The Importance of Light in our Lives[1]

An overview of the fascinating history and current relevance of Optics and Photonics

Lecture Notes

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[1] This subject is included in the University of Cantabria's Senior Program.

Figure 0. Frame of the movie Goldfinger, from the James Bond saga. Source: Tor.com https://bit.ly/2OSZH7K

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The Importance of Light in our Lives

Course Structure

This course is divided into 8 chapters and aims to provide an introduction to the main concepts of optics and photonics: from the use of the first magnifying glasses to the use of laser in a multitude of present-day devices and applications.

- **Chapter 1: The Historical Evolution of Optics and Photonics**
  With reference to the discoveries of key personalities such as Archimedes, Newton or Einstein, this chapter traces the fascinating history of the evolution of Optics through to Photonics, with the invention of the omnipresent laser and optical fiber.
- **Chapter 2: What is Light? Waves and Particles**
  This chapter aims to provide a clear and simple explanation of one of the "mysteries" that have most greatly concerned and occupied hundreds of scientists throughout the centuries: What is Light? Is it a wave or a particle?
- **Chapter 3: Sun, Light and Life: how the Sun and photosynthesis work**
  Life on our planet would not exist without the Sun and the energy it provides every second. Likewise, photosynthesis or the conversion of inorganic substances to organic compounds in plants, takes place thanks to the energy of light.
- **Chapter 4: The light that revolutionized the digital era: the laser and optical fiber**
  Today's society would not be the same if, back in 1958, the laser had not been invented and, thereafter, optical fiber. The Internet, the great communications phenomenon that has revolutionized our lives, is simply light (laser) travelling around the world through optical fiber. We will briefly review the invention of the laser, optical fiber and their fundamentals.
- **Chapter 5: Measuring the world using light: from biomedicine to civil work**
  Light not only serves for high speed communication via the Internet, but can also help us in a variety of applications: from precisely delimiting cancer cells to real-time monitoring of a bridge or dam. This chapter provides a brief explanation of some important examples that help us to better understand this "hidden" facet of light.
- **Chapter 6: The phenomenon of vision: how humans and animals see**
  This introduction to the world of light would not be complete if we were not to explain how one of the most incredible parts of our body works: the eye and the sense of sight. Furthermore, we will explore the differences between our sense of sight and that of other members of the animal kingdom.
- **Chapter 7: Photonics: current situation and future perspectives**
  This final chapter reviews some of the most recent advances in the world of optics and photonics and other possible future applications of this field of knowledge, which is fundamentally important today and will undoubtedly continue to be so in future decades.
- **Chapter 8: Experiments with light that you can do at home**
  Finally, we suggest a series of simple experiments that students can do to help assimilate the concepts explained during the course.

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Chapter 4

The light that revolutionized the digital era: the laser and optical fiber

In this chapter we will discuss two fundamental inventions that, almost unknowingly, greatly affect our lives today: the **laser and optical fiber**. An example of this is the fact that the **Internet**, the great revolution in communications at the end of the 20th century, is basically light (generated by lasers) that travels around the world through optical fibers.

The first part of this chapter deals with the laser, its invention, basic principles and applications, to then briefly discuss optical fiber as a key component in optical communications.

4.1. The birth of Photonics: the invention of the laser

With the invention of the laser at the end of the 1950s, a new discipline, photonics, emerged as a branch of optics, which can be defined as the discipline covering the area where optics and electronics overlap.

Important 1.1: The death ray

When the laser was invented around 1960, the media (obviously with an intention of making a sensation) called it **"the death ray"**. The film industry was quick to adopt this invention which has inspired a great number of devices used in action movies, like the one shown in the picture. Do you recognize the movie in Figure 1? The movie is "Goldfinger" from the James Bond saga.

Figure 1. Frame of the movie Goldfinger, from the James Bond saga. Source: Tor.com `https://bit.ly/2OSZH7K`

When did the concept of the laser come about? It is difficult to say exactly when. From the perspective of the idea of a "light beam" capable of transporting energy and therefore being used as a weapon, we have the example of the novel "The War of the Worlds" by H.G. Wells, which mentions not only the (anticipated) idea of the laser, but also other concepts, as described by **Miguel Uceda**[1] in his study:

"The War of the Worlds" was not the first piece of literature to address the existence of extraterrestrials, but it was the first one to do so from a new perspective, as previously the theme had been treated by writers from the arrogant industrial age as encounters with other more primitive civilizations. For many, the existence of a more advanced technology than that available to society at the end of the century was unimaginable, indeed the head of the New York Patent Office requested the closing of the service in 1899 for the simple reason that "everything that can be invented has been invented".

*Obviously that was not the opinion of someone with Wells' imagination, capable not just of thinking up premonitions like the ones poured into this novel –like space ships, **the laser beam**, chemical warfare or the organization of international aid in the event of large-scale disasters-, but also of using fantasy to portray his conception of colonialism.*

4.2. Einstein and the basic principles of lasers

The basic theory for the development of the laser was described by **Einstein** in his famous article "On the quantum theory of radiation"[2], explaining the phenomenon known as **stimulated**

[1] `https://bit.ly/2Ki2GWo`

[2] The original title of the article was *Zur Quantentheorie der Strahlung*.

emission that will be discussed further on.

Important 2.1: LASER

Laser, by the way, is the acronym of *Light Amplification by Stimulated Emission Radiation*.

4.2.1. Spontaneous emission of light

“Ordinary” light that we normally observe, for example Sunlight, is produced by means of what is known as **spontaneous emission**.

Spontaneous emission occurs when an atom loses energy. In fact, it is the electrons of the atom that lose that energy. Remember that an atom consists of a nucleus (protons, neutrons) and one or several electrons occupying different “shells” around the nucleus. If an electron in a shell further away from the nucleus “jumps” to a lower shell (see Figure 2), that electron loses energy in the process[1]. As we know that energy cannot “disappear” as if by magic, but instead is transformed, the energy that the electron loses must be converted or used in another process. What happens is that it is converted into a **photon**; in other words, into **light**.

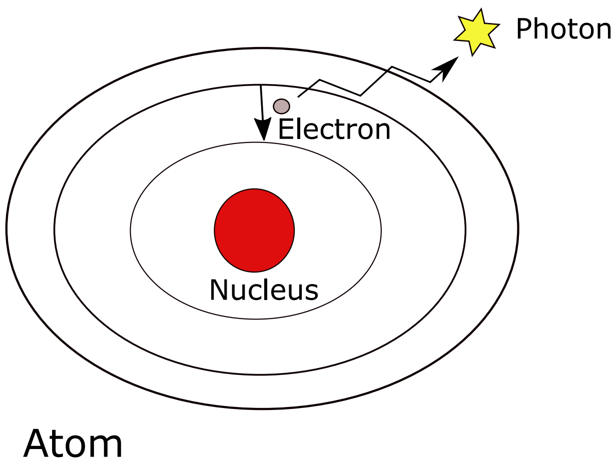


Figure 2. Diagram illustrating the process of the spontaneous emission of light. Source: Author’s own work.

Figure 2 shows a typical representation of an atom with its nucleus (red, at the center) and electrons. The latter can occupy different levels or shells. An electron loses energy when it “falls” from a higher level to a lower one.

Important 2.2: Color y λ

The color (wavelength λ) of the photon that is emitted in spontaneous emission depends precisely on the energy of that jump between “electronic” levels.

This takes us to the different ways of generating light by spontaneous radiation. We have the example of classic **incandescence**, where the energy required to make the electrons go up a level in

[1] The closer it is to the nucleus, the less energy it has.

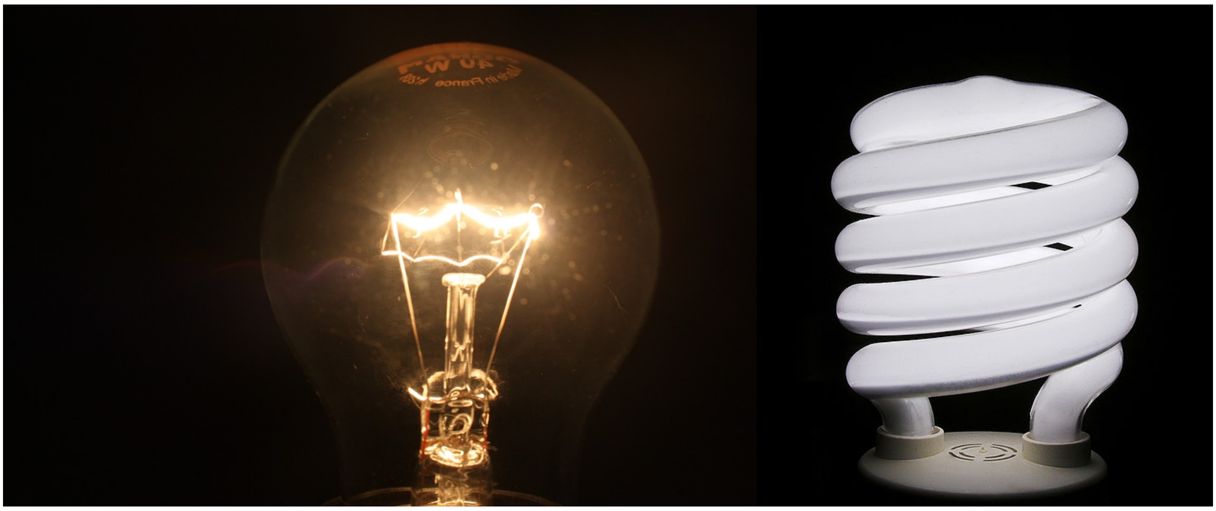


Figure 3. Examples of sources of incandescent light (left) and luminescent light (right). Source: Pixabay (CC0 Creative Commons) and Wikimedia (CC-BY-SA 3.0).

order to generate radiation is provided with heat, the radiation depending only on the temperature reached. On the other hand we have **luminescence**, where the energy can be provided with light, chemical reactions, electricity. An example of the first kind of radiation is classic filament bulbs and an example of the second kind is fluorescent lamps (see Figure 3).

Question 2.1: Fluorescent lamps

Find out how light is generated in a fluorescent tube. Is UV light generated at any point?

Is it dangerous if a fluorescent tube gets broken at home? Why?

Could the light generated by fluorescent lamps be adapted to other uses, for example for a greenhouse?

4.2.2. Absorption

In the same way as we have just said that atoms can emit light if an electron loses energy, the opposite can also occur: **An atom can absorb a photon that bumps into it**. What happens to that photon's energy? Inversely to emission, that energy will enable an electron to go from a lower shell or level to an upper one, as shown in Figure 4.

Important 2.3: Absorption of light (I)

As we know, the color black absorbs all incident radiation. However, materials behave differently, depending on the type of light used. Figure 5 shows a picture of a man with a black plastic bag on his arm, represented with "visible" light (left) and infrared light (right). Whereas the black bag is completely opaque to visible radiation (it absorbs all the light in that range of wavelengths), it lets the infrared light get through.

In fact, we can see that the opposite occurs with his glasses, which are transparent in visible light, but opaque in infrared light.

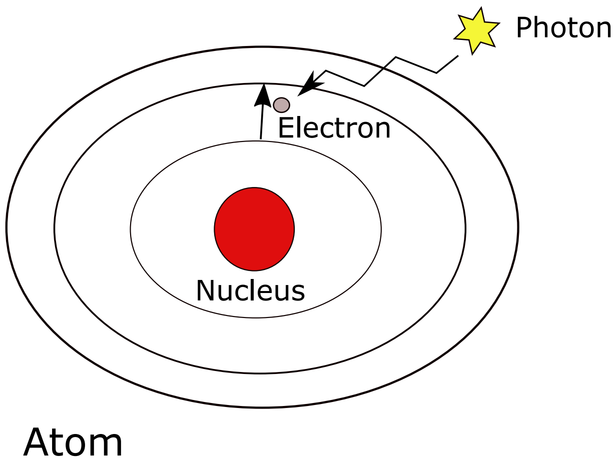


Figure 4. Diagram illustrating the absorption of light. Source: Author's own work.

Important 2.4: Absorption of light (II)

The following video shows the material that absorbs the most light in the world: interesting isn't it?

http://cnn.it/2oEk7o4

Figure 5. Picture of a person with a black plastic bag in visible and infrared light. Source: NASA/Caltech.

4.2.3. Stimulated emission of light

With spontaneous emission and absorption already known processes, Albert Einstein (back in 1916) considered a third possibility that, in fact, nobody had ever seen: **stimulated emission**.

In stimulated emission, the photon that bumps into the atom is not absorbed, but causes the emission of another photon whose characteristics are **completely identical** to the original one. This is **CRUCIAL** to understanding the concept of stimulated emission and is what gives laser light its special characteristics which are so different to "ordinary" light:

All the photons emitted by a laser are identical!

Einstein made a calculation of probabilities and determined that at ambient temperature this occurs: **once every 1000000000000000000 spontaneous emissions!** Therefore, this process does not occur **spontaneously** in nature, but has to be **stimulated**.

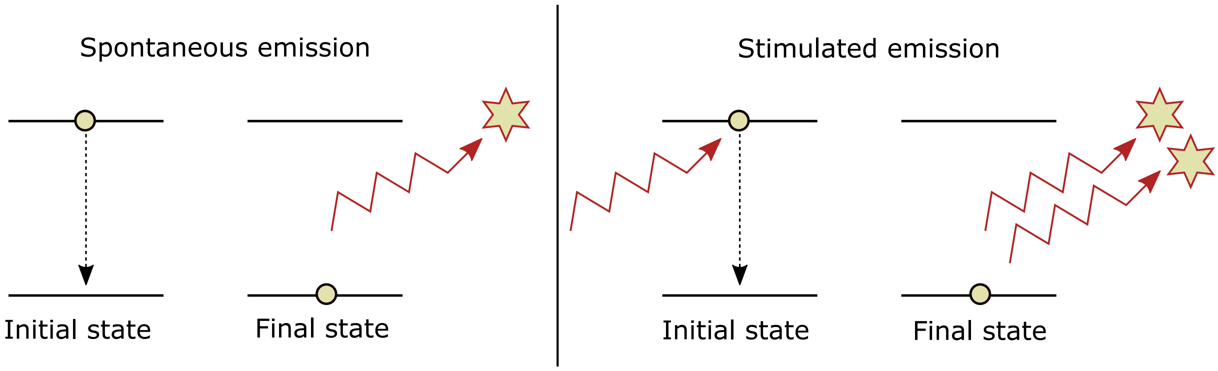


Figure 6. Diagrams illustrating the spontaneous emission and stimulated emission processes. Source: Author's own work.

Therefore, the main difference between the two processes lies in the fact that in spontaneous emission, movement of the electron from an upper level to a lower level occurs randomly, whereas in stimulated emission, that movement is stimulated by a photon with the same energy as the gap. The resulting photon has the same phase and frequency as the original one. **This point is fundamental and gives laser light its unique characteristics**.

As laser light is generated by stimulated emission and all the photons are "identical", it has very particular characteristics. Whereas "conventional" light, for example the light generated by incandescence, is composed of many colors and wavelengths, laser light is formed by one single color, by a *very narrow* wavelength.

Moreover, laser light is **coherent**, which means that **we can predict how the light will behave with distance and time**, which does not happen with conventional light. These characteristics derive from the fact that laser light is **collimated** in a certain direction, in other words, it forms a beam or a very small spot of light even at great distances, whereas a normal bulb generates light in many different directions.

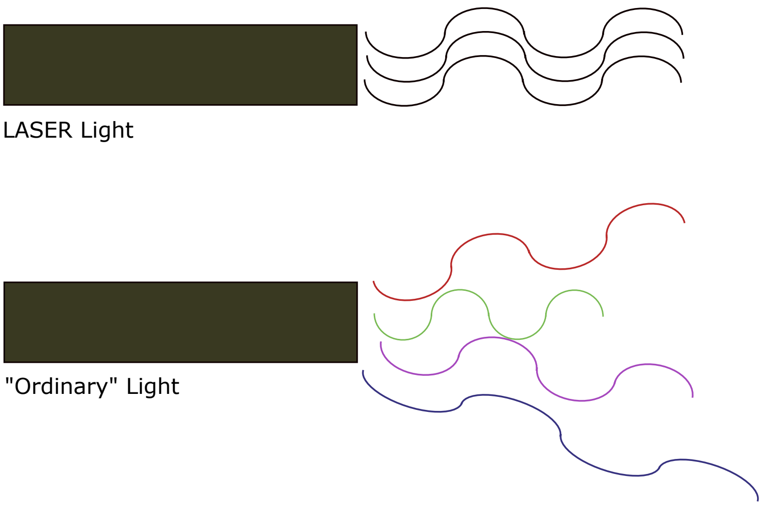


Figure 7. Laser light versus ordinary light. Source: Author's own work.

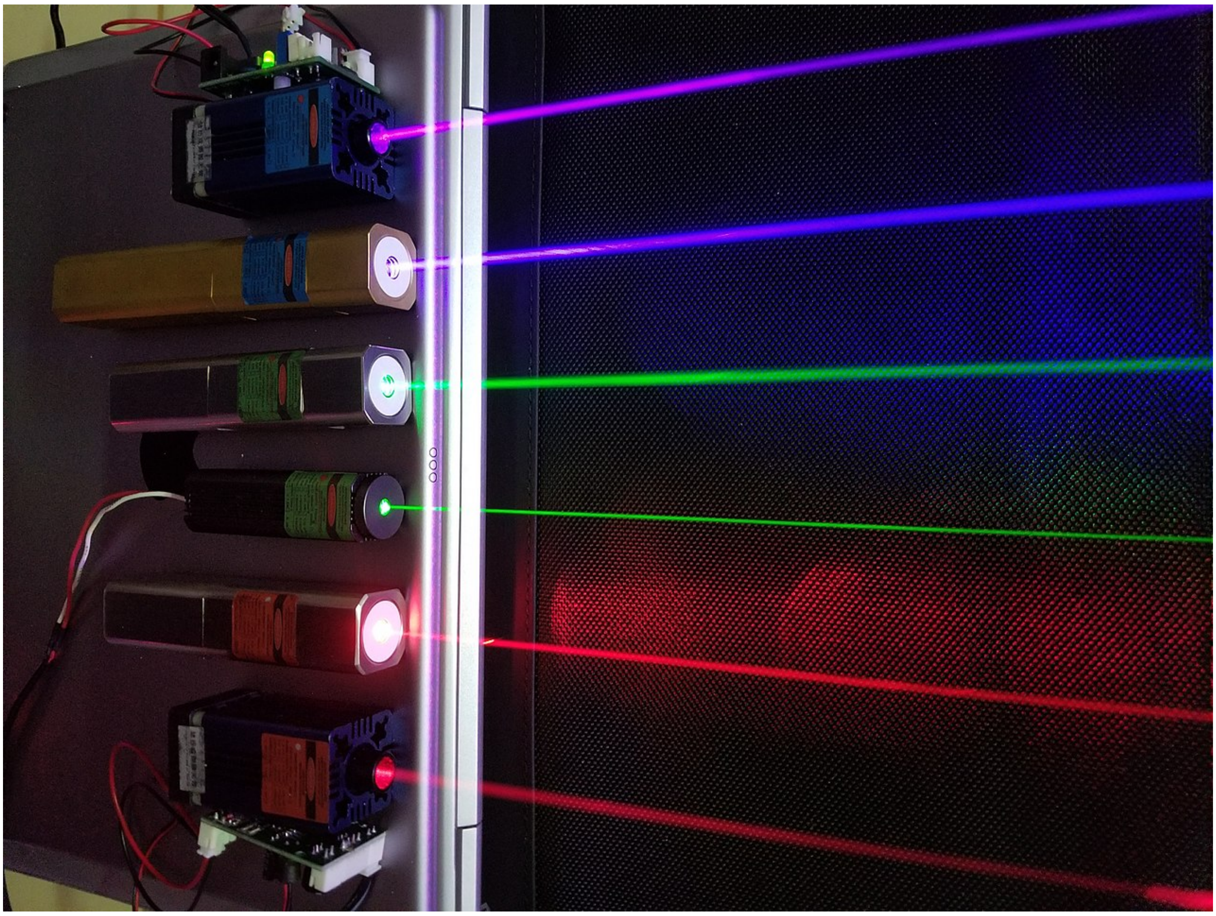


Figure 8. Lasers emitting at different wavelengths. Source: Wikimedia. License: CC BY 2.5. `http://bit.ly/2yzM9uF`

4.3. A brief history of the invention of laser

The history of the **invention of the laser** is fascinating, both owing to its importance and to the fight between different research teams and the subsequent recognition (and associated lawsuits) of their work.

As already mentioned, **Einstein** lay the theoretical foundations for the invention of the laser in 1916 with his idea of stimulated emission. In the 1950s, several teams (Townes and Schawllow of Bell Laboratories, Gould from Columbia University and Prokhorov and Basov from the Soviet Union (Lebedev Physics Institute) worked separately on the invention of the laser, but at practically the same time. In fact, Gould and Townes even made contact with each other, while the designs of the Russians Prokhorov and Basov and Gould were very similar.

However, recognition was mainly bestowed upon the **Bell Laboratories (Townes) and Prokhorov and Basov**[1], **Gould** being left out. In fact, Gould filed a **lawsuit** against Townes and the United States Patent Office which, no less than 28 years later, ended up admitting he was right as regards two patents related to the discovery of the laser. Ironically, Gould used the rights of the patent eventually granted to pay for the costs of the lawsuits, although his objective was to obtain the recognition that had been denied for so many years.

[1] These 3 scientists received the Nobel Prize in Physics in 1964 for their work on the laser.

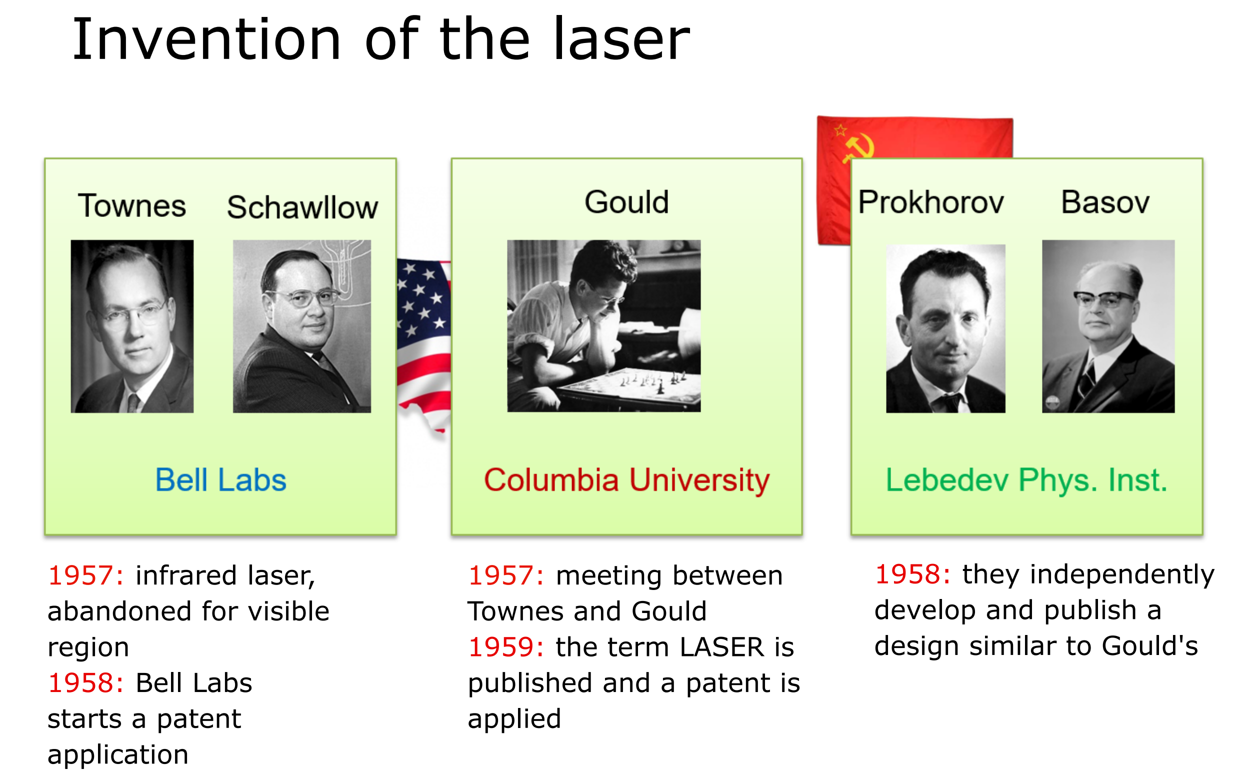


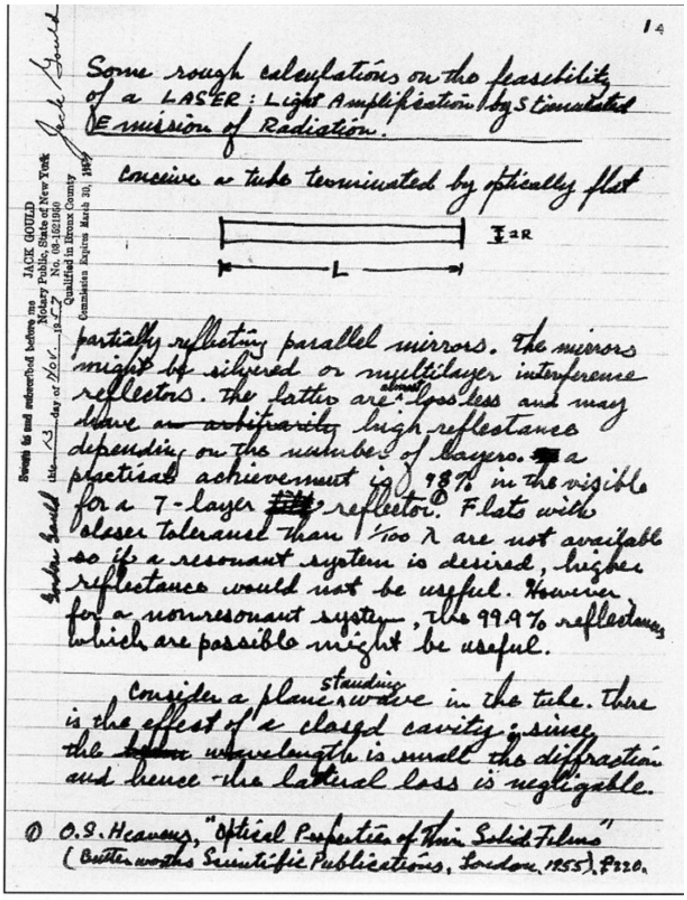
Figure 9. Teams working on the invention of the laser at the end of the 1950s. Source: Author's own work.

Important 3.1: Gould and the term LASER

The term LASER was coined by Gould. Figure 10 shows an extract from Gould's notes reflecting this term.

Another key figure in the race for the invention of the laser is **Theodore Maiman** who, **in 1960**, following a collaboration with Gould, **experimentally demonstrated a laser for the first time**, which was based on a pink ruby and a flash lamp. Interestingly, the journal Physical Review Letters initially refused to publish his results, which, following a second press conference, were published in the prestigious journal Nature. The fact that his results were published somewhat belatedly gave time for other parallel developments to get under way. For this reason, Townes and Arthur Leonard Schawlow are also considered to be inventors of the laser, which they patented in 1960. Two years later, Robert Hall invented the semiconductor laser. In 1969, the first industrial application of the laser was developed, that being its use in welding bodywork for manufacturing vehicles and the following year Gordon Gould patented many other practical applications for the laser.

Maiman's greatest success was in demonstrating the relative simplicity of building lasers, thus leading the way to their use in a great number of applications.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Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

Conceive a tube terminated by optically flat

partially reflecting parallel mirrors. The mirrors might be silvered or multilayer interference reflectors. The latter are almost lossless and may have an arbitrarily high reflectance depending on the number of layers. a practical achievement is 98% in the visible for a 7-layer reflector. Flats with closer tolerance than 1/100 λ are not available so if a resonant system is desired, higher reflectance would not be useful. However for a nonresonant system, the 99.9% reflectances which are possible might be useful.

Consider a plane standing wave in the tube. There is the effect of a closed cavity; since the wavelength is small the diffraction and hence the lateral loss is negligible.

① O.S. Heavens, "Optical Properties of Thin Solid Films" (Butterworths Scientific Publications, London, 1955) P220.

Sworn to and subscribed before me this 13 day of Nov. 1957
Gordon Gould
JACK GOULD
Notary Public, State of New York
No. 03-1621950
Qualified in Bronx County
Commission Expires March 30, 1959
Jack Gould

Figure 10. Extract from Gould's notebook where the term LASER appears. Source: Photonics.com.

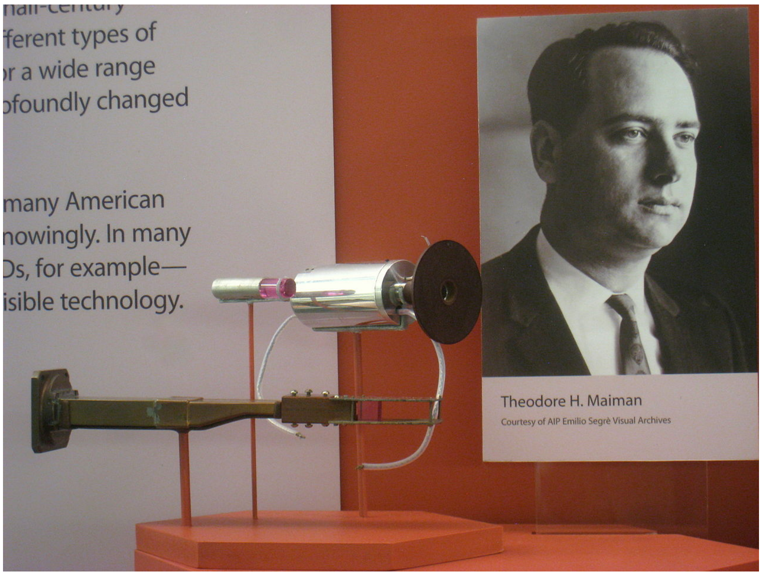


Figure 11. Picture of Maiman and the first laser demonstrated on 16th May 1960, displayed in the National Museum of American History in Washington. License: Public Domain.

4.4. How a laser works

The working principle of a laser is simple. Its construction is based on the so-called **resonator** (1 in Figure 12), which is basically a medium with atoms of the element that we want to use (and which will determine the wavelength (color) of the light emitted), limited by two mirrors (3 and 4) which make the photons rebound numerous times before exiting and generating the light desired.

In order to provoke stimulated emission, first of all energy (2) must be pumped to the atoms inside 1 (also called the active medium) to make their electrons go up a level in order to emit the necessary photons.

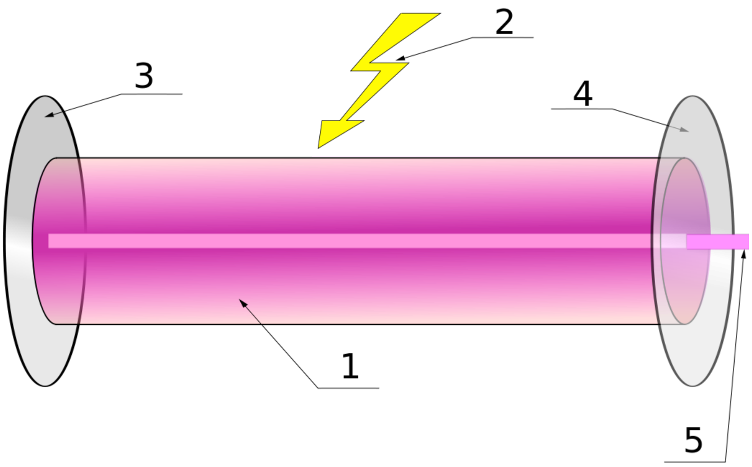


Figure 12. Diagram showing the working principle of a source of laser light. Source: Wikipedia. License: CC-BY- SA 3.0. `http://bit.ly/2hLvycE`

Important 4.1: How a laser works

In YouTube, there are numerous videos explaining the basic working principle of a laser. For example, see the following link: `https://youtu.be/vgbBPaoR3bw`

Important 4.2: Professor Martín Pereda

If you are interested in finding out about the origins of the laser and photonics in Spain, I highly recommend reading this interview with Professor Martín Pereda: `http://bit.ly/2lZxrqE`.

4.5. Evolution of the laser

Following its invention, the laser was defined as:

"A solution in search of a problem"

Indeed, the laser came about as a result of Einstein's theoretical studies but, at first, it was not clear what it could be used for. Over the years, the laser has found a multitude of applications in a great variety of fields: medicine, industry, consumer electronics, etc.

Once the laser had been invented, the race began to improve its features, in particular to achieve smaller, more powerful or faster lasers or lasers capable of emitting in a greater variety of colors, etc. Below we will discuss some of these improvements:

4.5.1. Smaller!

What is the minimum size of a laser? Figure 13 shows a striking example of a laser implanted in the head of a fly. However, even more amazing than this is that researchers have already succeeded in making lasers with **our own cells!!**[1]

Miniaturizing the laser has been possible thanks to the invention of the so-called **semiconductor laser**, developed around 1962 by various groups (General Electric, IBM, MIT) which allows converting electricity directly into laser light, thus permitting, for example, the modulation of light (transmitting information through light).

Figure 13. Laser implanted in the head of a fly.

The **laser diode**[2], today a basic device used in an infinite number of everyday appliances (e.g. CD, DVD players etc.) and in optical communications, has its origins in the work carried out by **Herbert Kroemer** in the mid-50s on semiconductors and in particular on heterojunctions. The first demonstration of coherent light emission from a semiconductor diode (gallium arsenide) was conducted in 1962 by the scientist **Robert N. Hall**, from the General Electric research center. The first laser diode to achieve emission in a continuous mode of operation was proposed by **Zhores Alferov** in 1970.

[1] For more information you can consult the following article in Nature: `https://go.nature.com/2TwcxfK`.

[2] Another term for semiconductor laser.

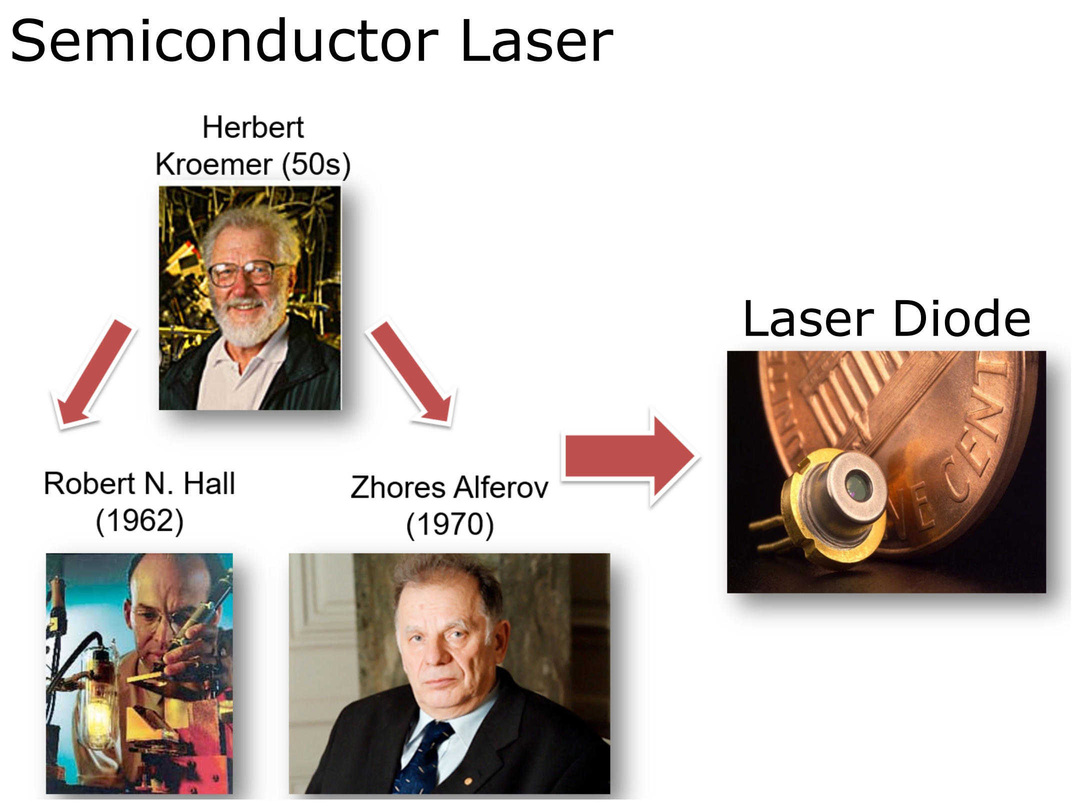


Figure 14. Scientists involved in the development of the laser diode. Source: Author's own work.

Alferov and Kroemer shared the **Nobel Prize in Physics in the year 2000**.

So what has the semiconductor laser made possible? For example, the development of information storage media in recent decades, **like the CD, the DVD and more recently Blu-ray**. The increase in storage capacity has been possible thanks to the fact that, using increasingly sophisticated lasers, it has been possible to decrease the size of the information recorded on these media.

Figure 15 shows the first ever CD, dating back to 1982. Figure 16 shows a comparison between **CD, DVD, HD DVD and Blu-ray** data storage media, with a gradual decrease in the size of the information recorded, going hand in hand with an increase in the "precision" of the lasers used.

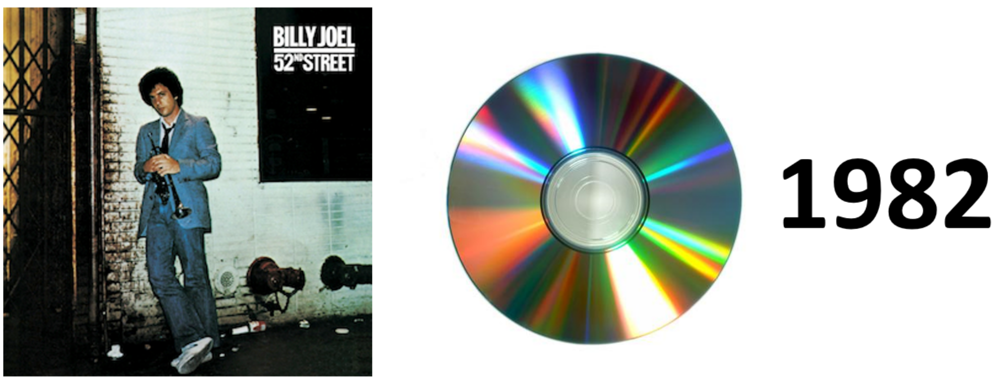


Figure 15. First CD (Compact Disc) released in 1982. Source: Author's own work (ultimateclassicrock.com).

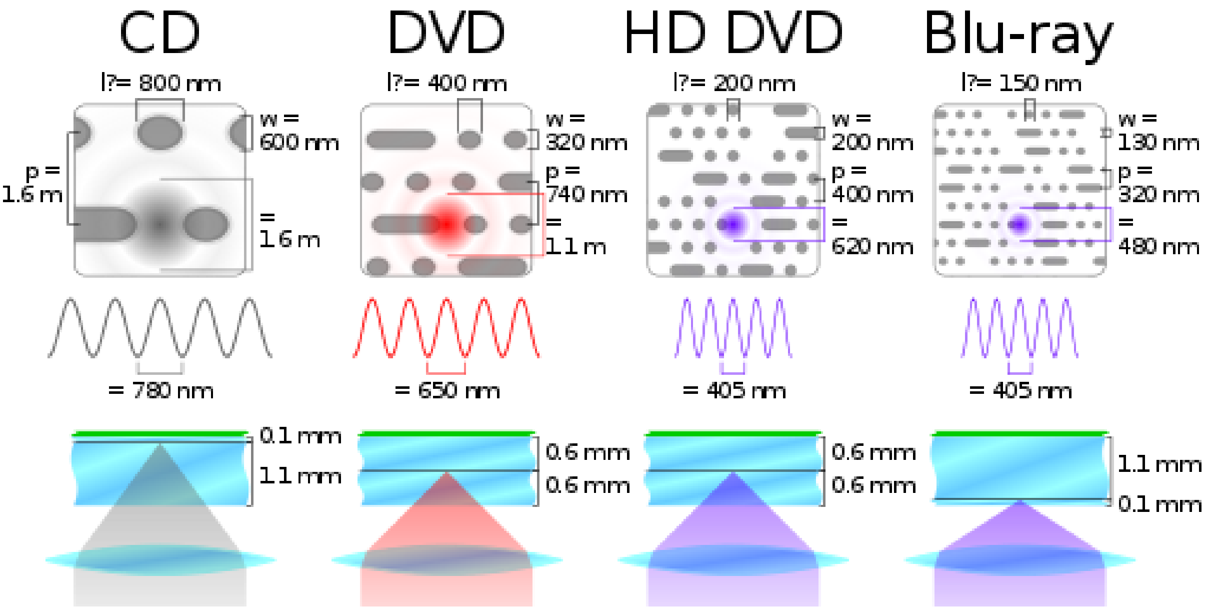


Figure 16. Comparison between CD, DVD, HD DVD and Blu-ray data storage media. Source: Wikimedia. License: CC BY-SA 3.0. `http://bit.ly/2zkFwf7`

4.5.2. More colors!

It has also been very important to extend the range of **colors or wavelengths** with which lasers can be manufactured, for uses in different applications. A very interesting example is the recently invented **X-ray laser**, which amongst other advantages includes taking an x-ray of small objects at a high resolution, as we can see below.

The difference between generating X-rays through laser-matter interaction and employing the usual techniques (X-rays tubes or synchrotron radiation) is mainly based on there being a point source of radiation. The focal point of the image obtained is small enough (some 200 microns) to produce high resolution x-rays. Figure 17 shows an x-ray of a European carpenter bee taken using this system[1].

In order to create lasers of different colors, it is necessary to find new materials. Laser emission has been demonstrated in gases, liquids, solids, plasmas, free electrons. . . however: it is not as easy as it looks!

4.5.3. Faster!

Why do we want to make faster lasers? Because **the faster the laser, the shorter the pulses of light generated**. . . and thus the greater the power associated with these pulses of light. As illustrated in Figure 18, a pulse of laser light (of the same energy) that lasts 1 nanosecond[2] is a lot less powerful than a pulse lasting femtoseconds[3].

Besides power, one of the main advantages of lasers with a very short pulse duration, femtoseconds, is that the **interaction between light and matter** is so short that there is no time for

[1] Source: `http://desayunoconfotones.org/2015/09/07/rayos-x-generados-laser/`
[2] 1 nanosecond = 0.000000001 seconds.
[3] 1 femtosecond = 0.000000000000001 seconds.

Figure 17. X-ray of a bee taken by means of a laser system. Source: desayunoconfotones.org.

thermal diffusion effects (transference of heat) to take place in the surrounding tissues. This is fundamentally important, for example, in cataract surgery, where we want to limit, as far as possible, damage to the tissue surrounding the point where the laser makes the cut. This effect can be very clearly seen in Figure 19, which shows the difference between machining material with a nanosecond laser (on the left) and a femtosecond laser (on the right).

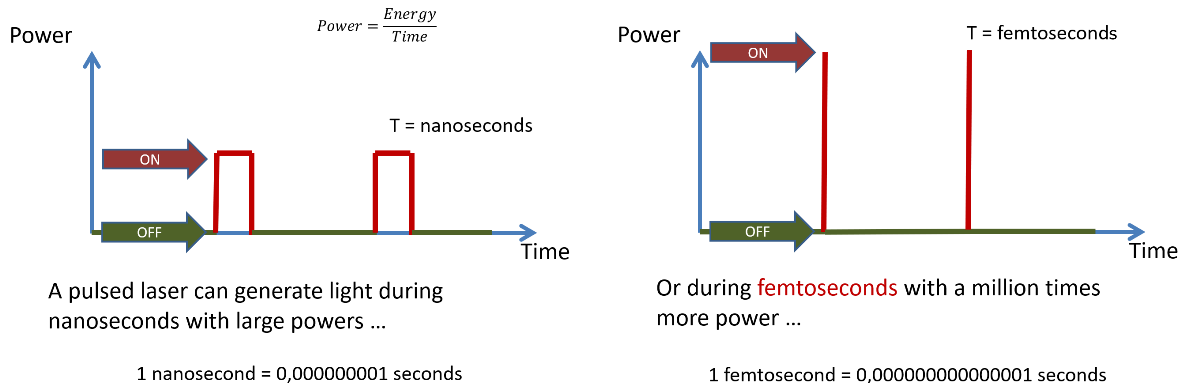


Figure 18. Emission of pulses with nanosecond or femtosecond lasers. Source: Author's own work.

4.6. The invention of the laser: conclusions

This part of the course has provided a brief overview of the fascinating history of the invention of the laser, a device of unquestionable importance (as we have seen, several Nobel Prizes in Physics are related to it), in view of the innumerable applications used today that require a source of laser. In the following chapter, we will take a look at the applications in which light in general and laser in particular play a key role. However, before that we will briefly discuss another key development for today's society: optical fiber.

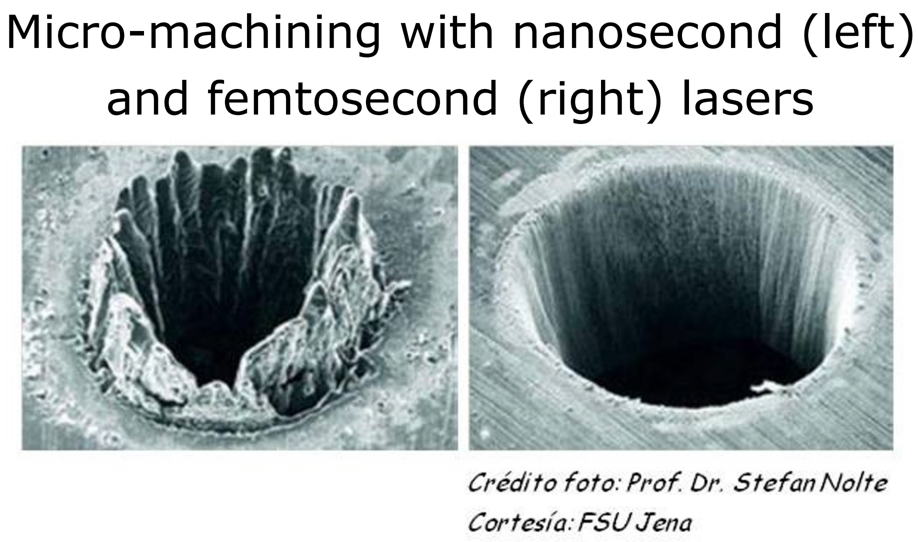


Figure 19. Difference between micromachining a material with a nanosecond laser (on the left) and a femtosecond laser (on the right). Source: Prof. Stefan Nolte / FSU Jena. `http://bit.ly/2hish7U`

4.7. Optical fiber: light that travels through glass

Today we are all familiar with the concept of **optical fiber** and many of us will have been offered a high-speed internet service in our homes. As already mentioned, the Internet, from a physical point of view, can be understood as (laser) light that travels around the world guided by optical fiber.

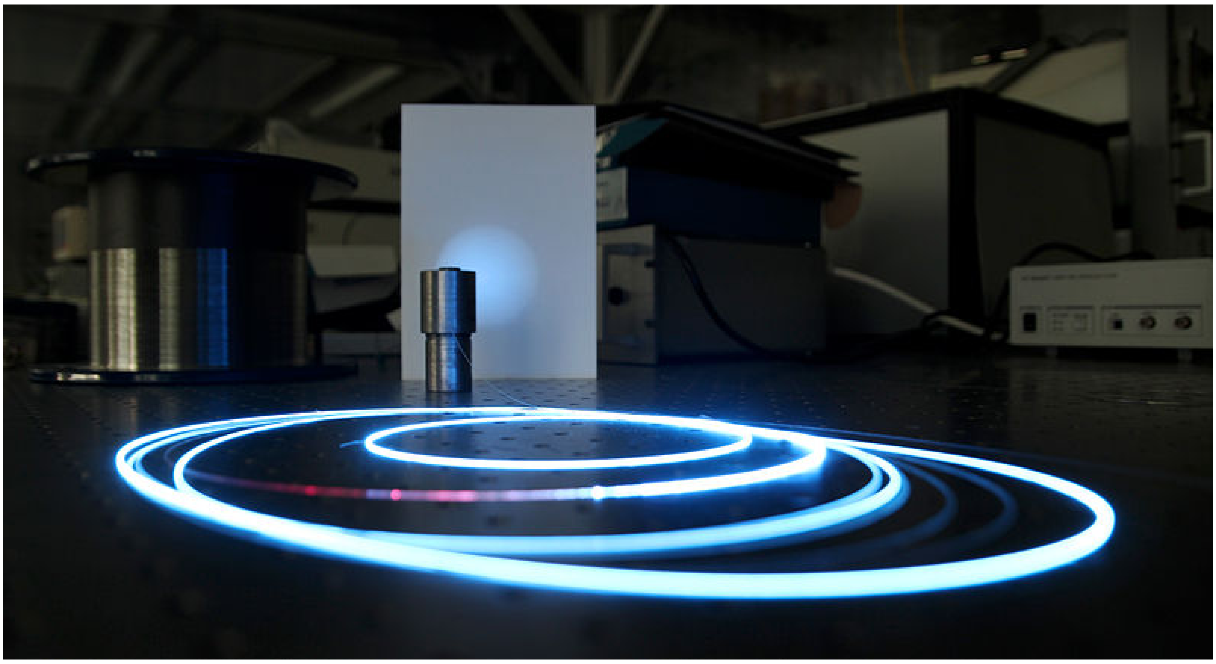


Figure 20. Optical fiber injected with infrared light, but which emits blue light due to the fluorescence phenomenon. Source: Wikimedia. License: CC-BY-SA 2.0. `http://bit.ly/2hQ6JfT`

Optical fiber is, therefore, **a transmission medium that enables confining and guiding light**. Even though it may appear to be a modern concept, the origins of optical fiber date back to the decade of the 1840s when Daniel Colladon and Jacques Babinet demonstrated the possibility of confining light by refraction[1]. Figure 21 shows the “source of light” described by Collandon in his article in 1842, with light confined in a liquid.

Sometime later, John Tyndall (1870) investigated the propagation of light in other materials (water, crystal) and discovered that it bends due to the so-called **internal reflection** phenomenon. Continuing on with this summary on the evolution of optical fiber, the medical endoscope was patented in 1956 by the University of Michigan.

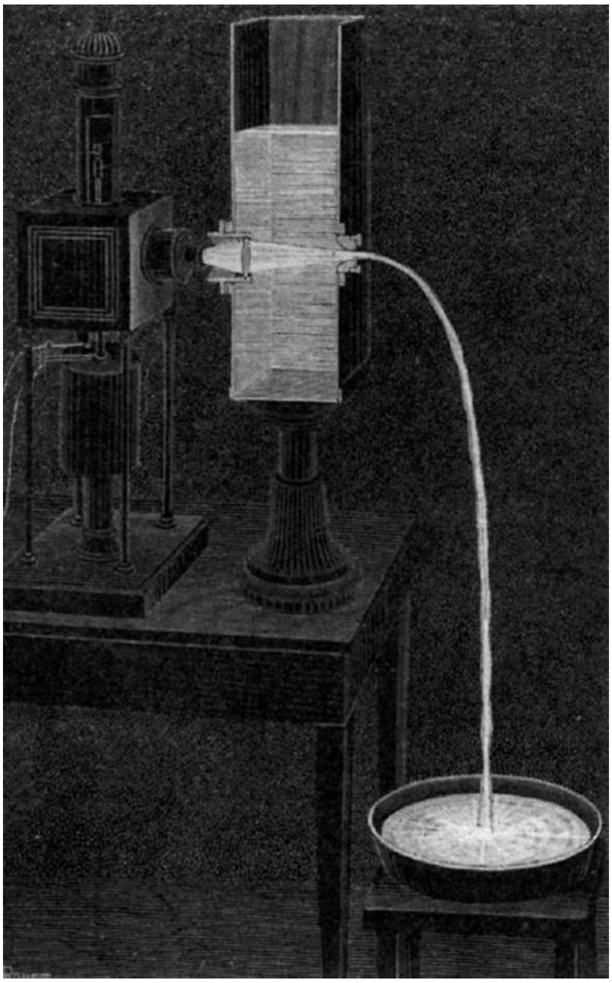


Figure 21. Source of light described by Collandon in 1842, demonstrating the principle of light guided through an optical fiber. Source: Wikimedia. License: Public Domain. `http://bit.ly/2hbNxbu`

4.7.1. Total internal reflection

The physical process whereby light is guided through a very narrow glass tube[2] is called **total internal reflection**. To understand this phenomenon, we must turn to **Snell’s Law** given in chapter 1, which explains the phenomena of refraction and reflection (more precisely, it enables

[1] If you cannot remember what refraction is, take another look at it in chapter 1 of this course.

[2] This could be an informal definition of optical fiber.

determining the angle of refraction if we know the angle of the incident ray and the refractive indexes of the media involved).

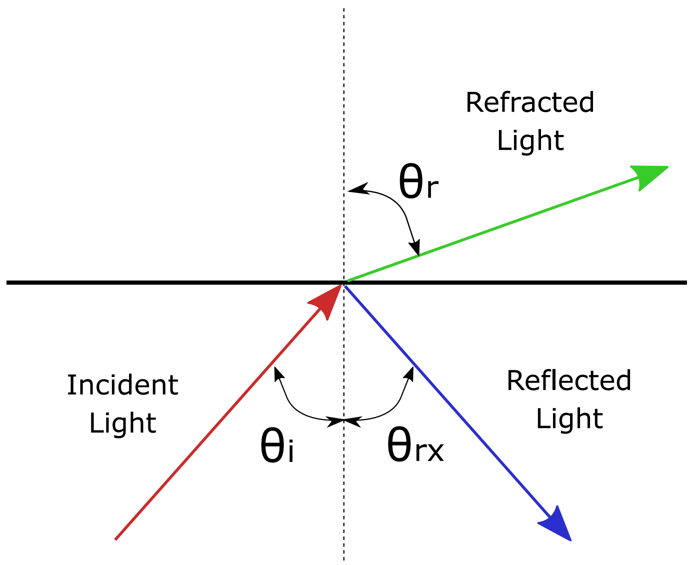


Figure 22. Representation of Snell's Law. Source: Author's own work.

As shown in Figure 19, if the refractive index of medium 1 (n1) is greater than that of medium 2 (n2) (the density of medium 1 is greater than that of medium 2), the angle of the refracted ray θ_r will be greater than that of the incident ray θ_i. In fact, the situation could arise where $\theta_r = 90°$. The angle of the incident ray making $\theta_r = 90°$ is called the **critical angle** θ_c. For any angle of incidence greater than θ_c, there will be no refracted ray and all the light from the incident ray will be reflected, giving rise to the total internal reflection phenomenon. This situation is clearly shown in Figure 23.

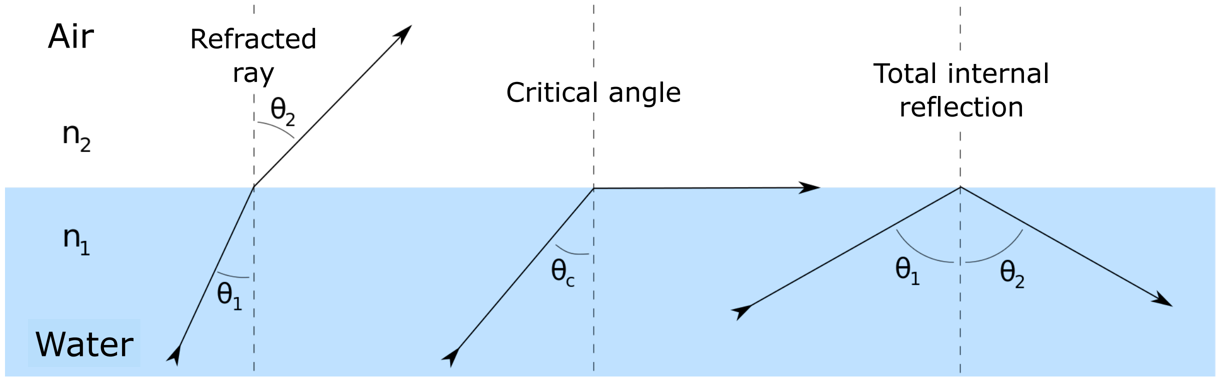


Figure 23. Total internal reflection phenomenon. Source: Wikimedia. License: CC BY-SA 4.0. `http://bit.ly/2zmgLg1`

Important 7.1: Total internal reflection

This video shows a practical demonstration of the total internal reflection phenomenon: `https://youtu.be/AT3oa7ER9zE`

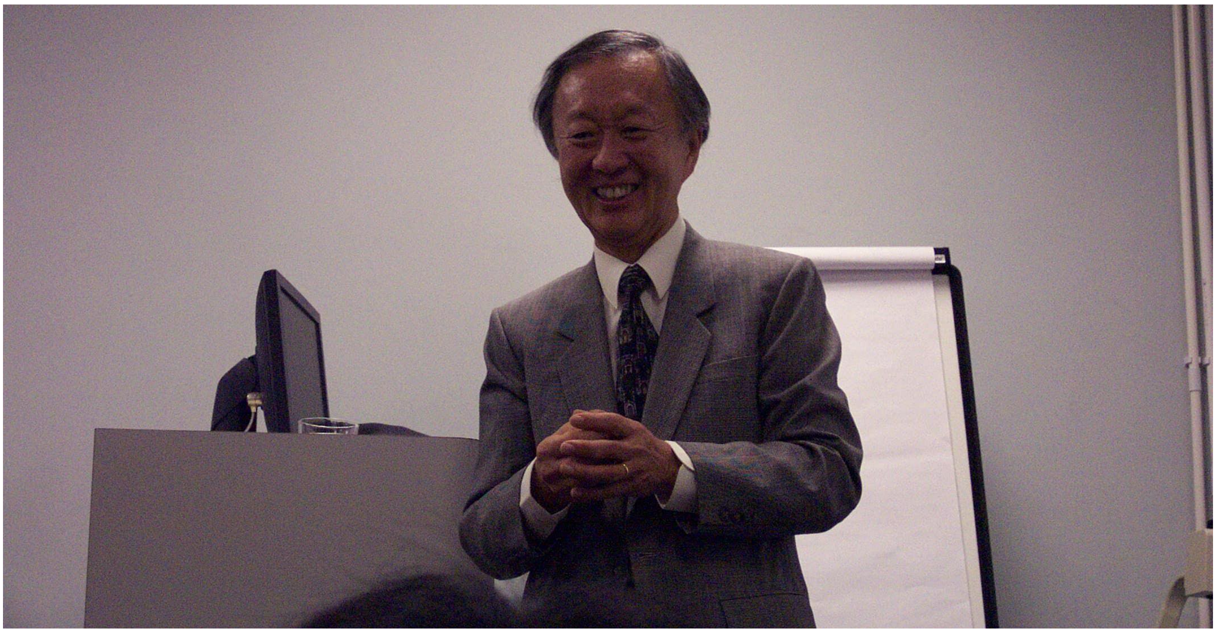


Figure 24. Charles Kao in the year 2003. Source: Wikimedia. License: CC BY-SA 3.0. http://bit.ly/2hjW9kf

4.7.2. Evolution towards optical fiber

Even though total internal reflection and its possibilities were well known, the development of viable optical fibers for the transmission of light was highly complex in the beginning. Optical fiber is made out of glass (silica) which is found in abundance on earth. However, the first optical fibers had extremely high **"losses"**: that is to say, the majority of the light entering one end was not capable of reaching the other end through just a few meters.

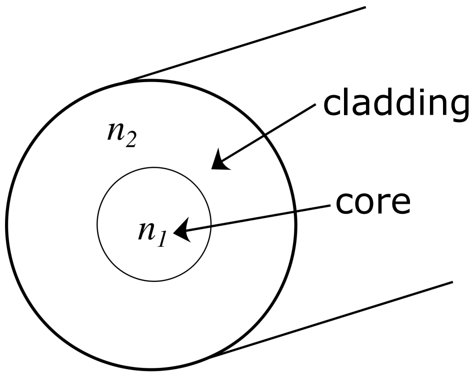
Improvement of optical fiber came about thanks to the work of **Charles K. Kao**, who wrote his doctoral thesis on this subject in the decade of the 60s substantially improving manufacturing processes to decrease the impurities, responsible for those aforementioned losses[1], within the fiber's core.

In 1970, Maurer, Keck, Schultz and Zimar manufactured an optical fiber with titanium impurities in silica: losses decreased from 100 to 17 dB per kilometer[2]. At the end of the 70s, losses decreased further to around 0.5 dB per kilometer, and on the 22nd April 1977 the first telephone transmission through optical fiber took place in California.

The groundbreaking work carried out by Charles Kao in the 60s was so important that he received the **Nobel Prize in Physics in the year 2009**.

[1] In 1966, Kao and Hockham published an article associating losses in OF with very small intrinsic impurities in glass.

[2] Losses in optical fiber are usually expressed in dB or decibels, a unit of measurement normally used in acoustics: https://bit.ly/1LZQMOm



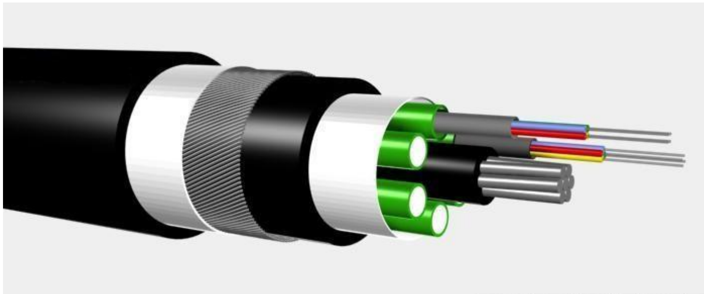


Figure 25. Structure and detail of an optical fiber. Source: Wikimedia. License: CC BY-SA 3.0. `http://bit.ly/2hk4DHP`

4.7.3. The structure of an optical fiber

A "standard" optical fiber (the one normally used for communications like the Internet) is a fiber made up of two parts: an internal core measuring about 9 microns[1] in diameter and a cladding which surrounds it with a diameter of 125 microns. As already mentioned, the core is manufactured with silica (SiO2) to which certain "dopants" are added (boron, germanium, phosphorous) to modify the refractive index in order to meet the total internal reflection condition; in other words, the refractive index of the core is slightly higher than that of the cladding.

The fiber also has an outer coating to protect it and aside from that, in real applications, there are other protective components, like kevlar fibers, plastic tubes, etc. Figure 26 shows (left) the basic structure of an optical fiber, with the core and cladding (covering). The right side of the figure shows how fiber is deployed in communications, where in reality multiple fibers (as seen on the far right of the picture) are guided through different tubes around a central component which provides sturdiness and protection to the whole assemblage.

4.7.4. Fiber optic communications

Today, optical fiber is present in an infinite number of locations: not just in our homes with **"fiber to the home"** technology[2], but also connecting continents and in overhead or underground electric cables or railway catenary systems, to name just a few examples.

Today, there are thousands of kilometers of optical fiber cable deployed both on land and under the sea. Figure 10, for example, shows the submarine cables servicing the African continent.

The FLAG (Fiber-Optic Link Around the Globe) cable serves as another good example, with 28000 kilometers of optical fiber connecting the United Kingdom, Japan, India and many more places in between[3].

[1] 1 micron = 0.000001 metres.
[2] FTTH: Fiber To The Home.
[3] More information at: `https://bit.ly/2Kobtq7`

Important 7.2: Submarine optical fiber

This video shows how submarine fiber optic cables are laid, in this case in Chile:

`https://youtu.be/4NzzYjsXzHY`

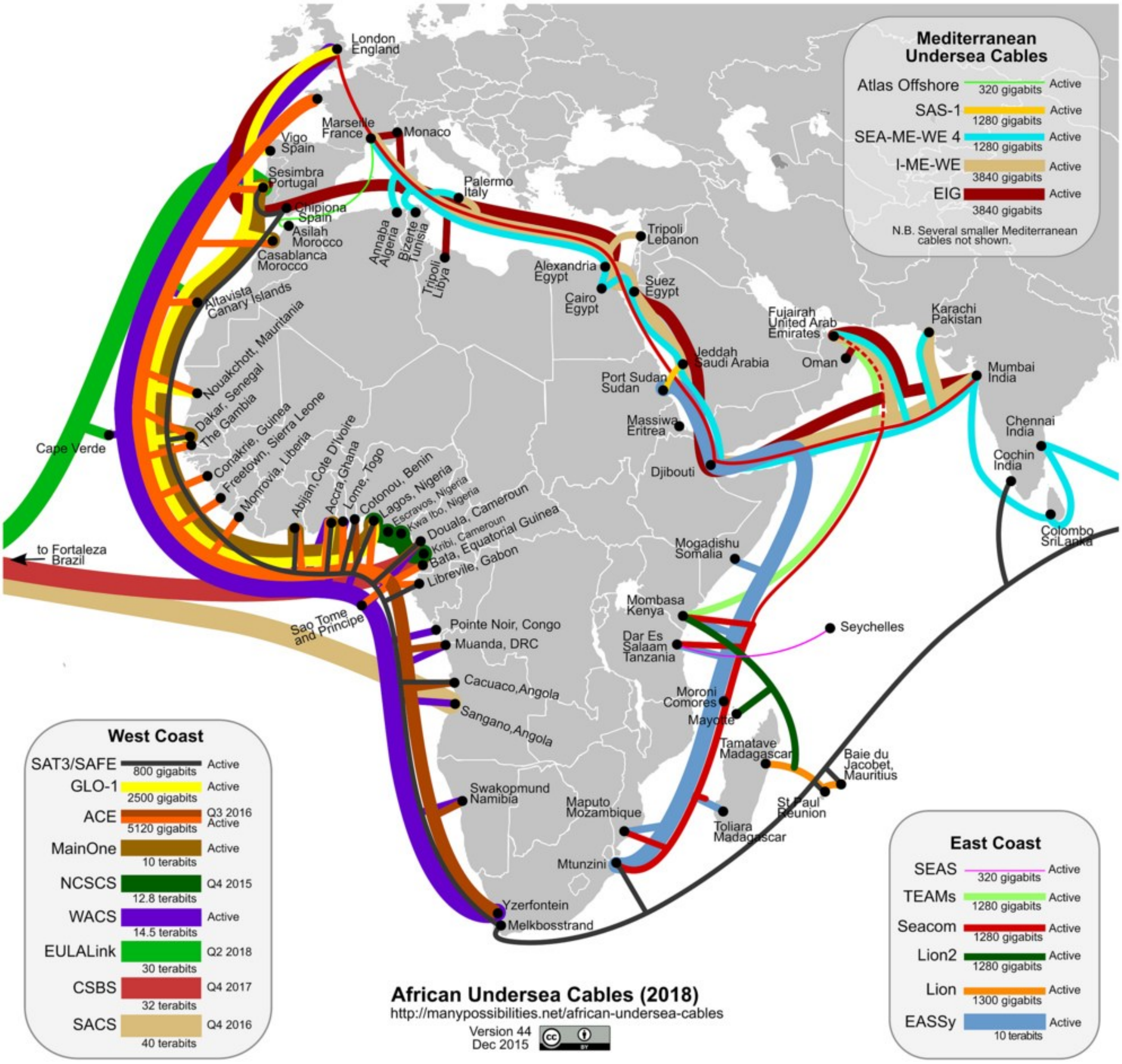


Figure 26. Map of optical fiber cables (existing and anticipated for 2018) around Africa. Source: Wikimedia. License: CC BY 2.0. `http://bit.ly/2zkRhCg`

Question 7.1: FTTH vs. ADSL

As mentioned earlier in the chapter, optical fiber has reached many of our homes thanks to Internet providers, offering increasingly faster access.

Look for information about the speeds provided by optical fiber (FTTH) and the former ADSL (that uses the telephone cable). Also investigate the current market shares of the two technologies.

List of Figures