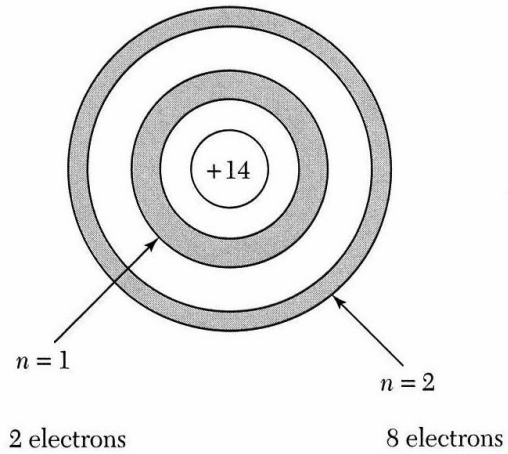
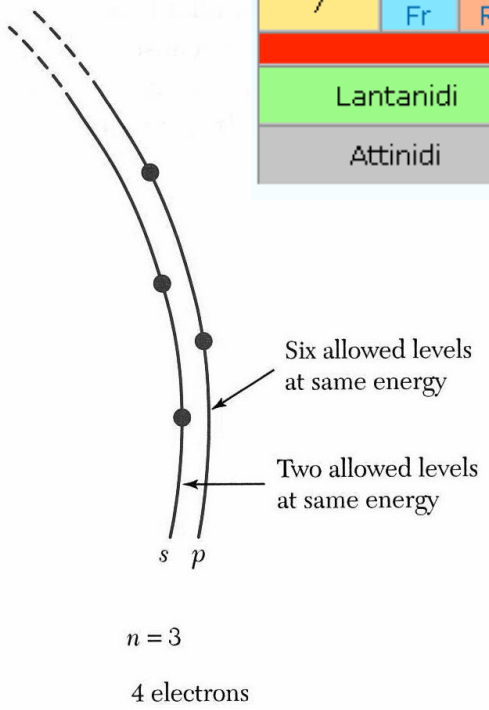
Characterization of optical (and IR) solid state detectors

SUMMER SCHOOL on
PHYSICAL SENSING & PROCESSING – V EDITION
Department of Physics & Astronomy – University of Bologna
July 17-21, 2023

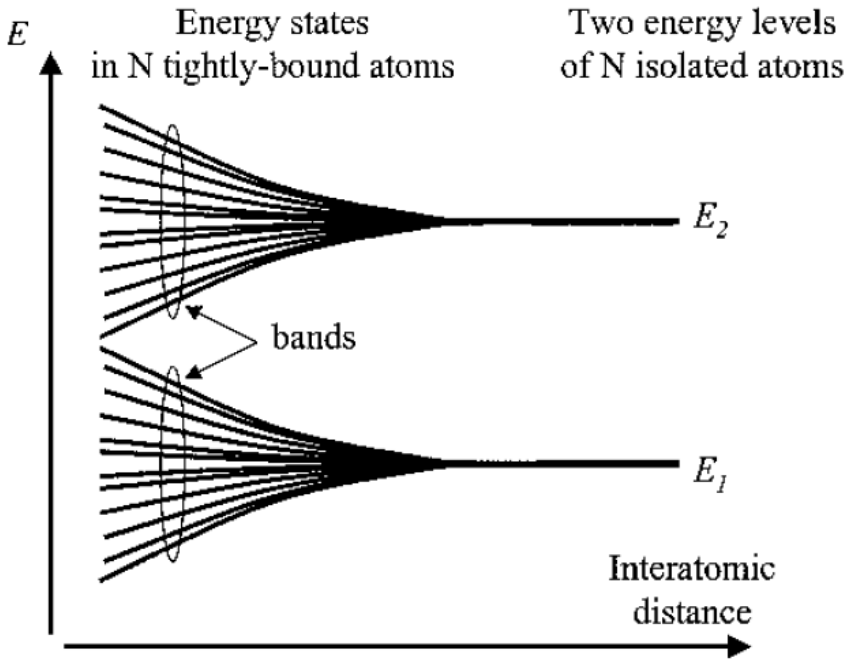
Atomic Silicon

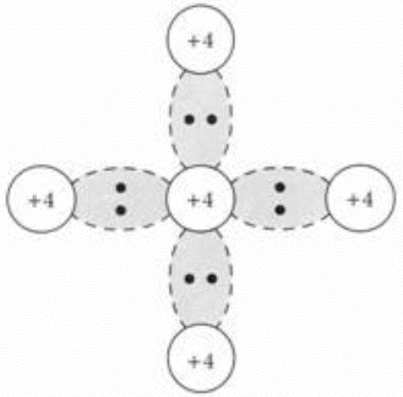
Gruppo	1 IA	2 IIA	3 IIIA	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
Periodo																		
1	1 H													Non metalli				2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	Metalli di transizione										13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba *	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra **	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
	Elementi di transizione interna																	
	Lantanidi *		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
	Attinidi **		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

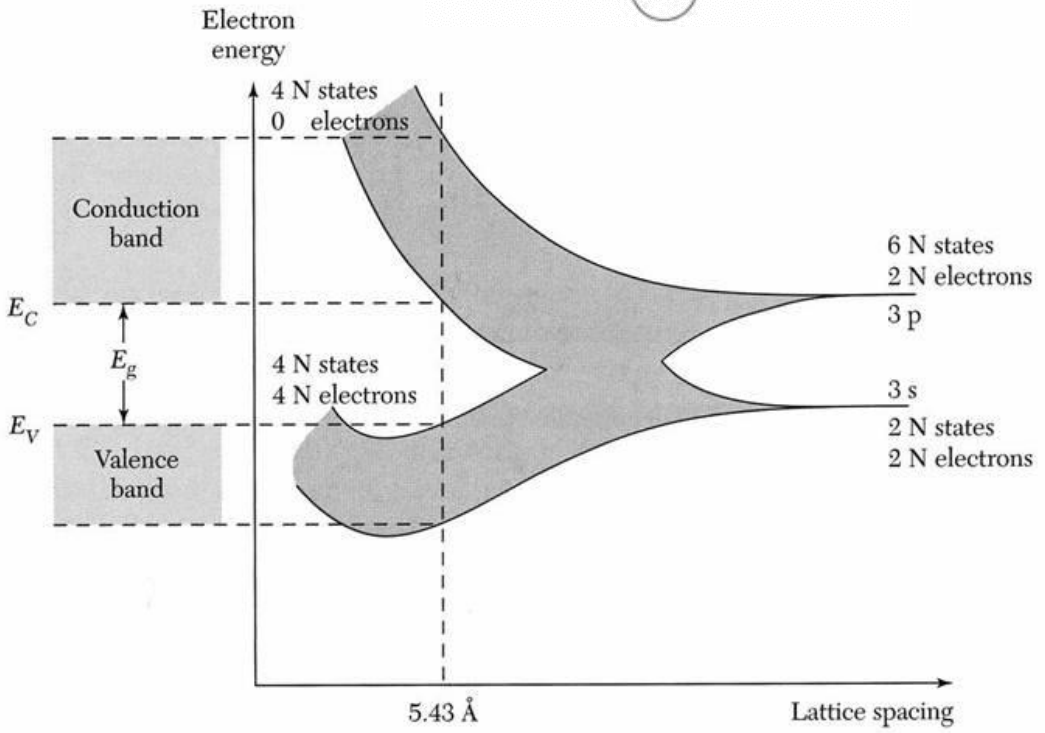




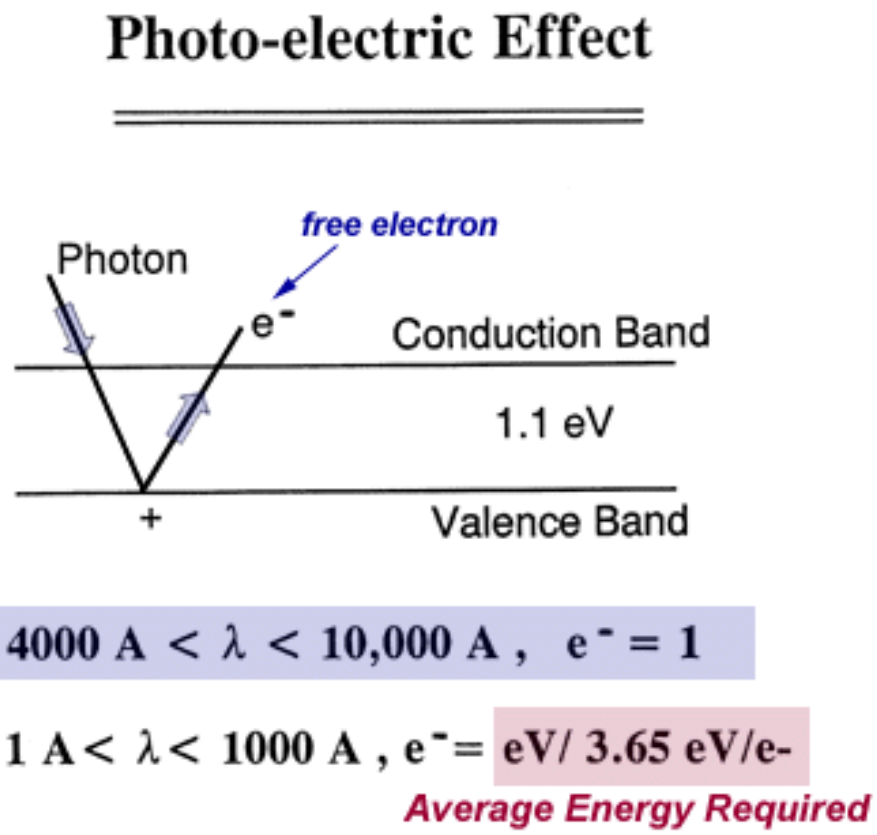
INFINITE crystal lattice of PURE Si







Photoelectric effect



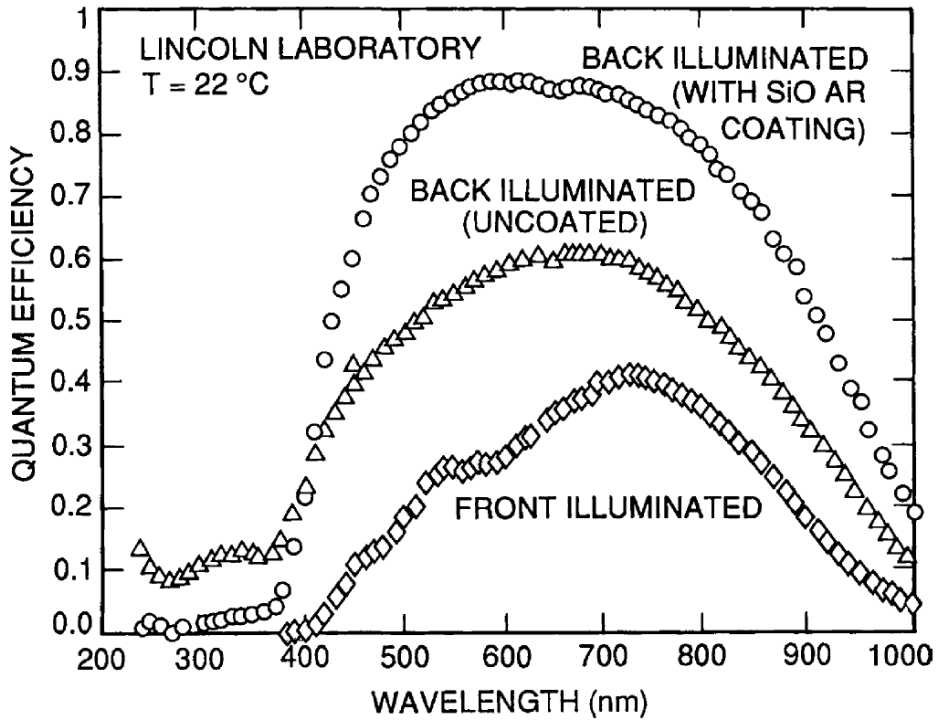
In the infrared the most used material for astrophysical imaging is the compound **HgCdTe**.

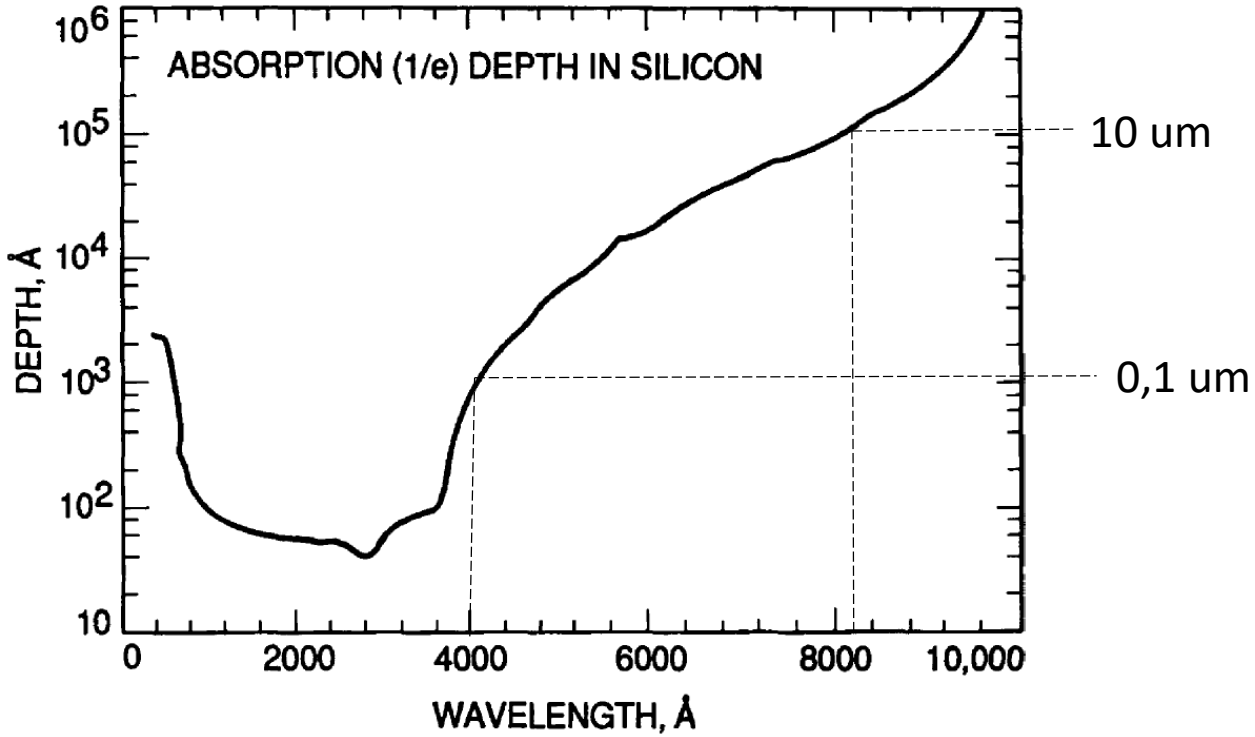
By varying the percentage of Hg to Cd the width of the forbidden energy gap is adjusted → cut-off wavelength is moved

$Hg_{1-x}Cd_xTe$

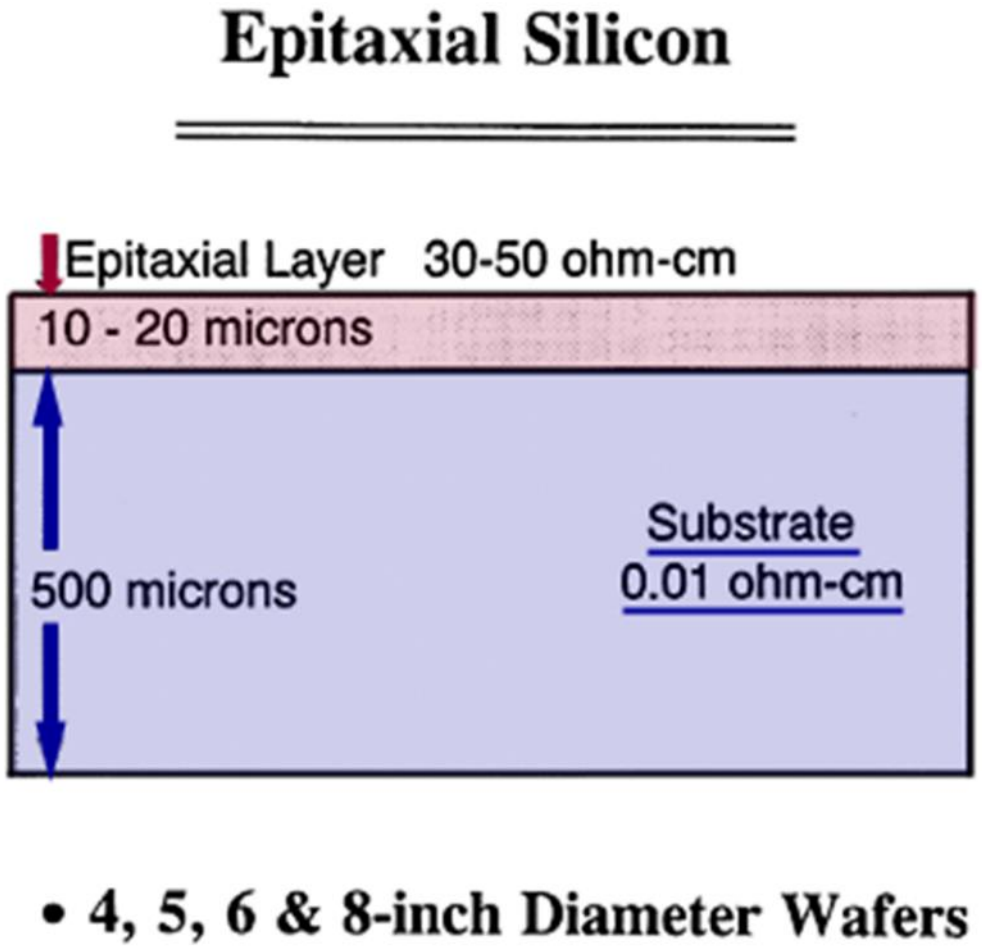
x=0.196 Eg=0.09Ev λ=14um
x=0.295 Eg=0.25Ev λ=5um
x=0.55 Eg=0.73Ev λ=1.7um

Quantum efficiency / depth of absorption





Physical dimensions

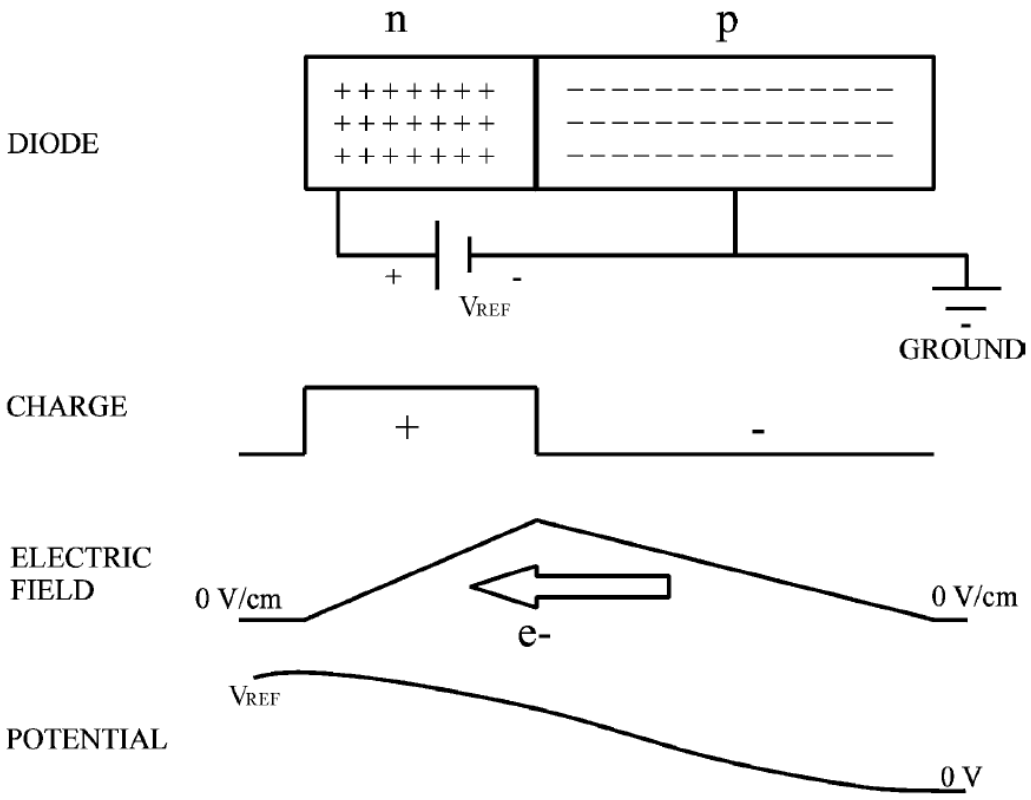


High quality epitaxial layer (high perfection of crystal lattice and absence of impurities – except dopant) is growth on top of a substrate. Detection takes place in this region.

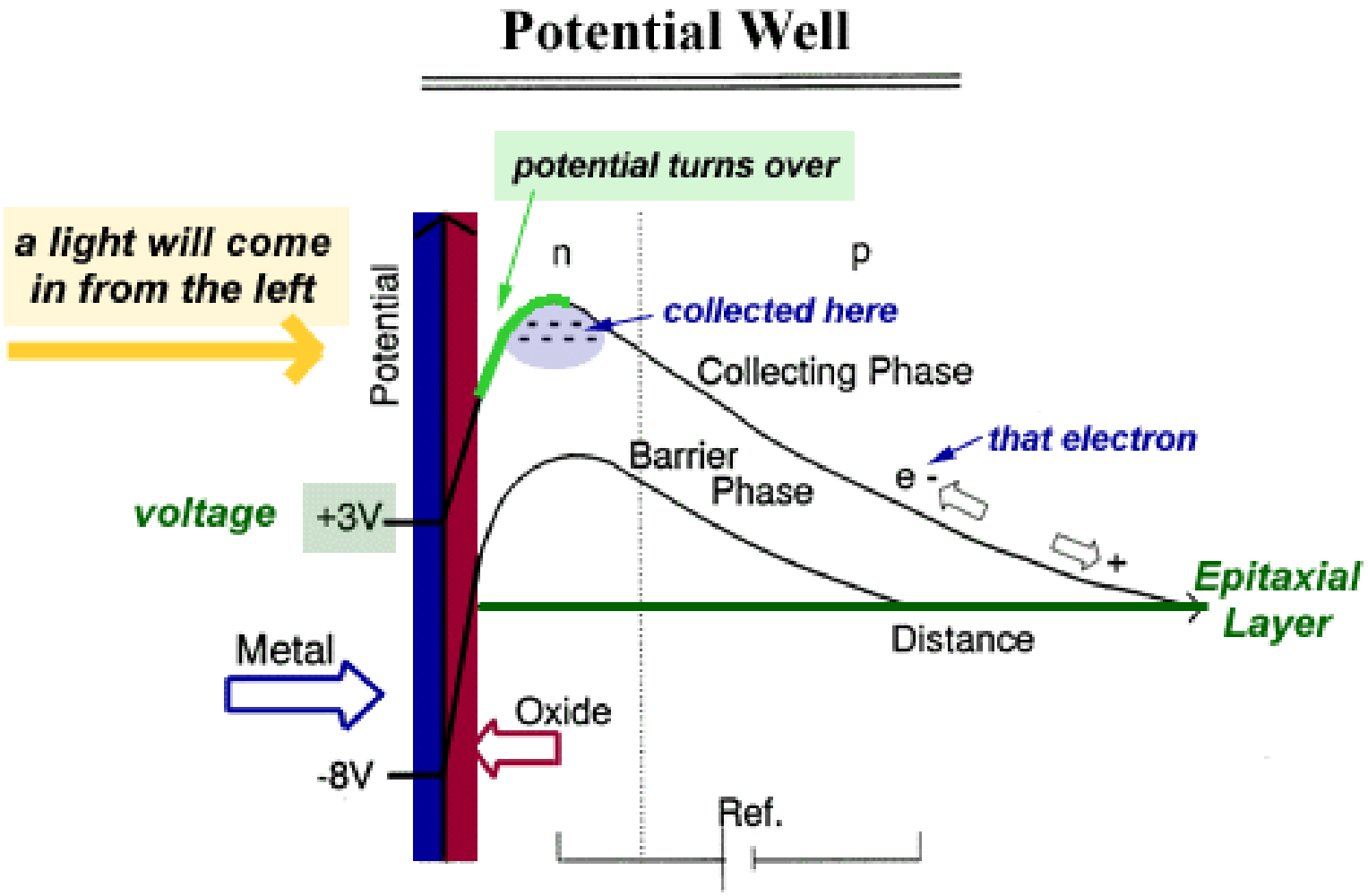
Substrate (optically tick) provides mechanical support and electrical groud.

- **4, 5, 6 & 8-inch Diameter Wafers**

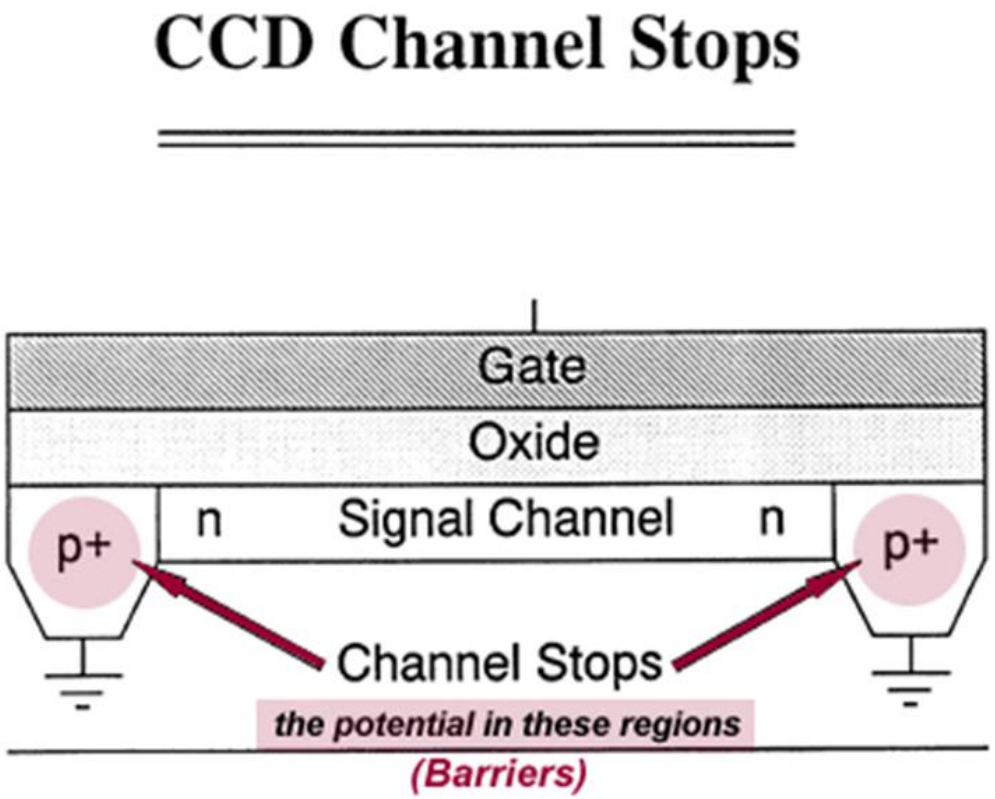
Charge collection 1: p-n junction depletion



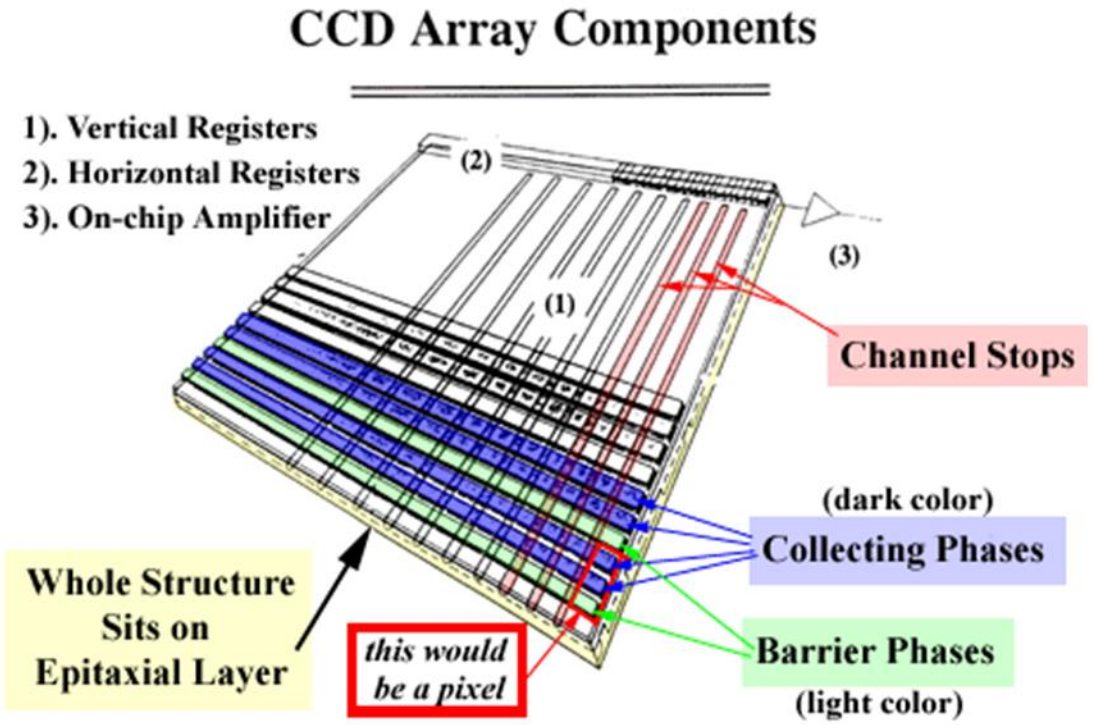
Charge collection 2

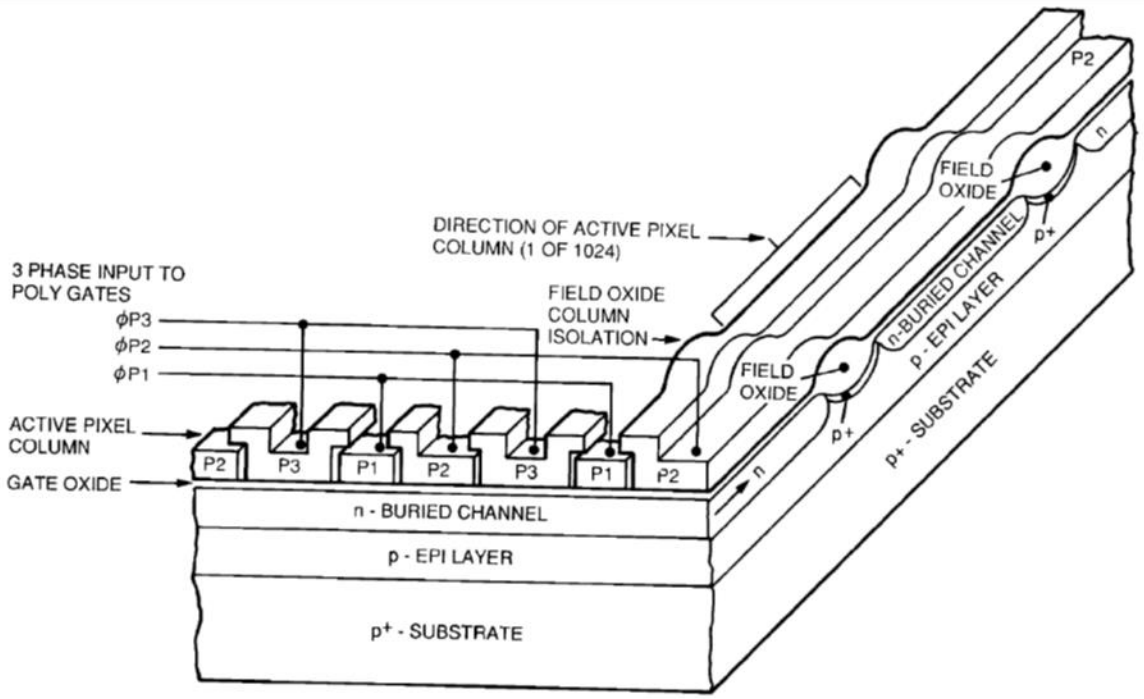


Pixels on CCD 1

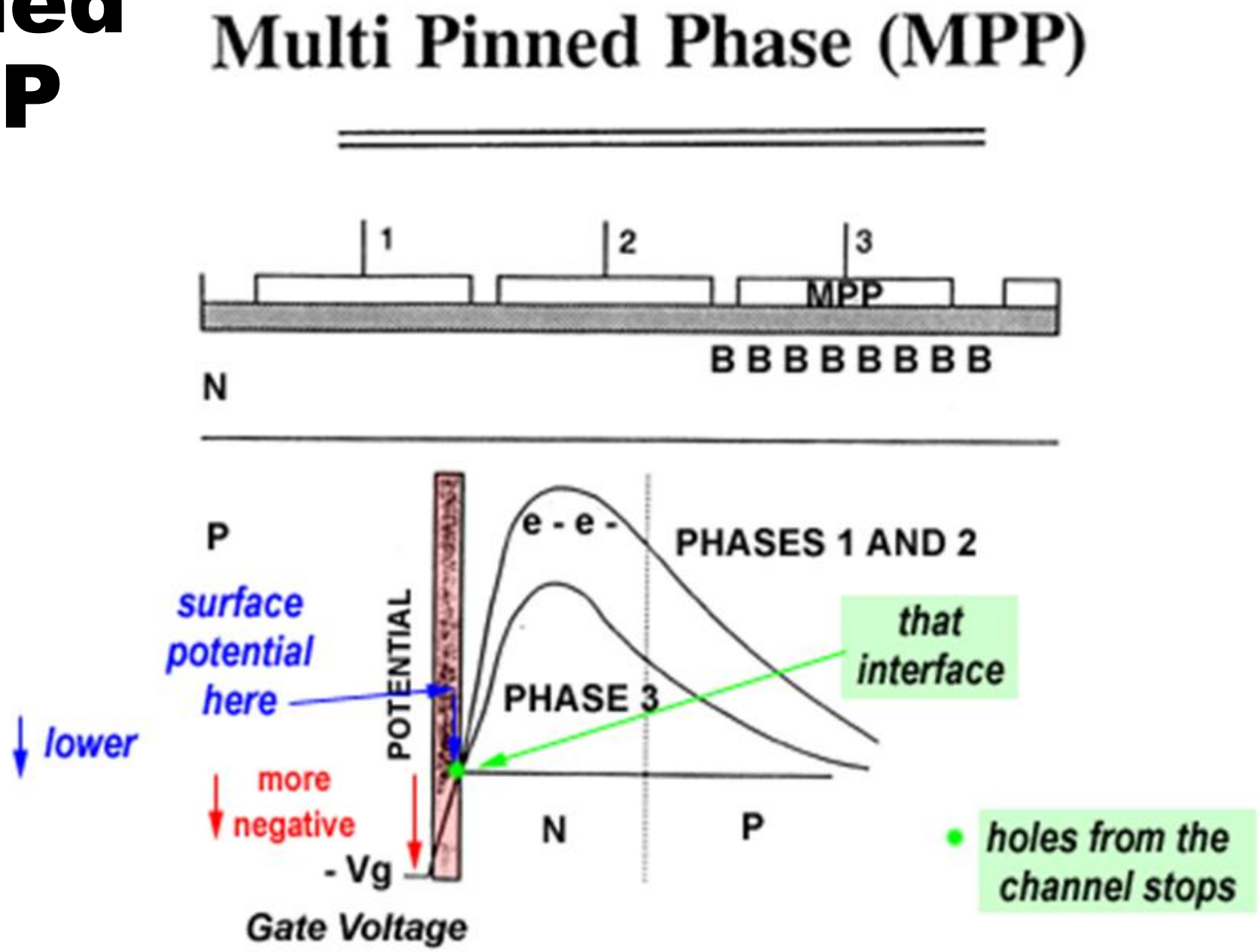


Pixels on CCD 2

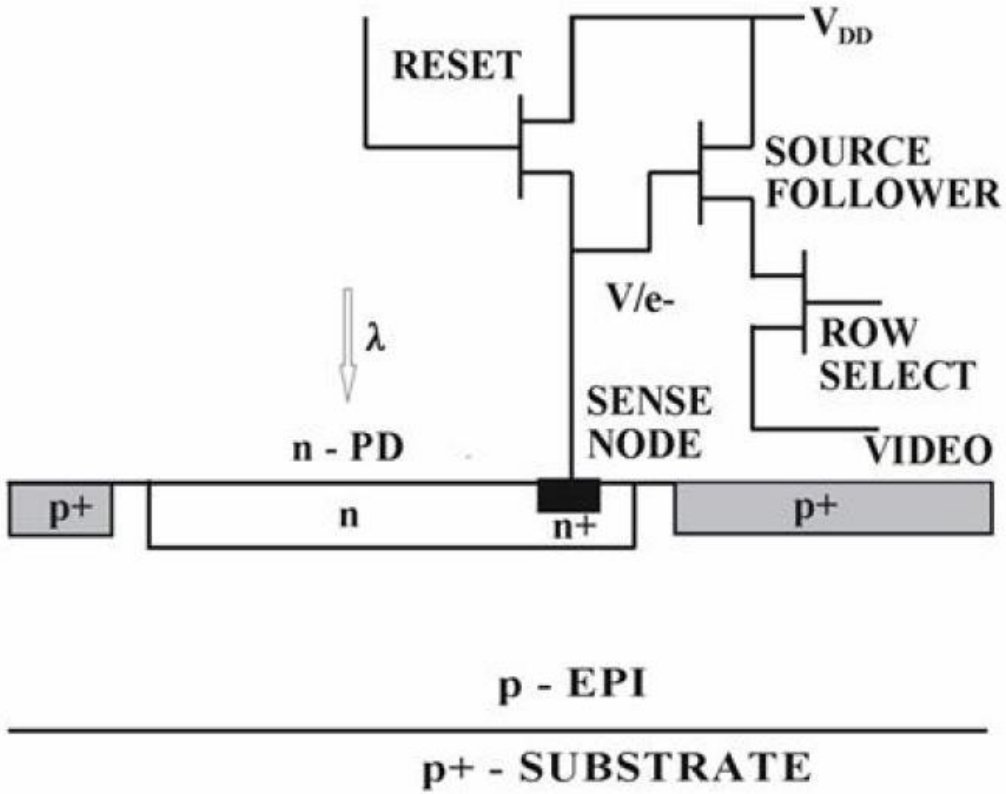




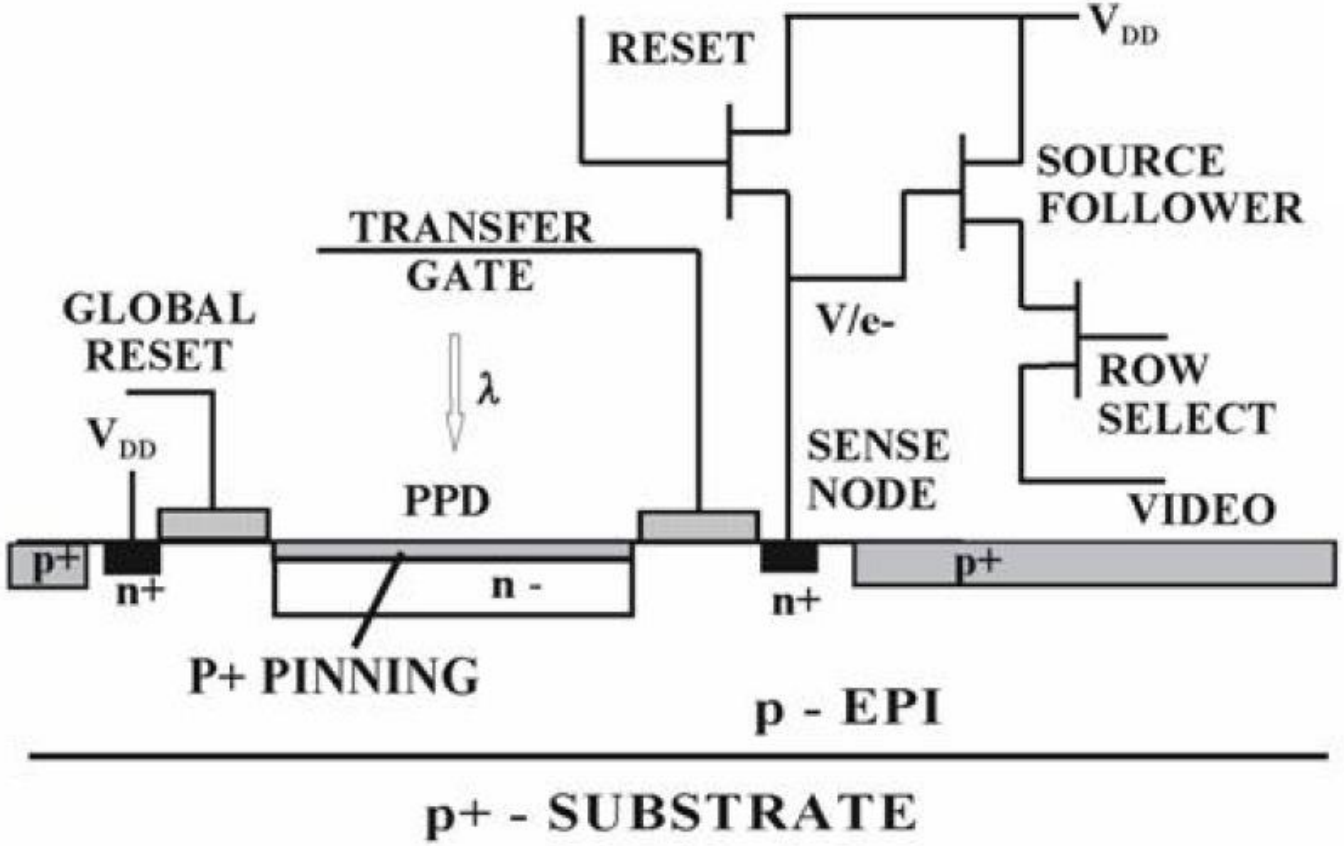
Multi Pinned Phase MPP

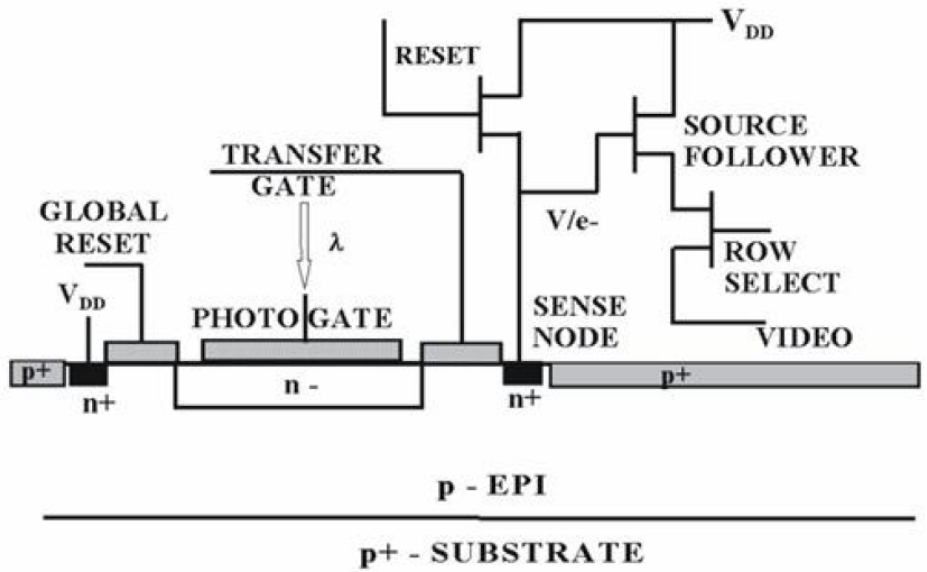


CMOS pixel architectures 1

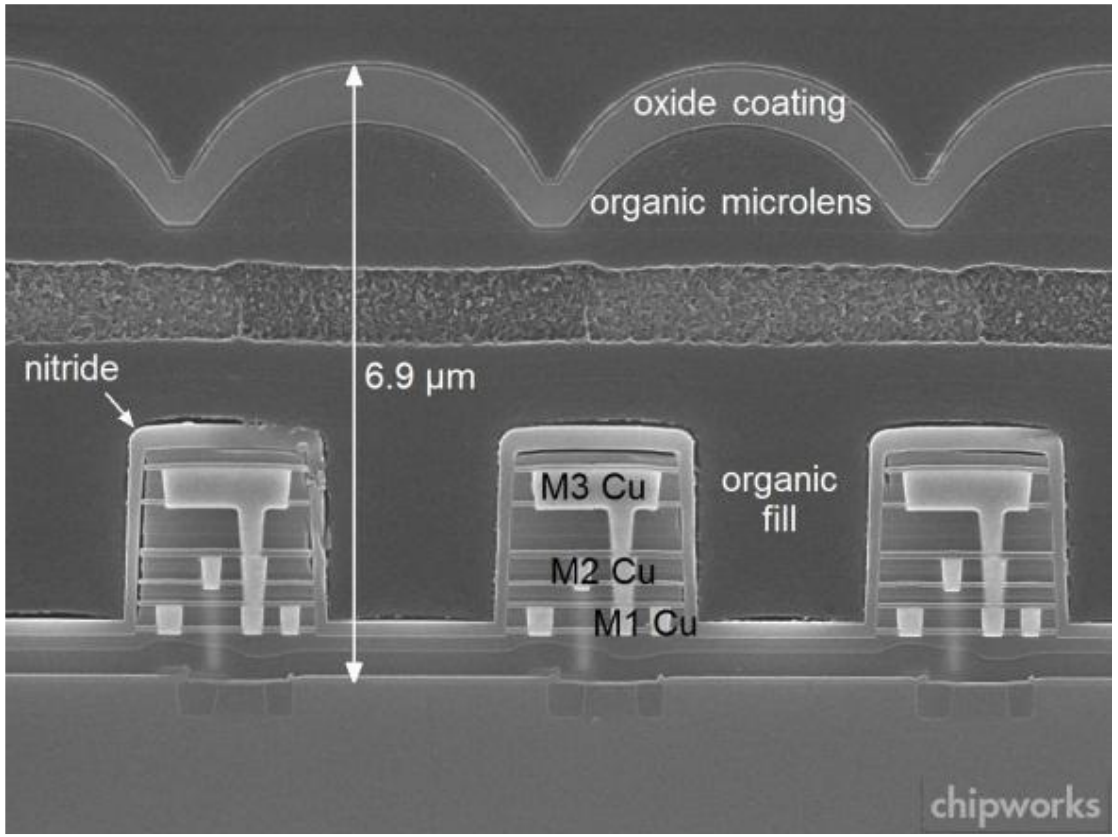


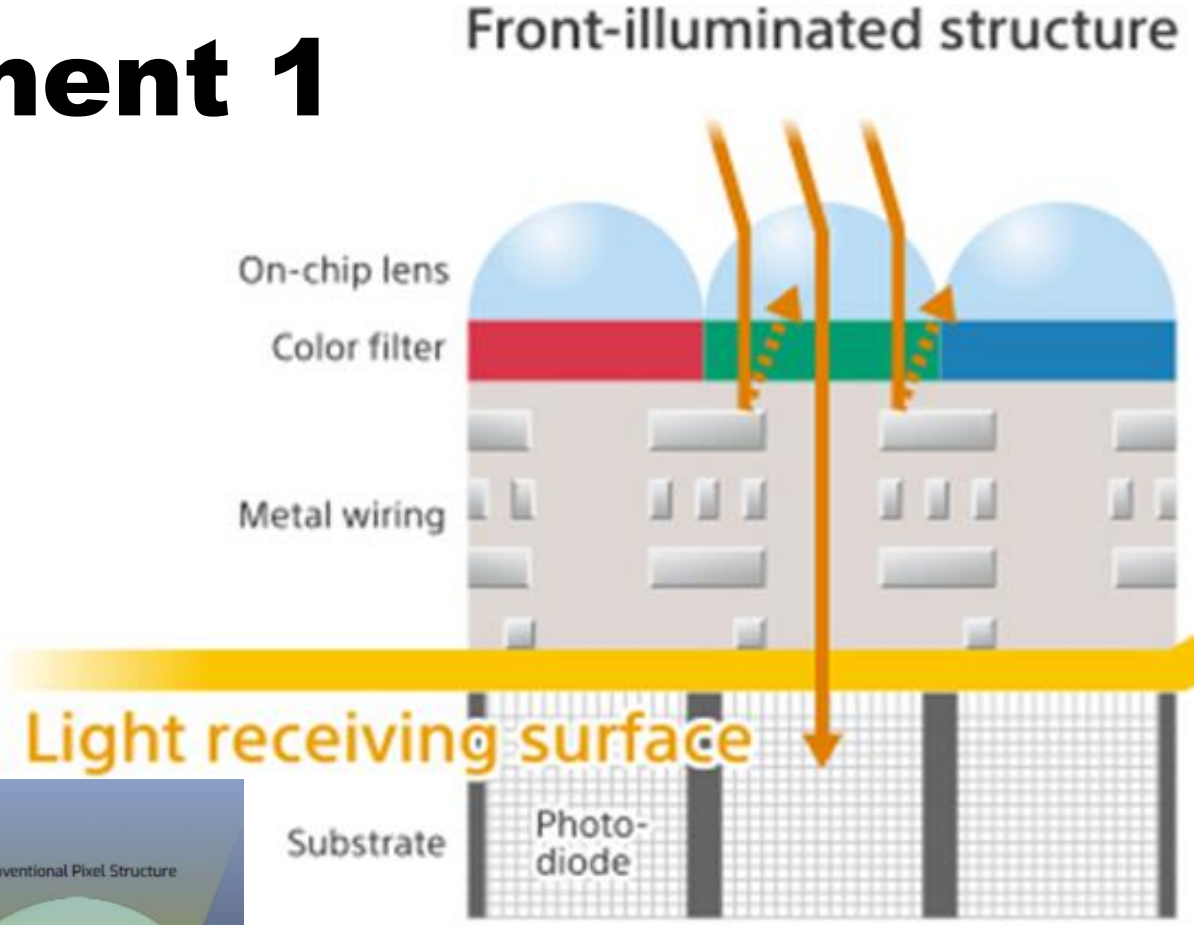
CMOS pixel architectures 2

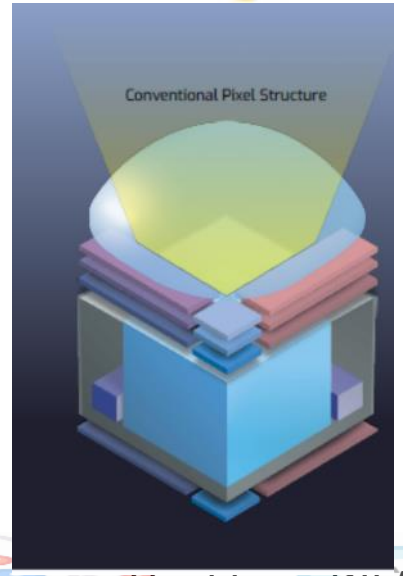




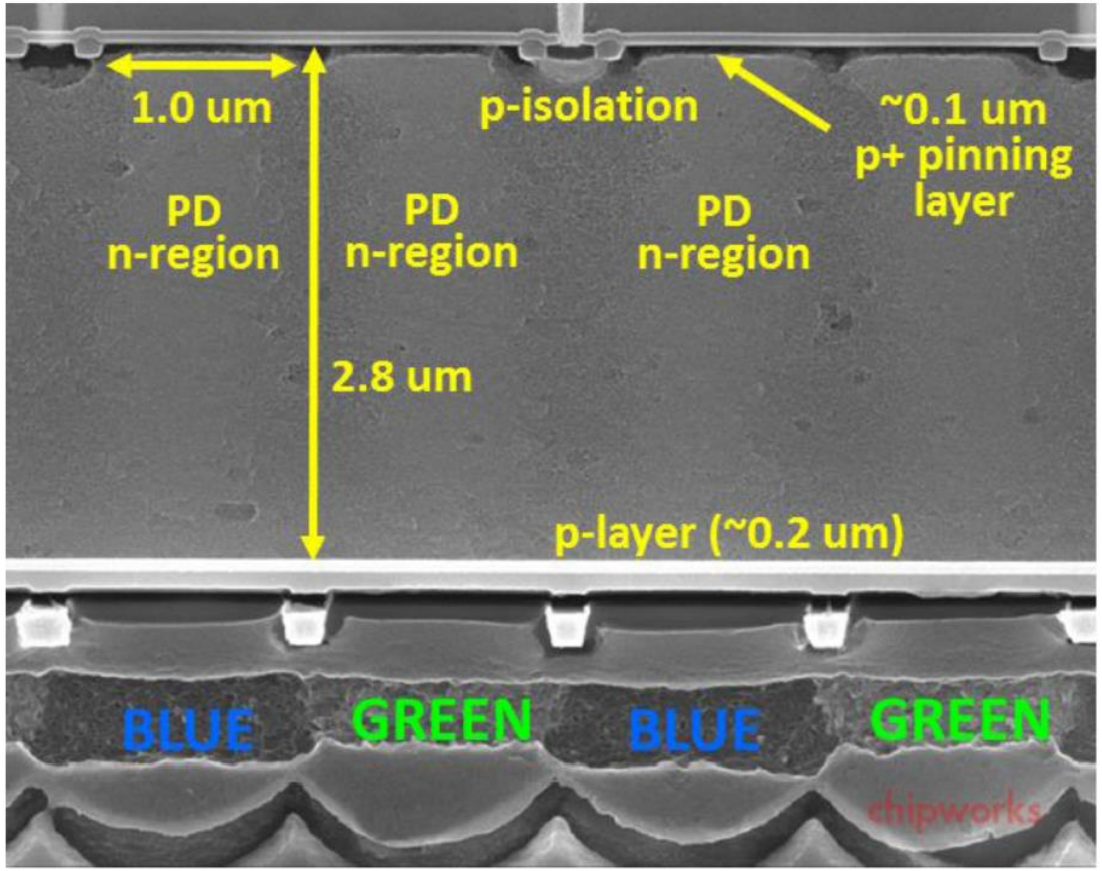
CMOS pixels arrangement 1 (front illumination)

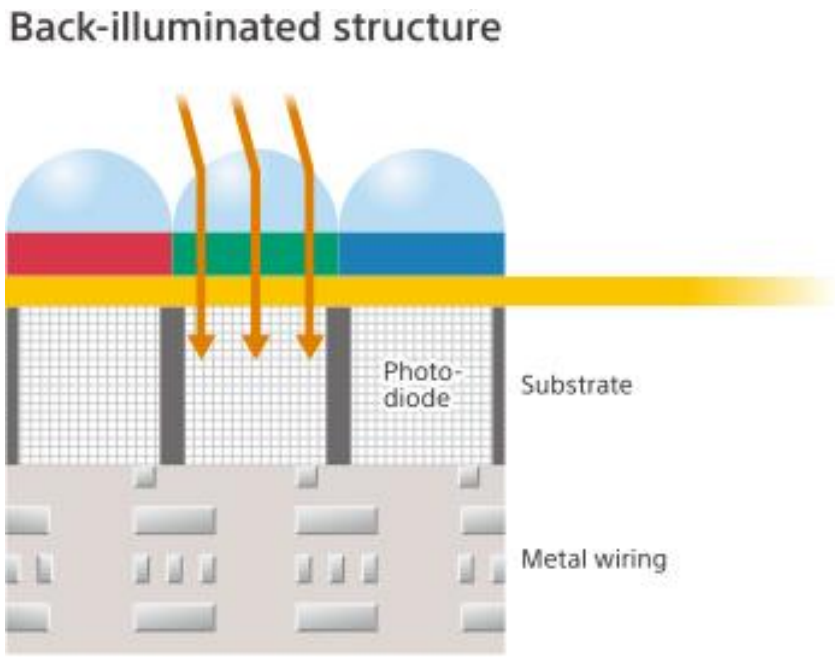




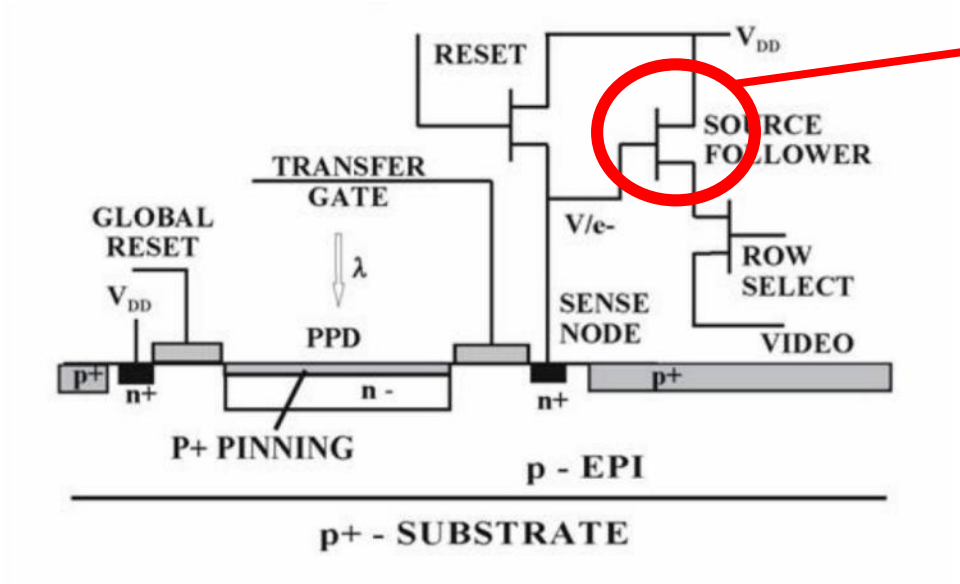


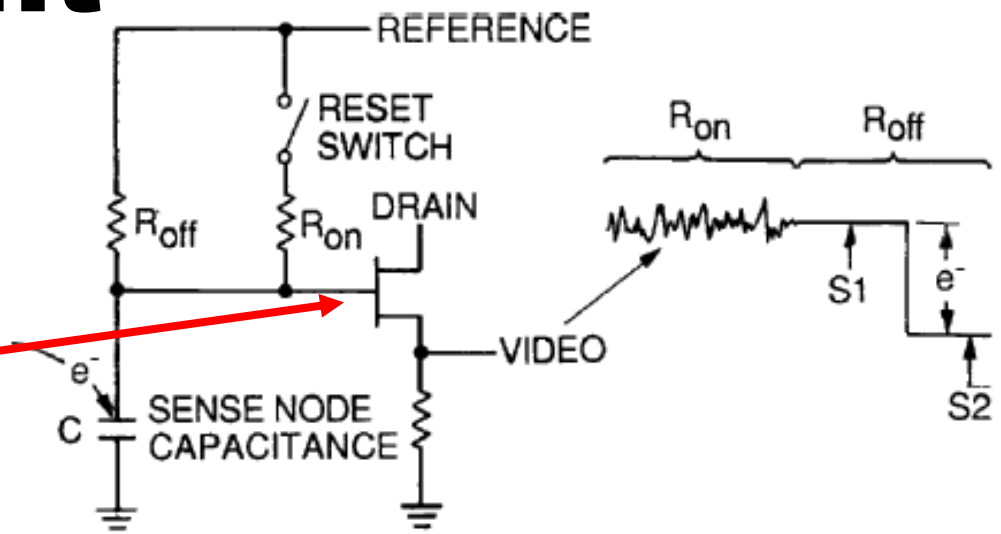
CMOS pixels arrangement 2 (backside illumination)

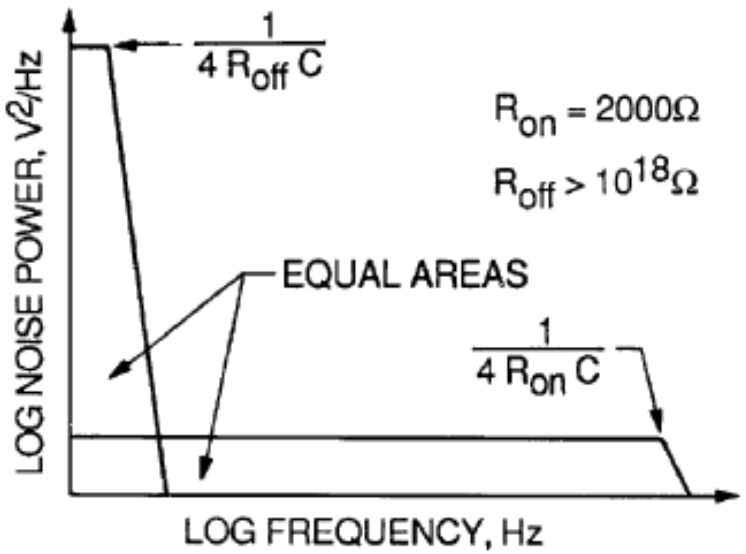




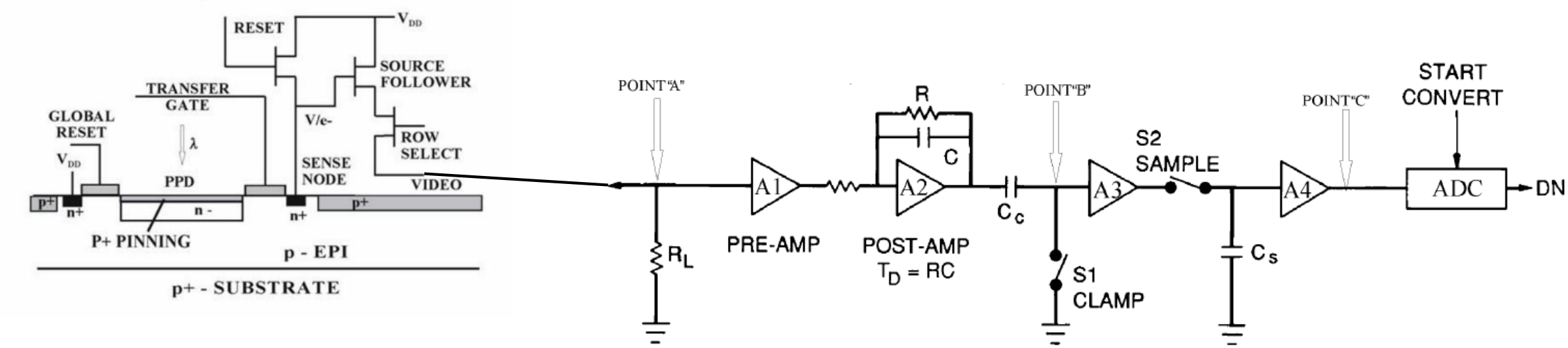
Charge measurement



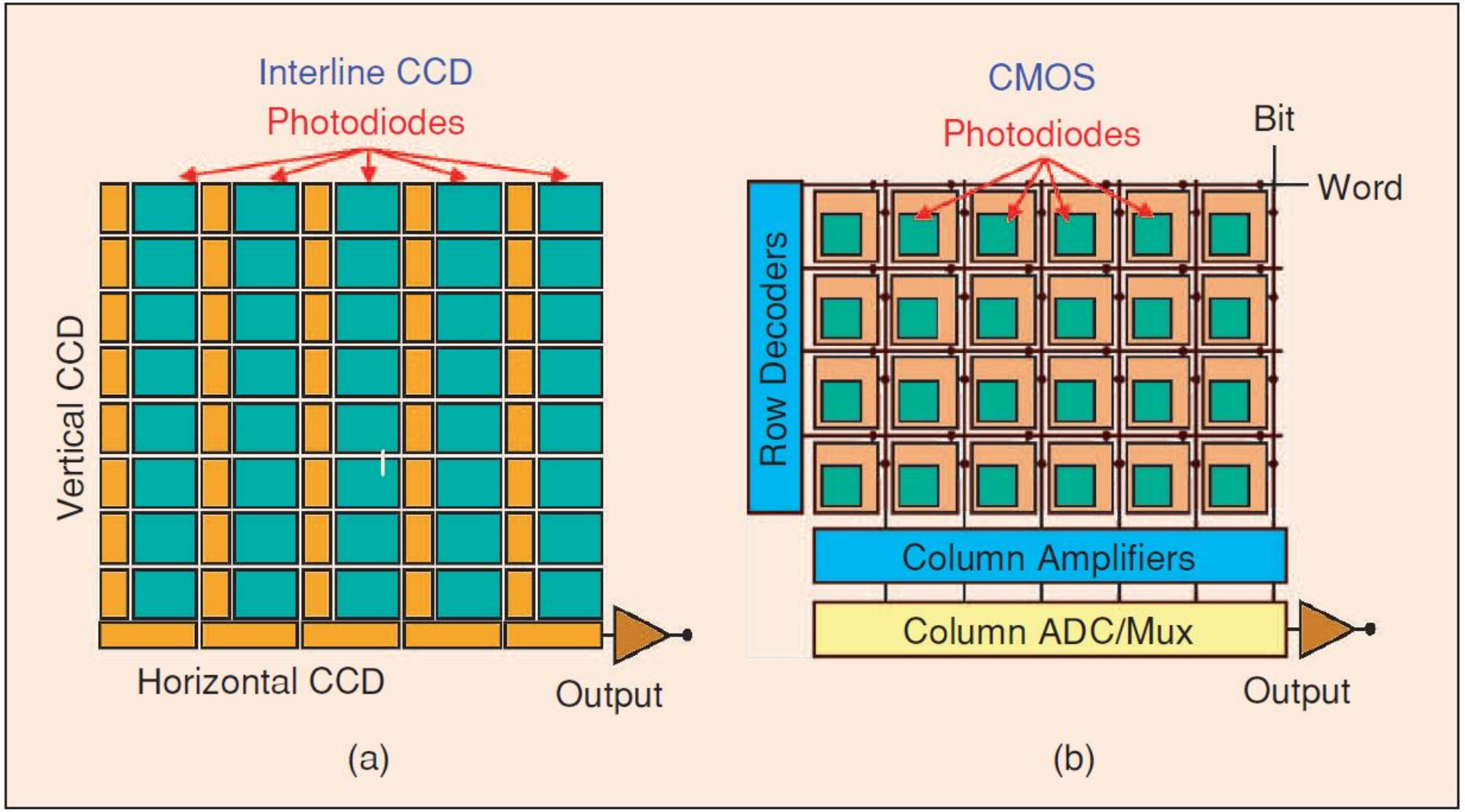




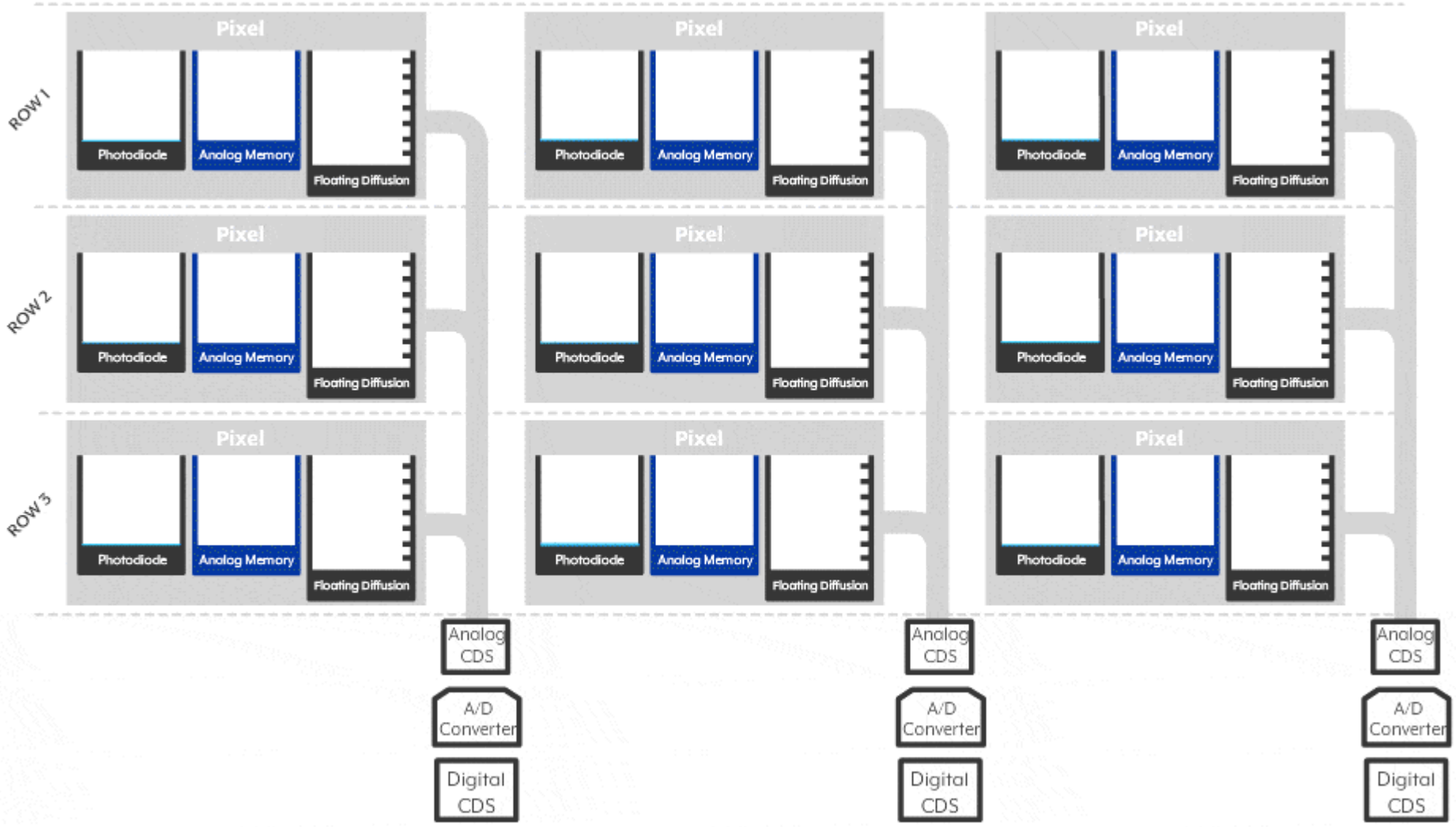
Correlated Double Sampling CDS



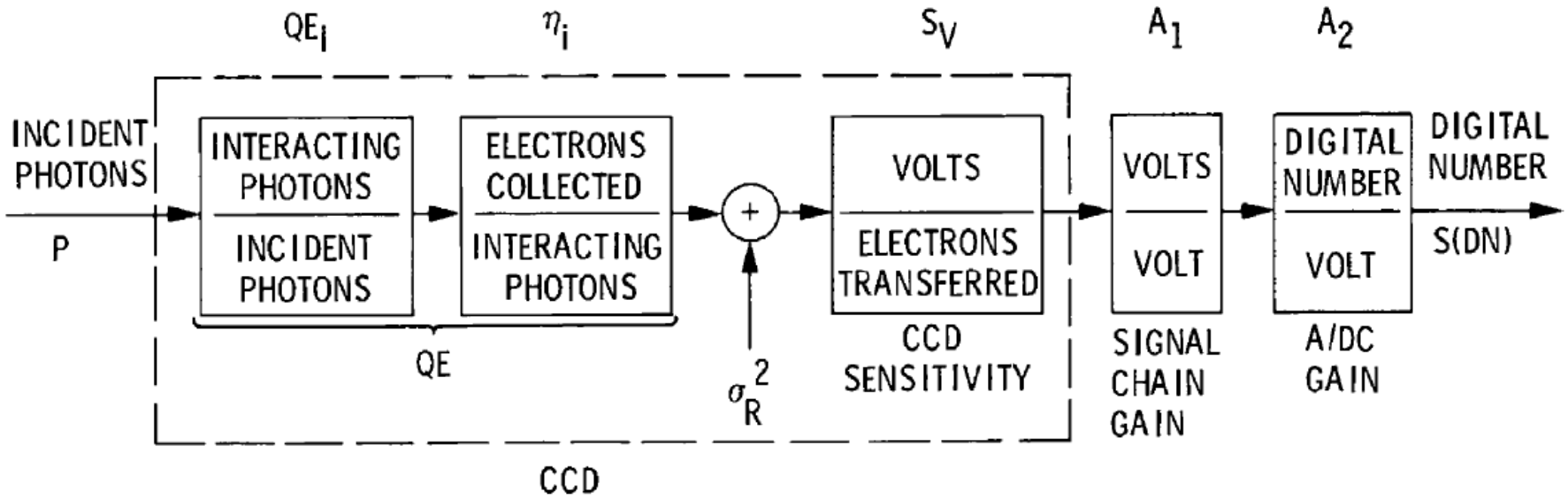
Charge measurement architecture 1



Charge measurement architecture 2



Transfer function



Camera gain constant $K = \dfrac{1}{S_V A_{CCD} A_1 A_2}$ (e^-/DN)

Photon Transfer function

Camera gain constant $K = \frac{1}{S_V A_{CCD} A_1 A_2}$ (e^-/DN)

$$S(DN) = \frac{n_e}{K}$$

$$\sigma_S^2(DN^2) = \frac{\sigma_{n_e}^2}{K^2} + \sigma_{RON}^2$$

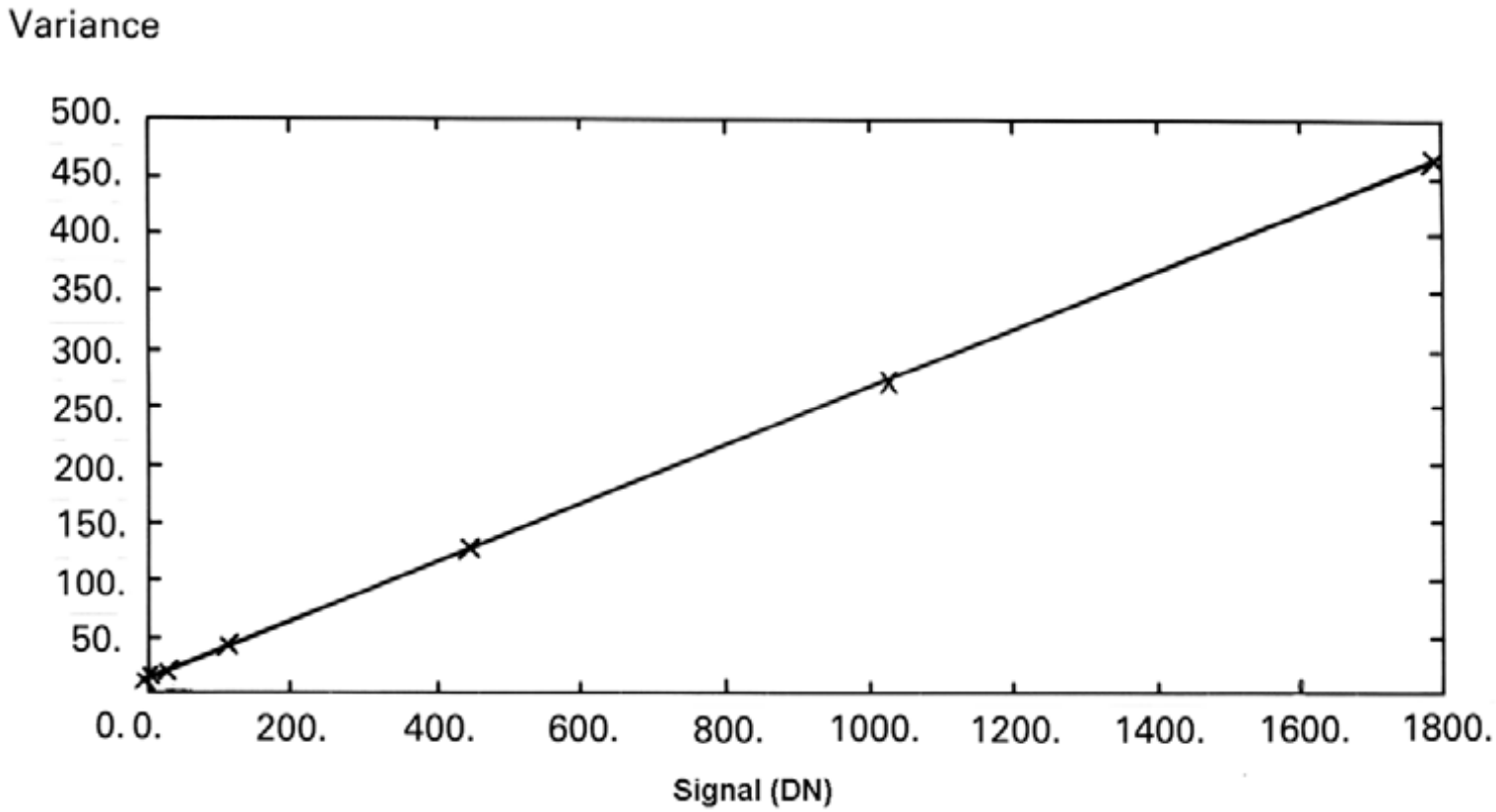
$$\sigma_S^2(DN^2) = \frac{n_e}{K^2} + \sigma_{RON}^2$$

$$\sigma_S^2(DN^2) = \frac{S}{K} + \sigma_{RON}^2$$

Poisson statistic
1) Independent events
2) Time invariant probability distribution
3) Probability of an event proportional to the time small interval
4) Negligible probability of two event in the same small interval of time

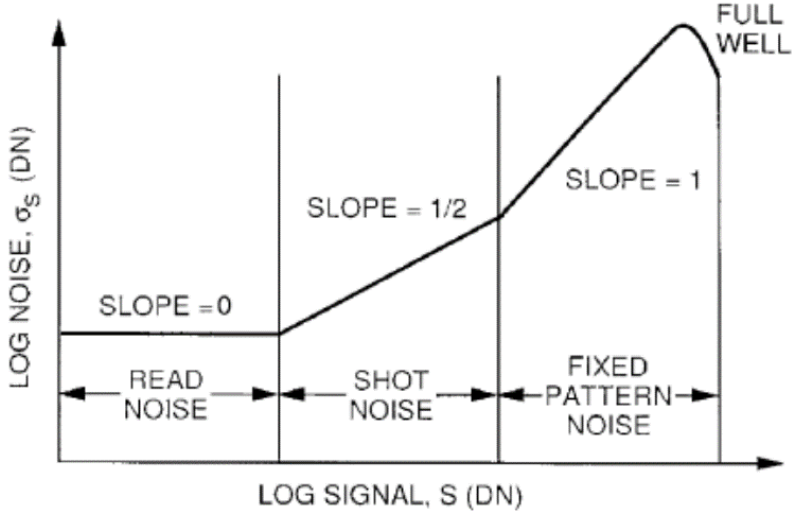
Photon Transfer: linear fit

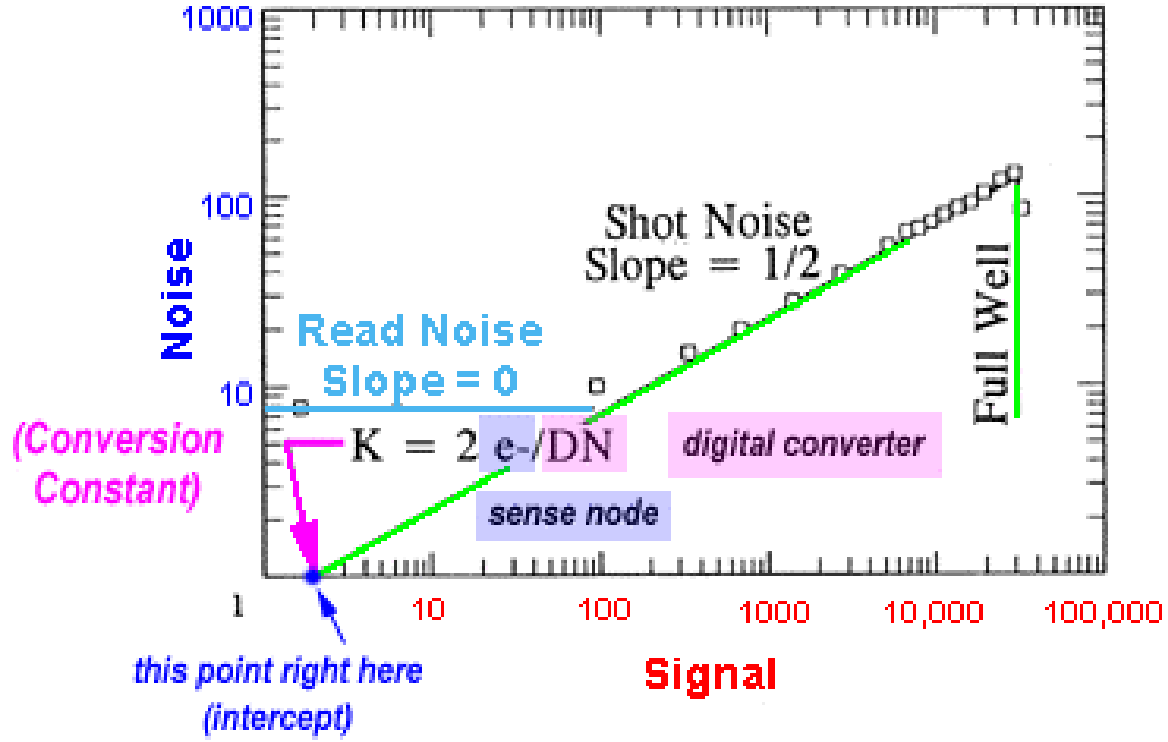
$$\sigma^2_{S_{out}}(DN^2) = \frac{S_{out}}{K} + \sigma^2_{RON}$$



Transfer function: log fit

$$Log(\sigma_S)(DN) = \frac{1}{2}\log\left(\frac{S}{K} + \sigma_{RON}^2\right)$$





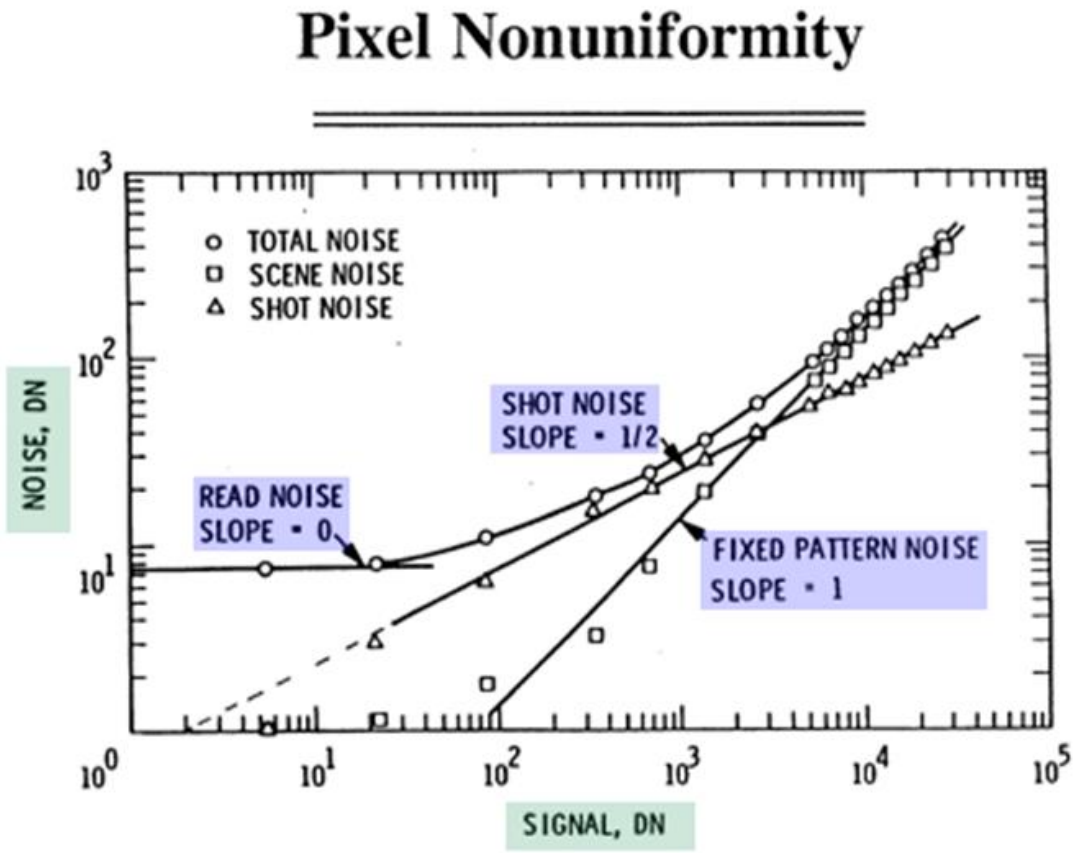
Estimators and estimators errors

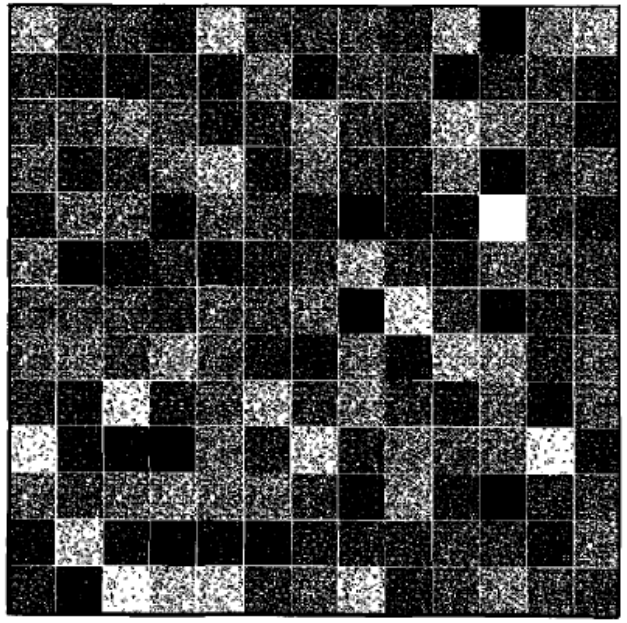
$$\sigma_S^2(DN^2) = \frac{S}{K} + \sigma_{RON}^2$$

$$\bar{S}(DN) = \frac{\sum_n S_n}{n} \qquad \sigma_{\bar{S}} = \frac{\sigma_S}{\sqrt{n}} \qquad n = number\ of\ samples$$

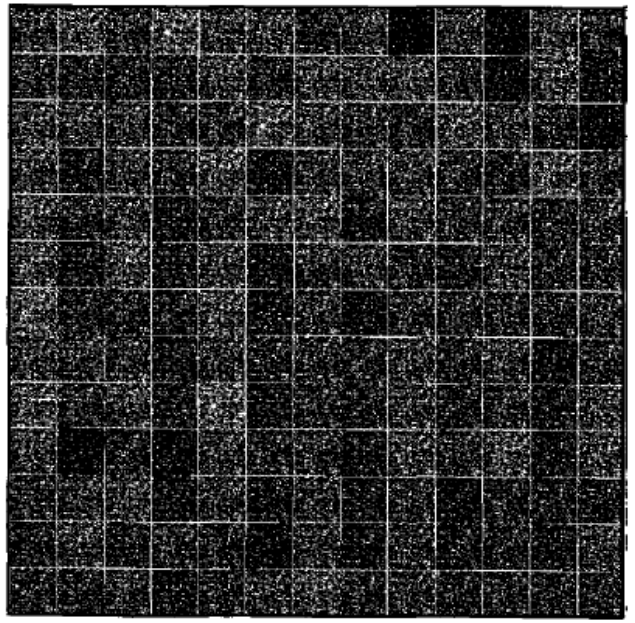
$$\overline{\sigma_S^2}(DN) = \frac{\sum_n (S_n - \bar{S})}{n-1} \qquad \sigma_{\overline{\sigma_S^2}} = \sigma_S^2 \sqrt{\frac{2}{(n-1)}}$$

Fixed pattern noise





NON INVERTED

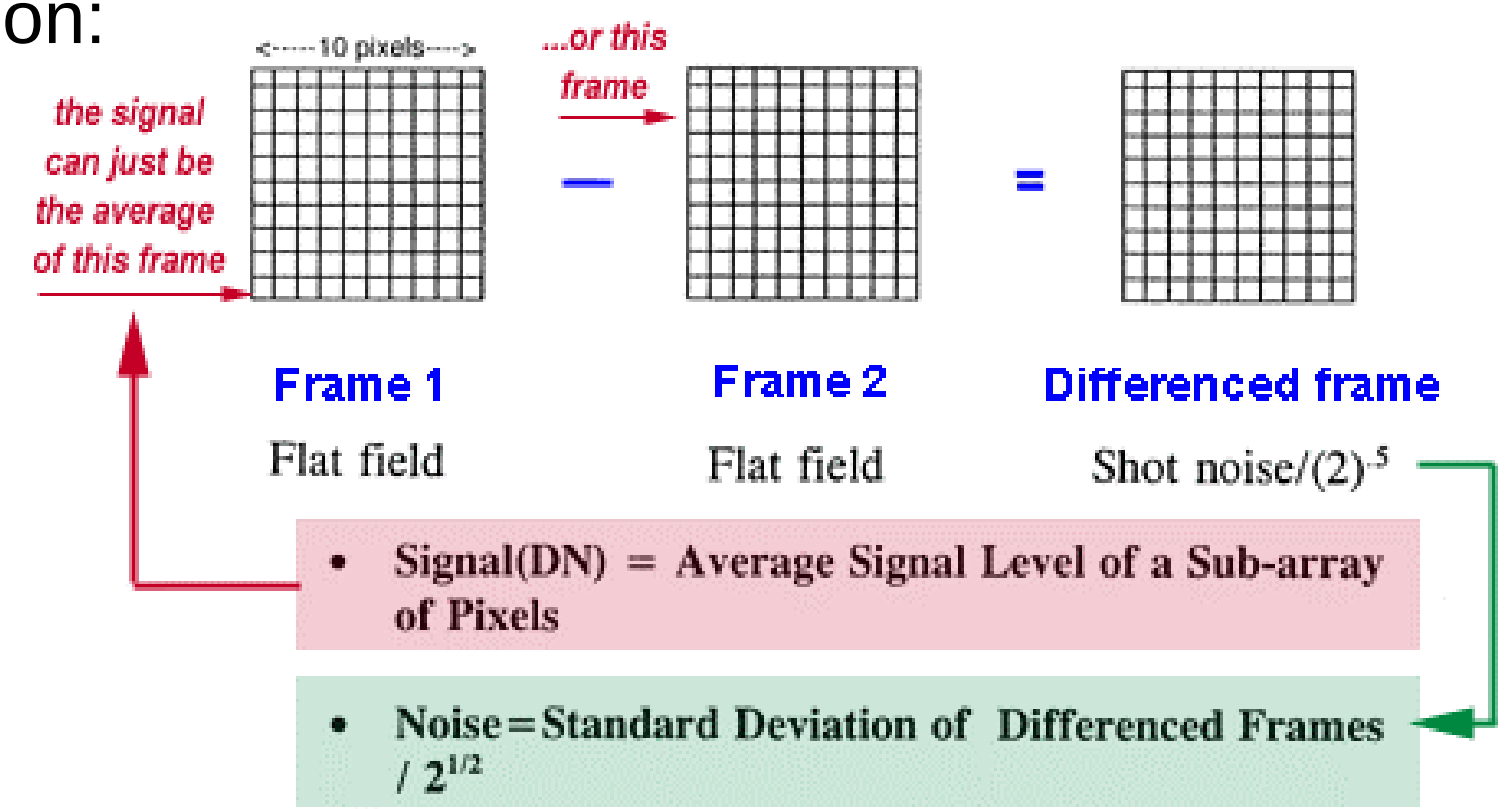


INVERTED

Pixels data analysis strategies

1. Flat fielding

1. Two images subtraction:



Pixels data analysis strategies

Pixel by pixel statistics on multiple images:

Advantages:

- Characterisation of each pixel measuring chain
- No need for matrix pre- analysis (hot or cold spots identification) or data normalization (flat fielding)
- Cumulative statistics (many pixel)
- Identification of matrix defect

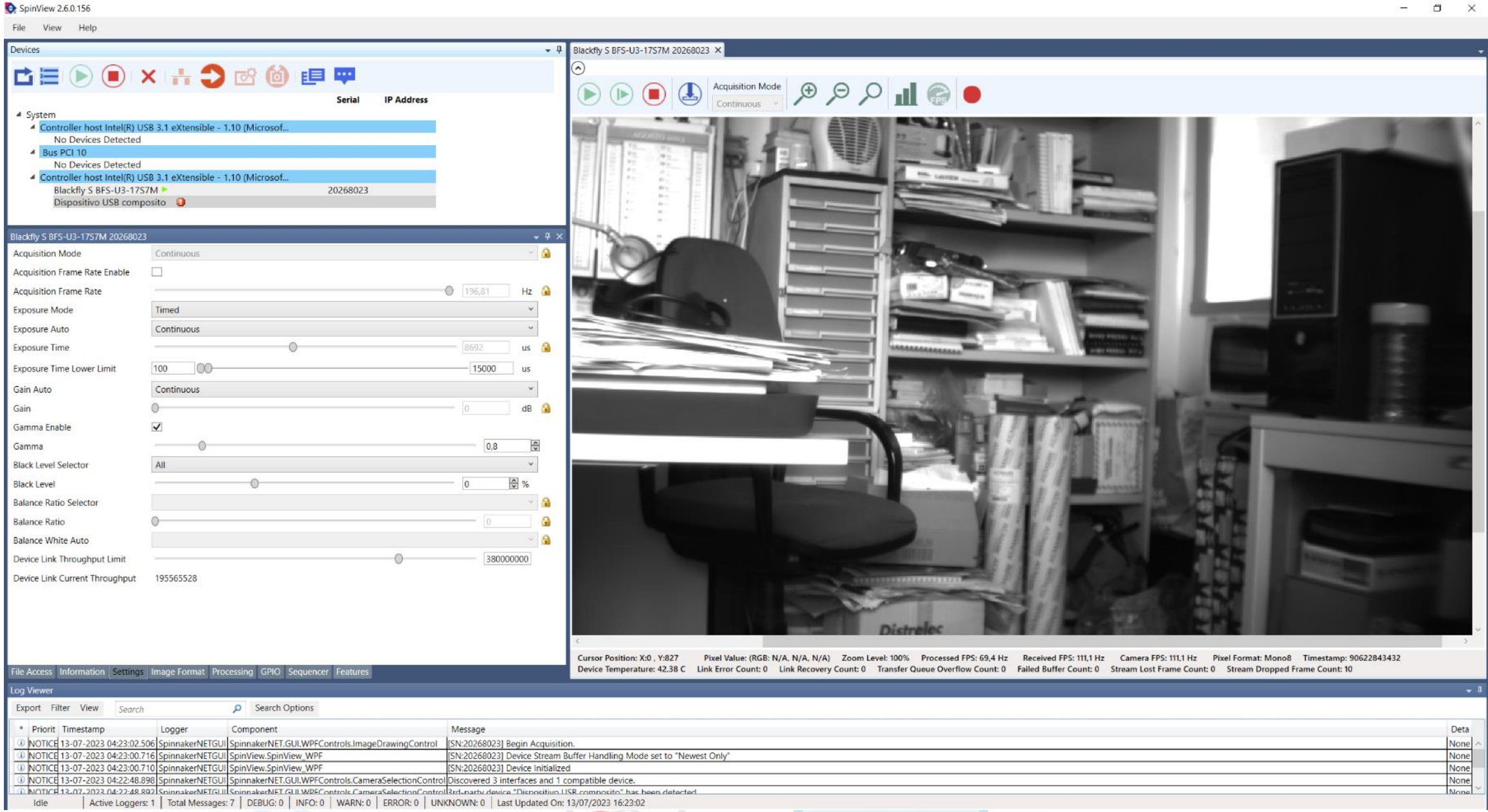
Disadvantages: multiple images acquisition (100 - 1000)

In the lab

SONY IMX425
Monochrome 12 bit camera
~125 Hz max frame rate
~ 1,3MB/image

DON'T TOUCH THE CAMERA: IT COULD BE VERY HOT UP 70 °C

In the lab


SpinView 2.6.0.156
File View Help
Devices
Serial IP Address
System
Controller host Intel(R) USB 3.1 eXtensible - 1.10 (Microsof...
No Devices Detected
Bus PCI 10
No Devices Detected
Controller host Intel(R) USB 3.1 eXtensible - 1.10 (Microsof...
Blackfly S BFS-U3-17S7M 20268023
Dispositivo USB composito
Blackfly S BFS-U3-17S7M 20268023
Acquisition Mode Continuous
Acquisition Frame Rate Enable
Acquisition Frame Rate 196,81 Hz
Exposure Mode Timed
Exposure Auto Continuous
Exposure Time 8692 us
Exposure Time Lower Limit 100 15000 us
Gain Auto Continuous
Gain 0 dB
Gamma Enable
Gamma 0,8
Black Level Selector All
Black Level 0 %
Balance Ratio Selector
Balance Ratio 0
Balance White Auto
Device Link Throughput Limit 380000000
Device Link Current Throughput 195565528
File Access Information Settings Image Format Processing GPIO Sequencer Features
Blackfly S BFS-U3-17S7M 20268023
Acquisition Mode Continuous
Cursor Position: X:0 , Y:827 Pixel Value: (RGB: N/A, N/A, N/A) Zoom Level: 100% Processed FPS: 69,4 Hz Received FPS: 111,1 Hz Camera FPS: 111,1 Hz Pixel Format: Mono8 Timestamp: 90622843432
Device Temperature: 42,38 C Link Error Count: 0 Link Recovery Count: 0 Transfer Queue Overflow Count: 0 Failed Buffer Count: 0 Stream Lost Frame Count: 0 Stream Dropped Frame Count: 10
Log Viewer
Export Filter View Search Search Options
Priorit Timestamp Logger Component Message Deta
NOTICE 13-07-2023 04:23:02.506 SpinnakerNETGUI SpinnakerNET.GUI.WPFControls.ImageDrawingControl [SN:20268023] Begin Acquisition. None
NOTICE 13-07-2023 04:23:00.716 SpinnakerNETGUI SpinView.SpinView_WPF [SN:20268023] Device Stream Buffer Handling Mode set to "Newest Only" None
NOTICE 13-07-2023 04:23:00.710 SpinnakerNETGUI SpinView.SpinView_WPF [SN:20268023] Device Initialized None
NOTICE 13-07-2023 04:22:48.898 SpinnakerNETGUI SpinnakerNET.GUI.WPFControls.CameraSelectionControl Discovered 3 interfaces and 1 compatible device. None
Idle Active Loggers: 1 Total Messages: 7 DEBUG: 0 INFO: 0 WARN: 0 ERROR: 0 UNKNOWN: 0 Last Updated On: 13/07/2023 16:23:02