EE113FZ
Solid State Electronics
Lecture 7: Energy & Photons

Zhu DIAO

Email: zhu.diao@mu.ie

What is to be Discussed Today?

- Describe what frequency is;
- Describe what wavelength is;
- Describe what a photon is;
- The relationship between energy, frequency and wavelength of a photon;
- Electron volts.
- The photoelectric effect.

What is Frequency?

- Frequency is a measure of how fast something passes a fixed point or simply how fast it shakes;
- It is measured in a unit called hertz (Hz), 1 Hz = 1 s^{-1};
- 1 Hz is the same as something shaking past a fixed point once every second;
- 10 Hz would be passing that point ten times a second;
- It is normally given the symbol, f;
- f is the inverse of the time period, T => $f = 1/T$.

What is Wavelength?

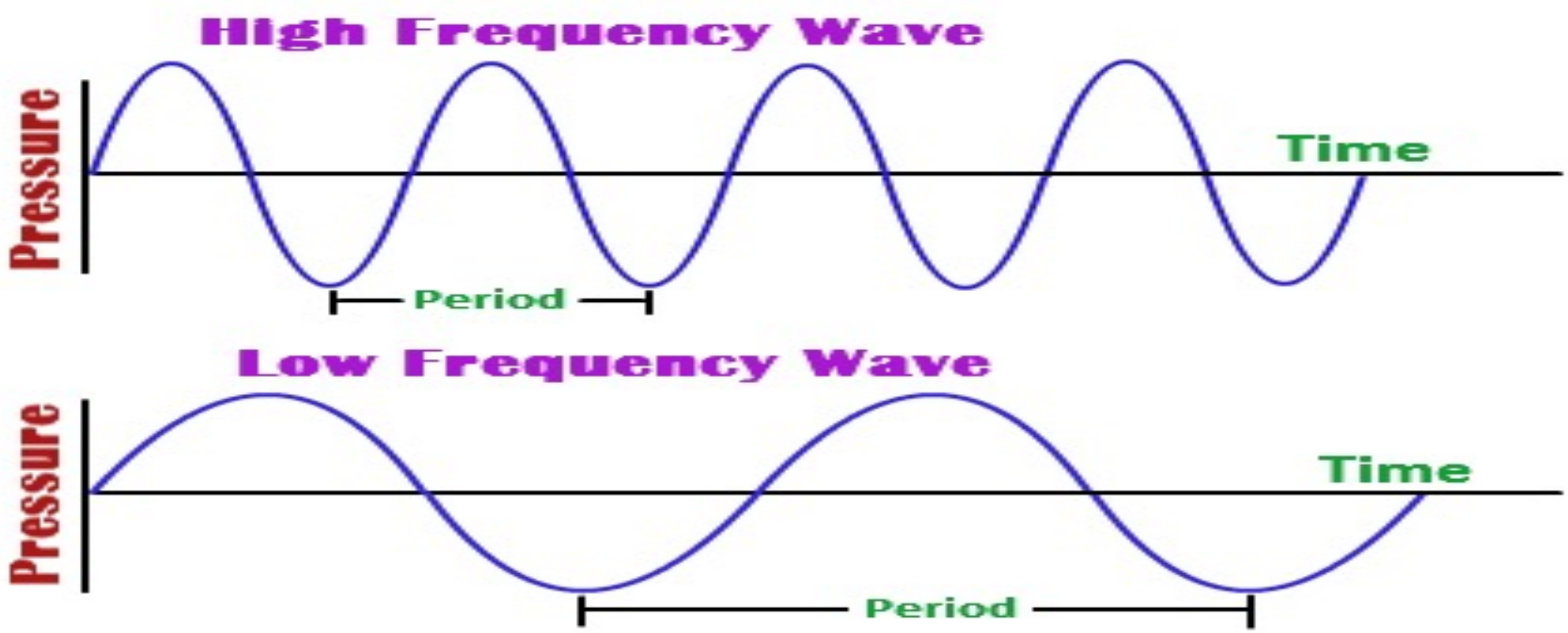
- Wavelength is the distance between two adjacent identical points on a wave;
- Normally it is between the peaks, the highest value, or the troughs, the lowest value of the wave;
- The time between these is called the period, T;
- It is measured in meters, m (or variations of this);
- It is normally given the symbol, λ, called lambda.

Frequency & Wavelength

- For light waves, frequency (f) and wavelength (λ) are related by the following equation:

  $c = f\lambda$, where c is the speed of light (3×10^8 m·s^{-1});
- The speed of light is a constant. It means that, effectively, one is proportional to the inverse of the other;
- In other words, if f is large then λ is small.

Frequency & Wavelength



https://www.tes.com/lessons/y9uqOZeTPr26gw/4th-grade-science-waves-their-applications-in-technologies-for-information-transfer

Photons

- Photons are the quanta of electromagnetic radiation;
- Photons are elementary particles, can’t be broken down into anything smaller;
- They are discrete packets of energy emitted from or absorbed by a body;
- In atomic spectra, the size of these energy packets is fixed (spectral lines) and it is dependent on the electron shell structure of an atom;
- Photons have no rest mass;
- They travel at the speed of light, $3 \times 10^8\ m \cdot s^{-1}$;
- Can be considered as light energy;
- Can be considered as both particles and waves.

Energy of a Photon

- Each photon has a fixed amount or quantum of energy;
- The energy of an individual photon is given by

$$E = hf$$

where h is Planck's constant (6.626×10^{-34} J·s), and f is the frequency of the electromagnetic radiation. This is called Planck's energy-frequency relation or simply the Planck relation.

Electron Volt

- The energy of a photon, *E*, can also be expressed in terms of what is called an 'electron volt';
- An electron volt is the energy given to an electron when it is accelerating through a potential difference of 1 volt;
- This energy is equal to 1.6×10^{-19} J;
- It is given the unit eV.

Example: Microwave Photons

- Calculate the microwave photon energy of an FM radio station transmitting at 100 MHz. Give your results in both joules and electron volts.

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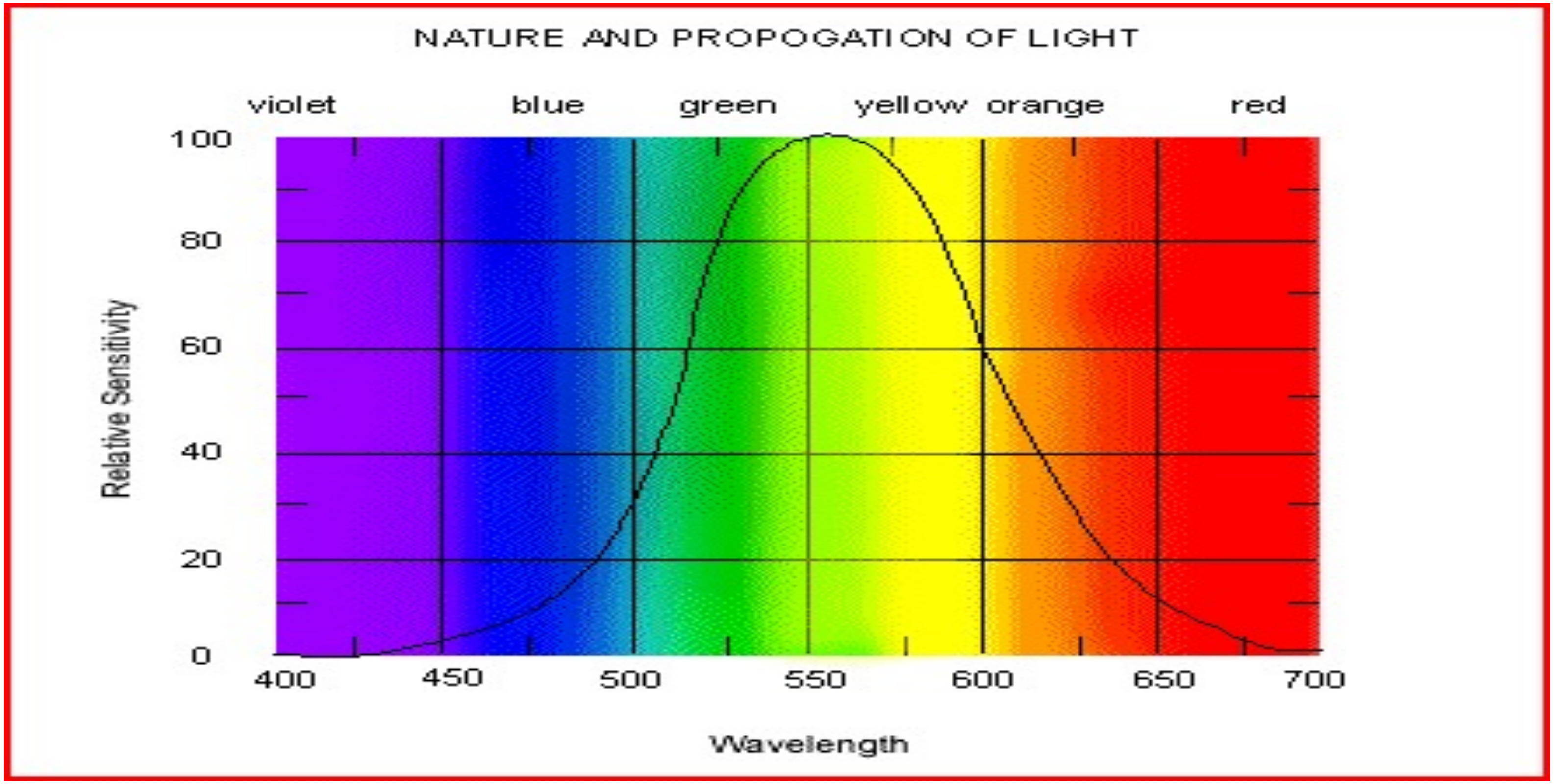
$$E = hf = (6.626 \times 10^{-34}\ \mathrm{J \cdot s})(100 \times 10^{6}\ \mathrm{Hz}) = 6.626 \times 10^{-26}\ \mathrm{J}.$$

$$6.626 \times 10^{-26}\ \mathrm{J} = \frac{6.626 \times 10^{-26}\ \mathrm{J}}{1.6 \times 10^{-19}\ \mathrm{J/eV}} = 4.14 \times 10^{-7}\ \mathrm{eV}.$$

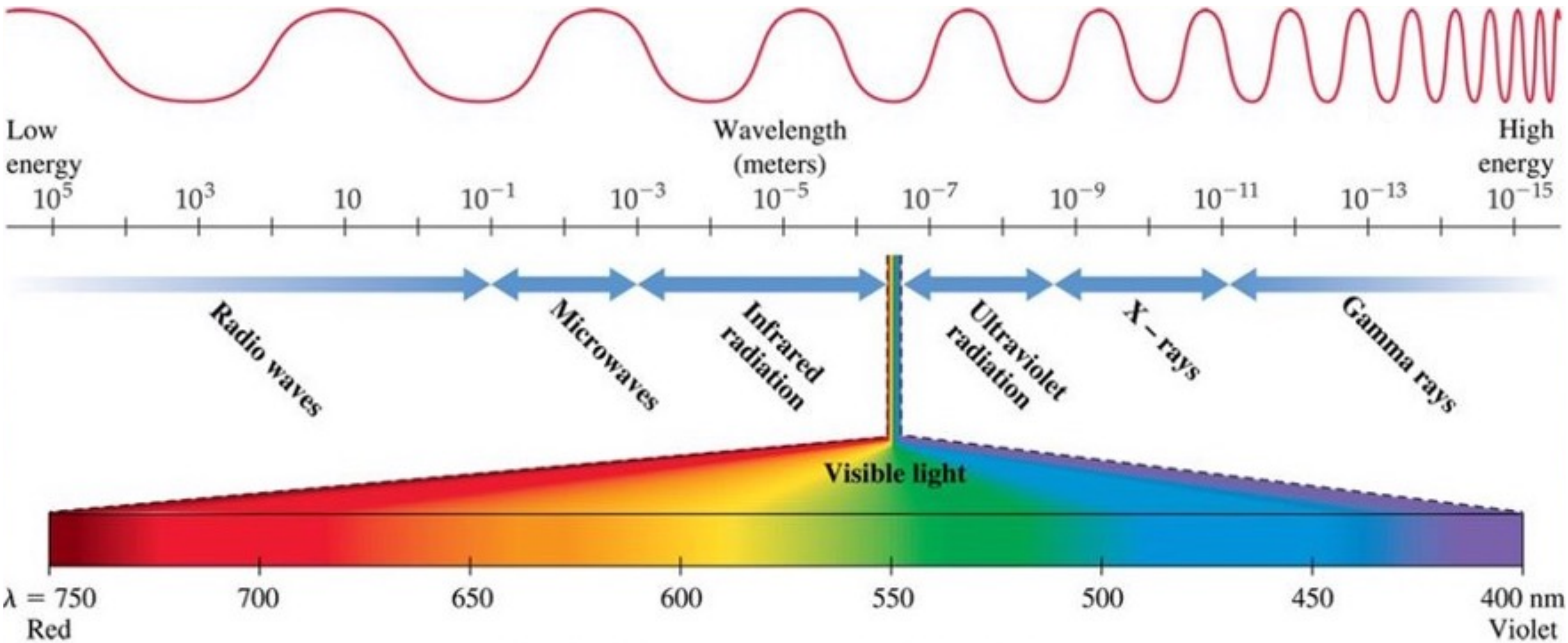
Compared to a typical photon energy of ~ 1.5 eV for visible light, it is a very small photon energy.

Light

- We can see a range of wavelengths, from ~400 nm to ~ 750 nm.



Electromagnetic Spectrum



Relating Energy, Frequency & Wavelength

- We have an expression that relates the amount of energy in a photon to its frequency:

  $E = hf$, with h being Planck's constant

- We have an expression that relates frequency, f, to the wavelength, λ:

  $c = f\lambda$, with c being the speed of light 3×10^8 m·s^{-1}

- So can we generate a relationship between energy, frequency, and wavelength of a photon?

Relating Energy, Frequency & Wavelength

- Yes, this is the answer!

$$E = hc/\lambda$$

- This means that if we know the frequency or the wavelength of a photon, it's energy can be calculated.
- It also means that if we know the energy of a photon, then its frequency or wavelength can be calculated.

Emission/Absorption of Photon Energy

- Photons have discrete energy values;
- Electron orbitals are set out at discrete levels or are quantised;
- So maybe one fits the other?
- Indeed, if an electron gets the right quantum of energy, via a photon, it will increase its energy level moving to a higher electron orbital;
- Conversely, if it loses the right quantum of energy it will fall into a lower orbital.

Absorption of Photon Energy

- Certain atoms absorb certain colours of light;
- If the energy of this colour (remember that colour is a wavelength and thus we can calculate its energy) matches the energy difference between electron orbitals in an atom, electrons will absorb it and go to the orbital with a higher energy level.
- If the energy is more than one level but less than two levels worth, what do you think happens to the excess energy?

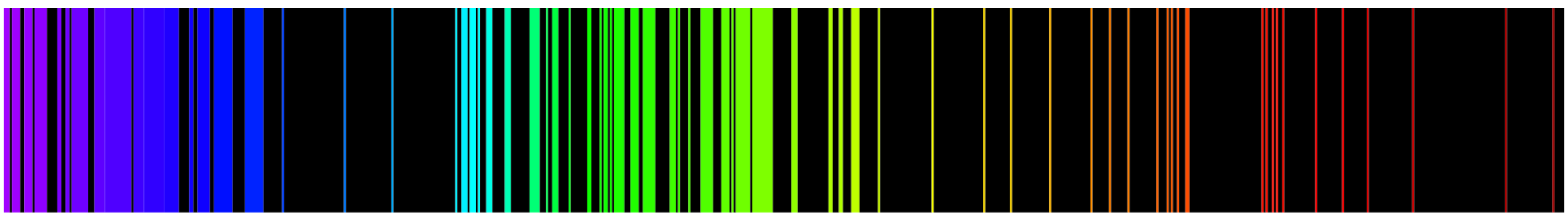
Emission of Photon Energy

- If an electron falls from one energy level to one below it, it emits a photon at an energy level matching the loss;
- This energy loss corresponds to a characteristic wavelength of light;
- If it is in the visible spectrum then it has a colour;
- The next slide has some atomic emission spectra and the second next slide has some LED colours.

Examples: Atomic Spectra

- Emission spectrum of hydrogen:

- Emission spectrum of iron:



https://en.wikipedia.org/wiki/Emission_spectrum

LED Colour & Voltage

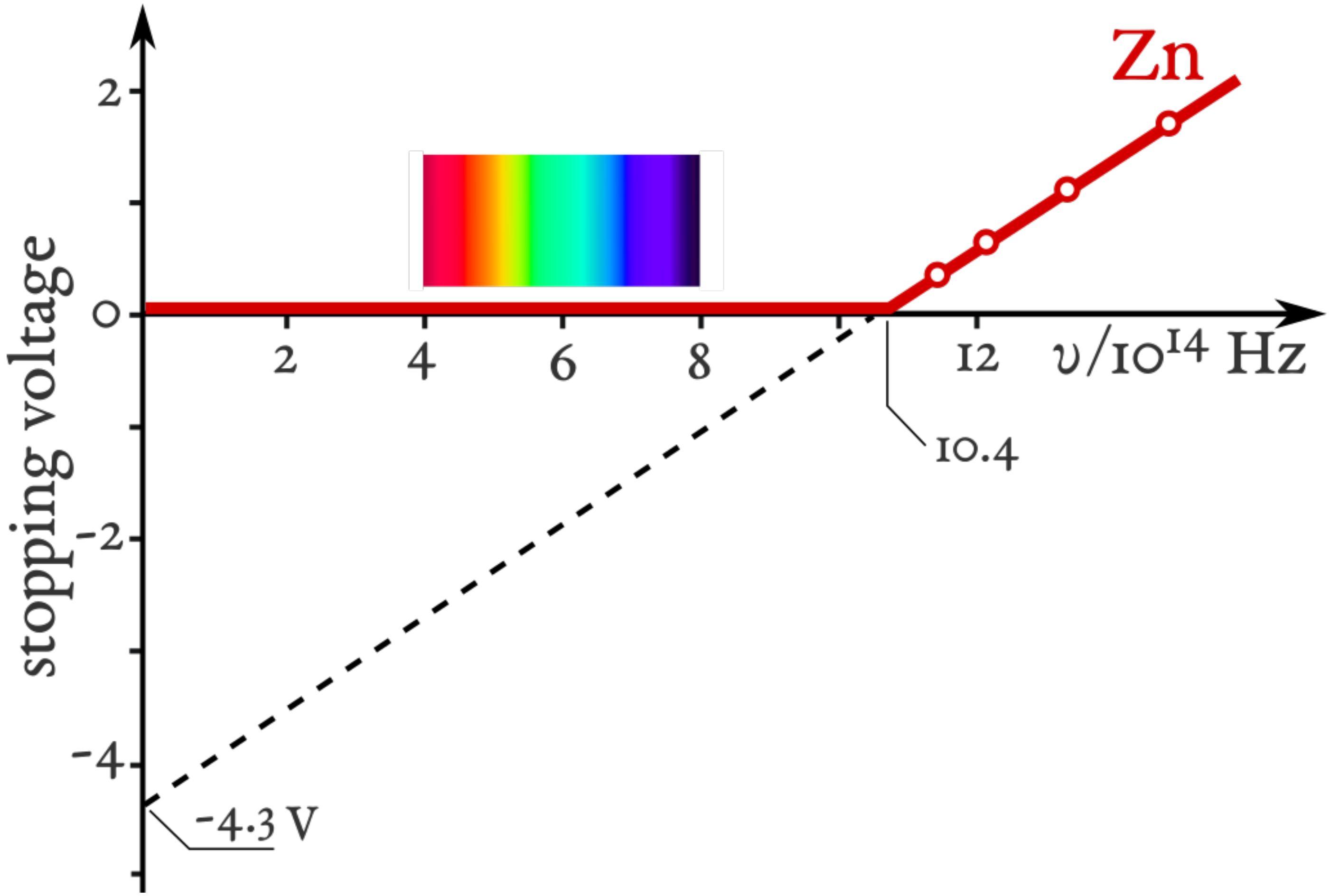
Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_F @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
AlGaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

- V_F is called the forward voltage, what is needed to turn on the LED.
- The 20 mA is current that should flow through that device at that V_F.

The Photoelectric Effect

- This is the emission of electrons from the surface of a material when light of a suitable frequency falls on it;
- This is called photoemission and the electrons are called photoelectrons;
- Experiment shows that electrons can only be dislodged from materials when the incoming light exceeds a certain frequency (regardless of the light intensity and the duration of exposure).

The Photoelectric Effect



https://en.wikipedia.org/wiki/Photoelectric_effect

The photoelectric effect can only be explained by the existence of photons!

Einstein's Photoelectric Effect Formula

- In 1905, Einstein proposed a theory of the photoelectric effect using the idea of photons;
- In this theory, the maximum kinetic energy of emitted electrons is

$$K_{\mathrm{max}} = hf - W_0$$

  in which W_0 is called the work function of the surface (the minimum energy required to remove an electron from the material) and hf is the incoming photon energy;
- This was what brought Einstein his Nobel Prize in Physics (1921), not his theory of relativity.

Applications of the Photoelectric Effect

- Solar panels: Incident light releases electrons and the flow of electrons is a current;
- Photocopiers;
- Photomultiplier tubes: Incident light is increased depending on the gas in the tube;
- Light meters;
- Photodiodes.