In this paper the mechanism of stimulated emission is described as the fundamental of laser technology. The types of lasers from the aspect of their operation are also given. The particular attention is paid to dental lasers and their effect on healing processes in bone, dentin, enamel etc.

Keywords: lasers; dental lasers; bone regeneration; hard dental tissue; soft tissue

INTRODUCTION

Based on Albert Einstein’s theory of spontaneous and stimulated emission of radiation, Maiman developed the first laser prototype in 1960 [1]. His device used a crystal medium of ruby that emitted a coherent light when it was stimulated by energy. A bit later, in 1961, Snitzer published his paper with the prototype of the Nd:YAG laser [2]. The first application of laser on dental tissue was reported by Goldman et al. and Stern and Sognnaes [3, 4]. In their papers, the effects of the ruby laser on enamel and dentin were described. Further application of lasers in dentistry was studied in the paper published in 1985 by Myers and Myers, where *in vivo* removal of dental caries using a modified ophthalmic Nd:YAG laser was presented [5]. Several years later, it was recommended that Nd:YAG laser could be used for oral soft tissue surgery, due to its effect on healing of various dental diseases [6].

The purpose of this review was to analyze wide area of laser applications and principle of its specific functions, as well as application of lasers in treating common oral soft and hard tissue problems.

Basic laser theory

Laser is the acronym of the words “Light Amplification by Stimulated Emission of Radiation”. Lasers have come a long way since Albert Einstein described the theory of stimulated emission in 1917. Einstein in his theory of stimulated emission predicted that excited atoms could convert stored energy into light in the process by which an incoming photon of a specific frequency can interact with an excited atomic electron (or other excited molecular state), causing it to drop to a lower energy level. The generated energy transfers to electromagnetic field, creating a new photon. This process has two important characteristics. First, it is multiplicative, because one photon induces two photons. If these two photons interact with two other excited atoms, this will yield a total of four photons, and so forth (Figure 1). Second and most importantly, these two photons have identical properties: wavelength, direction, phase, and polarization. This ability to “amplify” light in the presence of a sufficient number of excited atoms leads to “optical gain” that is the basis of the laser operation [7].

Figure 1 shows three and four level lasers. In three level lasers, a burst of energy excites electrons in more than half of atoms from their ground state to a higher state, creating a population inversion. The electrons then drop into a long-lived state with slightly less energy, where they can be stimulated to quickly shed excess energy as a laser burst, returning electrons to a stable ground state. In four level lasers a sustained laser beam can be achieved by using atoms that have two relatively stable levels between their ground state and a higher-energy excited state. As in a three-level laser, atoms first drop to a long-lived metastable state where they can be stimulated to emit excess energy. However, instead of dropping to the ground state, they stop at another state above the ground state from which they can easily be excited back up to the higher metastable state, thereby maintaining the population inversion needed for continuous laser operation.

A wide range of solid, liquid and gas-phase materials have been discovered that exhibit gain under appropriate pumping. A laser generally contains laser resonator (or laser
ser cavity), in which laser radiation can circulate and pass a gain medium that compensates optical losses (Figure 3). Exceptions are a few cases where a medium with very high gain is used, so that amplified spontaneous emission extracts significant power in a single pass through the gain medium, such as excimer laser. Additionally, a laser resonator typically contains multiple laser mirrors, enabling multiple pass of generating photons, through its gain medium, and additional optical elements e.g. for wavelength tuning, Q switching mode, or locking. The laser mediums can be crystals, semiconductors, or gas enclosed in an appropriate confinement structure. It is placed along the optical axis of the resonator. This unique axis with very high optical gain becomes also the direction of propagation of the laser beam. A somewhat different example of a uniquely long (and flexible) gain axis is the fibre laser [8, 9].

Types of lasers

Lasers, from the aspect of its way of operation can be divided in three basic categories: continuous wave (CW), pulsed and ultrafast.

Continuous lasers

Continuous wave lasers produce a continuous, uninterrupted beam of light, with high stable output power. The exact wavelength of laser beam is determined by the characteristics of the laser medium. For example, CO₂ molecules readily excite at 10.6 µm, while neodymium-based crystals (like YAG or vanadate) produce wavelengths in the range between 1047 and 1064 nm. Additionally, each laser wavelength is followed by corresponding line-width, which depends mainly on the gain bandwidth of the lasing medium, filters and design of optical resonator. The specific wavelengths of the output beam within this gain bandwidth are determined by the longitudinal modes of the cavity. A laser that produces multiple longitudinal modes has a
limited coherence, because different wavelengths cannot stay in phase over extended distances [10].

For some laser types with a narrow gain bandwidth, single-mode output is achieved with a very short resonant cavity. Generally, filtering elements are used to provide a preferential pass for only one mode generated into the cavity. The most common type of filter is called an etalon. Using various sophisticated design enhancements, it is possible to restrict the line-width of a laser to less than 1 kHz, useful for scientific applications. Some solid-state lasers have extremely broad bandwidths (order of hundreds of nanometers). This broad bandwidth enables the design of tunable and ultrafast (femtosecond and picosecond pulse width) lasers. Most applications of CW lasers require its stable power over long time (hours or weeks), as well as over short time durations (microseconds), depending on the specific application. To ensure this stability appropriate control of temperature and vibration, the aging of the laser itself and microprocessor control loops are very important factors [10, 11].

Pulsed lasers

Pulsed lasers are defined as laser devices that produce pulses of 0.5 to 500 ns (Figure 4). Some excited dimers (or “excimers”) of a noble gas with halogen, such as ArF and XeCl, show quick laser action for only a several nanoseconds. Other lasers, like Nd or Yb diode-pumped solid-state (DPSS) lasers, also can operate both in CW or pulsed regime, while laser diodes, are not suitable at all for pulsed operations. The most important characteristic of a nanosecond-pulsed laser is the capability to “store” and release energy very rapidly; i.e., on a nanosecond scale so that the laser output can achieve tens of kilowatts to megawatts of peak power. This high-energy peak enables ablation of processing materials. Nanosecond-pulsed laser is substantially different from CW laser. The key to producing these energetic pulses is storing energy from the pump in atoms or molecules of the lasing medium by preventing the laser gain and the amplification process. Then, when the stored energy is at its maximum, lasing action is rapidly enabled [12].

The stored energy induces in extremely high laser amplification during only a few round trips, when giant pulse builds up. This regime is called Q-switched operation and can be presented as a two-mirror cavity with an optical gate located between one of the mirrors and laser medium. When the gate is closed and the laser medium is pumped, photons cannot circulate in the cavity, and the excitation of the atoms builds up, while when the gate is opened, photons start to build up via stimulated emission with a very large gain at each round trip. Typical pulse duration is 1 to 200 ns. It depends on the type of gain medium and how much energy it can store, the cavity length, the repetition rate of the pulses and the pump energy [13]. Excimer lasers do not require a Q-switch to produce nanosecond pulses, which are produced by exciting the noble gas-halogen mixture with powerful and short electric discharge.

Ultrafast lasers

Ultrafast lasers are lasers that produce pulses in the range of 5 fs to 100 ps (1 femtosecond = 10^-15 seconds). Such short pulses can be produced with so-called mode-locking technique. With this technique, the modes are locked in phase (mode-locking regime) and their coherent interference causes the intra-cavity optical field to collapse into a single pulse traveling back and forth in the laser cavity. Generally, it is shown that as more as interfering modes, the pulse duration is shorter. Since larger lasing bandwidths support a larger number of oscillating modes, the pulse duration is inversely proportional to the bandwidth of the laser gain material. Ultrafast pulses are highly useful in research, due to short pulse duration and high peak power [14]. Recently developed femtosecond lasers enabled ground breaking research leading to Nobel prizes for femto-chemistry. Femtosecond lasers enabled multiphoton excitation (MPE) techniques that deliver three-dimensional imaging of live tissue. MPE is now widely used in several areas of biological research, presumably in neuroscience. In the case of femtosecond lasers, the high peak power of the amplified pulses can damage the laser optics. For this reason, the amplification is usually preceded by stretching the pulse (chirping) from 50 to 200 ps. The amplified pulse is then re-compressed to the fs domain. This is commonly referred to as chirped pulse amplification, or CPA (Figure 5).

In scientific research, amplified ultrafast pulses are used in photochemistry, pump-probe spectroscopy, terahertz (THz) generation and creating accelerated electrons and other small charged particles. The pulses can also drive nonlinear generation of extreme-UV light with pulse widths of tens of attoseconds [14, 15]. Ultrafast lasers are mainly based on titanium:sapphire (Ti:sapphire) because of its large bandwidth and broad tuning range, enabling them delivering pulses as short as 6 fs. Ti:sapphire lasers are typically pumped using a green-wavelength CW pump laser. Typical repetition rates of Ti:sapphire oscillators are 50 to 100 MHz, and peak powers several hundred kilowatts. The most common CPA systems based on Ti:sapphire operate at 1 to 10 kHz with the amplifier stages energized by nanosecond green lasers. It has ability to produce pulse

Figure 4. The pulses of a pulsed laser are temporally separated by the inverse of the repetition rate.

Slika 4. Pulsevi kod pulsog lasera su privremenoprazdvojeni inkverzijom ponavljajuće frekvence.
energies of several millijoules with pulse widths as short as 20 fs. These systems can produce power of petawatt range [16]. Most of these systems recently are based on Nd-doped bulk materials (e.g., YAG or glass) or fiber, or a combination of the two, although smaller gain bandwidth of Nd limited the ps regime [17].

Yb-doped materials combine to some extent the advantages of Ti:sapphire scientific lasers and Nd-based industrial lasers. For scientific research, the gain bandwidth of Yb means oscillator pulses can be as short as 50 fs, which is more than adequate for many applications, particularly in MPE microscopy [18]. As for the scientific applications extremely short (>6 fs) pulse widths and/or high pulse energies are needed, Ti:sapphire remains the preferred gain material for such purposes. Femtosecond laser pulses have two advantages over picosecond pulses for materials processing. First, the material interaction involves many simultaneous photons and becomes reasonably wavelength insensitive, unlike with nanosecond linear absorption. Second, the short pulses and nonlinear interaction influence that fs pulses can deliver even better edge quality and precision than ps pulses.

Typical laser properties

The photons inside the laser beam are all in phase, or “coherent,” causing propagation of electric field with a uniform wave front. Because a laser beam is highly directional, its brightness is much more intense than other light sources. An ideal laser should emit all photons with exactly the same energy and wavelength, and it would be perfectly monochromatic, but due to several broadening mechanisms as it is Doppler broadening frequently, frequency is often widened. Consequently, YAG lasers can have line widths of hundreds of gigahertz, while stabilized diode-pumped YAG lasers can have a line width <1 kHz [19].

Today, lasers enable for the first time DNA sequencing, and freezing the motion of electrons around atoms as it can generate very short pulses (below $10^{-16}$ s), and measurements of the absolute frequencies with an accuracy of $~10^{-15}$. The input energy can take many forms. Among them, two most frequent are optical and electrical. For optical pumping, lamp or another laser as energy source are used, while for electrical pumping DC current (as in laser diodes) electrical discharge (noble gas lasers and excimer lasers), or a radio-frequency discharge (some CO₂ lasers) are used [20].

There are several kinds of lasers used in dental practice, which are divided according to active medium that is stimulated. This medium can be gas (e.g. argon, carbon dioxide), liquid (dyes) or solid state crystal rod as in the case of the neodymium yttrium aluminum garnet (Nd:YAG), erbium yttrium aluminum garnet (Er:YAG) or a semi conductors (diode lasers). As it was explained above the active mediums contain atoms which electrons can be excited to a metastable energy level by an energy source: optical (e.g. xenon flash lamps, other lasers), electrical (e.g. gas discharge tubes, electric current in semi-conductors) or chemical method. Due to the high level of coherency of monochromatic laser beam, its energy can be delivered on to target tissue as a continuous wave, gated-pulse mode (laser is periodically in an on and off mode) or free running pulse mode (energy is emitted for an extremely short span, in microseconds followed by a relatively long time which the laser is off). Fibre optics for visible and near infrared lasers is used for more efficient transfer energy to the corresponding tissue, while the articulated arms, with mirrors at joints, was used for UV, visible and infrared lasers, and hollow waveguides (flexible tube with reflecting internal surfaces), for middle and far infrared lasers [21].

Recently, fibre optic delivery systems are mostly used, as they can deliver laser energy to most parts of the oral cavity, even within the complex root canal system. This system can deliver energy in forward direction, with minimal dissipation from the bare end of a plain tip. Therefore, it is applied in cases of cavity preparation or soft tissue surgery. In some cases, this drawback related to the energy dissipation may cause some difficulties in lateral transfer.
energy, limiting its use for applications in root canal treatment. Recently, a number of fibre optic modifications are suggested to overcome this limitation. Other factors that influence the laser choice for dental hard and soft tissue are absorption of laser beam by chromophores (water, apatite minerals, and various pigmented substances) inside of the target tissue because better absorption allows more efficient photo-thermal sterilization, ablation of dentin, etc. Besides, rapid heating of water molecules within enamel can cause rapid vaporization of water and build-up of steam that induce huge expansion of dental structures, leading to material breaks by exploding, through this process of ablation. In the case of high-powered lasers, tissue vaporization or coagulation through absorption in a major tissue component is known as photo-thermal ablation. Photomechanical ablation includes tissue disruption due to shock wave formation, cavitation, etc. The photochemical effects are induced by light-sensitive substances, and today are used for its antibacterial effect and in cancer treatment. The typical variables in laser application are wavelength, pulse energy or power output, exposure time, spot size (and thus energy density), and the tissue physical and chemical composition (e.g. water content, density, thermal conductivity and thermal relaxation) [22].

Lasers are grouped into seven classes depending on the potential for the beam to cause harm. The hazard and classification depend on the wavelength, power, energy and pulse characteristics. These groups are: class 1 and 1M (inherently safe); class 2 and 2M (where the eye is protected by the blink reflex); class 3R and 2B (where direct viewing is hazardous); and class 4 (where the laser power is above 0.5 Watts, and the laser is classed as extremely hazardous) [23].

Dental lasers

Most dental and medical lasers belong to class IV, and thus, compliance with safety standards is necessary to protect the dentist, patient and supporting staff. Lasers used in dentistry vary from ultraviolet light (100-400 nm), to infrared spectrum (750 nm-1 mm). The visible spectrum lies between these two wavelengths (400-750 nm). Lasers used in dentistry cover a broad range of procedures, from diagnosis of caries or cancer to soft tissue and hard tissue procedure.

The first application of laser on dental tissue was reported by Goldman et al. and Stern and Sognnaes, when the effects of the ruby laser on enamel and dentin were described [3, 4]. Many studies were done after 1985, after publishing the paper by Myers that described in vivo removal of dental caries using modified ophthalmic Nd:YAG laser (Figure 6) [5]. Four years later, Nd:YAG laser (neodymium doped yttrium aluminum garnet) was used for oral soft tissue surgery, and that introduced the use of these lasers in clinical periodontics [24]. Lasers commonly used in dentistry consist of a variety of wavelengths delivered as either a continuous, pulsed (gated), or running pulse waveform, e.g., CO₂, Nd:YAG, Ho:YAG, Er:YAG, Er, Cr:YSGG, Nd:YAP, GaAs, diode laser and argon laser (Figure 7). Lasers with shorter wavelengths and pulse widths combined with higher-power densities are not currently relevant to dental applications [25].
In biologic tissues, the laser energy is absorbed by surface tissues and will only exhibit scattered penetration in deep tissues. Absorbed light energy is converted to heat and cause various photo thermal events like warming, coagulation, or excision and incision through tissue vaporization. The energy absorption depends on various parameters like emission wavelength, power (watts), waveform (continuous or pulsed), pulse duration, energy/pulse, energy density, duration of exposure, peak power of pulse, angulation of the energy delivery tip to the target surface, and optical properties of the tissue (Figure 8) [26].

Optical properties of a tissue influence the interaction with specific laser wavelengths. In the case of periodontium, optical properties of tissues depend on its pigmentation, water content, mineral content, heat capacity that accounts for both thermal conductivity and tissue density, and latent heat transformation (i.e., denaturation of proteins, vaporization of water, and melting of mineral). Taking into account that bone is the classic composite tissue, consisting of 67% inorganic minerals (hydroxyapatite) and 33% collagen and non-collagenous proteins, or gingiva which is constituted from various densities of fibrous connective tissue, associated extracellular matrix components, and a high content of water (70%), their optical properties are also determined by its specific composition. Additionally, gingiva frequently exhibits melanin pigmentation. Other factors that are included in laser-tissue interactions are processes of heat conduction and dissipation, the degree of tissue inflammation and vascularity, and availability of progenitor cells to participate in the healing process. Each wavelength of laser energy is absorbed to a greater or lesser degree in their components, like water, pigment, or hydroxyapatite [27].

Knowing that CO₂ laser (10600 nm wavelength) has a high absorption coefficient in water, it is suitable for soft tissue surgery but recently it has no scientifically well-supported clinical application to mineralized tissues. Nd:YAG (1064 nm wavelength) and diode lasers (800 to 950 nm wavelength) have lower absorption coefficients in water than CO₂ lasers, but they are preferentially absorbed in pigmented tissues, while the Er, YAG and Er:YAG wavelengths (2780 and 2940 nm, respectively) are highly absorbed in both water and hydroxyapatite [28]. Therefore, the clinicians should, in each case, determine the specific clinical treatment aims and then select the adequate technology (laser or otherwise) to achieve the desired endpoint(s).

For many intraoral soft tissue surgical procedures, the laser is suitable alternative to scalpel. The CO₂, Nd:YAG, and diode lasers are primarily used for intraoral soft tissue procedures, such as frenectomy, gingivectomy and gingivoplasty, epithelization of reflected periodontal flaps, removal of granulation tissue, second stage exposure of dental implants, lesion ablation, incisional and excisional biopsies of both benign and malignant lesions, irradiation of aphthous ulcers, coagulation of free gingival graft donor sites, and gingival depigmentation. Besides, there are evidences of faster healing after using laser on soft tissue wounds that are wavelength specific and highly sensitive to energy density. Most studies used CO₂, Nd:YAG, or diode lasers. A comparison of wound healing induced by Nd:YAG and CO₂ lasers indicates that CO₂ laser used in oral, oropharyngeal and laryngeal mucosa caused significantly faster healing than Nd:YAG laser, but conventional scalpel-induced wound healed faster then after laser use. Wound healing was comparable between scalpel and Nd:YAG laser when laser was used at lower power of 1.75 W and 20 Hz. However, investigations based on tissue histology showed that high power (watts), long pulse duration, high repetition rates (hertz), and long interaction times (duration of target exposure) all increased the risk of negative outcomes. Comparison of laser and scalpel surgery was broadly investigated in numerous medical and veterinary journals. From the aspect of laser wavelengths and various tissue parameters like incision time, blood loss, swelling and oedema, pain, and general wound healing, great diversity of data has been reported. However, in most papers laser technology showed numerous advantages, like higher level of clinician control, operating efficiency, tip flexibility and accessory selection [27, 28].

Effect of lasers on bone healing

Laser-biologic tissue interactions are wavelength dependent photo-thermal events, as most of dental laser effects on bone are potentially damaging. It seems that only wavelengths of Er:YAG and Er,Cr:YSGG lasers are suitable for such application. It has been shown that bone surface exposed to the same total laser energy showed temperature increase for CO₂ from 1.4°C to 2.1°C and for Nd:YAG laser, it was 8.0°C to 11.1°C [29, 30]. These results indicate that for ablation relatively thin soft tissues supported by adjacent bone is needed (e.g. mandibular facial, gingival and alveolar mucosa). If the Nd:YAG laser is used it should have relatively low energy densities emitted in short time intervals to prevent risk of irreversible bone damage. It was found that Er:YAG laser, when used at a peak pulse energy of 100 mj/pulse and 10 Hz, produced well-defined intrabony cuts with no evidence of melting or carbonization [29–32]. Figure 9 shows that laser-treated group exhibited earlier new bone formation compared to non treated group [33].

**Figure 9.** Representative radiological images of tibia bone after artificial fracture

**Slika 9.** Reprezentativni rendgen snimci tibije nakon preloma.
Fourier transform infrared spectroscopy (FTIR), energy dispersive x-ray spectroscopy (EDX), and x-ray diffraction analysis revealed normal collagen/hydroxyapatite relationship with thin surface layer characterized by slight increase in calcium/phosphate ratio due to formation of tetracalcium phosphate, which was similar chemical composition formed after the use of rotary bur method. On the other hand CO2 laser–induced osteotomies exhibited extensive carbonization, melting of mineral phase, and delayed healing [29]. Also, some recent studies suggested that Er, Cr:YSGG wavelength is suitable for use on bone, as EDX analysis showed no change in calcium/phosphate ratio, and there was no evidence of charring or melting. Surface modification of cement and dentin exposed to variety of laser wavelengths, primarily CO2, Nd:YAG, and Er:YAG lasers showed that they can be efficiently used for removing calculus, if wavelength characterized by minimal penetration depth in mineralized tissue was selected. This is important to suppress both thermal damage to the pulp tissue and undesired removal of sound root structure. The mineral phase of both cement and dentin is carbonated hydroxyapatite that has intense absorption bands in the mid-infrared region [27–32]. Consequently, of all lasers studied, the Er:YAG laser would appear to be the laser of choice for effective removal of calculus, root etching, and creation of a biocompatible surface for cells and tissue reattachment. Contrary, if CO2 laser it used, even at the low energy, FTIR analysis showed presence of toxic chemical residues of cyanamide and cyanate, followed by lack of flap reattachment to the surface of treated root area. Therefore, CO2 lasers have restricted application in subgingival periodontal therapy.

The use of dental laser in the treatment of chronic periodontitis is based on regeneration of mucogingival attachment, cement, periodontal ligament, and supporting alveolar bone, and significant decrease in sub-gingival pathogenic bacteria. There is limited evidence suggesting that lasers cause greater reductions in subgingival bacteria than that achieved by traditional treatment. Most laser bactericidal studies report a dose/response relationship. However, in many studies, energy densities are often not reported or cannot be calculated due to incomplete listing of parameters. Finally, the angle of irradiation can vary from 0 to 90°, making computation of energy densities nearly impossible [38–41].

One of the first in vivo studies reporting reductions in pathogenic bacteria following irradiation with Nd:YAG laser showed decrease in Porphyromonas gingivalis (Pg), Prevotella intermedia (Pi) and Actinobacillus actinomycetemcomitans (Aa) [38]. However, teeth extracted 7-days post-treatment exhibited recolonization of laser-irradiated subgingival root surfaces by multiple morphotypes of bacteria. In vitro studies using Nd:YAG laser at low power settings have reported...
calcium ablation without detrimental effects to underlying cement or dentin. A linear relationship between energy level, microbial numbers, and concentration of hemoglobin (blood) has been found as well as minimal energy required for bacterial effect, different susceptibility of various microbes to laser energy, different susceptibility to damage of calculus, cement, and dentin, even within the same specimen. It also showed variability in color, thickness, composition, texture, and water content [38–41]. The diode laser (805 nm), when used adjunctively with traditional scaling and root planning method (SRP), have shown an additive effect in reducing subgingival bacterial populations in periodontal pockets of 4 mm depth. However, many in vivo studies showed the persistence of viable bacteria following subgingival laser irradiation [38, 40, 41].

CONCLUSIONS

In this paper irradiation of biologic tissues by a specific wavelength of laser was studied. Based on this review, interaction of dental tissue with laser depends on the type, energy and wavelength of lasers used. This knowledge should be implemented for the right choice of laser parameters, without destruction of treated soft and hard dental tissues. Beside specific laser applications, our review described basic elements of stimulated emission; principles of laser function, main types of laser instrumentation, advantages and disadvantages of certain types of laser applications.

REFERENCES

1. Maiman TH. Stimulated optical radiation in Ruby. Nature. 1960;187:493–4. [DOI: 10.1038/187493a0]
2. Snitzer E. Optical maser action of Nd+3 in a barium crown glass. Phys Rev Lett. 1961;7:444–6. [DOI: 10.1103/PhysRevLett.7.444]
3. Goldman L, Hornby P, Meyer R, Goldman B. Impact of the laser on dental caries. Nature. 1964;203:417. [DOI: 10.1038/203417a0]
4. Stern RH, Sognnaes RF. Laser inhibition of dental caries suggested by first tests in vivo. J Am Dent Assoc. 1967;72(5):1087–90. [DOI: 10.14179/jada.archive.1967-0941] [PMID: 4502781]
5. Myers TD, Myers WD. In vivo caries removal utilizing the YAG laser. J Mich Dent Assoc. 1985;67(2):266–9. [PMID: 3858548]
6. Midda M, Renton-Harper P. Lasers in dentistry. Br Dent J. 1991;170:343–6. [DOI: 10.1036/sj.bdj.407548]
7. Hooker S, Webb CE. Laser physics. Oxford University Press, 2010.
8. Najeef S, Khurshid Z, Zafar MS, Ajlal S. Applications of Light Amplification by Stimulated Emission of Radiation (Lasers) for Restorative Dentistry. Med Princ Pract. 2016;25(3):201–11. [DOI: 10.1159/000431441] [PMID: 26642047]
9. Honkala E. Primary Oral Health Care. Med Princ Pract. 2014;23:17–23. [DOI: 10.1159/000357916]
10. Shahbazi AH, Koohian A, Madanipour K, Azadeh M. Theoretical and experimental investigation of continuous-wave laser scribing on metal thin film: effect of power. Appl Opt. 2018;57(34):9988–96. [DOI: 10.1364/AO.57.009988] [PMID: 30645260]
11. Bourdet GL. Theoretical investigation of quasi-three-level longitudinal- finally pumped continuous wave lasers. Appl Opt. 2000;39(6):966–71. [DOI: 10.1364/ao.39.00966] [PMID: 18337973]
12. Franz LM, Novak J. Theory of pulse propagation in a laser amplifier. J Appl Phys. 1963;34:2346–9. [DOI: 10.1063/1.1702744]
13. Degnan J. Theory of the Optimally Coupled Q-Switched Laser. IEEE J Quantum Electron. 1989;25:214–20. [DOI: 10.1109/3.16265]
33. Son J, Kim YB, Ge Z, Choi SH, Kim G. Bone healing effects of diode laser (808 nm) on a rat tibial fracture model. In Vivo. 2012;26(4):703–9. [PMID: 22773585]

34. Spencer P, Cobb CM, McCollum MH, Wieliczka DM. The effects of CO2 laser and Nd:YAG with and without water/air surface cooling on tooth root structure: Correlation between FTIR spectroscopy and histology. J Periodontal Res. 1996;31(7):453–62. [DOI: 10.1111/j.1600-0765.1996.tb01409.x] [PMID: 8915947]

35. Feist IS, Micheli G, De Carneiro SRS, Eduardo CP, Miyagi SPH, Marques MM. Adhesion and Growth of Cultured Human Gingival Fibroblasts on Periodontally Involved Root Surfaces Treated by Er:YAG Laser J Periodontol. 2003;74(9):1368–75. [DOI: 10.1902/jop.2003.74.9.1368] [PMID: 14584872]

36. Schwarz F, Sculean A, Berakdar M, Szathmary L, Georg T, Becker J. [In vivo and in vitro effects of an Er:YAG laser, a GaAlAs diode laser, and scaling and root planing on periodontally diseased root surfaces: A comparative histologic study. Lasers Surg Med. 2003;32(5):359–66. [DOI: 10.1002/lsm.10179] [PMID: 12769658]

37. Coluzzi DJ, Goldstein AJ. Lasers in dentistry. An overview. Dent Today. 2004;23(4):120–2, 124–7. [PMID: 15112528]

38. Gutknecht N, Lampert F, Raoufi P, Franzen R. Reduction of specific microorganisms in periodontal pockets with the aid of an Nd:YAG laser - an in vitro study. J Oral Laser Appl. 2002;2:175–80. [DOI: 10.1111/j.1600-051x.1995.tb01773.x] [PMID: 7706542]

39. Radvar M, Creanor SL, Gilmour WH, Payne AP, McGadey J, Foye RH et al. An evaluation of the effects of an Nd:YAG laser on subgingival calculus, dentine and cementum. An in vitro study. J Clin Periodontol. 1995;22(1):71–7. [DOI: 10.1111/j.1600-051x.1995.tb01773.x] [PMID: 7706542]

40. Meral G, Taras F, Kocagöz S, Sener C. Factors affecting the antibacterial effects of Nd:YAG laser in vivo. Lasers Surg Med. 2003;32(3):197–202. [DOI: 10.1002/lsm.10128] [PMID: 12605426]

41. Harris DM, Yessik M. Therapeutic ratio quantifies laser antisepsis: Ablation of Porphyromonas gingivalis with dental lasers. Lasers Surg Med. 2004;35(3):206–13. [DOI: 10.1002/lsm.20086] [PMID: 15389740]
Primena lasera u stomatologiji – pregled literature

Vukoman Jokanović1,2, Dijana Trišić3, Marija Živković3
1ALBOS Ltd, Beograd, Srbija;
2Institut za nuklearne nauke Vinča, Beograd, Srbija;
3Univerzitet u Beogradu, Stomatološki fakultet, Klinika za ortopediju vilica, Beograd, Srbija

KRATAK SADRŽAJ
U ovom radu opisan je mehanizam stimulisane emisije, kao osnova tehnologije rada lasera. Navedeni su i tipovi lasera sa aspekta njihove primene. Posebna pažnja je posvećena laserima u stomatologiji, kao i uticaju njihovih karakteristika na mogućnost regeneracije kosti, dentina i drugih oralnih tkiva.

Ključne reči: laseri; laseri u stomatologiji; regeneracija kosti; čvsto zubno tkivo; meko tkivo

UVOD
Na osnovu teorije o spontanoj i stimulisanoj emisiji zračenja Alberta Ajnštajna, Majman je napravio prvi prototip lasera 1960. godine [1]. Njegov uredaj je koristio kristalni medijum rubina, koji je emitovao koherentno svetlo kada je bilo stimulisano energijom. Nešto kasnije, 1961. godine, Snicer je objavio rad koji je opisivao prototip lasera Nd:YAG [2]. Prva primena lasera na oralnim tkivima opisana je od strane Goldmana i sar., kao i Sterna i Sognesa [3, 4]. Opisana je primena rubinskog lasera u nagrizanju gledi i dentina. Dalja primena lasera u stomatologiji zabeležena je u radu publikованом 1985. od strane Majersa i Majersa, u kome je prikazano in vivo uklanjanje zubnog karijesa korišćenjem modifikovanog oftalmološkog laserskog laserNd:YAG [5]. Nekoliko godina kasnije preporučena je upotreba laser Nd:YAG u mekotkivnoj hirurziji za lečenje mnogobrojnih oralnih bolova [6].

Cilj ovog preglednog rada je analiza veoma širokog polja istraživanja sa aspekta rada lasera. Navedeni su i tipovi lasera sa aspekta njihove primene. Posebna pažnja je posvećena laserima u stomatologiji, kao i uticaju njihovih karakteristika na mogućnost regeneracije kosti, dentina i drugih oralnih tkiva.

Osnovna teorija lasera
Laser je akronim nastao od engleskih reči za amplifikaciju svetla stimulisano emisijom zračenja (eng. Light Amplification by Stimulated Emission of Radiation). Laseri su u svom razvoju prošli veliki put od kad je Albert Ajnštajn opisao teoriju stimulisane emisije 1917. godine. Ajnštajn je u svojoj teoriji predvidio da pobuđeni atomi mogu pretvoriti stimulisano energiju u jednu relativno stabilan stanje stvarajući laserski zrak.

Primena lasera u stomatologiji
Stomatološki glasnik Srbije. 2020;67(1):36-49

45
dužina laserskog snopa je određena karakteristikama laserskog medijuma. Na primjer, CO₂ molekuli ekscituju zrak na 10,6 µm, dok kristali zasnovani na neodimijumskim kristalima (kao što je YAG ili vanadati) produkuju zrak talasnih dužina između 1047 i 1064 nm. Dodatno, svaka talasna dužina praćena je odgovarajućim promerom, koji uglavnom zavisi od protoka kroz medijum, filtera i dizajnog optičkog rezonatora. Specifična talasna dužina izlaznog zraka u okviru datog frekventnog opsega određena je longitudinalnim modovima kutije. Laseri koji produkuju višestruke longitudinalne modove imaju ograničenu koherentnost, jer različite talasne dužine ne mogu ostati u fazi tokom velikih rastojanja [10].

Za neke tipove lasera sa uznanim poljem frekventnog opsega, pojedinačni izlazni mod je postignut uz veoma kratku rezonantnu kutiju. Uopšteno, filtrirajući elementi se koriste kako bi se omogućilo pronaći samo željenog modu iz kutije. Najčešći tip filtera naziva se etalon. Koristeći različite sofisticirane dizajne pojačavača, moguće je ograničiti promjer snopa lasersa na manje od 1 kHz, što je korisno za naučnu primenu. Pojedini laseri sa medijumom u čvrstom stanju imaju izravno slike osvjetljenja (izražene u stotinama nanometara).

Široka polja frekventnog opsega omogućavaju dizajn izravno slike brašnih pulsnih lasersa (pauze između pulsa izražene su u femtosekundama i pikosekundama). Primena kontinuiranih lasersa zahteva stabilnu snagu tokom dužeg perioda vremena (sati ili naredne sate), kao i tokom kraćih perioda (mikrosekunde), zavisno od primene. Kako bi se osiguralo adekvatna kontrola temperature i vibracija, vreme starenja samog lasersa i mikroprocesora su najpoželjniji laserski medij/material u ovoj oblasti istraživanja.

Pulsn mod lasersa

Pulsni lasersi su definisani kao uređaji koji produkuju pulse se između 0,5 do 500 ns (Slika 4). Pojedini ekscitovani dimeri (ekscimeri) plemenitih gasova sa halogenom, kao što su ArF i XeCl, omogućuju veoma brzo dejstvo lasersa, koji odgovara frekventnom opsegu između 0,5 do 500 ns (Slika 4). Primena laserskih vibracija, kohezija, vreme starenja samog lasersa i mikroprocesora su najpoželjniji laserski medij/material u ovoj oblasti istraživanja.

Upravljani lasersi

Upravljani lasersi omogućuju kontinuiran učestan proizvodnji prema frekventnom opsegu lasersa. Neke vrste lasersa korisne u industriji (uključujući lasersa YAG i Nd:YAG) omogućuju prenosa energije, a neke su specifične za istraživanja u fiziologiji i neurofarmaci.

Femtosekundni lasersi

Femtosekundi laseri omogućuju tehnike multifotonske ekscitacije, koje dalje daju trodimenzionalne slike živih tkiva. Tehnika multifotonske ekscitacije je danas široko primenjena u nekoliko oblasti bioloških istraživanja, posebno u neuronauci. U istraživanjima laserskih pulasnih lasersa, visoko energije, može se proizvesti polukratak impuls zraka sa dužinom talasnog zraka između 0,5 do 500 ns (Slika 4). Primena laserskih vibracija, kohezija, vreme starenja samog lasersa i mikroprocesora su najpoželjniji laserski medij/material u ovoj oblasti istraživanja.

Ultrabrzi lasersi

Ultrabrzi lasersi produkovaju energiju na nanosekundnim dužinama i postizaju visokih snaga [14]. Najčešći lasersi sa frekventnim opsegom u nanosekundnom režimu (CPA) (Slika 5).

U istraživanjima laserskih elektroda visokih energija, može se postići polukratak impuls zraka sa dužinom talasnog zraka između 0,5 do 500 ns (Slika 4). Primena laserskih vibracija, kohezija, vreme starenja samog lasersa i mikroprocesora su najpoželjniji laserski medij/material u ovoj oblasti istraživanja.

Femtosekundi laseri

Femtosekundi laseri omogućuju tehnike multifotonske ekscitacije, koje dalje daju trodimenzionalne slike živih tkiva. Tehnika multifotonske ekscitacije je danas široko primenjena u nekoliko oblasti bioloških istraživanja, posebno u neuronauci. U istraživanjima laserskih pulasnih lasersa, visoko energije, može se proizvesti polukratak impuls zraka sa dužinom talasnog zraka između 0,5 do 500 ns (Slika 4). Primena laserskih vibracija, kohezija, vreme starenja samog lasersa i mikroprocesora su najpoželjniji laserski medij/material u ovoj oblasti istraživanja.
Femtosekundne pulsnje lasere karakterišu dve prednosti u odnosu na pikosekundne lasere za obradu materijala. Prvo, interakcija materijala podrazumjeva mnoge simultane fotone, te materijal postaje neosjetljiv na talasnu dužinu, za razliku od nanosekundne linearnih apsorpcije. Drugo, kratki pulsevi i nelinearna interakcija utiču da is puls ledsevi mogu biti kvalitativniji i precizniji od ps pulseva.

Osnovne karakteristike lasera

Fotoni u laserskom svetu su svi u fazi, odnosno koherentni, prouzrokujući prolaz električnog polja sa uniformnim talasnim frontom. Usled velike usmerenosti laserskog zraka, jačina svetla je značajno intenzivnija u odnosu na druge izvore svetlosti. Ide- alni laser trebalo bi da emituje sve fotone potpuno iste energije i talasne dužine, koji bi bili savršeno monohromatski, ali usled nekoliko mehanizama širenja, što je kao Dopler efekat, frekvenca je proširena. Posledično, činjenice o drugim, laserskih YAG, Er:YAG, Er, Cr:YSGG, Nd:YAP, GaAs, diodni laseri i ostali faktori koji utiču na odabir lasera za rad.

Danas, laserski prvi put omogućavaju sekvenciranje DNK molekula, „zamrzavanje“ elektrona u pokretu oko atoma usled izaziva različite fototermalne efekte. Od strane tkivnih hromofora (voda, apatit, pigmenti) u ciljanom tkivu, jer je bolja apsorpcija praćena efikasnijom fototermalnom sterilizacijom, ablacijom dentina, i ostalim dejstvima. Pored toga, brzo zagrevanje molekula vode u gledi može uzrokovati vapo- rizaciju vode i stvaranja pare, što izaziva brzo širenje dentalnih tkiva, te vodi do minijesplozija u tkivu kroz process ablaacije. U slučaju lasera velike snage, vaporizacija ili koagulacija tkiva kroz apsorpciju energije u tkivnim komponentama naziva se i fototoranalna ablacija. Fotomehanička ablacija podrazumeva ukanjanje tkiva posredstvom stvaranja šok talasa, kavitacije. Fotomehaničko dejstvo nezapravo stvaranje svetlosti za razliku od infracrvenog zraka dolazi do ožiljavanja. Apsorbovana energija se prevodi u toplo, i danas se primjenjuje u antibakterijskom dejstvu i lečenju kancera. Indikacije za primenu lasera najčešće zavise od talasne dužine, pulsnje energija i izaziva oštećenje, vremena izlaganja, površine dejstva (samim tim i gustine energije), i tkivog fizičkog i hemijskog sastava (sadržaja vode, gustine, toplote provodljivosti i vremena oslobađanja od stvorene toplote) [22].

Svi laserski su grupisani u sedam klasa zavisno od potencijala izazivanog zraka da uzrokuje povrede, oštećenja, stoma- tologiji in vivo desila se 1985. godine, posle publikacije Majersa, u kojoj je opisano laserskih YAG, Er:YAG, Er, Cr:YSGG, Nd:YAP, GaAs, diodni laseri i očima, dok laserski stabilizovani diodni laserski sa UV, vidljivim i infracrvenim spektrom laserskog zraka, su laserski sa UV, vidljivim i infracrvenim spektrom laserskog zraka, su laserski sa UV, vidljivim i infracrvenim spektrom laserskog zraka, su laserski sa UV, vidljивим и infracrvenim spектром лазерског зрача, требовали су се у стоматологији за борбу са разне болести. Основне примене у стоматологији u stomatologiji karakterizuju se različitim talasnim dužinama i pulsnim energijama. Većina laserskih zraka prvenstveno se koristi za laserskih YAG, Er:YAG, Er, Cr:YSGG, Nd:YAP, GaAs, diodni laserski и угледавали су се у стоматологији за борбу са разне болести. Основне примене у стоматологији...
vanje, koagulacija, ekscizija i incizija tokom vaporizacije tkiva. Apsorpcija energije zavisi od talasne dužine zraka, snage, moda rada (kontinuirani ili pulsn), dužine trajanja pulsa, odnosa energija/puls, gustine energije, dužine izlaganja, najvećeg pika snage pulsa, angulacije distalnog kraja optičkog vlakna u odnosu na tkivo, kao i optičkih svojstava tkiva (Slika 8) [26].

Optička svojstva tkiva utiču na interakciju tkiva sa laserskim zracima specifičnih talasnih dužina. U slučaju tkiva parodonicum, optička svojstva zavise od stepena pigmentacije, sadržaja vode, mineralnog sastava, toplotnog kapaciteta, koji se odnosi i na toplotnu provodljivost i gustinu tkiva, i posledica transformacije toplote (denaturacija proteina, vaporizacija vode, topljenje minerala). Kako se zna da je kosi klasificiran kompozitno tkivo koje u svom sastavu ima 67% neorganskih minerala (kalcijum-hidroksiapatita) i 33% kolagena i nekolagenih proteina, dok je gongiva izgrađena od fibroznog tkiva različitih gustina povezanih međusobno komponentama vancheljskog matriksa uz veliki procenat vode (70%), njihova optička svojstva su određena navedenim specifičnim sastavom. Dodatno, gongiva može biti hiperpigmentisana u slučaju velikog nakupljanja melanina u podsuluzkožnom sloju. Ostali faktori koji određuju interakciju laserova i tkiva uključuju procese provođenja toplote i raspijanja, stepen prokrvljenosti i mogućeg zapaljenja tkiva, kao i spo sobnosti pagonitornih čelija da učestvuju u generaciji tkiva. Svaka talasna dužina energije laserova apsorbovan na je u većem ili manjem obimu u komponentama oralnih tkiva, kao što su voda, pigmenti ili hidroksiapatati [27].

Značajna je koža CO2 laser (10600 nm talasne dužine) ima visok koeficijent apsorpcije u vodi, pogodan je za primenu u mekotkivnoj hirurgiji, dok nema dovoljno kvalitetnih podataka u literaturi o opravdanosti aplikaciji na čvrstim tkivima usne duplje. Zrak lasers Nd:YAG (1064 nm talasne dužine) i diodnih lasers (talasne dužine od 800 do 950 nm) ima manji koeficijent apsorpcije u vodi u odnosu na CO2 lasers, a značajno su apsorbovani u pigmentnim tkivima, dok su lasers Er,Cr:YSGG i Er:YAG (2780 i 2940 nm talasnih dužina) visoko apsobrani u vodi i u hidroksiapatitu [28]. Stoga bi trebalo da kliničari za svaki klinički slučaj zasebno utvrde specifične ciljeve lečenja i adekvatna zamena skalpelu. CO2, Nd:YAG i diodni laseri se zatim odaberu odgovarajuću tehnologiju (laser ili neku drugu) na toplotnu provodljivost i gustinu tkiva, i posledica transformacije toplote i raspijanja, kao i spo sobnost različitih čelija da učestvuju u generaciji tkiva. Svaka talasna dužina energije laserova apsorbovan na je u većem ili manjem obimu u komponentama oralnih tkiva, kao što su voda, pigmenti ili hidroksiapatati [27].

Značajna je koža CO2 laser (10600 nm talasne dužine) ima visok koeficijent apsorpcije u vodi, pogodan je za primenu u mekotkivnoj hirurgiji, dok nema dovoljno kvalitetnih podataka u literaturi o opravdanosti aplikaciji na čvrstim tkivima usne duplje. Zrak lasers Nd:YAG (1064 nm talasne dužine) i diodnih lasers (talasne dužine od 800 do 950 nm) ima manji koeficijent apsorpcije u vodi u odnosu na CO2 lasers, a značajno su apsorbovani u pigmentnim tkivima, dok su lasers Er,Cr:YSGG i Er:YAG (2780 i 2940 nm talasnih dužina) visoko apsobrani u vodi i u hidroksiapatitu [28]. Stoga bi trebalo da kliničari za svaki klinički slučaj zasebno utvrde specifične ciljeve lečenja i adekvatna zamena skalpelu. CO2, Nd:YAG i diodni laseri se zatim odaberu odgovarajuću tehnologiju (laser ili neku drugu) na toplotnu provodljivost i gustinu tkiva, i posledica transformacije toplote i raspijanja, kao i spo sobnost pagonitornih čelija da učestvuju u generaciji tkiva. Svaka talasna dužina energije laserova apsorbovan na je u većem ili manjem obimu u komponentama oralnih tkiva, kao što su voda, pigmenti ili hidroksiapatati [27].

Značajna je koža CO2 laser (10600 nm talasne dužine) ima visok koeficijent apsorpcije u vodi, pogodan je za primenu u mekotkivnoj hirurgiji, dok nema dovoljno kvalitetnih podataka u literaturi o opravdanosti aplikaciji na čvrstim tkivima usne duplje. Zrak lasers Nd:YAG (1064 nm talasne dužine) i diodnih lasers (talasne dužine od 800 do 950 nm) ima manji koeficijent apsorpcije u vodi u odnosu na CO2 lasers, a značajno su apsorbovani u pigmentnim tkivima, dok su lasers Er,Cr:YSGG i Er:YAG (2780 i 2940 nm talasnih dužina) visoko apsobrani u vodi i u hidroksiapatitu [28]. Stoga bi trebalo da kliničari za svaki klinički slučaj zasebno utvrde specifične ciljeve lečenja i adekvatna zamena skalpelu. CO2, Nd:YAG i diodni laseri se zatim odaberu odgovarajuću tehnologiju (laser ili neku drugu) na toplotnu provodljivost i gustinu tkiva, i posledica transformacije toplote i raspijanja, kao i spo sobnost pagonitornih čelija da učestvuju u generaciji tkiva. Svaka talasna dužina energije laserova apsorbovan na je u većem ili manjem obimu u komponentama oralnih tkiva, kao što su voda, pigmenti ili hidroksiapatati [27].
površini zuba. Stoga CO₂ laseri imaju ograničenu primenu u subginglevalnoj parodontalnoj terapiji. Pri energijama od 100 do 400 J/cm² za CO₂ i 286 do 1,857 J/cm² za laser Nd:YAG opisan je određen stepen morfoloških promena na površini korena nastalih dejstvom laserja, kao što su efekat kavitacije, topljenje i remineralizovanje globula, promene u strukturi proteina korena, površinskih pukotina, i stvaranje površinskog sloja, što je direktno bilo zavisno od gustine primenjene energije. Suprotno u odnosu na navedene rezultate, kada je primenjen laser Nd:YAG, pri manjim gustinama energije ili kombinaciji niže gustine energije uz defokusiran zrak, pokazano je da je pogodan za uklanjanje razmazanog sloja na površini korena bez izazivanja posledica po tkivo cementa i/ili dentina, ili povećanja temperature do nivoa koji bi uzrokovalo ireverzibilno oštećenje pulpe [34, 35, 36].

Relativno nov laser, Nd:YAP sa talasnom dužinom 1340 nm, ispitivan na površini izvađenih zuba, pokazuje prisustvo promena na tkivu uzrokovana toplotom pri gustinama primenjenih energija od 509 do 1274 J/cm². Stepen oštećenja je direktno povezan sa podizanjem temperaturi u tkivu do nivoa kojim bi bio odgovoran za oštećenje pulpe. U takvim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu energije, može imati negativne posljedice za tvrzine i cement. U ovim slučajevima, provedba zračenja laserom Nd:YAG, uz nižu gustinu ener

**ZAKLJUČCI**

U ovom radu opisano je zračenje bioloških tkiva specifičnim talasnim dužinama laser. U pregledu literature su proučene interakcije zubnih tkiva i talasnih dužina, kao i različiti tipovi laserova, energija i talasne dužine, a prikazani rezultati mogu poslužiti za odabir adekvatnijih parametara za primenu laserova, bez uzrokovivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površini korena bez izazivanja destruktivnih efekata. Pored specifičnih primena laserova, u ovom radu su opisane i smanjenje subginglevalnih bakterija na površi