Clinical Approaches and
Procedures in Cosmetic Dermatology

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Lasers, Lights and Other Technologies

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Clinical Approaches and Procedures in Cosmetic Dermatology

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The series Clinical Approach and Procedures in Cosmetic Dermatology intends to be a practical guide in cosmetic dermatology. Procedures in cosmetic dermatology are very popular and useful in medicine, indicated to complement topical and oral treatments not only for photo-damaged skin but also for other dermatosis such as acne, rosacea, scars, etc. Also, full-face treatments using peelings, lasers, fillers, and toxins are increasingly being used, successfully substituting or postponing the need for plastic surgeries. Altogether, these techniques not only provide immediate results but also help patients to sustain long-term benefits, both preventing/treating dermatological diseases and maintaining a healthy and youthful skin. Throughout this series, different treatments in cosmetic dermatology will be discussed in detail, covering the use of many pharmacological groups of cosmeceuticals, the new advances in nutraceuticals, and emerging technologies and procedures.

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With 279 Figures and 25 Tables

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Foreword

When I received the invitation from Maria Claudia Issa, M.D., Ph.D., and Bhertha Tamura, M.D., Ph.D., to write one of the chapters of this marvelous book, I was very happy. Later, upon receiving the mission to write the prologue of this book, whose editors, with numerous publications in the international scientific field of cosmetic dermatology, dignify the Brazilian dermatology, left me extremely honored. In this book, some of the leading medical doctors and research scientists from Brazil and from all over the world present their professional experience in the cosmetic dermatology area.

Cosmetic dermatology is constantly evolving. Procedures for rejuvenating the skin are actively sought by people, nowadays. As dermatology grows as a specialty, an increasing proportion of dermatologists will become proficient in the delivery of different procedures. Even those who do not perform cosmetic procedures must be well versed in the details to be able to guide their patients.

Numerous major advances in the field of the cosmetic dermatology area, including botulinum exotoxin, soft tissue augmentation, chemical peels, cutaneous lasers, light source–based procedures, and the state of the art of dermatologic and cosmetic prescriptions, have been developed and enhanced by dermatologists and plastic surgeons.

Lasers, lights, and related energies are routinely used in cosmetic dermatology. These are very important tools in the armamentarium of the dermatology. Very interesting results in the treatment of photoaging, rosacea, scars, and stretch marks, among others, can be obtained with these procedures. However, accuracy in its management as well as the knowledge of possible complications and their management are of extreme importance. In this volume, different types of devices are thoroughly discussed.

The series Clinical Approach and Procedures in Cosmetic Dermatology offers a wonderful and embracing text. It was a pleasure to contribute in this unique book with so many well-renowned authors.

This work project is a text certainly of inestimable value for those who wish to deepen their knowledge in the field of cosmetic dermatology.

Hoping that you will enjoy learning a lot from this book!

Mônica Manela Azulay, M.D., Ph.D.

Preface

Nowadays, life expectation had increased and for a better quality of life, people are looking for beauty, aesthetics, and health. Dermatologists and plastic surgeons who work with cosmetic dermatology can help patients to maintain a healthy and youthful skin. Topical and oral treatments associated with full-face procedures using peelings, lasers, fillers, and toxins are increasingly being used, successfully substituting or postponing the need for plastic surgeries.

This series of book is very special among other ones already published as it encompasses all subjects related to this area of dermatology. All authors are experts in the field of cosmetic dermatology. Literature review and its correlation with authors' experience is a differential feature of this work.

This work had been divided into four volumes due to the breadth of the subjects, which cover skin anatomy and histopathology, physiology, patient's approaches, common cosmetic dermatosis, topical and oral treatments, and cosmetic procedures.

Over the last decades, laser technology had great improvement. This volume on *Lasers, Lights and Other Technologies* was designed to bring a basic structural framework of the use of lasers, lights, and related energies in cosmetic dermatology. Here, Prof. Maria Issa, Prof. Bhertha Tamura, and collaborators discuss different types of devices with their indications, parameters to achieve better results, and management of possible complications. Some particularities including the use of lasers for different phototypes and body areas are also described.

The *Clinical Approach and Procedures in Cosmetic Dermatology* was prepared to be a guide in cosmetic dermatology. It can be considered a complete encyclopedia in the field of cosmetic dermatology and, for this reason, it is extremely useful for those who already work with cosmetic dermatology as well as for beginners in this field. This is a new reference work project, and we are delighted to have you on board.

Maria Claudia Almeida Issa, M.D., Ph.D.
Bhertha Tamura, Ph.D.

Acknowledgments

When we were invited to write a book about cosmetic dermatology, we could not imagine the dimension of this work project.

After drawing the program content, we realized that a comprehensive handbook series in this field would be built. Nevertheless, it would not be possible without the efforts and experience of our invited partners. They deserve our acknowledgment and our deep appreciation.

To all collaborators, our very special thanks.

Maria Claudia Almeida Issa
Bhertha Tamura

Contents

About the Editors

Maria Claudia Almeida Issa is among the leading dermatologists in Brazil and Latin America, especially in what regards to cosmetic dermatology. Dr. Issa holds a Ph.D. in Dermatology from the Federal University of Rio de Janeiro (2008) and an M.Sc. in Dermatology from the Fluminense Federal University (1997). Dr. Issa is currently an Associate Professor within the Department of Clinical Medicine – Dermatology, at the Fluminense Federal University, Brazil. Her research focuses on photodynamic therapy, nonmelanoma skin cancer, lasers, photoaging, and dermal remodeling. Finally, Dr. Issa has an extensive clinical experience in cosmetic dermatology, being registered as a dermatologist at the Brazilian Society of Dermatology since 1995 and member of the American Academy of Dermatology.

Bhertha Tamura has M.Sc. and Ph.D. degrees in Dermatology from the Hospital das Clínicas de São Paulo – Universidade de São Paulo. Specialist in general surgery and dermatology. Counselor for the Brazilian Society of Dermatologic Surgery and for the Brazilian Society of Dermatology. Member of the Scientific Commission of the Brazilian Society of Dermatology. Chief of the Department of Dermatology at the Complexo Hospital Heliopolis (São Paulo, Brazil). Member of several international dermatological societies.

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Part I

Biophotonics, Lights, Ablative and Non-ablative Lasers

Biophotonics

Álvaro Boechat

Abstract

Light is one of the most beautiful forms of pure energy, we know some of its therapeutic properties, but there is still much to be explored. The aim of this chapter is to provide a better understanding of the best known light tools used in modern medicine, such as laser, intense pulsed light, the advent of fractional systems, radio frequency, and hybrid systems, which combine light and radio frequency, how they work, how to select which device will be better for your application, and how light and RF interact with the skin. Thus, this will enable the improvement of current treatment techniques as well as broaden the horizons of applications of these devices.

Keywords

Dermatological laser • Laser physics • Types of lasers • Pulsed light • IPL • Treatment platforms • Light-tissue interaction • Selective photothermolysis • Relaxation time • Radio frequency • Fractional lasers • Penetration depth • Ablative laser • Non-ablative laser • Sublative • Fractional radio frequency • ELŌS

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Introduction

The laser and pulsed light are simply sources of natural light. The visible light that we experience in our day to day is only one facet of a much broader physical phenomenon known as "electromagnetic radiation."

As shown in Fig. 1, the electromagnetic spectrum (Siegman 1986) includes several well-known phenomena, such as TV and radio waves, microwave, infrared, and, on the other side of the spectrum, ultraviolet and X-ray. However, our eyes are sensitive to only a very narrow range of the spectrum, which forms the visible light from violet to red. It is important to realize that each visible color or each emission spectrum is associated with a frequency or wavelength.

Thus, the differentiation between blue and green, for example, is related to their frequencies. It is similar to the musical notes; the difference of the note "do" (C) from the note "sol" (G) or "fa" (F) is their frequencies; one is low pitched and the other high pitched. Drawing a parallel with them, we can see that, in the light spectrum, the higher frequencies correspond to blue and violet and, on the other side of the spectrum, the lower frequencies correspond to red. As light frequencies are very high, of the order of millions of hertz, they are characterized by their wavelength or the distance between two adjacent peaks in the wave illustrated in Fig. 2 (Siegman 1986; Arndt et al. 1997).

Light radiation may be defined as the point-to-point power transmission in space, regardless of the medium in which it is being propagated. Light or electromagnetic radiation propagates at a high speed in the open space independent of the transmission medium in the form of waves that can travel in the vacuum or in spaces containing matter, such as gases, liquids, or solids. As it enters, or moves from, a different medium, it will suffer changes in direction and speed of propagation.

Lasers are sources of electromagnetic radiation, or light, with some special characteristics that are different from other light sources, such as a car headlight or a lamp.

The word **laser** is an acronym for **light amplification by stimulated emission of radiation**. We can divide this acronym into two well-defined parts: the stimulated emission phenomenon and the light amplification.

Stimulated Emission

Light is a form of energy generated, emitted, or absorbed by atoms or molecules. To emit energy, the atom or molecule is raised to an excitation energy level, above its natural resting state (in which there is excess energy to be discharged). Atoms cannot maintain the excitement for long periods of time. Consequently, they have a natural tendency to eliminate the excess energy in the form of emission of particles or packets of light waves called photons (Fig. 3a). This phenomenon is called spontaneous emission of light. The wavelength (λ), or the frequency of the emitted photons, is related to the photon energy through the relationship:

$$\mathbf{E_{photon} = hc/\lambda}$$

h – Planck universal constant $= 6.6260693 \times 10^{-34}$ J.s
c – Speed of light = 300,000 km/s
λ – Wavelength of the light (nanometers – nm)

We can draw an important conclusion from this equation: long wavelengths of light, such as red, carry less energy than shorter wavelengths, such as blue, which is at the other end of the spectrum.

Each atom or molecule in nature has different energy levels of excitement. Consequently, each element emits photons with different energies and different wavelengths (frequencies). All these primary radiations are monochromatic. The fact that the sunlight is polychromatic indicates that it is composed of a mixture of several distinct elements.

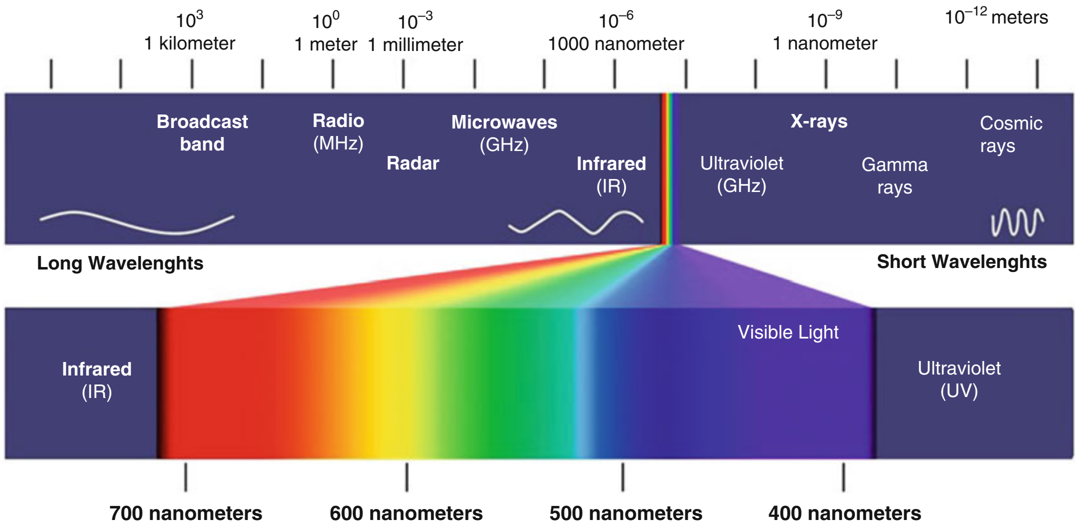
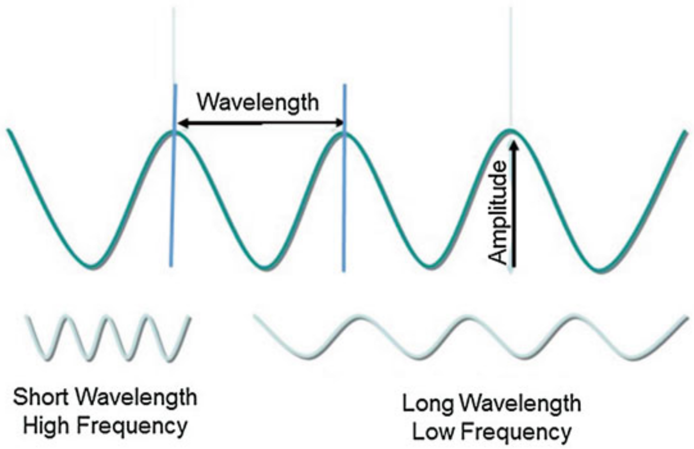


Fig. 1 The electromagnetic spectrum

Fig. 2 Electromagnetic waves of photons that transport energy



Another important relationship is the frequency with wavelength (Siegman 1986):

$$\mathbf{f} = \mathbf{c}/\boldsymbol{\lambda}$$

f – Frequency of the light wave (Hz)
c – Speed of light = 300.000 km/s
λ – Wavelength of the light (nanometers – nm)

We see that these two quantities are inversely proportional; that is, the higher the frequency, the smaller the wavelength. For example, the frequency of visible light, which is very high of the order of Terahertz, has a very small wavelength, being the size of a molecule. As an analogy, a FM radio wave, of the order of Megahertz, has a wavelength the size of a two-story house.

Atoms can be excited by different mechanisms: heat, mechanical shocks with other particles as an electrical discharge (collision with electrons), or when they selectively absorb electromagnetic radiation energy from other photons. This is a natural process that occurs all the time around us, but as its magnitude is very small and

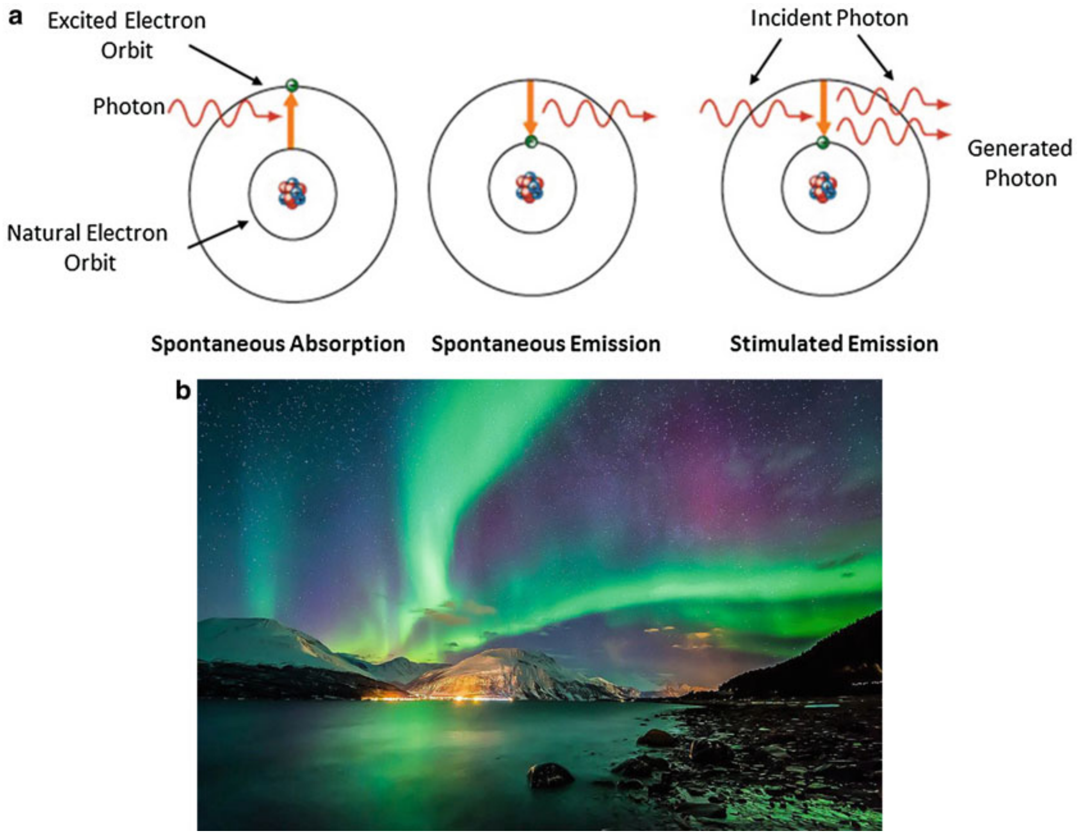


Fig. 3 (**a**) Spontaneous emission of light. (**b**) Northern Lights, or *aurora borealis*, an example of spontaneous emission of light

very narrow in the visible spectrum, we cannot see it. The location on Earth where we can more easily observe this phenomenon is, for example, near the North Pole, with the famous Northern Lights or auroras. It is produced by the impact between air molecules and cosmic particles from the Sun that constantly bombard Earth, producing a phenomenon of luminescence in the upper atmosphere (Fig. 3b).

However, atoms can also decay producing light radiation in a stimulated form. In 1917, Albert Einstein postulated and proved the existence of this mechanism (Siegman 1986; Wright and Fisher 1993; Arndt et al. 1997). When an excited atom collides with a photon, it instantly emits a photon identical to the first (Fig. 3a). This stimulated emission follows the following basic laws:

(a) The stimulated photon travels in the same direction of the incident.
(b) The stimulated photon synchronizes its wave with the incident; in other words, the waves of the two photons align their peaks adding their magnitudes and thereby increasing the intensity of the light. Photons with aligned peaks produce a coherent (organized) light. In a coherent beam, light travels in the same direction, in the same time, and with the same energy.

The end result of a stimulated emission is then a pair of photons that are coherent and that travel in the same direction. The stimulated emission of light is the working principle of a laser, invented more than 50 years after the discovery of Einstein.

Light Amplification

To illustrate the generation of light inside a laser, let us first imagine a rectangular box or a tube, as a straight cylinder, with a large amount of identical atoms or molecules, as an example, a fluorescent lamp tube with its gas. At each end of the tube, we place mirrors, which because of the construction will be parallel to one another. At one end, the mirror is totally reflective (100 % mirror), and at the other end (the exit window of the light – output coupler), the mirror is partially reflective (80 % mirror), so that part of the light is reflected back to the tube and part is transmitted through the mirror to the outside (Wright and Fisher 1993; Kulick 1998; Boechat 2009; Raulin and Karsai 2011; Kaminsky Jedwab 2010).

Let us also imagine that the atoms are excited to a higher-energy level by an external source (a light source or an electrical discharge), as if we had activated the switch turning on the lamp. Through the mechanism of spontaneous emission, which takes place completely randomly, the atoms emit photons that begin traveling in various directions within the tube. Those hitting against the tube wall are absorbed and lost as heat, disappearing from the scene. In the case of a lamp, they leave the tube into the environment, illuminating the room. On the other hand, the emitted photons traveling parallel to the tube axis are likely to find other excited atoms and thus stimulate the emission of additional photons, which are consistent with the stimulating photon and travel in the same direction – i.e., along the longitudinal axis of the tube. These two photons continue their journey, again with the likelihood of stimulating, through a similar process, two additional photons – all consistent with each other and traveling in the same axis. The progression continues indefinitely and 8, 16, 32, 64, etc., photons are produced, all traveling in the same direction, as illustrated in Fig. 4.

It is clearly established a light amplification process that generates a large luminous flux in the longitudinal direction of the tube.

The mirrors perpendicular to the tube axis reflect the photons back intensifying this effect of amplification. Each of these reflected photons traveling along the axis in the opposite direction contributes to the chain reaction effect generating a stream of coherent photons. When they reach the partially reflecting mirror, 80 % of the photons return to the tube continuing the amplification effect. The remaining 20 % goes out forming the laser beam (Fig. 5a, b). They represent in absolute terms a very intense beam of photons produced by the amplification effect. The tube and its excited medium, together with the mirrors, are called the resonator (or oscillator) which is the basic components of a laser in addition to the excitation source.

Characteristics of a Laser Light

As described above, the laser light has unique properties that make them different from other light sources (Goldman and Fitzpatrick 1994; Arndt et al. 1997; Kaminsky Jedwab 2010; Sardana and Garg 2014):

(a) **Monochrome**: it is generated by a collection of identical atoms or molecules; thus, all photons emitted have the same wavelength, a single frequency. This feature is important because of the selective absorption of the human tissue, which will be presented in the next section.

(b) **Coherent**: because of the stimulated emission and the way the light is amplified, which is only in the longitudinal direction inside the resonator, the photons are organized, as soldiers marching in a military parade. This is called spatial and temporal coherence. At any point of a laser beam, the photons (or light):
   (a) Have the same power
   (b) Travel in the same direction
   (c) Travel at the same time

Being coherent, light from a laser is called collimated. Traveling parallel to the tube axis, the laser beam has a very small divergence angle, i.e., the light does not spread; the photon beam is collimated (parallel). The small

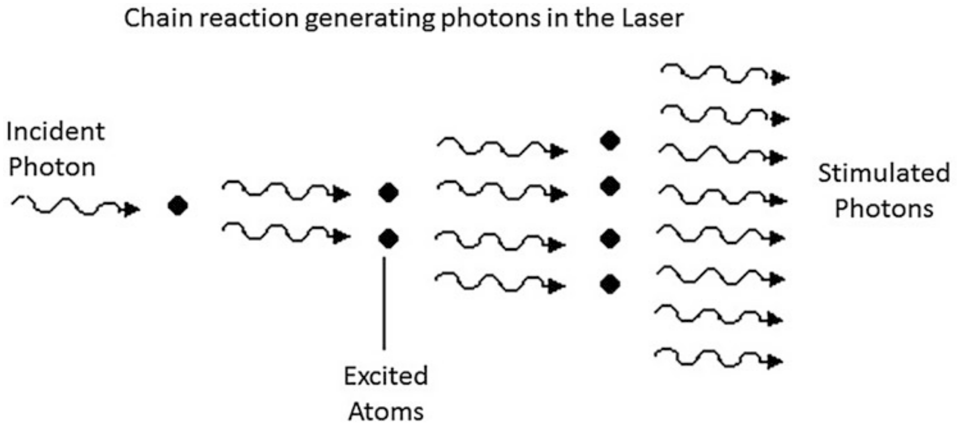


Fig. 4 Chain reaction producing photons inside the laser resonator

divergence allows the use of a lens system to concentrate all the energy of the laser in a precise way on a small focal spot (spot size), achieving a greater concentration of light energy or brightness. Optical laws tell us that the smaller the divergence, the smaller the focal point. When we focus a common light source such as a lamp, of incoherent light, the focal point will be too large and imprecise, whereas when using a laser, we have a very fine and extremely precise focal point and therefore a much more intense effect on the tissue.

Energy, Power, and Fluency

The increase of temperature or the effect of treatment on the tissue depends on the amount of energy that it receives. The energy, power, and fluency (energy density) are the physical parameters that control the treatment effect and determine the eventual increase in temperature.

Energy	Is measured in Joules (J)
Power	Is measured in Watts (W)

These are different parameters and they are related trough the following equation:

$$\mathbf{Energy}(\mathbf{J}) = \mathbf{power}(\mathbf{W}) \times \mathbf{time}(\mathbf{s})$$

Thus, energy is the amount of power delivered to the tissue in a given time or the laser pulse duration. The thermal effect of the laser is highly localized. In this way, the physical quantity that governs the thermal response of the tissue is the amount of energy delivered to a certain area, the overall size of the application area or the “spot size” produced by the laser handpiece. Thus, the energy density or fluency is measured in J/cm^2 (Boechat et al. 1991):

$$\mathbf{Fluency}\left(\mathbf{J}/\mathbf{cm}^2\right) = \mathbf{Energy}(\mathbf{J})/\mathbf{Area}\left(\mathbf{cm}^2\right)$$

The higher the fluency, the faster the temperature increases in the tissue and consequently the intensity of the desired effect. The effect of the treatment is achieved both by varying the laser output energy and the laser pulse duration, at the tissue application area. All commercial lasers allow us to change easily and continuously the energy.

For a fixed operating power, we can vary the fluency in the tissue by changing the application area (spot size – changing the lens that focus the laser beam in the handpiece) or by varying the distance of the handpiece from the tissue in a “focused” handpiece.

When we work with light in focus (Fig. 6), the power density is at its maximum because all the energy of the laser is concentrated in a small focal point (usually of the order of 0.1–1 mm), called “spot size.” At the focal point, it is possible to precisely cut the tissue, and the application has its maximum effect. When we move the handpiece away from the tissue to a defocus, or out of focus

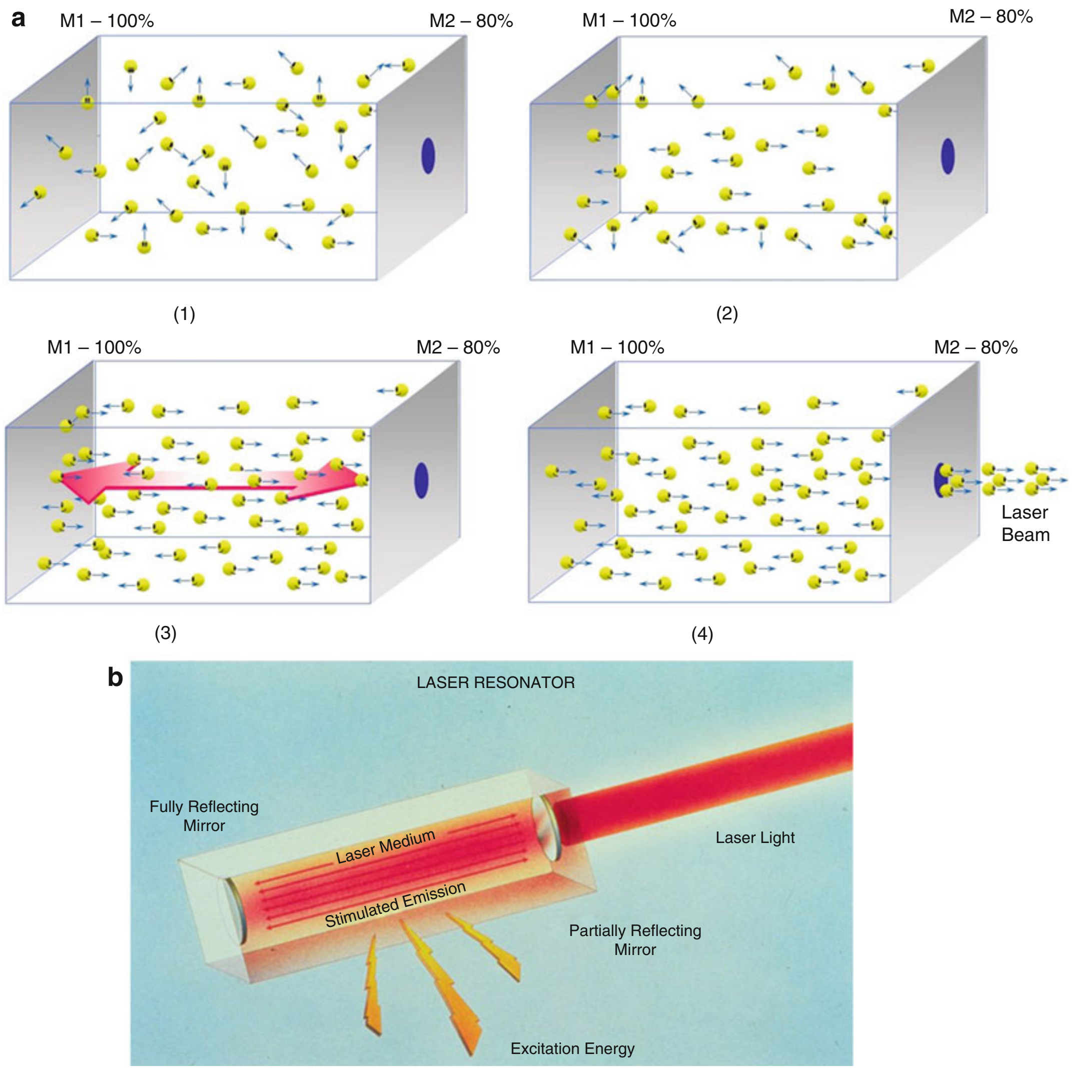


Fig. 5 **(a)** Light amplification and laser beam formation inside a laser resonator. M1 is the 100 % reflection mirror and M2 is the 80 % partial reflection mirror. The (1) and (2) are excited atoms that produce photons that begin to travel longitudinally along the resonator between the mirrors. The (3) and (4) are the photons traveling parallel to the axis of the resonator that stimulate new photons, producing the laser beam. (**b**) Schematic of the laser operation

position, the application area becomes larger reducing the power density (fluency) and increasing the temperature in the tissue. At this position, the effect becomes milder, producing a superficial effect of vaporization and coagulation (used in skin rejuvenation – skin resurfacing).

Another widely used laser handpiece is called "collimated." Here the laser beam remains parallel (collimated) and constant regardless of the distance from the tissue. It is used in hair removal systems and various types of skin treatment, such as tattoo and melisma removal (Fig. 7).

It is important to note how the cutting effect is controlled when using a laser. The surgeon is used to control the depth of the cut by the pressure exerted on the blade against the tissue. In the laser, as there is no mechanical contact with the tissue, the cut is determined by two factors:

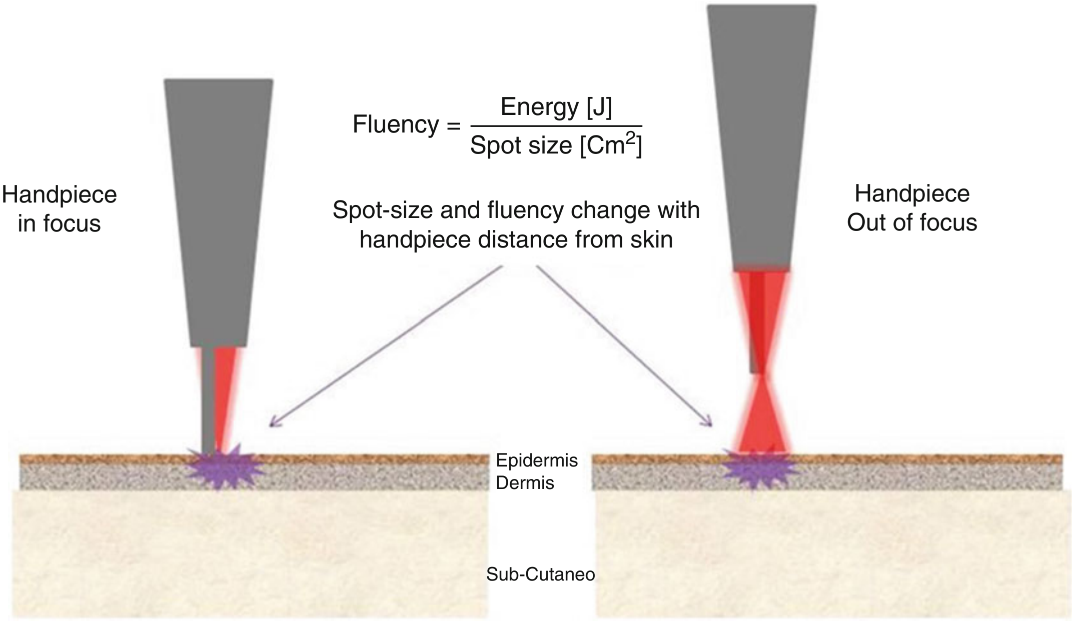


Fig. 6 Focused headpiece. Laser in focus: power density is at its maximum (vaporizing, cutting). Out of focus: power density is reduced (coagulation, milder treatment)

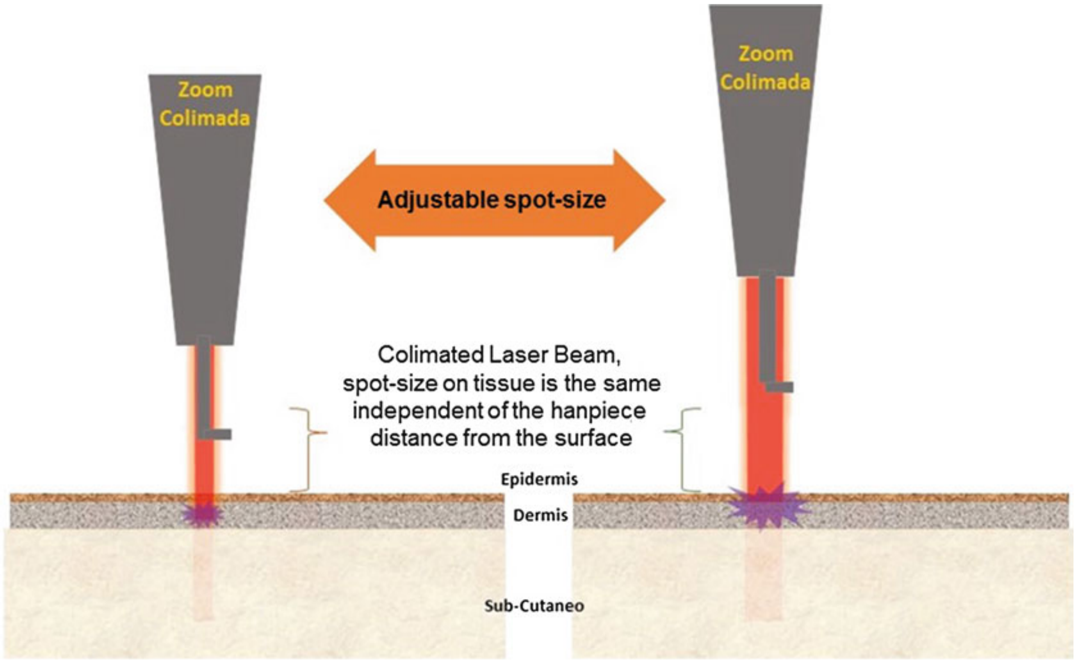


Fig. 7 Collimated handpiece. Regardless of the distance from the skin (touching or moving away), the spot size and fluency remain the same. Some handpieces have a zoom effect that allows the adjustment of the spot size

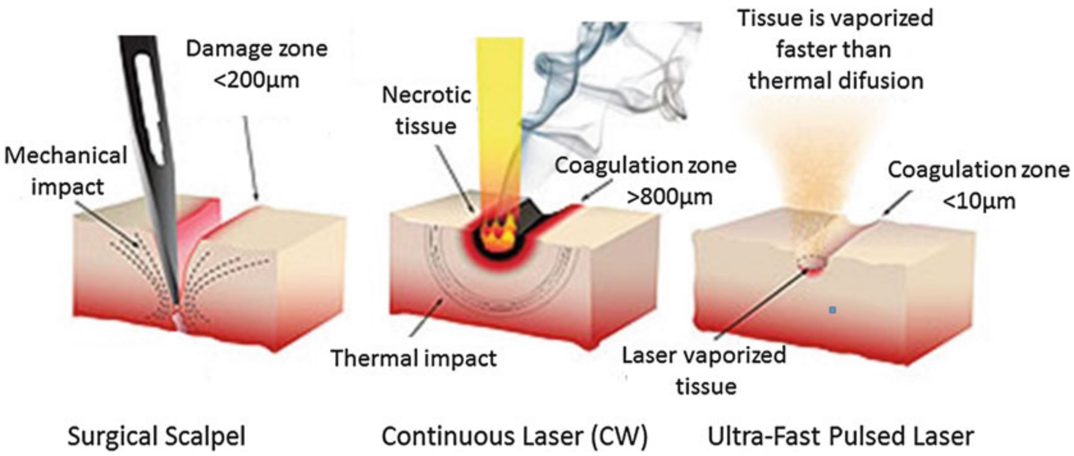


Fig. 8 Comparison of tissue laser cutting, showing continuous wave (CW) and ultrafast pulses that minimize the thermal damage to adjacent tissue

1. Hand movement speed
2. Laser energy

The speed is linked to tissue exposure time, because if we keep the laser acting on a point indefinitely, it begins to vaporize layer upon layer of tissue increasing the depth of the cut. Thus, for a constant power, if the surgeon moves the hand slowly, he or she will produce a deep cut. Likewise, for a movement with constant speed, the cutting will be deeper for a greater energy.

The laser exposure time also governs the amount of adjacent tissues which may be affected. Modern laser systems have mechanisms that quickly deliver energy to the tissue minimizing the thermal effect in adjacent areas. These mechanisms can be through ultrafast pulses ("ultrapulse" laser) or computerized rapid laser beam scanning systems (fractional scanners), used in skin rejuvenation treatments and more recently in fractional treatment systems. The "scanner" divides and moves the laser beam at high speed to position it over the skin minimizing damage to adjacent tissues. They are controlled by computer and can execute different types of scanning, with great precision and control over the amount of tissue being vaporized (Goldman and Fitzpatrick 1994; Arndt et al. 1997; Kulick 1998; Alster and Apfelberg 1999; Alster 1997).

Operating Modes of a Laser

Depending on the effect of the treatment we want to obtain on the tissue, laser systems can operate in the following modes (Boechat 2009; Raulin and Karsai 2011; Kaminsky Jedwab 2010; Sardana and Garg 2014):

1. **Continuous mode** – **CW**: In this mode of operation (also known as continuous wave), the laser stays on, just as a normal lamp, and emits a light beam of constant energy, as long as we keep the system powered by the foot switch or the power button on the handpiece (available on some devices). It is widely used in surgeries for coagulation or vaporization of tissue.
2. **Pulsed mode**: This mode works as if we turned a lamp on and off; the laser is pulsed electronically with the times and the intervals between pulses controlled by the equipment computer and selected via the panel. The repetition rate or frequency (given in Hz) of the laser pulse can also be programmed. Most lasers used in dermatology work with ultrafast pulses to vaporize the tissue faster than the thermal diffusion time of the skin in order to minimize damage to adjacent tissues, resulting in safe and effective treatments (Fig. 8).

According to the laser pulse duration, pulsed systems can be classified into:

(a) **Long pulses** – 0.001 s, millisecond (ms) 10^{-3} s
    (i) Hair removal, varicose veins
(b) **Quasi-CW** – 0.000001 s, microsecond (μs) 10^{-6} s
    (i) Skin rejuvenation, onychomycosis, inflammatory acne
(c) **Q-Switched** – 0.000000001, nanosecond (ns) 10^{-9} s
    (i) Treatment of melasma, tattoo removal
(d) **Mode-Locked** – 0.000000000001, picosecond (ps) 10^{-12} s
    (i) Tattoo removal and pigmented lesions
(e) **Femto** – 0.000000000000001, femtosecond (fs) 10^{-15} s
    (i) Refractive surgery in ophthalmology

Q-Switched: Nanosecond Laser

This mode is achieved by placing an optical accessory inside the resonator, at the side of the laser crystal, whose goal is to pulse optically the light (Siegman 1986; Goldman 1967; Raulin and Karsai 2011). It is generally used in crystal lasers such as ruby, alexandrite, and Nd:YAG, described below. The goal is to accumulate the laser energy at very high levels and release it at extremely rapid pulses. The result is a very high-peak-power laser pulse (often higher than the common pulse), which can penetrate deep into the tissue, with minimal side effects. Then a shockwave-induced mechanical action caused by the impact of the laser pulse onto the target tissue causes its fragmentation. In the long and Quasi-CW pulsed modes, the effect is purely thermal.

The Q-Switch can be **passive**, when using a crystal called "saturable absorber" that produces rapid pulses, or **active**, when using an electronic modulator crystal called "Pockels cell."

Passive systems using the saturable absorber are generally simpler and more compact resulting in smaller portable devices or systems installed into handpieces incorporated to a platform. They are more limited as it is not possible to control efficiently the stability of the fast pulse; the crystal is sensitive to higher energies, which limits the maximum working energy; and the application spot size is limited to a few millimeters (1–3 mm). They also fail to achieve high repetition rates of pulses (high frequencies), working in a maximum of 2–3 Hz.

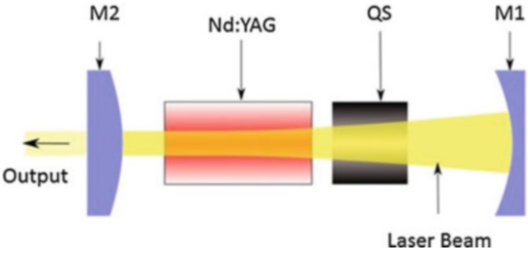


Fig. 9 Diagram of a Nd:YAG laser with Q-Switch (QS). M1 is the 100 % mirror; M2 is the output coupler

The active Q-Switch uses a Pockels cell which is a crystal subjected to a high electric frequency and is electronically controlled to produce a very fast and stable light switching effect. The result is faster pulses with very high peak powers that are not possible with passive systems. Thus, they can handle high energy, larger spot sizes (10 mm), and faster repetition frequencies of 2–20 Hz. Equipment with active Q-Switch allow the device to be turned off, and thus the laser can also work in the Quasi-CW mode, with micropulse, giving greater flexibility to the system (Fig. 9).

The classic application is in tattoo removal and the treatment of pigmented skin lesions such as dark circles, postinflammatory hyperpigmentation, and melasma (Goldman 1967; Reid and Muller 1978; Raulin et al. 1998; Chang et al. 1996; Shimbashi et al. 1997; Reid et al. 1983, 1990; Stafford et al. 1995; Ogata 1997; Chan et al. 1999; Jeong et al. 2008; Mun et al. 2010) (Fig. 10).

Mode-Locked: Picosecond Laser

To achieve picosecond pulses, a technique called "mode-locking" is used (Siegman 1986; Raulin and Karsai 2011; Sardana and Garg 2014). The base is a Q-Switch system as described above, in which nonlinear effects of the Q-Switch crystal are

Fig. 10 Laser tattoo removal

stimulated and modulated inside the resonator in order to create faster pulses with a technique in which only they are amplified. It is more commonly used in crystal lasers as alexandrite and Nd:YAG.

There is the passive, with the saturable absorber, and the active mode-locking, with the Pockels cell electronically controlled. The limitations and benefits of each are the same as in the Q-Switched systems.

The picosecond lasers for dermatology provide pulses ranging from 375 to 760 ps.

To understand the picosecond laser advantages over a nanosecond device, we need to go back to the relationship between energy, power, and pulse duration, described above. We see that the peak power is inversely proportional to pulse duration. In other words, faster (shorter) pulses generate higher powers for the same energy:

$$\mathbf{Power(W)} = \mathbf{Energy(J)/Duration\ of\ the\ Pulse(s)}$$

A picosecond laser generates a very high peak power, making the photomechanical fragmentation of the target tissue and consequently the treatment more efficient. It also does not need high-energy levels. Working with very low energy results in milder treatments and faster recovery time. For example, in tattoo removal, a picosecond laser needs fewer sessions than a nanosecond system, and applications can be performed every 15 days, while in nanosecond systems, sessions are 45–60 days apart. The faster the system is, the milder and more effective is the treatment. That is why the industry has been investing in the development of these ultrafast devices (Fig. 11).

Fig. 11 Picosecond Laser PicoWay™ Nd:YAG/KTP (Syneron Candela)

As we will see in the following chapter, the pulse duration governs the way in which light interacts with the tissue (selective photothermolysis), and by varying the pulse duration, we can completely change the laser application in dermatology.

Laser Types

All laser devices consist of the following parts (Siegman 1986; Goldman and Fitzpatrick 1994; Boechat 2009; Kaminsky Jedwab 2010):

1. The resonator/oscillator – with mirrors (total and partial reflectors) and active medium, which, when excited, produces the light and thus determines the wavelength
2. The excitation source (also called pumping) – which delivers power to the active medium producing the photons

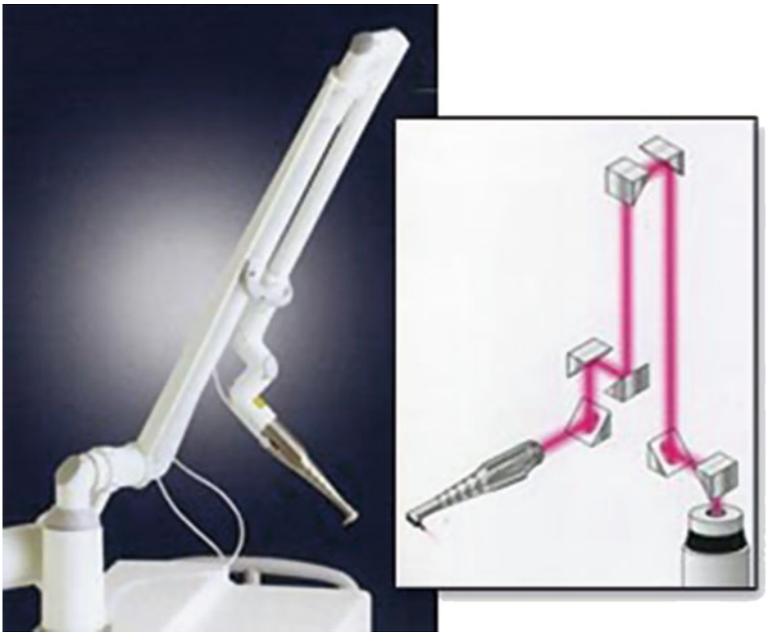


Fig. 12 Diagram of an articulated arm

3. Laser beam delivery system from the source to the hand of the operator
4. Handpiece, with focusing lens or a scanning system

The industry uses various elements in the manufacture of laser sources in order to cover a growing range of electromagnetic wavelengths. Today, we have ultraviolet lasers, visible light, and infrared. For this end, gases, liquids, crystals, fiber optics, and semiconductors (electronic components) are used.

The pumping of each element also varies; thus, electrical discharges, radio frequency, and light sources such as flash-lamps or even other lasers are used.

To carry the laser light from where it is generated in the resonator to the hand of the user who is making the application, various mechanisms are used depending on the wavelength and energy of the equipment. The most common are:

Articulated arm – a set of multiple mirrors positioned at the corners of articulated pipes to allow the freedom of movement in all directions (Fig. 12).

Optical fiber – thin waveguide with a core made of quartz covered with a thin layer called cladding, which is made of a slightly different material and encapsulated with plastic and metal coatings to give it flexibility. It delivers the laser beam by multiple internal reflections; that is, light enters the fiber, reflects on the core/cladding interface and keeps moving until it exits the optical fiber. Note that at the output of the fiber the laser beam has a wide divergence and is no longer collimated. In other words, the beam spreads, losing part of its coherence (Boechat et al. 1991, 1993) (Figs. 13 and 14).

A handpiece is placed at the end of the beam delivery system for either an articulated arm or an optical fiber. It contains the lens system which focuses the laser light on the working area facilitating the handling of the laser during treatment, as already described above. In fractional laser devices, described below, the handpiece holds the scanning systems, or scanners, in addition to the lenses.

Bellow we describe some typical commercial laser systems used in medicine, grouped according to the laser medium (Alster and

Fig. 13 Diagram of an optical fiber showing the beam divergence at the output

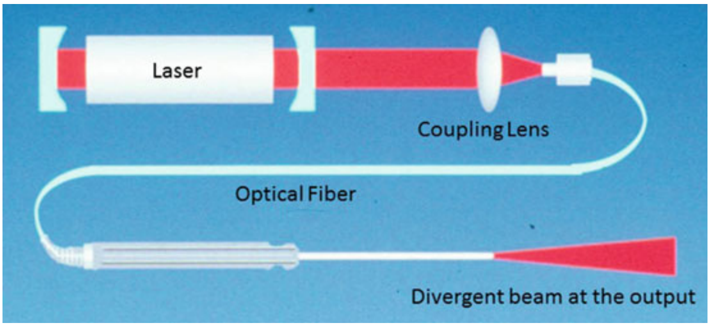


Fig. 14 Surgical laser with optical fiber

Apfelberg 1999; Alster 1997; Boechat 2009; Raulin and Karsai 2011; Kaminsky Jedwab 2010; Sardana and Garg 2014).

Gas Lasers

Excimer

Gas molecules that exist only in the excited state, called "dimers," form the excited medium; examples are molecules such as halogens combined with noble gases (ArF, KrF, XeCl, Xef). The word "excimer" is an abbreviation of the term "excited dimer." The emission covers some wavelengths in the ultraviolet range such as 193 nm ArF, 222 nm KrCl, 248 nm KrF, and 308 nm XeCl. The pumping is usually made by electric discharge or the shock of electrons with gas molecules. Quartz optical fibers are used as beam delivery system. Since the wavelength is very small and carries a high energy, these lasers are widely used for high precision incisions or tissue ablation, such as in ophthalmic refractive surgery (myopia). In dermatology, this system has shown excellent results in the treatment of psoriasis and vitiligo (Zelickson et al. 1996; Guttman 2000).

Fig. 15 RF-pumped CO_2 laser with articulated arm, eCO2™ (Lutronic Inc.)

Argon Ion

The excited ionized argon gas, Ar^+, forms the laser medium. Pumping is made by electrical discharge. The wavelength can vary between 488 nm (blue) and 514 nm (green). It uses quartz optical fiber as the delivery system (Siegman 1986; Boechat 2009).

Helium-Neon (He-Ne)

The excited medium is a mixture of helium and neon gases. It is also pumped by electrical discharge. The wavelength is in the visible range, 632.8 nm, i.e., red. These systems are generally used for low-power applications such as cell stimulation and laser pointers or aiming systems for infrared invisible lasers. It uses quartz optical fibers (Siegman 1986; Boechat 2009).

Carbon Dioxide (CO_2)

The CO_2 is still one of the most used lasers in surgery, dermatology, and industrial applications. Its power may vary from a few KW up to MW in a continuous or pulsed manner. The laser medium is a mixture of gases including N_2 (nitrogen – 13–45 %), He (helium – 60–85 %), and CO_2 (1–9 %). Pumping is achieved by high-voltage electric discharge or radio frequency (RF). The molecule of CO_2 is excited by mechanical shock with electrons, of the N_2 and He molecules. The wavelength is in the infrared range at 10,640 nm. This is a relatively efficient laser (30 % of electro-optical conversion), and because of that, it has low-power consumption and maintenance. It uses an articulated arm and special dielectric coated flexible hollow waveguides (Siegman 1986; Kulick 1998; Alster and Apfelberg 1999; Alster 1997) (Fig. 15).

Liquid Laser

Dye Laser

It uses a liquid Rhodamine solution (R6G), which is a fluorescent dye, as the laser medium. It is pumped by a flash-lamp or another laser. The wavelength may vary continuously from 300 to 1,000 nm, and the resonator can be tuned. It is most commonly used in yellow (585–600 nm). Its main application is the treatment of vascular lesions and inflammatory processes of the skin. It uses quartz optical fiber (Siegman 1986; Reichert 1998; Mcmillan et al. 1998; Reyes and Geronemus 1990) (Fig. 16).

Fig. 16 Flash-lamp-pumped dye laser, Vbeam Perfecta™ (Syneron Candela)

Solid-State Laser (Crystal)

Figure 17 shows the schematics of the most common solid-state laser systems in the market. The mirrors, the laser rod (the crystal), and the flash-lamp, used for the pumping inside a cavity made of a coated elliptical reflecting material – usually ceramic or a large resistance metal such as gold – compose the resonator (Siegman 1986; Boechat 2009).

Ruby: $Cr^{3+}:Al_2O_3$

It was the first laser developed by Maiman in 1961 (Siegman 1986; Goldman and Fitzpatrick 1994; Arndt et al. 1997) (Siegman (1986) *Lasers*), but it was some time before this system started to be used