# LASER DENTISTRY

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## CURRENT CLINICAL APPLICATIONS BY THE WORLD FEDERATION FOR LASER DENTISTRY

**WORLD FEDERATION FOR LASER DENTISTRY (WFLD)**

*Edited by Prof. Aldo Brugnera Junior &*
*Prof. Samir Namour*

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# 1

# LASER, HISTORY AND PHYSICS

**Antoni J. España, Dunia Espanya, and Josep Arnabat**

The initial contribution to the history of lasers was accomplished by Albert Einstein's (**Fig. 1**) publications in relation to the behaviour of the electrons inside an atom. He based his studies on Max Planck's (**Fig. 2**) work on the photoelectric effect. An atom is able to absorb or emit light, storing and releasing energy according to the position of its electrons. Between 1907 and 1915, Einstein developed the theory of general relativity, a classical field theory of gravitation that provides the cornerstone for modern astrophysics and cosmology. In 1917, Einstein published the idea for the Einstein–Brillouin–Keller method for finding the quantum mechanical version of a classical system. The famous Bohr model of the hydrogen atom is a simple example, but the EBK method also gives accurate predictions for more complicated systems, such as the dinuclear cations $H_2^+$. In 1918, Einstein developed a general theory of the process by which atoms emit and absorb electromagnetic radiation. This theory is the basis of lasers (stimulated emission) and shaped the development of modern quantum electrodynamics, the best-validated physical theory at present. As a rule, atoms can emit electromagnetic waves in a spontaneous way with no external intervention. Einstein predicted the possibility of stimulating the electrons of an atom to obtain light of a particular wavelength. The stimuli would be provided by an additional light of the same wavelength as the resulted wavelength. Even though Rudolf Ladenburg (**Fig. 3**) verified Einstein's prediction, nobody thought seriously about developing a device based on that phenomenon until the early fifties. It should be noted that the word laser means light amplification by stimulated emission of

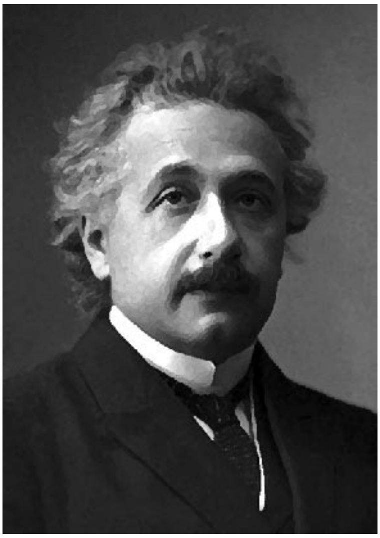

**Figure 1** Albert Einstein (March 14, 1879 – April 18, 1955).

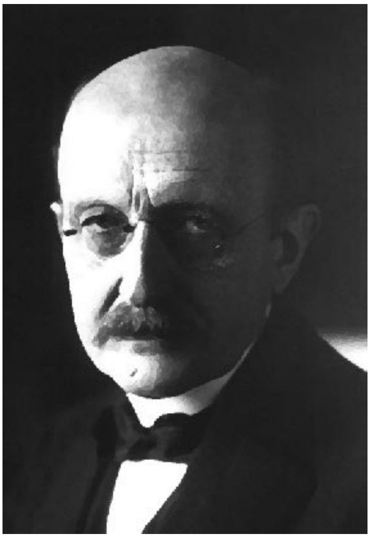

**Figure 2** Max Panck (April 23, 1858 – October 4, 1947).

**Figure 3** Rudolf Ladenburg (June 6, 1882 – April 6, 1952).

**Figure 4** Valentin Alexandrovich Fabrikant (October 9, 1907 – March 3, 1991).

radiation. Einstein only described the stimulated emission; however, to build a laser, an amplification of the mentioned stimulated emission is also needed.

The first proposal to obtain the amplification of the stimulated emission appeared in a Soviet patent applied by Valentin Alexandrovich Fabrikant (Fig. 4) and two of his

**Figure 5** Joseph Weber (May 17, 1919 – September 30, 2000).

**Figure 6** Nikolái Básov (December 14, 1922 – July 1, 2001).

students. Nevertheless, the mentioned patent was not published until 1959, so it did not affect to the other researchers. Fabrikant is still a current mystery, a neglected character in the laser route. In 1953, Joseph Weber (**Fig. 5**) from the University of Maryland also proposed an amplification of the stimulated emission, and a year later, the Russian Nikolái Básov (**Fig. 6**) and Alexander Mikhaylovich Prokhorov (**Fig. 7**) wrote an article deeply exploring the concept. Ever since, Weber has been known by his research on the detection of gravity waves as being based on some former ideas suggested by Albert Einstein.

In 1951, Charles Hard Townes (**Fig. 8**) worked with microwaves and proposed the conditions needed to amplify the stimulated emission of those waves. Charles H. Townes offered James Power Gordon (**Fig. 9**), who had just finished his degree in Columbia University, this subject as his doctoral thesis. Three years later, Townes, Gordon and Herbert Jack Zeiger (**Fig. 10**) built the first maser in Columbia.

In the years that followed, masers started to proliferate. The physics of the masers was fascinating, so this new field attracted a large number of researchers. Unfortunately, not many applications were found for these devices. Among their applications, masers are used in the amplification of radio signs astronomers receive from deep-space and could also be used in communication by satellite. Masers are also used as frequency measurement tools in atomic clocks, the most accurate clocks in the world. However, these devices amplify a severely limited range of frequencies, entailing just a few applications in the electronic field. Since masers had a very limited variety of applications,

**Figure 7** Alexander Mikhaylovich Prokhorov (July 11, 1916 – January 8, 2002).

**Figure 8** Charles Hard Townes (July 28, 1915 – January 27, 2015).

**Figure 9** James Power Gordon (March 20, 1928 – June 21, 2013).

**Figure 10** Herbert Jack Zeiger (March 16, 1925 – January 14, 2011).

this motivated the scientific community to start research into other wavelengths in the electromagnetic spectrum, specifically in infrared and visible lights. In this way, a race in the development of the first laser took place. In September 1956, Townes drafted the first project in the construction of an "optical maser" which would emit

**Figure 11** Arthur Schawlow (May 5, 1921 – April 28, 1999).

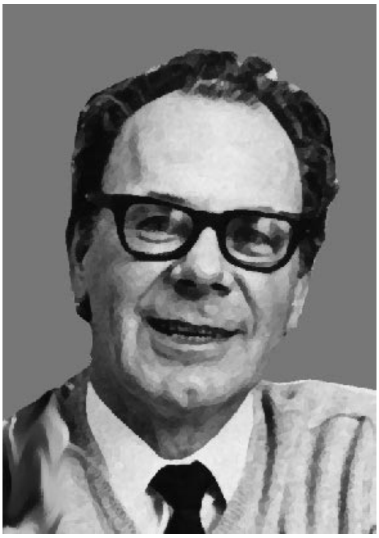

**Figure 12** Gordon Gould (July 17, 1920 – September 16, 2005).

visible light. He then contacted his old friend Arthur Schawlow (**Fig. 11**). Schawlow had previously left Columbia University to work in Bell Labs and had married Townes' sister. Schawlow and Townes together developed a detailed plan for the construction of a laser.

During those times, Gordon Gould (**Fig. 12**) was developing his PhD at Columbia University, at which Townes was professor. Gould had not been a pupil of Townes, but he was inspired by his ideas of the maser and was obsessed with constructing a device that would be able to emit light instead of microwaves. In November 1957, around two months after Townes had drafted the optical maser, Gould started to describe his own idea for the development of a similar device which would be called laser. While Gould was working on the development of the laser, he took advantage of the opportunity and made some prophetic statements. Gould admitted before any other laser pioneer that it would be possible to achieve fluences that had not been reached until then. He pointed out that the second law of thermodynamics does not limit the power of the laser. This law asserts that the temperature of a heated surface by a beam of a thermal radiation source cannot exceed the temperature of this source. Gould understood that the laser would be a non-thermal source of light and, therefore, it would be able to reach temperatures significantly higher than their own. Effectively, this means that a laser that would work at ambient temperature would be able to melt steel. Gould predicted in his notes that a well focalized laser beam could be used to generate thermonuclear fusion. He also affirmed that the laser could be used for online communications on the moon. After filling his notes, Gould contacted the owner of a sweet shop in New York to notarize his work as a witness. The owner of the sweet shop was called Jack Gould and, even though they shared surnames, they did not have any family relation. A certified reproduction of the first page of the notebook of Gordon Gould is on display in the Smithsonian Institution, in Washington, D. C.

Gould was not well advised by his lawyer and decided to summarize his ideas in a more practical way to patent them. Until April 1959, he had not finished the review of his ideas and did not requested the patent. During the summer of 1958, Townes and Schawlow first patented the laser and also sent a detailed report of their work to the journal Physical Review. The journal published their report on December 1958. The main mistake that Gould made was not only delaying the patent application of the laser but not reporting in a scientific journal his plans to construct a laser. Gould should have had published his work in a scientific journal so his colleagues could have had recognized his original ideas.

Gould left Columbia University without graduating as a doctor and started to work in a little company located in Syosset, New York. This company was called TRG Inc. TRG proposed Gould's ideas to the Advanced Research Projects Agency (ARPA) that would be later called Defense Advanced Research Projects Agency (DARPA). The army was especially interested in the heating potential of lasers. Gould purposed to use the laser in the military sphere. This caused so much impact on the Pentagon that, in 1959, a million dollars were awarded to TRG instead of giving them the 300.000 dollars that the company had previously requested.

Townes and Schawlow did no receive any kind of government aid, so they completely developed their work on laser technology at Columbia University and Bell Labs, respectively. Other teams were also working hard in the development of a laser as soon as possible. It should be noted that even though Townes, Schawlow and Gould had applied for the patent and developed detailed proposals, (as well as other Russian scientists), until the late fifties, nobody had built a laser.

At that time, in Malibu, California, a physicist named Theodore Harold Maiman (**Fig. 13**) was working at the Hughes airline company. He worked alone and with no government aid. Maiman built a small device that consisted of a cylindrical ruby crystal of about 1 centimeter in diameter that was encircled by a spiral flasher light. The ruby bar's ends were covered in a way to make them work as mirrors, which is indispensable to obtain laser oscillation. Thus, brief laser light pulsations were produced when the ruby crystal was exposed to flashes of light of around one-millionth of a second. On July 7, 1960 Maiman told the press that he had run the first laser. The first laser was a very little device of only a few centimeters length. The public relations person at

**Figure 13** Theodore Harold Maiman (July 11, 1927 – May 5, 2007).

Hughes Aircraft Company thought that Maiman's laser was too small, so he prevented photographers from taking pictures of it and offered them a photograph of a defective artifact that, although did not work, was bigger.

This first laser could only emit a shot or a pulse of a few millionths of seconds. The emitted light belonged to an extreme red, nearly invisible light in the electromagnetic spectrum. Delicate instruments were needed to test that the pulses of light were not fluorescence but a kind of light that nobody had seen before: the laser light. The age of lasers had only just started. Unfortunately, one of the most important journals of that time, the *Physical Review Letters*, did not consider Maiman's discovery improtant. In 1959 the reviewers of *Physical Review Letters* agreed that masers did not deserve any more urgent publication, which led them to refuse Maiman's report. The prestigious British journal Nature was second to report Maiman's work. In 1960, Nature reported on Maiman's paper, which consisted of no more than 300 words. It was the most concise report of a scientific discovery that had ever been published, but enough to allow its reproduction in different laboratories.

After studying Maiman's work, many other researchers focused their attention to the development of other kind of lasers. At the beginning, progress was slow. In 1960, the first gas laser was developed, as well as two new crystal models. One of the crystal models was Schawlow's. In 1961 two new kinds of lasers were discovered, one of them by Gould's team in TRG Inc. Gould's laser, like Maiman's, operated by optical pumping, but in this case, the active material was a metal (caesium vapour) instead of a crystal.

The real laser boom started in 1962 so that by 1965, lasers activity had been studied for a large variety of different wavelengths. Many researchers started to study the different applications of lasers since they were discovered. One of these applications consisted of calculating the distance from different objects so the army could use them to determine the enemy's exact position. Bell Labs researchers, among others, started to study laser applications in the electronic communications field, just as Townes and Schawlow had previously expected.

In no time, the work of the laser pioneers became recognized. In 1964, Townes, Basov and Prokhorov shared the Nobel Prize for physics. Townes was awarded with the maser patent that, since it comprised all the amplification by stimulated emission regardless of the wavelength, also affected laser light. Townes and Schawlow shared a basic patent on the laser, in other words, on an artefact that could operate mainly in visible and infrared wavelengths. Maiman received the patent on the ruby laser and, finally, he was paid a considerably amount of money after sending his participation on Korad Inc. to the Union Carbide Corporation.

Meanwhile, Gordon Gould seemed to have disappeared. Townes and Schawlow had advanced in nearly 9 months to Gould and had received the patent that Gould had wanted all along. When Gould attempted to obtain the appreciation of his application in 1959, he was involved in 5 to10 expensive and extended legal proceedings by the U. S. Patent Office to know to whom the laser patent belonged to. First of all, Gould crashed with Townes and Schawlow's patent. Gould fell into discredit and was rejected by many of the members in the scientific community that recognized Townes and Schawlow's prestige. Hereafter, Gould lost two other similar battles but won two others that later on would be the basis of the patents he would receive. After all, Townes' company had paid 300.000 dollars in legal expenses. In 1977, Gould recovered his patent rights from the company and started to insist to be personally on the applications. Finally, Gould could not continue funding further legal battles and was forced to resign to the 80% of his patent right to a licence and patent agency in New York called Refac Technology Development Corporation in exchange for committing the deal of the applications.

Refac's efforts finally had a successful resolution. On October 11, 1977 Gould was awarded the patent of the optical pumping, although he did not start to receive income on the copyright until 1988. In 1979, Gould received a second patent that, just like optical pumping patent, was superior to the one he requested in 1959 and covered a broad range of laser applications.

When Gould received the patent on the optical pumping, the laser industry became amazed. Townes and Schawlow's patent had just expired so the laser manufacturers believed that they would not have to keep paying for the use of basic concepts on lasers. Many industrial laser manufacturers were affected by this patent, as well as some military manufacturers that worked with the optical pumping technology. At this point, Refac requested 5% of the copyright but manufacturers prevailed against the validity of the patent.

On April 3, 1981 the original journal *Science* submitted a report of a group of scientists at the NASA's Goddard Space Flight Center. The leader of this group was Michael J. Mumma and informed the magazine that in Mars' atmosphere, laser amplification by optical pumping had been detected. Mumma's group discovered on Mars' surface that sunlight produces a population inversion of carbon dioxide between 75 and 90 Km, inducing amplified stimulated emission on the infrared range. The Control Laser Corporation received this news with true delight and stated that the flashing light of laser amplification by optical pumping was a natural phenomenon and, therefore, it could not be patentable.

## ■ ATOMIC MODEL

In the fourth century B.C., the ancient Greek philosopher Democritus (Δημόκριτος) (**Fig. 14**) questioned himself about the indivisibility of matter. At simple sight, substances are continuous but are able to be divided. However, can things be divided indefinitely? Democritus thought that there was a point in which particles could no longer be divided and he called these smallest particles atoms. Atom in Greek means indivisible.

In 1808 the first scientifically based atomic model was formulated. John Dalton (**Fig. 15**) was its author and he imagined atoms as minuscule spheres. This atomic model postulated that matter was constituted by very small particles called atoms. Atoms were indivisible and could not be destroyed. This theory also affirmed that all the atoms in an element had their own weight and own qualities.

Some years later, the English physicist Joseph John Thomson (**Fig. 16**) believed that atoms were a kind of positively charged sphere around which some electrons were displayed. This model meant something similar to negatively charged "plums" surrounded by positively charged "pudding", so it was called plum pudding model.

A Thomson's student called Ernest Rutherford (**Fig. 17**) established that Thomson's theory could not be true. He stated that all the positive charges and nearly all the mass of an atom should be located in a very small space that he called the nucleus. The rest of the charges in an atom would be negative and called the electrons. The electrons might be far from the nucleus, spinning around it. Therefore, the major part of an atom would be empty.

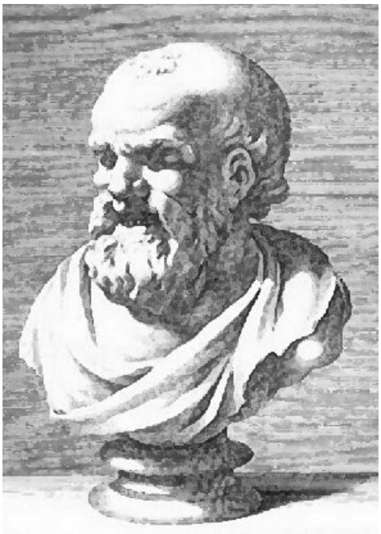

**Figure 14** Democritus (Δημόκριτος) (460 B.C. – 370 B.C.).

**Figure 15** John Dalton (September 6, 1766 – July 27, 1844).

**Figure 16** Joseph John Thomson (December 18, 1856 – August 30, 1940).

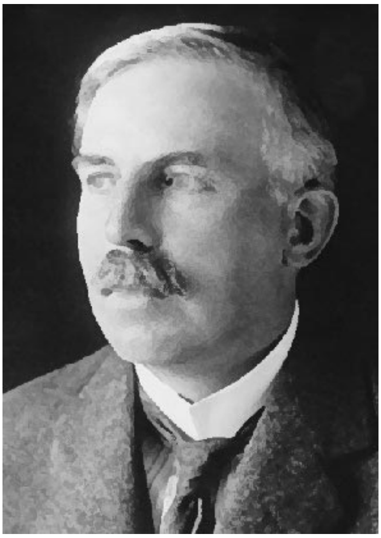

**Figure 17** Ernest Rutherford (August 30, 1871 – October 19, 1937).

Niels Bohr (Fig. 18) performed a model with his same name, on the basis of the hydrogen atom. Bohr wanted to develop an atomic model which could explain the stability of matter and also the discrete emission and absorption spectrums of gases. Bohr described the hydrogen atom as formed by a proton in its nucleus and only an

**Figure 18** Niels Bohr (October 7, 1885 – November 18, 1962).

electron circulating around it. Bohr's atomic model mixed some ideas from Rutherford's model and some incipient recent ideas about quantization from Max Planck and Albert Einstein's investigations. The simplicity of Bohr's atomic model (**Fig. 19**) makes clear why is it still used as a simple way of explaining the structure of matter.

According to Bohr's atomic model, the electrons of an atom travel in circular orbits around the nucleus. The electrons are located on the lowest energy orbit or on the nearest orbit to the nucleus. Bohr's model disassembled Rutherford's theory in which a charged particle orbiting the nucleus would release electromagnetic radiation, collapsing into the nucleus on a brief moment in time.

Bohr stated that electrons could only move among certain orbits. Each orbit would have a specific energy level that would be identified by means of a whole number "n" from 1 onwards. This value would be called the Principal Quantum Number.

Bohr also assumed that the angular momentum of each electron was quantized and that it could only vary according to entire fractions of Planck constant. According to the principal quantum number, he calculated for the hydrogen atom the distance from each available orbit to the nucleus. Originally, each energy level was classified by letters from "K" to "Q" but later they were sorted by numbers.

When an atom is excited, its electrons may have different energies that could be later released. One or more of its electrons are located in a different orbit to the ground state. After a stimulus, an energetic electron can jump from one orbit to another with lower energy until arriving to an appropriate orbit with free space (**Fig. 20**). Thus, the electron releases energy and returns back to the orbit it originally belonged to.