Key Element

Sensors

Sensor

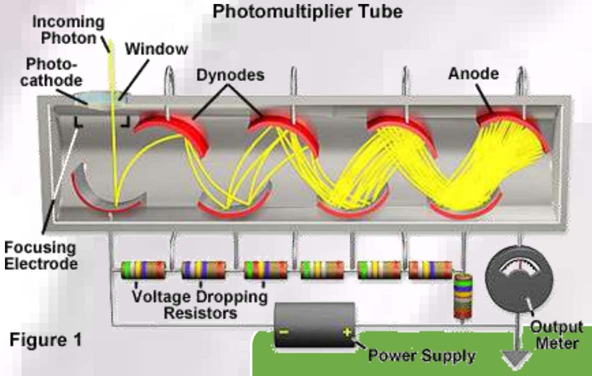
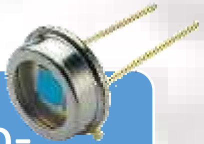


Figure 1

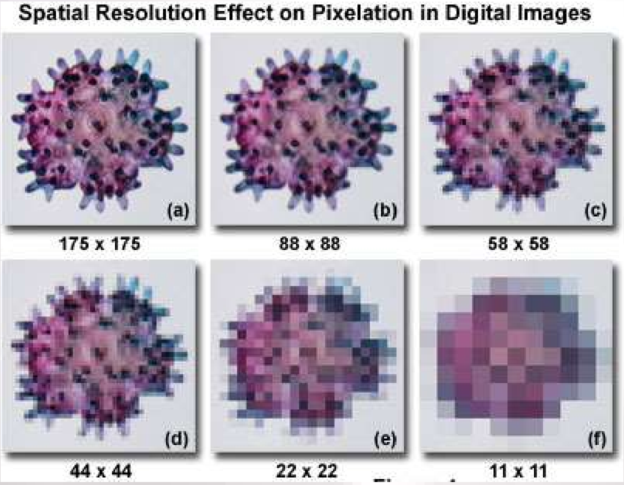
- Detector Type
  - Photomultiplier
  - SEMI-Conductor
    - Mono-Elements
    - Multi-Elements
      - Linear Array
      - Matrix

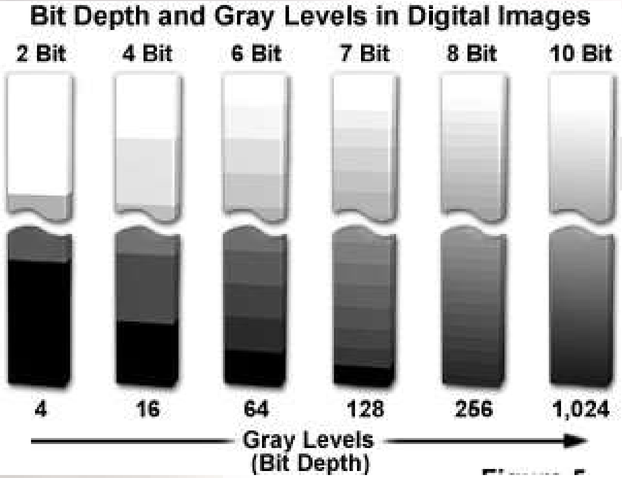


Key Parameters to evaluate detectors

- Spectral Responsivity (sensitivity)
- Quantum Efficiency
- Responsivity Area
- Responsivity Area Uniformity
- Response Linearity
- Conversion Gain
- Wavelength Bandwidth
  - peak wavelength/ cutoff wavelength
- Modulation Transfer function
- Noise Equivalent Power
- Dynamic Range

Spatial Resolution





A higher number of gray levels corresponds to greater bit depth and the ability to accurately represent a greater signal dynamic range

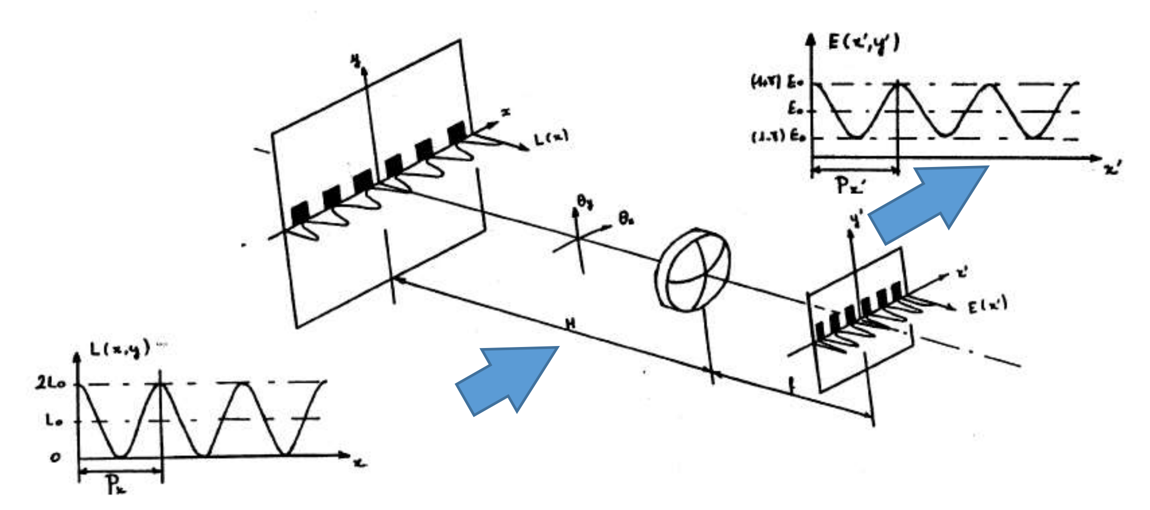
Bit Depth	Grayscale Levels	Dynamic Range (Decibels)
1	2	6 dB
2	4	12 dB
3	8	18 dB
4	16	24 dB
5	32	30 dB
6	64	36 dB
7	128	42 dB
8	256	48 dB
9	512	54 dB
10	1,024	60 dB
11	2,048	66 dB
12	4,096	72 dB
13	8,192	78 dB
14	16,384	84 dB
16	65,536	96 dB

bit depth

http://hamamatsu.magnet.fsu.edu/articles/digitalimagebasics.html

Modulation Transfer Functions (MTF)-1

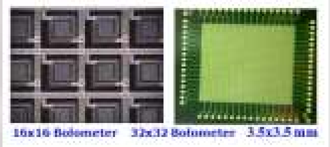
- MTF is always used for estimating quality of an imaging system
- $Contrast, \mathbb{C} \equiv \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
- $MTF = \frac{\mathbb{C}_{image}}{\mathbb{C}_{object}}$
- $MTF = f(spatial\ frequency)$

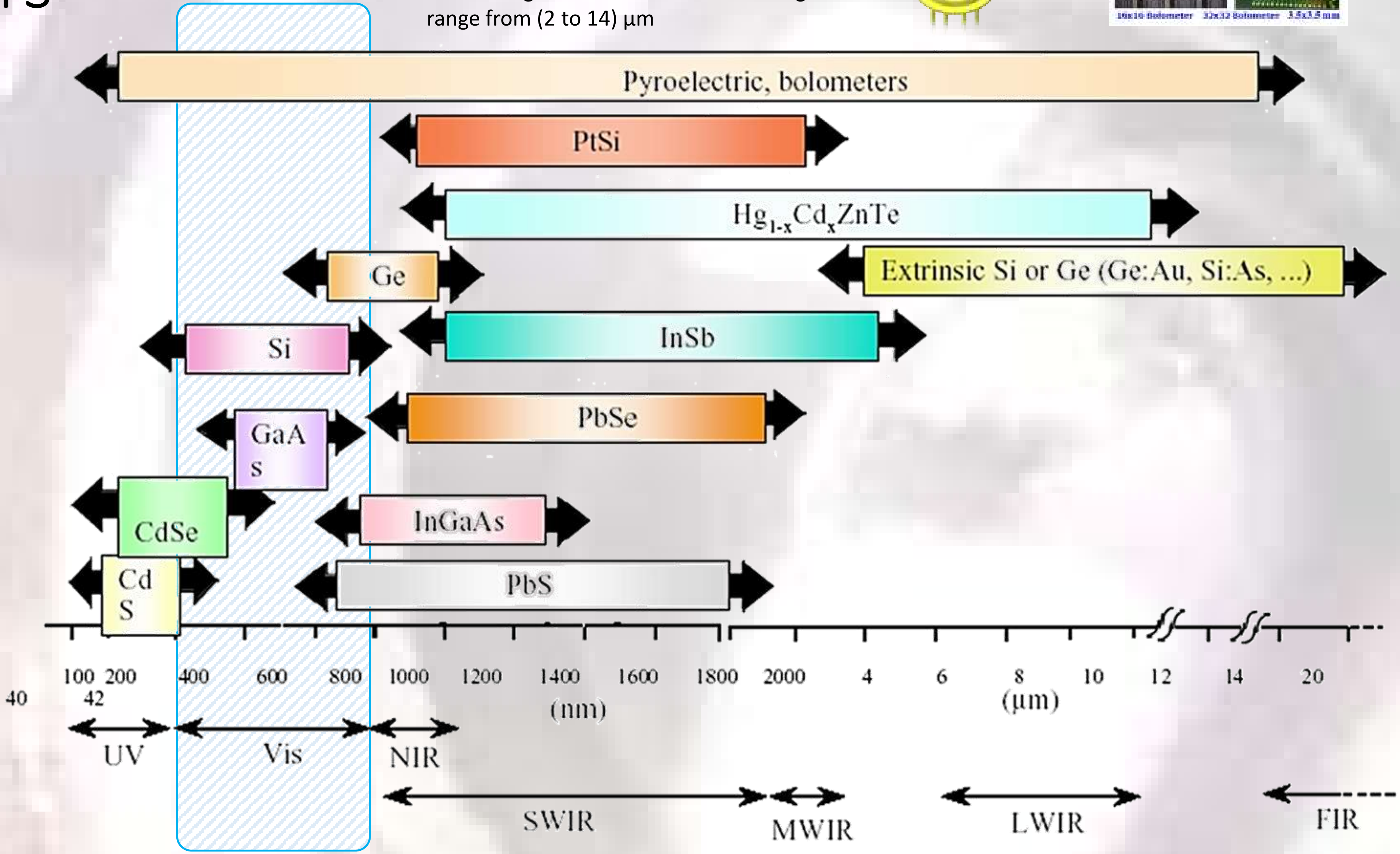


Sensors

A Pyroelectric detector is an infrared sensitive optoelectronic component which are specifically used for detecting electromagnetic radiation in a wavelength range from (2 to 14) µm

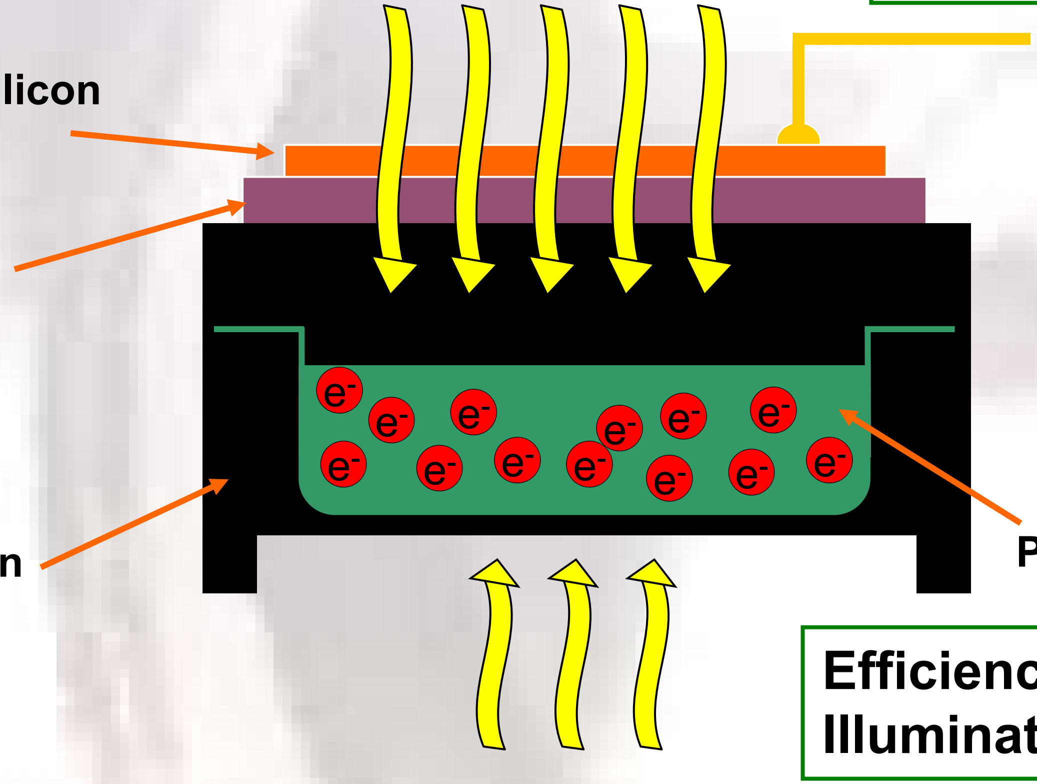
Microbolometers





Basic Pixel Architecture

Peak Efficiency when Front-Illuminated: ~65% CCD or ~57-65% scientific CMOS



Incident Light

Electrical Connection

Polysilicon Gate

Silicon Dioxide

Silicon

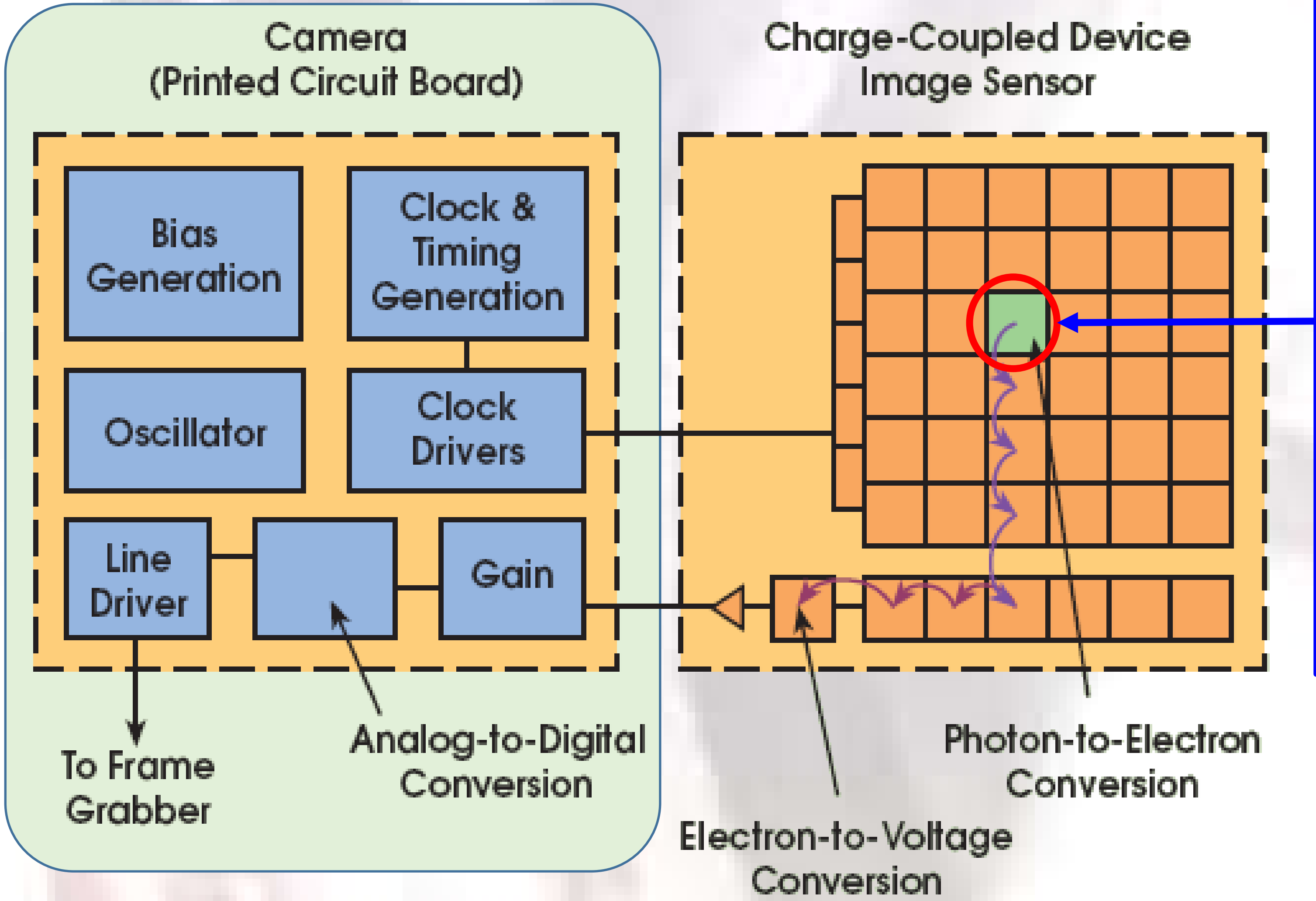
Potential Well

Light when Back-Illuminated

Efficiency when Back-Illuminated: ~95%

https://slideplayer.com/slide/5723718/

Architecture of CCD



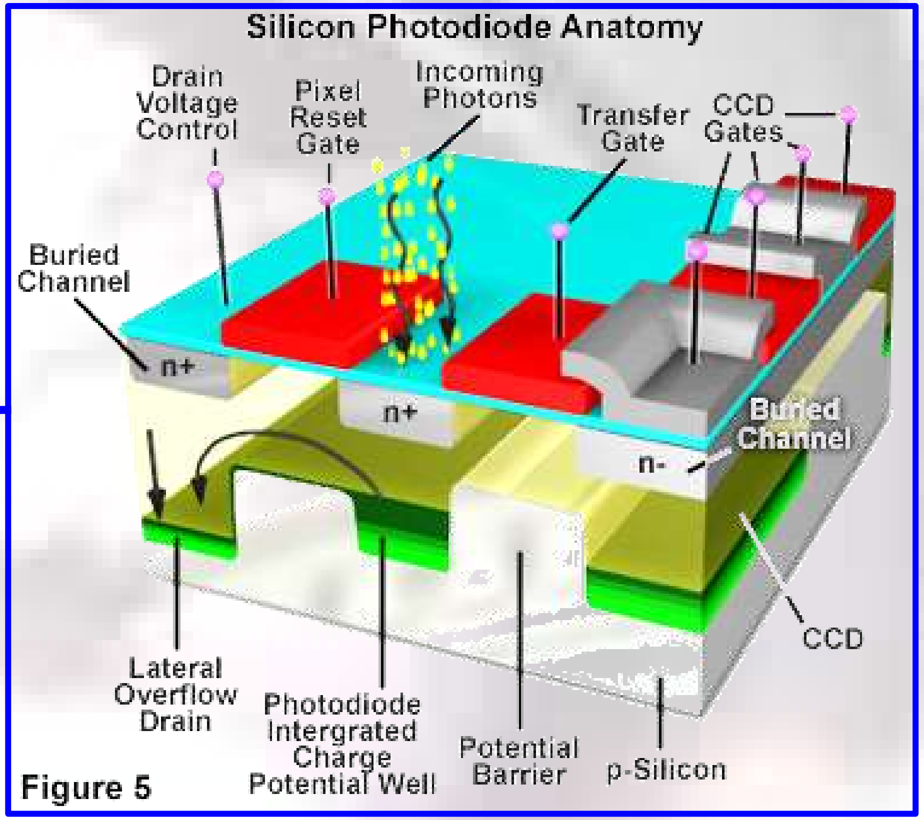
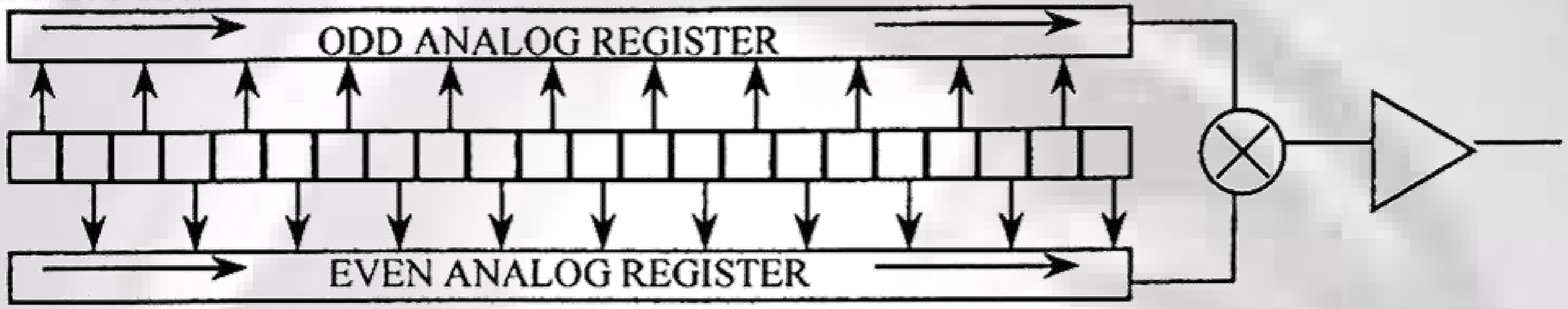


Figure 5

Basic structure of a single metal oxide semiconductor (MOS) element in a CCD array
The substrate is a p/n type silicon wafer insulated with a thin layer of silicon dioxide

https://www.fer.unizg.hr/_download/repository/ST03-Photonics_Spectra_CCDvsCMOS_Litwiller.pdf
http://hamamatsu.magnet.fsu.edu/articles/microscopyimaging.html

1/ LINEAR ARRAYS



ODD ANALOG REGISTER

Image zone

EVEN ANALOG REGISTER

2/ MATRIX

Image transfer

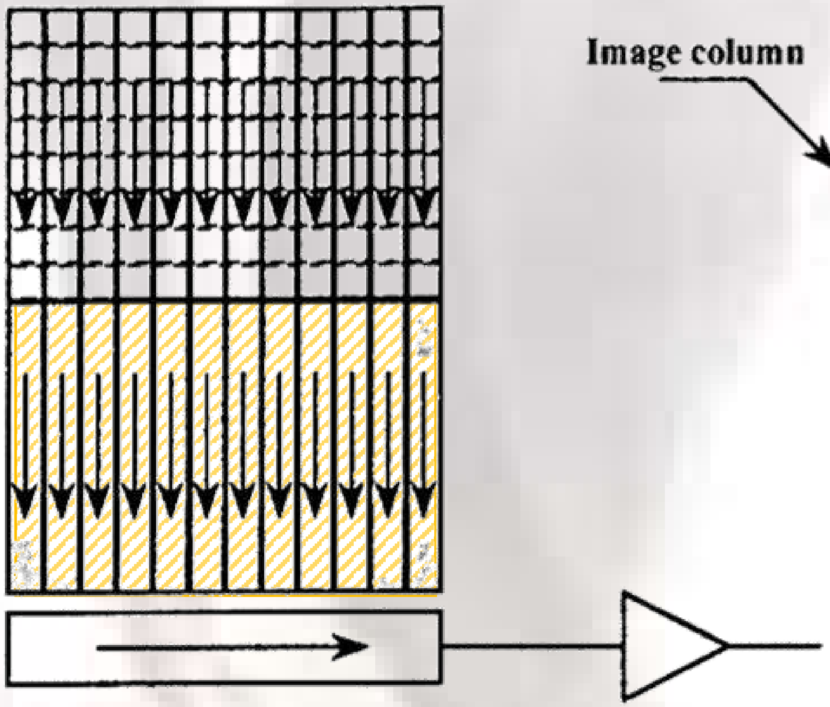
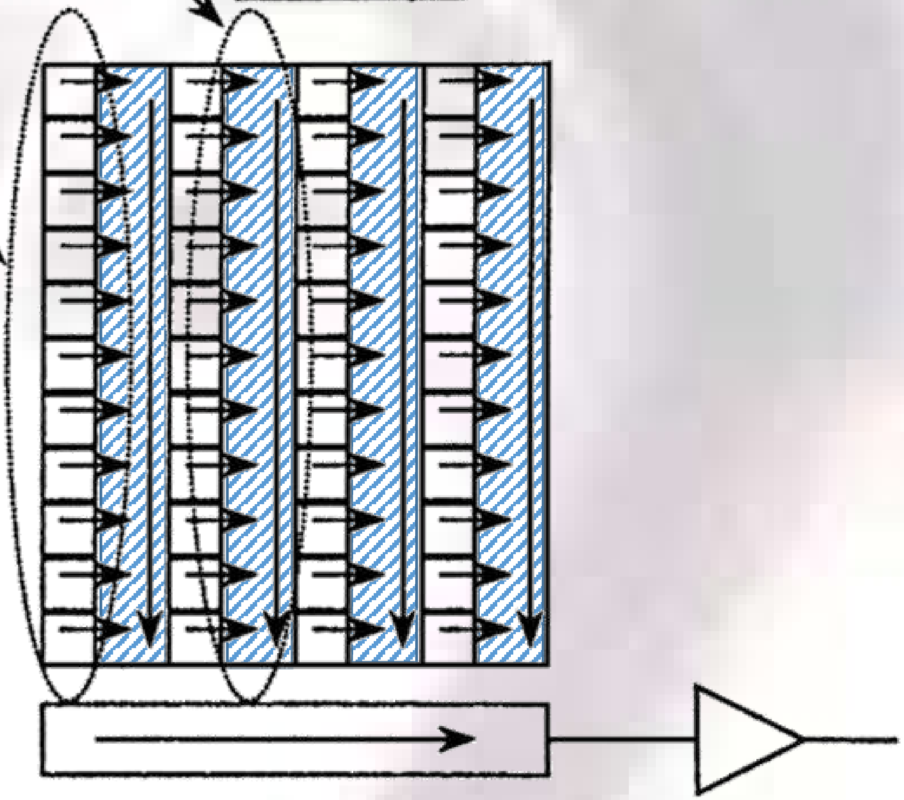


Image zone

Memory zone
(not photosensitive)

Read-out register

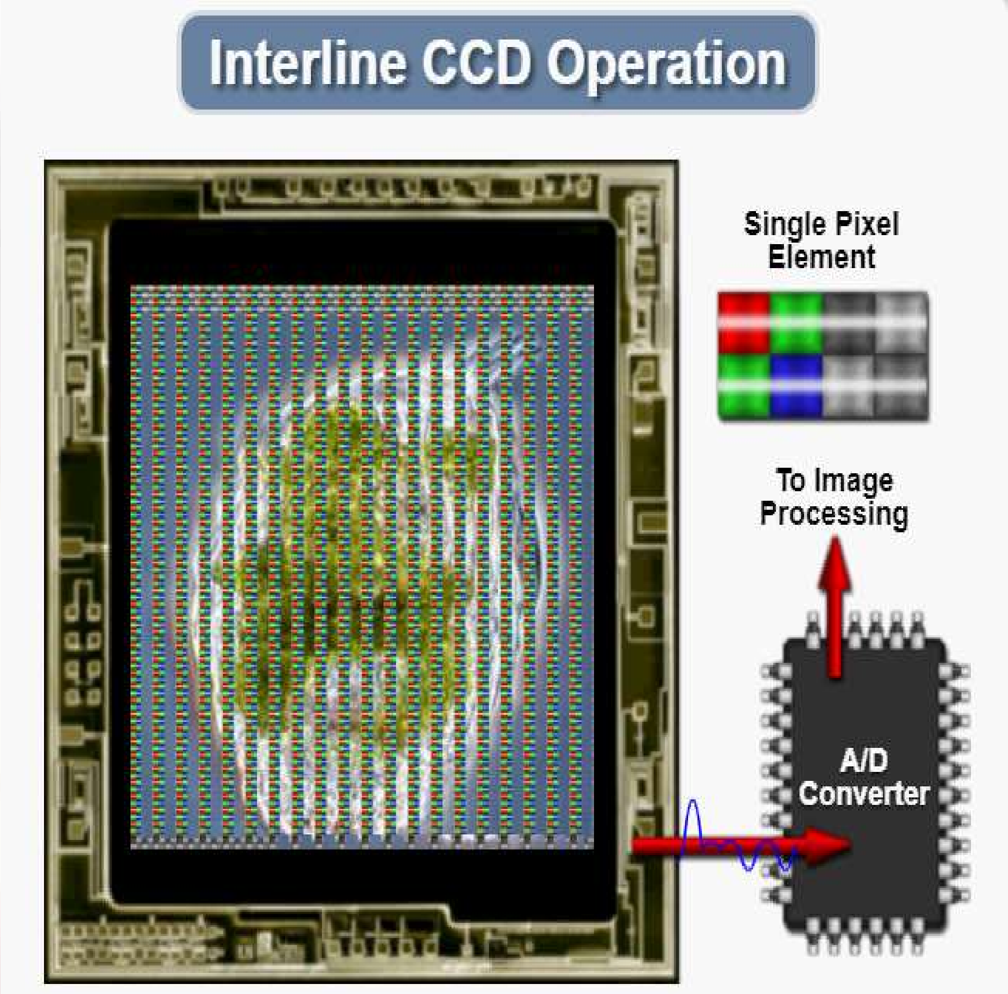
Line transfer

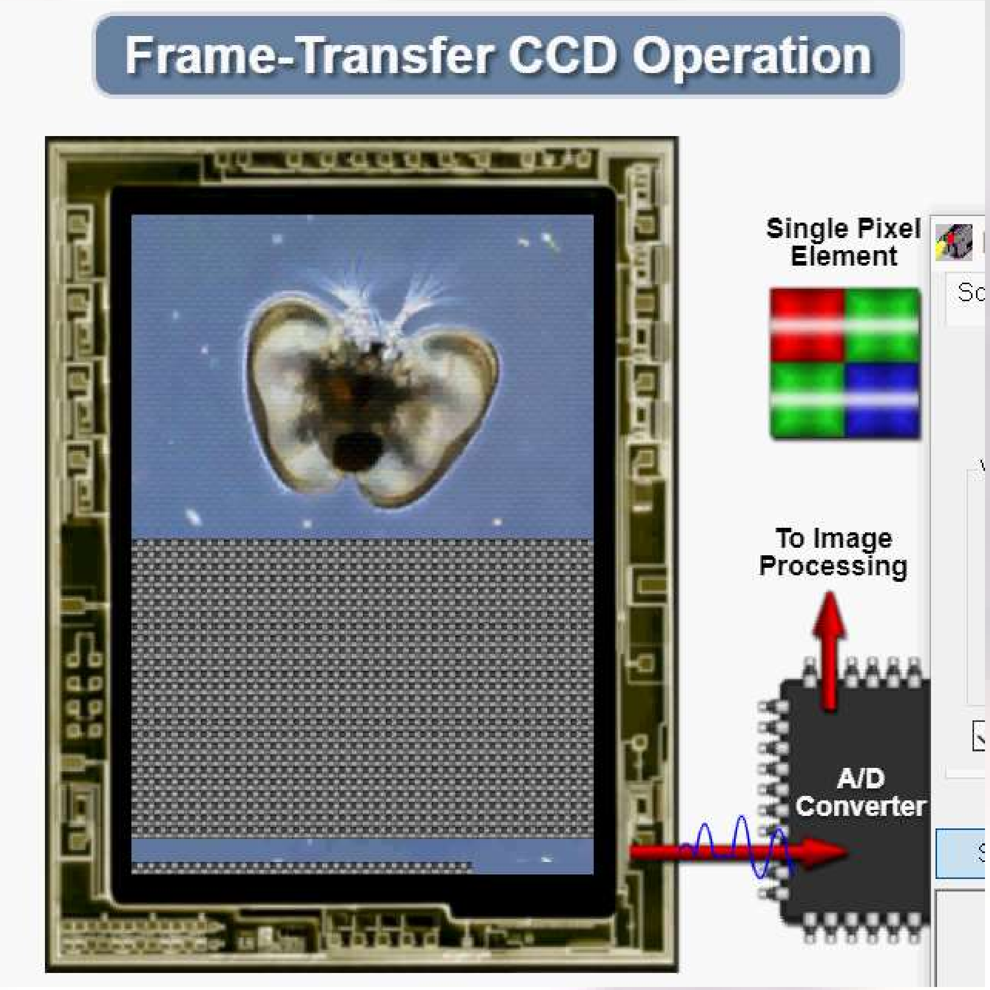


Memory column

Image column

CCD Sensor—Interline/Frame transform

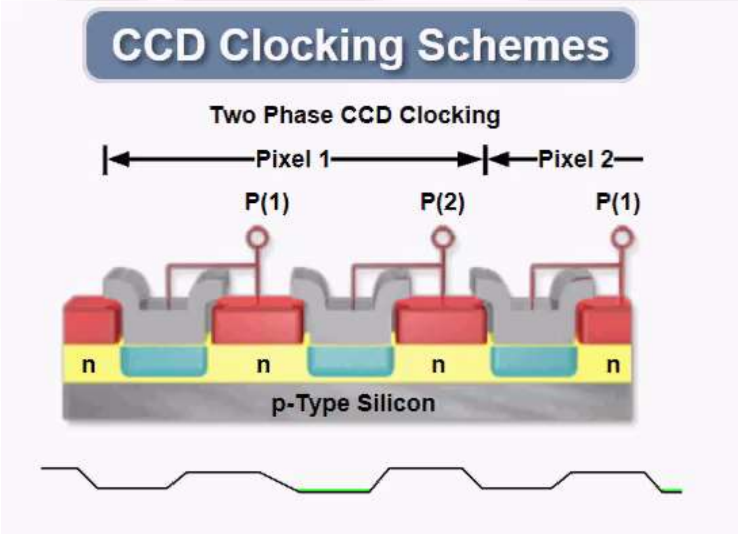




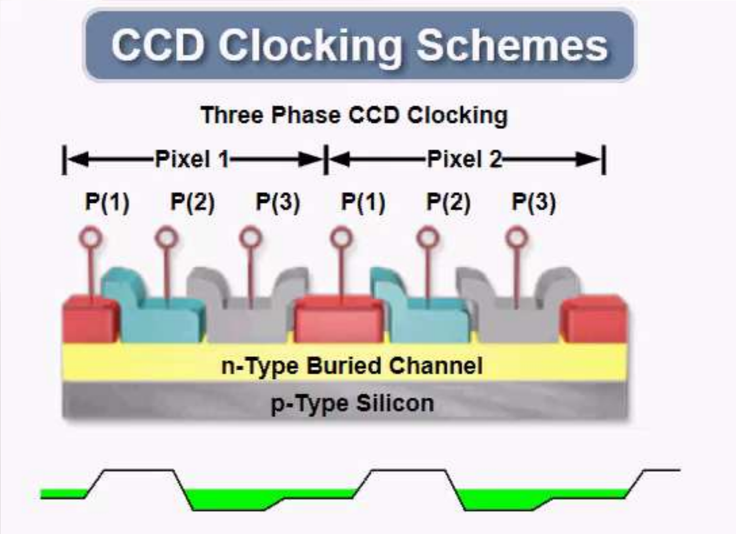
How to transfer the accumulated voltage of each pixel as signal to A/D for the following digitization

CCD Sensor—Operation clock

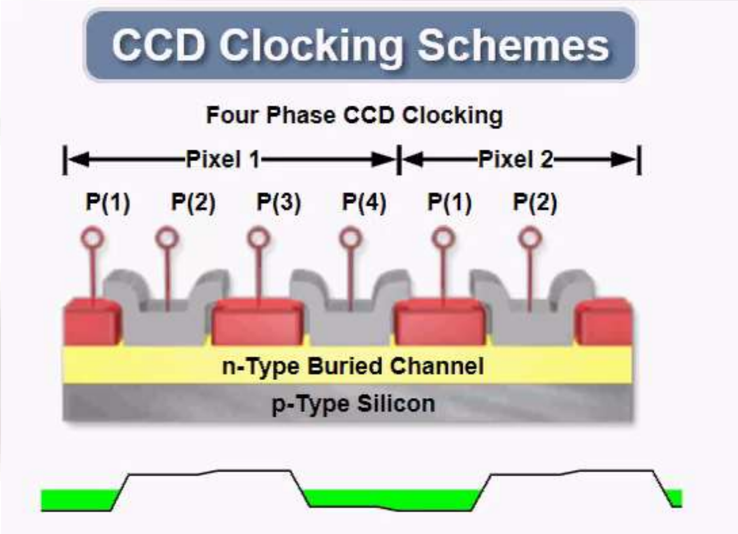
Clock modes



2 phase



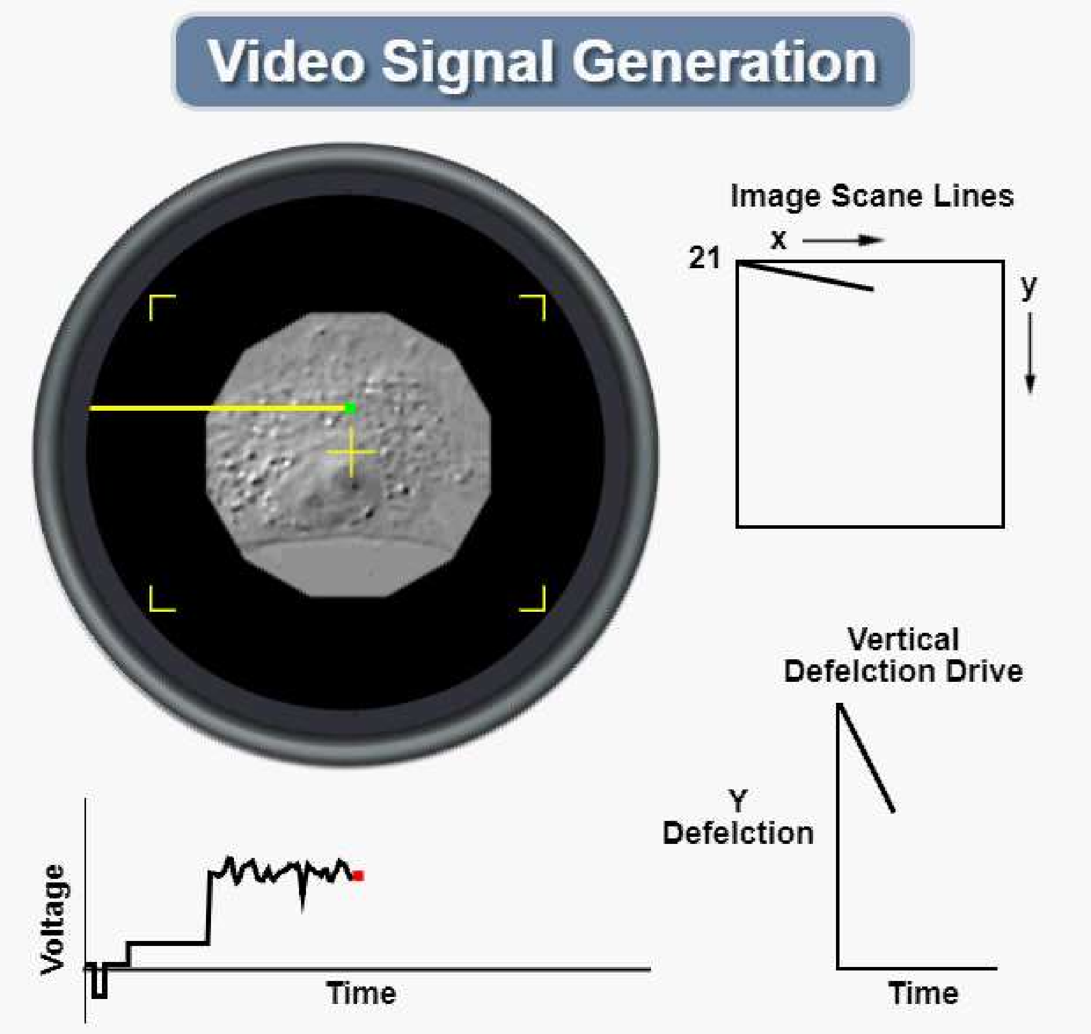
3 phase



4 phase

Controlling exposure time interval
Dumping photo-conducted-electronic out sensor site

Generating Video Signal—Analogy output



CCD Primary Noise Sources

SN = Shot (Photon) noise = $\sqrt{\text{signal}}$ (Physical property of light due to individual photons)

DN = Dark noise = $\sqrt{\text{dark current}}$ (Temperature dependent)

RN = Read noise (Gaussian distribution of values imparted by single output node/readout amplifier)

CCDs SNR

$$SNR = \frac{S}{\sqrt{DN^2 + RN^2 + SN^2}}$$

S = Signal = Photon flux * time * QE

DN = Dark noise = $\sqrt{\text{dark current}}$

RN = Read noise

SN = Shot (Photon) noise = $\sqrt{\text{signal}}$

Dark Current is typical temperature dependence

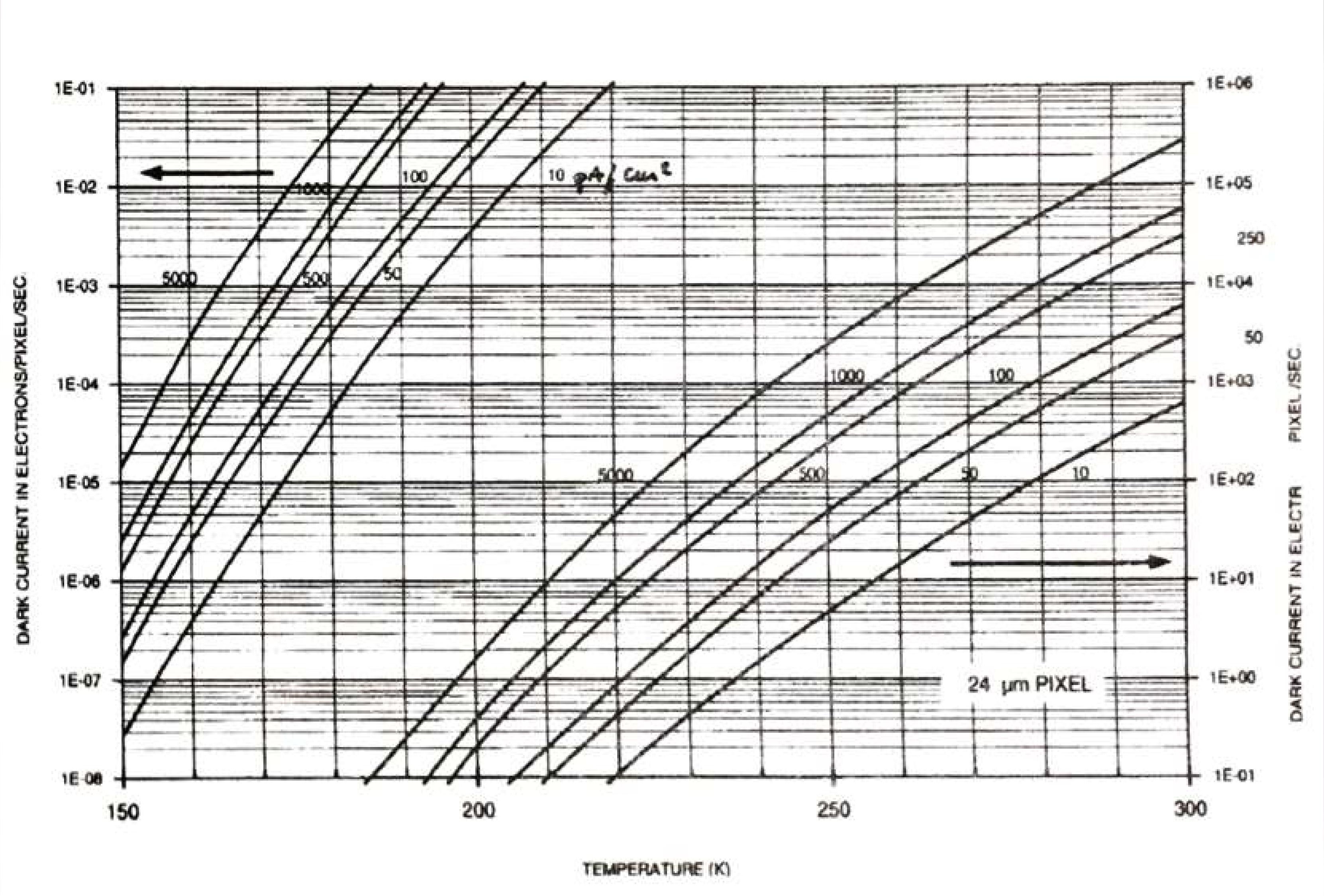
$$I_{DK} = 2^{(T-T_0)/7}$$

➔ Dynamic range reduction

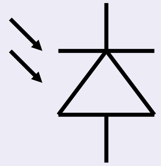
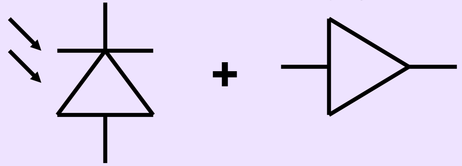
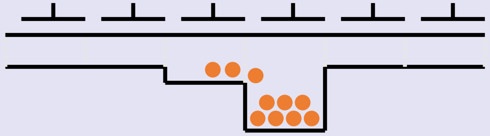
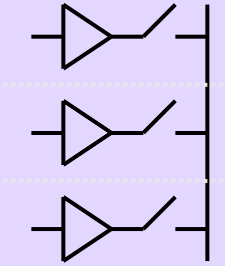
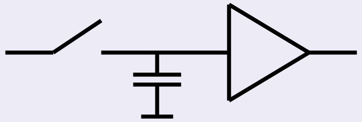
➔ Associated noise

https://slideplayer.com/slide/5723718/

Dark Current vs. Temperature



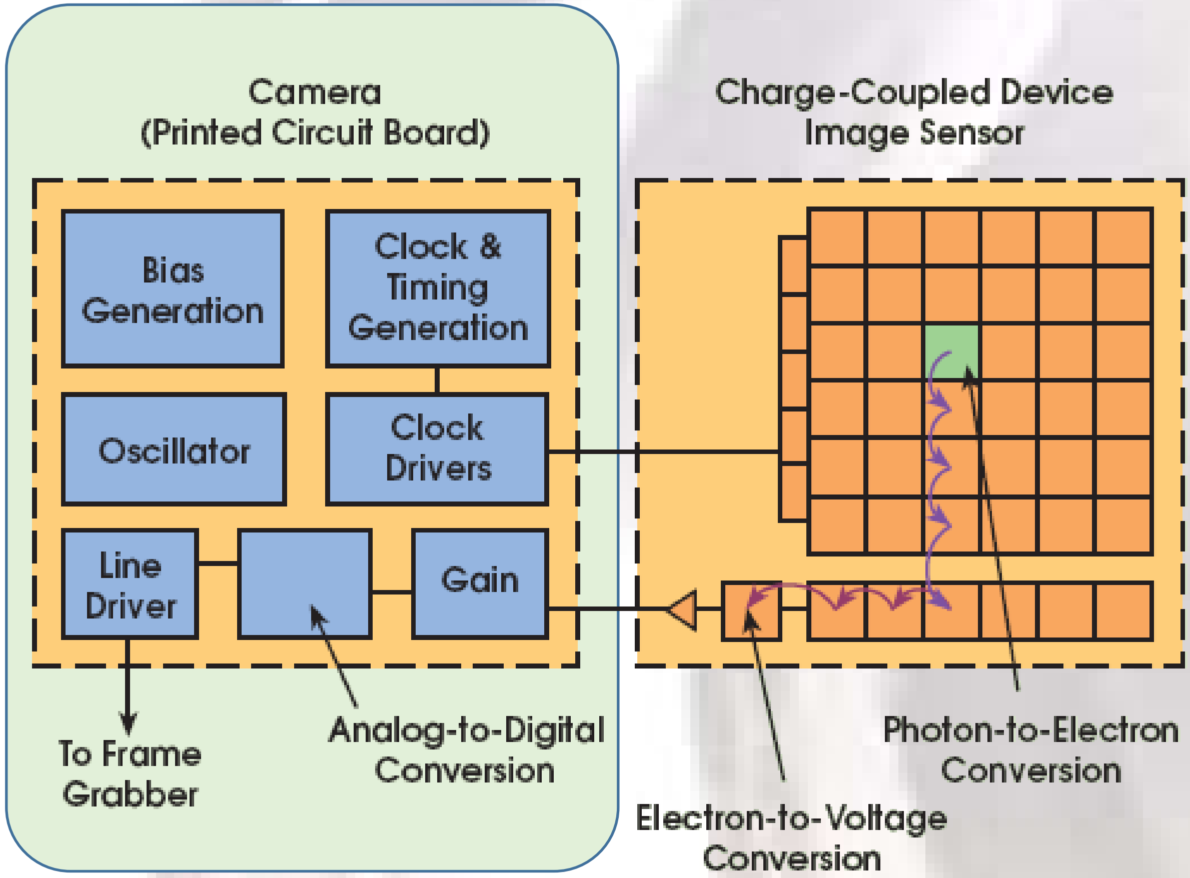
General CCD/CMOS Detector

	CCD Approach	CMOS Approach
Pixel	 Charge generation & charge integration	 Charge generation, charge integration & charge-to-voltage conversion
Array Readout	 Charge transfer from pixel to pixel	 Multiplexing of pixel voltages: Successively connect amplifiers to common bus
Sensor Output	 Output amplifier performs charge-to-voltage conversion	Various options possible: - no further circuitry (analog out) - add. amplifiers (analog output) - A/D conversion (digital output)

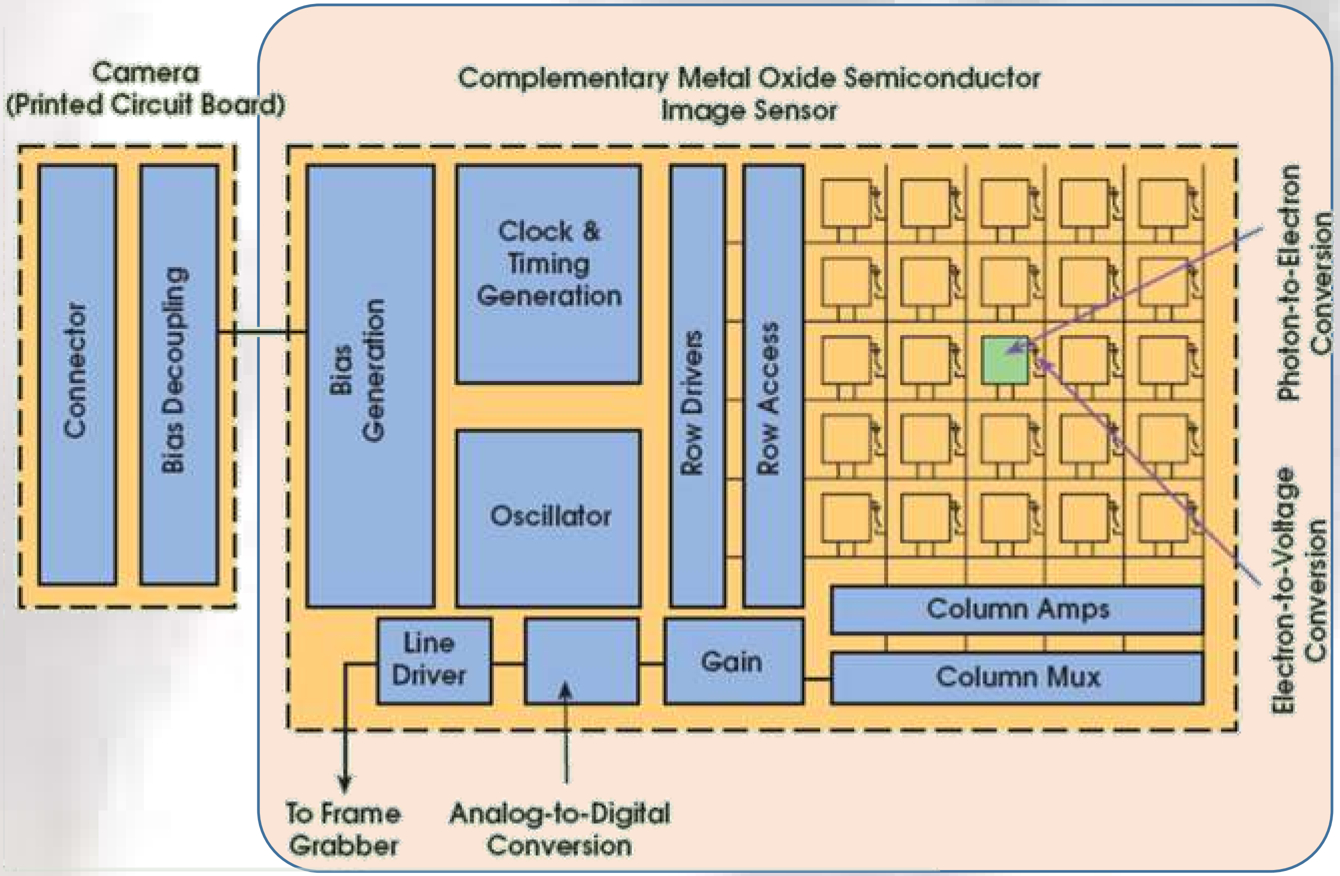
Markus Loose, Alan Hoffman, Vyshnavi Suntharalingam, “CMOS Detector Technology”, present at Scientific Detector Workshop, Sicily, Italy 2005

Architecture of CCD and CMOS Sensor

Highly complied with
standard CMOS
fabrication procedures



Typical Architecture of CCD Sensor



Typical Architecture of CMOS Sensor

https://www.fer.unizg.hr/_download/repository/ST03-Photonics_Spectra_CCDvsCMOS_Litwiller.pdf

Common CMOS Features

- CMOS sensors/multiplexers utilize the same process as modern microchips
  - Many foundries available worldwide
  - Cost efficient
- CMOS process enables integration of many additional features
  - Various pixel circuits from 3 transistors up to many 100 transistors per pixel
  - Random pixel access, windowing, subsampling and binning
  - Bias generation (DACs)
  - Analog signal processing (e.g. CDS, programmable gain, noise filter)
  - A/D conversion
  - Logic (timing control, digital signal processing, etc.)
- Electronic shutter (snapshot, rolling shutter, non-destructive reads)
  - No mechanical shutter required
- Low power consumption
- Radiation tolerant (by process and by design)

Markus Loose, Alan Hoffman, Vyshnavi Suntharalingam, “CMOS Detector Technology”, present at Scientific Detector Workshop, Sicily, Italy 2005

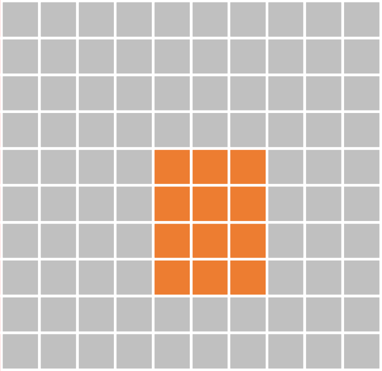
Selecting image output by CMOS

Different scanning methods are available to reduce the number of pixels being read:

1. Allows for higher frame rate or lower pixel rate (reduction in noise)
2. Can reduce power consumption due to reduced data

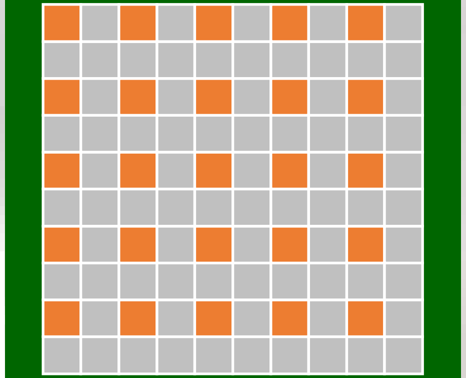
Windowing

- Define one or multiple ROI
- Used to achieve higher frame rates (e.g. AO, guiding)



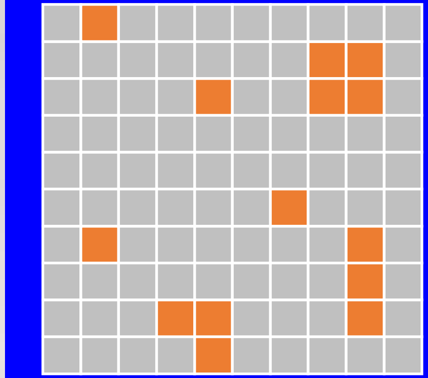
Subsampling

- Skip defined pixels (columns or rows) when output the signals
- Enable higher frame rates in compare with full-field images



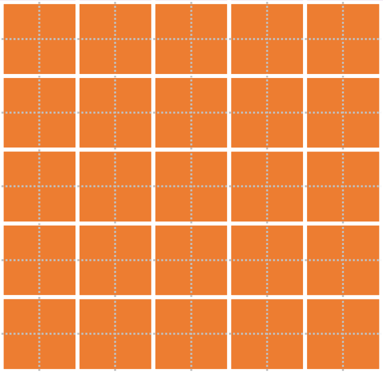
Random Read

- Random access (read or reset) of certain pixels
- Selective reset of saturated pixels
- Fast reads of selected pixels



Binning

- Combining several pixels into larger pixels
- Achieve lower noise and higher frame rates



Markus Loose, Alan Hoffman, Vyshnavi Suntharalingam, “CMOS Detector Technology”, present at Scientific Detector Workshop, Sicily, Italy 2005

CMOS Primary Noise Sources

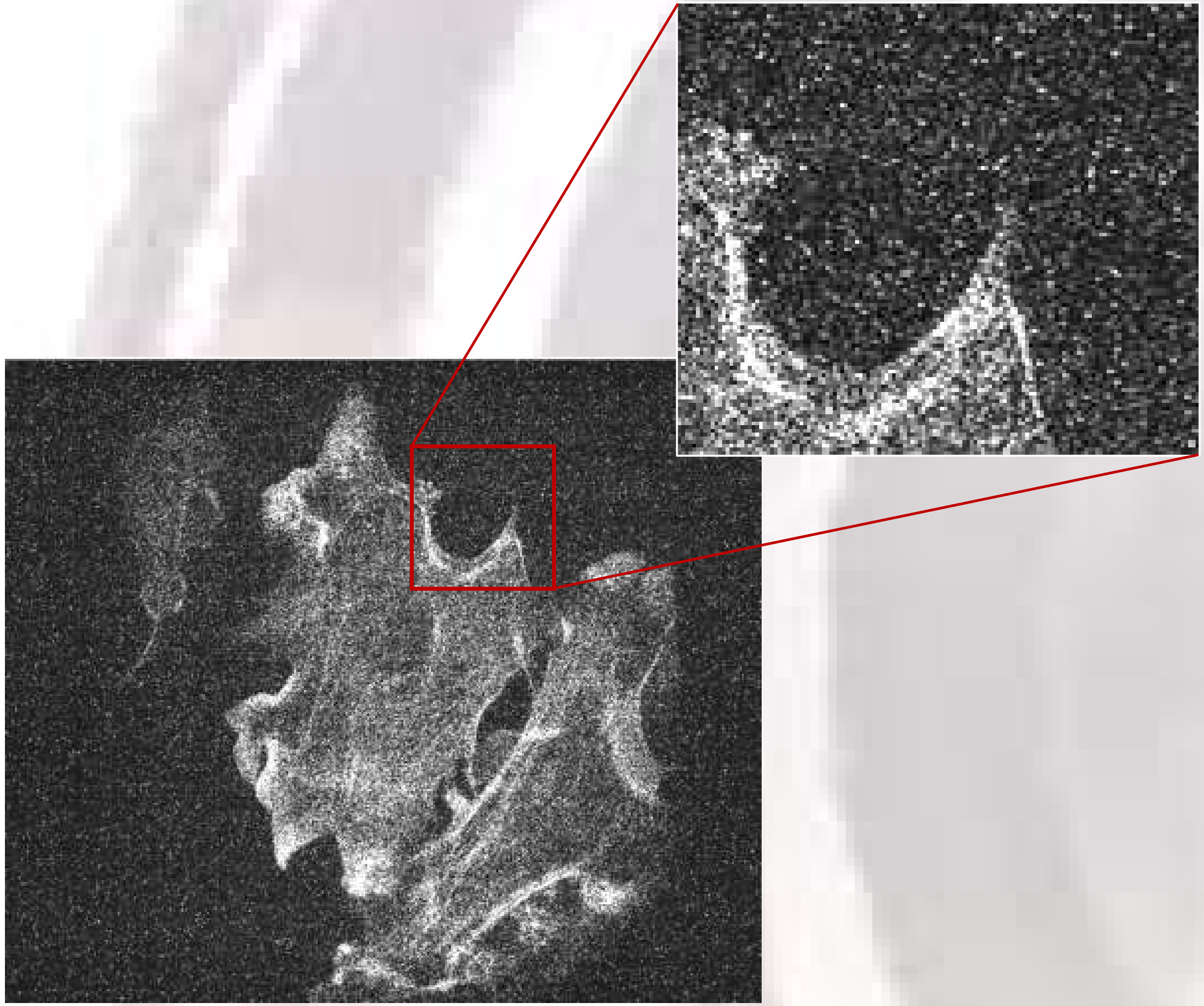
SN = Shot (Photon) noise = $\sqrt{\text{signal}}$ (Physical property of light, regardless of sensor)

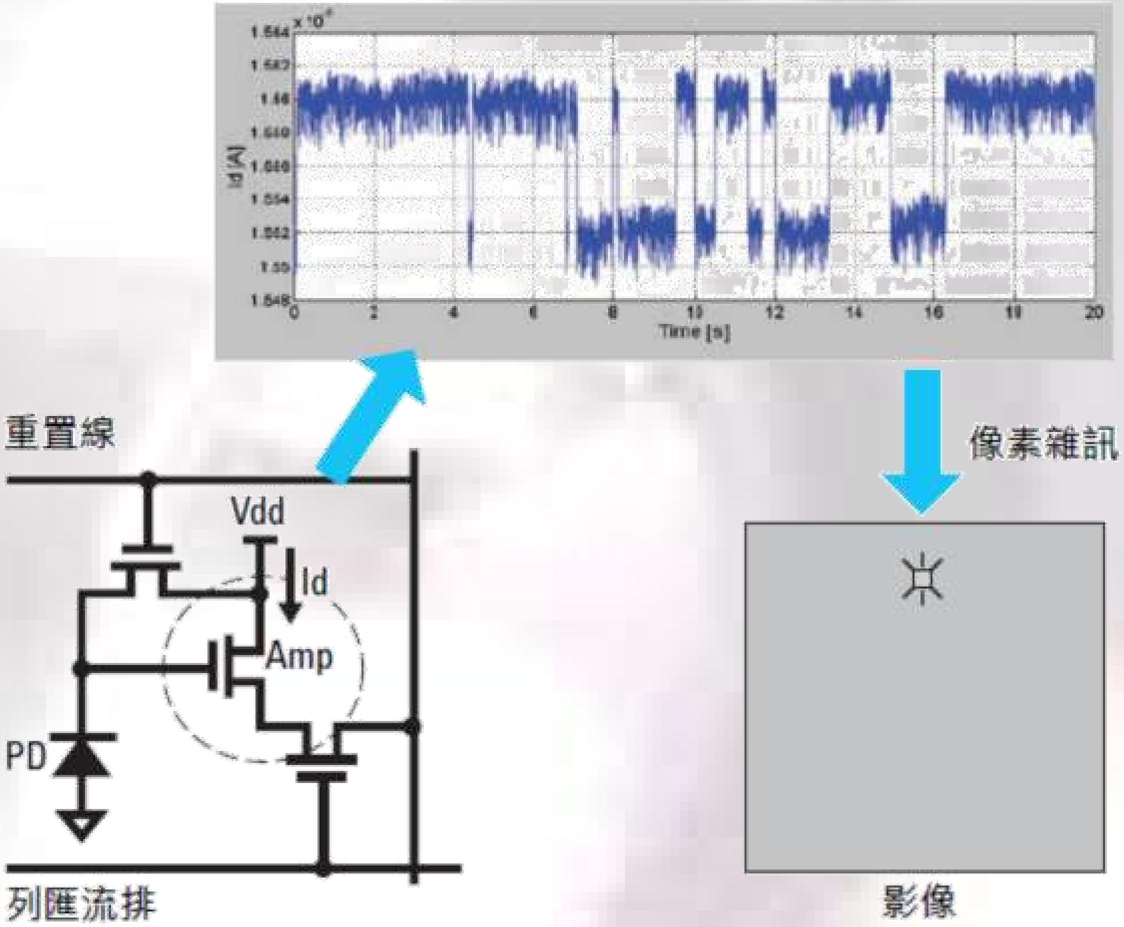
DN = Dark noise = $\sqrt{\text{dark current}}$ (Temperature dependent and higher for global shutter)

RN = Read noise (This includes **Random Telegraph Noise (RTN)**, which is non-Gaussian, and depends on multiply column and pixel amplifiers)

https://slideplayer.com/slide/5723718/

CMOS Random Telegraph Noise (Salt-and-Pepper Noise)





https://slideplayer.com/slide/5723718/

SNR for CMOS

$$SNR = \frac{S}{\sqrt{DN^2 + RN^2 + SN^2}}$$

S = Signal = Photon flux * time * QE

DN = Dark noise = $\sqrt{\text{dark current}}$

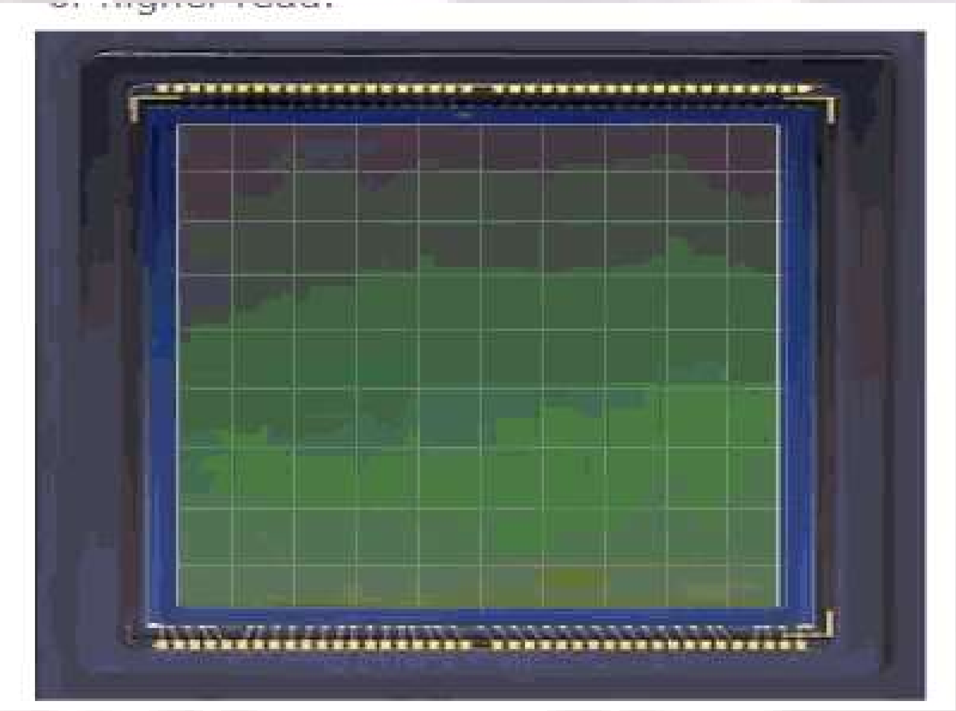
RN = Read noise (This includes Random Telegraph Noise (RTN), a significant component of CMOS noise)

SN = Shot (Photon) noise = $\sqrt{\text{signal}}$

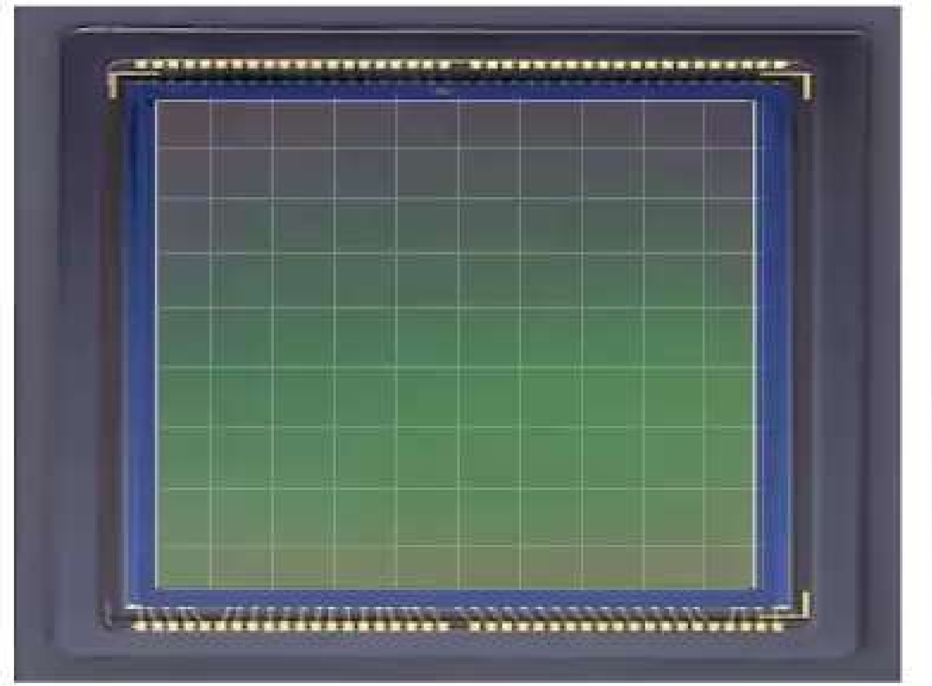
https://slideplayer.com/slide/5723718/

CMOS Sensor Readout Modes

Global Shutter

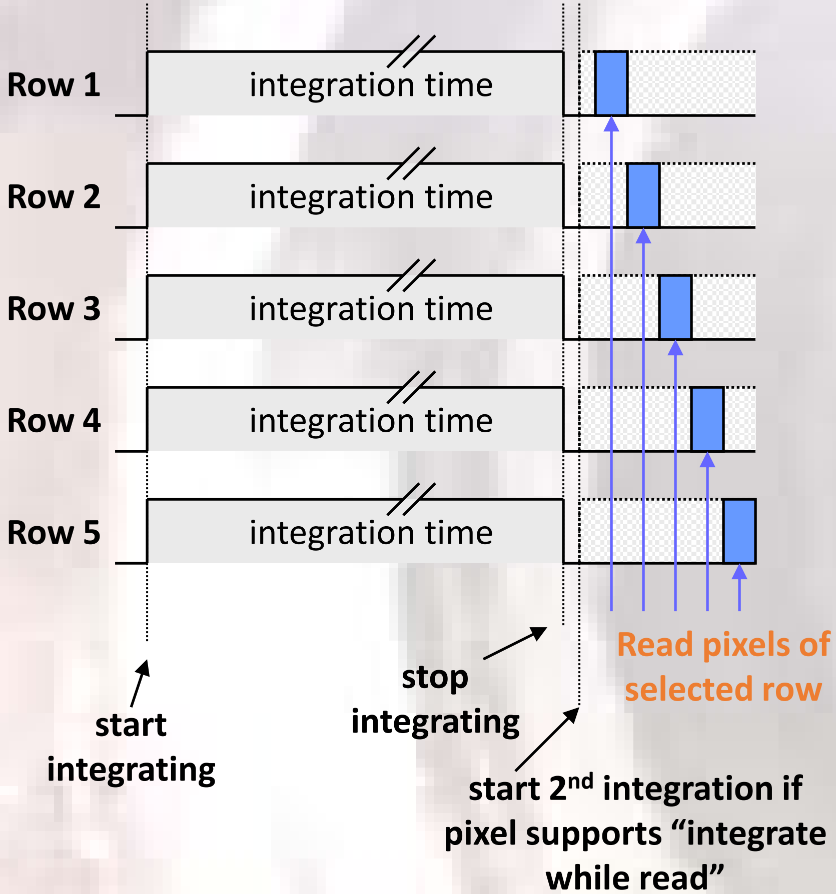


Rolling Shutter (More Common)

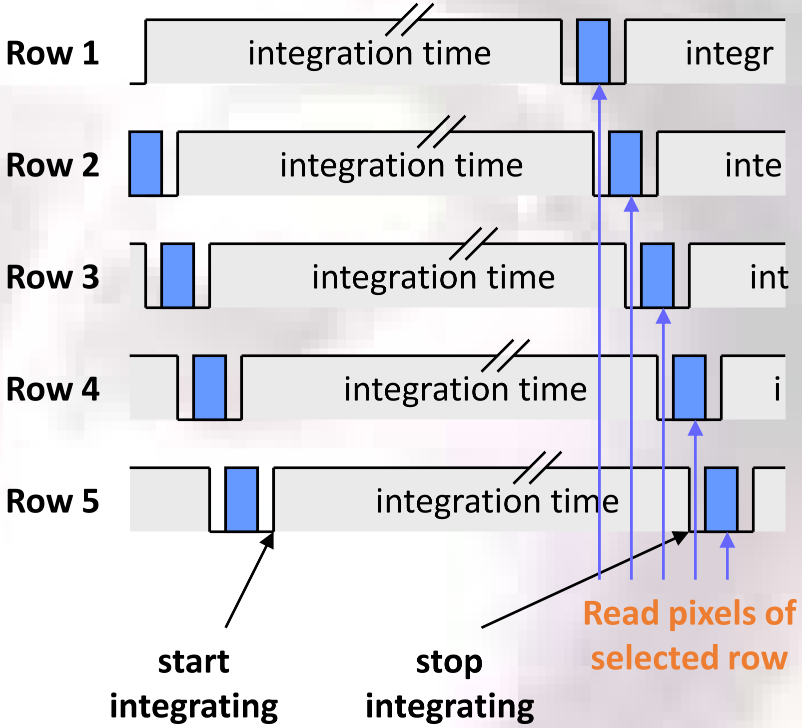


Electronic Shutter— Snapshot & Rolling Shutter

- Snapshot(Global) Shutter
  - All rows are integrating at the same time.
  - Typically more transistors per pixel and higher noise.



- Rolling Shutter (Ripple Read)
  - – Each row starts and stops integrating at a different time (progressively).
  - – Typically less transistors per pixel and lower noise.



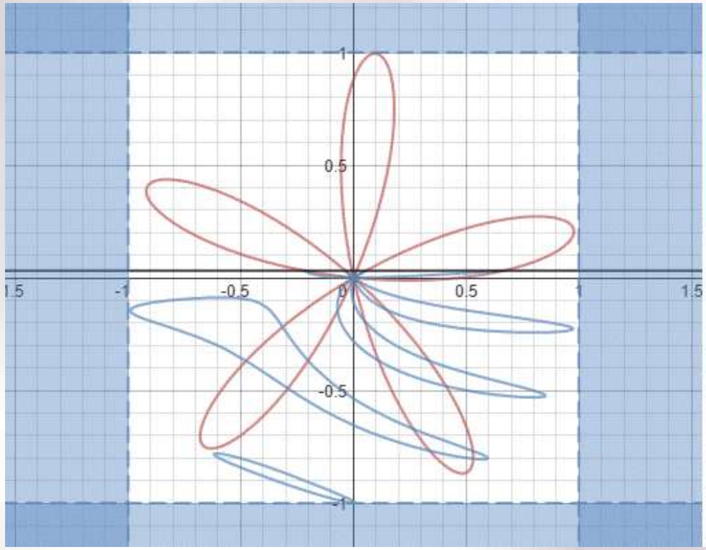
Markus Loose, Alan Hoffman, Vyshnavi Suntharalingam, "CMOS Detector Technology", present at Scientific Detector Workshop, Sicily, Italy 2005

Problem of Rolling Shutter

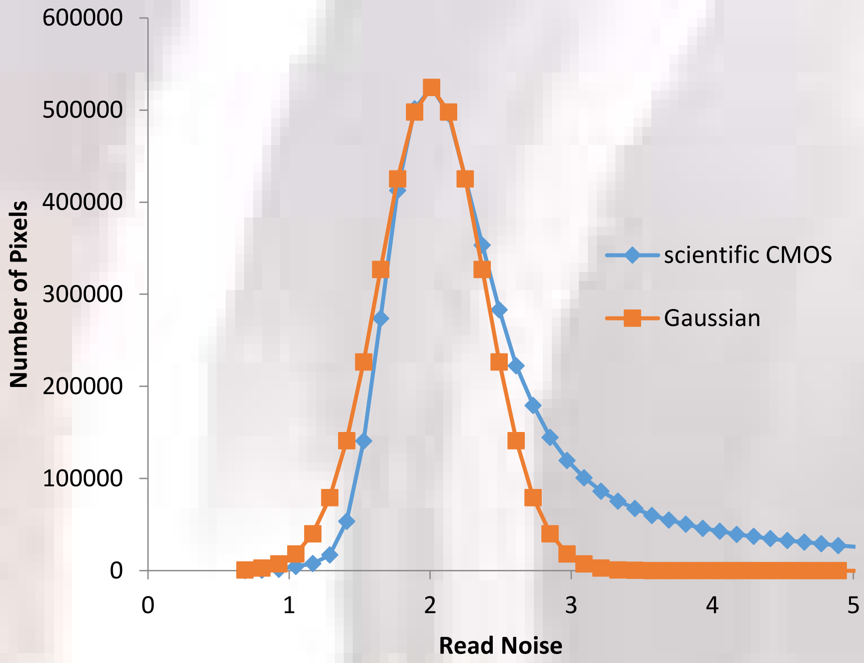
Rolling Shutter

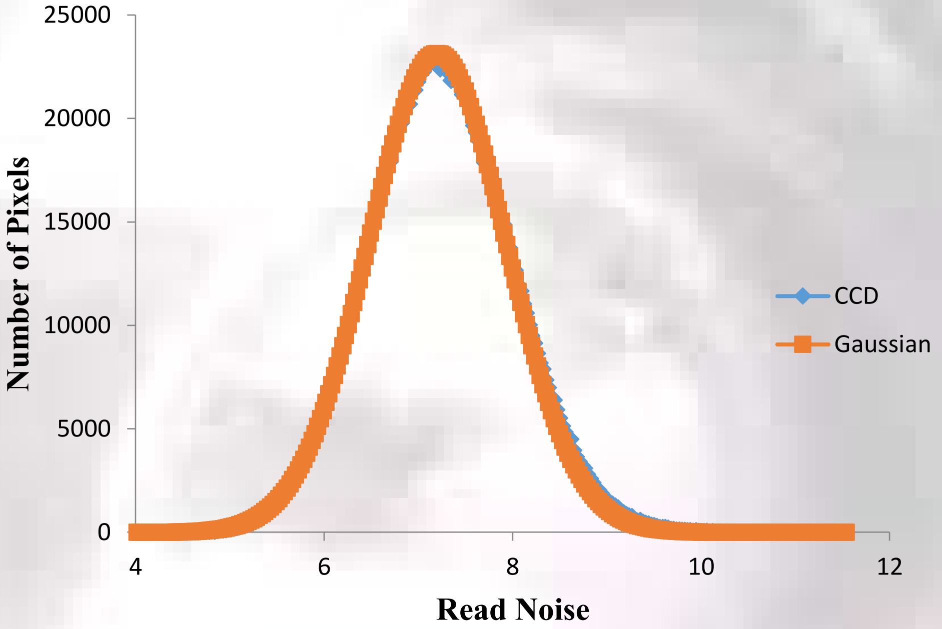
https://www.youtube.com/watch?v=LVwmtwZLG88

https://www.bhphotovideo.com/explora/video/tips-and-olutions/rolling-shutter-versus-global-shutter



CMOS Read Noise





- 40% outside of Gaussian fit
- 3% outside of Gaussian fit

- The CCD has a read noise distribution close to Gaussian
- The CMOS read noise distribution is skewed to much larger values due to the noisy pixels (RTN). It is skewed from Gaussian.

https://slideplayer.com/slide/5723718/

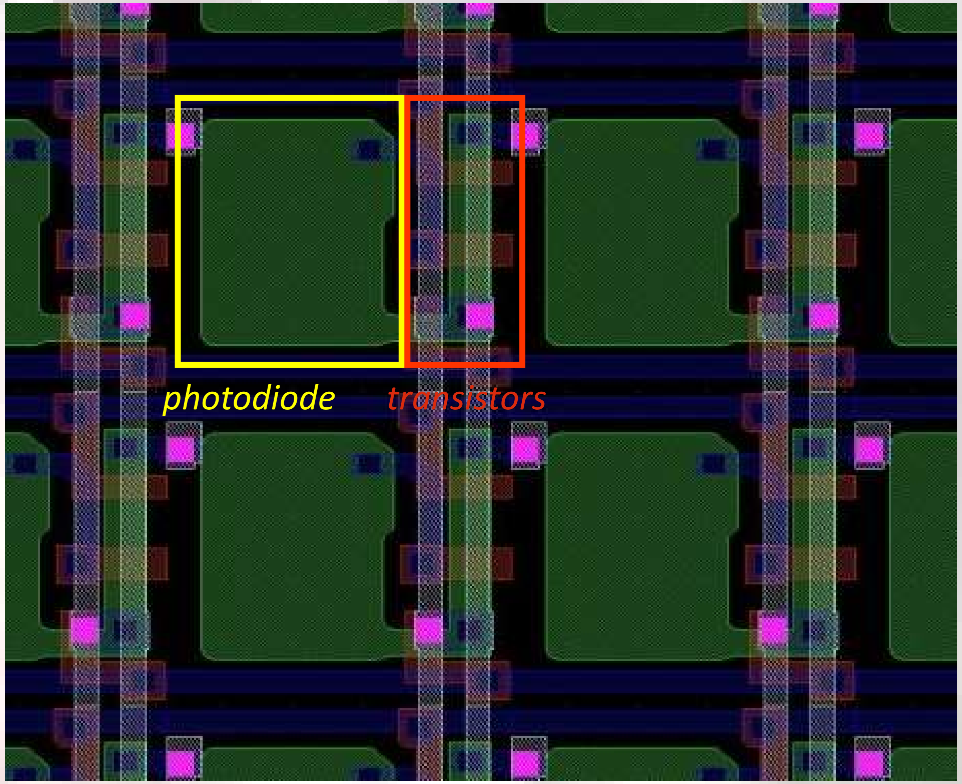
Fill Factor

Fill factor refers to the percentage of a photo site that is sensitive to light.

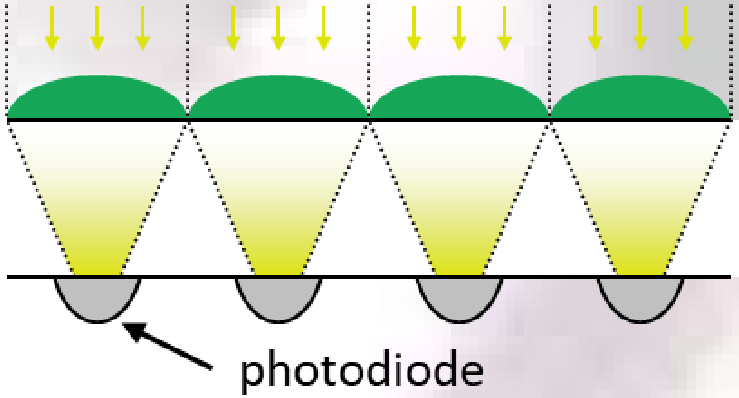
A monolithic CMOS image sensor combines the photodiode and the readout circuitry in one piece of silicon

Photodiode and transistors share the area => less than 100% fill factor

Small pixels and large arrays can be produced at low cost => consumer



- **Microlenses increase fill factor:**



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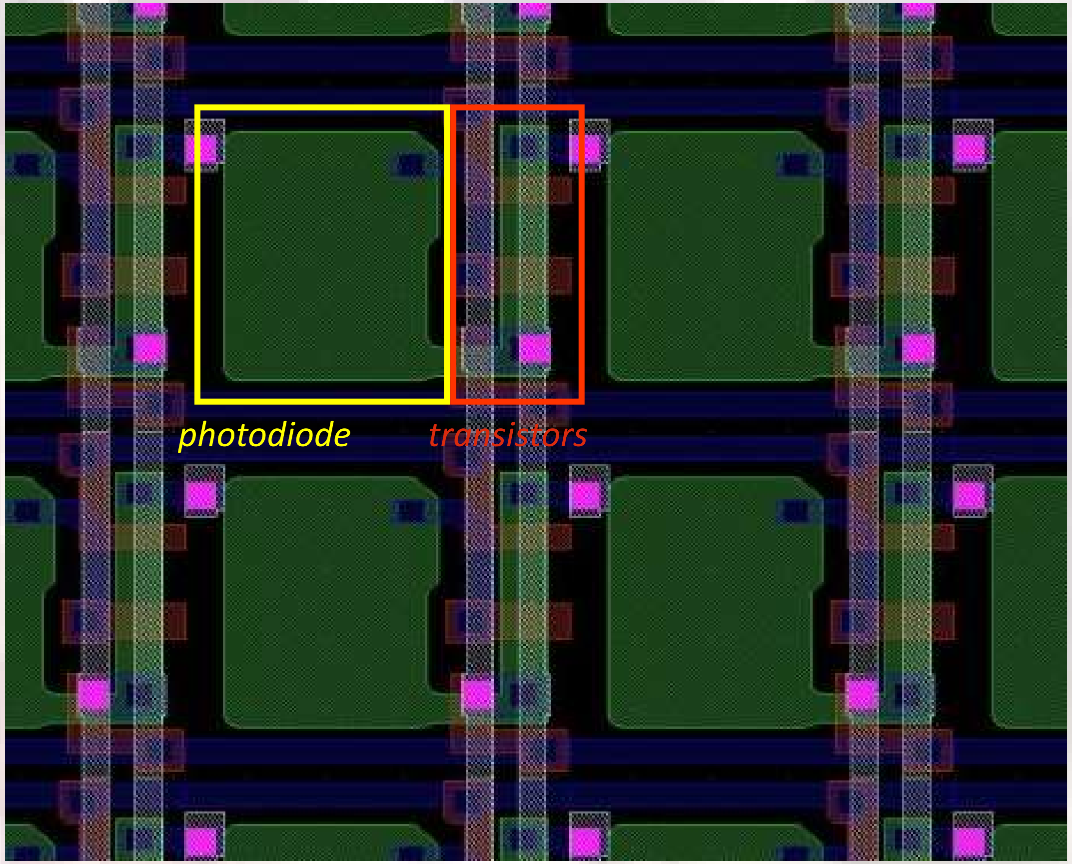
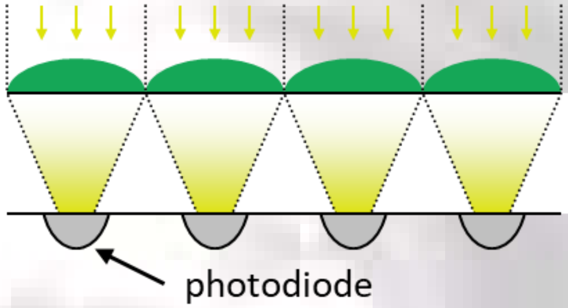
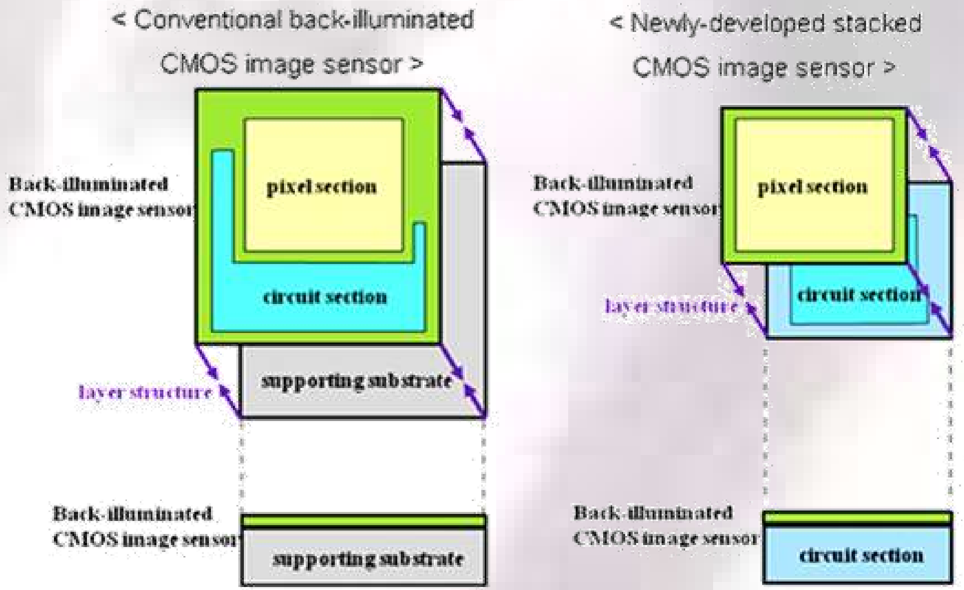


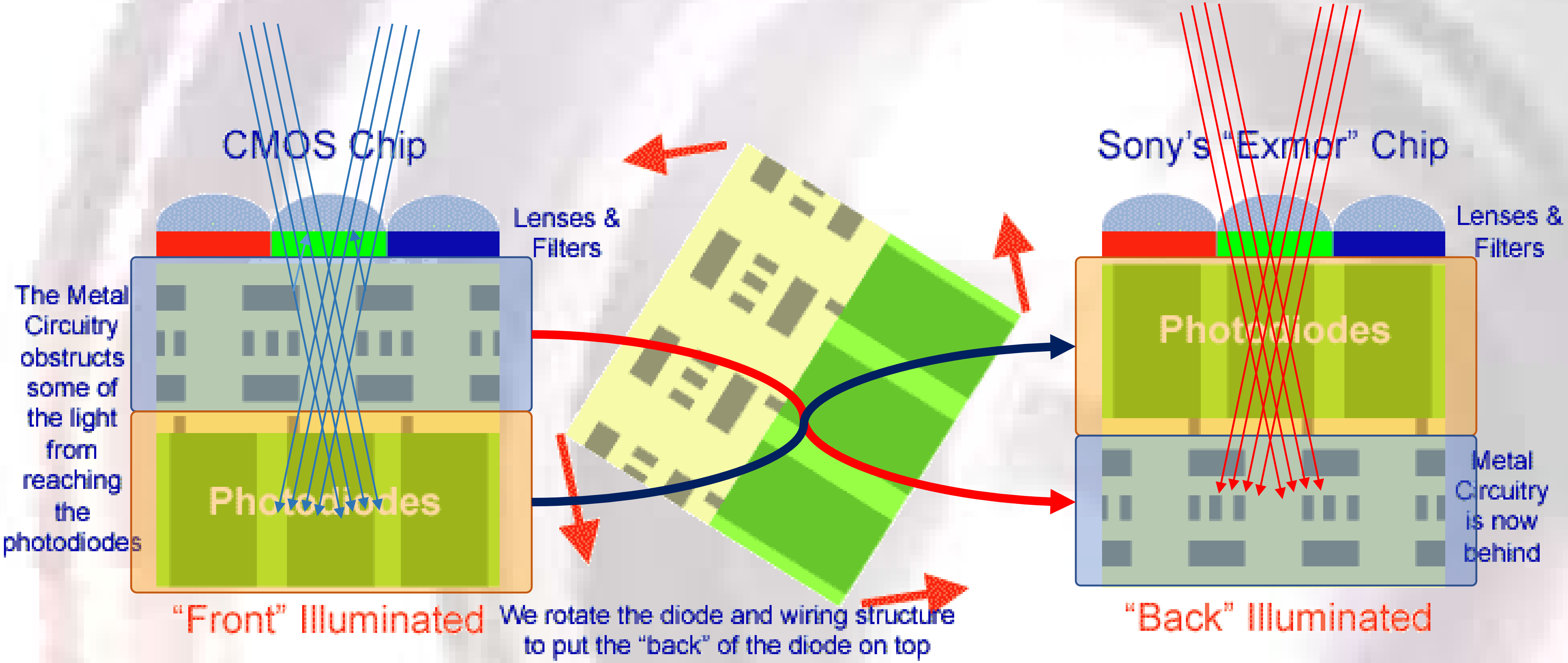
- **Microlenses increase fill factor:**





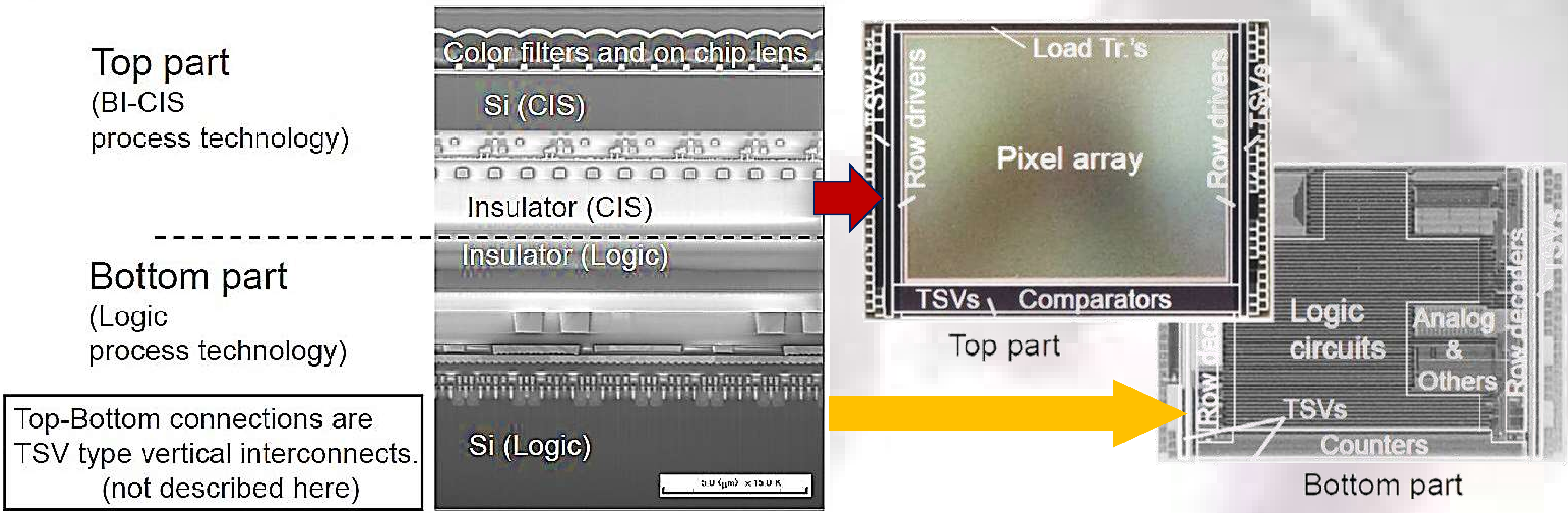
https://www.sony.net/SonyInfo/News/Press/201201/12-009E/index.html

Back-illuminated structure pixels



http://www.artfuldancer.com/Lessons/topics/Common/PixelSizeEffects.asp

Back-illuminated structure pixels



Top part
(BI-CIS
process technology)

Bottom part
(Logic
process technology)

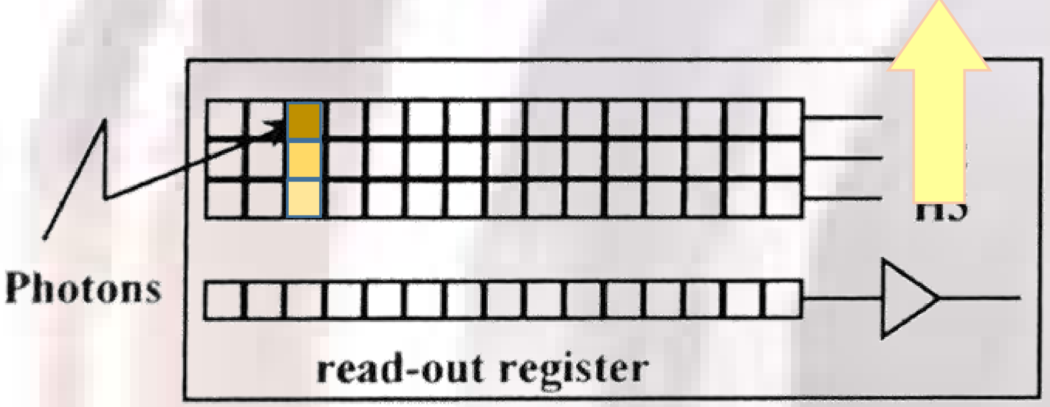
Top-Bottom connections are
TSV type vertical interconnects.
(not described here)

http://www.artfuldancer.com/Lessons/topics/Common/PixelSizeEffects.asp
https://tech.nikkeibp.co.jp/dm/english/NEWS_EN/20130222/267487/?SS=imgview_en&FD=47651877

TDI- Time Delay Interaction Device

“like a larger aperture or a lower F-number“

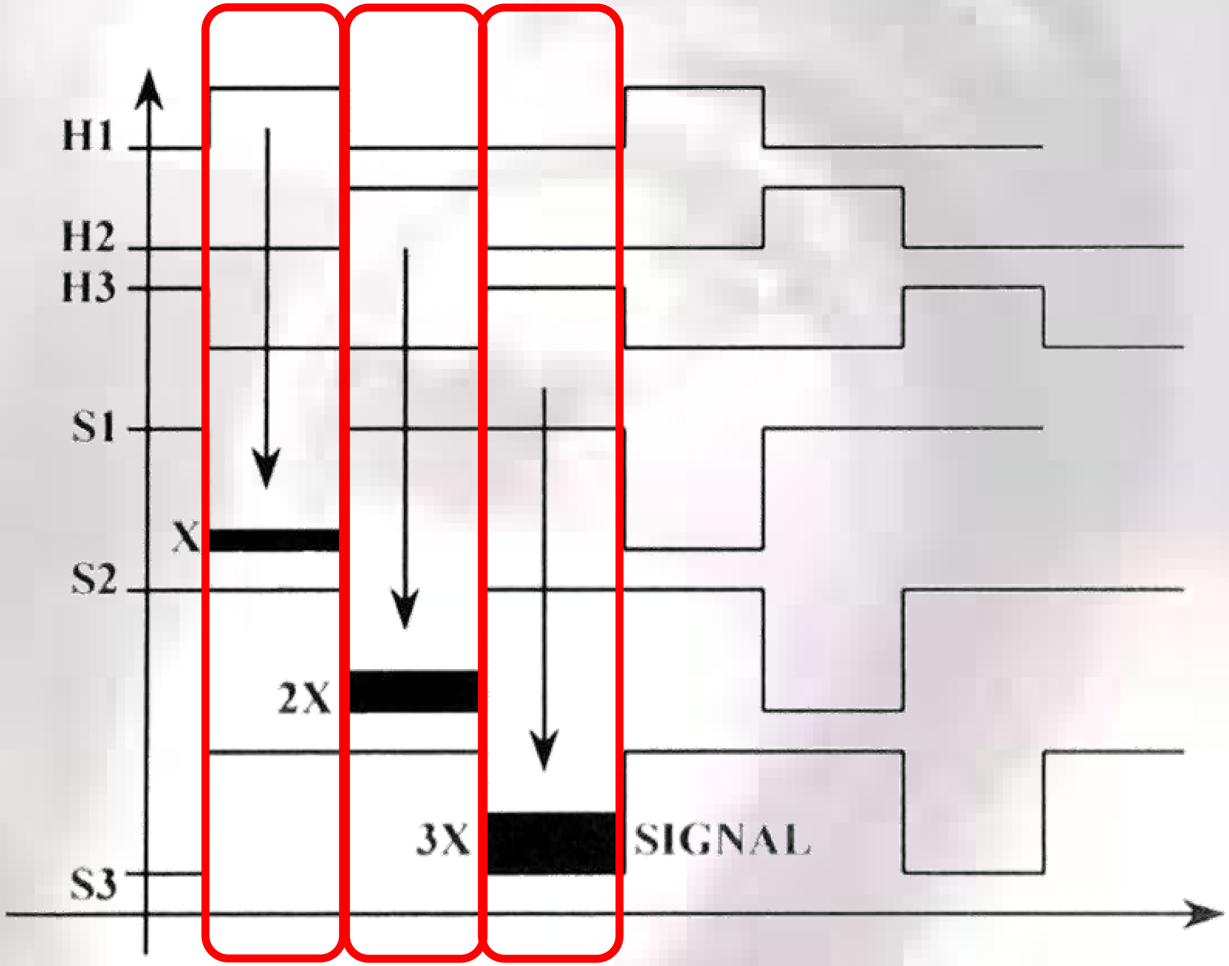
Sensor Moving Direction



$$SNR_{TDI} = SNR_{PD} * \sqrt{N}$$

N: TDI steps

Purpose of TDI:
To maximize SNR ratio
instead of to maximize detecting Signal



Some Facts of TDI sensor

TDI: by accumulating multiple exposures of the same object(moving object/ scanning) through effectively

ncident

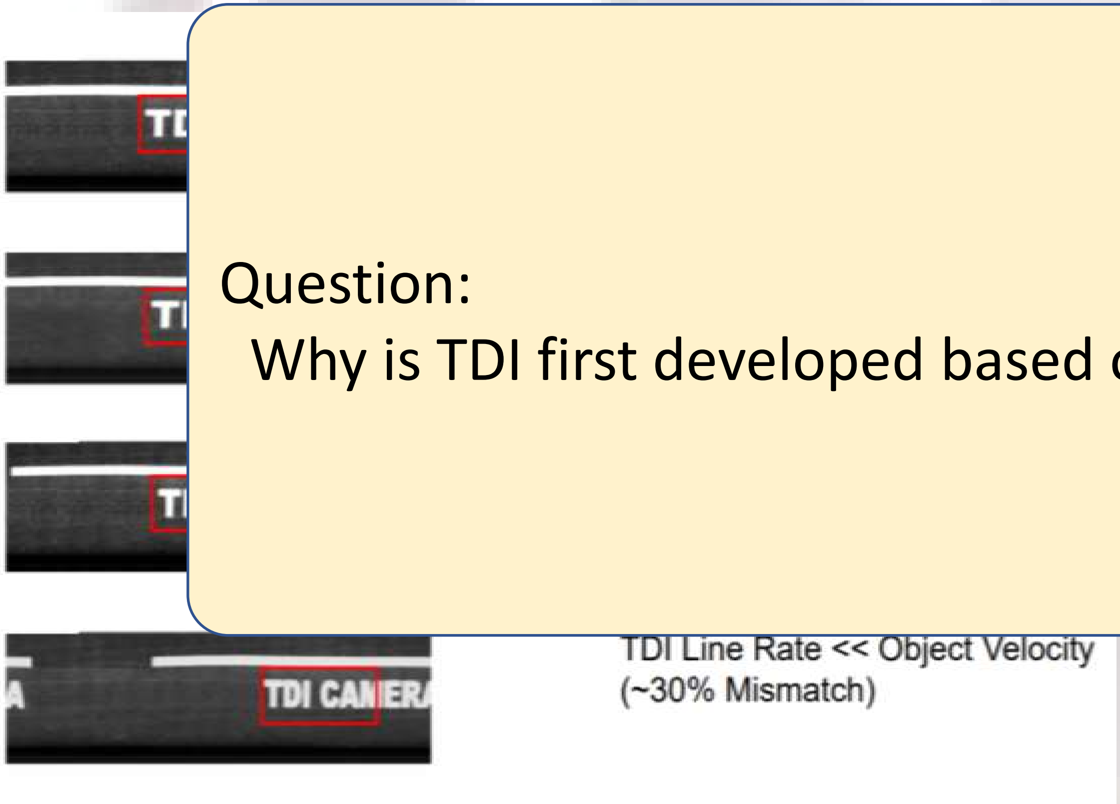
nslational

uality. A

pixel)

le the

n



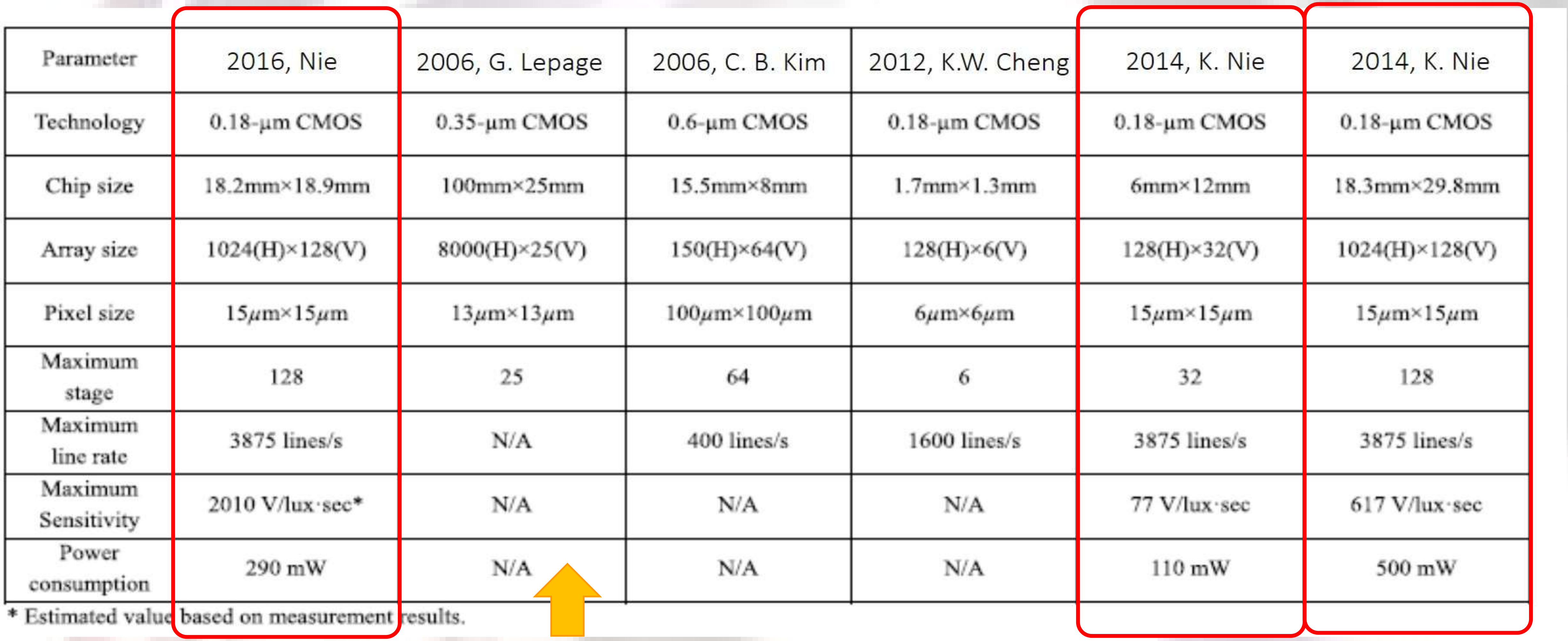
Question:

Why is TDI first developed based on CCD sensor instead of CMOS sensor?

4. TDI is developed for **light-starved applications,** typically, the sensor designed with no anti-blooming function
5. The TDI is developed based on CCD, however, CMOS TDI is proposed in recent years (why?)

https://www.teledynedalsa.com/en/learn/knowledge-center/tdi-primer/

CMOS TDI



Parameter	2016, Nie	2006, G. Lepage	2006, C. B. Kim	2012, K.W. Cheng	2014, K. Nie	2014, K. Nie
Technology	0.18-µm CMOS	0.35-µm CMOS	0.6-µm CMOS	0.18-µm CMOS	0.18-µm CMOS	0.18-µm CMOS
Chip size	18.2mm×18.9mm	100mm×25mm	15.5mm×8mm	1.7mm×1.3mm	6mm×12mm	18.3mm×29.8mm
Array size	1024(H)×128(V)	8000(H)×25(V)	150(H)×64(V)	128(H)×6(V)	128(H)×32(V)	1024(H)×128(V)
Pixel size	$15\mu m \times 15\mu m$	$13\mu m \times 13\mu m$	$100\mu m \times 100\mu m$	$6\mu m \times 6\mu m$	$15\mu m \times 15\mu m$	$15\mu m \times 15\mu m$
Maximum stage	128	25	64	6	32	128
Maximum line rate	3875 lines/s	N/A	400 lines/s	1600 lines/s	3875 lines/s	3875 lines/s
Maximum Sensitivity	2010 V/lux·sec*	N/A	N/A	N/A	77 V/lux·sec	617 V/lux·sec
Power consumption	290 mW	N/A	N/A	N/A	110 mW	500 mW

* Estimated value based on measurement results.

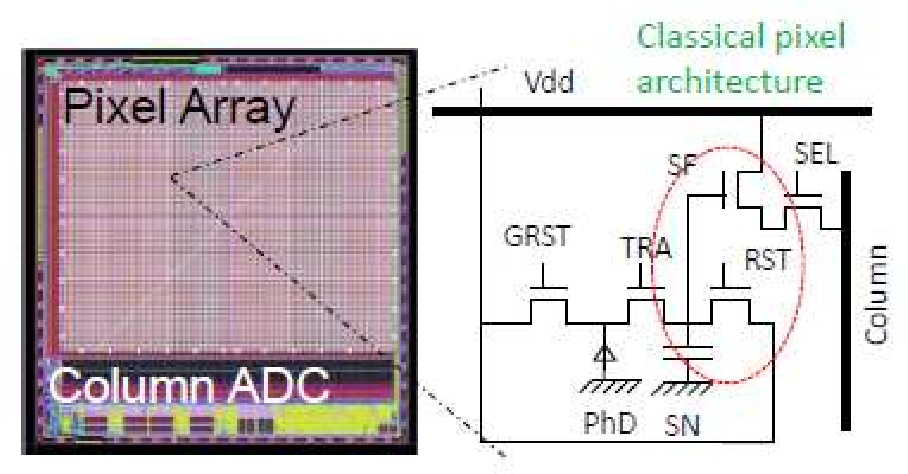
Tianjin University

Space Application

CMOS TDI- 2 approaches (solution of e2V)

Summation done in the digital domain—Standard CMOS

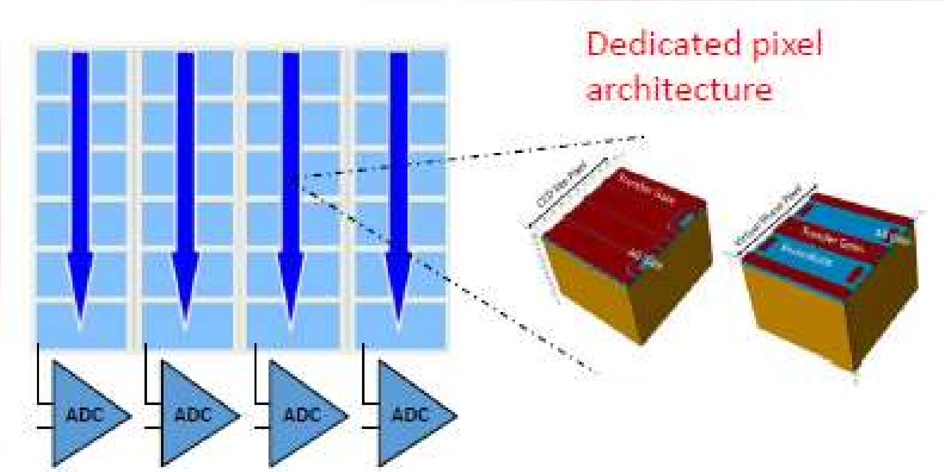
- Charge to voltage conversion is done at pixel level



- Virtually Unlimited saturation→ high saturation equivalent signal
- N-lines Conversions → High Noise Equivalent Signal
- $Dynamic\ Range_{|max} = \sqrt{N} \times \frac{Full\ Well\ Capacity}{Noise}$

Summation is done inside the pixel along the track—CCD Like

- Charge to voltage conversion is done at column level after the charge summation

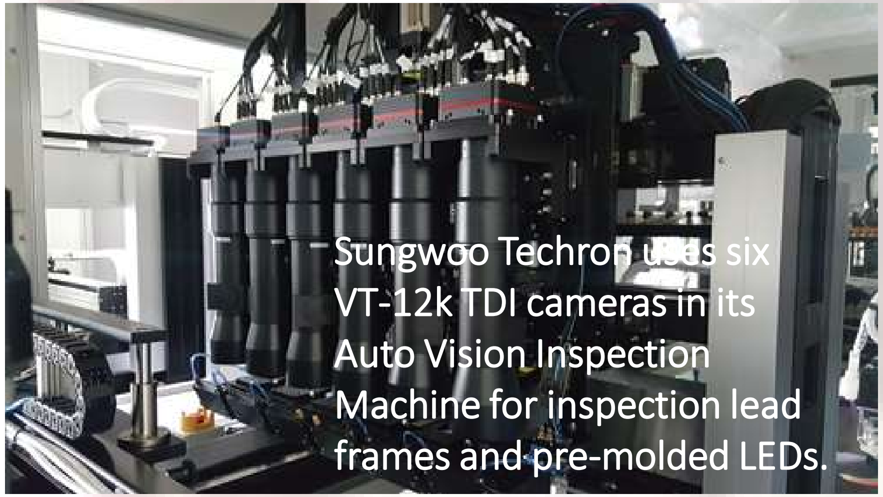


- Saturation limited by one pixel→ Low saturation equivalent signal
- Only one Conversion → Low Noise Equivalent Signal
- $Dynamic\ Range_{|max} = \frac{Full\ Well\ Capacity}{Noise}$

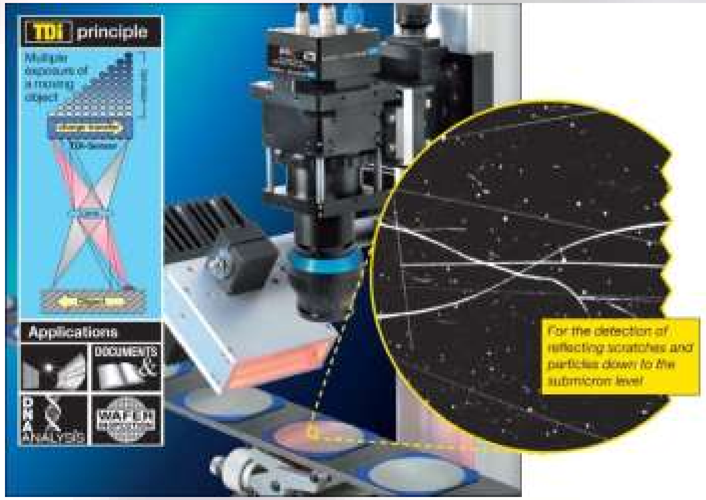
https://www.e2v.com/content/uploads/2016/03/2nd_Gen_CMOS_Charge_Tranfer_TDI_Mayer_1_v2.pdf

Applications of TDI sensors

- **Si-Wafer inspection**: Detection of voids on and inside (lighted by SWIR) Si-wafers
- **High-speed parts inspection**: Acquire image with high speed and high sensitivity
- **Sorting**: Fast automatic sorting of letters and parcels
- **Glass inspection**: Inspect blemish or scratch on a large size glass with high-speed by bi-directional readout
- **Fluorescence detection**: in liquid flow Observation of fluorescence images and measurement of intensity simultaneously
- **DNA chip reader**: High sensitivity and minimized damage of samples by excitation light
- **Virtual Microscope/ Digital Pathology** : Fast and high resolution conversion of fluorescence glass slides into digital slides


Sungwoo Techron uses six VT-12k TDI cameras in its Auto Vision Inspection Machine for inspection lead frames and pre-molded LEDs.


Glass sorting for recycling



For the detection of reflecting scratches and particles down to the submicron level

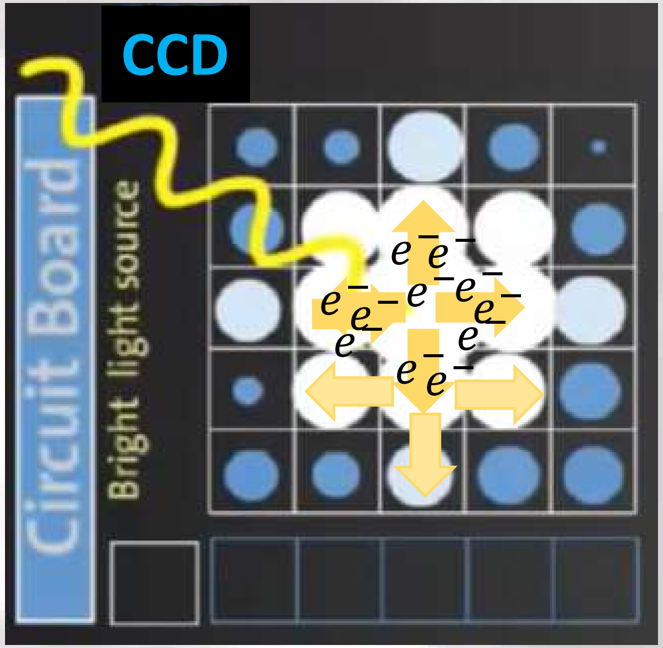
Blooming Effect

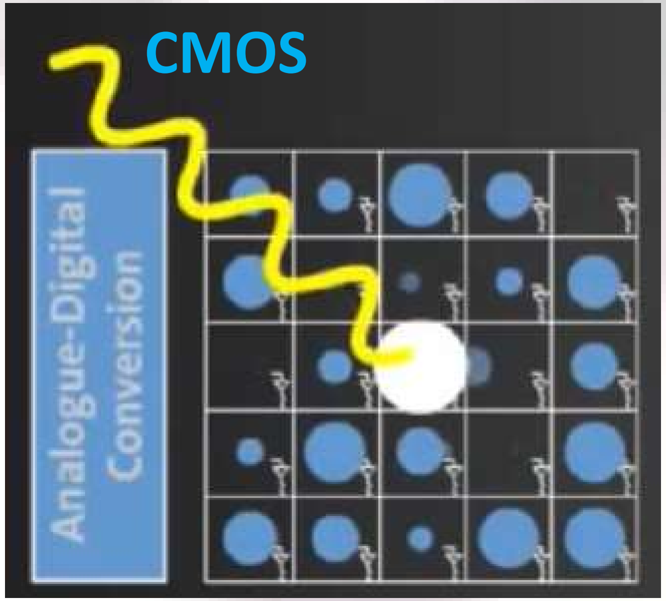
Blooming Phenomenon

CCD Camera

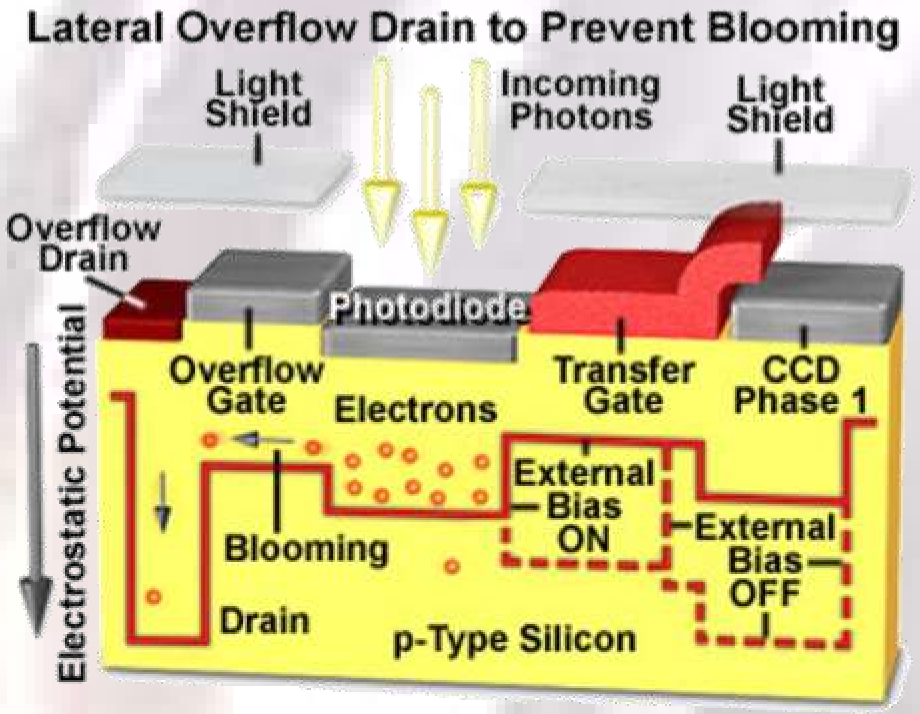
CMOS Camera

https://www.adimec.com/ccd-versus-cmos-blooming-and-smear-performance/

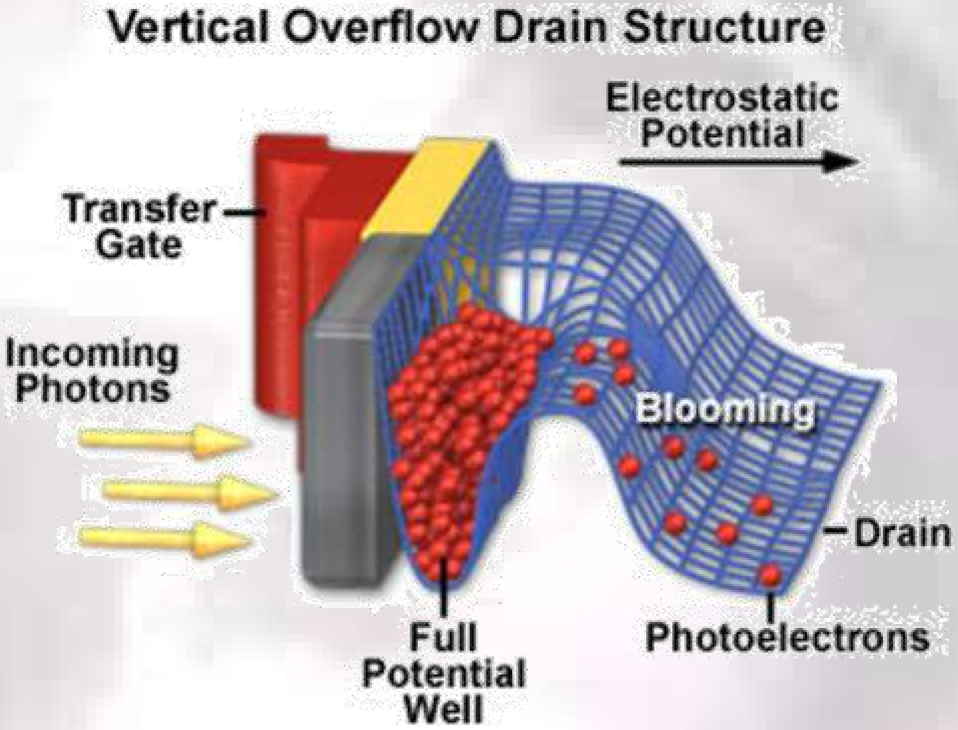




Blooming Effect—Antiblooming



Lateral Overflow Drain—Reduce ~30% pixel size



Vertical Overflow Drain—

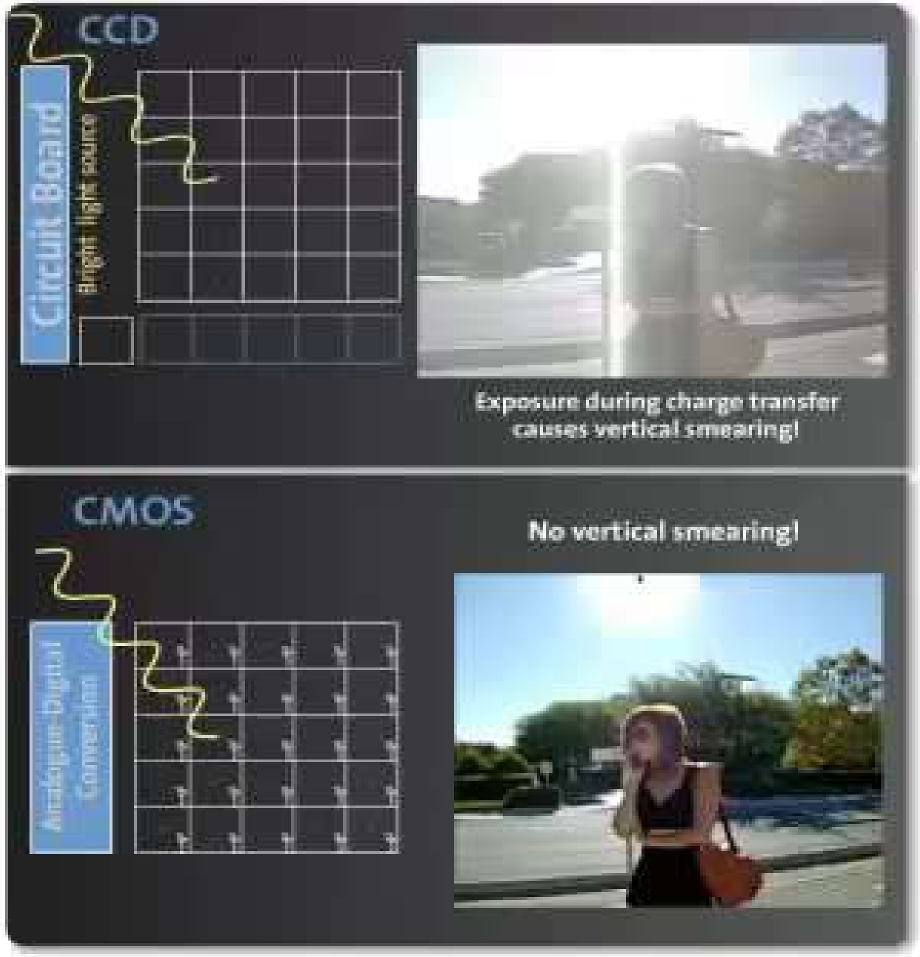
1. lower dynamic range
2. preclude thinning and backside illumination methods
3. device complexity conducts fabrication cost increased
4. overall quantum efficiency is low; typically, the peak value reduced approximately 25%

http://hamamatsu.magnet.fsu.edu/articles/ccdsatandblooming.html

Smearing

1. Can be observed only for CCD sensor
2. Occurred together with blooming

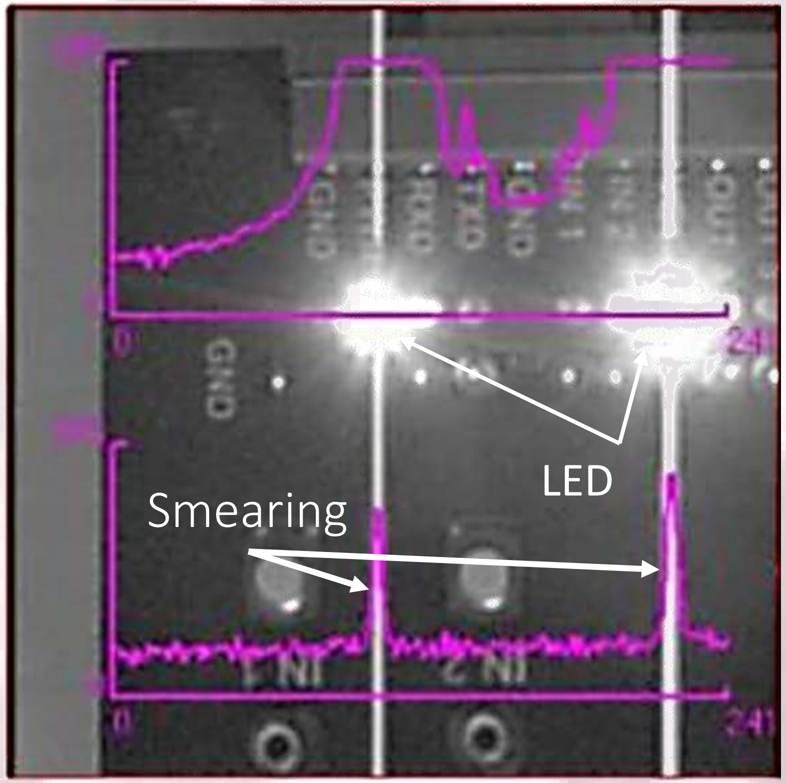
Mechanism



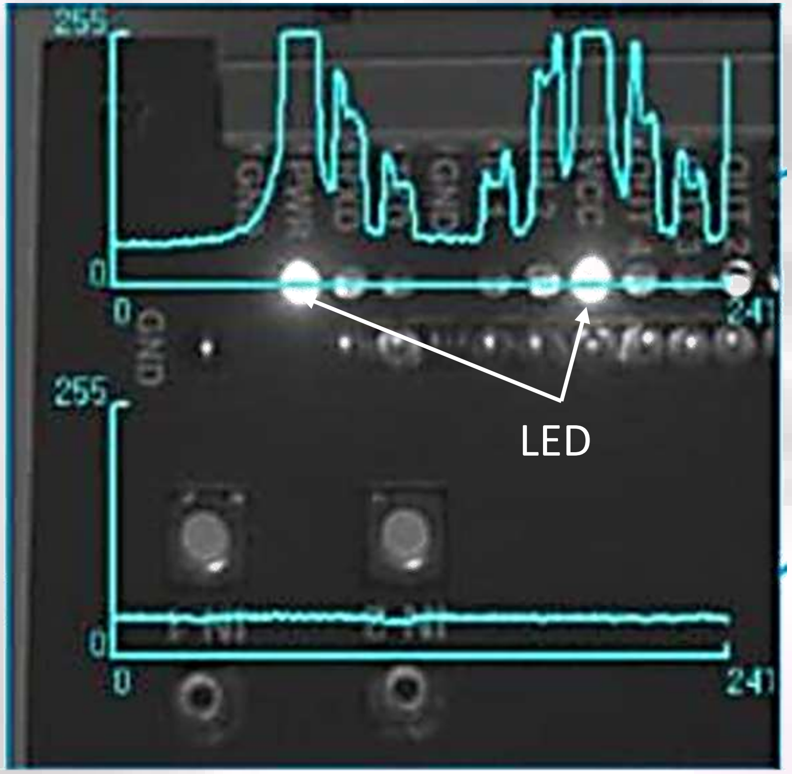
https://www.youtube.com/watch?v=Dw9wBcVYQzA

https://www.youtube.com/watch?v=_E2HglaV2Mo

How Blooming& Smearing effects change the image



CCD(Sony ICX 655)

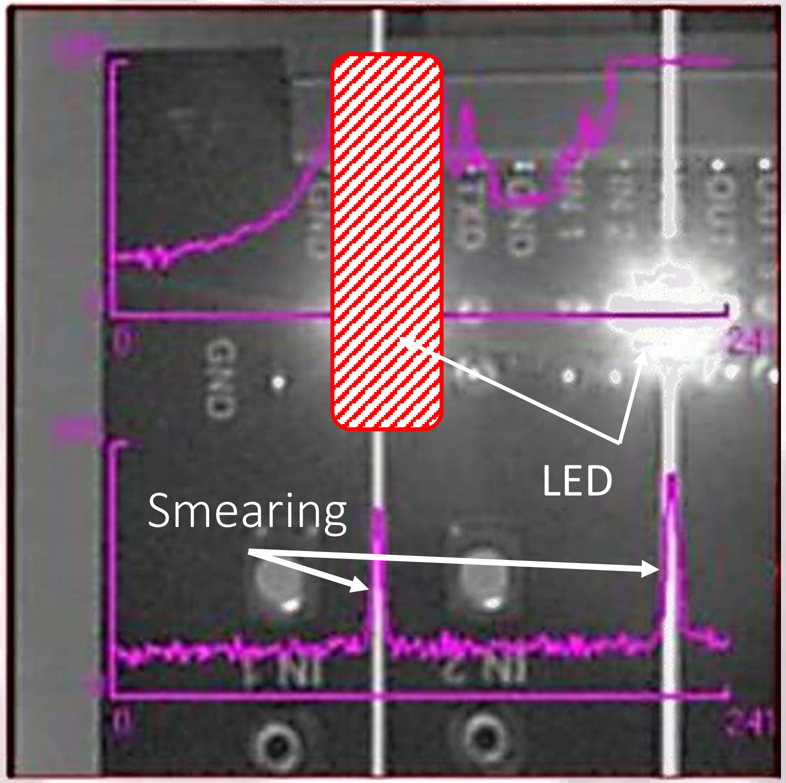


CMOS(Sony IMX 264)

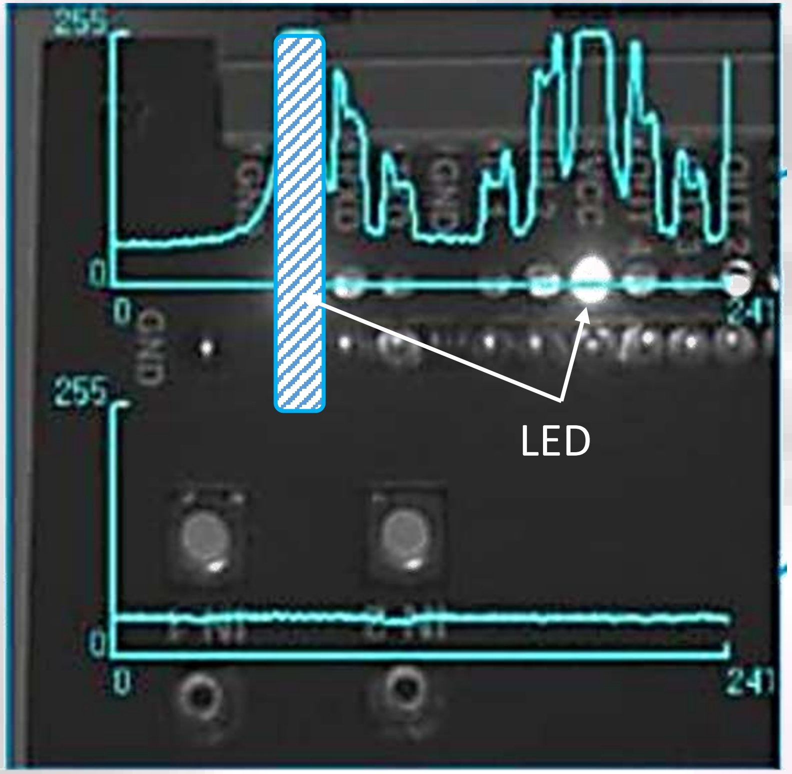
1. No smear problem for CMOS sensor
2. Blooming problem can be observed for both CCD and CMOS sensors; however, in general case, CMOS sensor performs better than CCD sensor
3. Sensors of high “Dynamic Range” always perform better for resisting the blooming/ smearing affects

https://www.1stvision.com/machine-vision-solutions/2018/06/ccd-vs-cmos-industrial-cameras-excel-in-allied-vision-industrial-camera.html

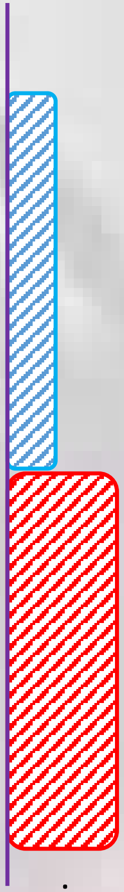
How Blooming& Smearing effects change the image



CCD(Sony ICX 655)



CMOS(Sony IMX 264)



Dimension changed by Blooming

1. No smear problem for CMOS sensor
2. Blooming problem can be observed for both CCD and CMOS sensors; however, in general case, CMOS sensor performs better than CCD sensor
3. Sensors of high “Dynamic Range” always perform better for resisting the blooming/ smearing affects

https://www.1stvision.com/machine-vision-solutions/2018/06/ccd-vs-cmos-industrial-cameras-excel-in-allied-vision-industrial-camera.html

Moiré effect

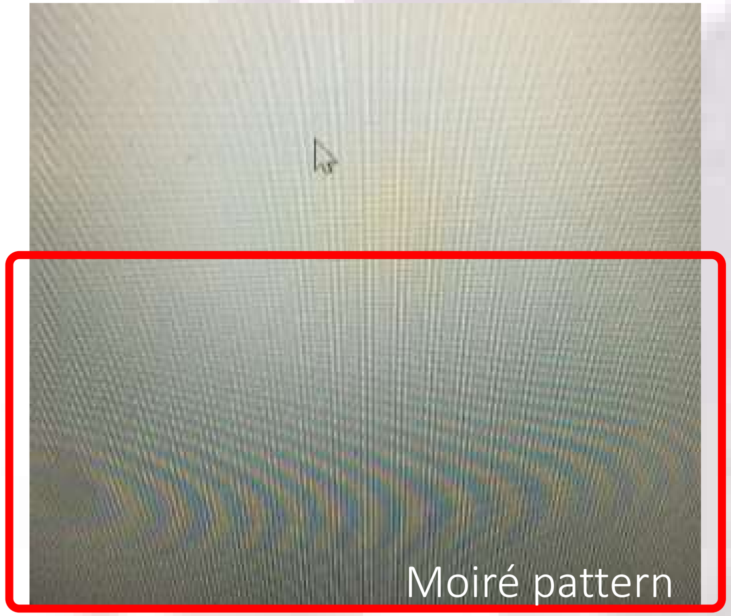
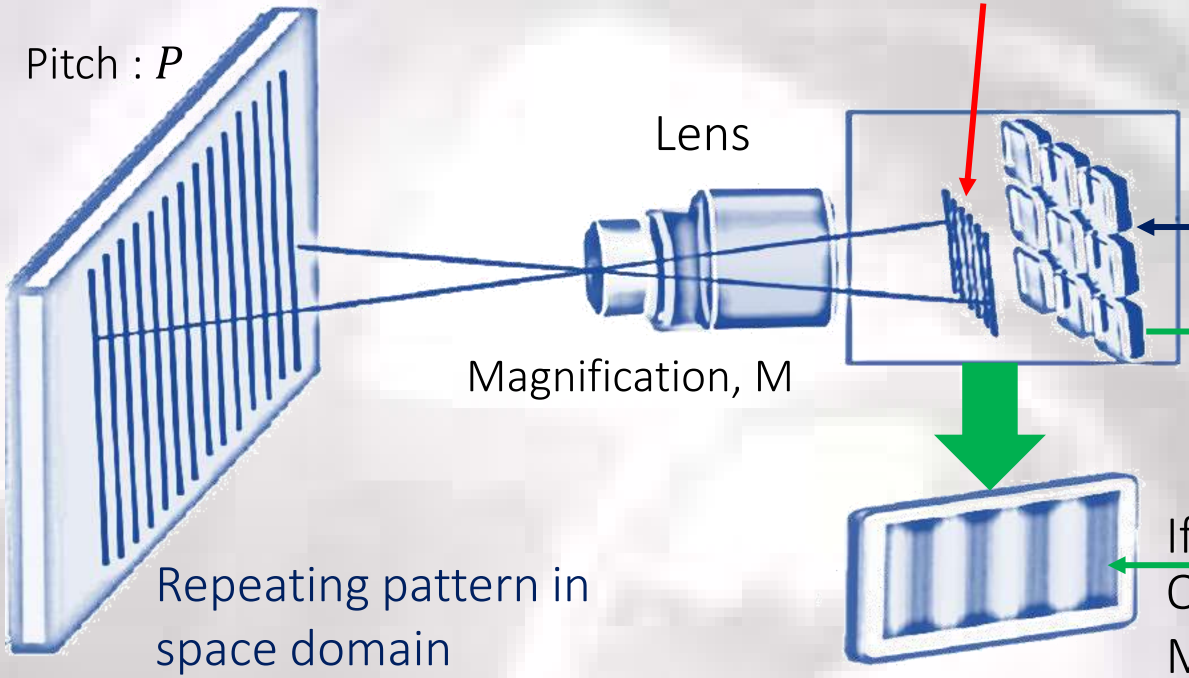


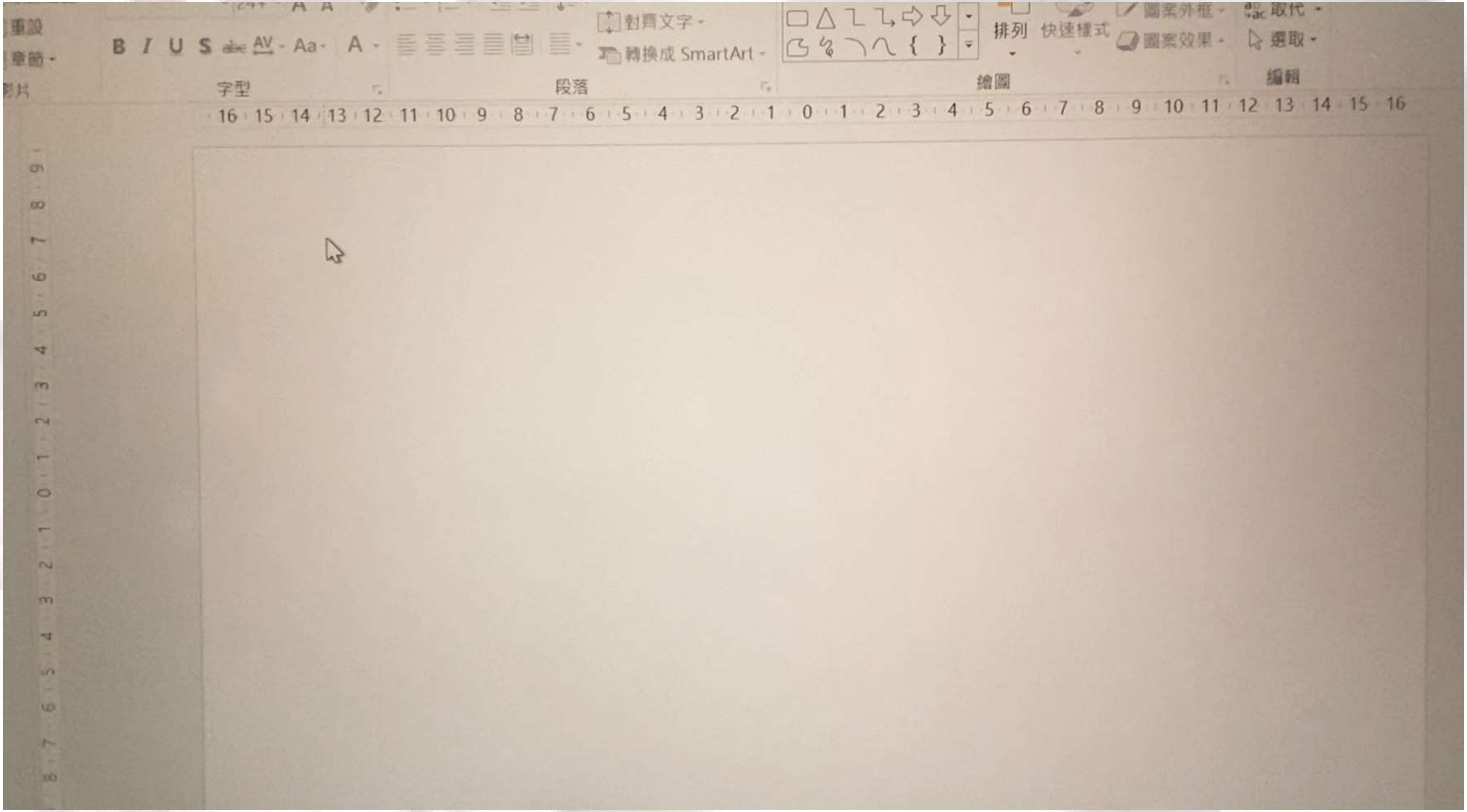
Image of LCD taken by iPhone 6 plus



Possible ways to reduce the moiré effects:

1. Rotating the camera or the object to different angle might can minimize the moiré effect;
2. Change the position of the camera (changing the image height)
3. Change the focus;
4. Replacing a lens with a different focal length

https://www.smartheadshots.com/blog/articles/how-to-dress-for-business-headshots.html


重設
章節
影片
字型
段落
對齊文字
轉換成 SmartArt
排列
快速樣式
圖案外框
圖案效果
繪圖
取代
選取
編輯

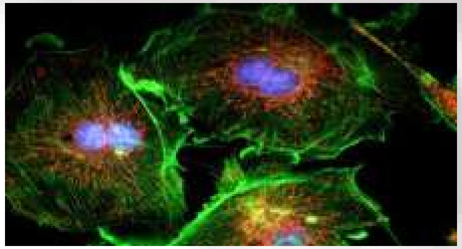
Can CCD survive?

Based on Applications

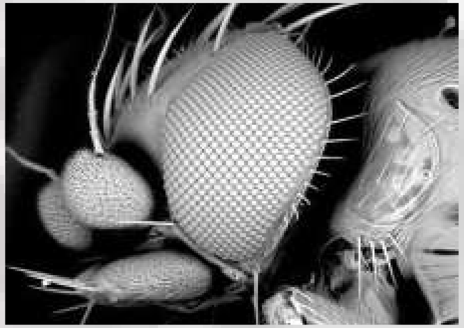
Acquisition with minimal noise Low light intensities

1. Microscopy
   - Fluorescence microscopy
   - High resolution microscopy
2. Astronomy (long exposure time)
3. High resolution and high quality images
4. Bioluminescence / Chemoluminescence
5. Science
   - Knowing collected data well

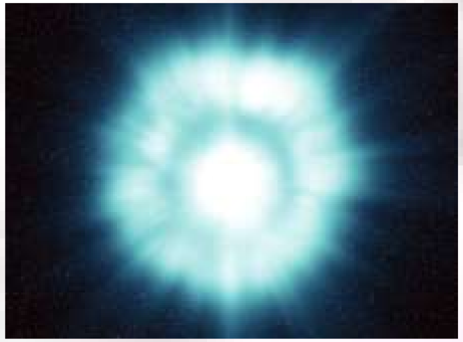
https://docplayer.net/22764114-Which-sensor-or-interface-suits-for-which-application-jurgen-bretschneider-2015.html



Fluorescence microscopy

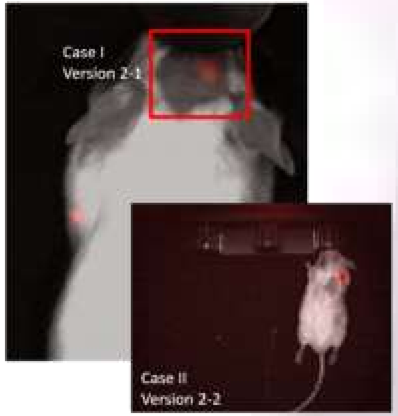


High resolution microscopy



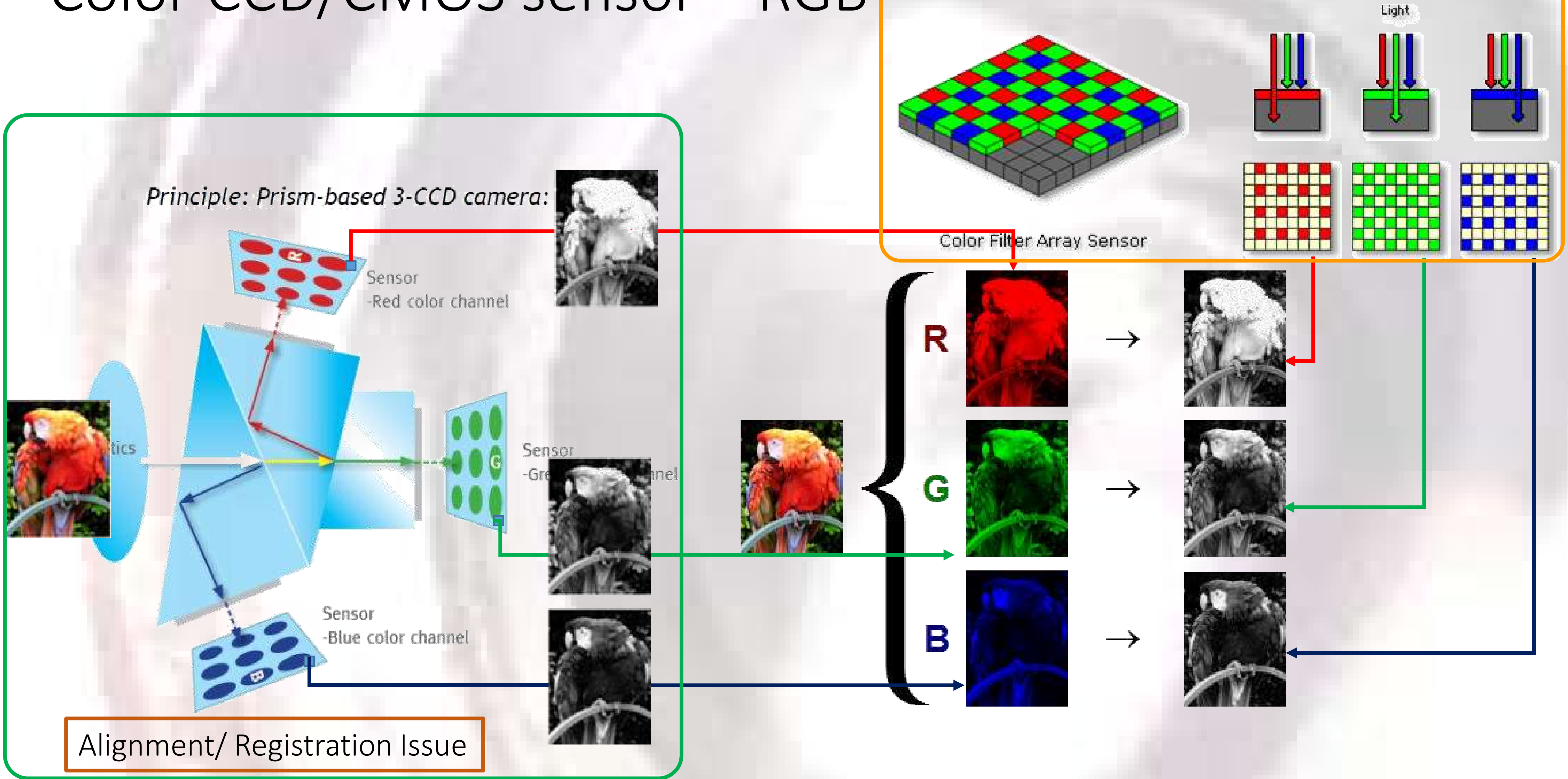
Long exposure time

High resolution and high quality images



Bioluminescence

Color CCD/CMOS sensor—RGB



Spatial Resolution/ Interpolation

Principle: Prism-based 3-CCD camera:

Alignment/ Registration Issue

What you see is Different from CCD/CMOS sensors

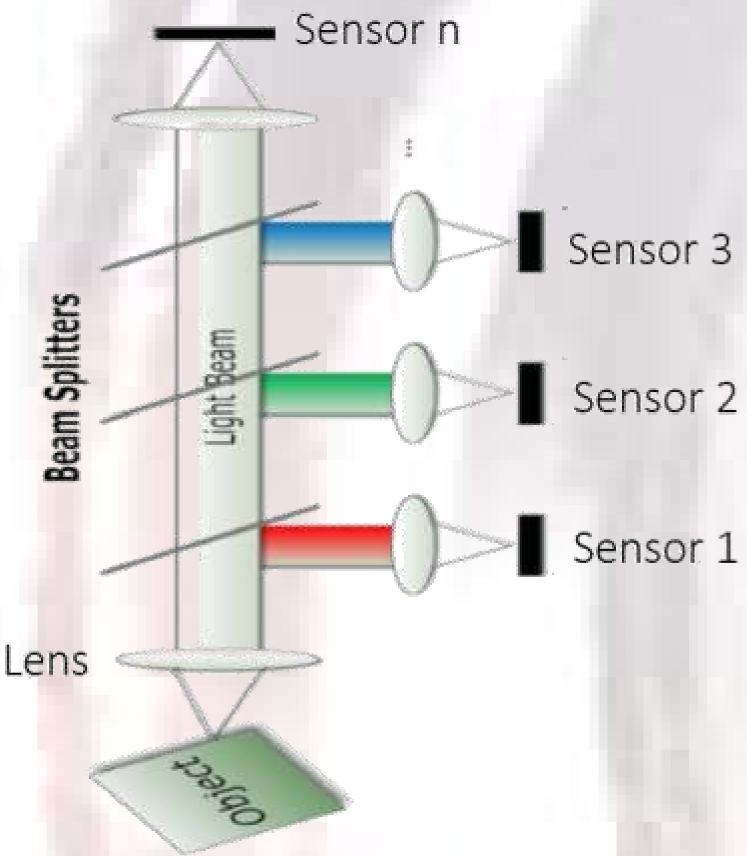
Picture taken by CCD sensor with IR-cut in front of sensor removed

Snow?

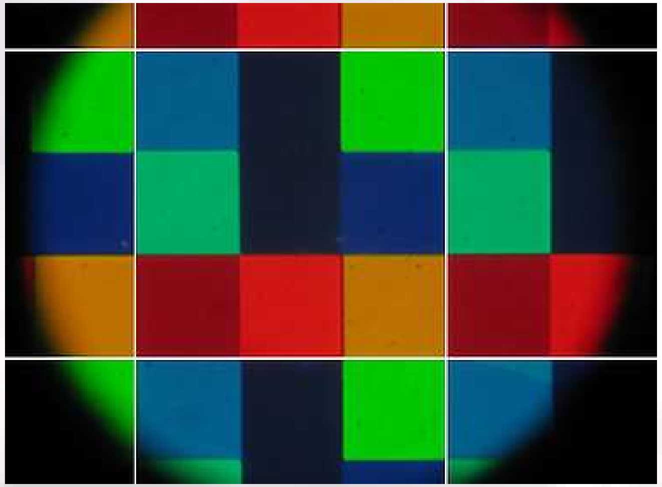
Picture source: Instrument Technology Research Center, NARLabs

Picture source: Dr. Te-I Cheng

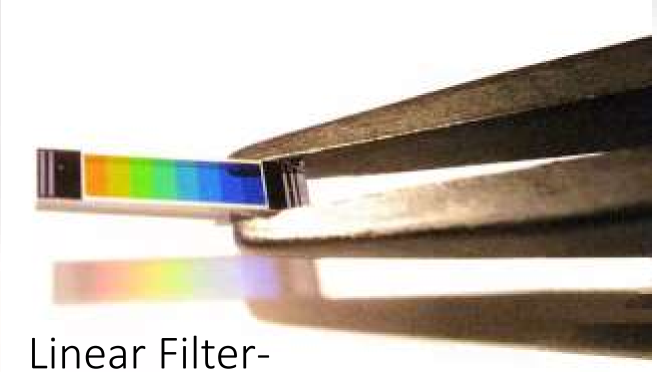
Devices for implementing multispectral imagers



Multi-Sensors

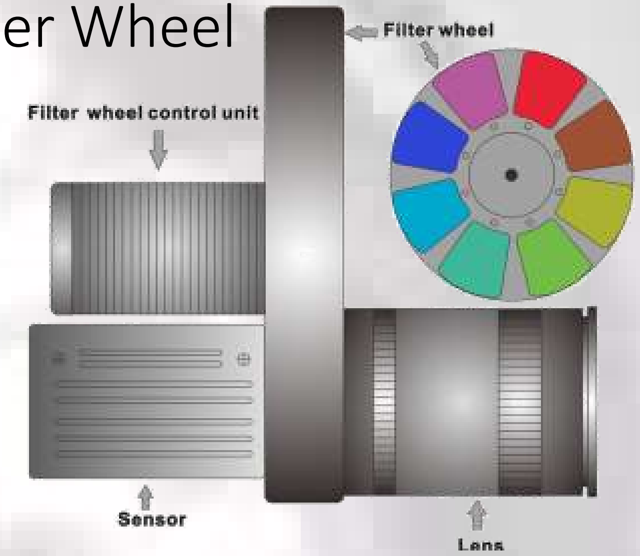


Mosaic Filter-
Spatial interpolate (demosaic) Required

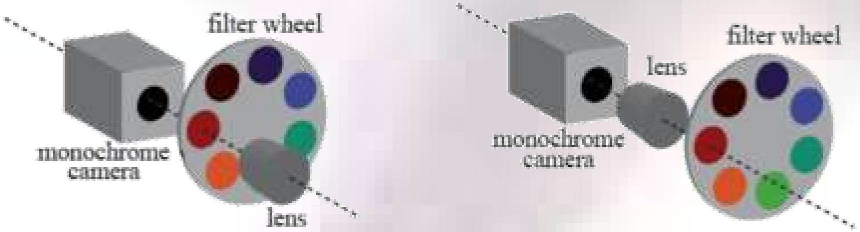


Linear Filter-
Scanning mechanism Required

Filter Wheel

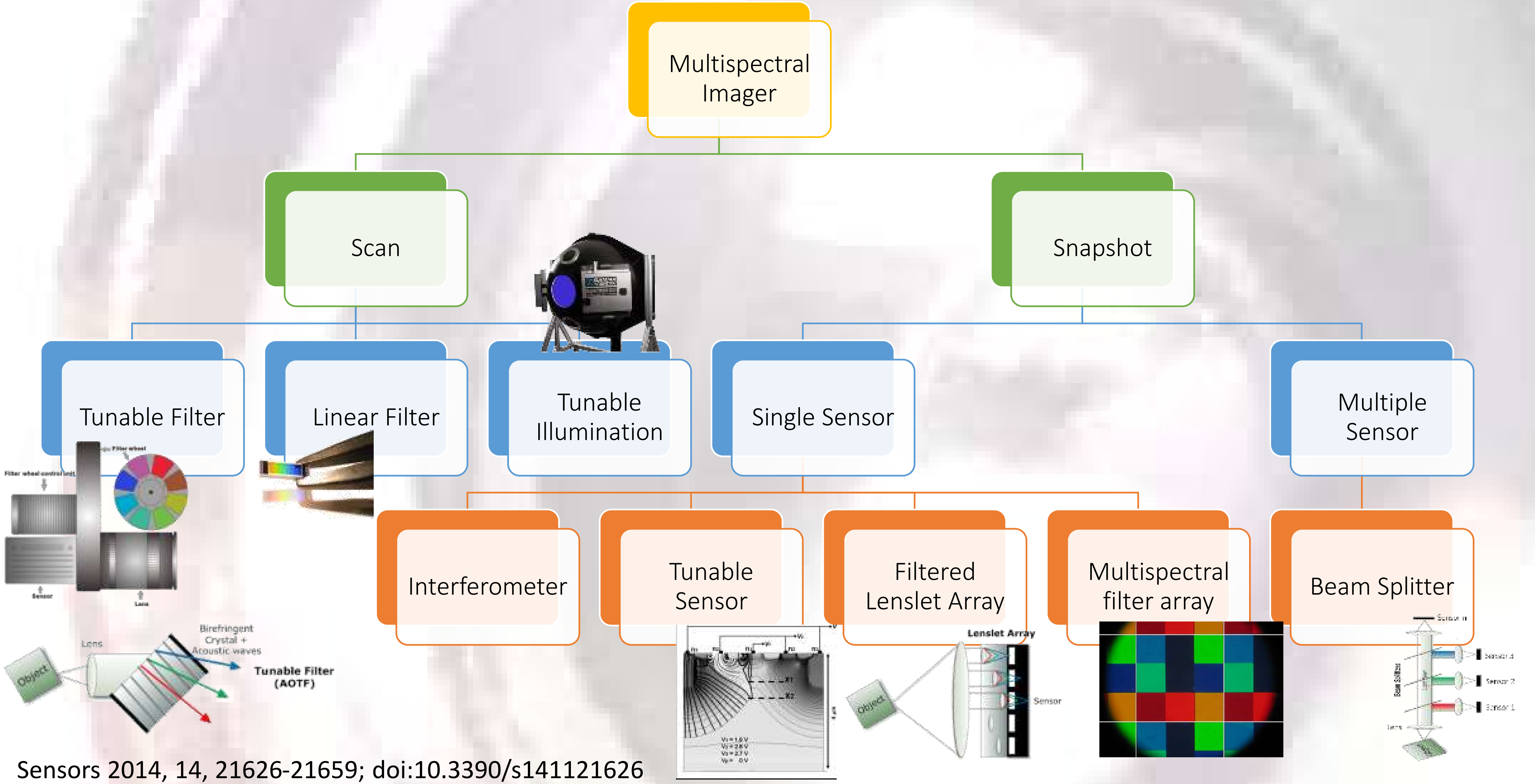


Typical Motorized Filter Wheel



Wheel can be located in front/ beyond of optical Lens

Peng Xu, Peng Xu, Haisong Xu,"Filter selection based on light source for multispectral imaging," Optical Engineering 55(7), 074102, 2016; doi:10.1117/1.OE.55.7.074102
Julie Klein, "Multispectral imaging and image processing", Proc. SPIE 9019, Image Processing: Algorithms and Systems XII, 90190Q,2014; doi: 10.1117/12.2048565
https://www.silios.com/multispectral-imaging

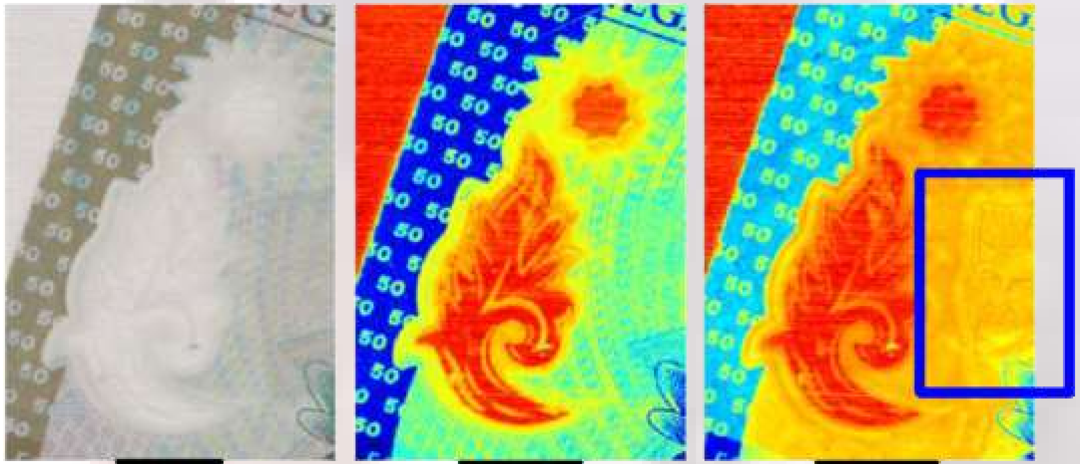


- Multispectral Imager
  - Scan
    - Tunable Filter
    - Linear Filter
    - Tunable Illumination
  - Snapshot
    - Single Sensor
      - Interferometer
      - Tunable Sensor
      - Filtered Lenslet Array
      - Multispectral filter array
    - Multiple Sensor
      - Beam Splitter

Sensors 2014, 14, 21626-21659; doi:10.3390/s141121626

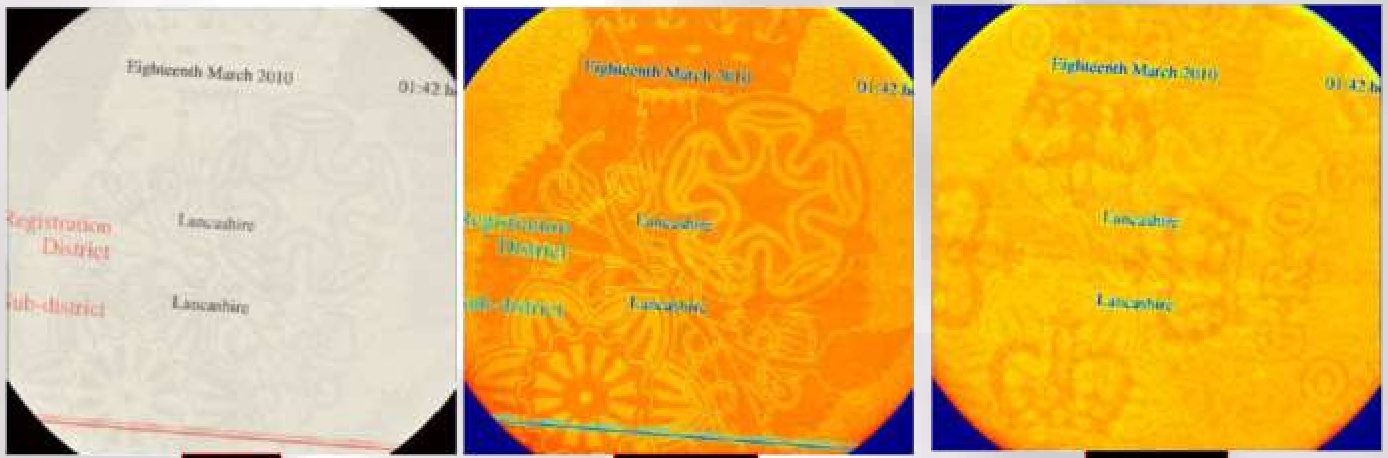
Applications of Multispectral imager

Security



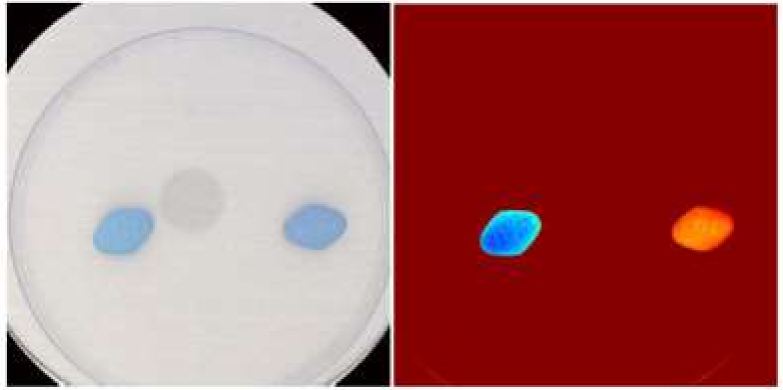
RGB 375nm 870nm

Watermarks

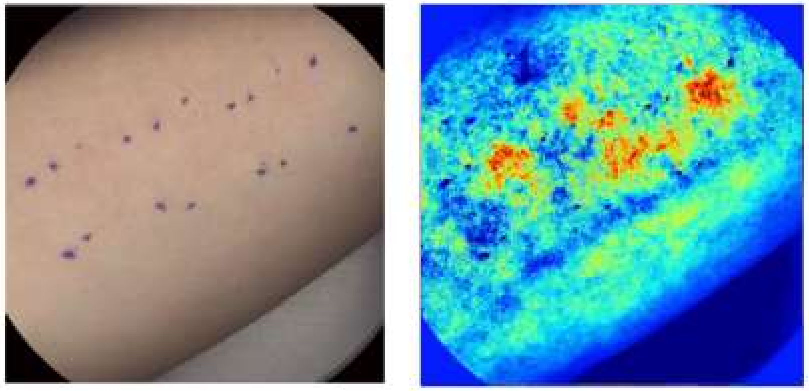


RGB 405nm 660nm

Counterfeit Drugs



Allergen testing



Comprising Multispectral/ Hyperspectral Imagers

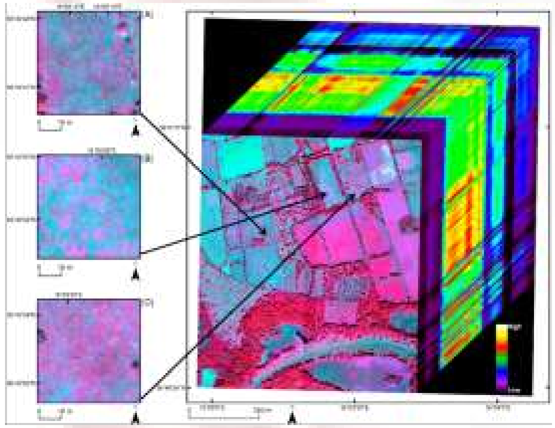
Spectral Image
→
$I(x, y, \lambda)$
Knowing as Data Cube

Multispectral Image (MI)

HSI generally captures tens to hundreds of spectral bands while multispectral imaging has much less bands.

Hyperspectral Image (HSI)

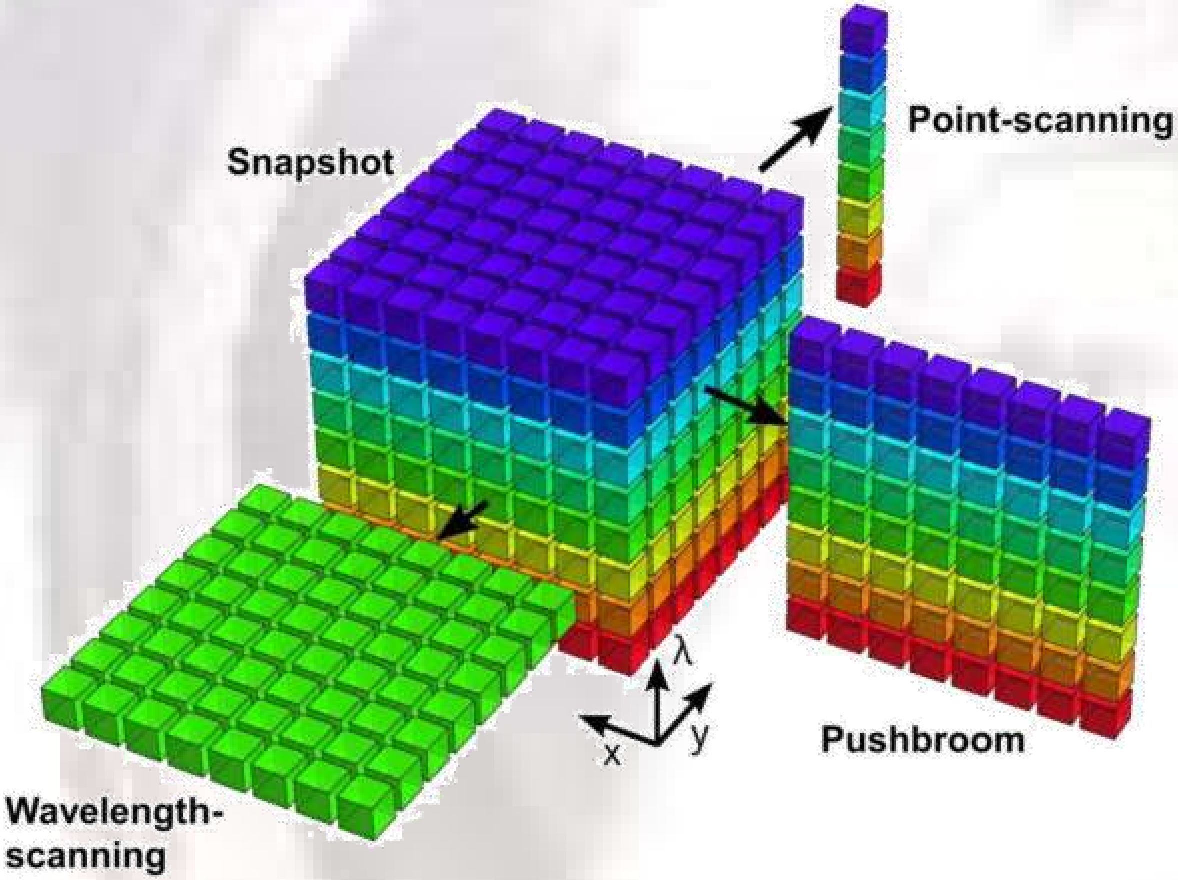
HSI continuously measures the spectrum while multispectral imaging normally acquires non-continuous, spaced spectral bands



Ref: DOI: 10.3390/rs6087732

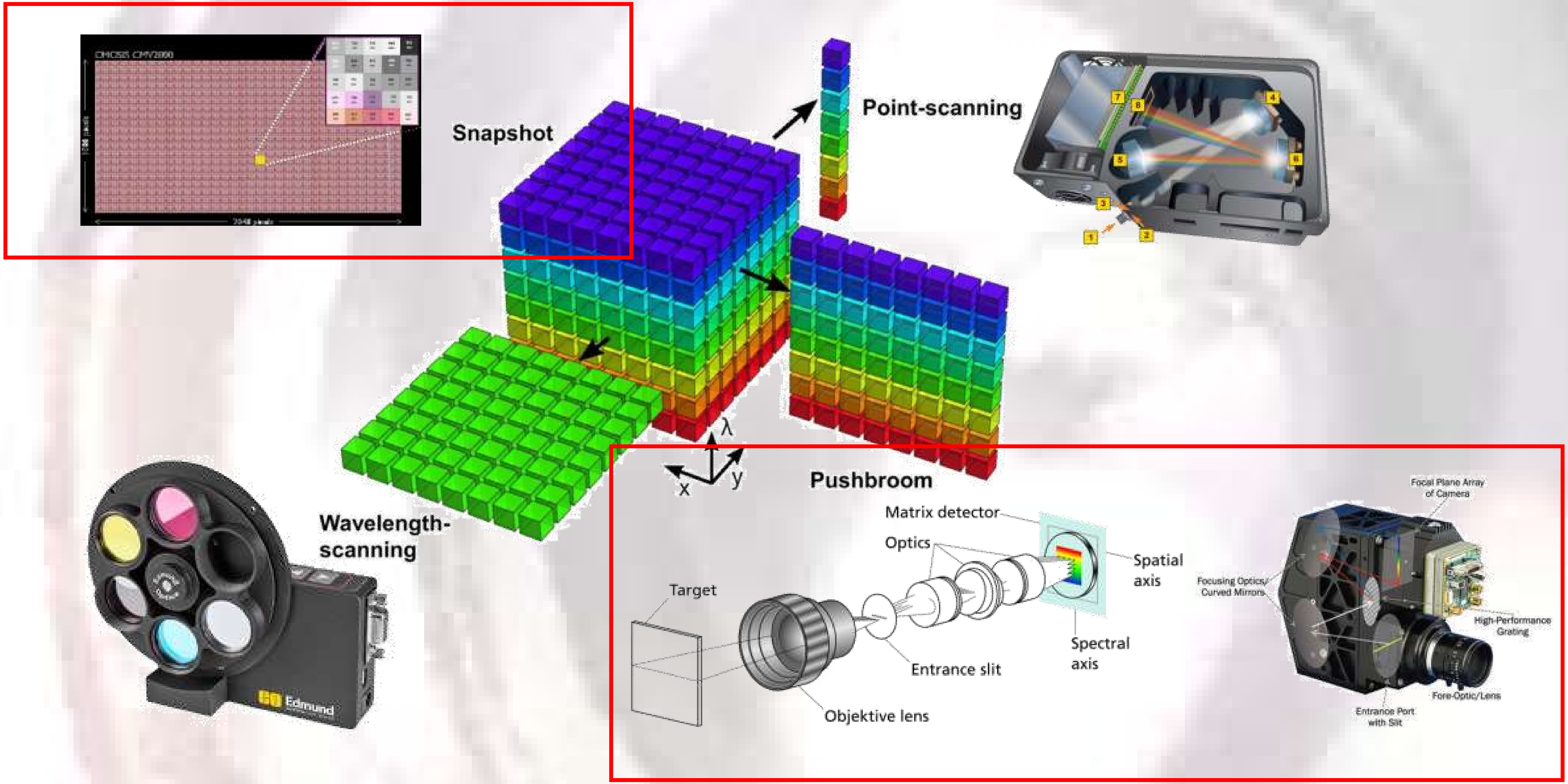
What you see is Different from CCD/CMOS sensors

Strategic for Generating Data Cube



Ref: DOI: 10.3390/rs6087732

Core Devices for Generating Data Cube



Design of a classical hyperspectral imaging camera with grating

Gratings/prims

- → long distance between a sensor and diffractive element
- → large instrument
- → misalignment caused by mechanical influences

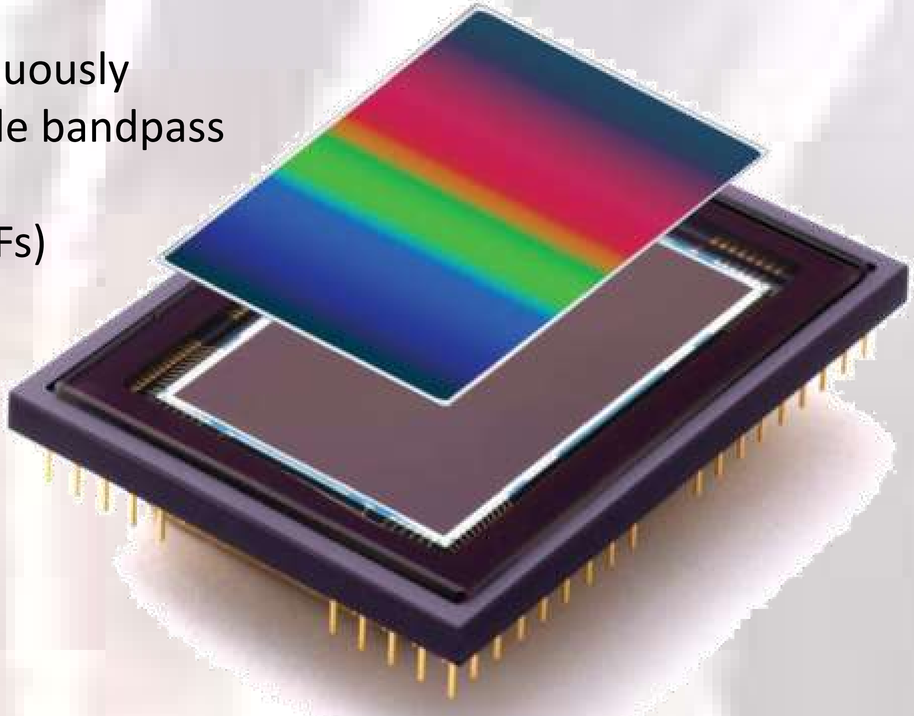
Slit (to obtain high spectral resolution)

- → limits the light throughput
- → signal-to-background light level is typically not better than 1000:1

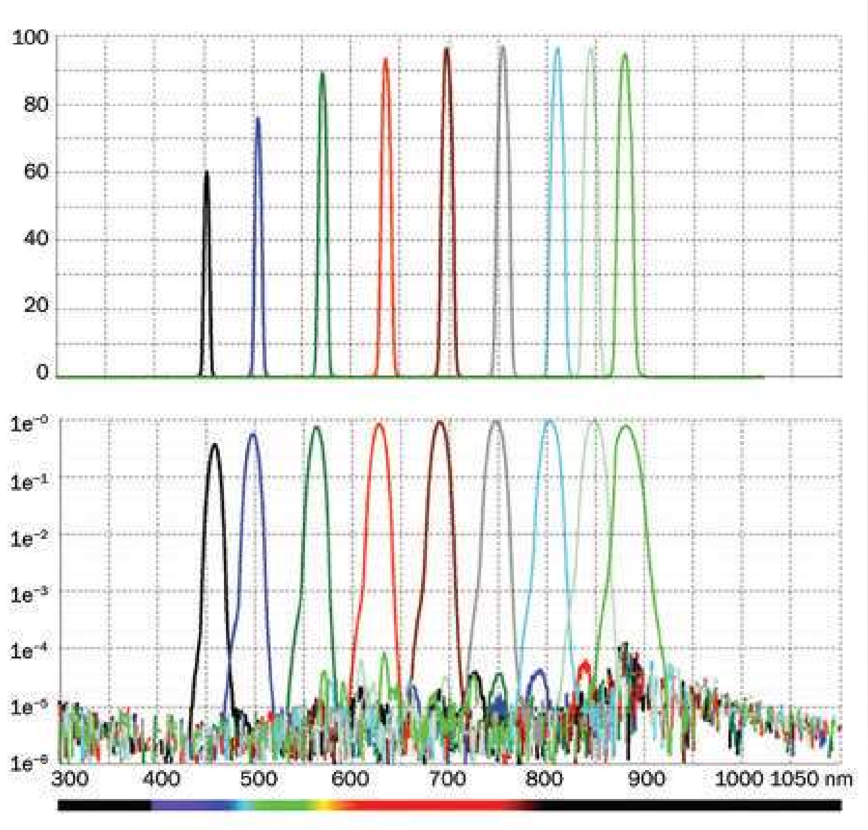
OLIVER PUST, HENRIK FABRICIUS, “Continuously Variable Bandpass Filters Aid Optics and HIS,” Photonics Spectra, pp. 51-55, June 2018

Continuously Variable Bandpass Filters Aid Optics and HSI

Continuously variable bandpass filters (CVBPFs)



wavelength range of 450 to 880 nm with a bandwidth of approximately 2 percent of its center wavelength.

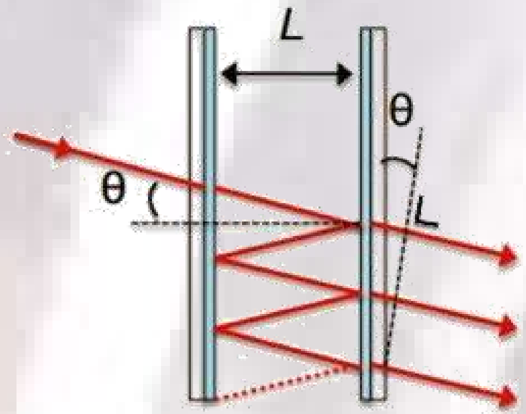


Transmission and blocking characteristics of a linear variable bandpass filter.

These micropatterning techniques allow for filters that have a staircase of different center wavelengths in one direction (also called stepped filters), suited for the pushbroom technique, or 2D mosaics, which are suited for the snapshot technique.

OLIVER PUST, HENRIK FABRICIUS, “Continuously Variable Bandpass Filters Aid Optics and HIS,” Photonics Spectra, pp. 51-55, June 2018

Fabry-Perot Spectral Filter—imec’s approach

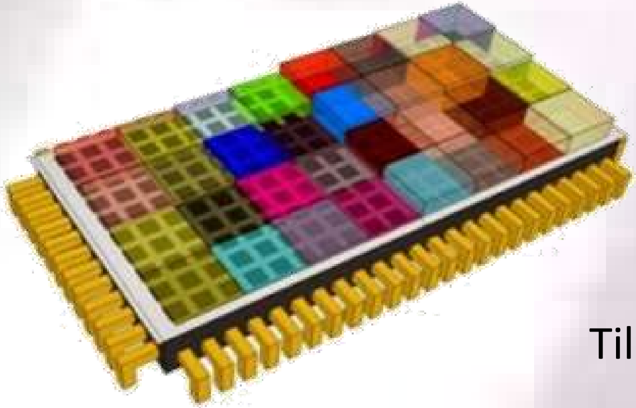


Wavelength selection depends on cavity length L

$$k\lambda = 2nL\cos\theta$$

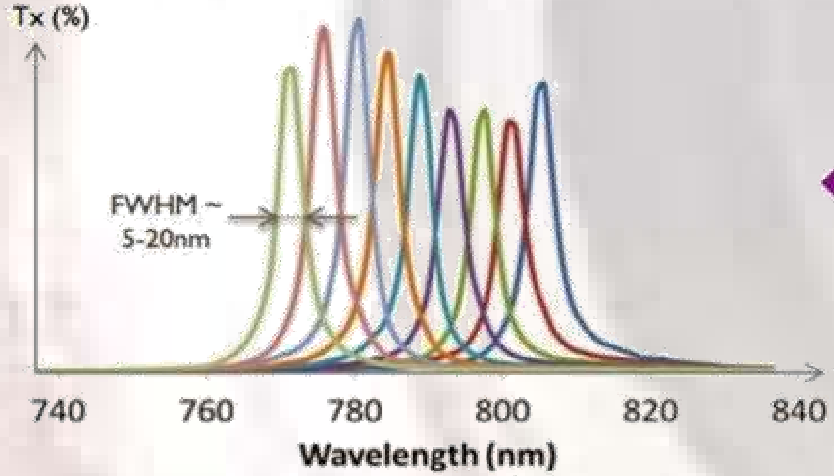
Discussion—
Why Fabry-Perot?

Different cavity heights = different spectral wavelengths captured!

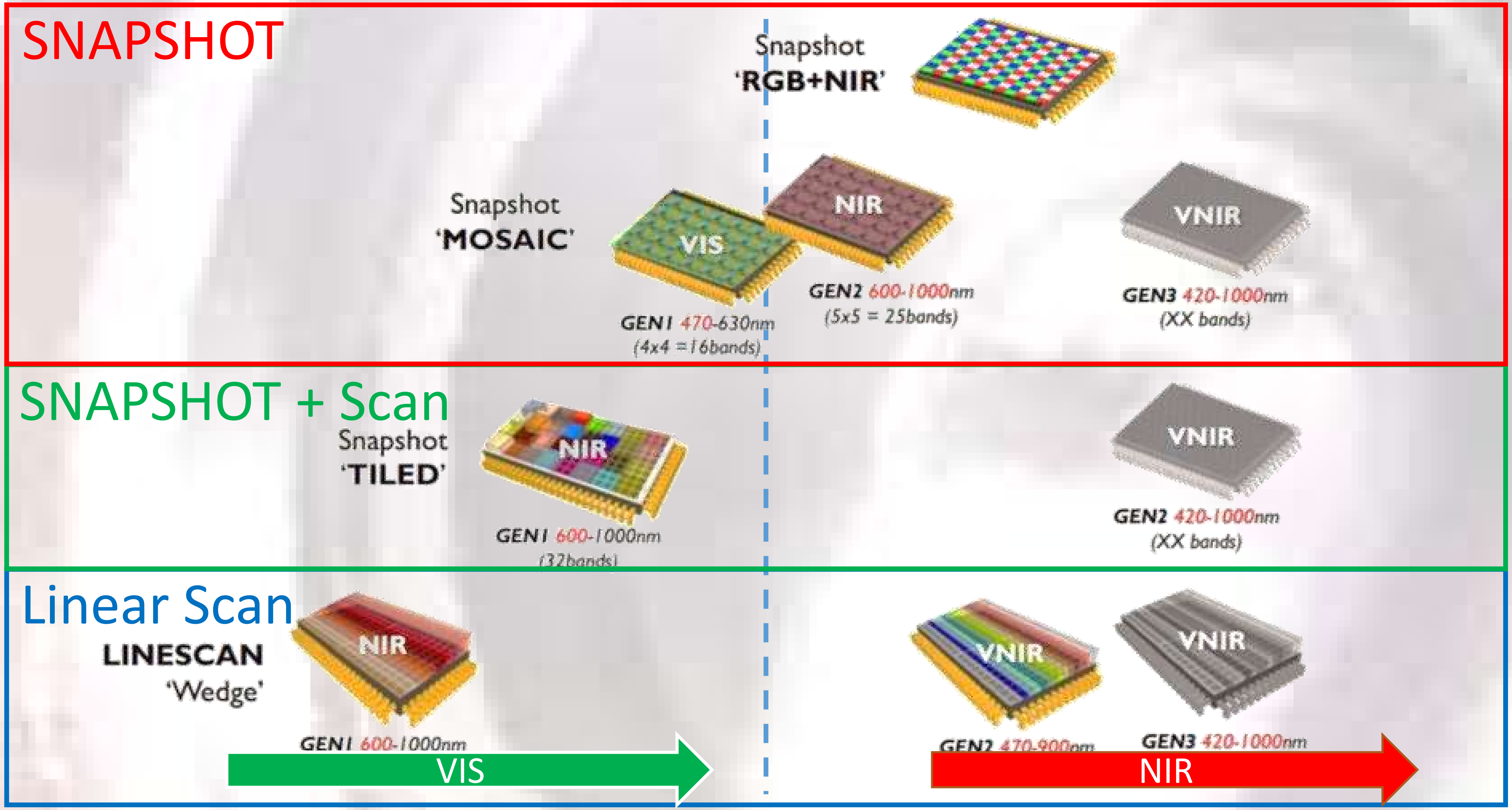


Tiled Sesnor Design

Narrow-band & high transmission efficiencies spectral filters



Sensor Technologies Associated with HSI—
based on imec's roadmap


SNAPSHOT

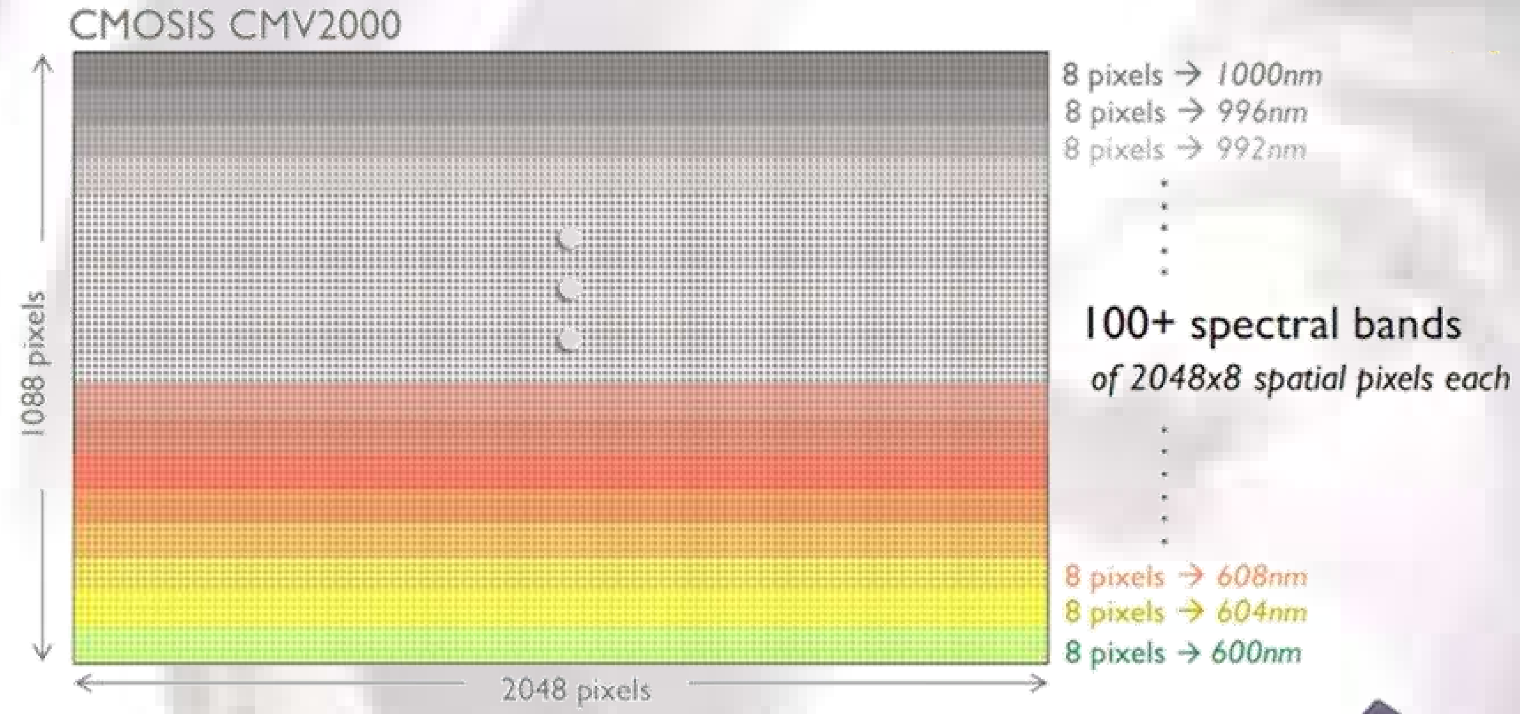
SNAPSHOT + Scan

Linear Scan

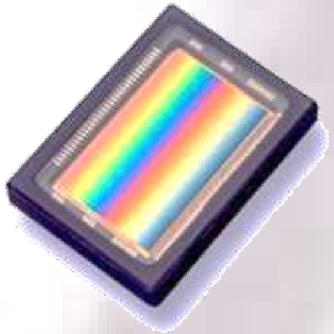
VIS

NIR

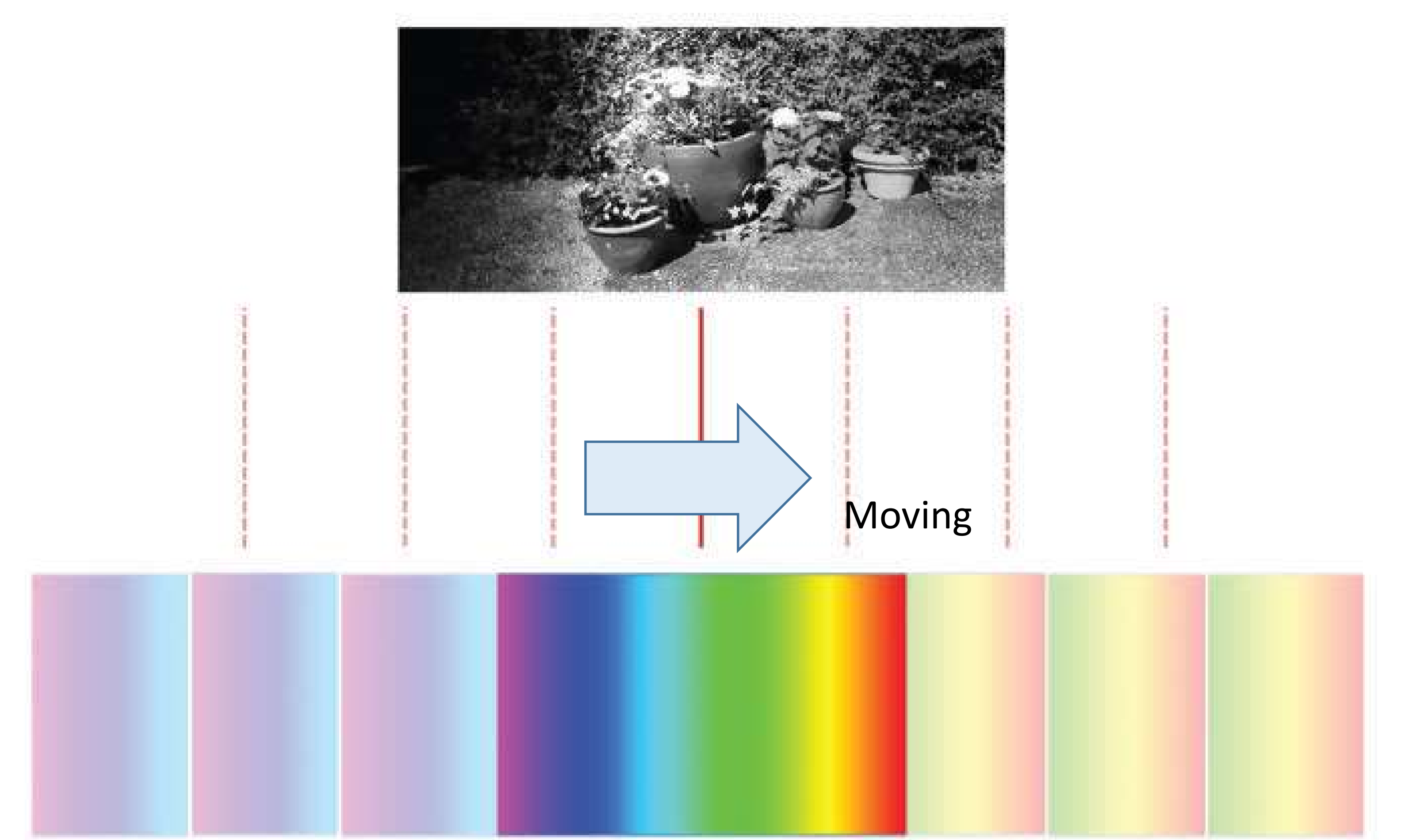
Typical Linear Scan HSI Sensor Design—imec



- Key specifications
  - **Spectral resolution**: 128 bands in 600-1000nm
  - **FWHM**: ~ 10-12nm
  - **Spatial resolution**: 2048 pixels x length of scan
  - **Speed**: up to 340 fps (full sensor frame)

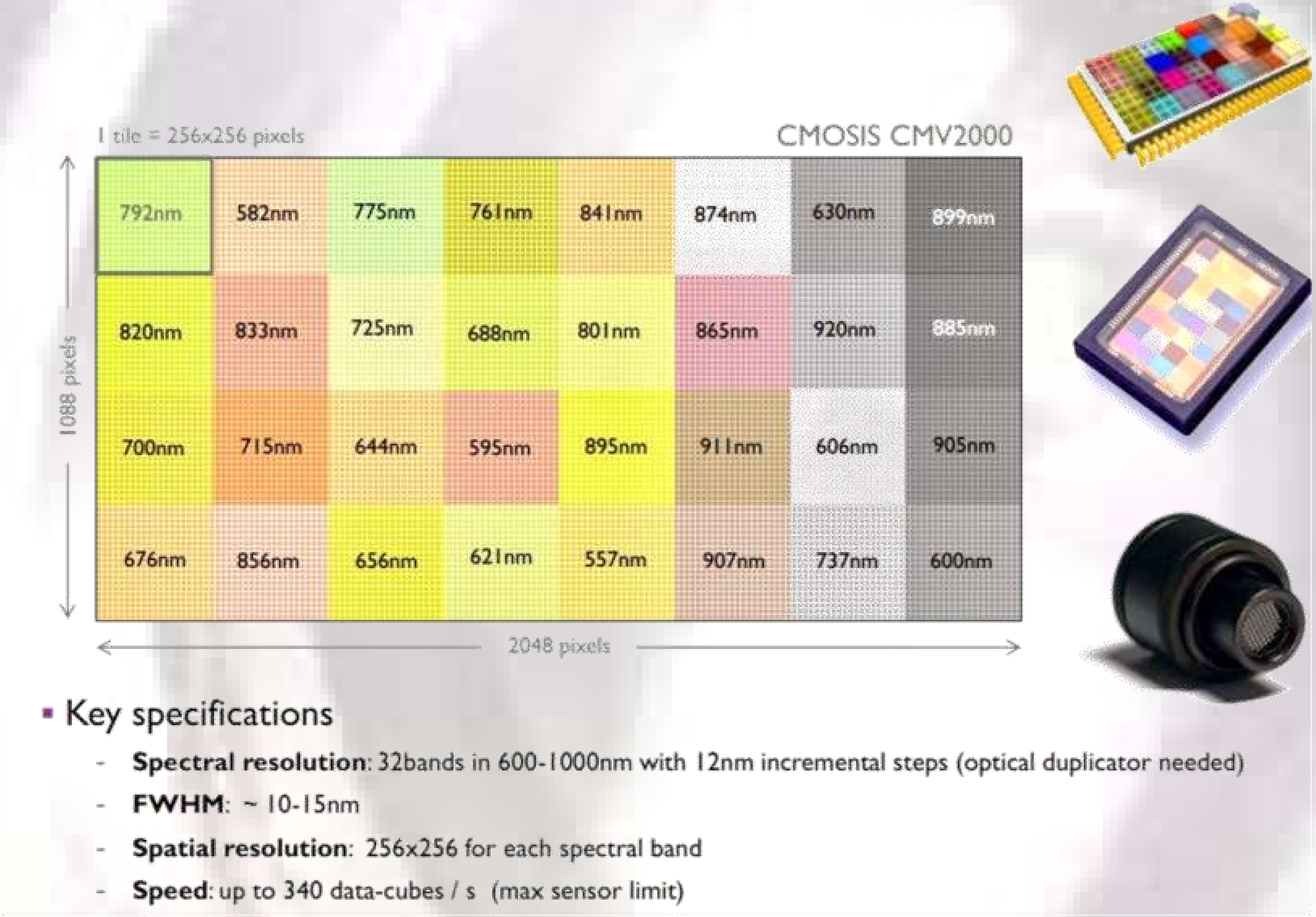


Relative movement between the camera and object enables 3D hyperspectral imaging –Linear Scan HIS sensor



OLIVER PUST, HENRIK FABRICIUS, “Continuously Variable Bandpass Filters Aid Optics and HIS,” Photonics Spectra, pp. 51-55, June 2018

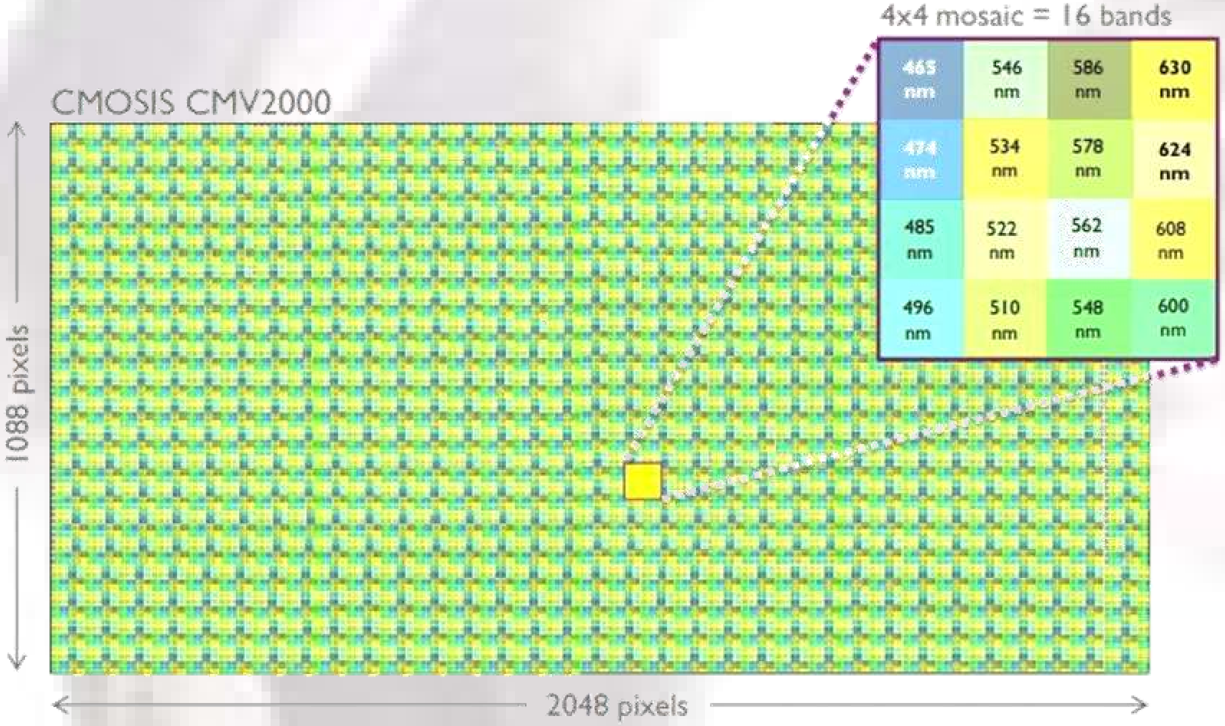
Snapshot HSI with Tiled Sensor Format



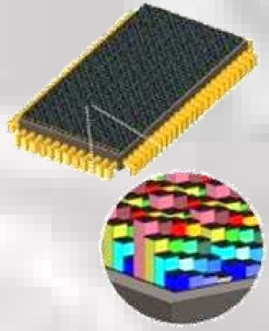
792nm	582nm	775nm	761nm	841nm	874nm	630nm	899nm
820nm	833nm	725nm	688nm	801nm	865nm	920nm	885nm
700nm	715nm	644nm	595nm	895nm	911nm	606nm	905nm
676nm	856nm	656nm	621nm	557nm	907nm	737nm	600nm

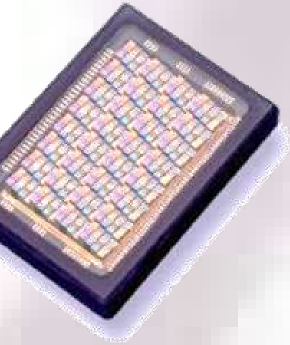
- Key specifications
  - **Spectral resolution**: 32bands in 600-1000nm with 12nm incremental steps (optical duplicator needed)
  - **FWHM**: ~ 10-15nm
  - **Spatial resolution**: 256x256 for each spectral band
  - **Speed**: up to 340 data-cubes / s (max sensor limit)

Snapshot HSI with Mosaic Sensor Design



465 nm	546 nm	586 nm	630 nm
474 nm	534 nm	578 nm	624 nm
485 nm	522 nm	562 nm	608 nm
496 nm	510 nm	548 nm	600 nm





- Key specifications
  - **Spectral resolution**: 4x4 mosaic (1filter / pixel) = 16bands in 470-630nm
  - **FWHM**: ~ 15nm
  - **Spatial resolution**: from 512x272 (RAW per band)
  - **Speed**: up to 340 data-cubes / s (max sensor limit)