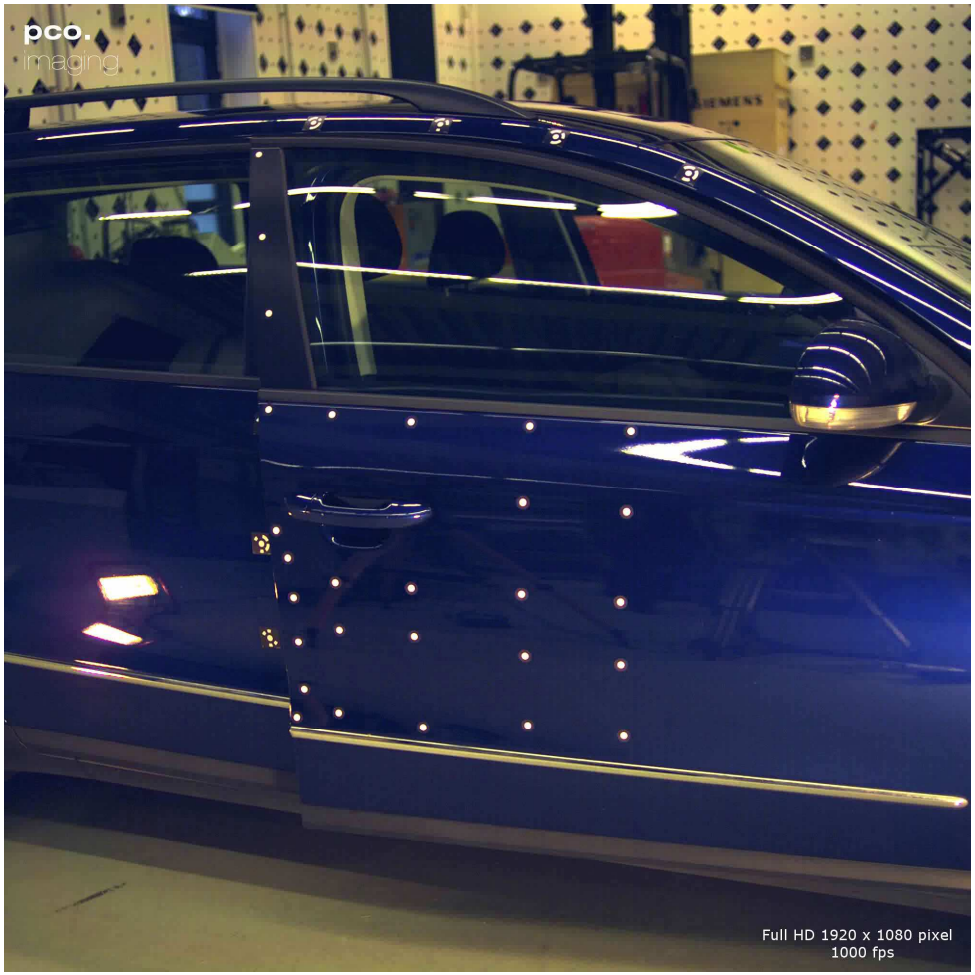
{measured by EMVA1288 test laboratory, AEON Verlag & Prof. Jähne, HCI Heidelberg}

Highspeed CMOS Image Sensor

pco.dimax Application - 2D & 3D Analysis



- safety tests
- 2D & 3D dynamic analysis
- component tests



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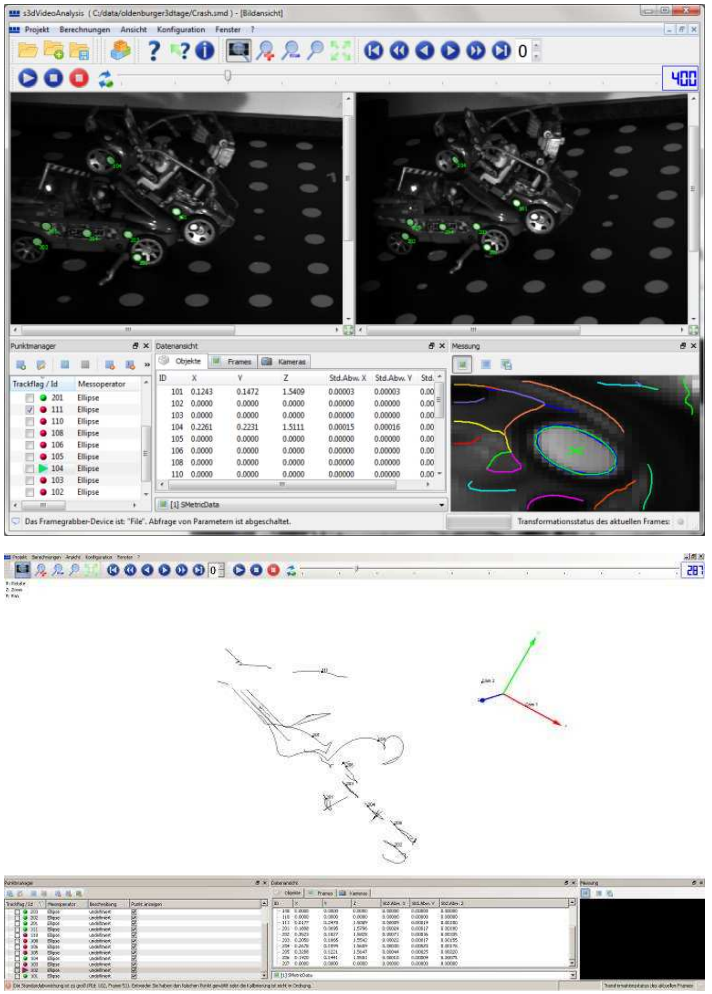
Highspeed CMOS Image Sensor

pco.dimax Application - 3D Measurement with Mirror Set-Up

- airbag inflation
- deformation under charge
- 2 x 1 Mpixel at 2500 frames/s



{courtesy of SOLVing3D, www.SOLVing3D.de}

Highspeed CMOS Image Sensor

pco.dimax Application - Measurement, Documentation, NASA

NASA competitive test with highspeed cameras:
The start of the shuttle should have been recorded with maximum resolution at 400 fps

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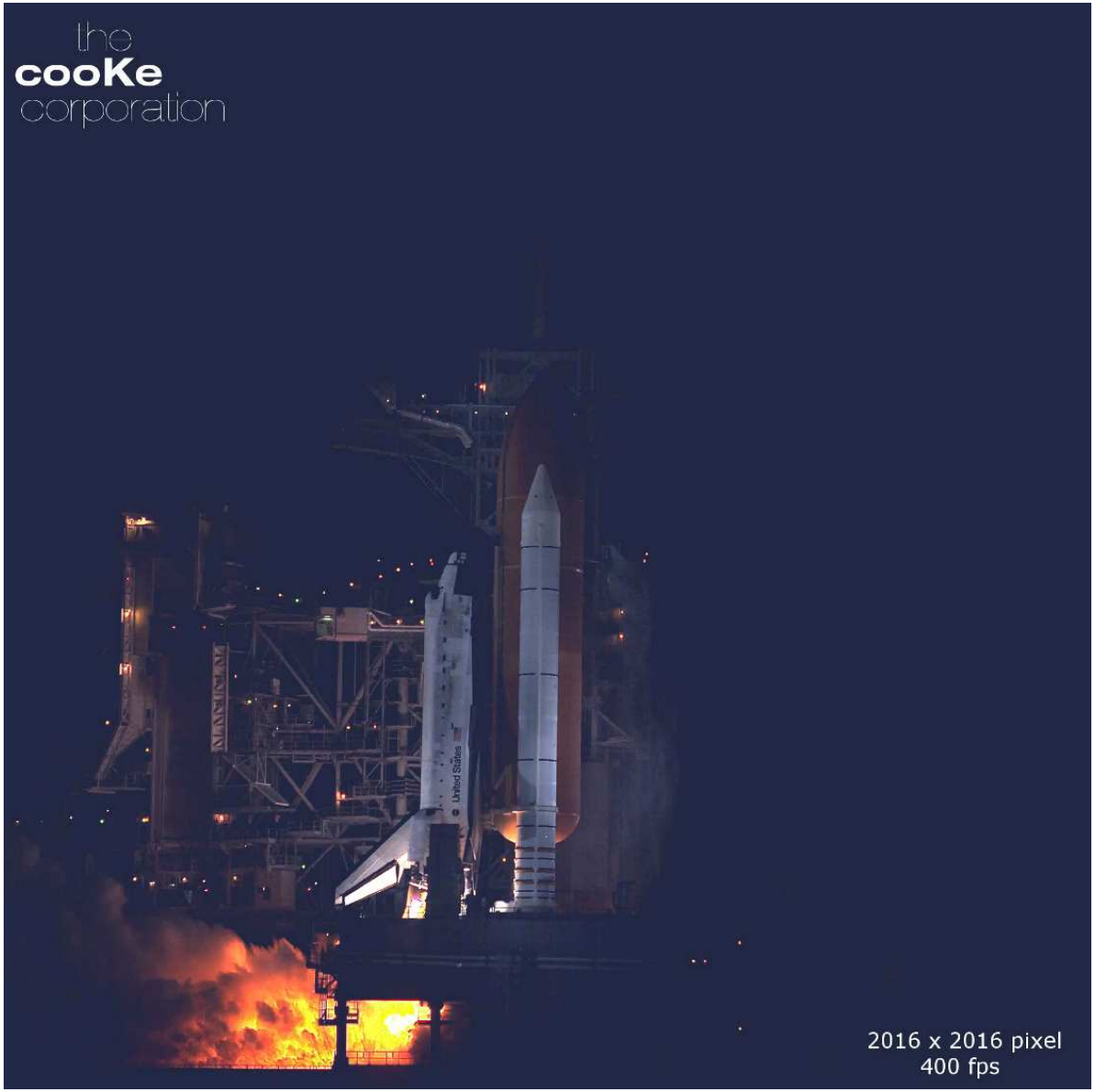
Highspeed CMOS Image Sensor

pco.dimax Application - Measurement, Documentation, NASA



Highspeed CMOS Image Sensor

Weisscam HS-2 - TV / Advertising / Broadcasting

camera system Weisscam HS-2

camera HS-2

digimag DM-2

hand unit HU-2

software HS-2

{courtesy of Stefan Weiss, www.weisscam.de}

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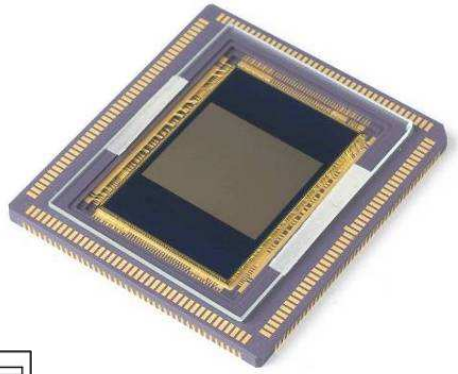
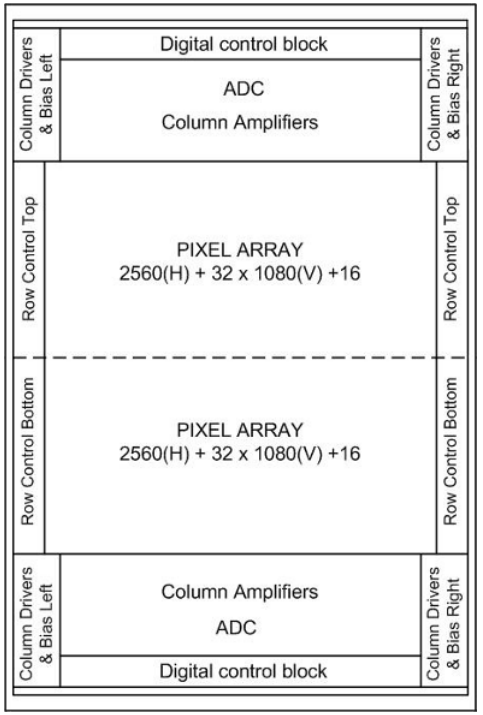
Scientific CMOS Image Sensor

sCMOS Image Sensor

- high quantum efficiency:
  FI = 57% and BI > 90%
- low readout noise:
  rolling shutter < 1.4 e- rms
  global shutter < 2.8 e- rms
- 2560 x 2160 pixel
- 6.5 µm x 6.5 µm pixel pitch
- dynamic range > 1 : 22 000
- maximum frame rate 100 frames/s





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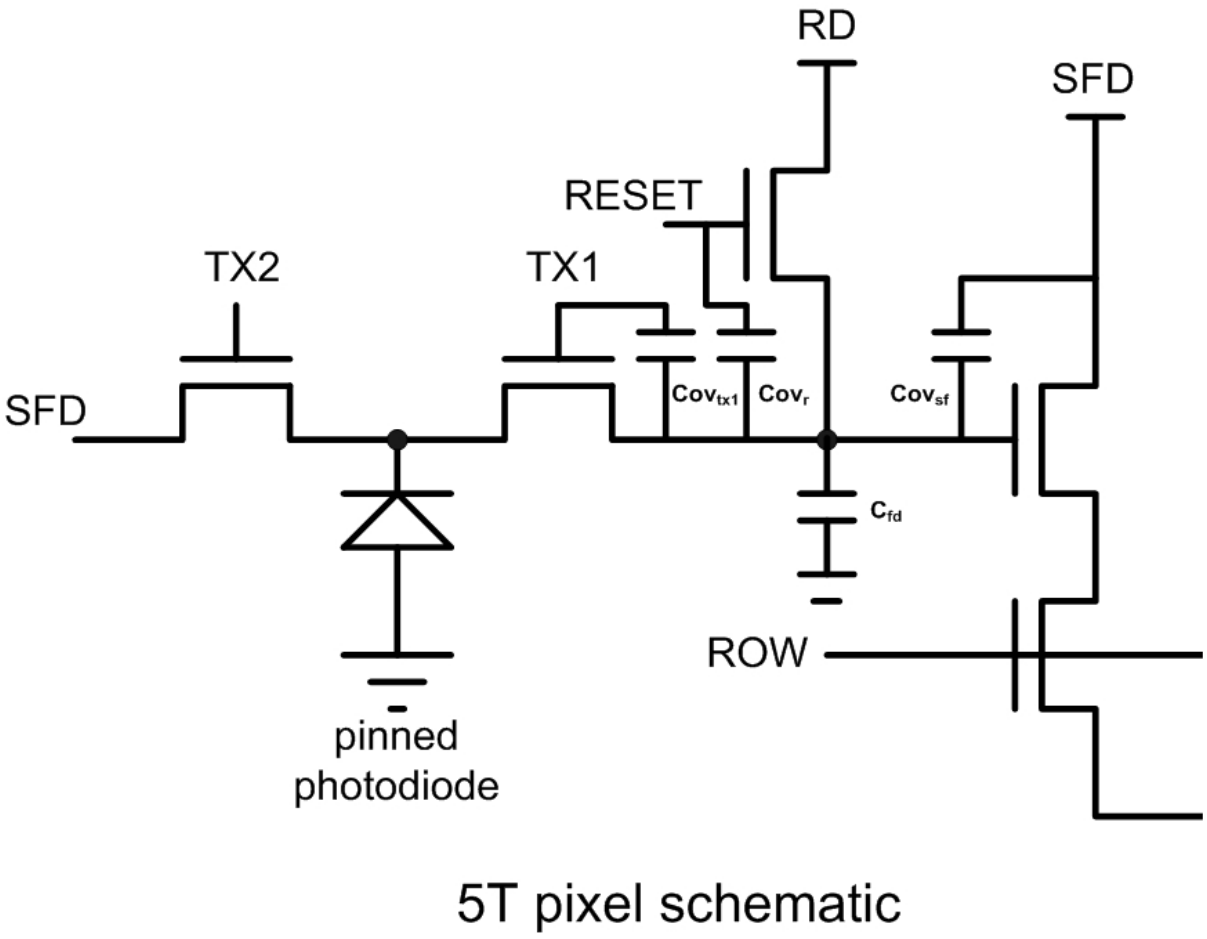
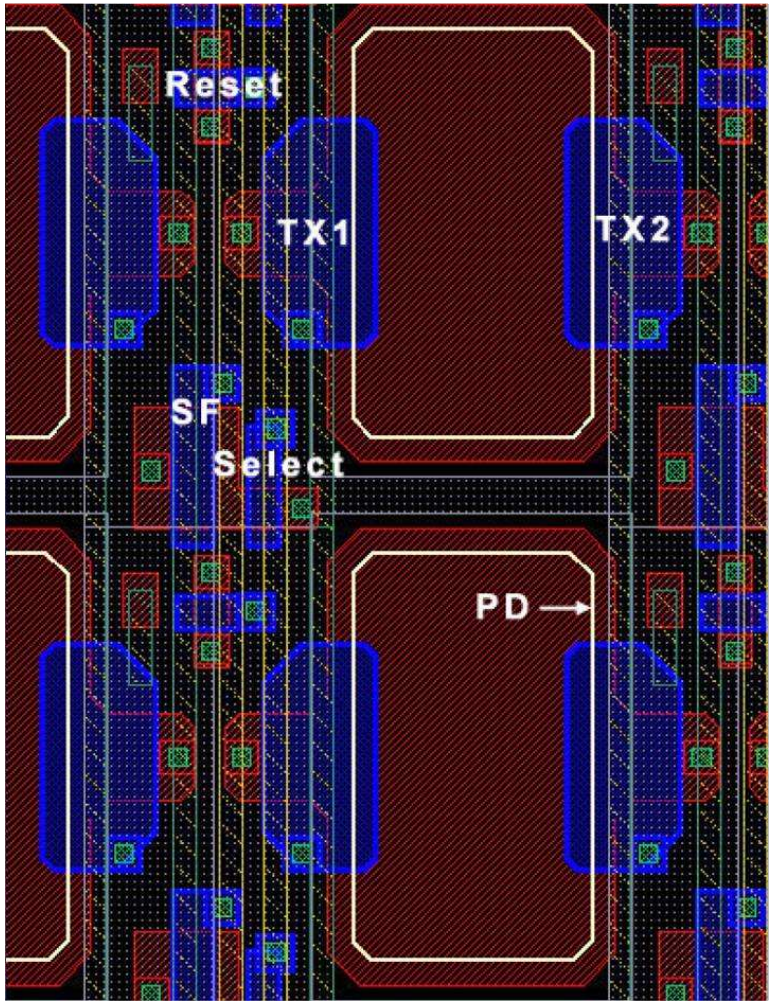
Scientific CMOS Image Sensor

Pixel Architecture



5T pixel schematic



{graphics & schematics courtesy of B. Fowler, Fairchild Imaging}

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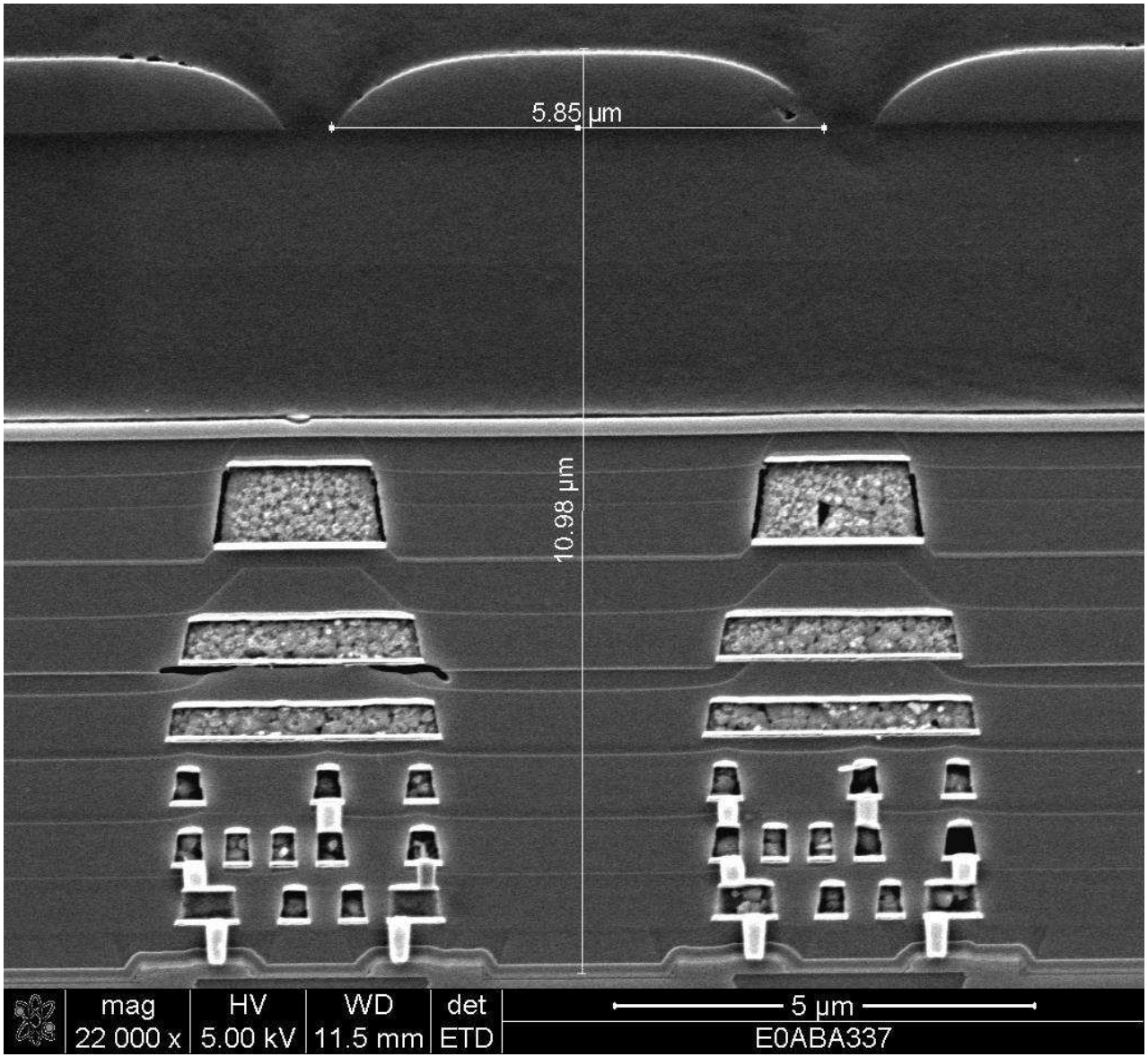
Scientific CMOS Image Sensor

SEM cross section



{photo Fairchild Imaging}

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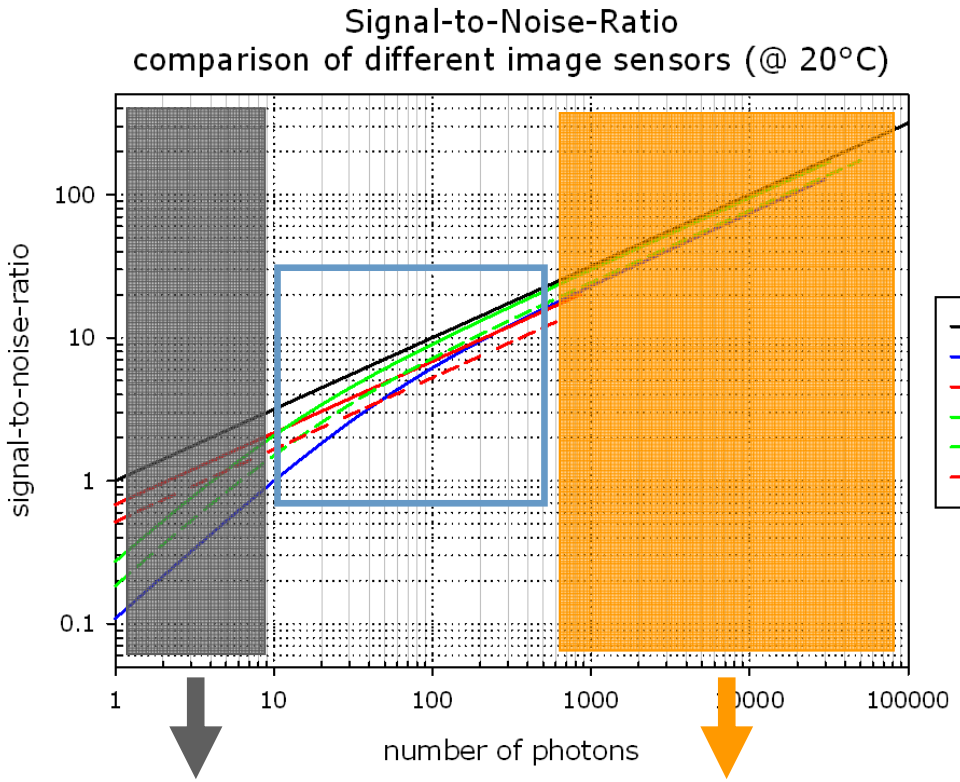
Scientifc CMOS Image Sensor

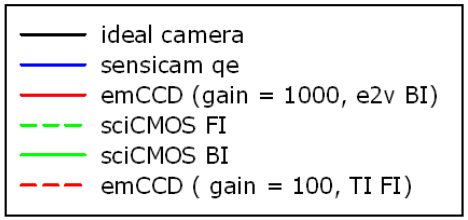
Comparison - CCD vs. emCCD vs. sCMOS

Parameter	Unit	Interline Transf. CCD	emCCD	sCMOS
sensor format	pixel	1.3M	1M (max.)	5.5M
pixel pitch	µm x µm	6.45 x 6.45	8 x 8	6.5 x 6.5
frame rate	fps	12 (@ 20 MHz)	> 30	100
readout noise	e- rms	4 - 7	< 1 (@ gain > 30)	< 1.4 (@ 30 fps)
QE	%	60 (FI)	60 (FI) / 90 (BI)	57 (FI) / 90 (BI)
dynamic range		3000 : 1 (@ 11 fps)	8500 : 1 (@ 30 fps)	22000 : 1 (@ 30 fps)

Scientifc CMOS Image Sensor

Comparison - CCD vs. emCCD vs. sCMOS

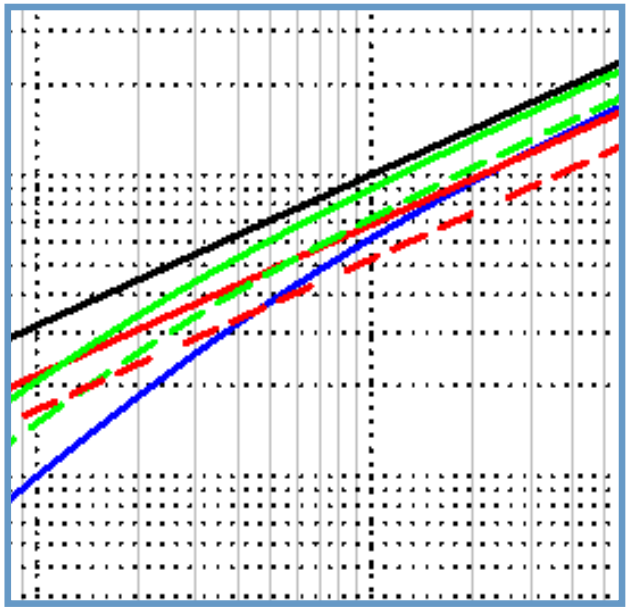




single photon counting
1-10 photons

"enough" light range
500 - many photons

low light
10 - 500 range



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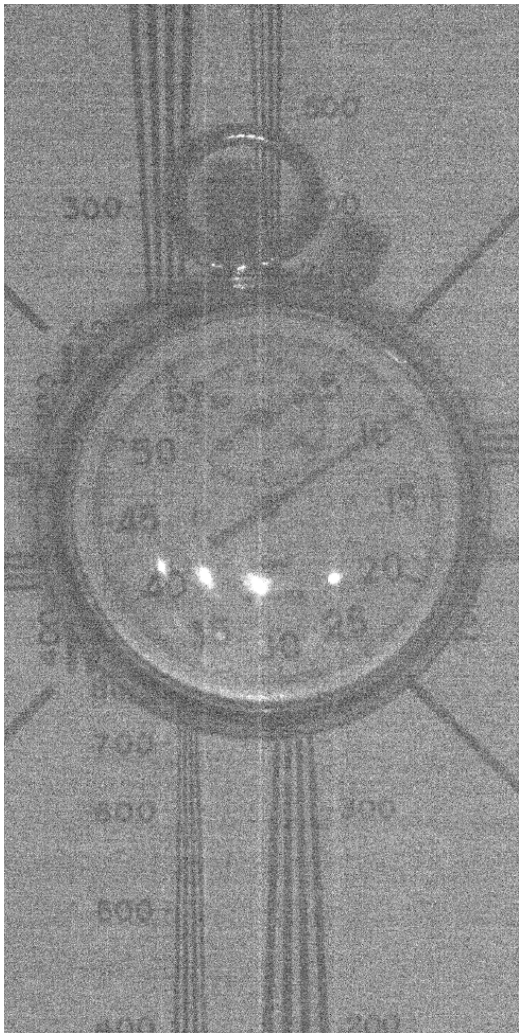
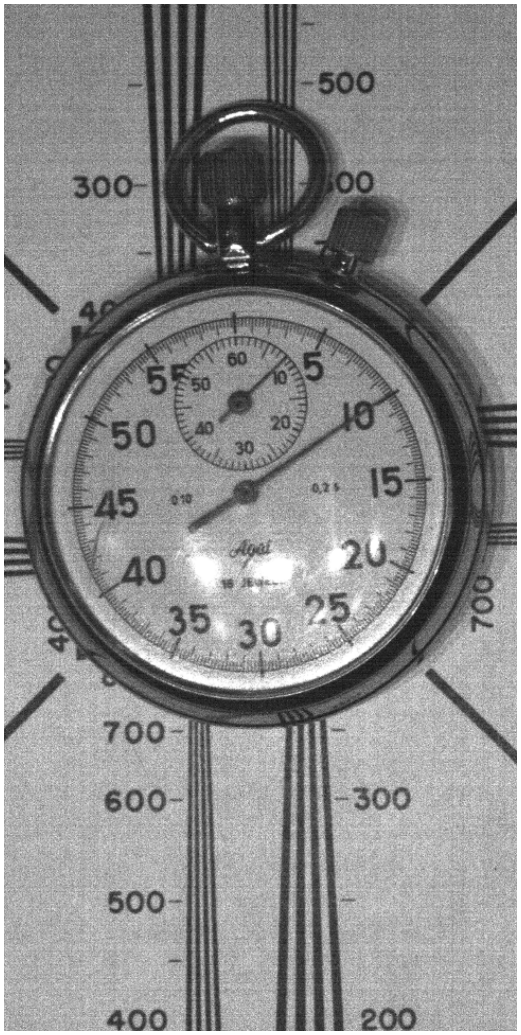
sCMOS - first Results

Cooled Interline Transfer CCD	sCMOS





Demonstration in June 2009 during the Laser - World of Photonics show, Munich, with a scientific CCD camera pco.2000 and a sCMOS prototype system

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Scientific CMOS Image Sensor

sCMOS - pco.edge

88 mm

70 mm

76 mm

- camera link (full) interface
- trigger in / out

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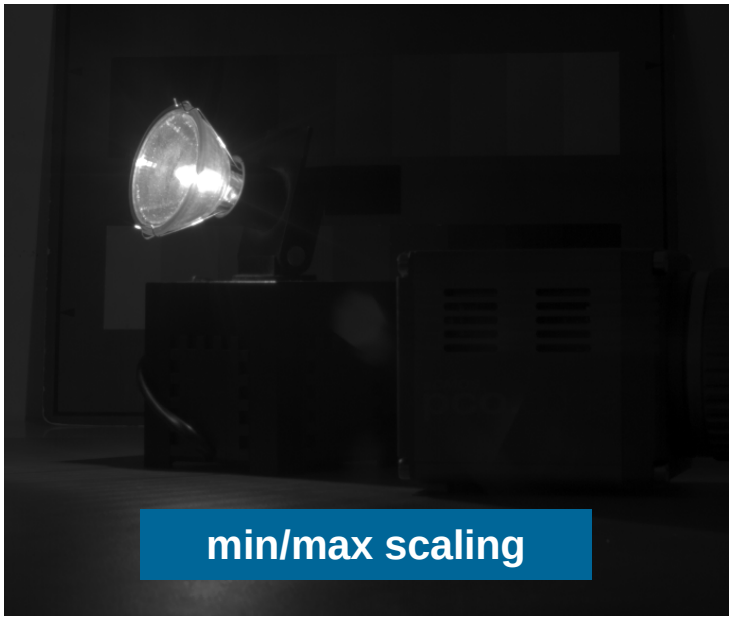
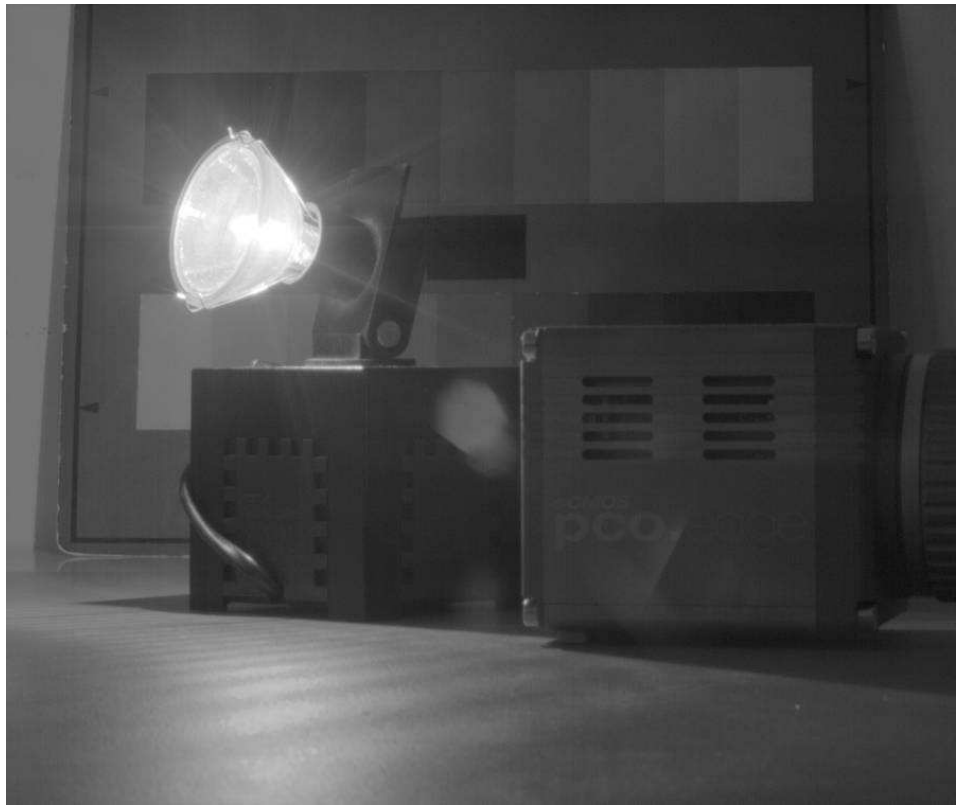
Scientific CMOS Image Sensor

pco.edge – 15 bit dynamic



logarithmic scale



exposure time - 10 ms,
f-stop=22, f=50 mm, rs

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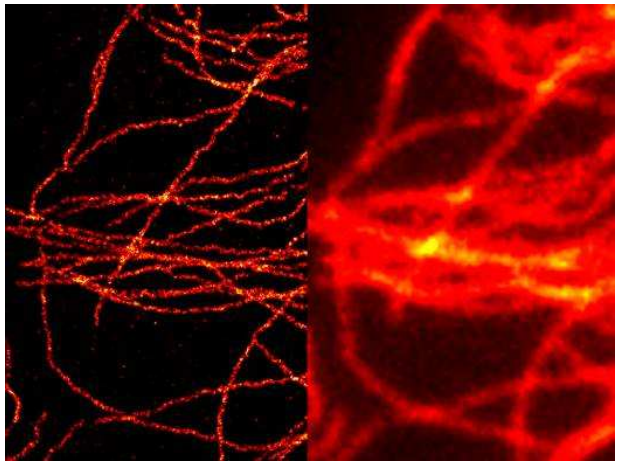
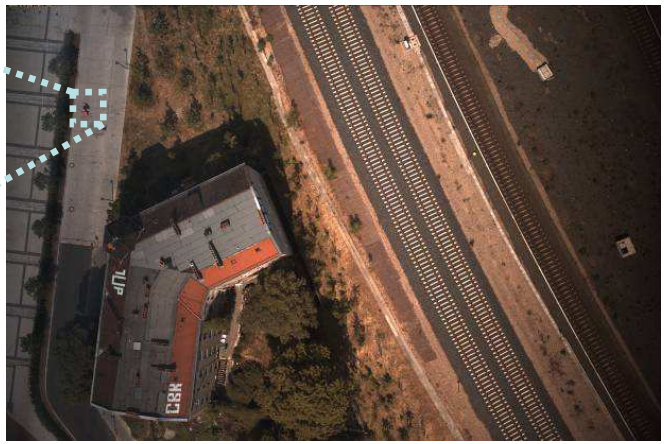
Applications

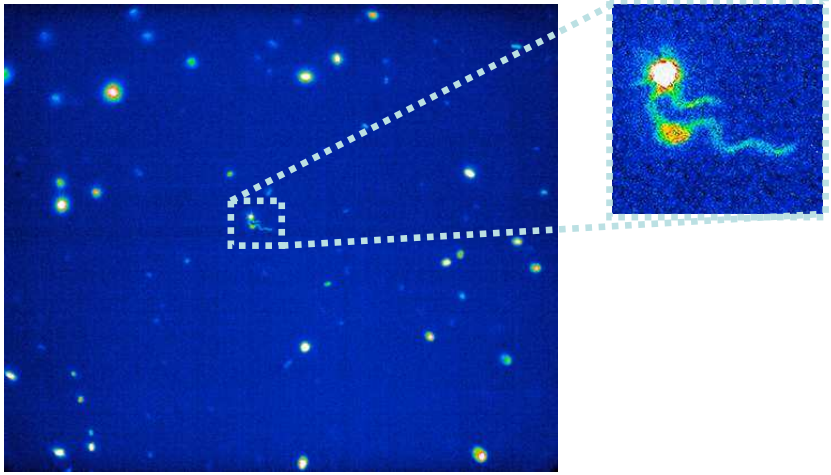
super resolution microscopy

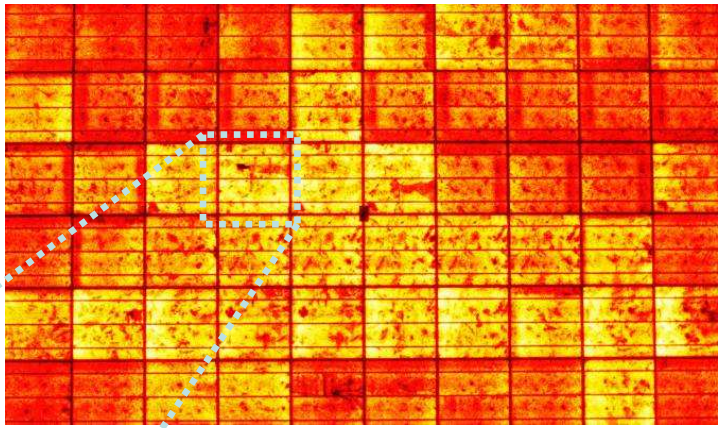


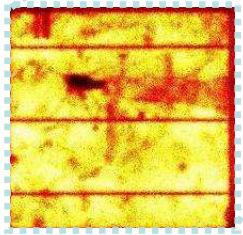


aerial photography

widefield micros. with large field of view







solar cell quality control

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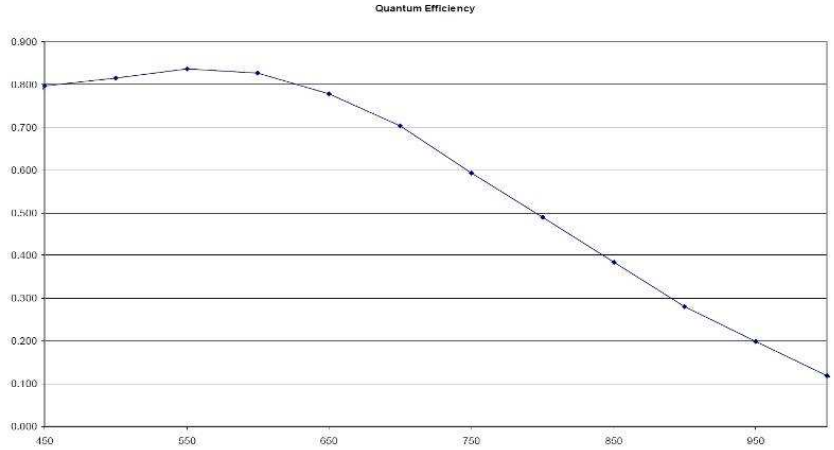
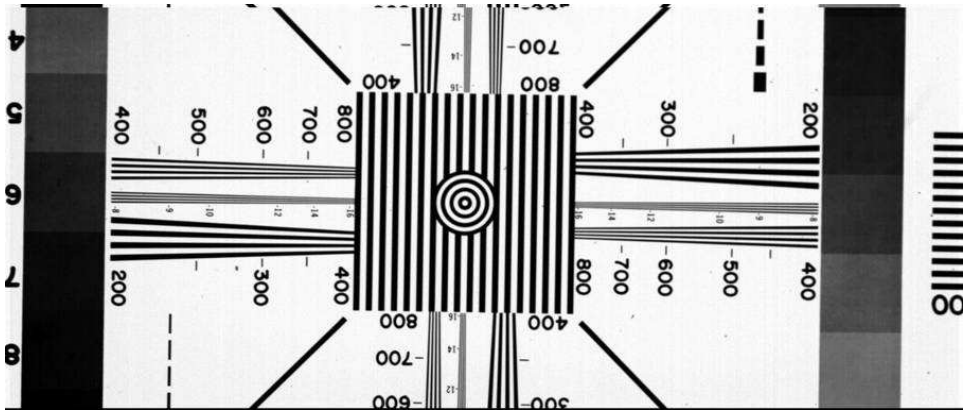
Scientific CMOS Image Sensor

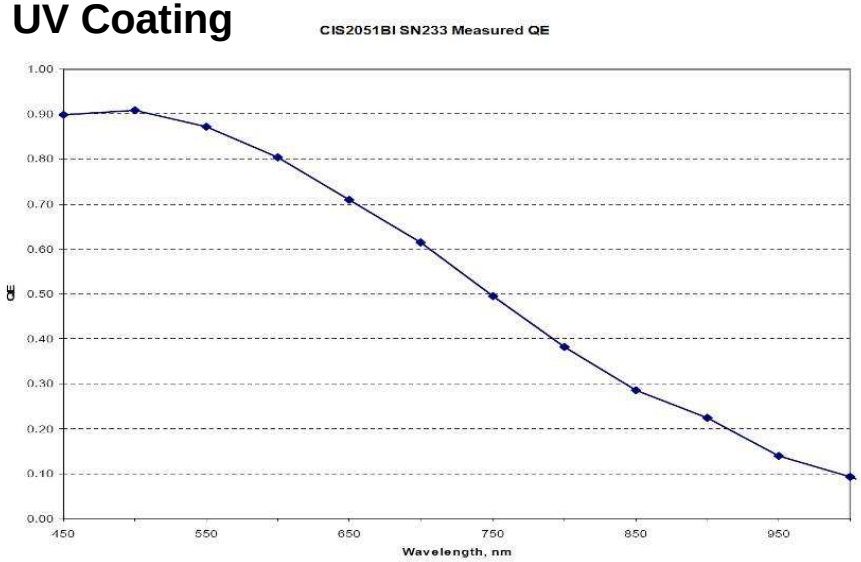
Outlook - back illuminated sensor

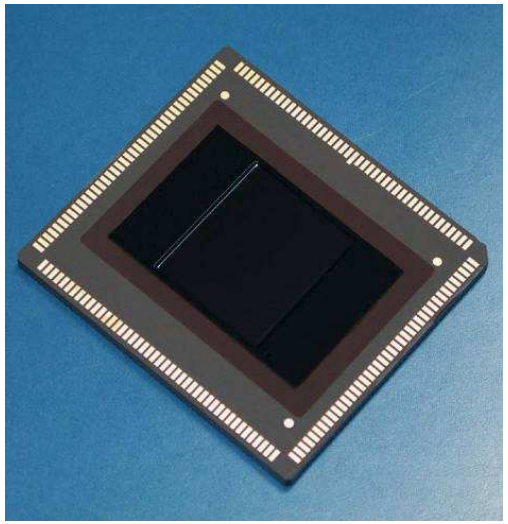
Broadband Coating





UV Coating





{data courtesy of Fairchild Imaging}

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Summary

- Recent advances in CMOS technology prove, that newer CMOS image sensors start to have the qualities, which were expected for a while.
- The hitherto existing "wisdom", which states that high frame rates belong to the domain of CMOS image sensors while high image quality and lowest readout noise belong to the domain of CCD image sensors, is no longer valid.
- New structures of image sensors e.g. for extremely low readout noise have been realized as CMOS image sensors.
- Therefore the next generation of CMOS image sensors will be capable to open new application fields and help scientists to answer their questions.
- The image data transfer rate, the processing and archiving of large data volumes will be the next to be solved issues in the near future.