

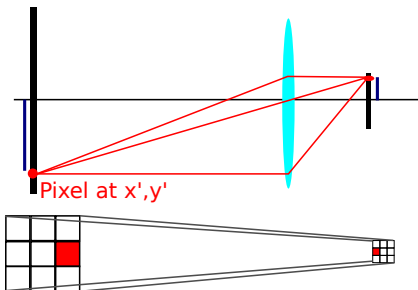
Advanced light microscopy

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- 1 Measuring light
 - History
 - Semiconductor
- 2 Digital signal processing



History: Film

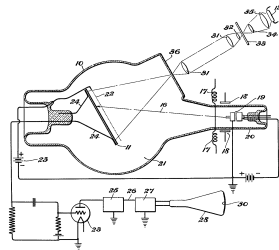


Wikimedia: Film

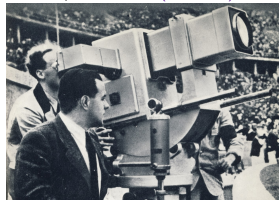
- Uses a photo-induced chemical reaction
- Today made obsolete by semiconductor devices and computer processing
- Question: How was live TV done before semiconductors?

History: Iconoscope

- Photo-sensitive coating on charged plate
- Photons allow local discharge of electrons
- Current of a read-out electron beam measures remaining charge

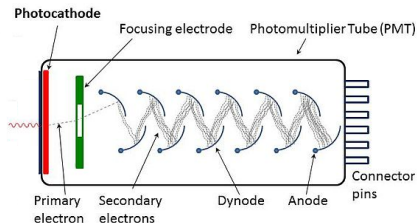


From US patent 2021907 (Wikimedia)



The "Olympic Cannon" (Wikimedia)

Point detectors: Photo multiplier tubes (PMTs)



Wikimedia: PMT

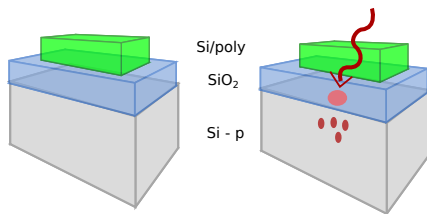


Wikimedia: PMT photo

- Photo effect yields one electron
- Cascade effect yields a few thousand electrons after some stages
- Read-out electronics has a much easier job measuring these
- Avalanche photo diodes: semi-conductor version of this effect

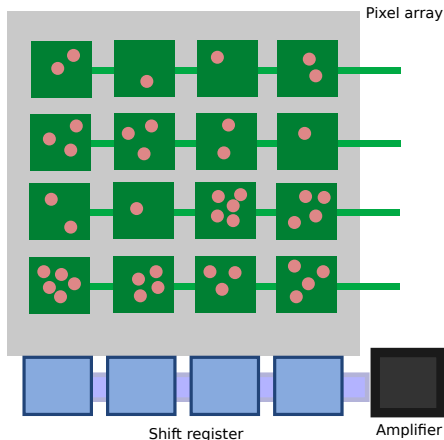
Semiconductors

Photosensitiv semi-conductor pixel

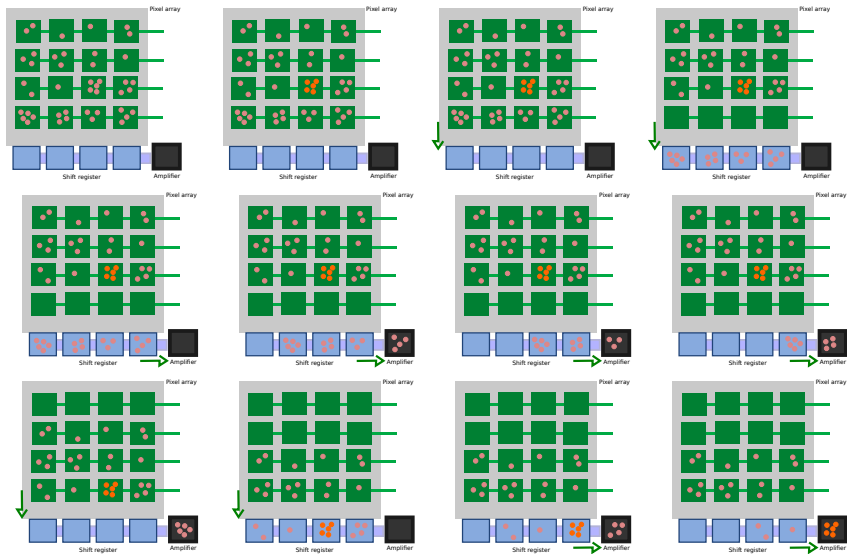


- Top layer: Conductive, transparent material, e.g. poly-crystalline silicon
- Middle layer: Insulating material, e.g. silicon dioxide
- Bottom layer: positively doped semiconductor, again silicon
- Top electrode charged negatively, creates depletion zone
- Incoming photon creates electron/depletion pair, electrons accumulate
- Question: How to measure the amount of collected electrons?

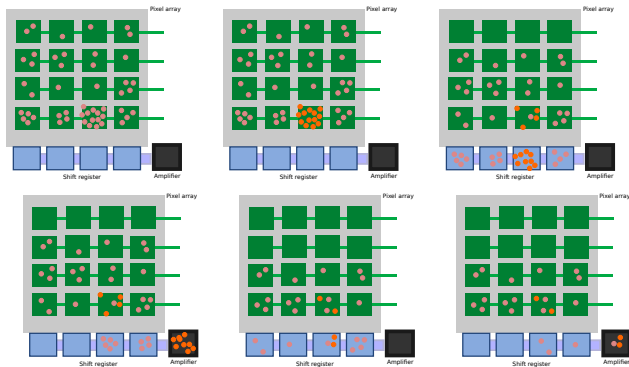
- *Charge coupled device*: Named after the working principle
- Invented late 1960, Nobel Prize 2009
- After exposure, charge is moved down pixel by pixel.
- Reaching end of the sensor, charge is moved right into a shift register
- Note: charges are moved by applying a field, not by creating a circuit.



CCDs: Readout

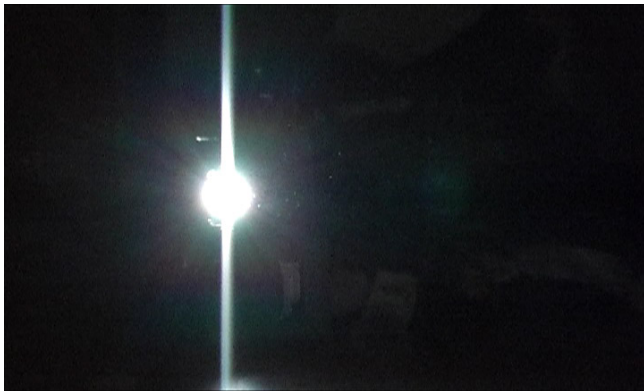


CCDs: Readout of overexposed pixels



Problem of CCDs: Overexposed pixels can influence a complete vertical readout line, as their charge is not completely transferred.

CCD: Overexposure and vertical blooming



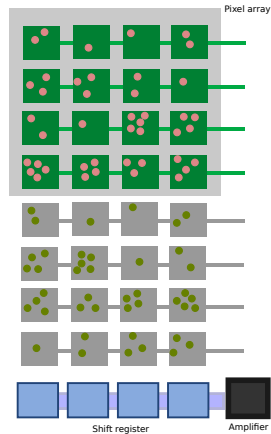
Blooming of overexposed pixel and along readout. [Wikipedia](#)

Effect of this problem: Vertically smeared lines around overexposed pixels.

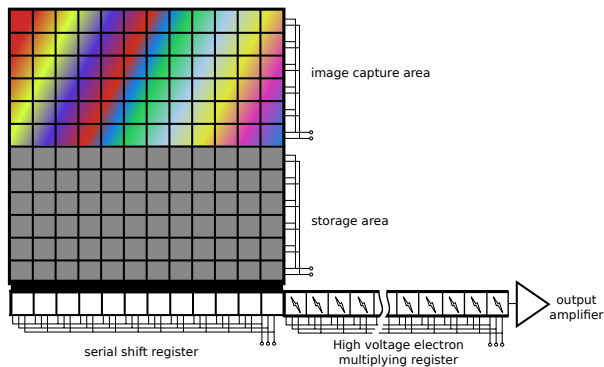
CCDs: Types / faster readout modes

Speed of CCDs:

- Each pixel has to pass through the same electronics, makes it slow
- Readout while exposure can give artifacts
- Shift each line of even a full frame to a non-light sensitive area
- Parallelize read-out



em-CCD: Precise readout through pre-amplification



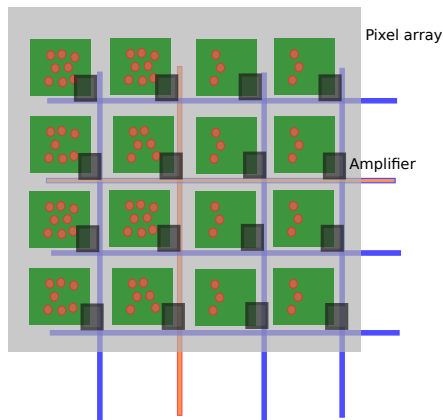
emCCD working principlly (Wikimedia)

Advantage of CCDs: One (or few) amplifiers for all pixels.

- Build an electron-multiplying pre-amplifier
- Pre-amplification gives low noise, high sensitivity
- Sensor content is shifted into storage, allows read-out during next exposure
- Cameras are rather expensive

cMOS: No more need for shifting electrons

- *Complementary metal-oxide-semiconductor* named after how they are produced
- **Active pixel sensor**
Arguably the more correct term
- Place the amplifier (transistor/diode combinations) with each pixel
- Simple switching matrix, only measure a voltage: fast
- With CMOS process: cheap(er) to produce
- *Scientific CMOS*: nice marketing term for CMOS chips optimized for scientific use.



So far, the CCD/CMOS signal is still analog (electron count / voltage).

Next lecture: How to digitally process these measurements:

Analog-digital-conversion, sampling theorem, ...