PREGLEDNI RAD
REVIEW ARTICLE

BIOFIZIKA LASERA - I DEO

BIOPHYSICS OF LASERS - PART I

Jovanović Goran, Burić Nikola, Krunić Nebojša

MEDICINSKI FAKULTET, KLINIKA ZA STOMATOLOGIJU, ODELJENJE ZA ORALNU HIRURGIJU, NIŠ, SRBIJA

MEDICAL FACULTY, CLINIC OF STOMATOLOGY, DEP. OF ORAL SURGERY, NIŠ SERBIA

Kratak sadržaj

Rad ima za cilj da upozna čitaoce sa osnovnim karakteristikama laserske fizike i biološkim dejstvom zračenja na eksponirana tkiva. Opisan je kratak hronološki istorijat nastanka kvantnih optičkih generatora, kao i osnovna načela spontane i stimulisane emisije zračenja iz kojih proizilaze mehanizmi nastanka laserskih zraka. Takođe, navedeni su osnovni parametri koji karakterišu laserske zrake, konstrukcija i podela laserskih aparata sa kratkim osvrtom na režim rada i doziranje.

Ključne reči: *fizika lasera, laseri male snage, laseri velike snage*

Abstract

The aim of this work is to introduce to the readers the basic characteristics of laser physics and the biologic influence of radiation to expanded tissues. There has been given a brief review of chronologic history of quantum optical generator appearance, as well as basic principles of spontaneous and stimulated emission of radiation which produce the laser rays. There were also mentioned basic parameters which characterize laser rays, construction and classification of laser devices with brief review on working treatment and dosage.

Key word: *physics of laser, low power lasers, high power lasers*

Uvod

Otkriće lasera predstavlja značajan doprinos savremenoj nauci. Njihova primena je širom sveta sve aktuelnija, tako da se danas sa velikim uspehom koriste u tehnici i industriji, a sve češće i u medicini. Dok se laseri velike snage (LVS) uveliko primenjuju u hirurgiji za sečenje i koagulaciju tkiva, gde pokazuju mnogobrojne prednosti u odnosu na standardne metode lečenja, laseri male snage (LMS), čiji je glavni efekat biostimulacija, svoj puni razvoj doživljavaju u poslednjih petnaest godina i nalaze široku upotrebu u mnogim oblastima. medicine i stomatologije.

Kako su laserski aparati sve prisutniji u stomatološkim ordinacijama ovaj rad ima za cilj da upozna čitaoce sa osnovnim postulatima

Introduction

Discovery of lasers is very important contribution to the contemporary science. Its usage is more and more actual all over the world, so they are today used with great success in technique and in industry, and also more frequently in medicine. While high power lasers are used in surgery for cutting and tissue coagulation, where they show many advantages in comparison with standard methods for treatments, low power lasers, with biostimulation as main effect, their great development have achieved in last fifteen years and have spacious usage in many fields of medicine and stomatology.

As lasers are each day more and more represented in stomatology ordinations the aim of this work is to introduce to the readers basic postulates of laser physics and emphasize the laserske fizike i da istakne efekte laserskih zraka na tkiva sa kojima dolaze u kontakt.

Pojam i istorijat

LASER predstavlja akronim za **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation, što znači pojačanje svetla stimulisanom emisijom zračenja.[1]

Prvu ideju o stimulisanoj emisiji zračenja i kvantnim optičkim generatorima dao je Albert Einstein 1917. godine[2]. Kasnije N.G. Basov i A.M. Prohorov u Sovjetskom Savezu i nezavisno od njih C.H. Townes u SAD aktivno rade na novim principima stimulisane emisije zračenja u kvantnim sistemima, zašta su sva trojica dobili Nobelovu nagradu za fiziku 1964. godine.[3] Prvi uređaj, gasni amonijačni laser, koji koristi stimulisanu emisiju zračenja stvorio je Charles H. Townes sa saradnicima 1958. godine i nazvao ga je MASER ili Microwave Amplification by Stimulated Emission of Radiation.[4] Prvi impulsni rubinski laser koji emituje u vidljivom delu spektra konstruisao je Teodore H. Maiman 1960. godine, po kome je ovaj vid stimulisane emisije zračenja i dobio ime.[5] Godinu dana kasnije konstruisan je prvi gasni laser sa helijumneonskom aktivnom materijom. 1962. godine nastao je prvi poluprovodnički laser koji se pobuđivao neposredno električnom strujom.[6] Prvi rezultati eksperimentalne primene lasera u stomatologiji objavljeni su 1965. godine.[7]

Razvoj lasera i laserske fizike doživljava punu ekspanziju u narednom četrdesetogodišnjem periodu.

Savremeni laser predstavlja generator koherentnog elektromagnetnog zračenja koji prema vrsti može da emituje u ultra-violetnom, vidljivom ili infracrvenom spektralnom dijapazonu.

Spontana i stimulisana emisija

Atom se sastoji od pozitivno naelektrisanog jezgra i negativno naelektrisanih elektrona koji kruže oko njega po tačno ustaljenim putanjama (orbitalama), koje se nalaze na strogo određenom rastojanju od jezgra. Atom se tada nalazi u stabilnom stanju u kome niti apsorbuje niti zrači elektromagnetne talase. Pod dejstvom spoljne energije elektroni apsorbuju određenu količinu ili kvant energije i prelaze u više orbit-

effects of laser rays to the tissues they are in contact with.

Apprehension and history

LASER is the acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.[1]

First idea about stimulated emission of radiation and quantum optical generators was given by Albert Einstein, 1917.[2] Later N.G.Basov and A.M. Prohorov in Soviet Union and apart from them C.H Townes in SAD work actively on new principles of stimulated emission of radiation in quant systems. Three of them got a Nobel Price for physics, 1964.[3] First device, gas ammonium laser, which use stimulated emission of radiation was made by Charles H. Townes with its associates in 1958, and he called it MASER or Microwave Amplification by Stimulated Emission of Radiation.[4] First impulsive rubin laser which emits in visible part of spectrum was constructed by Teodore H. Maiman in 1960. According his name this kind of stimulated emission of radiation has gained its name.[5] One year later there was constructed first gas laser with helium-neon active substance. First semiconductor laser which was induced immediately with electric current was made in 1962.[6] First results of experimental use of lasers in stomatology were established in 1965.[7]

Development of laser and laser physics has reached complete expansion in next forty year period. Contemporary laser is generator of coherent electromagnet emission which can emit, according to its type, in ultra violet, visible and infrared spectral diapason.

Spontaneous and stimulated emission

An atom consists of positive charged nucleus and negative charged electrons which circulate round it on exactly fixed orbitals that are in correctly fixed distance from nucleus. Atom is then in stable state and it neither absorbs nor radiates electromagnetic waves. Electrons absorb certain quantity or quant of energy by the action of foreign energy and they pass in higher orbital ellipses and atom is then in impulsive state.[8] However, electrons can not stay for a long time at new levels, because atom gravitate to return itself to a former stable state, so after a short time (10^8 sec) atoms return on lower alne putanje i atom se tada nalazi u pobuđenom stanju.[8] Međutim, elektroni ne mogu dugo da se zadrže na novim nivoima, jer sam atom teži da se vrati u prvobitno stabilno stanje, te se posle kratkog vremena od 10^{-8} sec vraćaju na niže energetske nivoe.[9] Prelazak elektrona sa energetski viših na energetski niže orbitalne nivoe emituje kvant energije u vidu elektromagnetnog zračenja koji se još naziva foton.[10] Ovako nastali fotoni su različitog pravca, faze i talasne dužine (frekvence) i kao takvi čine belu svetlost (Slika 1).[11]

Pri spontanoj emisiji samo mali broj atoma se nalazi u pobuđenom stanju, te je energija bele svetlosti relativno mala.[9]

Ukoliko već pobuđeni atomi stupe u kontakt sa fotonima koji poseduju određenu količinu energije doći će do stimulacije zračenja pobuđenih atoma, tako što elektroni iz njihovih viših energetskih nivoa prelaze u niže i pri tom emituju nove fotone.[12] Ovi fotoni ponovo deluju na pobuđene atome i tako nastaje lančana reakcija izbijanja fotona[13], sa karakteristikom da se kreću istim pravcem, da su iste faze i talasne dužine (frekvence).[11] Grupacije fotona ovih osobina čine laserski zrak.

Kod stimulisane emisije, kakvu stvara laserski aparat, daleko veći broj atoma ili više od 50% se nalazi u pobuđenom stanju, tj. što je veći broj atoma pobuđen, energija laserskog zračenja biće veća[9] (slika 1).

Kada se pobuđeni atom pogodi fotonom koji poseduje istu energiju, indukuje se zračenje pobuđenog atoma, tako da sada postoje dva fotona sa istom energijom.

Parametri laserskog zračenja

Monohromatičnost - podrazumeva postojanje samo jedne talasne dužine laserskih zraka, pri čemu se oni, za razliku od bele svetlosti koja se sastoji od zraka različitih talasnih dužina, prolaskom kroz prizmu ne mogu razložiti na više boja (Slika 2).[14]

Razlaganje bele svetlosti na više boja.

Koherentnost - svi talasi laserskog zračenja se nalaze u istom smeru i istoj fazi, a to znači da se mogu fokusirati u jednoj tački sa razvojem ogromne energije.[15]

energetic levels.[9] Transition of electrons from higher energetic levels to lower energetic orbital levels emit a quant of energy in form of electromagnetic radiation which is called also photon.[10] Photons which appeared in this way are of different directions, phases and frequency and they make white light. (Figure 1) [11]

At spontaneous emission only little number of atoms are in impulsive state, so the white light energy is relatively small.[9]

If impulsive atoms are in contact with photons which posses certain quantity of energy there will appeared the stimulation of impulsive atoms, because electrons from their higher energetic levels go to lower levels and in that way they emit new photons.[12] These photons work again on impulsive atoms and in that way a chain reaction of photons sprouting appears[13], with characteristic that they move in a same direction, that they are with same phase and same frequency.[11] Groups of photons with these characteristics make a laser ray.

At stimulated emission which is made by laser device the number of atoms is more numerous. More than 50% of atoms are in impulsive state, i.e. the more number of impulsive atoms, the greater energy of laser radiation (Figure 1).[9]

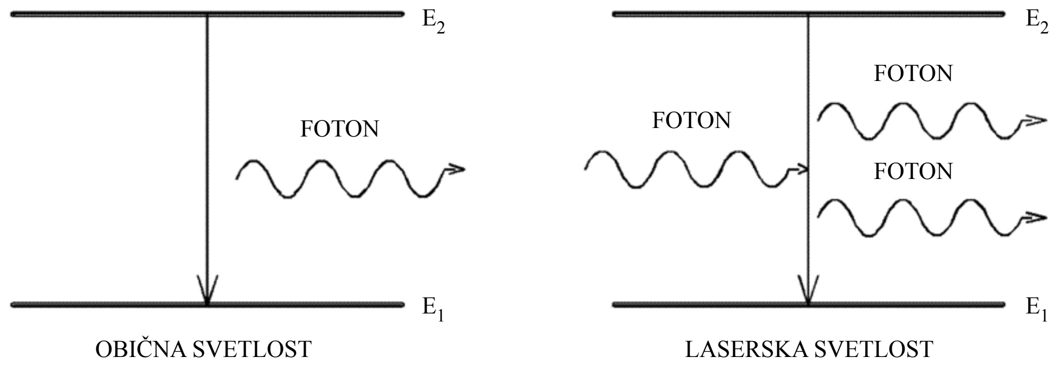
When impulsive atom is hitted with photon which has same energy, the radiation of impulsive atom has been inducted, so there are two photons with same energy.

Parameters of laser radiation

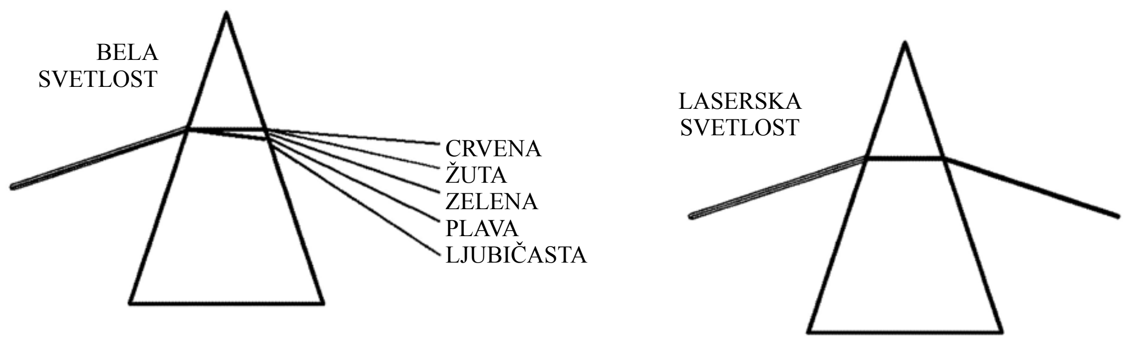
Monochromacy – is the existence of only one frequency of laser rays when they can not be dissembled on many colors while passing through prism, in contrast to white light which consists of rays with different frequency (Figure 2).[14]

White light disassembling on many colors

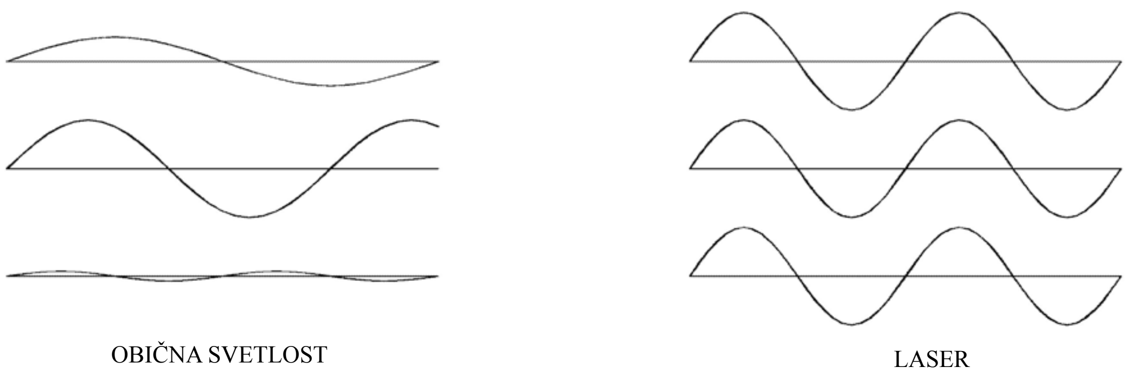
Coherency – all laser radiation waves are in same direction and in same phase, so that means they can be focused in one point with development of great energy.[15]



Slika 1. Spontana i stimulisana emisija
Figure 1. Spontaneous and stimulated emission



Slika 2. Monohromatičnost
Figure 2. Monochromacy



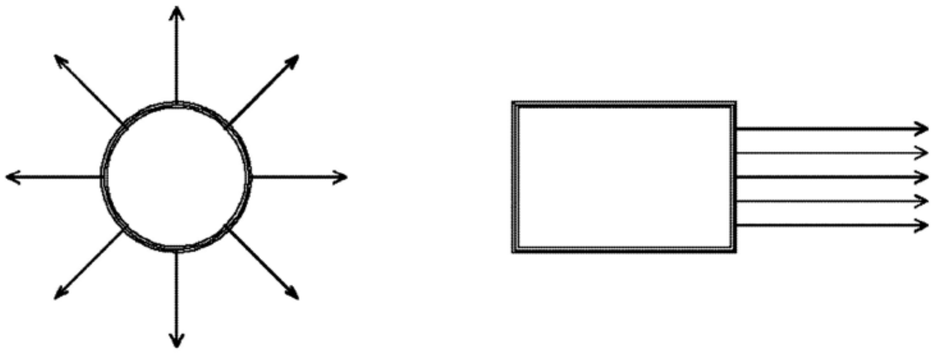
Slika 3. Koherentnost
Figure 3. Coherency

Amplitude laserskih zraka su uvek identične (Slika 3).

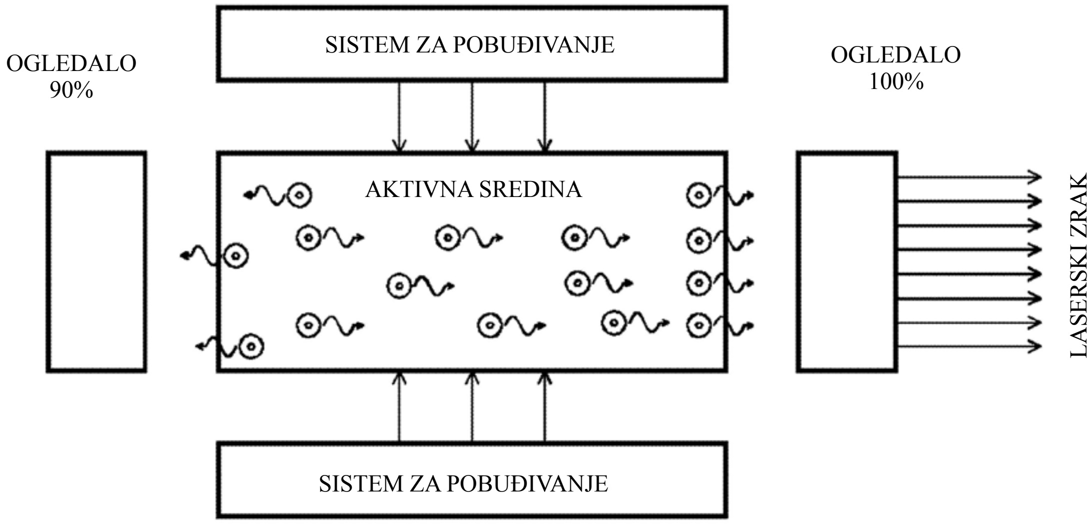
Usmerenost - laserski zraci su gusto koncentrisani, te ih je moguće poslati na velike daljine, a da se pri tom ne rasipaju u većoj meri kao što je to slučaj kod bele svetlosti.[16]

The amplitude of laser rays is always identical (Figure 3).

Direction – laser rays are dense concentrated, so it is possible to send them to the great distances by avoiding the bigger diffusion as it is case with white light.[16]



Slika 4. Usmerenost
Figure 4. Direction



Slika 5. Konstrukcija laserskog aparata
Figure 5. Construction of laser device

Dok se svetlosni zraci bele svetlosti prostiru na sve strane, laserski zraci su strogo usmereni (Slika 4).

While the rays of white light are spreading over all ways, laser rays are strictly directed (Figure 4).

Konstrukcija i rad lasera

Sistem za pobuđivanje – pod pobuđivanjem, pumpanjem ili inverznom populacijom (IP) podrazumeva se stvaranje takve aktivne sredine u kojoj je broj pobuđenih atoma veći od broja

Construction and work of laser

System of inducting – impulsion, pumping or inverse population (IP) is making such active environment in which the number of impulsive atoms is bigger than number of atoms in basic atoma u osnovnom stanju.[17] Postoje sledeće metode pobuđivanja[18]:

- optičko pobuđivanje (kristalni laseri),
- električno pražnjenje (gasni i poluprovodnički laseri),
- pobuđivanje hemijskom reakcijom (hemijski laseri), i
- gasno pražnjenje (gasno-dinamički laseri).

Aktivna sredina – predstavljena je aktivnom materijom u kojoj se postiže inverzna populacija atoma. U zavisnosti od vrste lasera ona može biti u gasnom, tečnom i čvrstom stanju.

Rezonatorni sistem - predstavljaju dva paralelno postavljena ogledala od kojih je jedno potpuno reflektujuće i ima ulogu da stvorene fotone ponovo vrati u aktivnu sredinu koji će nastaviti reakciju pobuđivanja. Kada emitovani fotoni dođu do drugog ogledala koje je polupropustljivo, oni se delimično reflektuju i vraćaju u aktivnu sredinu te se proces pobuđivanja nastavlja, a delimično prolaze kroz njega i čine laserski zrak sa svim njegovim karakteristikama.[12]

Sistem polupropustljivog i nepropustljivog ogledala strogo usmerava formiranje laserskog snopa (Slika 5).

Podela lasera

Postoji veliki broj klasifikacija lasera. Sa kliničkog aspekta čine se interesantim dve podele i to:

1. Prema agregatnom stanju aktivne supstance[19] :

a) gasni laseri – IP postižu pomoću raznih gasova, njihovih smeša i para metala (ugljen dioksidni – CO_2 helijum neonski – HeNe, i argonski –Ar laser),

b) tečni laseri – IP postižu preko različitih tečnosti (laseri sa lantanidima i organskim bojama), i

c) čvrsti laseri – IP postižu kristalnom aktivnom sredinom ili amorfnom supstancom kojoj se dopiru joni različitih hemijskih elemenata (rubinski, neodijum itrijumalumitgranat – Nd: YAG, erbijumitrijumalumitgranat – Er: YAG i neodijum staklo – Nd: staklo laser). Posebno poglavlje u okviru čvrstih lasera pripada poluprovodničkim laserima – aktivna sredina im je kristalna, a IP postižu snopom elektrona visoke energije ili električnim pražnjenjem

state.[17] There exist the following methods of inducting[18]:

- optical inducting (crystal lasers)
- electric discharge (gas and semi conductive)
- inducting by chemical reaction (chemical lasers),and
- gas discharge (gas-dynamic lasers).

Active environment – is an active substance in which there has been achieved inverse population of atoms. According to the type of laser it can be in gas, liquid or hard state.

Resonant system – it is system of two parallel mirrors. One of them is completely reflective and it has a role to bring back again produced photons in active environment which will continue the reaction of impulsion. When emitted photons came to the second mirror which is semi leaky, they are partly reflected and then they have been brought back in active environment so the process of impulsion continues, and they partly pass through it and make laser beam with all its characteristics.[12]

System of semi leaky and no leaky mirror strictly directs the creating of laser beam (Figure 5).

Type of lasers

There are a great number of laser classifications. By clinical point of view, two classifications are interesting:

1. According to the aggregate state of active substance[19]:

a) gas lasers – they achieve IP with different gases, their mixtures and para metals (carbon dioxide – CO_2, helium neon – HeNe and argon – Ar laser),

b) liquid lasers – they achieve IP by different liquids (lasers with lanthanides and organic colors), and

c) hard lasers – they achieve IP by crystal active environment or amorphous substance on which is put ions of different chemical elements (rubin, neodium-itrium-alumit-granat – Nd: YAG, erbium-itrium alumit granat – Er: YAG and neodium glass – Nd: glass laser). Particular chapter of hard lasers belong to semi conductive lasers – its active environment is crystal, (galijum arsenidni – GaAs i galijum aluminijum arsenidni – GaAlAs laser).

2. Prema snazi emitovanja laserskog zračenja:

a) laseri velike snage, tvrdi, hard, visokoenergetski laseri – rade sa snagom preko 100 mW pa do više W ili KW, a odlikuju se visokom gustinom energije, fokusiranjem laserskih zraka i izraženim termičkim efektima koji izezivaju denaturaciju belančevina, fotokoagulaciju, karbonizaciju i isparavanje tkiva[20] (CO_2, Nd: YAG i Er: YAG), i

b) laseri male snage, meki, soft, niskoenergetski laseri – rade sa snagom od 5 do 100 mW, odlikuju se malom gustinom energije, defokusiranim laserskim zracima, bez izraženih termičkih efekata te je njihovo prvenstveno dejstvo biostimulacija ćelijske aktivnosti (HeNe, GaAs i GaAlAs). Talasna dužina najčešće korišćenih mekih lasera iznosi 632,8 nm za HeNe i 780, 840 i 904 nm za poluprovodničke GaAs i GaAlAs lasere. Pri tom, prvi zrači u oblasti vidljivog, a druga dva u oblasti infracrvrnog dela spektra. Tek u zadnje vreme su se pojavili poluprovodnički laseri sa zračenjem u vidljivoj oblasti spektra (630 i 670nm).[21]

Režim rada i doziranje

Režim rada lasera može biti:

a) kontinuiran - emisija laserske svetlosti se ne menja u toku vremena, i

b) impulsni - emisija laserske svetlosti traje samo za vreme trajanja impulsa.

To znači da se impulsni režim rada odlikuje frekvencijom (f) koja se izražava u hercima (Hz), a predstavlja broj impulsa u jednoj sekundi. Frekvencija impulsa od 20 Hz znači da se lasersko zračenje uključuje i isključuje 20 puta u sekundi. Srednja snaga impulsnog lasera je uvek manja od izlazne snage upravo zato što laser ne vrši emitovanje u pauzi između dva impulsa.

Energija koju tkivo treba da primi da bi se ostvario biostimulativni efekat kreće se od 1-15 J/cm^2 po tretmanu.

and IP is achieved by beam of high energy electrons or by electric discharge (gallium arsenic – GaAs and gallium aluminum arsenic – GaAl-As laser).

2. According to the emission power of laser radiation:

a) High power lasers, hard, high energy lasers – the work with strength over 100 mW and till more W or KW, and they are characterized with high energy density, focusing of laser rays and expressive thermal effects which provoke denaturizing of albumen, photocoagulation, carbonization and tissue evaporation[20] (CO2, Nd: YAG and Er: YAG), and

b) Low power lasers, soft, micro energetic lasers – they work with strength of 5-100 mW. They are characterized with low energy density, laser rays defocusing, without expressive thermal effects so their particular action is biostimulation of cell activity (HeNe, GaAs and GaAlAs). The frequency of mostly used soft lasers is 632.8 nm for HeNe, 780.840 and 904 nm for semi conductive GaAs and GaAlAs lasers. First of them radiate in visible area, while the following two radiate in area of infrared part of spectrum. In latest years there have appeared semi conductive lasers with radiation in visible area of spectrum (630 and 670 nm).[21]

Working treatment and dosage

Laser working treatment can be:

a) Constant - emission of laser light does not change in working period

b) Impulsive - emission of laser light lasts only during the time of impulse duration.

That means that impulsive treatment of working is characterized with frequency (f) which is expressed in herc (Hz), and it shows number of impulses in one second. The impulse frequency of 20 Hz means that laser radiation turns on and turns off 20 times in second. Middle strength of impulsive laser is always lower than exit strength just because laser does not emit during the intermission between two impulses.

Energy which tissue should receive in order to achieve biostimulative effects is 1-15 J/cm^2 by a treatment.

Zaključak

Poznavanje dela koji se odnosi na lasersku fiziku značajno je sa aspekta razjašnjenja mnogih nepoznanica koje se vezuju za ovu problematiku. Biološko dejstvo lasera na eksponirana tkiva biće obrađeno u sledećem delu.

Conclusion

Cognition of the part which belongs to laser physics is very important from the viewpoint of many obscurity clarification which are in connection with this matter. Biological effect on exposed tissues will be discussed in second part.

LITERATURA / REFERENCES

1. Featherstone J, Blankenau RJ, Zakariasen K, Barron JR, Dederich D.: What is the future of lasers in dentistry? Quintessence International, 1996, 27: 286-291.

2. Einstein A.: Zur Quantum Theorie der Strhlung. Physikalische Zeitschrift, 1917, 18: 121. Citat iz: Pick R.: Using lasers in clinical dental practice. JADA, 1993, 124: 37-47.

3. Prokhonchukov A. Laser in dentistry: summing up 30-year experience. Stomatolog M, 1995, 4: 68-73.

4. Midda M, Renton- Harper P. Laser in dentistry. British Dental J., 1991, 170: 343-346.

5. Myers M. The effect of laser iradiation on oral tissues. J Prosthetic Dentistry, 1991, 66: 395-397.

6. Antić A, Strajnić V, Antić N. Laseroterapija u polikliničkoj patologiji. Zbornik radova Kongresa ljekara za fizikalnu medicinu i rehabilitaciju Jugoslavije, Igalo, 28.09-01.10, 1993.

7. Anić I. Primjena galij-arsenid lasera u lečenju adultnog parodontitisa. Acta Stomatol Croat, 1988, 22: 141-147.

8. Cernavin I, Pugatschew A, Boer N, Tyas MJ. Laser applications in dentistry: A review of the literature. Australian Dental J, 1994, 39: 28-32.

9. Mitrović M, Džinić M. Laser u medicini. Medicinska knjiga, Beograd-Zagreb, 1983, str. 9-32.

10. Harris D, Pick R. Laser Physics. In: Miserendino L, Pick R. (ed.): Lasers in Dentistry. Quintessence Publishing Co., Chicago-Berlin, London-Tokyo, Sao Paulo-Moscow-Warsaw, 1995, pp. 27-38.

11. Wilson M. Bactericidal effect of laser light and its potential use in the treatment of plaque-related diseases. International Dental J, 1994, 44: 181-189.

12. Pick R. Using lasers in clinical dental practice. JADA, 1993, 124: 37-47.

13. Letokhov V. Laser-induced chemistry. Nature, 1983, 305: 103-108.

14. Midda M, Renton- Harper P. Laser in dentistry. British Dental J, 1991, 170: 343-346.

15. Miller M, Truhe T. Laser in dentistry: An Overviev. JADA, 1993, 124: 32-36.

16. Pick R. Using lasers in clinical dental practice. JADA, 1993, 124: 37-47.

17. Konjević N.: Uvod u kvantnu elektroniku. Naučna knjiga, Beograd, 1981.

18. Jovanović G. Uticaj lasera male snage na zarastanje ekstrakcionihi hirurških rana usne duplje. Doktorska disertacija, Medicinski fakultet, Niš, 1998.

19. Rentzepis P. Lasers in biological research. SPIE - Lasers in Medicine, 1986, 712: 99-102.

20. Masse J, Landry R, Rochette C, Dufour L, Morency R, Aoust P. Effectiveness of soft laser treatment in periodontal surgery. International Dental J, 1993, 43: 121-127.

21. Labat J. Primena lasera u akupunkturi. U (grupa autora): Ka integraciji savremene i tradicionalne medicine. ECPD, Beograd, 1995, str. 321-329.

Adresa za korespondenciju:
Prof. dr Goran Jovanović
Bul. Zorana Đinđića 52
18000 Niš
Srbija
Telefon: 018 / 226 216

Address of correspondence:
Assoc. Prof. Goran Jovanović, DDS, MSD, Ph. D.
52 Buld. Zorana Đinđića
18000 Niš
Serbia
Phone.: + 381(0)18 226 216