The History of the Laser

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1.1 Stimulated Emission

The theoretical basis for the development of a laser was provided in 1917 by Albert Einstein, who, in a work he published, described the principle of **stimulated emission**. Einstein assumed that light consists of individual energy particles (light quanta, later called photons) that fly continuously in one direction. The energy of this flight depends on the wavelength of the energy particles. When a light particle hits an atom, it absorbs the energy of the particle (photon) and is in an excited (but also unstable) state, which it cannot hold for long. It returns to its (more stable) ground state by emitting a nondirectional light particle (spontaneous emission). If, however, while the atom is still in an excited state, another light particle hits it, and the atom emits another photon with identical properties. The emitted photons cause the same effect when hitting other atoms, so that a kind of chain reaction develops, from which many light particles of the same "kind" emerge: The light beam becomes more intense, the light is amplified. Einstein called this effect stimulated emission. The difference to the spontaneous emission (see above) is that here **coherent light** is produced (i.e., light with elementary waves of the same phase), and this is the prerequisite for laser technology.

1.2 MASER (Microwave Amplification by Stimulated Emission of Radiation)

The physicist Charles H. Townes was one of the first to put Einstein's idea of stimulated emission into practice. However, he did not experiment with light rays but with microwaves. During the Second World War, radar technology and thus also the field of microwaves had become interesting for many scientists. In 1951 Townes built a device that could generate and amplify microwaves. He called his construction the MASER, based on Einstein's theory, for *microwave amplification by stimulated emission of radiation*.

At the same time as Townes' discovery, Alexander M. Prokhorov and Nikolai G. Basov of the Lebedev Physics Institute in Moscow also developed their first burl. All three scientists received the Nobel Prize in 1964 for their discovery.

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1.3 LASER (Light Amplification by Stimulated Emission of Radiation)

Exactly the same thing that Townes, Basov, and Prokhorov had discovered for the function of microwaves was now to be made possible for infrared and conventional light. But how this was to be possible was not clear and caused a real competition. But one thing was certain, the discovery should be LASER for *light amplification by stimulated emission of radiation* (light amplification by stimulated emission of radiation).

The further development of the maser to the construction of a LASER was coined by the publication by Charles Townes and Arthur Schawlow in the physical review with the name “infrared and optical maser,” which contained suggestions for the extension of the maser procedure.

The basics and the material were thus available, but it was not until 1960 that a physicist, Theodore Maiman, was able to combine all the pieces of the puzzle into a large whole and bundle the first beam of light. For this he used ruby, which could already be produced industrially in very high purity at that time, and a flashlamp. Mirrors directed the light beam through the ruby crystal, and atoms were excited according to the principle of stimulated emission, which in turn emitted light beams and excited other atoms. The result was such an intense beam of light that it could not be found in nature: The first laser was created.

In 1961 a former student of Townes, Ali Javan, together with his colleagues William Bennett and Donald Herriott, succeeded in developing the first gas laser.

The helium neon laser was built 1 year later, in 1962, by Alan White and Dane Rigden, and in the same year, Johnson and Nassau invented the first neodymium laser.

Three years later Geusic, Marcos, and van Uitert introduced the neodymium yttrium aluminum garnet (Nd:YAG) laser, followed in 1964 by the first CO_2 laser (by Kumar and Patel) and the argon laser (by William Bridges).

In 1966 Peter Sorokin and John Lankard developed the first ruby-pumped dye laser, a year later with flashlamp-pumped technology. In 1970 the Argon-pumped dye laser followed (by Benjamin Snavely).

As spectacular as all these discoveries were, as little interest was generated in the beginning by them in the professional world, hardly anyone took notice of the new technology. First, a possible application for this ultimately powerful technology had to be found. On the way there, there were also approaches to measure the performance of the laser. In the beginning, this was measured—a small anecdote—in “Gilette,” i.e. in the number of razor blades that could be cut by a laser pulse.

Only with time it did become clear what was possible with laser technology. Today, laser technology is an omnipresent market: medical treatments, industrial work such as cutting thick steel plates, electronic microchips, the Internet, Global Village—all these are achievements that Einstein, Townes, Shavlow, Basov, Prokhorov, and Maiman, as well as the scientists who were willing to follow them, owe to.

1.4 Laser in Dermatology and Aesthetic Medicine

In medicine, the laser is now established primarily in skin and ophthalmology as well as in aesthetic treatment. The first medical use of a ruby laser took place in the 1960s in the USA for photocoagulation of the retina with a then still very high side effect rate. The continuous wave laser of the late 1960s and early 1970s was then used in surgery as a precise surgical tool. The argon laser became the standard instrument in the treatment of retinal detachment.

Leon Goldman was a central figure in the medical history of the laser, through which numerous new laser variants and their use found their way into practice (see Table 1.1). The table shows which lasers were used in medicine and how.

Table 1.1 Laser types and medical use (in alphabetical order)

Laser type	First use	Today's use
Alexandrite laser	In the late 80s first in urology to lithotripsy	Treatment of hypertrichosis, tattoos and benign pigmented and vascular skin changes, epilation
Argon laser	By Leon Goldman 1968 on scars, hypo- and hyperpigmentations	Formerly tattoos, adenoma sebaceum, epidermal nevi, now in dermatology mainly replaced by specific effective lasers
CO_2 laser	1966 in cutting and at the same time hemostatic function described by Yahr	Treatment of wrinkles and acne scars (skin resurfacing), collagen shrinking, tissue ablation
Diode laser	End of the 1970s in ophthalmology	Aesthetic medicine, vascular and pigmented skin changes, laser epilation
Erbium:glass laser	In the 1990s first in ophthalmology, later in dermatology	Non-ablative treatment of age- and UV-related facial wrinkles (so-called "skin rejuvenation")
Erbium:YAG laser	As a surgical instrument in the field of dental surgery and intraocular microsurgery	Tissue ablation, wrinkles and acne scars, benign tumors
Excimer laser	In the late 1970s, early 1980s, in the ophthalmology (corneal surgery)	Hypopigmentation, psoriasis, UV-B sensitive dermatoses
Dye laser	By Rox Anderson and John A. Parrish in 1981, who observed a selective destruction of vessels by a flashlamp-pumped dye laser, 1983 first photothermolysis	Port-wine stains, hemangiomas and telangiectasias
Neodymium:YAG laser	At the beginning of the 1970s, primarily in urology and gastroenterology for the treatment of tumors and bleeding	Treatment of nodular or deep subcutaneous vascular changes, treatment of tattoos
Ruby laser	By Leon Goldman 1963 for pigmented skin changes	Treatment of jewelry and dirt tattoos as well as benign pigmented skin changes, hypertrichosis

Fractionated Laser Therapy

Modern laser therapy uses more and more minimally invasive methods to improve skin structure. These systems can use non-ablative and ablative thermal energy to induce dermal remodeling. The fractionated non-ablative systems should close the gap between the standard laser systems and the ablative systems. This milestone in laser therapy was the principle of fractional photothermolysis first described by Manstein et al. in 2004, which revolutionized laser therapy once again. The purely ablative systems used in the past often led to severe side effects. In particular, the downtime after the treatments was often very long. For this reason, new fractionated ablative CO_2 and Erbium:YAG laser systems, which have significantly fewer side effects during treatment, were introduced. In particular, scar therapy has been significantly improved by these fractionated laser systems in recent years.

The latest development in fractionated laser systems is the combination with Externa. This combination allows the targeted introduction of medical and cosmetic active ingredients into the skin, which was previously not possible. Here, too, the coming years must show which treatment concepts will establish themselves in the long term.

Picosecond Laser

These lasers (755 nm alexandrite lasers) have ultrashort light pulses in the range of picoseconds (pulse duration between 10^{-9} and 10^{-12} s). The picosecond lasers are mainly used for the removal of tattoos. In comparison with nanosecond lasers, the color particles are to be broken down to a greater extent and thus degraded and transported away from the body more quickly. However, large comparative studies are still pending here.

Intense Pulsed Light (IPL)

The IPL (intense pulsed light) systems were developed in the 1990s of the last century. These high-energy flashlamps had a very wide therapeutic range compared to the lasers of the time. This was achieved by the variable use of different optical filters. With a single IPL device, different target structures of the skin could be treated. By changing the wavelength of the filter, both superficial structures and deeper structures of the skin could be treated (Figs. 1.1 and 1.2).

The previously used lasers with light of only a single wavelength (monochromasia) allowed a more precise control of the therapeutic application, but this was at the expense of the therapeutic width.

Fig. 1.1 IPL handpiece with a replaceable wavelength filter

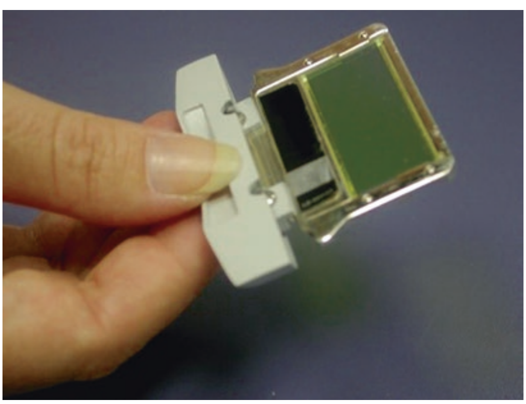

Fig. 1.2 Wavelength cutoff filter for an IPL handpiece

The core of the IPL devices is the **system console** which contains the entire high-voltage electronics, computer control, and the integrated closed cooling circuit. It supplies the treatment head with the necessary electrical voltage and cooling water via a spiral cable. The high-power short arc lamp located in the treatment head delivers short, intense light pulses, either individually or as a sequence of several consecutive pulses. Both the length of each individual light pulse and the pause between two pulses can be varied within the system specifications. The **light application** is performed via a quartz crystal inserted into the treatment head.

In order to minimize coupling losses and for additional cooling of the treatment surface, the **cooling gel** between crystal and skin is necessary. Depending on the IPL system used, the quartz crystal can be provided with a thin filter layer that only allows a defined wavelength range to pass through. Or separate filter units are inserted into the treatment head. By exchanging this filter unit, the spectral composition of the light pulse can be adapted to the individual requirements of different indications and patients.

With the **PhotoDerm**® (ESC, Yokneam, Israel), the first market-ready system based on IPL technology was available in 1994. In the version PhotoDerm® VL was originally designed only for the treatment of vascular lesions, in the following years, the treatment spectrum was also extended to pigmented lesions (PhotoDerm® PL) and photo epilation (PhotoDerm® HR, Epilight™). PhotoDerm® and Epilight™ were abandoned in favor of Multilight™. Thus, all indication spectra were united in one device.

In a further step in 1998, IPL technology was combined in a device platform with a long-pulsed Nd:YAG laser. The reason for this combination was the fact that the long-pulsed Nd:YAG laser made treatments significantly more effective even in deeper skin layers. The aim was also to enable the treatment of varicosis (spider veins, lateral branch varicosis, perforating varicosis). Under the name Vasculight™, this device was again available as a multifunctional unit or also in different single versions.

In 2002 the "Quantum" series (Lumenis, Yokneam, Israel) was introduced. By improving the IPL technology, it was possible to treat with a reduced energy density. In addition, a limited choice of parameters has simplified handling and thus made it safer. These devices were much smaller and cheaper and for the first time had a cooling unit integrated into the treatment head.

In the early years, the wide treatment spectrum of the IPL devices was also the major disadvantage compared to the easy-to-use laser systems. Therefore, the third generation of a multiplatform was introduced in 2003. In addition to the IPL, an Nd:YAG and the LightSheer epilation laser could also be integrated into this platform. The great advantage in the handling of the IPL devices was an integrated user platform, which can be adapted to the skin types, therapy indications, etc. The IPL devices can be used in a variety of ways. The new device has been designed to reduce the risk of side effects and to make the device much easier to learn.

However, the disadvantage of these presets is the fact that many nonmedical users rely blindly on these settings. Such complex devices with different filters and treatment heads require highly qualified training and sound basic medical knowledge. Under no circumstances can these be learned in weekend courses or as part of a laser safety course.

An alternative to the devices mentioned above is the Ellipse Relax Light (Danish Dermatologie Development, Hoershom, Denmark), which has a wavelength spectrum of 400–950 nm thanks to a dual filter system integrated into the handpiece. This system also works with different cutoff filters. The large number of new developments shows that continuous further training is necessary in order to master such systems.

A further development in laser and IPL therapy is the so-called ELOS®—Technology (Electrical-Optical Synergy®), which is used for non-ablative skin resurfacing and photoepilation (Aurora®Syneron R&D, Israel). It combines IPL technology with radiofrequency (RF) power. The RF current preheats the epidermal and dermal skin layers, so that only reduced energy densities are necessary for the selective heating of the target structures by IPL technology. The aim is a reduced painfulness of the treatment as well as a reduced side effect spectrum with constant or even improved effectiveness. These systems have proven themselves over the years.

The complex combination of the current (RF) with IPL or with a laser requires a lot of experience in the application. As a result, these systems have not been able to assert themselves in the broad market compared to pure laser and IPL systems.

Meanwhile there is a multitude of different IPL systems. There is no laser company anymore that does not also sell an IPL system. This shows the value and importance of these devices in daily treatment. An up-to-date list of all IPL systems is not possible in this context due to the constant innovation of the devices.

In addition to laser and IPL systems, other optical radiation sources have established themselves in medical and aesthetic treatments over the past 20 years. All systems have comparable effects and side effects on human skin. In addition, more and more light-emitting diodes (LEDs) have been coming onto the market in recent years. This makes it possible, for example, to carry out photodynamic therapy (PDT). PDT is a procedure for the treatment of tumors and other tissue changes such as the formation of new vessels with light in combination with a light-activatable substance, a so-called photosensitizer, and oxygen present in the tissue. For this purpose, the patient is administered such a primarily nontoxic sensitizer or one of its metabolic precursors either systemically (dispersing throughout the body) or locally, which accumulates more or less selectively in the tumor or tissue alteration due to certain properties of the tumor or tissue alteration (such as increased cell growth, increased metabolic activity, or increased blood flow). After a certain waiting period, the tumor or the tissue change is irradiated with light of a suitable wavelength. Photophysical processes produce toxic substances, above all reactive oxygen species, which damage the tumor or the tissue alteration. At the moment, this method is mainly used for medical purposes. However, it can also be used in aesthetic indications.

As the last step in this development, the American FDA (US Food and Drug Administration) has launched an initiative for Medical Device Home Use in 2010. The aim is to develop the basis for the safe use of these new medical devices. The FDA has thus taken a leading role in providing information to manufacturers, healthcare professionals, home care professionals, consumers, and users of these medical home use devices. These systems can also massively influence the barrier function of the skin. In combination with the use of creams and other substances, completely new medical and aesthetic treatments are possible. The big problem, however, is that we do not have an overview of these possible applications and their effects/side effects or only understand them in broad outlines.

The extension of the application possibilities, the apparently easy applicability, and the favorable price have led to the fact that lasers and above all IPL devices are also used by medical laymen for the most diverse medical and cosmetic corrections such as hair removal, wrinkle, and pigment removal or for the removal of tattoos. In the trend of the beauty boom and a massively growing health market, these IPL and laser treatments are a good source of income and have therefore found widespread use in cosmetic and hairdressing salons. But the industry also has an interest in earning a share of these developments. The sale of lasers and other optical radiation sources to medical laypersons opens up new markets, as the legislator has not yet fulfilled its regulatory tasks in this area.

This circumstance, however, led to the dangerous development that powerful laser and IPL systems, in particular, are used uncritically on humans without any knowledge of the exact effect and of the dangers of handling lasers and that dangers to the health of those treated in this way are accepted. It can be observed that these users are using more and more powerful laser and IPL devices. For these interventions, lasers up to class 4 are used in accordance with the BGV B2 "laser radiation" [BGV 97], the application of which can represent a high risk, since eye and skin damage, including diffusely scattered radiation, as well as fire and explosion hazards are to be expected. Often there are no suitable precautions in place to prevent damage to the patients and the users themselves.

The same dangers exist for the use of IPL devices. Currently, users are not forced by any legal regulation to prove their qualification to operate a laser or IPL device and their knowledge of protection and safety measures. However, if Class 3B and Class 4 lasers are used, laser protection officers shall be appointed.

1.5 Historical Overview

An overview of all important points in the historical development of laser technology can be found in Table 1.2.

Table 1.2 Milestones in the development of laser technology

1917	Einstein publishes the theory of spontaneous emission (section 1.1), the "light amplification by forced emission"
1928	The physicists Rudolf Ladenburg and Hans Kopfermann succeed in proving experimentally the effect postulated by Einstein
1954	Build Gorden, Hands and Townes on at Columbia University in the USA and at the Lebedev Physics Institute in Moscow, the first MASER
1957	The US physicist Gordon Gould gives a name to the laser, an abbreviation that refers to the effect: light amplification by stimulated emission of radiation
1958	Townes and Shavlow release "infrared and optical masers"
1960	The bundled, deep red light beam is generated by a ruby laser built by the US physicist Theodore Maiman
1960	The Iranian physicist Ali Javan develops the first gas laser at Bell Laboratories in the USA
1961	Javan, Bennett, and Herriott develop the first helium-neon gas laser
1961	For the first time in the USA, a ruby laser is used in ophthalmology and moves into minimally invasive surgery
1962	The technological race for the laser begins. From 500 research institutes and companies worldwide, 20–30 are developing a marketable product
1964	Bridges produces the first argon laser, Patel the first CO_2 laser. Due to its high beam power, the latter is suitable for cutting, drilling, or welding metals and is widely used in the industry
1964	Townes, Prokhorov, and Basov receive Nobel Prize in Physics for their discovery of MASER
1964	Goldman et al. publish first experiences with the ruby laser in nevi and melanomas
1966	Sorokin and Lankard introduce the first dye laser at the same time as Schäfer. Thus, the wavelength of laser light is freely selectable along the spectrum of fluorescent dyes
1968	Goldman treats vascular skin lesions with argon laser for the first time
1970	Basovet al. develop the first excimer (Xer) laser
1972	Semiconductor lasers are used for optical data storage on CDs and CD-ROMs and penetrate the mass market
1980	Laser diodes as modulatable light sources and glass fiber transmission merge into a new technology: photonics
1981	Schawlow is awarded the Nobel Prize in Physics
1983	Anderson and Parrish publish the principle of selective photothermolysis
1983	Strempel publishes first successes in the treatment of nevi flammei with the pulsed dye laser
1989	Kaufmann and Hibst report for the first time on the ablative possibilities of the Erbium:YAG laser
1991	Fitzpatricket al. begin clinical preliminary work on pulsed CO_2 laser
1996	Grossman et al. publish first results on laser epilation
1998	Nanolasers are being developed: The laser diodes become smaller than the wavelength of the light they emit. Quantum effects allow tailor-made use in optical signal transmission, data processing, and medicine
2010	US researchers at Lawrence Livermore National Laboratory test laser-induced nuclear fusion

Modified according to Raulin C, Greve B, et al. Laser und IPL-Technologie in der Dermatologie und Ästhetischen Medizin. 2. Aktualisierte Ausgabe. Stuttgart: Schattauer-Verlag; 2003

Conclusion

Laser technology was pioneered by Einstein, Townes, Shavlow, Basov, Prokhorov, and Maiman, who laid the foundations for the following technological developments. Nowadays the laser has become an indispensable part of medicine, industry, and technology.

For medicine, for which the laser was and is a great benefit, especially in dermatology, ophthalmology, and aesthetic medicine, it is always necessary to critically weigh the benefits against the risks and thoroughly examine other therapy options. Like Leon Goldman said:

> If you don't need a laser, don't use one.

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