The Viewpoint

Happy Birthday Laser!

May 16, 1960. A day like many others, except, of course, for the fact that on this day the laser was born. A candy store owner, a photographer, and at least four American and two Russian scientists took part in the story that led to this accomplishment. This was a humble event, which could not foreshadow the future success of the newborn laser. This year the world celebrates the 50th birthday of the laser through an initiative jointly organized by various optics and photonics organizations: the LaserFest. Happy birthday laser!

2010: LaserFest

Light! What comes to your mind when you hear this word? The Sun maybe? Or a light bulb?

If you, like me, work in a photonics institute, the first thing you might think of is a laser. This year, 2010, is very special for people dealing — consciously or unconsciously — with lasers on a daily basis. And the number of the people actually working with lasers is greater than one might think — you, in fact, are one of them! In 2010 we celebrate the 50th anniversary of the invention of the laser. In order to honor such an important event, a year-long celebration, the LaserFest [1], has been jointly organized by some professional societies connected to optics and photonics, such as the Optical Society of America (OSA), the American Physical Society (APS), the International Society for Optical Engineering (SPIE), and the IEEE Photonics Society.

The LaserFest has the objective of honoring both the scientists and the entrepreneurs who contributed to the development of the laser. It is also a way to inspire people to pursue a career in optical science and an opportunity to raise public awareness of how fundamental research is linked to economic growth.

Figure 1: LaserFest 2010. Year-long celebration of the 50th anniversary of the invention of the laser.

What is a laser?

Nowadays, the word "laser" is widely spread in everyday language. Open any dictionary and you will quckly find a definition for it: laser — or better L.A.S.E.R. — is the acronym for *Light Amplification by Stimulated Emission of Radiation*. These words contain, in a nutshell, the explanation of the very working principle of the laser.

In order to better grasp the idea behind such a complex acronym, we may do well to try and explain the working principle behind the anti-laser, i.e. a D.A.S.A.R.: *Dark Amplification by Stimulated Absorption of Radiation*. This was actually a jokeacronym created in the 1960s [2,3], but it can be meaningfully applied to several everyday objects. Take, for example, a black sheet of paper. If you shine a bright light on it, the light will get absorbed, producing a warming of the paper as a side effect. This is the same effect that makes wearing a black t-shirt on a hot summer's day not a very good idea. The laser working principle is just the opposite of that of a dasar. If the paper were a laser, light would be amplified instead of absorbed.

There are some evident properties that lead us to believe that there is something special about the light from a laser. Laser light travels in a certain direction, i.e. it is *directional*. Laser light is also — nearly — of only one color, i.e. it is *monochromatic*. Furthermore, a third characteristic, which might be more difficult to grasp, but is nevertheless of utmost importance when using a laser as a research tool, is that all the waves coming out of the laser are synchronized, i.e. it is *coherent*.

The dawn of the laser

The history of the invention of the laser is a quite colorful one and it involves many people: a candy store owner, a photographer, and at least four scientists who share the honor of being the laser inventors, as cited in the US National Hall of Fame.

We can trace the seed of the invention of the laser back to the beginning of the twentieth century, when, 1916, Einstein introduced the concept of *stimulated emission*. Atoms assume discrete energy levels. When an atom is in its lowest energy state, its ground state, and is hit by a photon, it can absorb the photon and become excited. An excited atom will not remain in its excited state forever, but eventually it will spontaneously release the extra energy by emitting light. Einstein went a step further: he realized that, if an excited atom is hit by a photon, it becomes *un-excited* and releases its energy in the form of a second photon identical to the first one. Since this emission is induced by a photon, it is called *stimulated emission*.

The possibility of using stimulated emission to amplify radiation was first proposed in the late 1920s. Atoms, as we find them in nature, are normally in their ground state, so that most of them will only absorb any incident radiation. In order to get net amplification, it is necessary to create an artificial, non-equilibrium situation, called *population inversion*, in which most atoms are in an excited state. When this is the case, a photon emitted by an atom will likely hit another excited atom, causing the emission of another identical photon, which will likely hit a third excited atom, and so on, literally resulting in light amplification by stimulated emission of radiation: a laser!

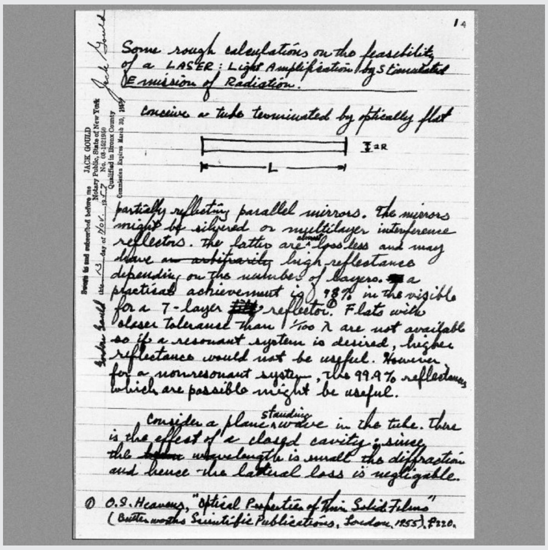
It would be fair to say that non-equilibrium situations were not very popular in the physics community at the beginning of the 20th century. This could be one of the reasons for which the possibilities of using stimulated emission to amplify radiation only began to emerge in 1951: Charles H. Townes, a young Columbia University physics professor, was sitting on a bench in Franklin Park in Washington D.C when he conceived the idea of how to blend some of the components stated in the laser acronym to create a working device — and here we meet the first scientist of our story who made it to the US National Hall of Fame.

First the maser, then the laser

Charles H. Townes put together most of the ingredients present in the laser acronym. In 1954, Townes and his group implemented his idea of amplifying microwave radiation in what was called the maser — *Microwaves Amplification by Stimulated Emission of Radiation*. However, getting the amplification in the optical domain, and therefore the "L" in the laser acronym, was not that simple.

In the summer of 1957 Townes started to work as a consultant for Bell Labs. There, he worked closely with his brother-in-law Arthur Schawlow — the second scientist who joined Townes in the Hall of Fame — and in December 1958 they published a theoretical paper [4] in which they described the basic principles of what they called an optical maser emphasizing that it was "simply" an extension of the maser idea, but at optical wavelengths. This paper triggered the race to implement a device capable of amplifying optical radiation.

In 1957, Gordon Gould, a graduate student at Columbia, — who would eventually also make his way to the Hall of Fame— went to see Townes to share ideas and data about the optical maser. Gould and Townes could not be more different. Unlike Townes, Gould was an intuitive inventor, not an analytical researcher, and he immediately understood the practical potentialities of the laser. He was a peculiar character in the race to make the laser — not precisely a scientist as defined by the establishment, but a visionary that preferred to obtain patents before discussing his scientific ideas. At the time, Gould already had in mind the idea of what he called "a laser." And this is where our candy store owner comes in. Indeed, Gould, cautious as he was, had his notes notarized [5]: the candy store owner was also a public notary. These notes were to become an important piece of the laser patent war that ensued.



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 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% reflectance 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) p.220.

Figure 2: "Laser" in Gordon Gould's notes. This famous page of Gordon Gould's laboratory notebook records the laser working principle and acronym. It is dated November 13, 1957.

Figure 3: Charles H. Townes' statue. As Charles H. Townes recalls [3], he was sitting on a park bench in Franklin Park, Washington DC, USA, when he got the inspiration for the amplification by stimulated emission of radiation.

Gould needed money to build his laser and proposed the project to the Pentagon. He was exceptionally good at impressing the military scientists, who imagined the laser as a "death ray" and consequently provided him with more funding than he had originally asked for. But there was a problem: Gould had been related to some communist propaganda activities and the Pentagon could not allow a potential Soviet spy to work on a project that had become classified, despite the fact that this was his own project. Gould was neither authorized to know the results of the experiments he proposed, nor given the security clearance to physically enter the building where they were being performed. TRG, the company for which Gould was working, even had to refurbish the building to allow Gould to go to the bathroom without violating security!

By 1959, the possibility of creating a device able to amplify stimulated emission at optical wavelengths had become a hot topic and the first conference in quantum electronics was organized. It was held at the Schawanga Lodge in the state of New York. Amongst the participants were Schawlow, Townes, Gould, Theodor Maiman — our fourth scientist — and the Russians Nicolay Basov and Aleksandr Prokhorov who go on to share the Nobel Prize with Townes in 1964 for their fundamental work leading to the construction of devices based on the maser-laser principle. In his conference talk, Schawlow concluded in his talk that pink ruby was not a good material for laser operation. Maiman had already presented his work on ruby masers and it seems that he left the conference with the intent of working on ruby.

Maiman was a self-reliant, competitive and obstinate individual, who was not convinced by Schawlow's arguments. Back at work, he carried out some experiments on ruby and found that it could actually work. Maiman was a practical person with an engineering background: he knew how to make things work and how to make them simple. One of the issues he had to resolve was how to obtain the necessary amount of energy required to excite atoms and obtain population inversion. Maiman was looking for a working laser, not for a textbook experiment, and he wanted to build it with things that were easy to find. And this is where our amateur photographer comes in. Indeed, it was an amateur photographer working with Maiman who gave him the simple idea he needed: to simply use a flashlamp!

After a few months of experiments, Maiman was ready to test his extraordinarily simple creation: a small ruby rod coated by a silver reflective layer inserted in a coiled flashlamp. The flash of the lamp excites the ruby, causing the stimulated emission of light, which, after bouncing and amplifying in the cavity, eventually escapes as a concentrated beam. Nice and easy. On May 16 1960 at Hughes research laboratories facing the ocean, he fired the lamp, the lamp flashed and an intense red beam illuminated the room [6]: the laser was born!

The lasers today

Since Maiman demonstrated the first ruby laser in 1960, uncountable types of laser have been developed: solid state lasers, excimer lasers, diode lasers, fiber lasers, and quantum cascade lasers are only some examples of the variety of laser types that exist nowadays.

For applications requiring high powers, such as to cut or to weld, CO_2 lasers have filled the market delivering powers of up to thousands of watts. Nowadays, however, new types of solid state laser, like for example fiber lasers and disk lasers, can reach an even higher power.

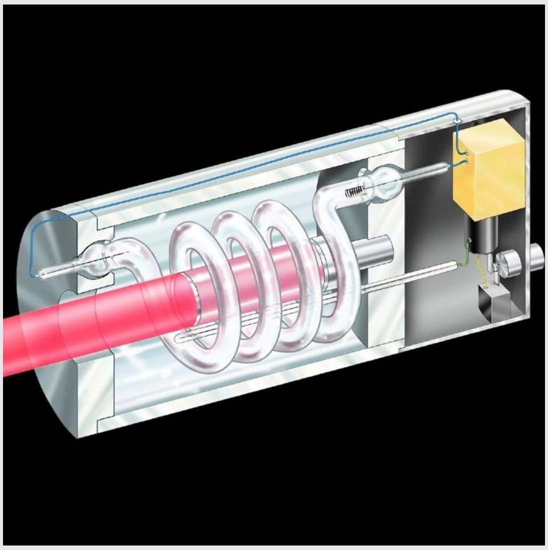


Figure 4: The first ruby laser. Sketch of the first ruby laser. The ruby crystal is surrounded by a serpentine flashlamp, which produces the population inversion necessary for the amplification of laser light.

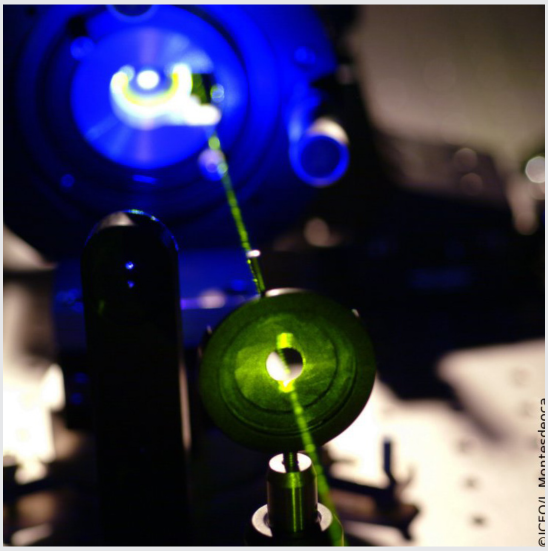


Figure 5: New lasers. Research in lasers has generated in the last years sources with better tunability, higher powers, and greater versatility. Copyright: ICFO/L.Montesdeoca.

Optical telecommunications systems today, something which would have been unthinkable in the 1960s, rely on semiconductor lasers. The first semiconductor laser appeared in the 1970s, using GaAlAs and emitting at 800 nm. By the end of that decade, the development of new materials allowed lasers to work at longer wavelengths, which permitted higher speed and longer distances in the data transfer. Indeed, in 1976 the first optical transmission system was implemented over 11 km of fiber at 45 Mbit/s. Today signal transmission at Tbit/s over transoceanic distances is possible for broad bandwidths. Edge emitters and vertical-cavity surface-emitting lasers (VCSELs) are the two types of semiconductor laser used. There is ongoing development of this type of lasers in order to meet the demands of the optical transmissions systems: higher speed, lower production cost, and lower power dissipation.

Another current trend is towards microelectronics and thin-film technologies. This has led to the development of lasers working in the UV spectral domain. Nowadays excimer lasers with wavelengths of 193 nm, 248 nm or 308 nm are used in the microelectronics industry to manufacture microchips with a feature size of 45 nm and also by eye-surgeons to correct visual defects.

For fundamental research in areas such as physics, biology and chemistry, the flourishing of femtosecond pulse lasers in the near infrared region has been of paramount importance. Ti:Sa lasers, in particular, paved the way towards the study of nonlinear optical phenomena, and multiphoton microscopy. In the near future we will also have lasers capable of generating attosecond pulses. These may allow the study of molecular dynamics at a temporal rate never achieved before.

The impact of laser on our society

The laser is one of those scientific and technological achievements that have deeply penetrated our society. At the time of its invention it was difficult to foresee all its future applications. Irnee D'Haenens, Maiman's coworker, defined the laser as "a solution searching for a problem," and as time goes by the laser has really found a lot of problems to solve. Nowadays, lasers are used, as a matter of course, in medicine, telecommunications, and also in further industrial productions.

Thousands of kilometers of optical fiber that transmit laser light through the oceans allow us to have high speed internet and make millions of telephone calls at the same time all thanks to the development of optical communications.

Charles H. Townes said that he never imagined the applicability of the laser in medicine. However, today eye refractive surgery as well as various aestetic procedures are possible thanks to laser light capability to cut or burn only the affected tissue.

The automotive industry, ship building, microchip manufacturing, material processing, and telecommunications are but a few of the areas that employ the use of lasers on a daily basis. Indeed, it would be no exaggeration to say that most products in the market today have, in some way or other, been touched by a laser at the production stage.

The laser is one of the best examples of fundamental research finding its way into our everyday lives, leading to unthinkable applications, technological innovations, and economic growth.

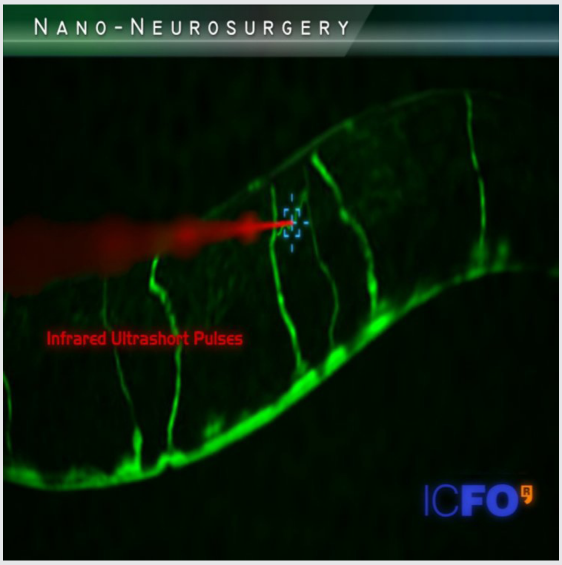


Figure 6: Nano-neuro-surgery. The laser can be used as a ultra-precise scalpel to perform extremely challenging nanosurgery tasks. In the artistic illustration a laser beam is cutting an aberrant union between neurons in a worm. Copyright: ICFO.

[1] Laserfest 2010 webpage, www.laserfest.org.

[2] C. H. Townes, *Astronomical masers and lasers*, Quant. El. **27**, 1031-1034 (1997).

[3] C. H. Townes, How the laser happened. Oxford University Press (1999).

[4] A. L. Schawlow & C. H. Townes, *Infrared and Optical Masers*, Phys. Rev. **112**, 1940-1949 (1958).

[5] J. Hecht, Beam the race to make the laser. Oxford University Press (2005).

[6] T. H. Maiman, *Stimulated Optical Radiation in Ruby*, Nature **187**, 493 - 494 (1960).

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