PHOTONICS AND SPECTRAL ANALYSIS

Liceo Statale "G. Ricci Curbastro – De Bron

Carlotta Caravita
Xenia-Alexandra Cordonnier
Beatrice Dalle Vacche
Eline Debaere
Alessia Federici
Céline Oosterlinck

PHOTONICS

Nowadays, we live in our globalized world, where light technologies, in particular photonics, are helping to revolutionize many sectors.

What is it?

Photonics is defined as the physical science of light generation, detection and manipulation through different techniques: emission, transmission, modulation, signal processing and amplification. The concept of photonics comes down from the outcome of the first practical semiconductor light emitters and of the optical fibres. Photonics is made up of photons, which are particles of light.

Figure 1. How does photonics work?
Credits: Smebook

What is it used for?

The characteristics of the waves and photons can be used to explore the universe and cure diseases. Photonics involves the use of tools such as lasers, fibre-optics and electro-optical devices in numerous fields of technology. These fields are: aerospace, agriculture, biomedicine, construction (to track the progress of construction), alternate energy (the production of Photovoltaic devices), information technology and many others.

For instance, the employment in biomedicine consists in observing molecular details in cells and tissues, through specific lasers; while the use in agriculture involves the practice of "smart farming" that monitors crop health using advanced technologies, such as laser scintillation to supervise heat flux in agricultural fields.

Furthermore, photonics is linked to spectral analysis: scientists are making new experiments such as spectral sensors based on photonic crystal slabs.

What is its purpose?

The photonics field's purpose is to develop new and innovative products for medicine, telecoms, manufacturing, construction and other areas. It gives also the opportunity to create and invest in new jobs. In 2019, three Nobel laureates declare that Europe is now a world-leader in photonics science and innovation, and photonics is recognized as a vital research area. In conclusion, it's essential to study photonics nowadays, due to the fact it will have a central role in the future.

SPECTRAL ANALYSIS

Electrons within atoms can only occupy some orbits and these orbits have a fixed energy for each type of atom. When an electron passes from an external orbit to a more internal one, it loses part of its energy which is emitted in the form of light and it generates a line in emission. While, an absorption line is generated when the electron jumps into a more external orbit, after absorbed the energy of a photon equal to the energy difference of the two levels. Indeed, there are 2 types of spectra: the emission spectra and the absorption spectra.

Emission spectra are typical of light emitted from a light source and they can be divided into two subcategories: first of all, the continuous emission spectra which present all visible electromagnetic radiation wavelengths and they are characterized by a succession of shaded colours in each other. These spectra are emitted by solids and incandescent liquids, but also by strongly compressed gases. Then, there are the striped emission spectra, which are characterized by defined lines on a black background. The various frequencies of the spectrum are presented as separate and coloured lines depending on the frequency to which they correspond. This is the type of spectrum typical of low-pressure incandescent gases.

While, when a continuous radiation passes from a solid or liquid body through a gas or vapour, the continuous spectrum lacks certain monochromatic radiations, which have been absorbed by the interposed gas. This type of spectrum is called absorption spectrum and it is characterized by one or more black lines on a continuous coloured background.

If we compare an emission spectrum and an absorption spectrum of the same substance, then we will notice that the black lines of the absorption spectrum coincide with the coloured lines of the emission spectrum.

Indeed, in this case the hydrogen absorbs light radiations of the same wavelength and frequency as those he is able to emit.

Moreover, it’s important to underline that each element has its own emission and absorption spectrum and the analysis of this spectrum is called spectroscopy which allows to identify not only the element but also its characteristics.

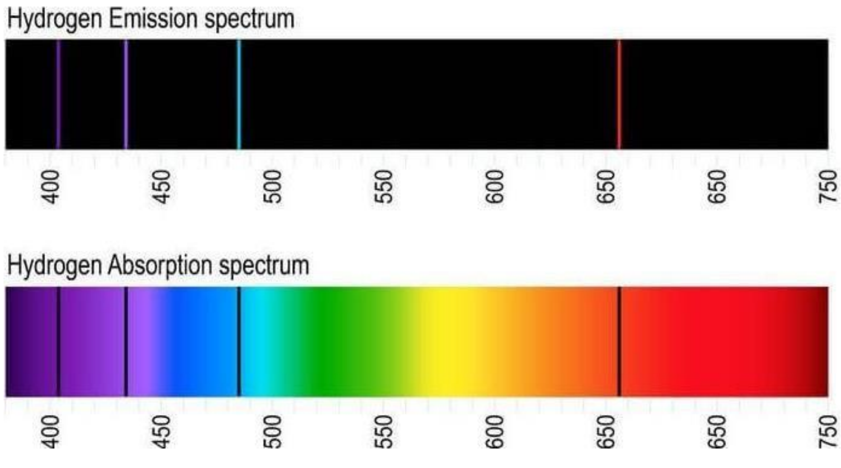

Figure 2. The spectrum of hydrogen atom. Credits: ThoughtCo

Photonics is becoming a major player in the Agri-food industry. The speed and accuracy of light sources will greatly help farmers and food specialists improve their products.

Detecting crop and water quality

Photonics helps farmers to determine the protein levels in wheat crops using advanced optical detection methods. For example, in their planted fruit and vegetables, photonics are responsible for the screening of contaminants. They can also use it to observe water quality.

So-called ‘lidar’ (light detection and radar) technology can accurately map large land areas. At the moment, the scanners are mainly used in aircrafts to measure large-scale crop effects in agricultural regions, for instance. Lidar works on the same principle as radar: a signal is emitted and will be received again sometime later by reflection. The distance to the object or surface is determined by measuring the time that elapses between sending a pulse and receiving a reflection from that pulse. Determining the distance can help farmers to know how the growth of a crop is evolving. The difference between lidar and radar is that lidar uses laser light while radar uses radio waves. This allows many smaller objects with lidar to be detected.

Current example

Multispectral phone case for 3D food analysis

More than 200 million people worldwide have to deal with type 1 or type 2 diabetes and obesity. Every day they have to check what is in each bite or sip. FoodPhone director Christoffer Mutti therefore developed a phone case equipped with RealSense 3D camera. The smartphone is transformed into a smart multispectral food meter with which the food is analysed directly on the plate. After you take a picture of a meal, the FoodPhone app with SpectraPixel technology will recognize the content of the meal, in particular the chemical composition, the amount in grams and the quality. This SpectraPixel technology allows each pixel of an image to acquire many bands of light intensity from the spectrum. With the aid of the multispectral cameras and NIR (near infrared) sensors, the user immediately receives a scientific meal analysis.

Figure 3. Multispectral phone. Credits: The Factory Files.

Multispectral imaging measures light in a small number (typically 3 to 15) of spectral bands. This meter combines 3D vision with an RGB-sensor and an infrared projector. The way the sensors' output is merged into a multispectral image closely mimics the way people identify their food. The device has an accuracy of 90%, so the results are certainly reliable.

Applications to medicine

In medicine, photons and spectral analysis are used on a daily basis to ensure our health and life quality. Lately this has played a major role in the corona crisis, but it is also utilized to combat other diseases i.a. cancers.

The molecular diagnosis of COVID-19

A molecular diagnostic test is needed if the patient has symptoms. This screen, based on a technique called real-time reverse transcription polymerase chain reaction (RT-PCR), uses sensitive spectroscopic methods to detect extremely small quantities of viral genetic material from a nasal or throat swab.

Real-time RT-PCR works by copying specific nucleic acid sequences within that sample, using probes, nucleic-acid primers, that selectively bind exactly to the RNA sequences present in the SARS-CoV-2 virus. The probes are tagged with molecules of fluorescent dye.

The fluorescent dye below 250 nm are revealed by a light microscope. It uses light and non-ionizing radiation; therefore, it is able to reveal nanostructures. The LM is mainly used for biological samples such as cells, tissues, and organisms.

Sometimes it is necessary to define the exact position of RNA (DNA is transcribed into RNA during DNA replication), like detecting variants. These can be identified by a fluorescence microscope, with a maximum of 358 nm.

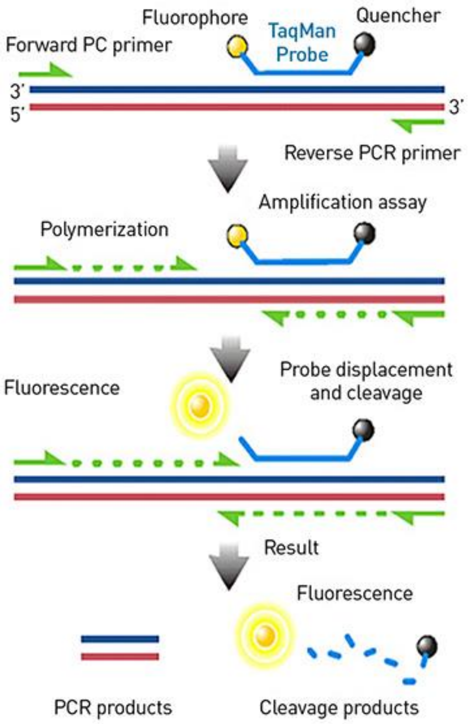

Figure 4. RT-PCR below ~ 250nm
Credits: Wikimedia Commons

Improved 3D imaging technology

Using 3D technology, radiologists can determine a tumour's exact size and determine whether the treatment is shrinking the tumour. The researchers illuminate the tumour with short pulses of light at two different wavelengths using a laser. Inside the body, the light pulses are absorbed and converted into ultrasonic waves. These waves can then be measured outside the organism and two images of the body's interior can be reconstructed based on this data.

Tumours, e.g., are hard to measure given their unusual sizes and shapes. Current protocols call for measuring them using dimensions data. The models also help families understand surgeries and help train medical students and residents.

Astronomical spectroscopy

Spectral analysis in astronomy, also called astronomical spectroscopy, is used to measure the spectrum of electromagnetic radiation emitted from celestial objects, such as stars, planets and even galaxies. For more information about spectra see chapter “Spectral Analysis” on page 3. By studying the spectrum, scientist can find out the temperature, the chemical composition and the motion of these objects.

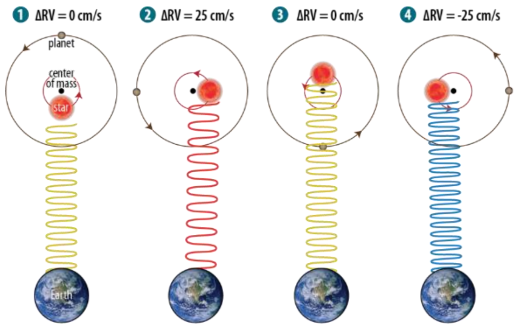

Figure 5. A schematic of the Doppler effect.
Credits: Neid.psu

Doppler effect

All spatial objects move, with the use of the Doppler effect, astronomers can determine whether an object is moving towards us or away from us. They can also calculate the velocity at which they move. The Doppler effect is the detected change in frequency of sound, light or other wave forms, due to a velocity difference between the transmitter and the recipient.

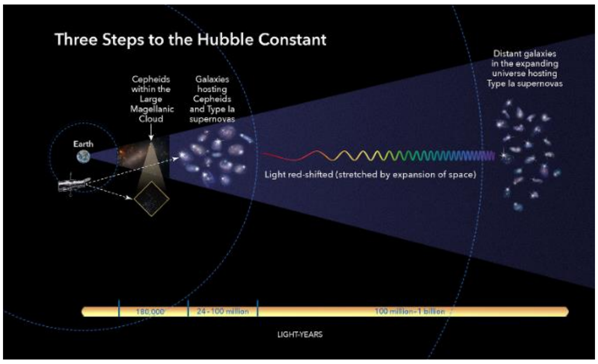

Figure 6. Three steps to the Hubble Constant
Credits: Nasa

In astronomy, we can divide the Doppler shift into the red- and the blueshift. To explain this, we will use the example of a star. Each star emits absorption lines, which can be detected by any telescope, the frequency of such a line is quite peculiar to the composition of a star. As ultraviolet represents a large amount of energy, blue light has a higher frequency. So the wavelengths are shorter. Hence we can conclude that the object is coming towards us. This is called blueshift. When a star moves away from us, there will be a longer wavelength, therefore a lower frequency, which corresponds to less energy and therefore implies a red colour. This is called redshift.

Due to the fact that most distant stars show redshift, which can be detected by a Hubble Space Telescope, scientists assume that the universe is expanding, which means that there is no centre and that everything has been moving away from everything else since the Big Bang. An interesting note is that the expansion is happening in an not - constant acceleration. This means that we are approaching 'heat death' ever more quickly. In short, heat death means that the density in the universe is too low for the galaxies to form new stars, due to the lack of gas. This could be the end of our universe.

DOPING

Doped optical fibres are used in the field of telecommunication to transport signals using light. Due to the fact that using light allows you to transmit much more information, electrical signals that used copper wires have been replaced by optical fibres. But when light is passing through an optical fibre about 5% of the signal per km is lost. So, as long as long-distance optical fibre is concerned, the transmission loss can't be ignored.

An optical amplifier is capable of increasing the power of an optical signal without converting it to an electric signal. Indeed converting an optical signal to an electric signal, amplifying and then converting back would lead to a loss of transport velocity.

Optical amplifiers can be distinguished into three kinds:

- **Semiconductor Optical Amplifiers (SOA)**, similar to semiconductor lasers, are useful to amplify access networks and in short-distance transmissions.
- **Fibre Raman Amplifiers (FRA)** are more used in long-distance transmissions and the amplification effect is achieved by a nonlinear interaction.
- **Erbium Doped Fibre Amplifiers (EDFA).**

Doped fibre amplifiers (DFAs) use a doped optical fibre as a means to amplify optical signals. The mode of operation is related to fibre lasers: the optical signal and a pump laser are multiplexed into a doped optical fibre so that the signal, through doping ions, is amplified. Successively ions are excited by the pump laser, bringing them to a higher energy level and, due to a population inversion, as they decay they emit a photon. When signal photon passes, it stimulates the electrons in the excited ions to decay and emit new photons. In this way, for each signal photon, several new photons are generated and hence the signal is amplified.

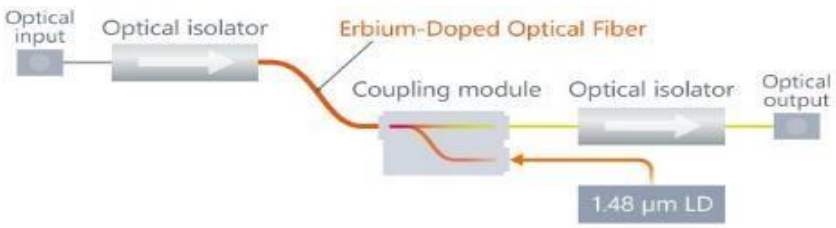

Figure 7. Example EDFA Configuration. Credits: Anritsu

This is an example: inside a coupling module is pumped light at 1.48 µm. This allows the light to be stored in part as energy, and light in the 1.55 µm band is amplified when it propagates.

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