Quick facts #2: Optical detectors

1 Photographic plates

These record the arrival of photons by a chemical process. When a photon hits a silver halide crystal (such as Ag Br) it liberates a photoelectron, which can diffuse through the crystal and combine with a silver ion to give a silver atom. A group of such atoms gives a speck of silver sufficiently big to constitute part of a *latent image* – too diffuse to see, but able to be amplified using a *development process*. By adding a reducing agent to the latent image, remaining silver ions are converted ('developed') to silver metal through a process catalysed by the presence of silver atoms in the latent image. The image can then be *fixed* by removing remaining silver ions.

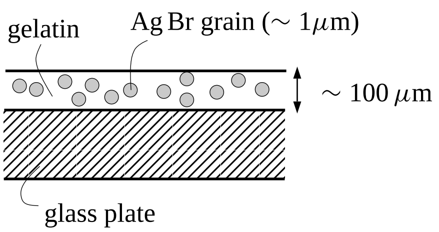

Figure 1: Photographic plate.

Advantages

- amplification factor of $\sim 10^9$
- cheap, permanent, rigid record
- multichannel detector
- very large number of pixels ($\sim 10^{10}$)
- wide spectral response at high frequencies

Disadvantages

- insensitive to longer wavelengths ($\lambda > 500$ nm)
- low quantum efficiency (~ 0.1 %)
- limited dynamic range
- non-linear response
- reciprocity failure

2 Photomultiplier tubes

These are single channel detectors (i.e., just one 'pixel') that use the *photoelectric effect* to convert a low-intensity light signal into an electric signal. A photon hitting the *photocathode* causes it to emit a photoelectron. This electron is accelerated by a strong electric field so it crashes into a *dynode* at a more positive potential than the photocathode. As a result, this dynode emits a number of secondary electrons. These are themselves accelerated into another dynode at a still higher potential, and so on. This amplification process in continued along a sequence of dynodes until the final pulse of $\sim 10^7$ electrons passes out through the anode as a current pulse.

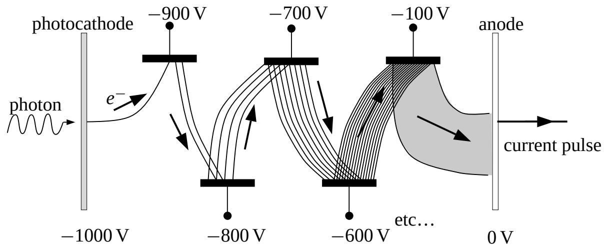

Figure 2: Photomultiplier tube.

Advantages

- can detect single photons
- about 10^7 electrons per incident photon
- very linear relationship between illumination and current
- ∼20 % efficiency
- sensitive to a wide range of wavelengths (20 → 1200 nm)
- rapid response (∼ 1 ns)

Disadvantages

- photocathode work function limits infrared sensitivity
- UV performance limited by cascade
- thermal emission gives a *dark current*
- no imaging capability
- lower efficiency than a CCD

3 Image intensifiers

Similar to photomultipliers, but the ejected electrons are focused by an axial electric magnetic field, so that an electron image is formed on the anode. Phosphor on the anode creates a visible image.

Advantages

- as photomultiplier, but the detector is now able to create an image – a multichannel detector

Disadvantages

- similar to photomultiplier, but limited gain
- bulkier than a microchannel plate

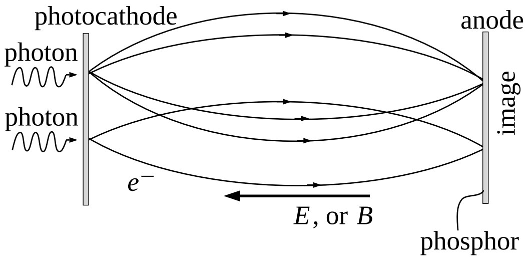

Figure 3: Image intensifier.

4 Microchannel plates

These comprise an array of microchannel tubes, similar to miniature photomultipliers, that amplify the signal from a photon hitting the photocathode and channel the ejected electrons to a phosphor screen. Each ejected electron is accelerated along the tube by a strong electric field, and there is a channel serving each pixel. Each time the electron impacts on the semiconductor walls of the microchannel tube, a number of secondary electrons are ejected, giving amplification.

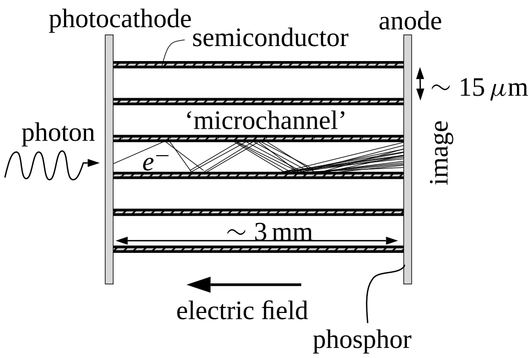

Figure 4: Microchannel plate.

Advantages

- as photomultiplier, but the detector is now able to create an image – a multichannel detector
- very compact and rugged
- potentially high pixel count
- gain of $\sim 10^6$

Disadvantages

- similar to photomultiplier, but limited gain
- expensive

5 Charge coupled device

CCDs are the most common form of detector used as photon imagers. When a photon impinges on a semiconductor, an electron can be promoted from the valence energy bands, where it cannot contribute to conductivity, to the conduction band, where it can move through the crystal. In a CCD, these promoted electrons are collected electrostatically under a metallic electrode (called a *gate*), insulated from the semiconductor by a layer of silicon dioxide ($Si\,O_2$).

A CCD comprises a dense, two-dimensional array of such gates. During the exposure phase of a CCD, illuminating photons promote electrons from the valence bands to the conduction bands. For a p-type semiconductor, a gate held at a positive potential allows these electrons to be trapped below it in a potential well. A CCD is constructed so that the packets of charge accumulated in each well can be passed between wells and 'clocked out' of the chip sequentially. This greatly simplifies the electrical connections to the array. Once clocked out, each packet of charge is measured by an on-chip amplifier and is presented at a pin on the chip as a voltage.

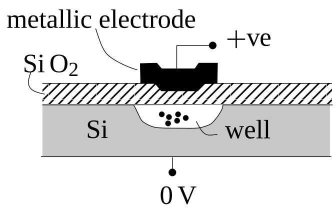

Figure 5: Charge collection beneath a semiconductor gate.

Advantages

- small, cheap chip
- good pixel count (2048×2048 straightforward)
- low dark current, if cooled
- high efficiencies, approaching 100 %
- high dynamic range ($\sim 10^6$)
- good linearity
- wide spectral response ($0.1 \rightarrow 1000$ nm)

Disadvantages

- cannot be clocked-out rapidly
- easily damaged by cosmic rays
- needs to be cooled and carefully calibrated to take account of the dark current.

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