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Dipartimento di Astronomia e Scienza dello Spazio

XUVLab

Dr. Mauro Focardi

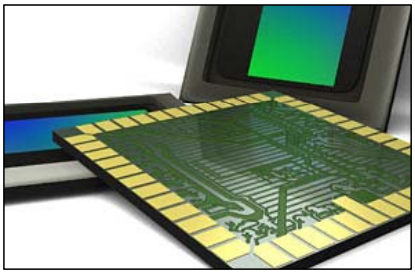
Dip. Astronomia e Scienza dello Spazio

Università di Firenze

E-mail: mauro@arcetri.astro.it

Tel: 055 2307 762

w³: http://www.arcetri.astro.it/~mauro/



CMOS sensor: resolution 3,264H x 2,448V; Pixel Size:1.75 µm x 1.75 µm

CCD sensor

Sensori CCD vs CMOS APS in applicazioni spaziali

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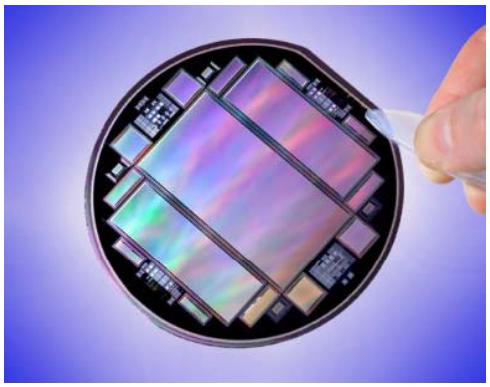
Rivelatori al silicio

CCDs and CMOS APS sensors are manufactured on silicon wafers using the same photo-lithographic techniques used to manufacture computer chips. Scientific CCDs are very big ,only a few can be fitted onto a wafer. This is one reason that they are so costly.



The photo shows a silicon wafer with three large CCDs and assorted smaller devices. A CCD has been produced by Philips that fills an entire 6 inch wafer.

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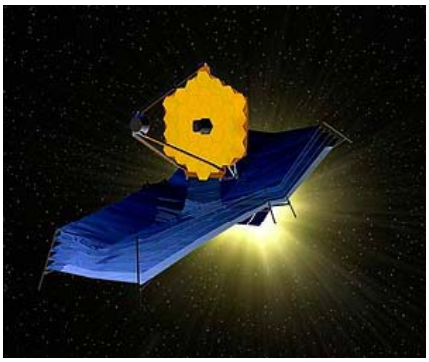
Caratteristiche dei rivelatori per l'imaging dallo spazio

Per la ripresa di immagini scientifiche dallo spazio sono fondamentali alcune caratteristiche dei sensori che possono contribuire singolarmente o globalmente alla durata nominale della missione e ad eventuali estensioni della medesima.
Fra queste:

- Radiation hardness;
- High sensitivity;
- Very low noise;
- Large area;
- Solar blindness;
- Chemical inertness;
- Low mass;
- Low consumption.



JWST- James Webb Space Telescope

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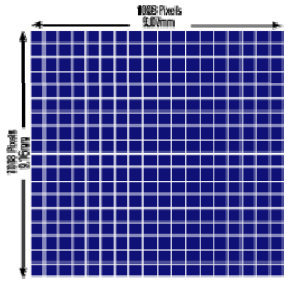
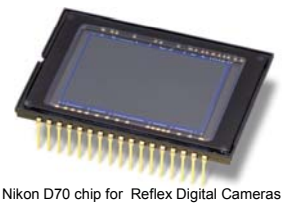
CCD s – Charge Coupled Devices

- ✓ CCDs are arrays of MOS capacitors;
- ✓ Typical pixel sizes are 10 - 40 µm per side;
- ✓ Pixels are not always square;
- ✓ Arrays come in all sorts of sizes from 16 x 16 to 4048 x 4048 and beyond;
- ✓ Quality varies *tremendously* depending on the application and the cost;
- ✓ Linear over large ranges of illumination;
- ✓ High quantum efficiencies (60%+);

Fairchild linear CCD 191 is a 6,000 element linear CCD with 10 µm pixels. This device offers the ultimate in dynamic range, QE and resolution.





Nikon D70 chip for Reflex Digital Cameras

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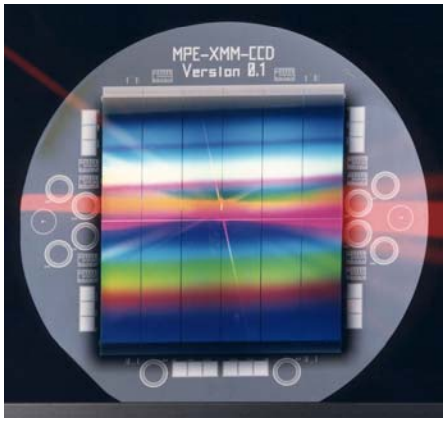
CCD utilizzati in missioni spaziali

XMM - Newton



HST

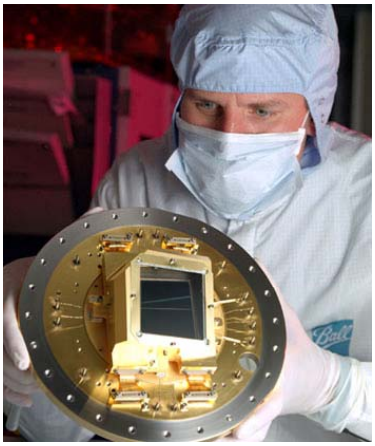


Image courtesy of Bell Aerospace & Technologies Corp.

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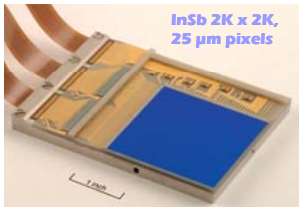
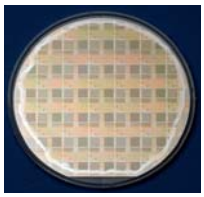
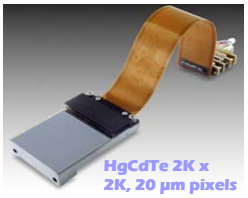
CMOS Active Pixel Sensors



InSb 2K x 2K, 25 µm pixels

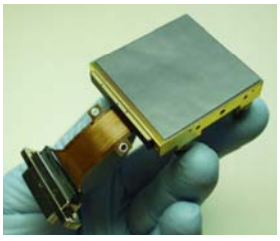


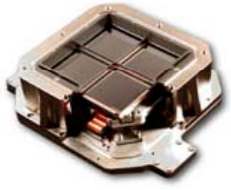
3D stacked CMOS Silicon wafer sandbox



HgCdTe 2K x 2K, 20 µm pixels

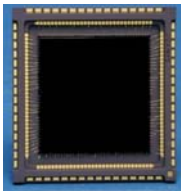
HgCdTe 2K x 2K, 18 µm pixels





HgCdTe 4K x 4K mosaic, 18 µm pixels

Monolithic CMOS 4K x 4K, 5 µm pixels



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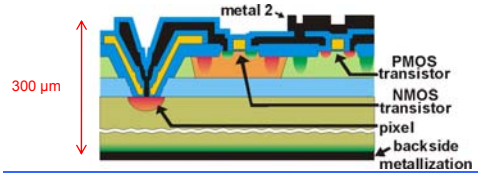
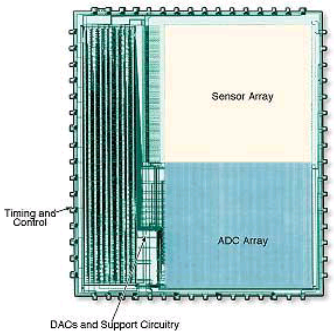
CMOS APS – caratteristiche

- ✓ CMOS APS are arrays of photodiodes and transistors;
- ✓ Photosites are phodiodes;
- ✓ Typical pixel sizes are 1 - 10 µm per side;
- ✓ Pixels are not always square;
- ✓ Arrays come in all sorts of sizes from 64 x 64 to 4048 x 4048;
- ✓ Linear over medium ranges of illumination;
- ✓ Low quantum efficiencies (50%);
- ✓ Low fill factor (< 50%).





CMOS APS di 256 x 256 pixels. Array sviluppato al Jet Propulsion Laboratory (NASA) per applicazioni relative a programmi spaziali.

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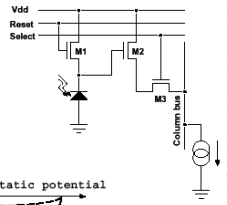
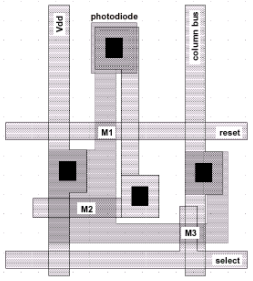
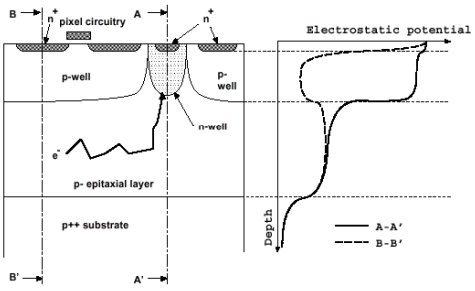
CMOS APS – architetture e layout del pixel

Schematico circuitale





Layout (in pianta)



Sezione trasversale

Andamento del potenziale

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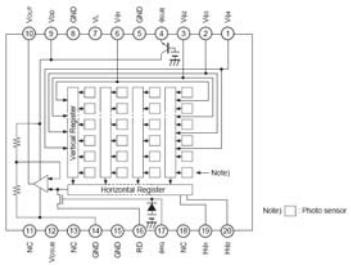
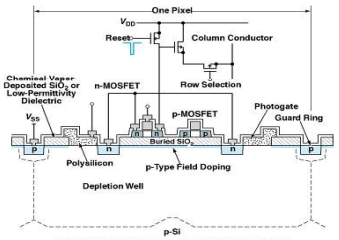
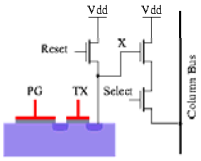
CMOS APS – architetture e layout del pixel

EX VIEW H.A.D. e SUPER H.A.D. (Hole Accumulation Diode) Sony.
CCD o CMOS APS?

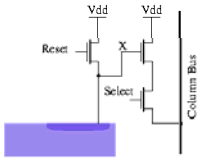




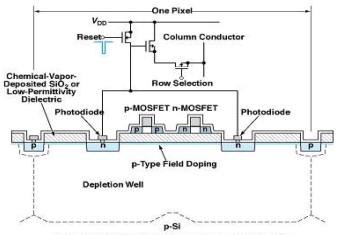
APS WITH PHOTOGATE AND JUNCTION GUARD RING



(a)
Photogate pixel



(b)
Photodiode pixel



APS WITH PHOTODIODE AND JUNCTION GUARD RING

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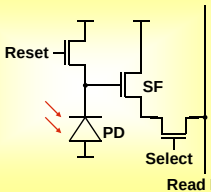
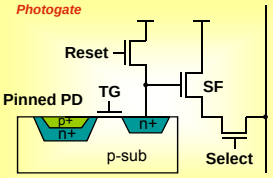
CMOS APS – architetture e layout del pixel

A monolithic CMOS APS 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.

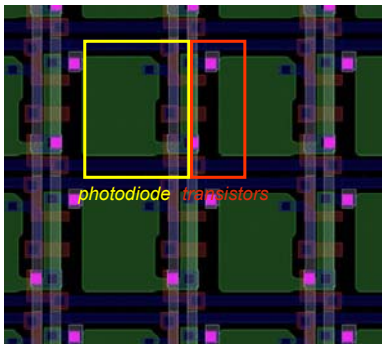
Photodiode



Photogate



Typical applications: digital cameras, cell phones, etc…



Design layout

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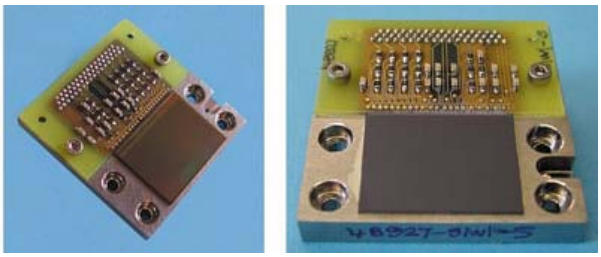
Sensori CMOS APS per lo spazio

The Imaging Systems Division at the Rutherford Appleton Laboratory (RAL) are developing science-grade CMOS Active Pixel Sensors (APS) for future space science missions. Recent work has included successful testing of back-thinned devices, and the production of a new test APS chip.



A 4k x 3k CMOS APS (left), with a back-thinned version (right). Pixels of 5 µm per side fabricated on a 0.25 µm CMOS imager process.

Charge Coupled Devices (CCDs) are the current detector of choice for most scientific space instruments, for X-rays to infrared radiation. CMOS sensors promise significant advantages over today's CCD technology. Firstly, modern CMOS processing enables smaller pixels than current science-grade CCDs, permitting more compact and lower mass instruments. Secondly, on-chip integration of the readout electronics minimises the size, mass and power requirements for ancillary control electronics and the associated problems of space-flight component procurement and radiation tolerance. Finally, deep sub-micron CMOS technology promises significantly higher radiation tolerance in the space environment compared to CCDs.

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Comparison CMOS vs CCD for Astronomy

Property	CCD	Hybrid CMOS
Resolution	> 4k x 4k	2k x 2k in use, 4k x 4k demonstrated
Pixel pitch	10 – 20 µm	10 – 40 µm, < 5 µm demonstrated
Typ. wavelength coverage	400 – 1000 nm	400 – 1000 nm with Si PIN 400 – 5000 nm with InSb or HgCdTe
Noise	Few electrons	Few electrons with multiple sampling
Shutter	Mechanical	Electronic, rolling shutter
Power Consumption	High	Typ. 10x lower than CCD
Radiation	Sensitive	Much less susceptible to radiation
Control Electronics	High voltage clocks, at least 2 chips needed	Low voltage only, can be integrated into single chip
Special Modes	Orthogonal Transfer, Binning, Adaptive Optics	Windowing, Guide Mode, Random Access, Reference Pixels, Large dynamic range (up the ramp)

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CCDs o CMOS sensors?

Principali limitazioni dei sensori CMOS in applicazioni spaziali (e non solo):

- Non sono lineari su ampi intervalli di illuminazione;
- Read-out noise elevato (tendenzialmente superiore a quello dei CCDs);
- Bassa efficienza quantica (< 50%);
- Basso filling factor (circa 50% o inferiore in quanto fotorivelatore e transistors condividono la medesima area);
- $QE*Ff_{max}$ = 60% (buono), generalmente < 20%;
- Piccola depletion well nel silicio (dinamica ridotta);
- Assorbimento e riflessione dei fotoni nel polysilicio (Si policristallino), nelle metallizzazioni e negli strati di ossido (SiO);
- Effetti di ricombinazione negli strati di interfaccia Si/SiO_2;
- Limitato range dinamico (12 bits in analog mode);
- Range spettrale limitato al visibile (SiGe CMOS).

Probabilmente, ancora oggi, uno dei fattori più importanti nella scelta di un sensore CCD o CMOS per lo spazio consiste nell'affidabilità e nella conoscenza dei sensori e delle camere CCD su un arco temporale che copre più di 35 anni di studi e ricerche.