CAMERA & FRAME GRABBER TECHNOLOGY

Enrico Bravin - CERN BE/BI

9th DITANET topical workshop
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TAKING AN IMAGE

- Object / Source (illumination)
- Optics
- Sensor
- Digitizer
- Post processing

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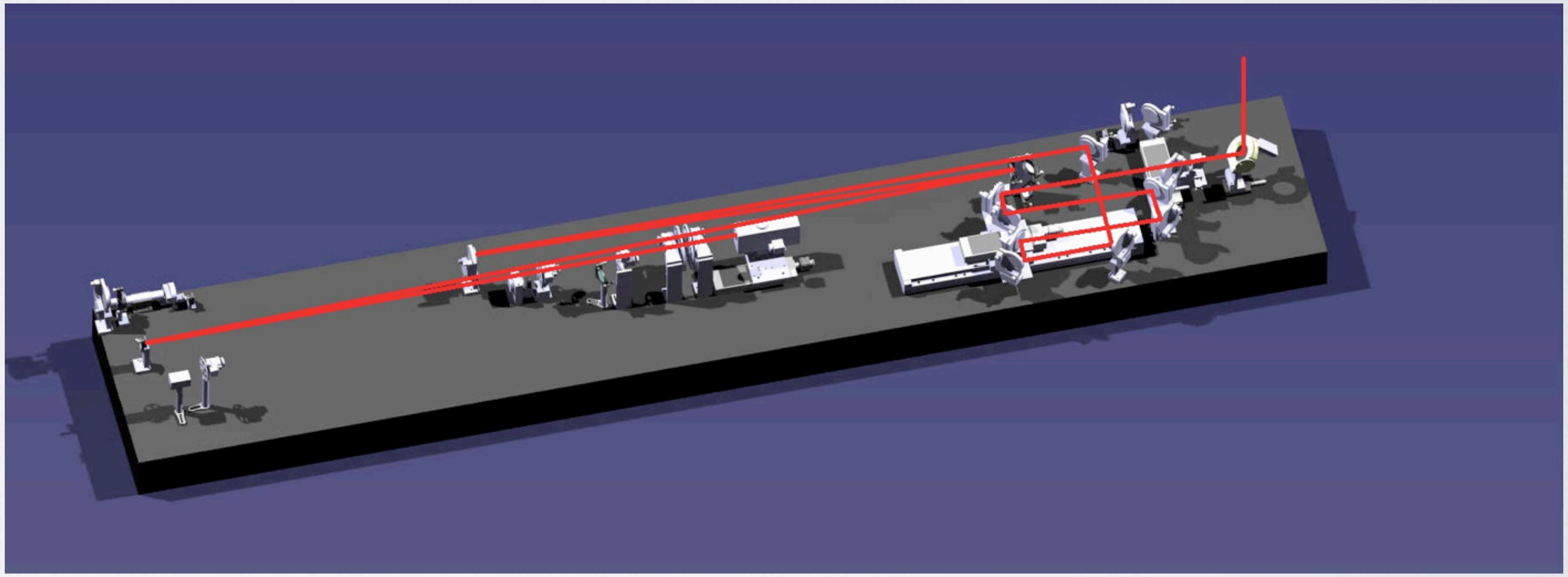

IMAGING FOR BEAM DIAGNOSTICS

- Difficult light conditions
- IR / UV light
- Small objects (compared to object/sensor distance)
- Fast shutter speed (synchronized)
- High frame rate
- Radiation environment

IMAGE SENSORS

- Convert light into electric signals with a monotone and well defined relation between light intensity and output signal
- Provide information on the spatial distribution of light on image plane (eventually for different colors)

TYPE OF SENSORS

- CCD
- CMOS
- CID
- Video tubes

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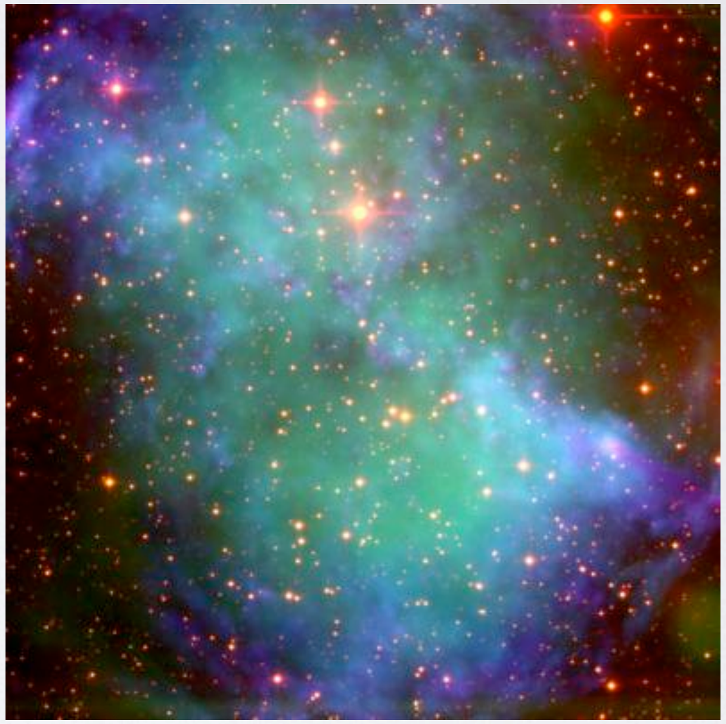

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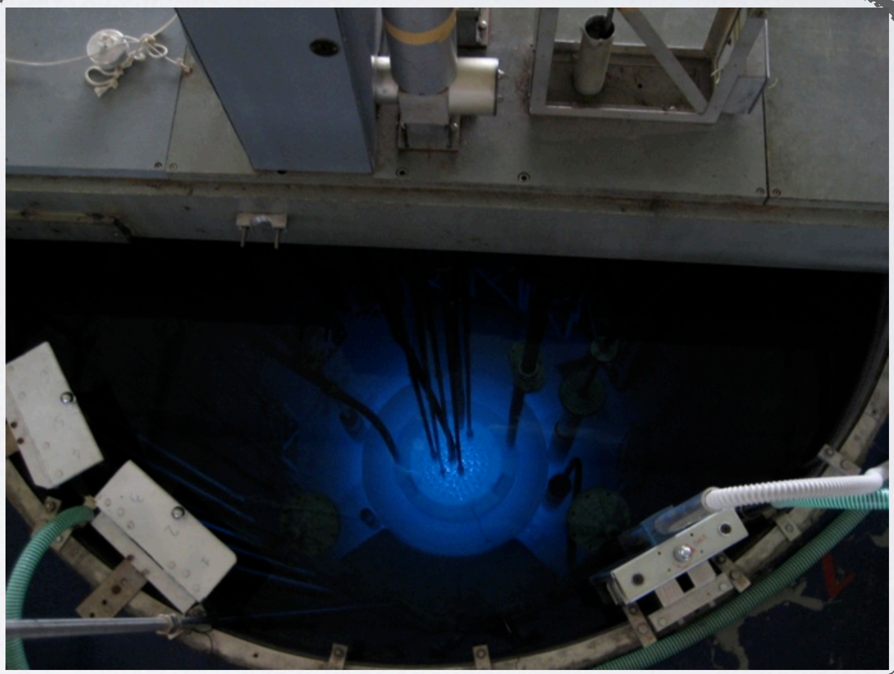

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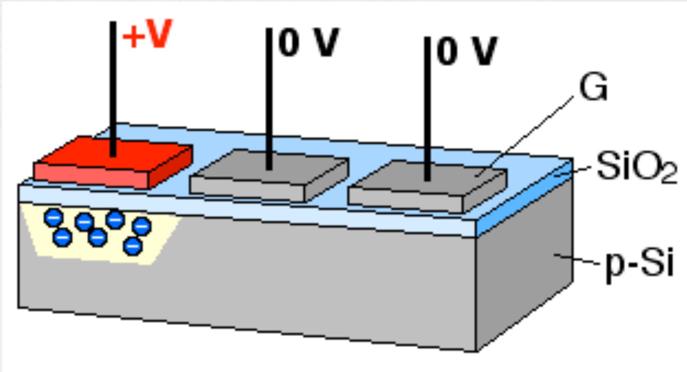
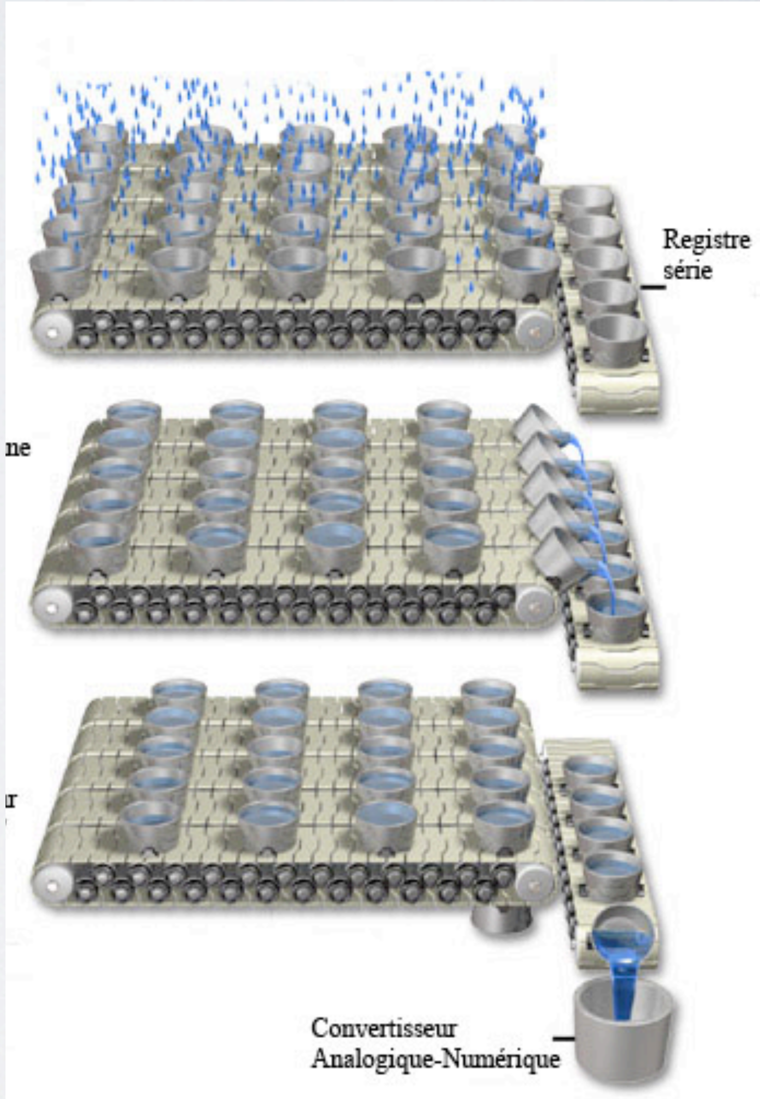
CCD

- Charge-Coupled Device
- Invented in 1969 by W.Boyle and E.Smith (AT&T Bell Labs) who got a Nobel prize for it
- Based on MOS capacitors
- Principle still the same, but technology refined a lot in the past 40 years

CCD PRINCIPLE

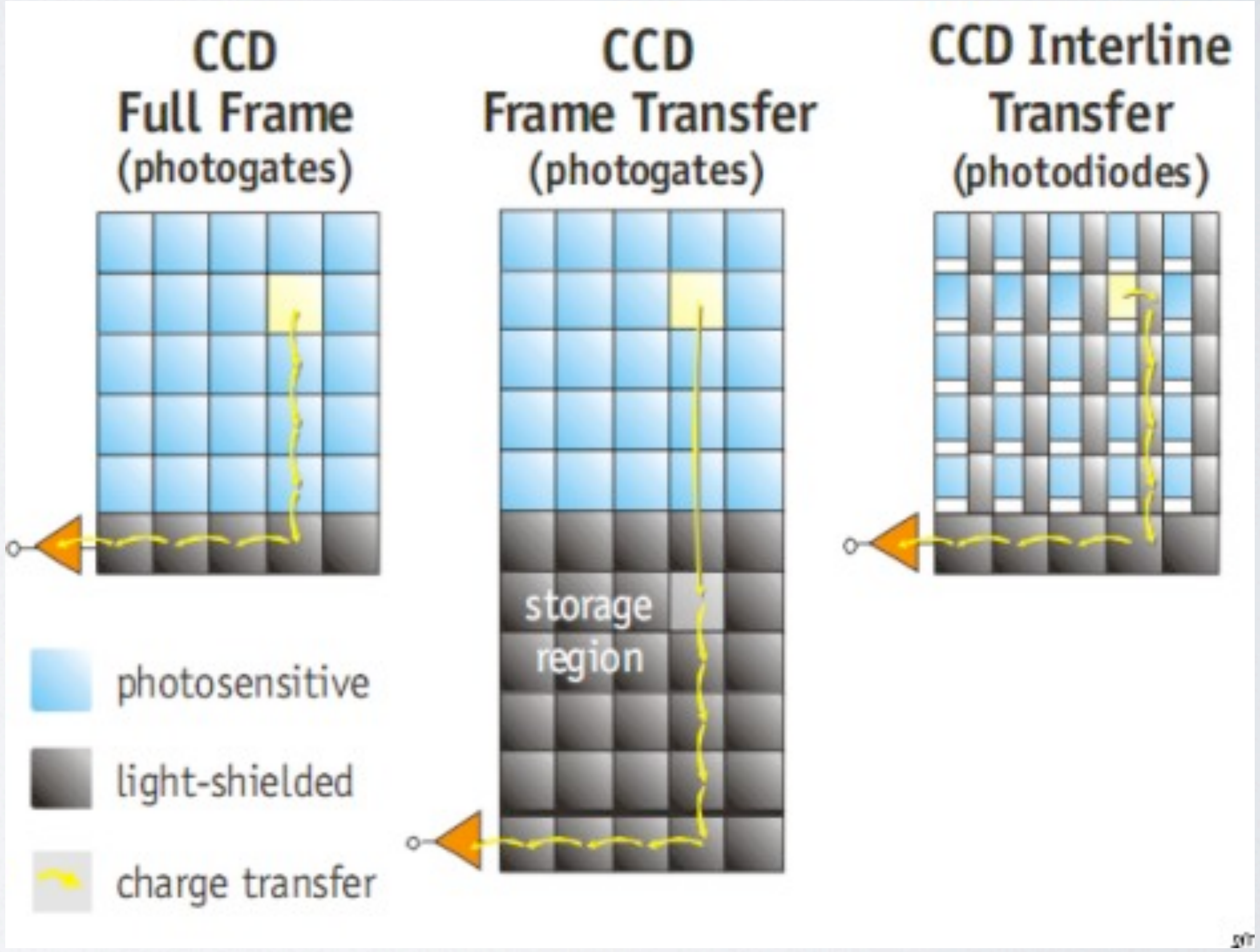
- Electrons are collected below the electrode
- The charge is shifted towards the readout by shifting the voltage on the electrodes (like in a linear motor)





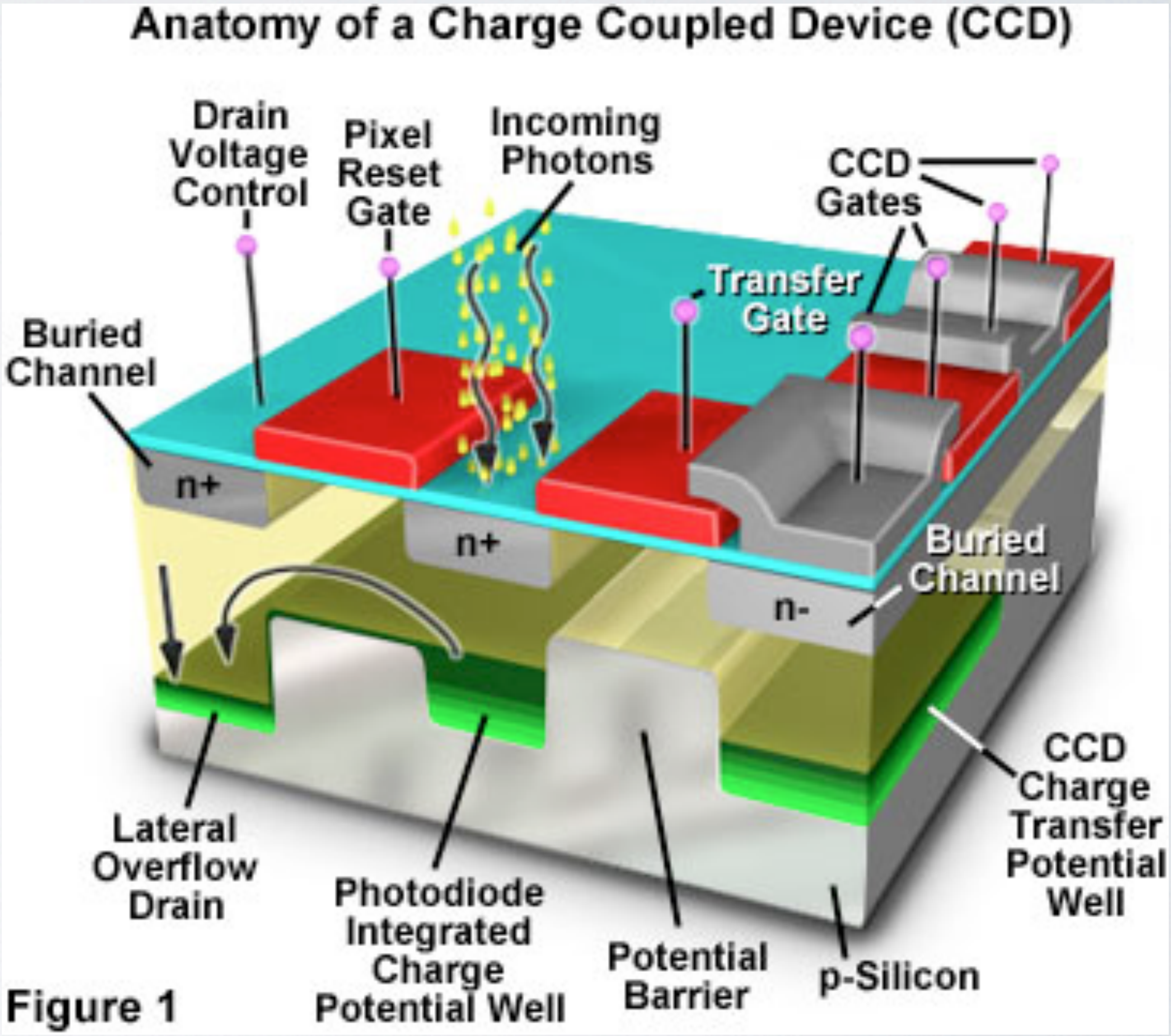
TYPES OF CCD

- Full frame requires an external shutter, strobed light or long integration times
- Interline CCD can provide electronic shutter down to few us
- (iCCD, EMCCD, EBCCD)



MODERN INTERLINE CCD

- Light is detected by a pinned photodiode (like C-MOS)
- Based on a n- buried channel (avoid defects in the Si-SiO_2 interface)



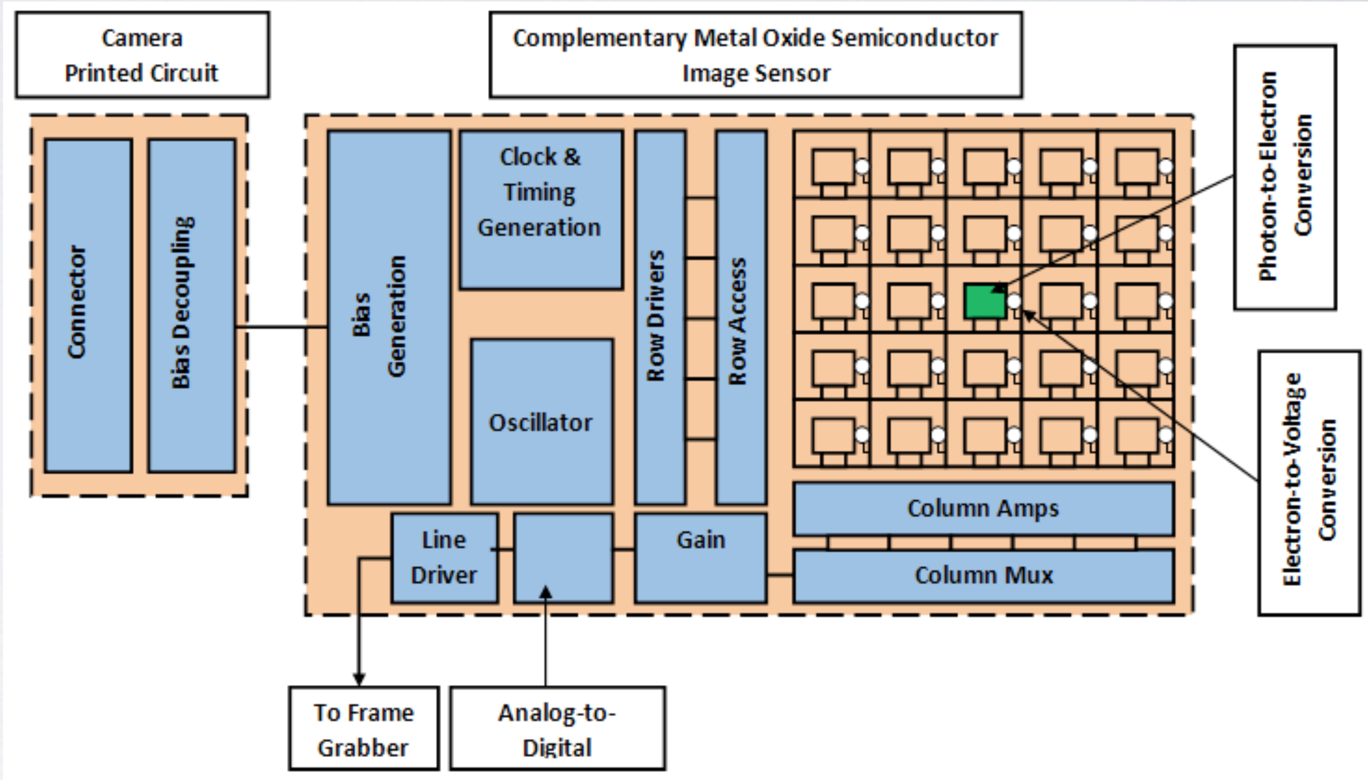
CMOS SENSORS

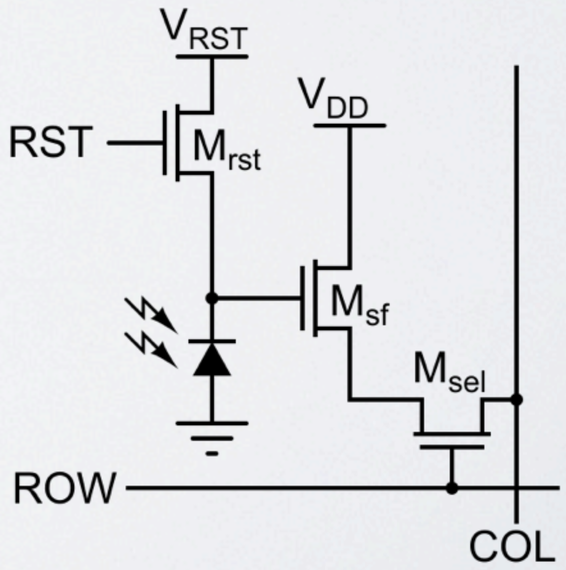
- Invented around 1968 by P. Noble
- Based on active pixels (CMOS transistors)
- Each pixel can be addressed separately (ROI, high speed)
- Not a match for CCDs until recent improvements in the CMOS technology (driven mainly by memory and CPUs)
- Replacing the CCD as the dominant type of sensors

CMOS APS

- The "standard" configuration of a CMOS pixel consist of a pinned photodiode a 3 CMOS transistors

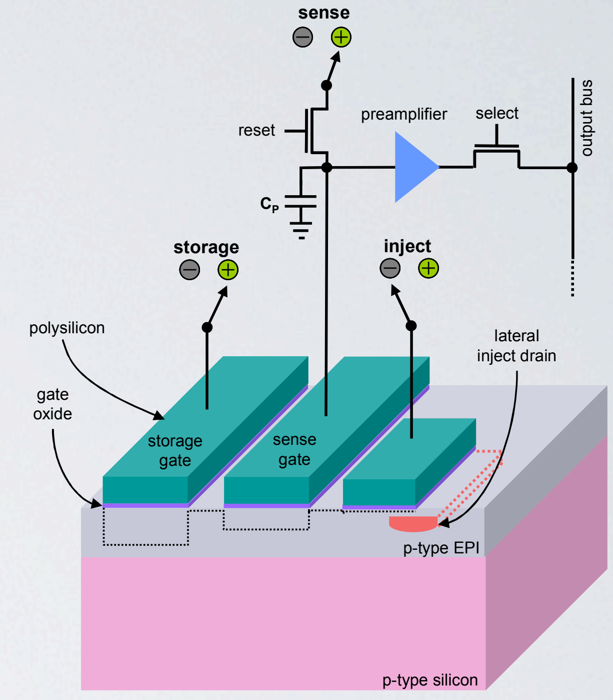
- Large fraction of the pixel is (was) occupied by the transistors



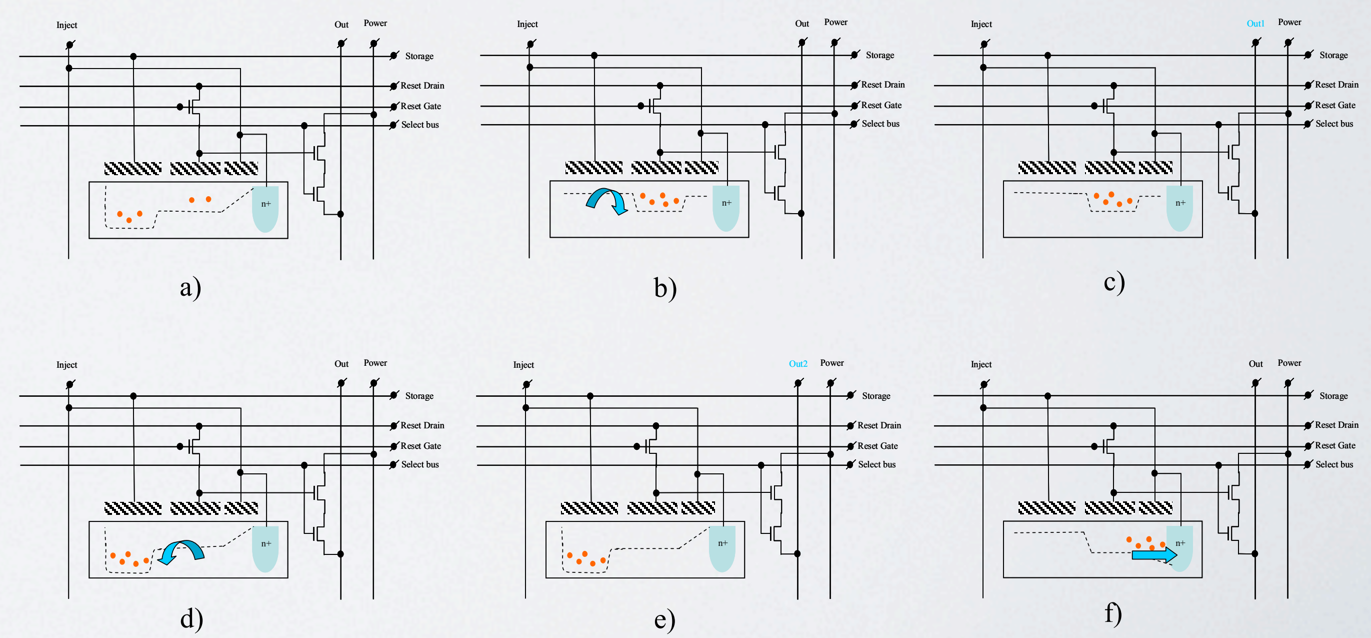


CID SENSORS

- Invented in 1973 by H.Burke and G. Michon of General Electric



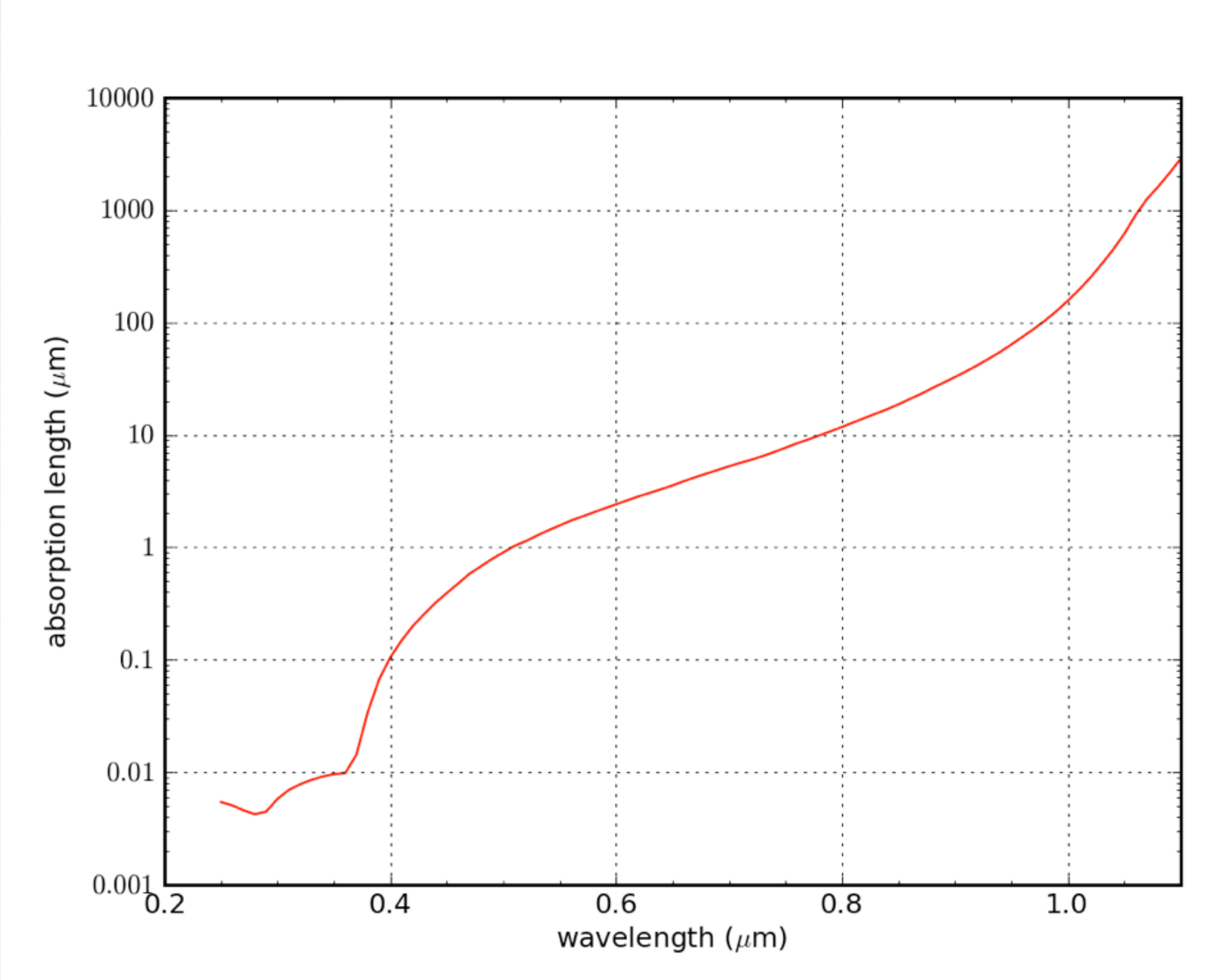
- Commercially developed by CIDTEC (now Thermo Fisher Scientific)



- Radiation hard (p type Si)

LIGHT ABSORPTION IN SILICON

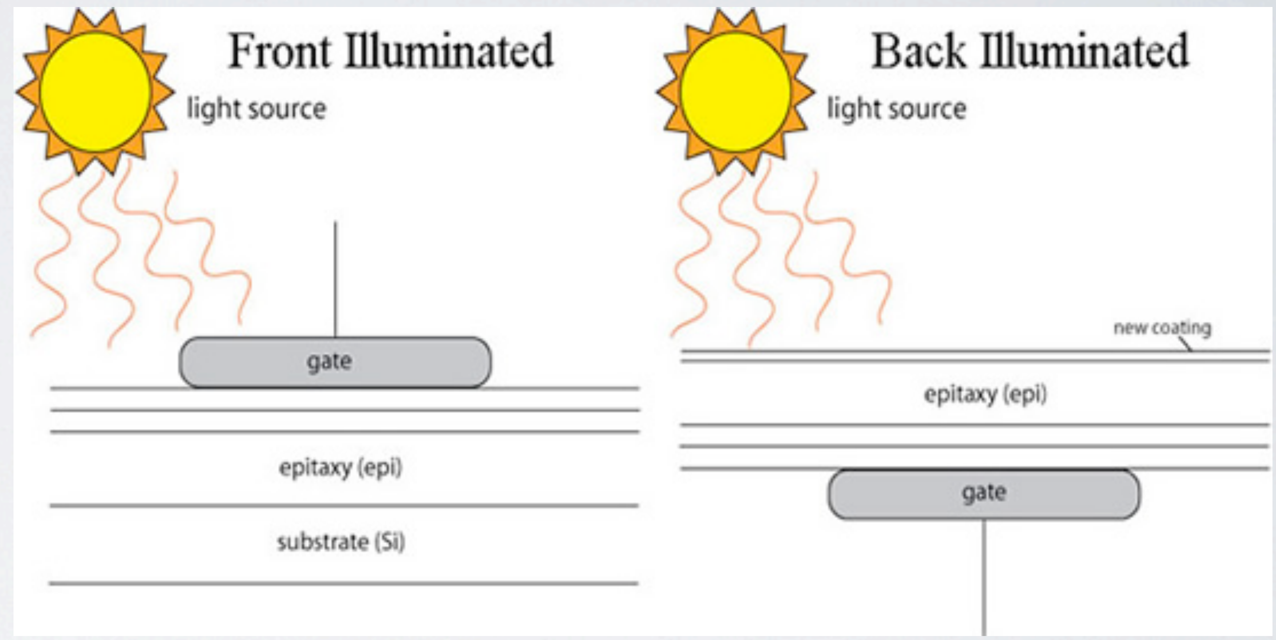
- Above 800nm light is not absorbed in the epitaxial layer
- Below 400nm the light is absorbed in the gates and oxides above the sensitive area

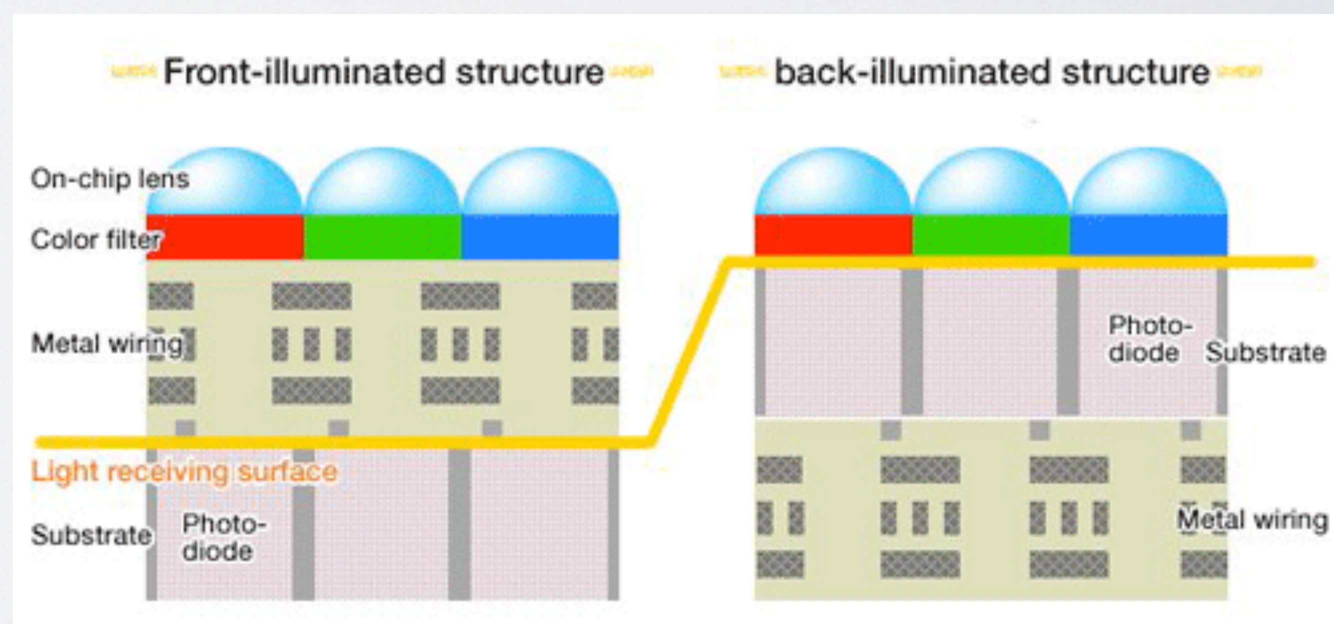


BACK THINNED SENSORS

- Back thinned CCD have been around for a while to extend sensitivity to above 1000nm and below 400nm

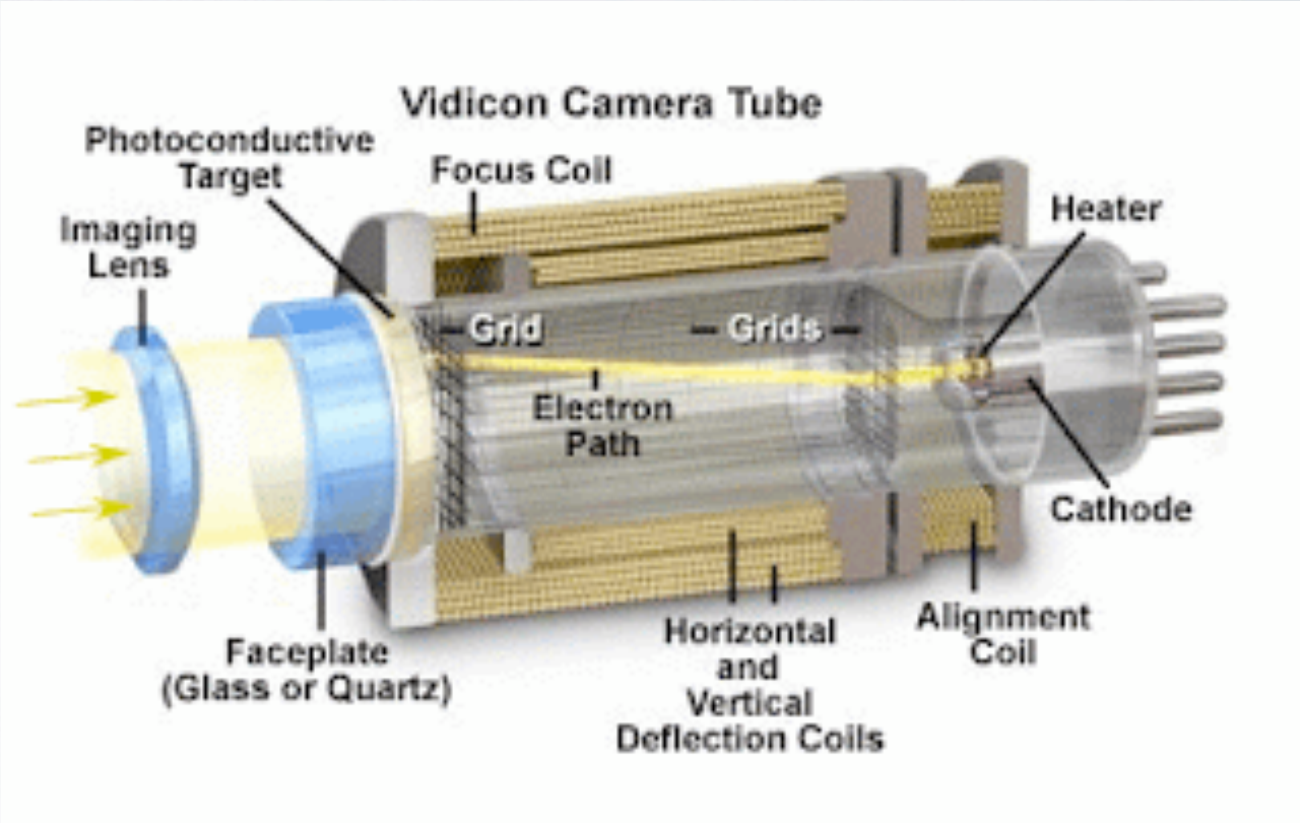
- Back thinned CMOS are quite recent and make up for the small fill factor





VIDEO TUBE

- First device for electronic acquisition of images
- Base on photoconductivity of a thin film
- Induced charge read out by a pencil electron beam
- Tube itself is very radiation hard



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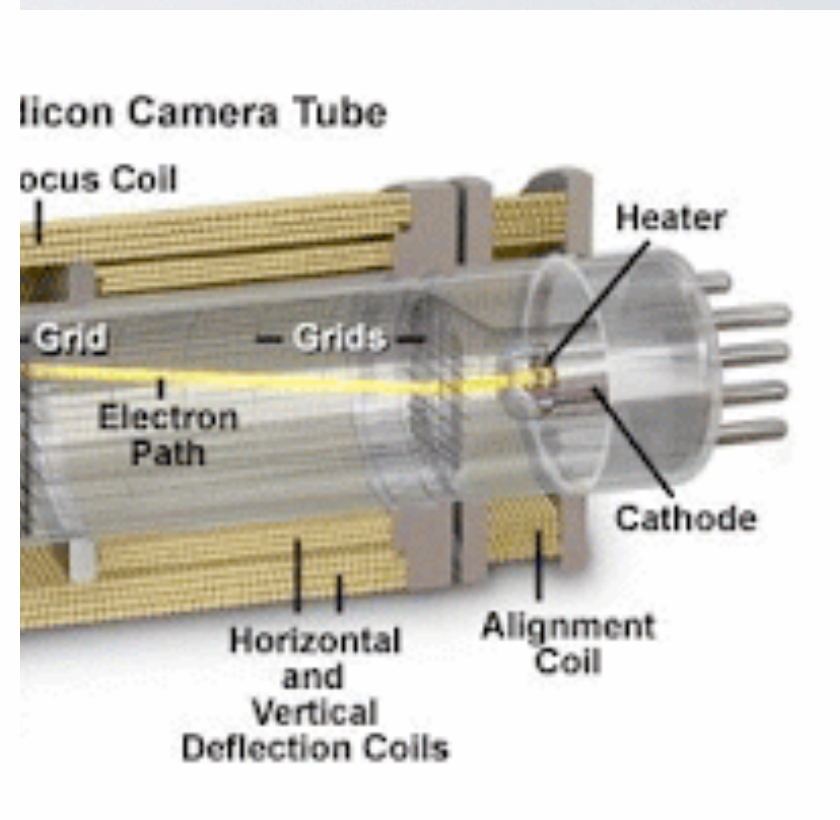
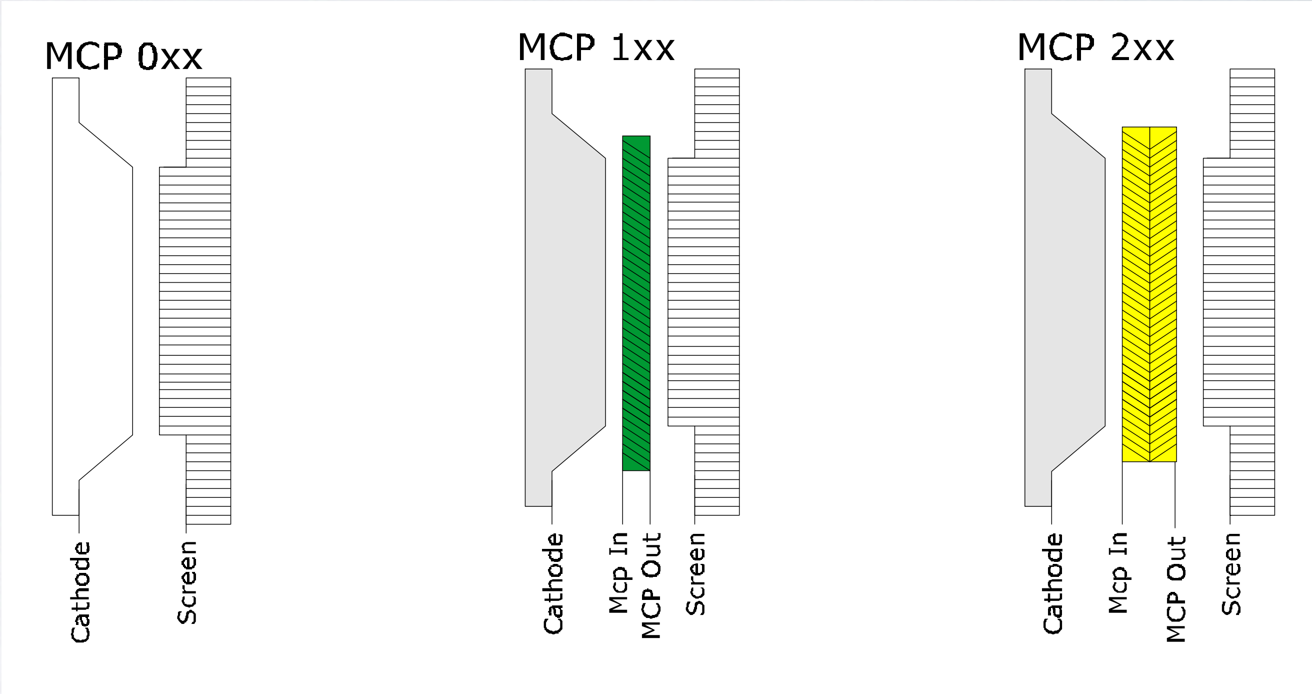


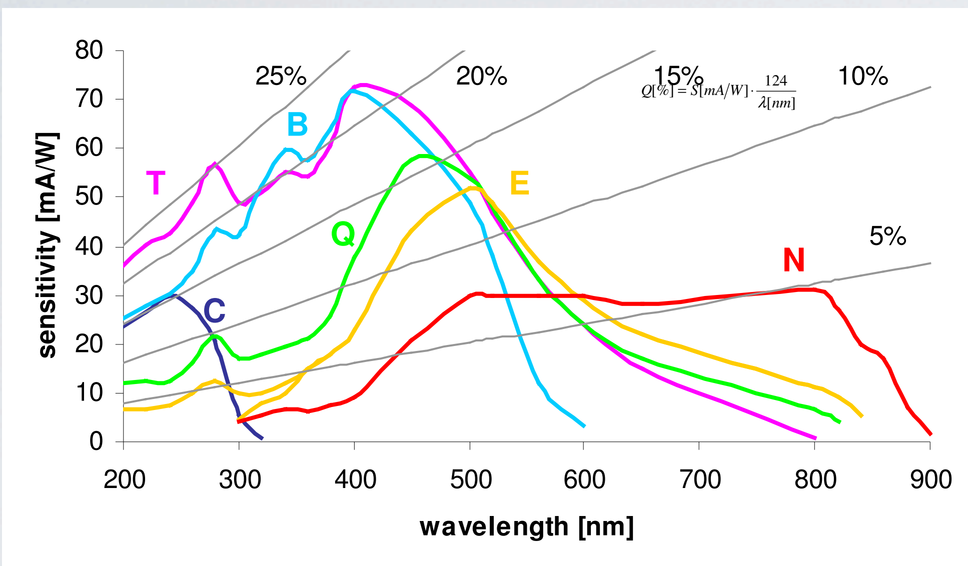
IMAGE INTENSIFIERS

- Modern intensifiers are based on MCPs
- Can amplify the light by more than 1000 times (single photons)
- Resolution is reduced by large amplification
- Can be gated to ~ns



EX. PROXIVISION

Spectral Sensitivity *S* [mA/W]



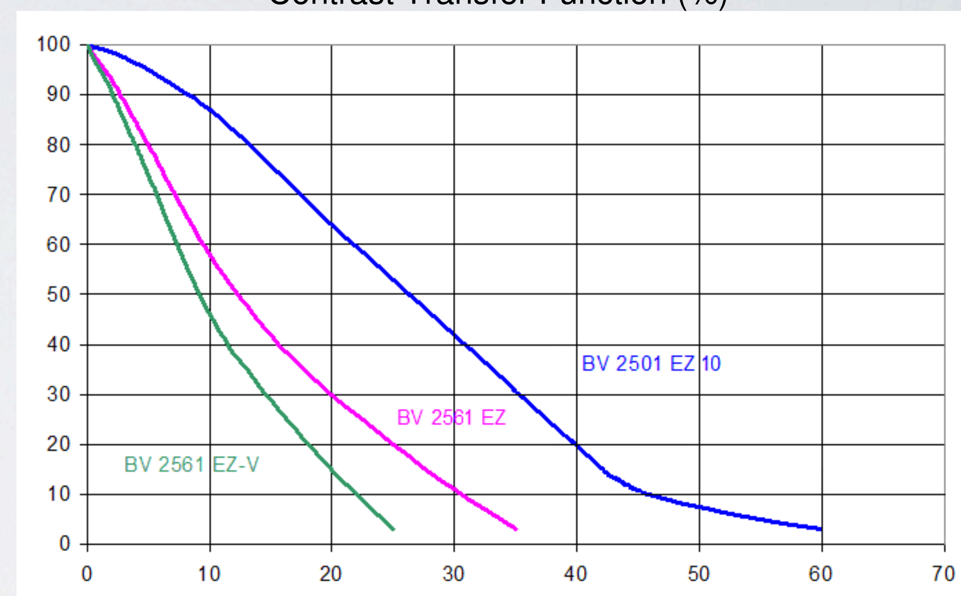
The spectral response characteristic depends on the photocathode type used in the camera.

Photocathode Types			
C	Advanced Solar Blind / quartz	T	UV Enhanced S 20/ quartz
B	Bialkali / quartz	Q	S 20 / quartz
E	S 25 / clear glass		
N	NIR / Fiber optic		

Type	Composition	Light Emission				Decay Time	
		Range		Maximum	Color	Decay of Light Intensity	
		from	to	typically at		from 90 % to 10 % in	from 10 % to 1 % in
P43	Gd_2O_2S:Tb	360 nm	680 nm	545 nm	green	1 ms	1,6 ms
P46	$Y_3Al_5O_{12}$:Ce	490 nm	620 nm	530 nm	yellow green	300 ns	90 µs
P47	Y_2SiO_5:Ce,Tb	370 nm	480 nm	400 nm	blue white	100 ns	2,9 µs

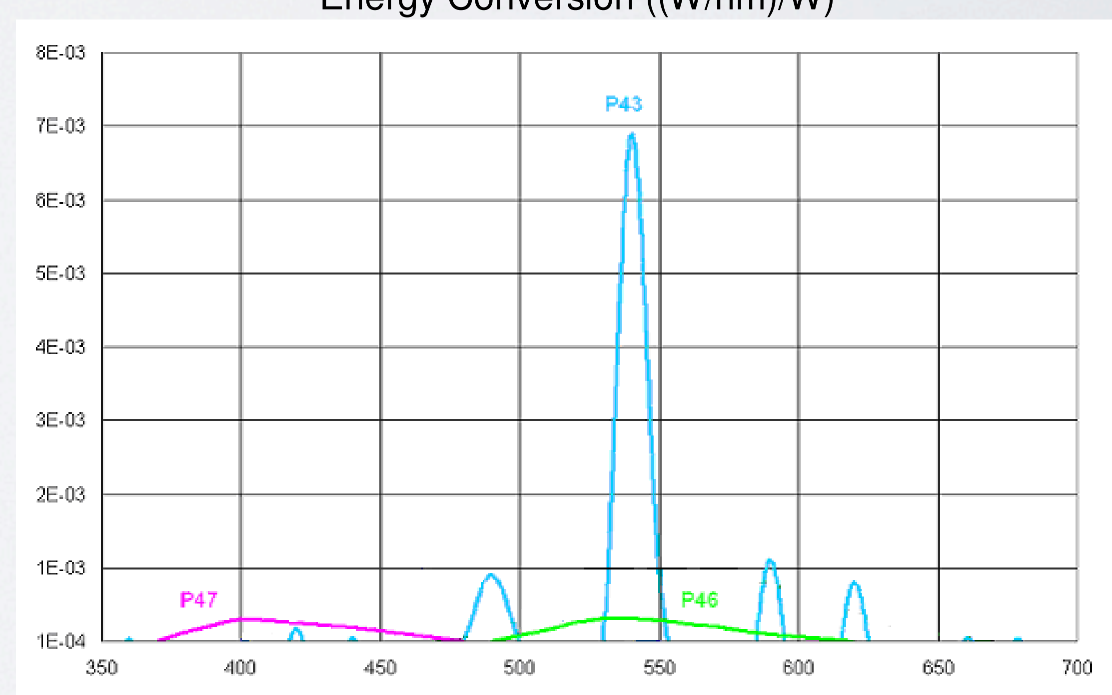
Type	Efficiency (lm/µA)				Efficiency (W/mA)				Efficiency (ph/el)			
	6kV	10kV	12kV	15kV	6kV	10kV	12kV	15kV	6kV	10kV	12kV	15kV
P43	0,24	0,43	0,54	0,71	0,43	0,77	0,97	1,28	185	330	420	550
P46	0,08	0,15	0,19	0,25	0,22	0,39	0,49	0,65	90	160	200	265
P47	0,06	0,11	0,14	0,18	0,62	1,35	1,71	2,24	212	380	480	630
	MCP	PROXIFIER			MCP	PROXIFIER			MCP	PROXIFIER		

Contrast Transfer Function (%)



Spatial Frequency (lp/mm)

Energy Conversion ((W/nm)/W)



Wavelength (nm)

LINEAR ARRAYS

- Both CCD and CMOS versions exists
- Up to 50MHz readout clock possible

ROLLING SHUTTER

- Image integration delay differ from line to line
- Peculiarity of CMOS and CID (tube cameras as well)
- Problem for moving objects (or pulsed)
- Global shutter CMOS exist

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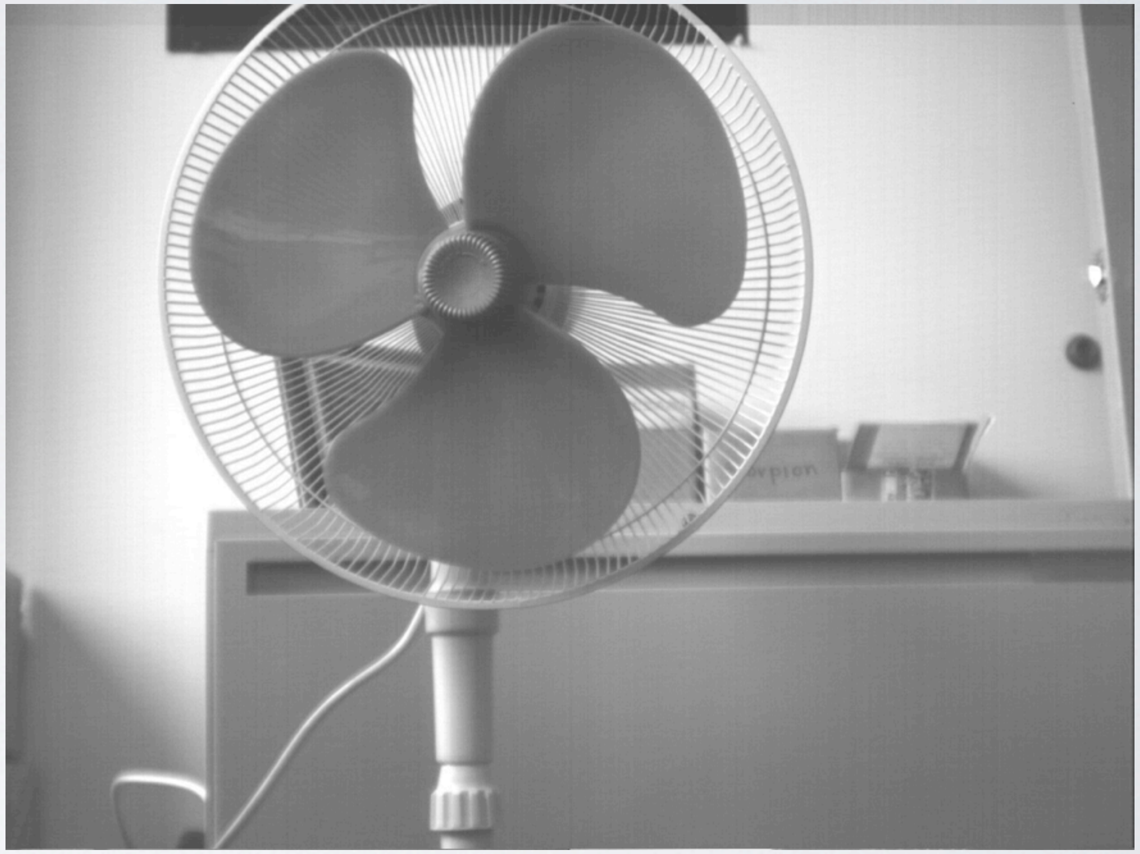

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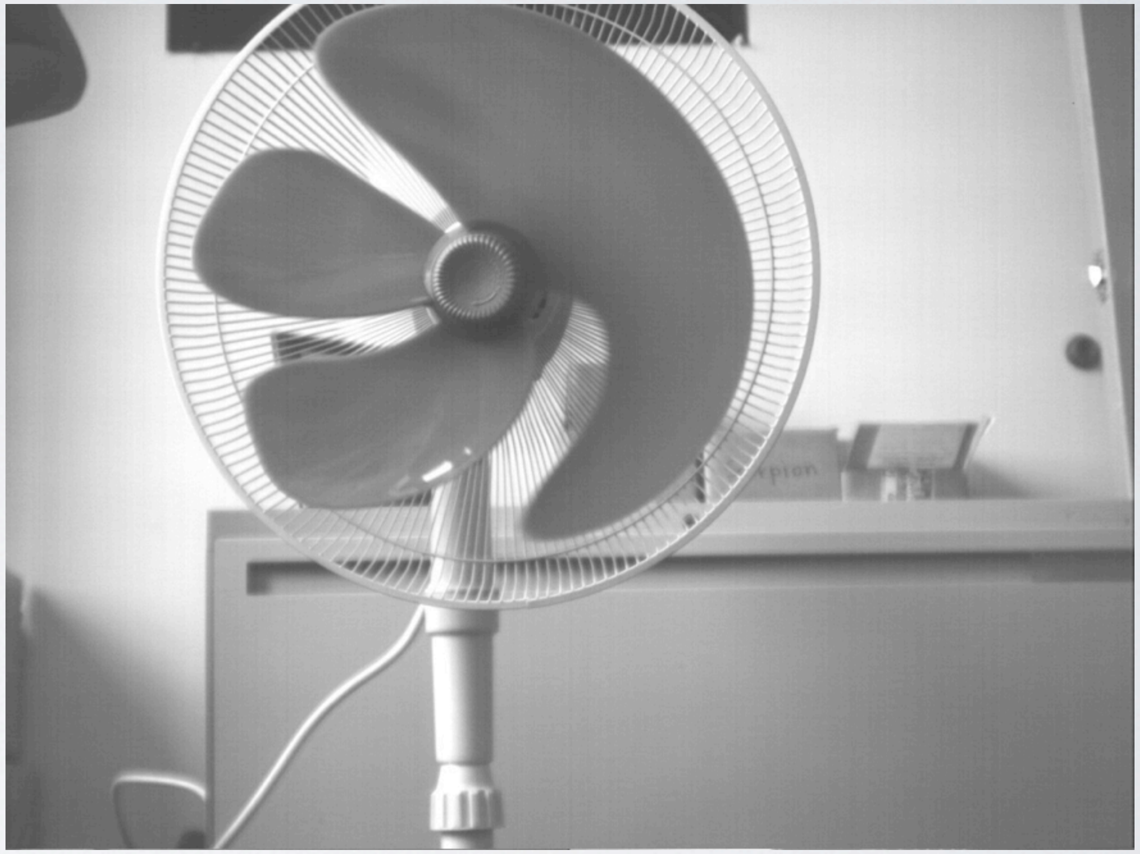

RADIATION IN MOS

- Charge creation in the oxide layer (flat band) ⇒ reduce the oxide layer
- De-passivation of the interface layer
- Traps creation in the bulk, prominent for n type Si (due to phosphor doping) ⇒ p channel devices (collecting holes?) (LBNL, e2v)

RADIATION HARDNESS

- CCD and CMOS typically not radiation hard ~100Gy (10kRad) max, can be improved with dedicated designs
- CID up to 50kGy (5MRad)
- Vidicon tubes ? never seen a radiation damaged tube provided “no” local electronics

WHERE DO WE STAND

- Dramatic progress of CMOS and CCD in terms of pixels and sensitivity in the past 10 years
- Unfortunately radiation hardness has not improved (more the opposite)
- Tubes are obsolete and difficult/impossible to procure

IMAGE ACQUISITION

- Three options available
  - Analog video camera and external frame grabber
  - Digital camera with dedicated protocol and external acquisition board (like camera link)
  - Digital camera and standard BUS (Gbit ethernet, USB, firewire...)

DIGITAL VS ANALOG

- In terms of performance (S/N, speed, cost, complication) digital wins hands down

- Analog still has an edge for the radiation problem, less electronics in the tunnel = less failures (... depends...)

ANALOG FRAME GRABBERS

- Typically used for CCIR (SD)
- Becoming obsolete as are analog cameras. We should probably expect a sharp end (like tube TVs and vinyl records)
- Since years "only" available for PCs (mainly WINDOWS, some support for Linux), not easy to integrate and maintain in large control systems (like at CERN)
- Can be replaced by a mid-range ADC/FPGA board (~40MHz)

DIGITAL FRAME GRABBERS

- Getting obsolete as well. Will probably survive for very special applications (super high speed with multiple Gbit links)
- Same situation as for analog frame grabbers for the hardware choices, mainly PCs with WINDOWS or Linux

FIELD BUS CAMERAS

- Large choice, very fluid situation
- USB (1, 2, 3), Firewire (400, 800, S1600, S3200), Gigabit ethernet
- Transfer rates up to several G bits/s
- USB and Firewire only short cables (extension possible)
- Gbit Ethernet allows up to 100m (twisted pair)

FIELD BUS CAMERAS

BUS PROTOCOLS

- The physical layer is public (is or can be installed in any PC or crate)
- The data protocol is often proprietary and requires the use of binary only libraries/drivers, again with the same support as for the frame grabbers
- Some open standard exists and is used by some company

POST PROCESSING

- In our case means mainly
  - Background subtraction
  - Geometric corrections
  - projection and or fitting of ROI

ANALYSIS TOOLS

- Scientific camera provider have some tools on their catalogues
  - Typically targeted at specific type of measurements
- Most of the time use of in-house developed tools (LabView, Java, C/C++...)
- Little reusability because not considered in the design
- Possible to create collaborative tools?

CONCLUSIONS

- Technology is giving us a lot of possibilities/opportunities in the imaging world
- Some times, unfortunately, our needs go opposite to the big market
- Radiation is our real enemy!
- A field where collaboration would help a lot!

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Thttp://www.willowgarage.com/blog/2010/04/27/reinventing-wheelext

THANKS!