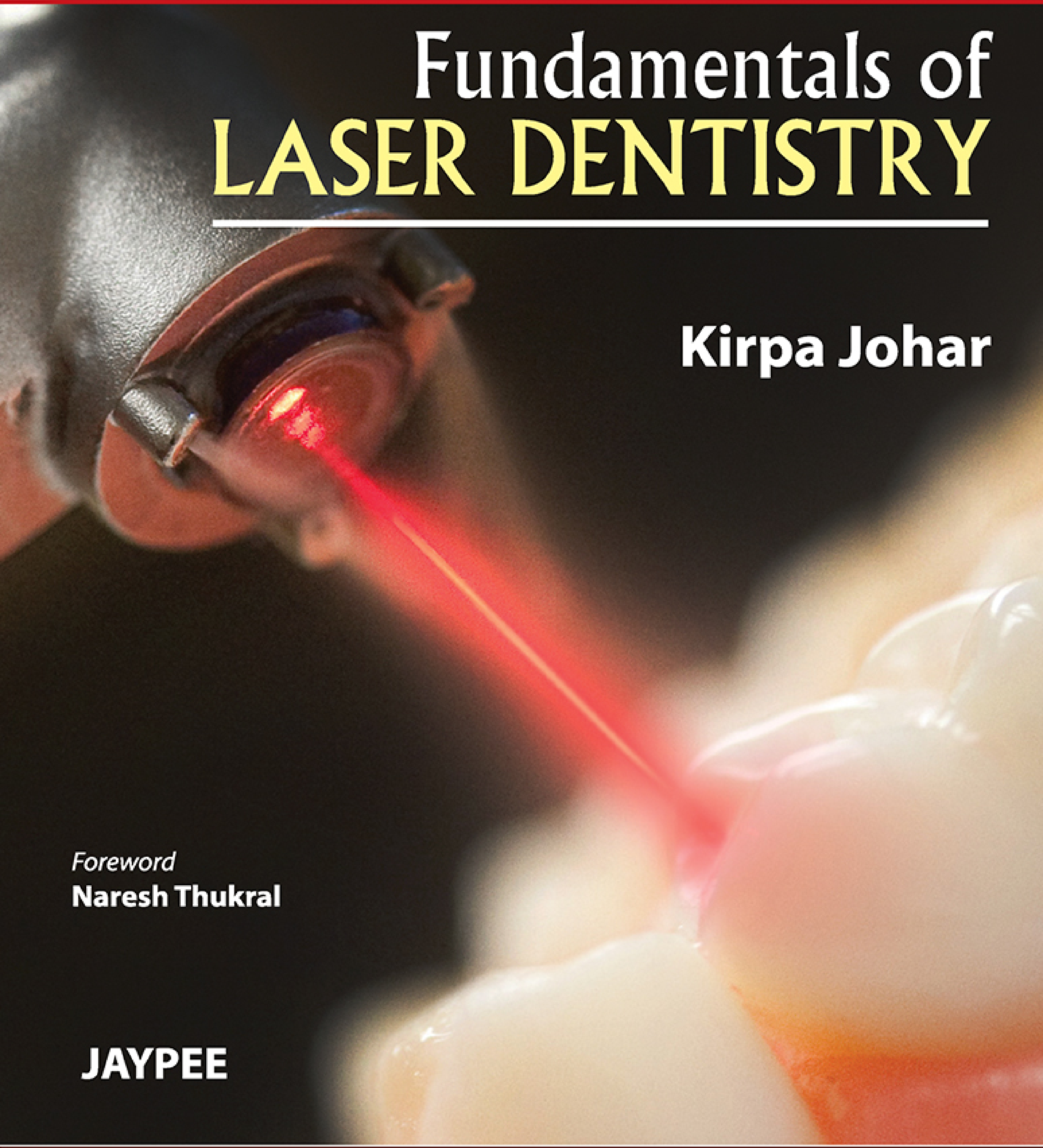
Fundamentals of LASER DENTISTRY

Kirpa Johar

Foreword
Naresh Thukral



JAYPEE

Contents

CHAPTER 1

Basic Physics and Concepts of Lasers used in Dentistry

- Introduction
- Properties of Light
- Function of Laser Involving Optical Concepts
- Laser Tissue Interactions
- Laser Media
- Pumping Methods and Schemes
- Laser Concepts

INTRODUCTION

The word laser represents an elegant Acronym as "Light Amplification by Stimulated Emission of Radiation". It was demonstrated for the first time in 1960 by Maiman.

Typical lasers, which emits in the visible and the adjacent areas of the UV and IR wavelengths comprise of a large number of Individual laser materials and laser oscillator setups working in the continuous wave or pulsed mode.

The development and application of lasers, emitting rather collimated or more or less intensive beams of narrow bandwidth coherent light, in association with optical and electro-optical components, has been recognized as a new field of optical science called photonics, comprising of aspects of quantum optics, electro-optics and linear and non-linear optics.

PROPERTIES OF LIGHT

Light is a form of Electromagnetic energy that travels in waves at constant velocity. The basic unit of this radiant energy is called a Photon or a particle of light. A wave of photons can be defined by two basic properties:

Amplitude: Defined as total height of the wave oscillation from the top of the peak to the bottom. It is the measurement of the energy in the wave. The unit of energy is Joule.

Wavelength: It is the distance between any two corresponding points on the wave. It is the measurement of physical size measured in Meters.

Frequency: The measurement of a number of wave oscillation per second. It is inversely proportional to the wavelength, shorter the frequency, higher the wavelength.

Ordinary light is usually diffuse, not focused, e.g. light produced by a table lamp is a warm white glow. It is polychromatic, noncollimated and incoherent type.

Real light waves are circumscribed and hence subject to diffraction, i.e. the distribution of amplitude over the cross section varies during propagation.

In case of confined light distribution called a beam, the direction of propagation is not sharply defined but is distributed over a certain range of vectors.

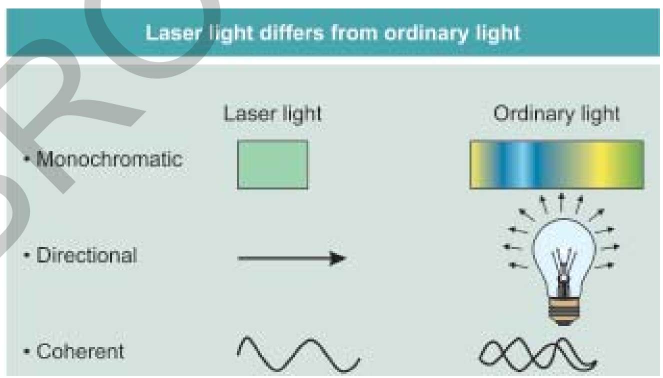
Light produced by laser has opposite properties. It is monochromatic, coherent and collimated type.

Laser light has the property of one specific color which is finely focused called **Monochromatism.** The precision of the monochromatic beam is due to additional characteristics: collimation and coherency.

Collimation refers to the beam having specific spatial boundaries which ensures that there is a constant beam size and shape that is emitted from the laser unit.

Coherency refers to unique property of lasers. The light waves are a specific form of electromagnetic energy that are physically identical. They are all in phase with one another, i.e. they have identical amplitude and identical frequency **(Table 1.1).**

Table 1.1



FUNCTION OF LASER INVOLVING OPTICAL CONCEPTS

Interaction Between Light and Matter

Threefold interaction between light and matter has three important features: Absorption, spontaneous emission and stimulated emission.

Absorption (Fig. 1.1) is the process indicated by the transfer of an electron from energy level E_1 to E_2.

Spontaneous emission (Fig. 1.2) is the mechanism for the reciprocal electronic transition E_2 to E_1, which is the result of typical radiative decay of excited electronic states of atoms or molecules.

It is comparable to radioactive decay of excited or unstable nuclear states.

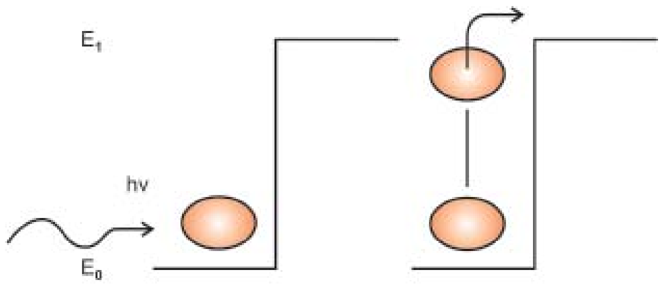


Fig. 1.1: Absorption

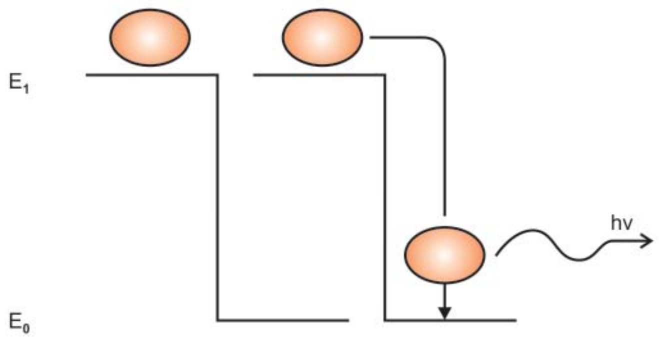


Fig. 1.2: Spontaneous emission

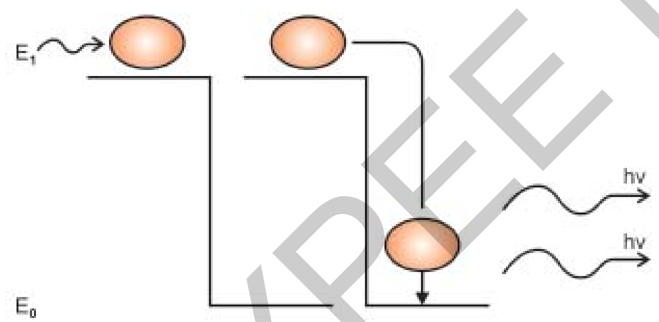


Fig. 1.3: Stimulated emission

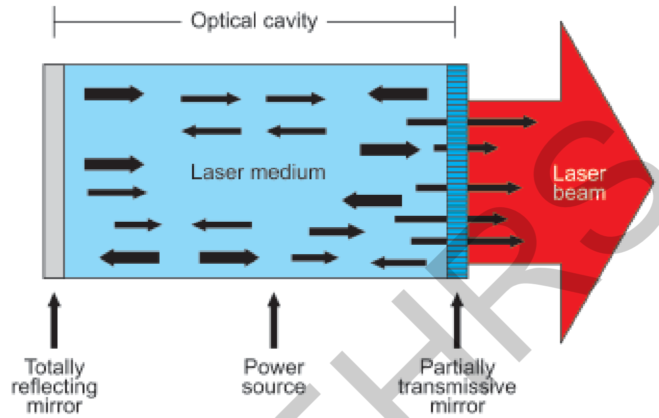


Fig. 1.4A: Basic scheme of laser

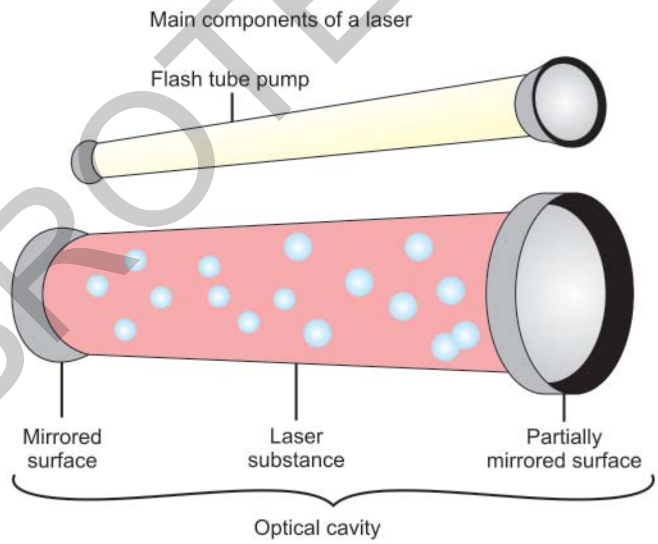


Fig. 1.4B: Main components of a laser

Stimulated emission (Fig. 1.3) represents the decay mechanism, that can only occur if a photon interacts with an atom in the excited state causing the emission of a second, identical photon.

The higher the energy of a photon, the shorter the wavelength. All dental lasers emit either a visible light beam or an invisible infrared light beam in the portion of the nonionizing spectrum called thermal radiation.

Basic Scheme of a Laser

The basic scheme **(Figs 1.4A and B)** of each laser comprises of laser medium, which is excited by an external source. Light can travel to and fro many times along a defined axis by being repeatedly reflected by mirrors of different reflection [R] forming an **optical oscillator or Resonator** (also called cavity). The laser oscillator stores light via multiple reflection of its mirrors, but also emits light through the partially transmitting out-coupling mirror. The laser light oscillates and is amplified during each pass through laser medium. If the resonator is filled with radiation at one instant of time, it emits a beam.

Population Inversion

Population inversion is a situation in which the occupation of a higher energy level is greater than the occupation of a certain lower level under nonlinear optical conditions, so that net amplification takes place.

This inversion cannot be achieved by strong pumping of two-level system because the probabilities of absorption and stimulated emission are the same. Hence three-level and four level systems are required in order to realize inversion and hence amplification.

For lasing, the upper laser level should have a higher population density. Pumping always has to be done at a shorter wavelength than the laser activity.

In a three-level system **(Fig. 1.5)**, the atoms or molecules are raised from ground level O to level 2 by a pumping mechanism. If the material is such that after reaching level 2 decays rapidly in a radiative or non-radiative manner to the longer life time level 1, population inversion can be obtained between level 2 and level 1.

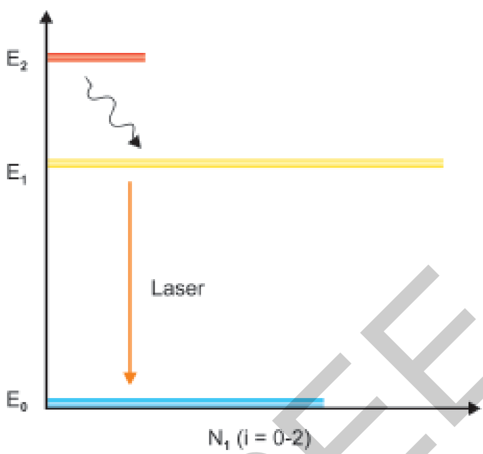


Fig. 1.5: Three level system

In a four level laser **(Fig. 1.6)**, atoms are raised from ground level 0 to level 3. If the atoms or molecules decay rapidly to level 2, it should remain as long as possible so that population inversion can be obtained accordingly between levels 2 and 1. Once oscillation starts, the atoms will be transferred to level 1 via stimulated emission for continuous wave operation. In a four level laser it is necessary that the transition $1 \rightarrow 0$ should be ultrafast to keep level 1 at a lower population than level 2.

Gaussian Beam and Laser Resonator

Gaussian beam represents the shape of a laterally confined wave which is easily treated theoretically as well as practically. Its Amplitude [E] as well as its Intensity [I] profile distribution follow a Gaussian bell

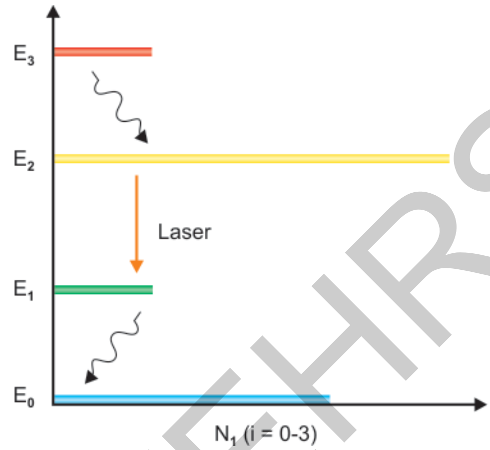


Fig. 1.6: Four level system

curve, which in principle extends to Infinity, although with a very rapid loss of height.

Laser resonators are the active medium contained within an optical enclosure in which the laser light oscillates and is amplified during each pass through the laser medium.

For the beam of laser quality to be generated adequate resonator mirrors have to be put in place in the medium.

Stimulated emission, like that of the laser amplification mechanism, requires the interaction of light with an Inverted laser medium. All the resonator configurations shown are symmetric or half symmetric and stable.

The common stable resonator configuration are:
- Coplanar (plane mirrors)
- Over-confocal (large radii of curvature)
- Confocal
- Spherical (concentric)
- Hemi-spheric (half concentric).

Beam Delivery System

The coherent collimated beam of light, must be delivered to the target tissue in a precise manner. Beam is delivered in three ways–fixed beam path, articulated arm path and the fiber.

Two delivery systems are used in dental lasers. One is a flexible hollow wave guide or tube that has interior mirror finish. The laser energy is reflected along this tube and exists through a hand piece, with the beam striking the tissue in a non-contact fashion.

The second delivery system is a glass fiberoptic scale. The fiber fits snugly into a hand piece with the bare end protruding or with an attached glass-like tip. This fiber system can be used in contact or non-contact mode.

Emission Modes

Contact mode: In this type the distal end of an optic fiber is placed in direct contact of the target tissue.

Non-contact mode: The hand piece is held away from the tissue and a guide is provided to focus the beam at the desired target tissue.

The laser device can emit the light energy in one of three basic modes. The first is continuous wave, the second is gated pulse mode and the third is free running pulsed mode.

In continuous wave mode the beam is emitted at constant power continuously by continuous pumping. The average power is equal to the peak power.

In gated pulse mode there are periodic alternations of the laser energy which is achieved either by opening or closing of a mechanical shutter in front of the beam path of a continuous wave emission. The duration of this type of laser is normally as small as a few milli seconds.

Free running pulsed mode is unique. The pulses are delivered with high peak power. Large peak energies of laser light are emitted for an extremely short time period.

The important principle of any laser emission mode is that the light energy strikes the tissue for a certain time, producing a thermal interaction.

LASER TISSUE INTERACTIONS

The light energy from a laser can have four different interactions with the target tissue and these interactions depend on the optical properties of that tissue and the wavelength used.

The first interaction is **reflection (Fig. 1.7A)** in which the beam redirects itself off the tissue surface without any effect on the target tissue.

The second interaction is **absorption (Fig. 1.7B)** of the laser energy by the intended target tissue.

The third interaction is **transmission (Fig. 1.7C)** of the laser energy directly through the tissue, with no effect on the target tissue.

The fourth interaction is **scattering (Fig. 1.7D)** of the laser light, weakening the energy and possibly producing no useful biologic effect.

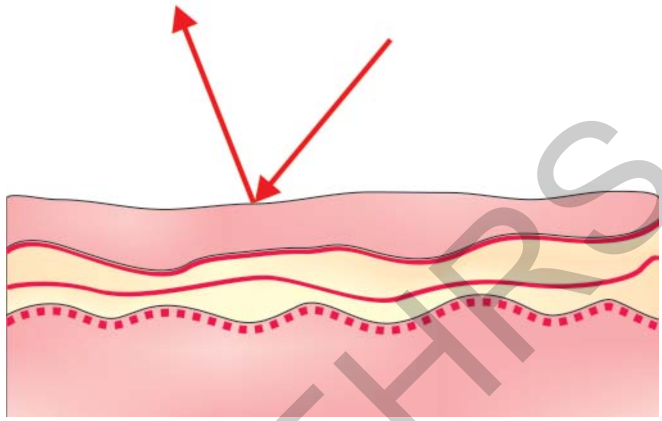


Fig. 1.7A: Reflection of laser by target tissue

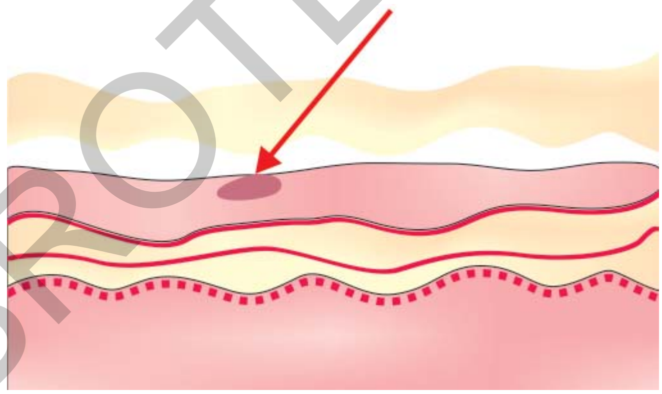


Fig. 1.7B: Absorption of laser by target tissue

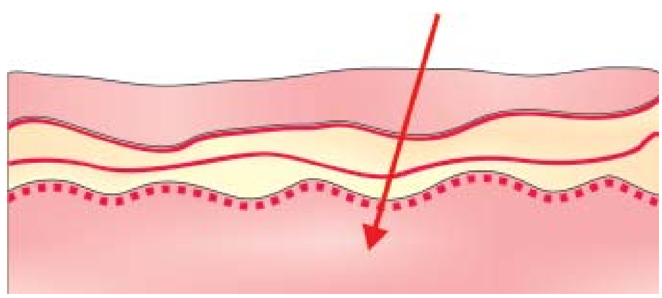


Fig. 1.7C: Transmission of laser by target tissue

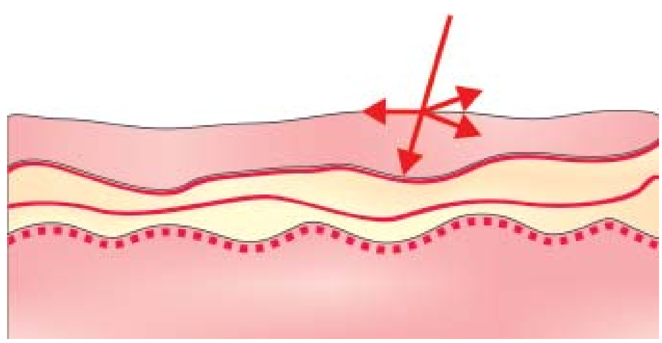


Fig. 1.7D: Scattering of laser by target tissue

The primary and beneficial effect of laser energy is absorption of the laser light by intended biological tissue. Dental laser surgery optimizes these photo-biologic effects. Incisions and excisions accompanying precision and hemostasis, is one of the advantages of lasers. Besides photo thermal effects, lasers also have photo-chemical and photo-acoustic effects.

Effects of Temperature on Target Tissue

The thermal effect of laser energy on soft tissue primarily revolves around the water content of the tissue and the temperature rise of the tissue **(Table 1.2)**.

Table 1.2

Tissue temperature [°C]	Observed effect
37-50	Hyperthermia
60	Coagulation, protein denaturation
70-90	Welding of tissue
110-150	Vaporization
>200	Carbonization

LASER MEDIA

Gas Lasers

Laser medium → Gas

Gases are contained within appropriate tubes, which are sealed either by special windows or by di-electric mirrors, e.g. HeNe laser, CO_2 laser, Excimer laser, Ion laser.

Dye Lasers

Laser medium → Liquid suspension

Liquid laser media are primarily dyes dissolved in alcoholic solutions. The most prominent and efficient dye is Rhodamine 6G.

Semi-conductor—Diode Lasers

Laser medium → Doped semiconductor crystal

It is based on uniting laser and host properties, thereby containing the highest density of energy state to be potentially inverted (allowing highest amplifications) **(Fig. 1.8)**.

Fig. 1.8: Diode machine

Solid-state Lasers

Laser medium → Doped crystals

They consist of a host medium with laser ions or molecules embedded in it. The medium chosen is a crystal because it may offer optimum heat transportation properties. The doping ions for solid state lasers are taken out of two groups in the periodic system: either rare earths (such as Nd^{3+}, Yr, Ho, Er) or transitional metals (such as Cr^{2+}, Cr^{3+}, Cr^{4+}, Ti^{3+}).

E.g.:- Nd:YAG (Neodymium: Yttrium, Aluminum Garnet), Er:YAG (Erbium: Yttrium, Aluminum Garnet), Er.Cr: YSGG (Erbium, Cromium: Yttrium Scandium Gadolinium Garnet), Ho: YAG (Holinium: Yttrium, Aluminum Garnet), KTP.

PUMPING METHODS AND SCHEMES

There are a wide range of options for pumping, in order to transfer energy into the laser medium.

The following processes may be employed:

- Optical pumping by strong lamps or lasers.
- Electric pumping by gas discharges.
- Chemical pumping by reactions yielding excited molecules.
- Impact pumping by inelastic collisions between partners.
- Electronic pumping by diffusion of carriers in semi-conductors.
- Pumping by acceleration of electrons (free electron laser).

Electronic pumping deals with the semiconductor laser. This is the best laser to date with respect to effectivity (>50%), cost and maintenance. It is the cheapest source of monochromatic light of substantial power and is excellent when used for optical pumping.

LASER CONCEPTS

The following are brief descriptions of the available laser devices that have dental applications. The laser is named according to its active medium, wavelength, delivery system, emission modes, tissue absorption and clinical applications.

Excimer Laser

Excimer laser is a special gas laser based on unstable molecules called Excimer (Excited Dimers). They exist only in the excited state for nanoseconds which is enough for long pulsed laser action.

The emitted beam has the shape of a window. This type of laser represents the most important source of short-wave length radiation.

Wave Lengths

F_2	158 nm
ArF	193 nm
KrF	249 nm
XeCl	308 nm
XeF	351 nm

Medium

Typically mixture of rare gas (e.g. Kr) 5-10%
Halogenide (e.g. F_2) 0.1-0.5%
Buffer gas (e.g. He/Ne)
Pumping → Plasma discharge
Operation mode → Pulsed

Dye Lasers

Wavelengths → 500-800 nm (Depending on dye suspension).
Medium → Liquid suspension of dye.
Pumping → Flash lamp (other laser sources).

Argon Ion Laser

Argon lasers have an active medium of Argon gas that is fiber optically delivered in continuous wave and gated pulse modes. The laser has two emission wavelengths and both are visible to the human eye: 488 nm blue in color and 514 mm blue green in color is very expensive to purchase and to maintain.

Uses

- Polymerization of resin in light cured composites materials.
- Hemostasis.
- Treatment of acute inflammatory periodontal disease.
- Aid in caries detection.

CO_2 Laser

The CO_2 laser is one of the oldest laser. It is a gas-active medium that must be delivered through a hollow tube-like wave-guide in continuous or gated pulse mode. It is well absorbed by water and has a shallow depth of penetration into tissue and effective in soft tissue excision. It is especially useful in cutting dense fibrous tissue.

The CO_2 laser cannot be delivered in an optic fiber. Instead, a hollow wave-guide with a hand piece is used. Large lesions can be treated easily using a simple back and forth motion. The loss of tactile sensation is a disadvantage for the surgeon.

Wavelength

9.6 µm IR
10.5 µm IR

Medium

mixture of CO_2, N_2, He ratio depending on the wavelength
typically CO_2: N_2: He = 0.8: 1:7
Pumping → Plasma discharge
Operation mode → Cw, pulsed.

Semi-conductor Lasers/Diode Lasers

It comprises of solid active medium that uses a combination of aluminum, gallium and arsenide to change electric energy into light energy.

The available wavelength for dental use range from about 800 to 980 nm **(Fig. 1.9A and B)**.

Delivers laser energy fiber optically in continuous wave and gated - pulsed mode.

Fig. 1.9A: Example of diode laser

Fig. 1.9B: Diode hand piece

Fig. 1.9C: Diode laser tip

Advantages of diode lasers are:

- Excellent hemostasis.
- Soft tissue surgery can be performed effectively, as it is poorly absorbed by tooth structure.
- Indicated for cutting and coagulating gingiva and mucosa and for soft tissue curettage or debridement.
- Flexibility of the delivery system to target issues.
- Laser units are portable, compact and are lowest priced laser currently available.

Wavelength

Variation from VIS down to IR is commonly between 860 to 980 nm for surgery.

Medium

In Ga As - Indium Gallium Arsenide typically for Infrared diodes.

Heterostructure set up (i.e. multiple buyers of different doped semiconductor crystals).

Pumping → Most commonly by injection of carriers.

Operation mode → CW, pulsed.

Solid State Laser

Nd:YAG, Ho: YAG, Er: YAG and Er, Cr: YSGG.

Nd:YAG

- The most important is the Neo-dymium laser based on the rare - earth ion Nd.
- This ion can be incorporated into different host materials, the most important ones being YAG (Yttrium, aluminum garnet) and several glasses.
- YAG offers favorable mechanical and thermo-optical properties allowing its use for CW and pulsed lasers, even at high power.
- Most commercial laser emit the wavelength 1064 nm corresponding to transition of energy levels.
- Excitation is achieved by optical pumping into broad energy bands followed by radiation.
- It consists of a hollow cavity with gold-coated internal surfaces revealing an elliptical cross section.
- In medicine, this laser has been used for long time, taking advantage of its greater depth of penetration into the tissue and dispersion in tissue as a result of scattering.

- Coagulation stops bleeding effectively and immediately after the incision.
- Another advantage, in comparison with the CO_2 laser, is the propagation through silica fibers allowing for endoscopic use or for fibers to be inserted in root canals, etc.

Erbium and Erbium-Chromium Lasers

- In crystalline Er-lasers, the host crystals are usually YAG (Yttrium Aluminum Garnet), YALO (Yttrium Aluminum Oxide), YSGG (Yttrium Scandium Gadolinium Garnet) or YLF (Yttrium Lanthanum Fluoride).
- Doping is relatively high, i.e. about 50% of the Y ions in YAG are replaced by Er ions.
- In medical applications and especially in dentistry, the Er lasers represent highly developed commercial lasers with very high yield and efficiency in tissue removal.
- It is the type of laser currently used for dental hard tissue ablation **(Fig. 1.10)**.

Wavelength

Nd: YAG	1.064 µm
Ho: YAG	2.14 µm
Er, Cr: YSGG	2.79 µm
Er YAG	2.94 µm

Fig. 1.10: Example of Er:YSGG unit

Host Crystals

YAG (Yttrium Aluminum Garnet)
YSGG (Yttrium Scandium Gadolinium Garnet)

Pumping → Optical by flash lamps or laser diodes.
Operation mode → Cw, pulsed

Fundamentals of LASER DENTISTRY

Salient Features

- A ready reckoner handbook
- Presents the basics of laser physics, laser safety and laser-tissue interaction
- Deals with all the clinical and relevant aspects, procedures and equipment of laser dentistry in an easy-to-follow pattern
- Includes colored clinical photographs, illustrations and diagrams for clear understanding of the concepts
- Presents a Chapter: Integrating Lasers into Your Practice: Practice Management, for the practical aspect of laser-assisted dentistry
- Serves as an indispensable guide for students and teachers of dentistry, practicing clinicians and dentists.

Kirpa Johar did his postgraduation in laser dentistry from Vienna University, Austria. He heads an exclusive private practice in Bengaluru, Karnataka, India, where he uses both hard and soft tissue lasers in his routine practice. He has seen his patients benefit tremendously from his laser-assisted treatment due to the noninvasive nature of treatment, faster recovery time and lesser postoperative discomfort. Being deeply committed to the spread of knowledge of laser dentistry, he recently established Laser Dentistry Research and Review to form a platform for the dental fraternity to access, exchange and learn the latest techniques and procedures in the field of laser dentistry.

JAYPEE BROTHERS
Medical Publishers (P) Ltd.
www.jaypeebrothers.com

ISBN 976-93-5025-377-9