# 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.** Nobel Prize Winner Shuji Nakamura, inventor of blue LED, during his lecture at the ISLiST UIMP Summer School, in Santander (June 2017). Source: Photonic Engineering Group of the University of Cantabria.

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## *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.

# Table of Contents

# Chapter 7

# Photonics: current situation and future perspectives

In previous chapters we have introduced numerous concepts associated with **Optics and Photonics**. We have provided a historical overview through the most significant milestones that have marked the evolution of these disciplines, in order to understand the basic concepts of what light is, how the Sun generates light and energy, how the laser works and fiber optics.

This chapter, which concludes the theoretical-expository part of the course[1], presents some **lines of research concerning light sciences and techniques that will most likely lead to key advances in future decades**.

## 7.1. The relevance of Photonics today

However, before moving on to those future perspectives, it may be a good moment to briefly highlight the major importance of photonics in modern-day society. We will mention two significant examples: the United States and Europe.

### 7.1.1. Optics and Photonics: essential in the USA

In the **United States**, Optics and Photonics have been considered **key technologies** for the country's technological development, in a document written by the **National Research Council**[2] (see Figure 1).

Even though in this course we have already mentioned several different fields in which light applications are used, it may also be interesting to look at the different fields in which Optics

[1] The final chapter explains some simple experiments that students can do at home.

[2] If you so wish, you can consult the original document at the following link: `http://bit.ly/2zFksgi`

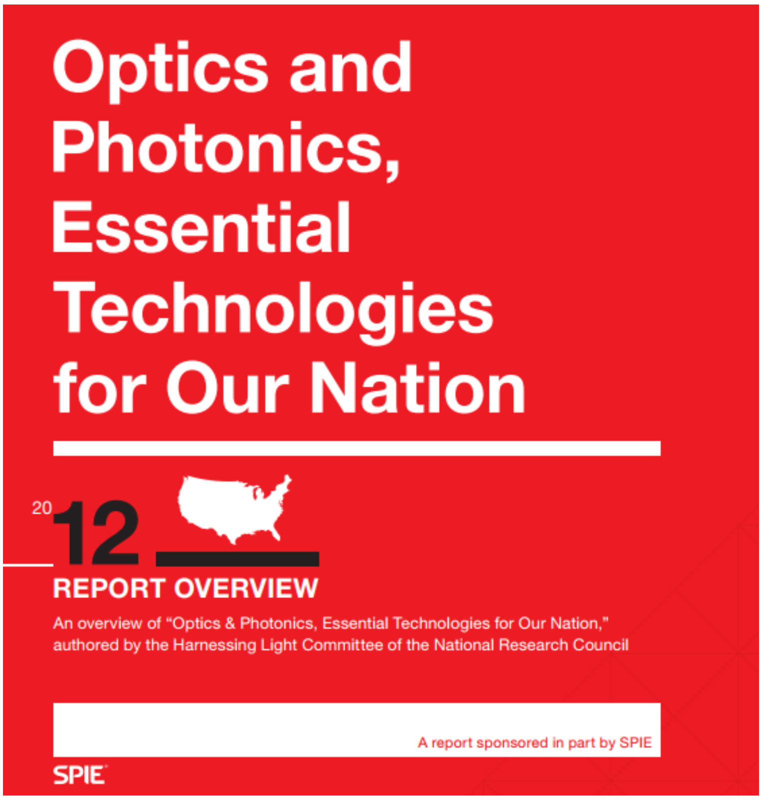


**Figure 1.** Front page of the report: "Optics and Photonics: Essential Technologies for our Nation". Source: SPIE.

and Photonics are considered to have made key contributions according to the aforementioned document:

1. Communications, information processing and data storage
2. Defense and security
3. Energy
4. Health and medicine
5. Sensors
6. Advanced manufacturing processes
7. Materials
8. Screens

### 7.1.2. Key enabling technologies in the European Union

The **European Union** has chosen **6 key enabling technologies** involved in the technological development of EU countries. These technologies are: nanotechnology, micro- and nano-electronics, advanced materials, advanced manufacturing technologies, biotechnology and, of course, **Photonics**.

**Important 1.1: Key technologies in the EU**

If you are interested in the matter, you can look up more information about KETs (Key Enabling Technologies) on the European Commission's Portal at: `http://bit.ly/2zDCRtZ`

### 7.1.3. Optics and Photonics in Nobel Prizes in Physics

Another factor indicating the importance of fields of knowledge associated with light is the number of Nobel Prizes received by researchers working on different lines of research concerning this study area. Below is a list of some examples illustrating this:

**1901: Wilhelm Conrad Röntgen** for his discovery of the remarkable X-rays.

**1918: Max Plank** for contributions made to the advancement of physics by his discovery of energy quanta.

**1921: Albert Einstein** for his contributions to theoretical physics and, in particular, for his discovery of the law of the photoelectric effect.

**1922: Niels Bohr** for his services in the investigation of the structure of atoms and of the radiation emanating from them.

**1964: Nikolái Gennádiyevich Básov, Aleksandr Mijáilovich Prójorov y Charles Hard Townes** for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle.

**1997: Steven Chu, Claude Cohen-Tannoudji y William Daniel Phillips** for the development of methods to cool and trap atoms with laser light.

**2009: Charles Kao** for groundbreaking achievements concerning the transmission of light in fibers for optical communication.

**2014: Shūji Nakamura, Hiroshi Amano e Isamu Akasaki** for the invention of blue light-emitting diodes.

## 7.2. Challenges for light sciences in future years

As we already know, Optics and Photonics or, generically speaking, light sciences and technologies, encompass a great number of different areas, ranging from medicine to industrial sectors and including communications or energy. In this sense, **a great number of exciting challenges lie ahead**.

### 7.2.1. Light in communications: collapse of the INTERNET

Despite being a recent invention (the Internet started to become commonplace in Spanish homes towards the mid-nineties), **the Internet** is today an essential tool without which many people cannot imagine how they would carry out their professional and/or personal activities.


**Figure 2.** Nobel Prize Winner Shuji Nakamura, inventor of blue LED, during his lecture at the ISLiST UIMP Summer School, in Santander (June 2017). Source: Photonic Engineering Group of the University of Cantabria.

Since then, and particularly in recent years with the arrival of optical fiber to homes, the capacity[1] of the Internet has increased at a rapid pace, with several operators today offering speeds above 100Mbps (megabits per second).

Even though this capacity for transmitting information through optical fibers is huge, it is, nevertheless, limited. This has led various experts to warn of a possible **"capacity crunch"** or that the Internet could collapse by 2023. Despite continuous research in the field of optical communications, the transmission media, whether they be coaxial cable or optical fiber, have a physical limit of capacity. Moreover, internet data demand is constantly on the rise: films, video-conferences and photographs with an increasingly better quality, increasingly bigger files, etc. With today's rate of growth in demand, this limit could be reached by 2023 and researchers warn of the radical change that this situation could lead to, such as the Internet not always being "on" or a much higher cost of connection.

This situation arises due to the limited capacity of conventional optical fiber, but alternatives are being studied involving **special optical fibers**. An example of these special fibers is the so-called **photonic crystal fiber (PCF)**, whose design is different to that of conventional communication fiber. In this fiber there is not the typical core where the fiber's guiding mechanism is based on the difference in the core/cladding refractive indexes. In this case, the entire length of the fiber has a cross-section with a micro-structured pattern consisting of several tiny "cores" that

[1] In this context, a physical medium's capacity is the volume of information that it is capable of transmitting in a certain amount of time.

are typically hollow (they can also be solid). This structure is responsible for confining and the fiber, as shown in Figure 3.

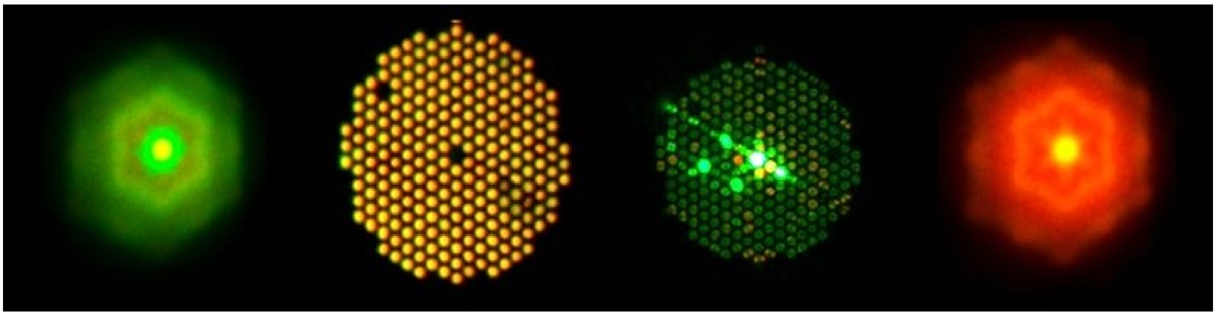

**Figure 3.** Light confined in a photonic crystal fiber. Source: Wikimedia. License: CC-BY-SA 3.0. `http://bit.ly/2ASpJVX`

**Figure 4.** Philip Russel, the inventor of photonic crystal fiber, being awarded the title of Doctor Honoris Causa by the UIMP within the framework of the ISLiST-2016 summer school. Source: UIMP.

### 7.2.2. Light in energy: the renewable energy era

Without a doubt, the generation and supply of energy to the growing world population is one of the main challenges which our society is facing. Furthermore, the generation of **sustainable energy**, within the framework of the phenomenon known as **climate change**, has become a priority in a large number of countries that have opted strongly for the development of non-polluting renewable energies, like solar photovoltaic or wind energy, to mention just a couple of examples.

Within the field of **solar photovoltaic energy**, which is currently experiencing remarkable growth worldwide, one of the main challenges is to obtain an increase in the **efficiency of commercial solar panels**, which at present is about 14-16% at the most. Even though the price of this technology has dramatically decreased in recent years as the number of installations has increased, this improved performance is necessary for this technology to make a qualitative leap. Efficiencies exceeding 20% will probably be achieved by new photovoltaic technologies such as, for example, organic solar cells (see Figure 5).

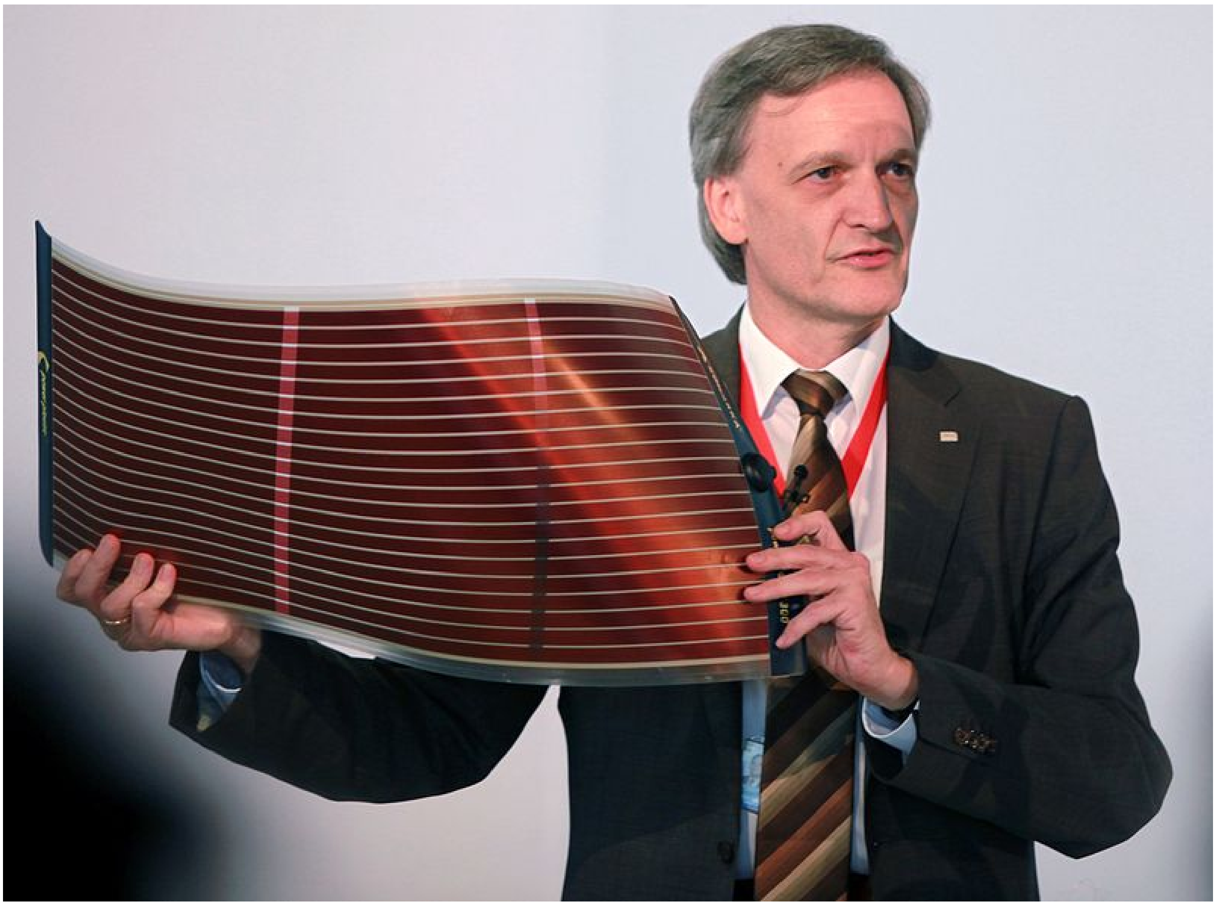

**Figure 5.** Organic solar cell presented by Dr. Thomas Geelhaar (President of Merck KGaA). Source: Wikimedia (Armin Ku¨ belbeck). License: CC-BY-SA 3.0. `http://bit.ly/2ASKYX0`

Furthermore, c**oncentrating solar power** or solar thermoelectric power is sure to be one of the main actors within the framework of renewable energies in future years. This technology involves the use of a mirror farm to concentrate the Sun's energy at the focal point of a tower where a liquid is then heated which, subsequently, is used to generate electricity by means of a turbine. Improvement in the performance of these plants and their development in different countries will be essential for a greater renewable energy contribution in future years. It is worth noting that Spain is, at present, the world's leading country in concentrating solar plants.

Finally, **fusion energy reactors**, in other words, reactors that aim to **imitate energy generation in stars**, could revolutionize the energy sector if they eventually become a reality. As explained in previous chapters, there are projects like **ITER** which, for some years now, have been trying to develop the technology required.

**Figure 6.** Ivanpah concentrated solar plant (USA). Source: Wikimedia. License: CC-BY-SA 4.0. http://bit.ly/2jdz14r

### 7.2.3. Light in medicine

As already discussed earlier on in the course, **there are numerous applications of light sciences in the field of biomedicine** apart from the simple use of laser as a surgical or therapeutic tool. Techniques based on **absorption spectroscopy, scattering or luminescence can be very useful for diagnosing and treating important diseases like cancer**. In this sense, improvement in the diagnosis and delimitation of tumors would be a key advancement in this context. Furthermore, the use of photodynamic therapy not only opens the way to diagnosing this disease, but also to treating its variants through an intelligent use of light, probably using certain particles which, once inside our body, would be capable of finding and attaching themselves to tumors and subsequently reacting in the desired manner to light irradiation.

**Important 2.1: Gold nanoparticles for attacking cancer**

An example of the abovementioned application of light can be found in the work of the scientist **Naomi Halas**, the inventor of **gold nanoparticles**, who is currently investigating their potential for use in dosing treatments in tumors by means of their remote activation by laser. For more information, go to the following link: http://bit.ly/2zzvN13

### 7.2.4. Quantum computing: computers of the future

For quite some years now, different research groups from all around the world have been focusing their efforts on designing and developing quantum computers or **quantum computing**. This is a new computer paradigm which will no longer work with bits that can have digital values 1 and 0. Instead, these computers will work with **qbits that can have both values 1 and 0 simultaneously (what is known as superposition of states)**. This system, which may appear to be contradictory at the very least, is based on the laws of quantum physics which attempts to explain phenomena occurring in the world of the "very small", applying to atoms, photons, etc. In fact, this is related to a matter mentioned earlier on in the course concerning **wave-particle duality**.

If we analyze Figure 7, we can see how the same object casts two different shadows on two different walls: depending on which one we look at, we will get a different impression of the object. This analogy can be extrapolated to qbits and their superposition of states, which is the concept upon which quantum computers are based for carrying out parallel operations, therefore making them much faster than a conventional computer.

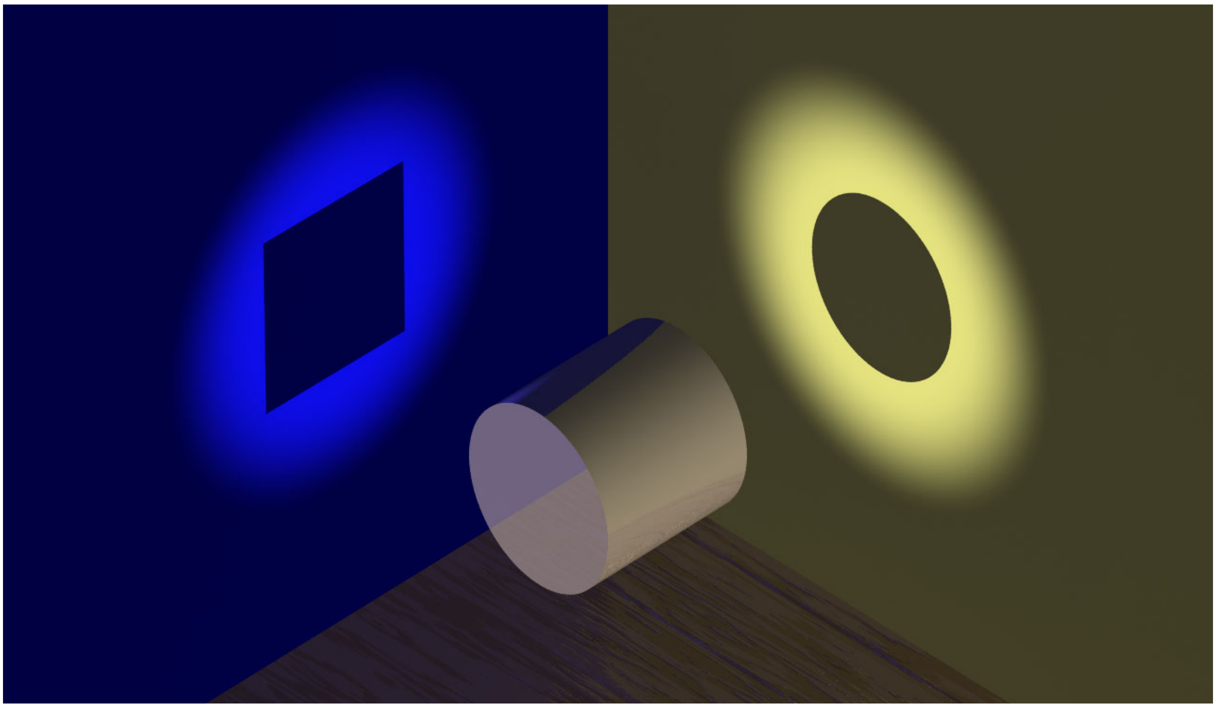

**Figure 7.** Image illustrating wave-particle duality: one single phenomenon can have two different perceptions. Source: Wikimedia. License: CC-BY-SA 2.5. `http://bit.ly/2iJWkpM`

One notable advancement towards quantum computing is a finding made by physicists at the Australian National University, who have managed to stop light in the air using a photon "trap"[1].

[1] For more information: `http://bit.ly/2BJYoCP`.

**Important 2.2: Quantum Physics**

The laws of quantum physics/mechanics are **so strange and disconcerting** at times that they have given rise to famous quotes by eminent scientists. Below are a couple of examples:

***"If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet."*** (Niels Bohr)

***"I think I can safely say that nobody understands quantum mechanics."*** (Richard Feynman)

## 7.3. Conclusions

This chapter, which puts an end to the theoretical part of this course, has presented some key lines of research in light sciences and technologies applied to different fields. As we have seen throughout the course, **Optics and Photonics** are present in numerous fields of application. In the world of **communications**, the development of new optical fibers is required in order to satisfy the ever-increasing growth in internet demand. In the field of **energy**, it is hoped that ongoing research will enable the development of new solar photovoltaic cells that are more efficient, sustainable and viable for an economic point of view. Furthermore, demonstration of the fusion generator would, undoubtedly, be one of the milestones that would mark the future of the present century.

**Biomedical sciences** will also benefit from advances in these fields of knowledge and, most probably, many of them will be aimed at treating cancer. Finally, **quantum computing** promises to radically change the kind of computers that we will use in future decades: much faster computers which will therefore be capable of carrying out much more complicated operations in less time.

This chapter concludes our journey through the study of **Optics and Photonics**, which serves as an introduction to understanding light-related phenomena and, by extension, science and technology which use light for carrying out an infinite number of tasks.

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