Photonics and spectral analysis

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Photonics

Photonics is the science of light involving the properties of detection, generation and manipulation of photons. This manipulation can be done by emission, transmission, modulation, amplification (...) The field of photonics started in 1960 with the invention of the laser. The purpose then was to use light instead of electronica, for example in telecommunications. Now the purpose of photonics is to use light to help the mankind. It has its function in medicine, food, communication (...) The word photonics comes from ‘photon’, which is the smallest unit of electromagnetic radiation or in other words light. This is one component in which light exists and the other one is waves.

How does photonics work?

Photonics uses light sources based on semi-conductors. In most applications the light goes through transparent medium and in some applications glass fiber or plastic optical fiber are used to get the light in a specific direction. In this case the light is sent through the core of the fiber. You can see this on the figure alongside. The light can even be boosted by optical amplifiers. In the end the photons are detected by photodetectors. These use photodiodes, fast to very slow ones. They can also be based on other effects. This depends in which applications they are used for.

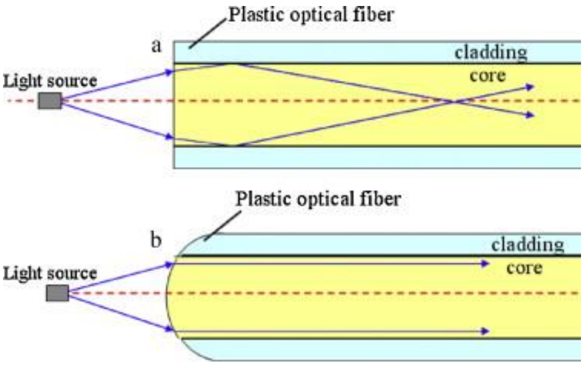

Image 1: Light through a plastic optical

Another part of photonics is modulation of a light source. A modulator is used to encode information. This can be done in two different ways. The first one is that the light source is modulated directly. The second one is to use the light of a light source and let it be modulated by an extern optic modulator.

Application 1: Detection of cardiovascular diseases

An application in medicine is the detection of cardiovascular diseases. The device we use for this is a light gun.

This light gun measures the stiffness of the blood vessels using a laser.

Each heartbeat is accompanied by a pressure wave that travels through the blood vessels.

The laser from the light gun bounces the light off the skin just above an artery. The reflected laser beam is analysed and a Doppler shift occurs, because at the time the pressure wave passes through the blood vessels there is a movement of the skin.

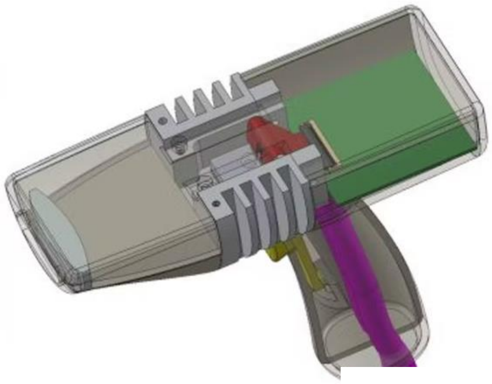
Image 2: Light

The light gun works on the Doppler effect: the emitted wavelength deviates from the measured wavelength due to a frequency shift.

Based on the speed at which a blood pressure wave moves through the arteries, you can measure how stiff the aortic wall is. In healthy and young people this is about five meters per second, but as you get older, the aortic wall can stiffen. Then the blood pressure wave will move much faster, namely ten to fifteen meters per second, this is a normal value in old age. If the value is higher than the average value, it can therefore be a reference for cardiovascular diseases.

Application 2: Photonic Integrated Circuit.

A photonic integrated circuit (PIC) is a chip that contains photonic components. It works like a regular integrated circuit, but instead of using electricity, it uses light. The photons pass through waveguides (guides the light through the circuit), lasers, polarizers (optical filters that let the light pass or block it) and phase shifters (controls the phase of the light). An advantage of photonic integrated circuits is that it has a bigger integration capacity than a regular integrated circuit which means data can be transported faster. PIC are also faster and smaller. On the image, you can see a simplified image of a PIC.

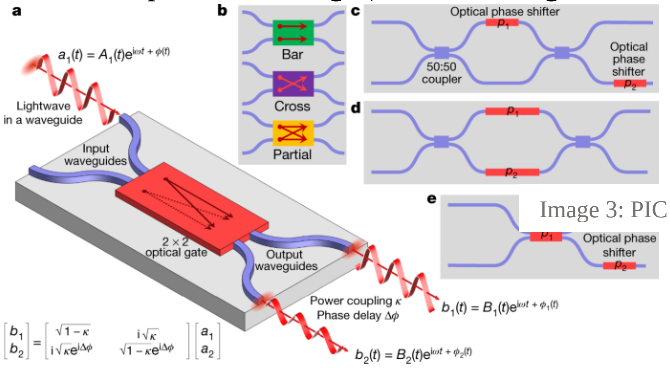

Image 3: PIC

Photonic integrated circuits can be classified in different ways. One of the classifications is based on the function of the PIC. There are passive photonic integrated circuits, those circuits are only optical circuits, because they do not manipulate, detect or generate light. These PIC can integrate optical filters and other passive optical devises. Then there are the active photonic integrated circuits also known as the photoelectric integrated circuits. These can integrate lasers, PIN detectors and optical amplifiers, but they can also integrate passive PIC.

There are many applications for photonic integrated circuits, such as fiber-optic communication. For example by sending pulses of infrared light through an optic fiber, data is sent from one place to another. Other applications are in the biomedical sector, aerospace industries, and astronomy (…)

Spectral analysis

The study of the composition of matter by the analysis of the spectra of electromagnetic waves emitted or absorbed by it is called spectral analysis.

First of all: what is the electromagnetic spectrum? It is the distribution of the intensity of the radiations when the wave frequencies change. For example: the visible light spectrum, dispersed by a glass prism, is the sequence of all the colours of the rainbow, also known as continuous spectrum.

Each wave frequency corresponds to a different colour, from purple to red: the visible light spectrum has a wave length between 400-700 nm. Shorter wavelengths correspond to ultraviolet, x and gamma rays, longer lengths are infrared, microwave and radio waves.

Let’s suppose to put between a light source and a diffraction grating a cold hydrogen mass. Behind the grating we’ll see a continuous spectrum, but with some black lines. This is called absorption spectrum and shows that the specific element that composes the quantity of matter analysed, in this case hydrogen, has absorbed some energy from the electromagnetic waves of the light source. The energy is absorbed only for certain wavelengths (hence the black lines) and is used by the electrons inside the hydrogen atoms to jump to higher energetic levels, in fact the difference between two energy levels is related to the wavelengths of absorbed light.

At some point excited electrons will put the energy out again in another form. In this case, if a hot hydrogen mass is put beyond the diffraction grating, we'll see a black spectrum with just a few coloured lines, specifically violet, blue and red. It is called emission spectrum: the electrons inside the atoms have dropped to lower energetic levels and freed some energy, in other words they have emitted it.

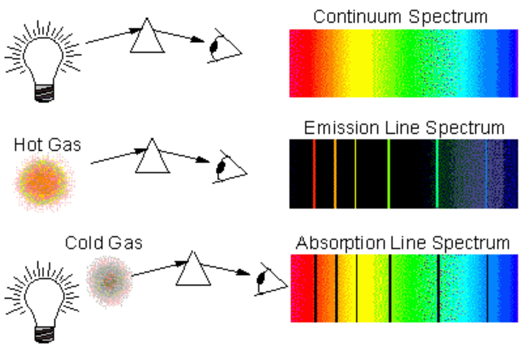

Image 4: Examples of light and gas spectra

The emission and the absorption spectra of the same object combining together form the continuous spectrum. The lines of the emission spectrum we can observe through experiences form the Balmer series, in which the amount of energy that an electron drops from energetic level N=3 to N=2 corresponds to a photon (in a wavelength seen be human eye).

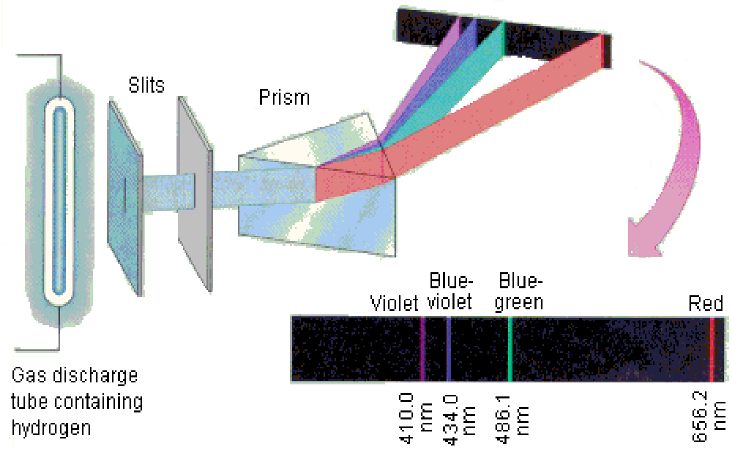

Image 5: How a spectroscope works (prism) and H emission spectrum

The equipment typically used to make experiences of spectral analysis is the spectroscope. It is composed of two scopes, one opposite the other, between them there is a diffraction grating (in the picture there is prism instead, but it's not always used in official experiments). Beyond one of the scopes it's put the object that's going to be analysed and beyond it a source of light.

The emission spectrum can be seen as the fingerprint of the material that's being analysed. Another interesting fact about spectral analysis is that each element of the periodic table has its own spectrum, so that combining both the emission and the absorption spectra of an object, such as two hands holding each other, it is possible to improve the detection of the exact elements it is made of. However, for many other applications either the absorption or the emission spectrum are enough detect the composition of the object of the experiment.

In this way many great discoveries have been carried out, for example in the astronomic or the pollution field.

Application 1: Spectral analysis in astronomy

Spectral analysis is one of the most useful tools to help understand the Universe. Planets, stars and galaxies are too far from us to be analysed in a laboratory, but we can understand their characteristics thanks to the light they emit. To be read, light must be split into its different colours (or wavelengths), in the same way that rain droplets disperse the light to form a rainbow. Newton called this rainbow of colours a "spectrum", the Latin word for "appearance".

The first astronomical application of spectroscopy was in the analysis of sunlight by Fraunhofer (1787 - 1826) and Kirchhoff (1824 - 1887), in the early 19th century.

It was expected that the white light emitted from the Sun would have produced a clean rainbow when passing through a prism. But, for the very first time, a pattern of dark lines was also noticed. As we can see in the first photo, each chemical element produces a distinct signature in the spectrum and, due to this, scientists can discover properties of any celestial body that emits or absorbs light (for instance how hot, big and far from us they are, what mass they have, what is their chemical composition). To give an idea, the most abundant elements present in the Sun are Hydrogen and Helium (this one discovered by yellow lines in the spectrum).

Nowadays the instrument used by scientists in these researches is the spectroscope, which splits the light collected by a telescope into its colours. In particular, the second photo shows how light from a star goes through the gas of a nebula, or just the star's atmosphere, radiations are absorbed by the elements contained in the gas, resulting in dark lines. The energy that is absorbed by the gas is then re-emitted in all directions in specific colours characteristic of the elements present in the gas, producing in the spectrum bright lines at certain wavelengths; this is known as emission spectrum.

Spectra can also tell us about motion: the speed of a star or a galaxy can be measured by using the Doppler effect. Lastly, this effect has also been used to discover extrasolar systems.

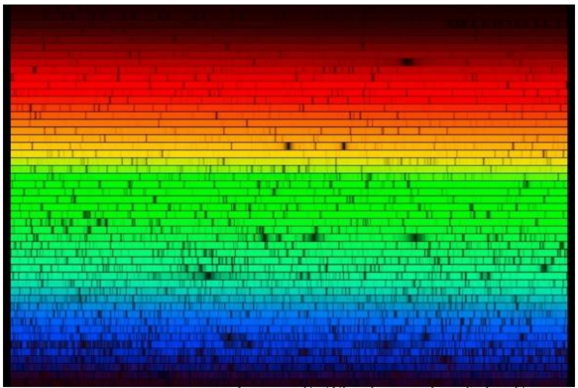

Image 6: The barcode of the Sun

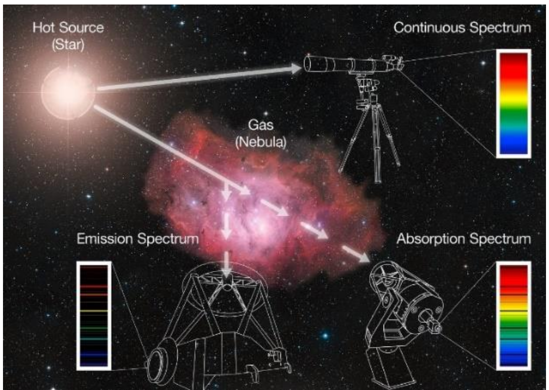

Image 7: A star that emits light across the spectrum

Application 2: Spectral analysis of pollution

The pollution of air is one of the main problems nowadays in all the world; spectral analysis is used for discovering the different gasses which are present in the atmosphere. Optical analyzers are the most used for these purposes because they have the considerable advantage of being able to measure several species of gasses together.

Optical analyzers use the principle of absorption spectroscopy which refers to spectroscopic techniques that measure the absorption of radiation, as a function of frequency or wavelength, due to its interaction with a sample which absorbs energy from the radiating field. The strength of the absorption varies as a function of frequency, and this variation is the absorption spectrum. Infrared spectroscopy is particularly common in analytical applications.

For this purpose, two different techniques can be used in which infrared are involved, illustrated in the two figures shown.
In the first picture, it can be seen how the procedure is carried out through the use of two machines: the first (A) emits infrared rays, the second receives them.

The procedure is as follows: in the presence of an environment whose air composition is to be analyzed, the two machines are positioned. Machine A emits infrared rays: some are absorbed by particles, others dispersed in the environment and still others are reflected and captured by machine B. The resulting data are then studied and the particles present in the air are traced.

The second figure shows the second technique in which the two machines, seen previously, are summarized in a single one. The principle is always the same: you want to analyze the exhaust gas of a factory and using infrared you can understand which gases are involved. The machine emits infrared and some of these are reflected and captured by the same device. The wave frequencies are analyzed below and the gasses emitted are analyzed.

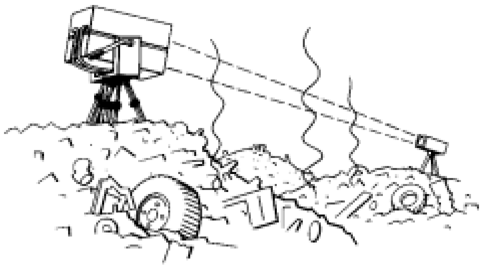

Image 8: IR receiver

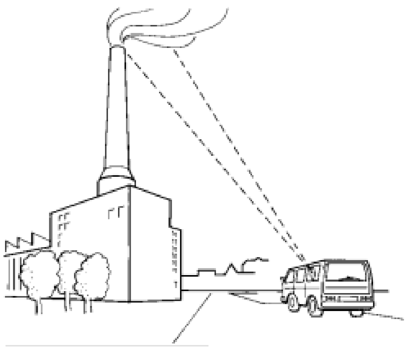

Image 9: IR emitter

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