Strumentazione Astronomica: Camere per Immagini

Le camere per immagini: Charge Coupled Device (CCD)

Sono sensori a stato solido (semiconduttori) che convertono i fotoni in elettroni.

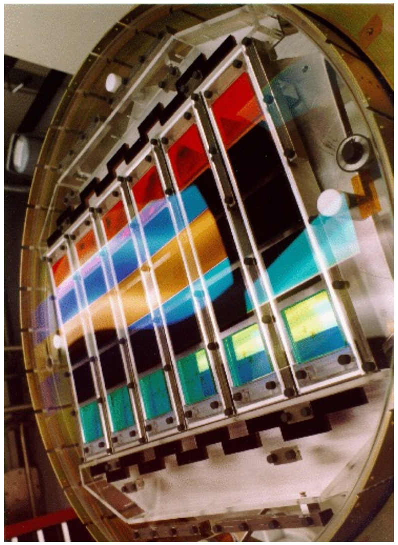
Non hanno, almeno per i fotoni nel dominio visibile, risoluzione energetica.

Hanno un’elevata efficienza quantica (QE).

Si possono comporre a mosaico.

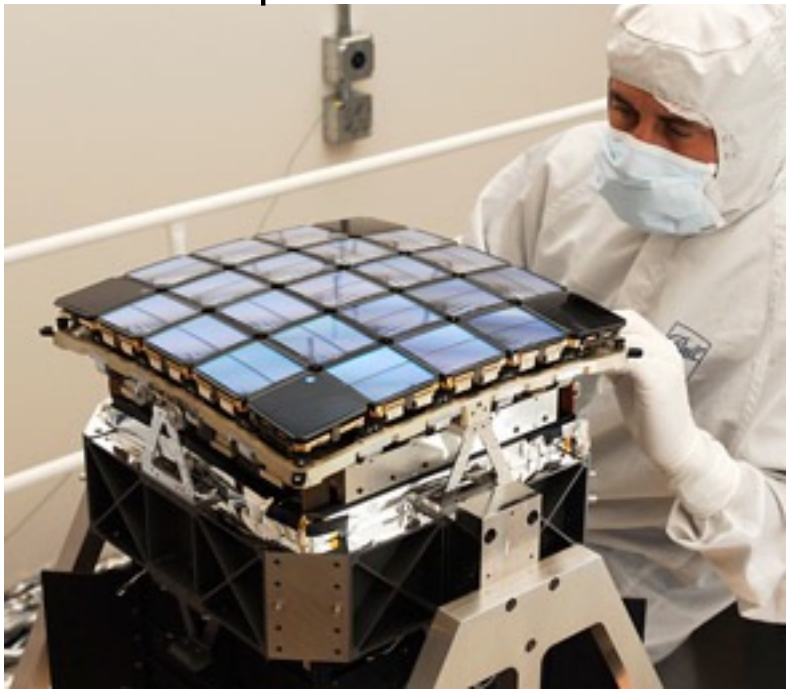
Si basano sul principio del trasferimento di carica.

Non hanno filtri colorati per comporre un’immagine a colori



SDSS 30 CCD

Kepler mission 42 CCD



Strumentazione Astronomica: IR-VIS detectors

Dominio dei rivelatori a matrice (CCD, CMOS, IR-ARRAY)

Principio di funzionamento basato sull'effetto fotoelettrico (soglia)

Nei semiconduttori si viene a creare una struttura a bande:
l'assorbimento di un fotone provoca il passaggio di un elettrone dalla banda di valenza a quella di conduzione

$$E_{Th}(eV) = kT = 0.026\left(\frac{T}{300}\right)eV$$ Energia di eccitazione termica

$$\lambda_C = \frac{hc}{E_G} = \frac{1.24}{E_G(eV)}$$ Cut-off wavelength (μm)

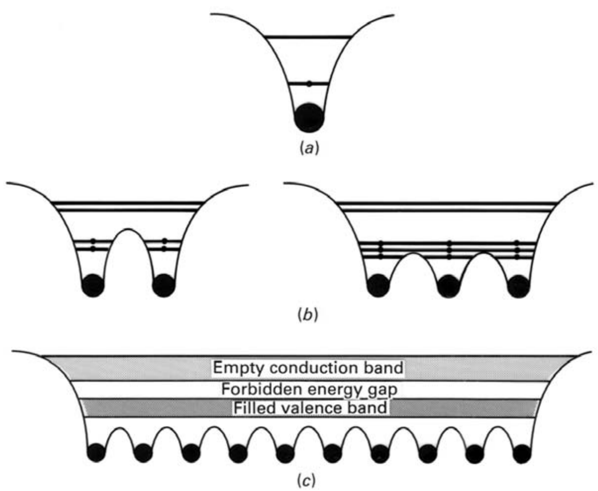
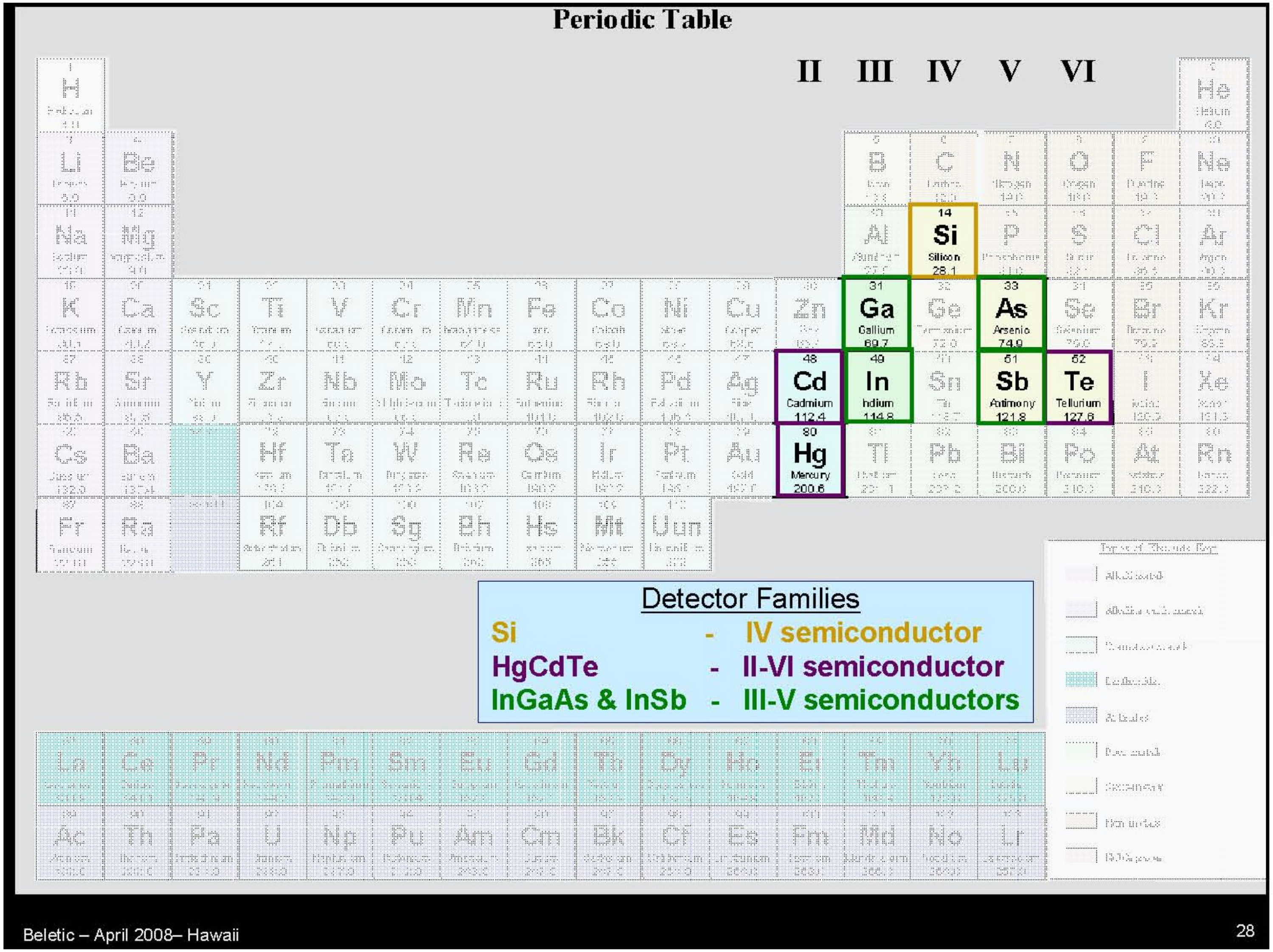


Figure 5.13. Simplified schematic of the formation of a bandgap in a semiconductor crystal.

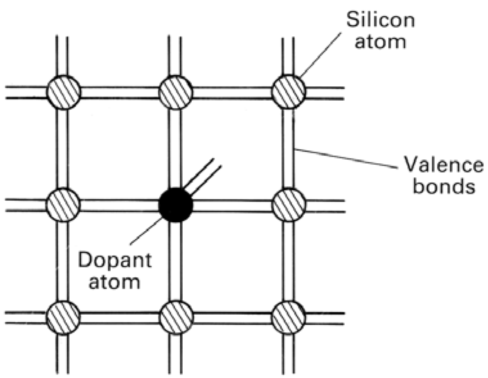
Table 5.2. Forbidden energy gaps for some common semiconductors.

Name	*Symbol*	*T* (K)	E_G (eV)	λ_c (μm)
Gallium nitride	GaN	295	3.45	0.36
Silicon carbide	SiC	295	2.86	0.43
Cadmium sulfide	CdS	295	2.4	0.5
Cadmium selenide	CdSe	295	1.8	0.7
Gallium arsenide	GaAs	295	1.35	0.92
Silicon	Si	295	1.12	1.11
Germanium	Ge	295	0.67	1.85
Lead sulfide	PbS	295	0.42	2.95
Indium antimonide	InSb	295 77	0.18 0.23	6.9 5.4
Mercury cadmium telluride	$Hg_xCd_{1-x}Te$	77	0.1 ($x = 0.8$) 0.5 ($x = 0.554$)	12.4 2.5

Strumentazione Astronomica: IR detectors



Strumentazione Astronomica: IR-VIS detectors



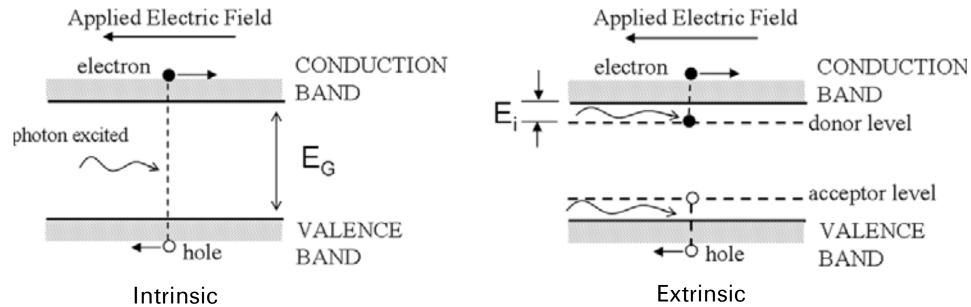


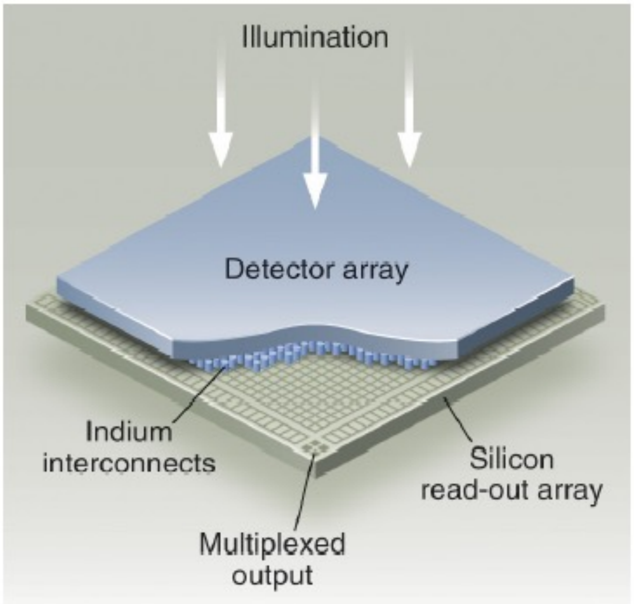
Figure 5.15. An intrinsic bandgap and the location of energy levels within the bandgap due to doping to form an extrinsic semiconductor.

Il *drogaggio* (doping) nei cosiddetti semiconduttori *estrinseci* ha l'effetto di creare dei livelli energetici intermedi rendendoli adeguati alla rivelazione dei fotoni IR

Table 5.3. Extrinsic semiconductors, doping material, and long-wavelength cutoff.

Base	*: Impurity*	λ_c (μm)	*Base*	*: Impurity*	λ_c (μm)
Silicon (Si)	: In	8.0	Germanium (Ge)	: Au	8.27
	: Ga	17.1		: Hg	13.8
	: Bi	17.6		: Cd	20.7
	: Al	18.1		: Cu	30.2
	: As	23.1		: Zn	37.6
	: P	27.6		: Ga	115
	: B	28.2		: B	119.6
	: Sb	28.8		: Sb	129

Strumentazione Astronomica: IR-VIS detectors

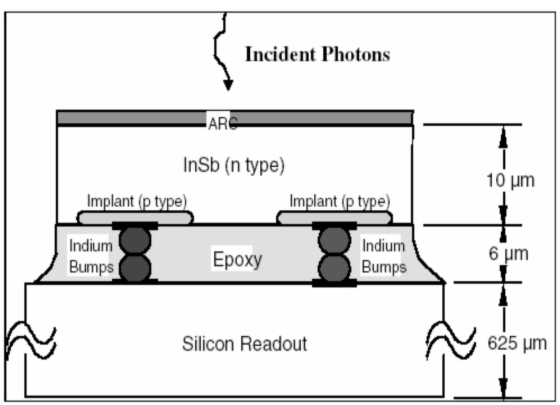


	Digital Imaging Step	Technologies
1	Get light into the detector	• Anti-reflection coating • Substrate removal
2	Charge generation	• Detector material growth
3	Charge Collection	• p-n junctions
4	Charge-to-Voltage Conversion	• Amplifiers optimized for flux, speed, and noise – Source follower – Capacitive Transimpedance Amplifier – Direct Injection
5	Signal Transfer	• Multiplexer • Scanner
6	Digitization	• Analog-to-digital converters

Steps 1–3: Infrared Detector Material

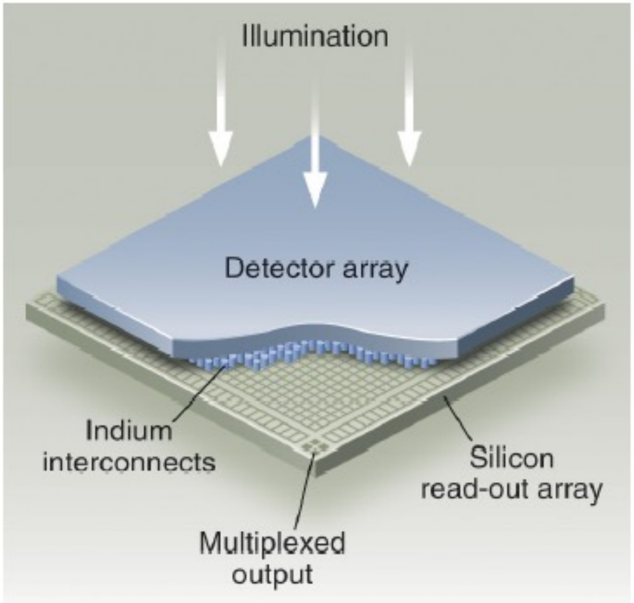
Steps 4–6: CMOS Integrated Circuit

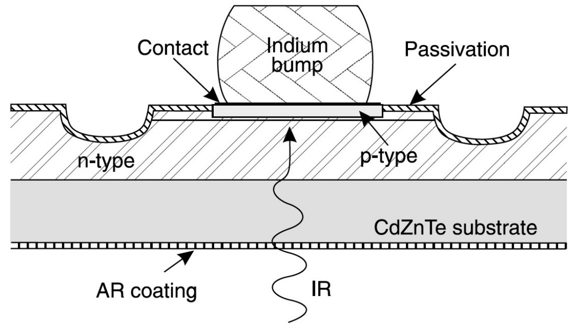
Fig. 2: Hybrid CMOS image array architecture (left) and the 6 steps of digital imaging. Drawing on left is courtesy of *Laser Focus World*. CMOS denotes complimentary metal-oxide-semiconductor.

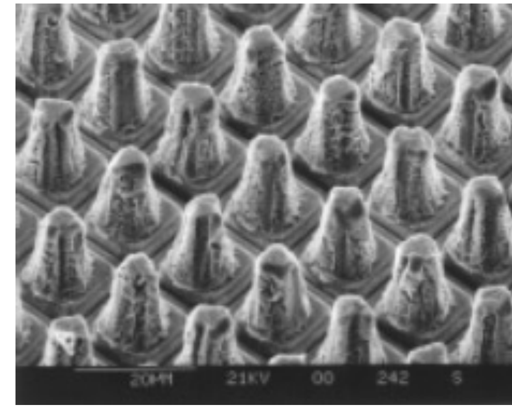


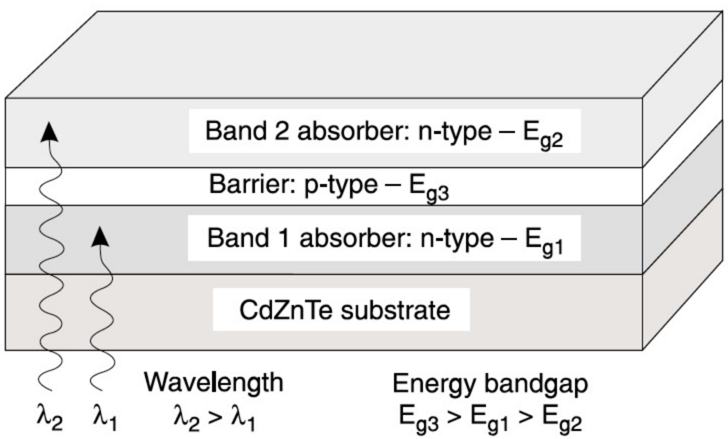
CMOS: complementary metal-oxide semiconductor

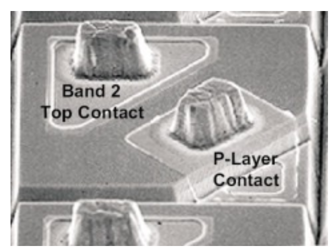
Strumentazione Astronomica: IR-VIS detectors





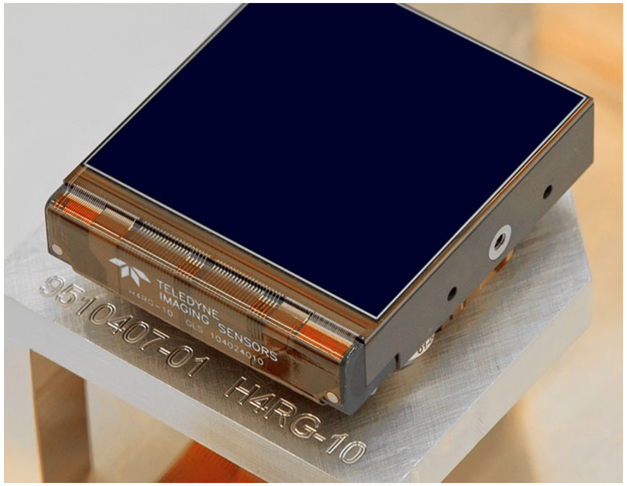




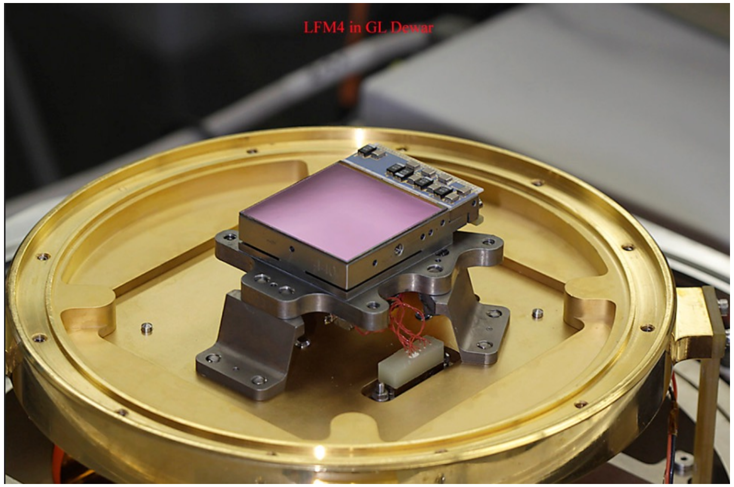


Sfruttando la lunghezza d’onda di penetrazione si possono realizzare sensori che lavorano a 2 colori

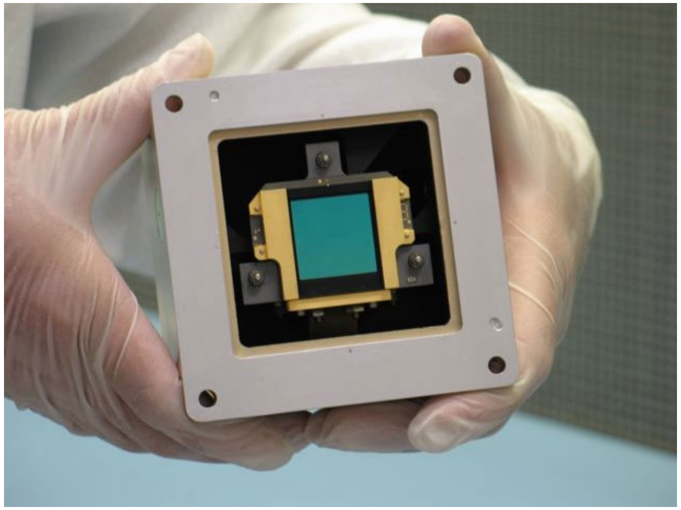
Strumentazione Astronomica: IR-VIS detectors



4096x4096 HAWAII-4RG Teledyne HgCdTe sensor



2048x2048 HAWAII-H2RG Teledyne HgCdTe sensor for JWST NIRcam



1000x1000 Si:As Raytheon Vision Systems mid-IR sensor

1024x1024 Si:As AQUARIUS Raytheon Vision Systems mid-IR sensor for VLT

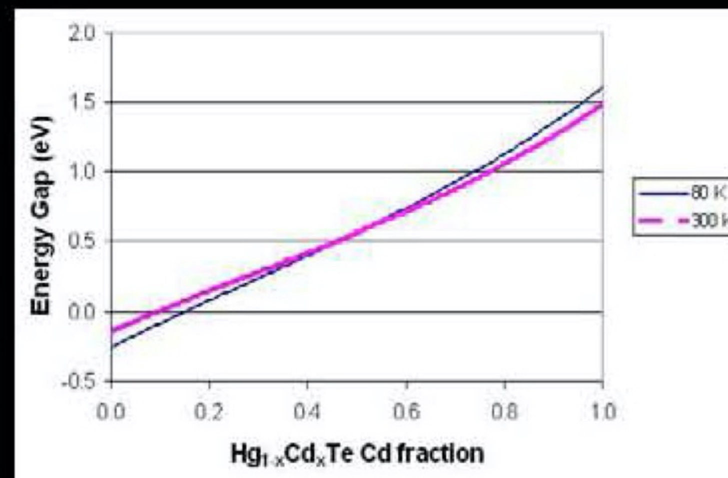
Strumentazione Astronomica: IR detectors

Tunable Wavelength
Unique property of Mercury-Cadmium-Telluride

$Hg_{1-x}Cd_xTe$

Modify ratio of Mercury and Cadmium to "tune" the bandgap energy

x	E_g (eV)	λ_c (μm)
0.196	.09	14
0.21	.12	10
0.295	.25	5
0.395	.41	3
0.55	.73	1.7
0.7	1.0	1.24



Bandgap is temperature dependent. Numbers in table are approximate.

$$E_g = -0.302 + 1.93x - 0.81x^2 + 0.832\,x^3 + 5.35\times10^{-4}\,T(1-2x)$$

G. L. Hansen, J. L. Schmidt, T. N. Casselman, J. Appl. Phys. 53(10), 1982, p. 7099

Strumentazione Astronomica: IR detectors

Regola del pollice: lo spessore dello strato sensibile deve essere dell'ordine della $\lambda_{cut\ off}$

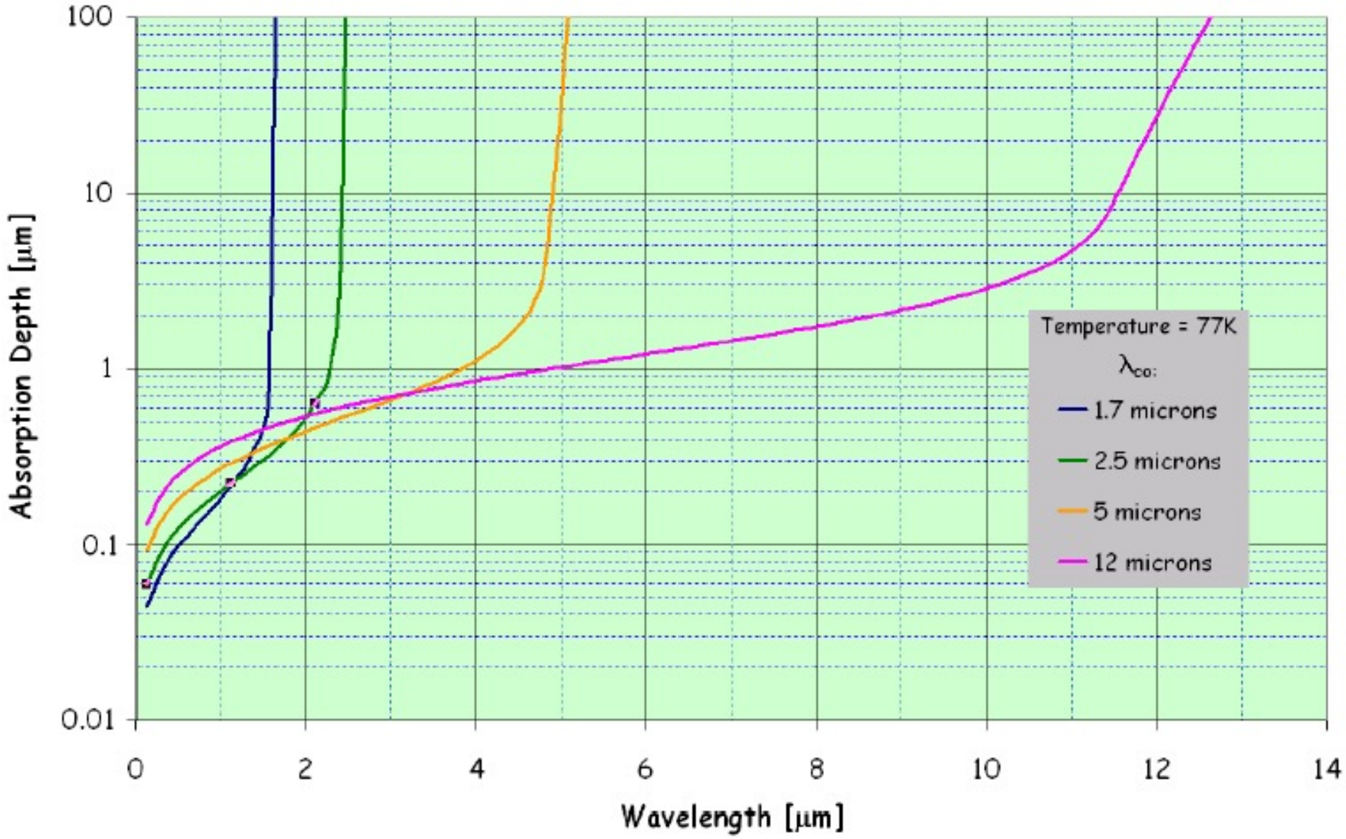


Fig. 5: Absorption depth of photons in HgCdTe as a function of cutoff wavelength. Values are shown for 77K temperature. For high quantum efficiency, the thickness of the HgCdTe detector layer should be at least equal the cutoff wavelength of light.

Strumentazione Astronomica: IR detectors

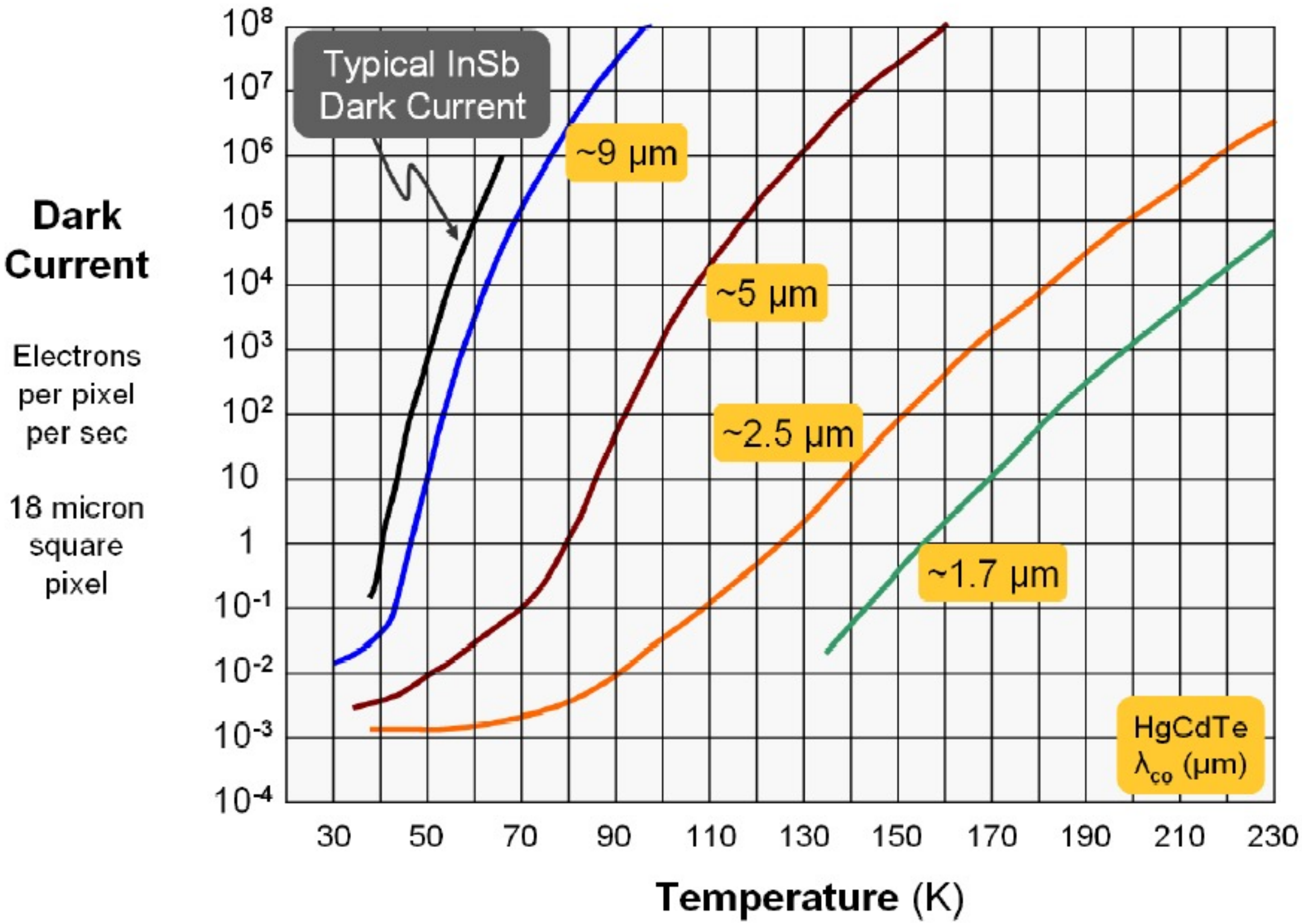
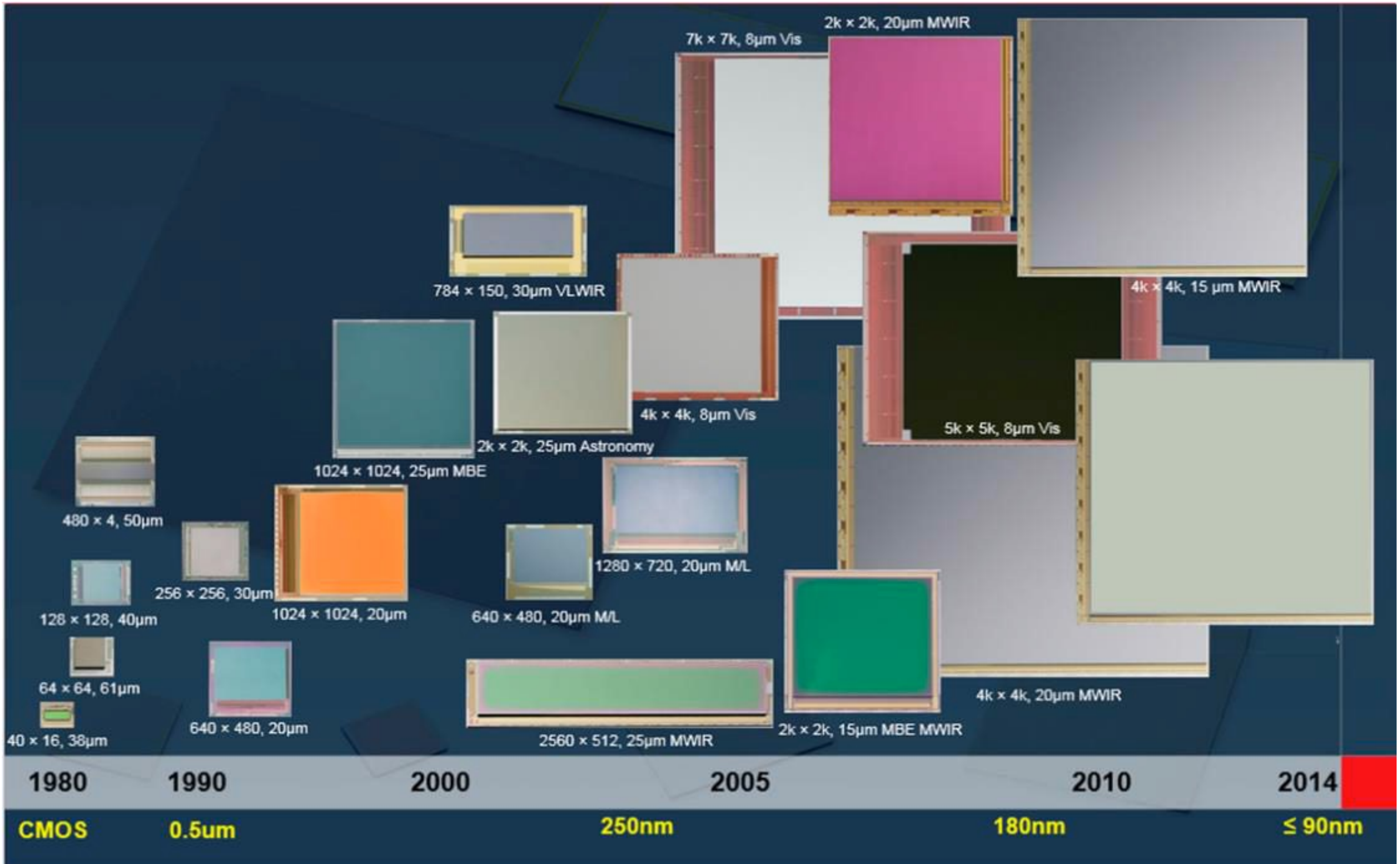


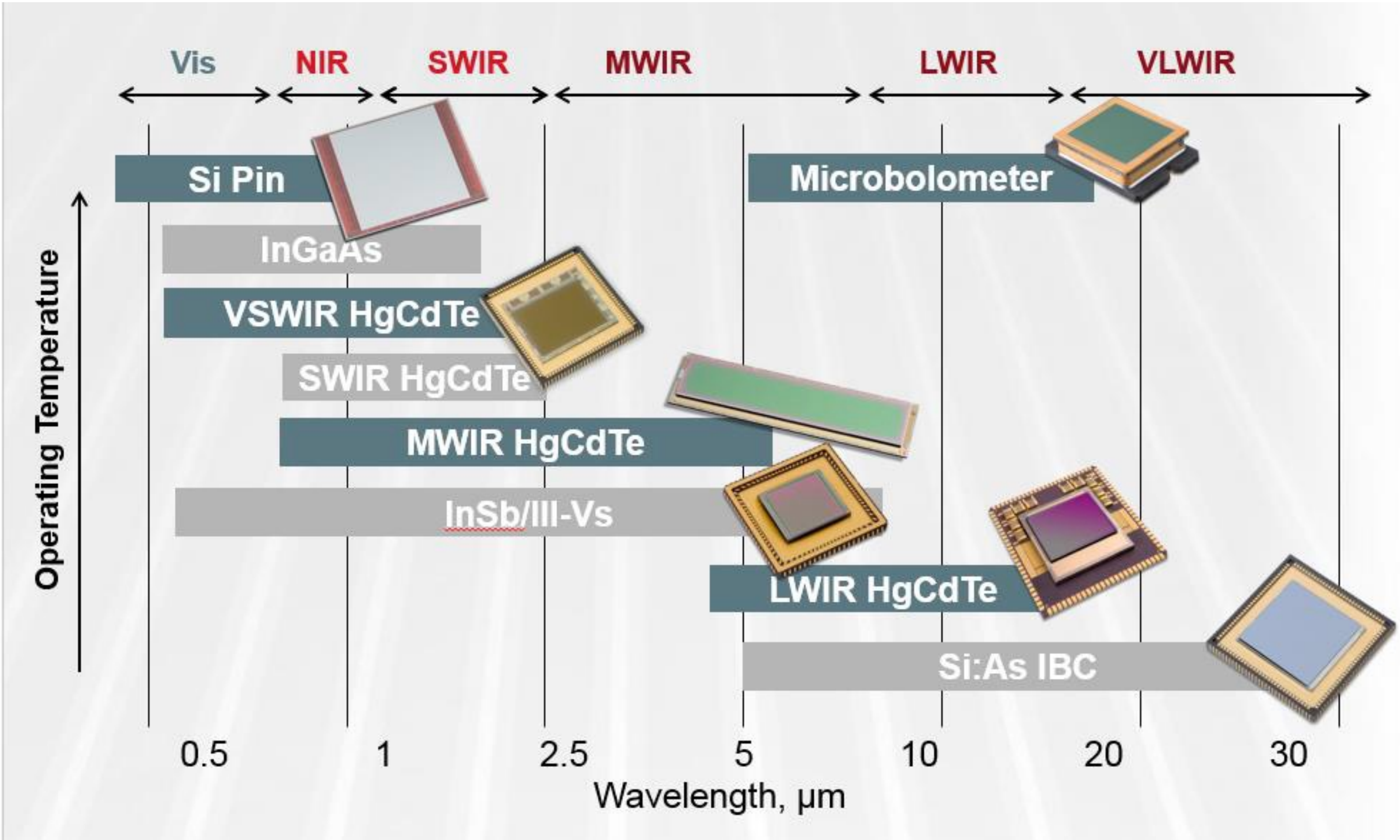
Fig. 8: The dark current of MBE grown HgCdTe detector material. The dark current is shown for an 18 µm pixel and can be scaled for smaller or larger pixel pitch. The cutoff wavelength (λ_{co}) is shown with the approximation symbol, since λ_{co} is a function of temperature and there will be slight variation in cutoff wavelength of a HgCdTe detector as it cools.

Strumentazione Astronomica: IR detectors



Evoluzione dei sensori infrarossi

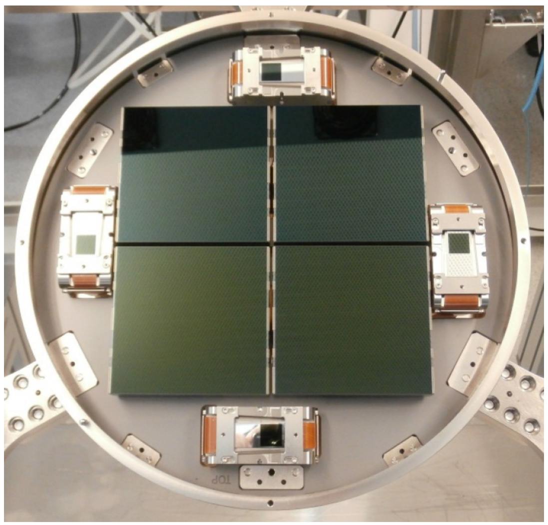
Strumentazione Astronomica: IR detectors



Differenti materiali utilizzati per i rivelatori infrarossi nell'intera banda

Strumentazione Astronomica: CCD

CCD per il visibile



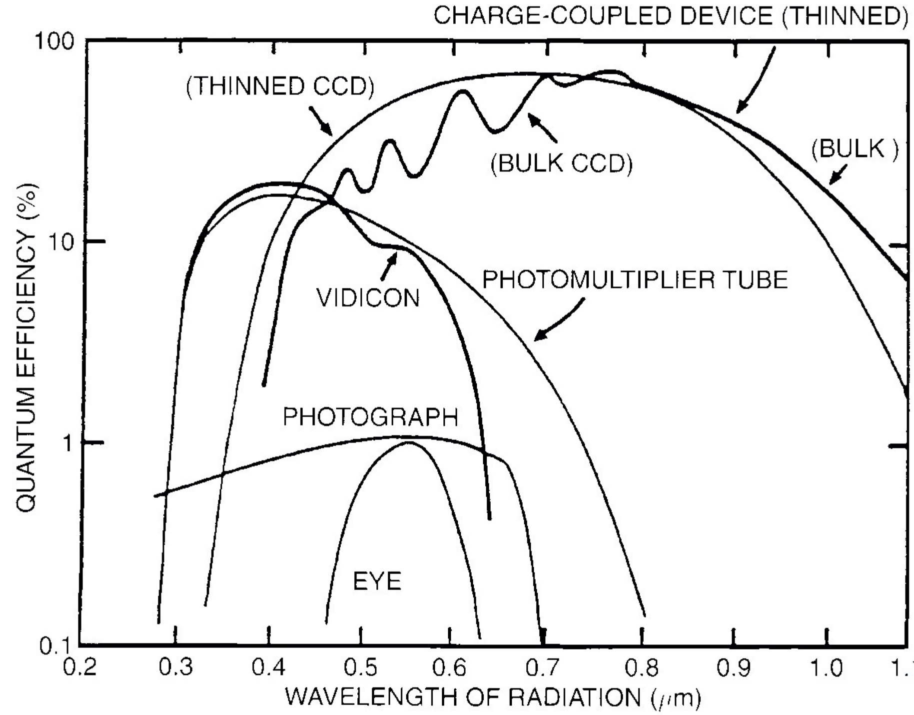
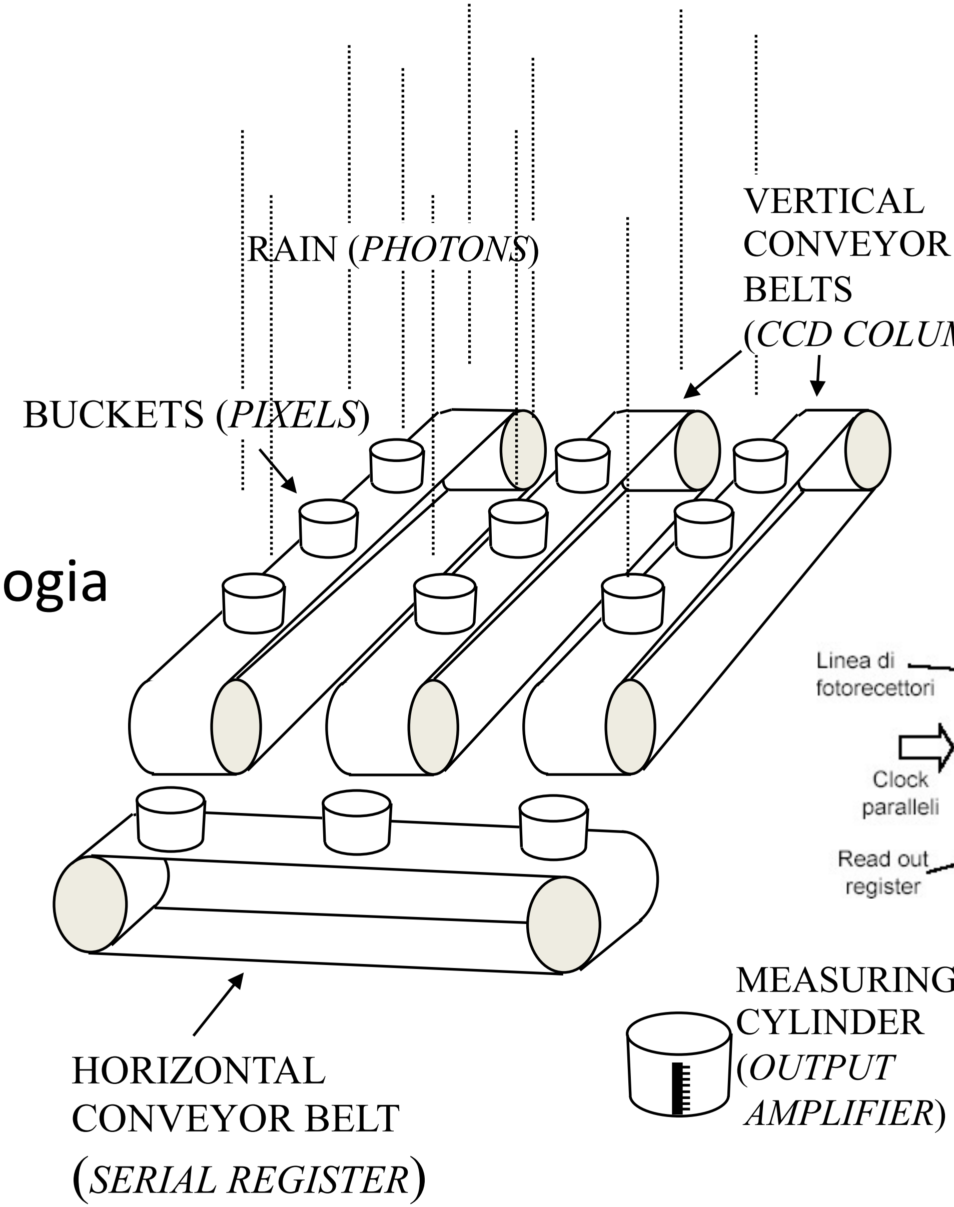


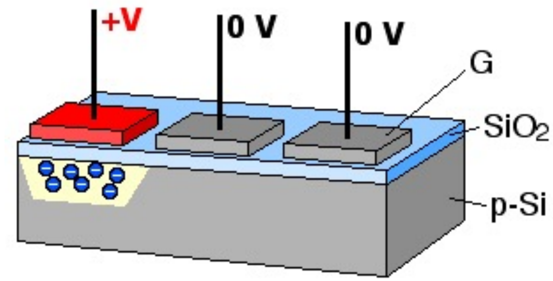
Fig. 3.2. QE curves for various devices, indicating why CCDs are a quantum leap above all previous imaging devices. The failure of CCDs at optical wavelengths shorter than about 3500 Å has been essentially eliminated via thinning or coating of the devices (see Figure 3.3).

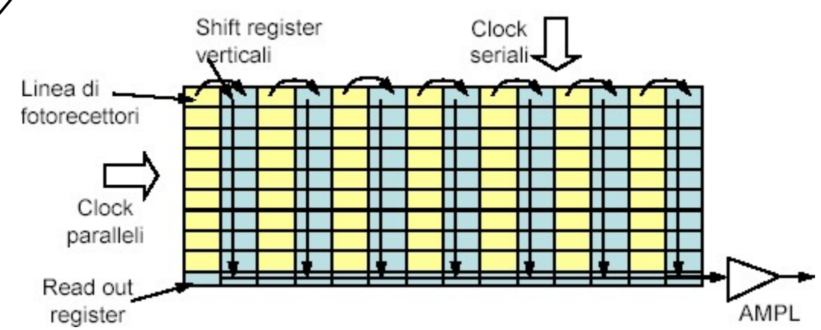
Detector type	QE	Special property
Photographic plates	2% (3% Kodak IIIaJ)	Sensitive to UV + blue light ⇒ need special coating to be sensible in visible.
Hypersentitized plates	10%	(chemically processed and cooled)
Electronic devices	20-40% bandpass similar to CCD	not precise in flux and position need high voltage to work
CCD	90%	reach ~ 60% over 2/3 of bandpass

Strumentazione Astronomica: CCD

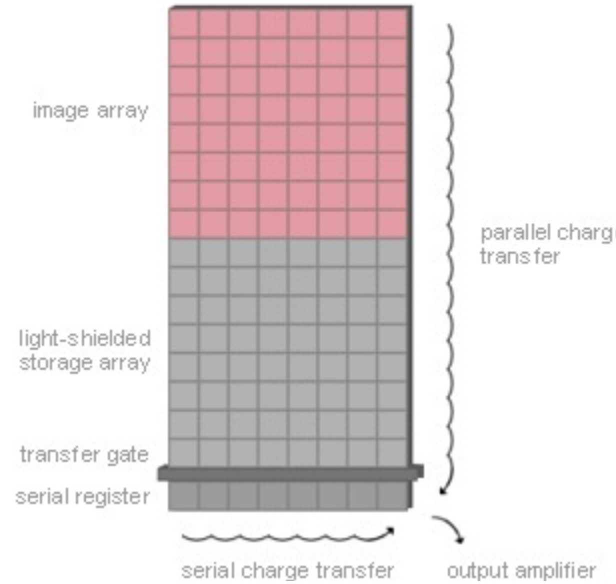
CCD: analogia







Strumentazione Astronomica: CCD



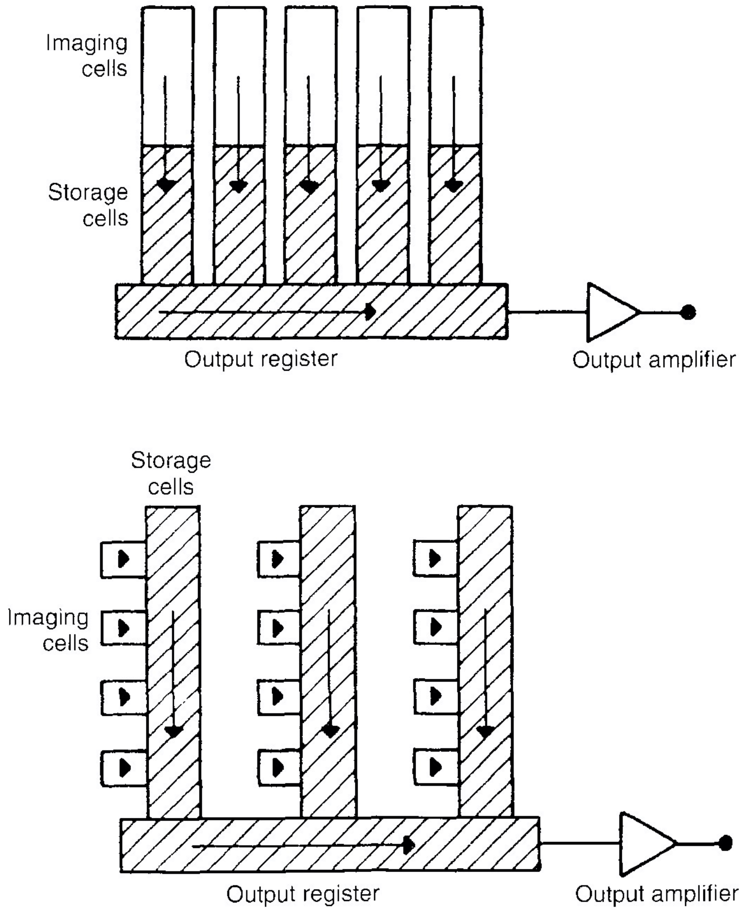
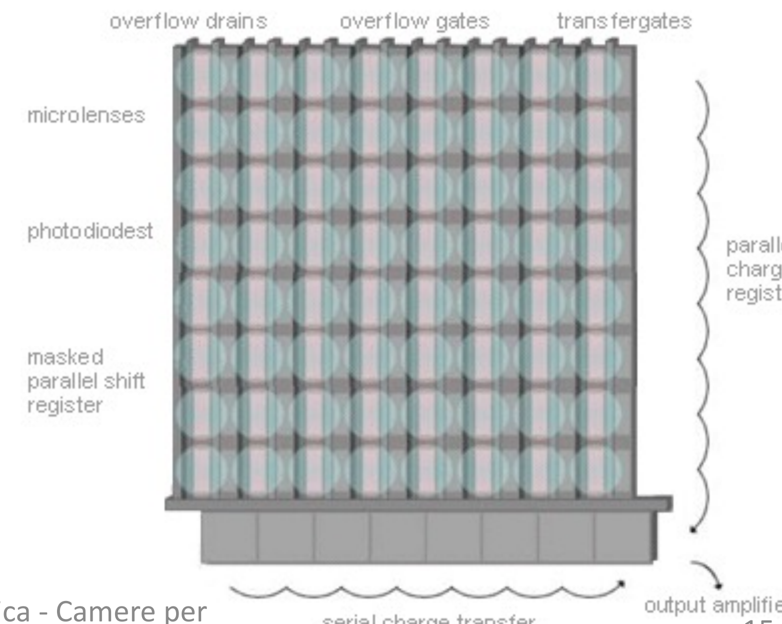


Fig. 2.5. Cartoon view of (top) a frame transfer CCD and (bottom) an interline CCD. From Eccles, Sim. & Tritton (1983).



Strumentazione Astronomica: CCD

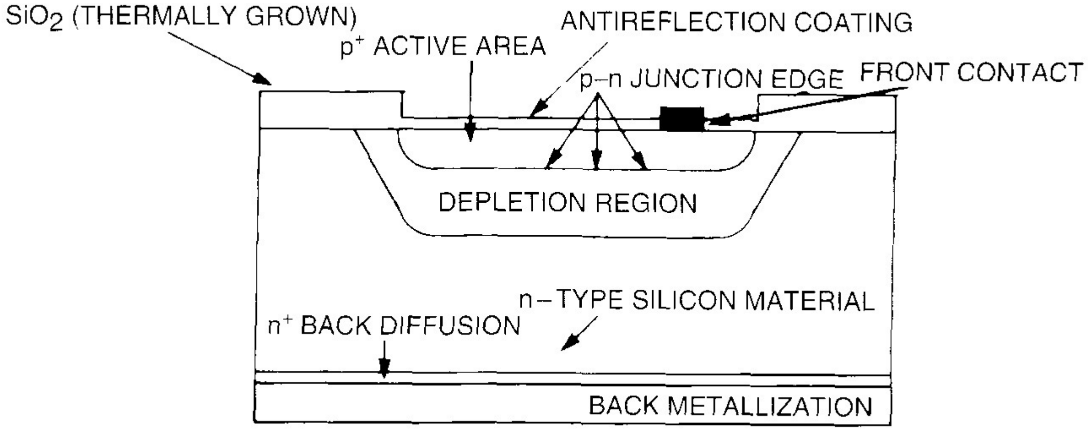


Fig. 2.4. Schematic view of a single front-side illuminated CCD pixel. The square labeled "front contact" is a representation of part of the overall gate structure. The letters "p" and "n" refer to regions within the pixel consisting of silicon doped with phosphorus and boron respectively.

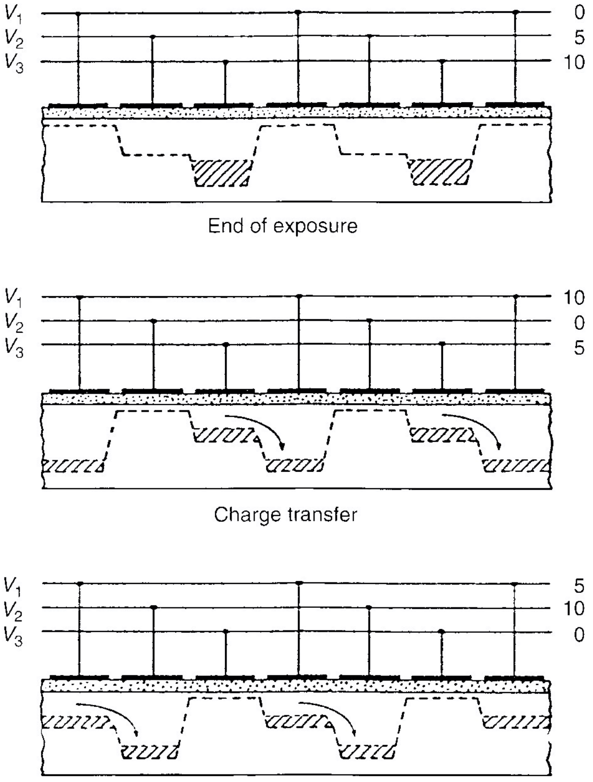
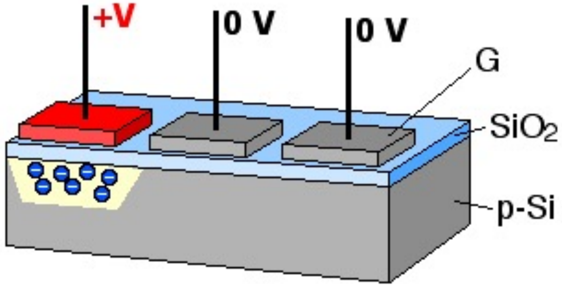
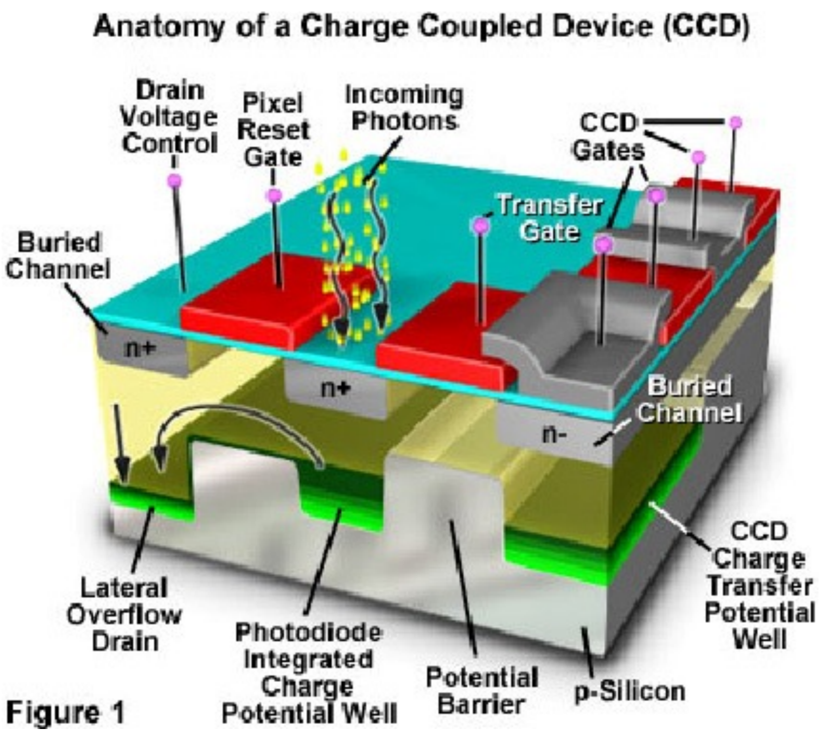
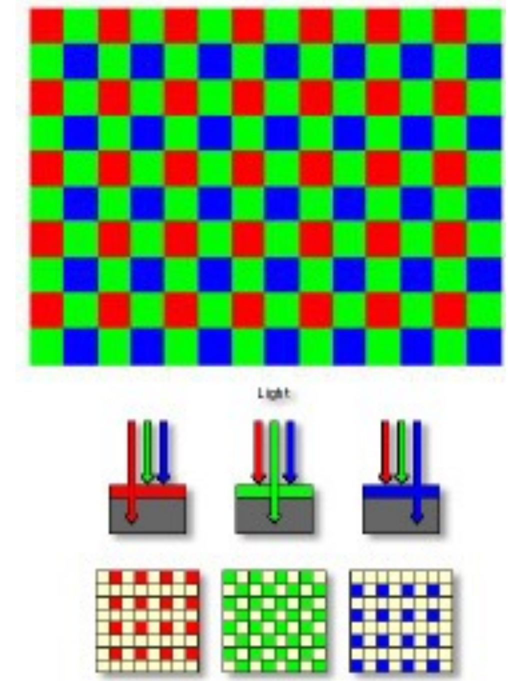


Fig. 2.2. Schematic voltage operation of a typical three-phase CCD. The clock voltages are shown at three times during the readout process, indicating their clock cycle of 0, 10, and 5 volts. One clock cycle causes the stored charge within a pixel to be transferred to its neighboring pixel. CCD readout continues until all the pixels have had their charge transferred completely out of the array and through the A/D converter. From Walker (1987).



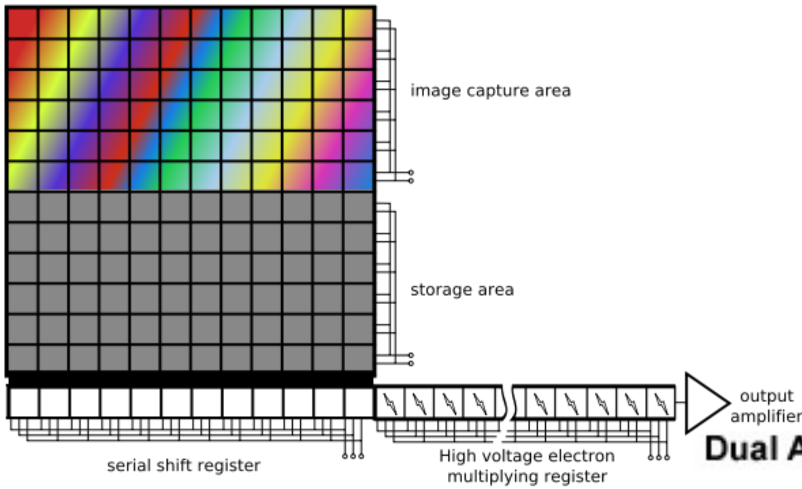
Strumentazione Astronomica: CCD

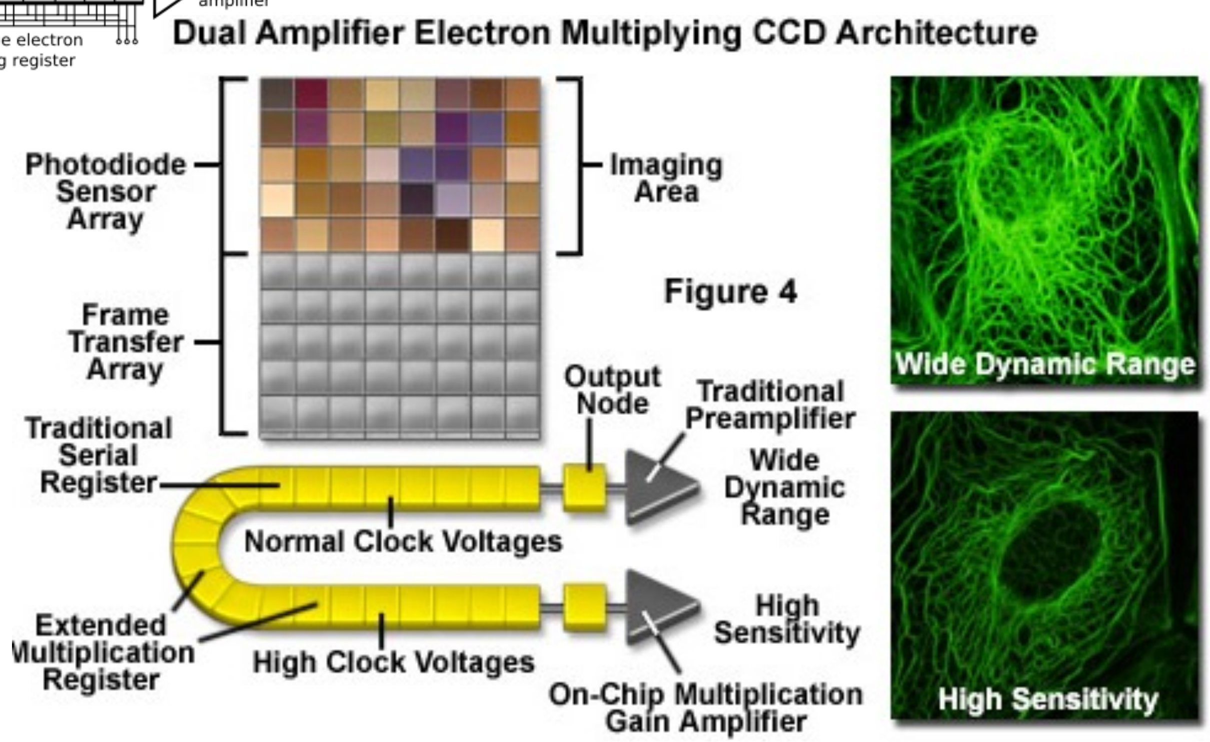




In una macchina fotografica il CCD (o CMOS) ha integrati dei filtri colorati per catturare colori

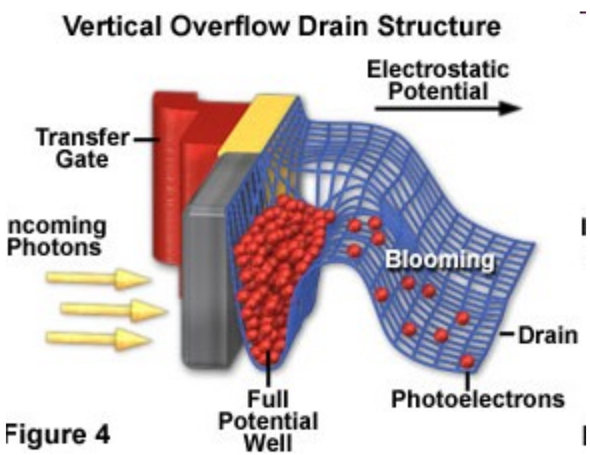
Strumentazione Astronomica: CCD

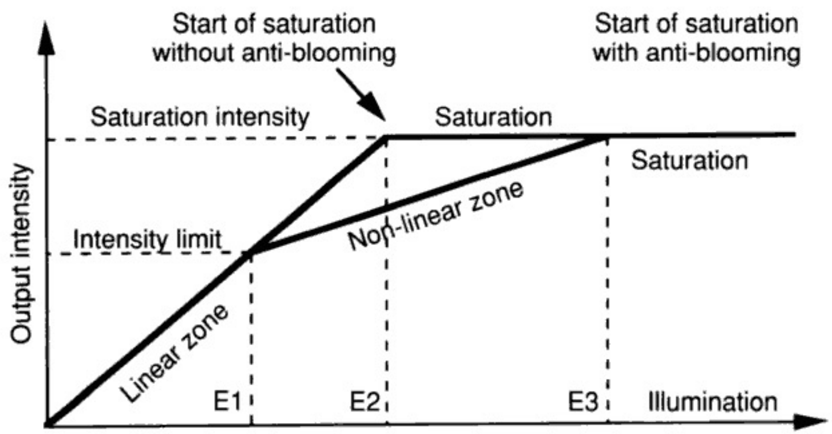




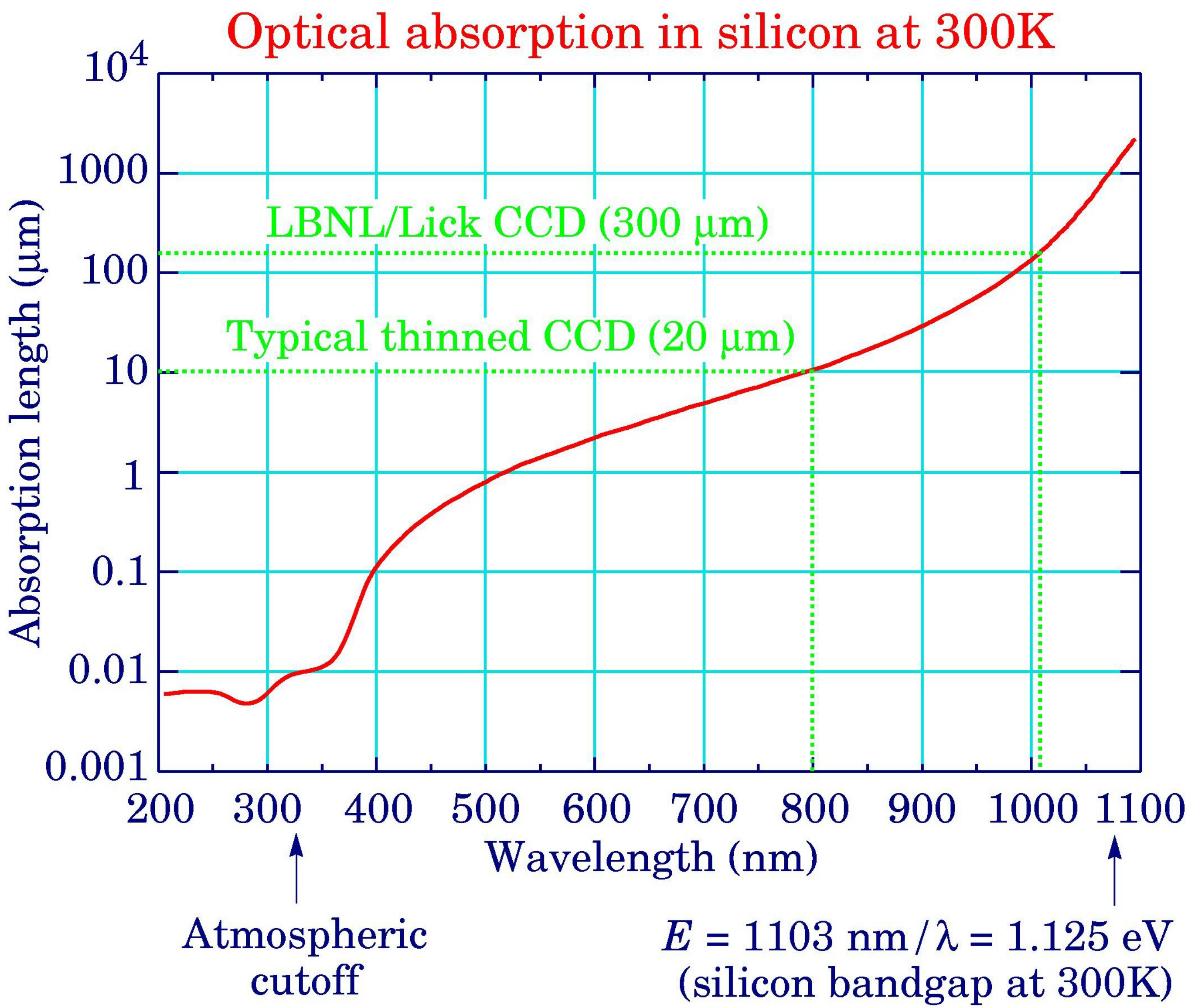
Strumentazione Astronomica: CCD

Blooming

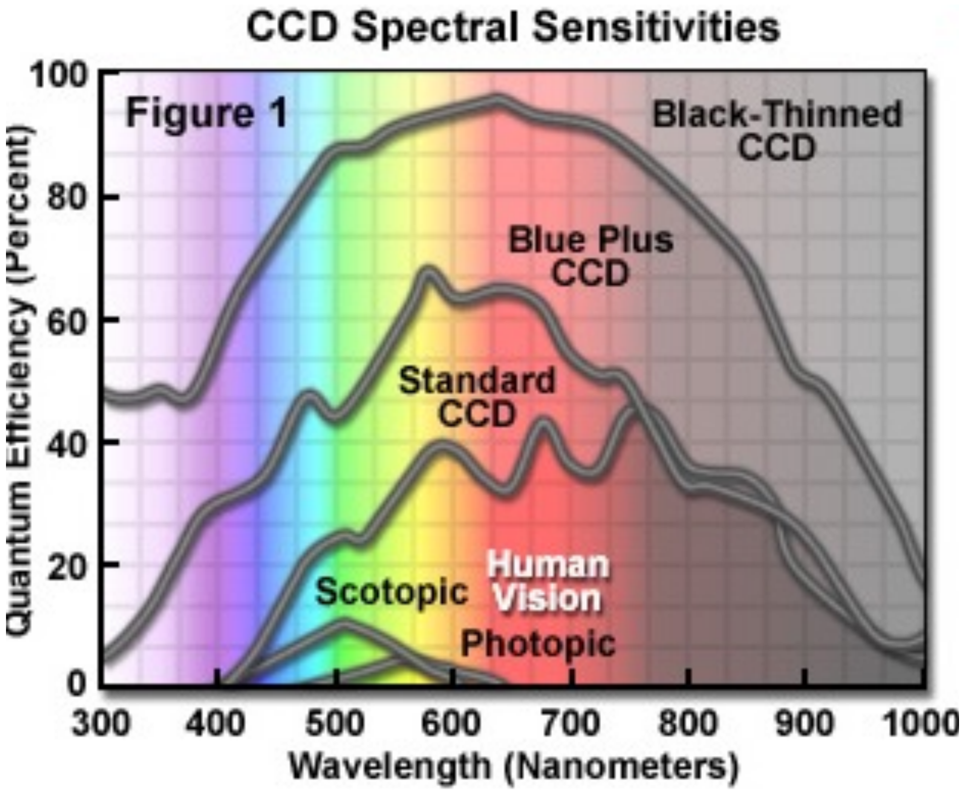


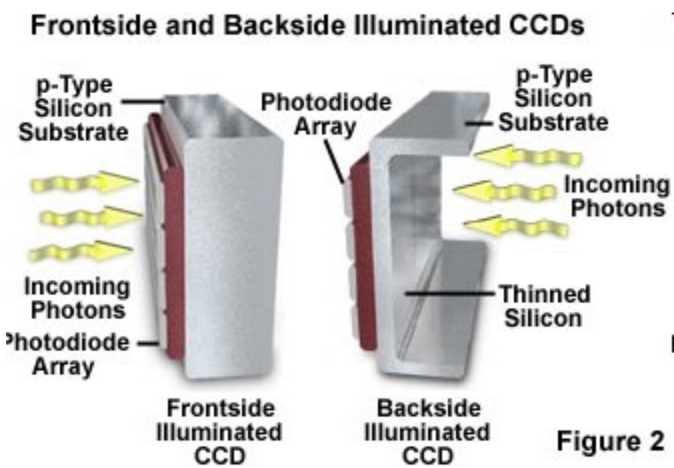


Strumentazione Astronomica: CCD



Strumentazione Astronomica: CCD





Assottigliare i CCD per estenderne il range spettrale

Strumentazione Astronomica: CCD