

PRIMENA LASERA u FIZIČKOJ HEMIJI

IMPULSNI LASERI I PFH

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- PLAN IZLAGANJA:

- **ŠTA je to LASER ?**
- **OSOBINE LASERSKOG ZRAČENJA**
- **KLASIFIKACIJA LASERA**
- **PRINCIPI RADA LASERA**
- **SAVREMENI IMPULSNI LASERI**
- **PRIMENE LASERSKIH SISTEMA**



- ŠTA je to LASER ?

-Termini: LASER; ЛАЗЕР; ОКГ;

- LASER;

Light Amplification by Stimulated Emission of Radiation

- 1964. god. (A. Prokhorov, N. Basov, C. Townes)- Nobelova nagrada.

- C. Townes, 1954. god. MASER; NH_3 , $\lambda = 1,25 \text{ cm}$, $P_L = 10^{-10} \text{ W}$.

- Maiman (Hughes Lab.), 1960. god., LASER, Rubinski laser.



- OSOBINE LASERSKOG ZRAČENJA

- Intenzivno
- Monohromatično
- Usmereno
- Koherentno

- Intenzivnost zračenja:

$$I_L = (E/t)/A = P/A, (W/cm^2)$$

Tabela 1. Intenzivnost “izvora”

Tip “izvora”	Intenzitet, W/cm ²
Sunce	530
Crno telo ($\lambda=10 \mu\text{m}$, $T= 1473 \text{ K}$)	53
Lampa	$3 \cdot 10^3$
He-Ne laser	$4 \cdot 10^4$
Ar- laser	$4 \cdot 10^8$
TEA CO ₂ laser	$4,5 \cdot 10^{11}$



Tabela 2. Radiometrijske veli. "izvora"

- $I_L(a) = (E/t)/\pi\theta^2 = P/\Omega, (W/sr)$

- $B = P/\Omega\omega_0^2, (W/cm^2 \cdot sr)$

- $B_\lambda = B/\Delta\lambda, (W/cm^2 \cdot sr \cdot nm)$

Tip izvora	$I_L(a), W/sr$	$B, W/cm^2 \cdot sr$	$B_\lambda, W/cm^2 \cdot sr \cdot nm$
Sijalica (66 W)	5	/	/
He-Ne laser	300	$2,5 \cdot 10^5$	$4 \cdot 10^{14}$
Hg-lampa	/	95	9,5

(He-Ne laser: $P_L = 2 \cdot 10^{-3} W$, $\lambda = 632,8 nm$, $\Delta\lambda = 6 \cdot 10^{-10} nm$.
Hg-lampa: $P = 100 W$, $\lambda (Hg) = 546 nm$, $\Delta\lambda = 10 nm$).

- Monohromatičnost zračenja:

$\Delta\nu/\nu = 10^{-15}.$

LASER: $R_\lambda^L = 1 \cdot 10^7,$

SUNCE: $R_\lambda^S = 1 \cdot 10^{-4},$

$W/(cm^2 \cdot nm),$

$W/(cm^2 \cdot nm).$



- Usmerenost zračenja:

$$\theta = \lambda / \pi \omega_0, \text{ (mrad).}$$

- Koherentnost zračenja:

- Vremenska (slika 1),

$$L_K = c \cdot \Delta t, L_K = c / \Delta \nu, \text{ (cm).}$$

$$L_K(\text{Hg}) = 2 \text{ cm},$$

$$L_K(\text{He-Ne las.}) = 30 \text{ cm} - 10^7 \text{ m, (Km).}$$

- Prostorna,

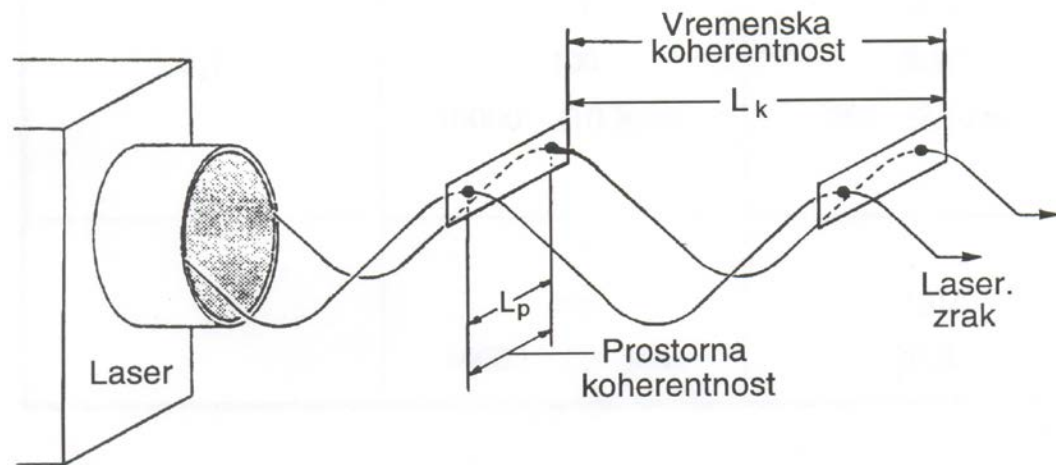
$$L_P = 1,22 \cdot \lambda / \theta, \text{ (cm).}$$

Tabela 3. Prostiranje laser. snopa

$\omega_0,$ cm	Z, m	$\omega,$ cm
0,1	1 100 10000	0,1 2,02 201
1	1 100 10000	1 1,02 20,2

He-Ne laser: $\lambda = 632,8 \text{ nm}$, TEM₀₀.



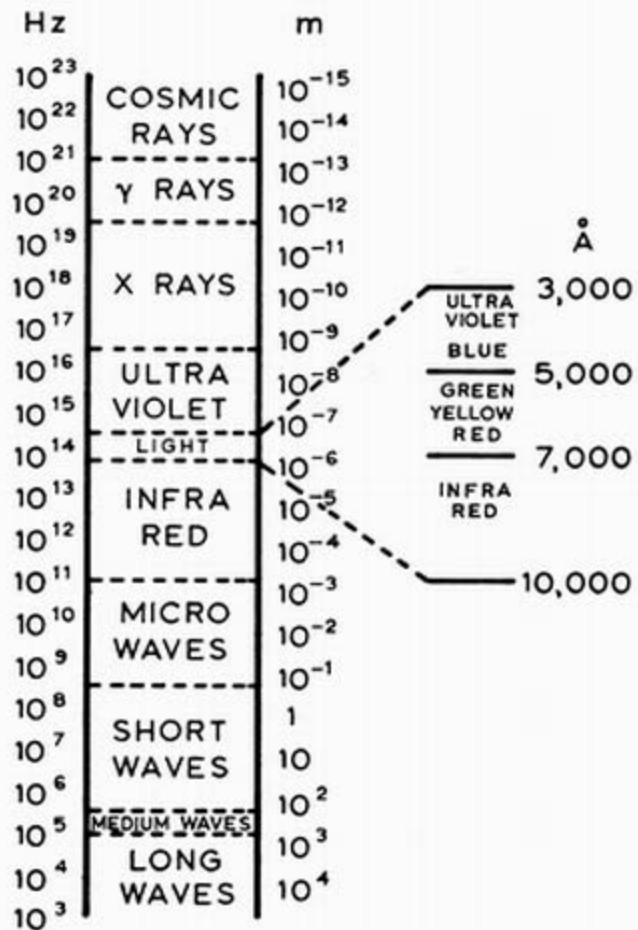


Slika 1. Koherentnost las. zračenja.

- KLASIFIKACIJA LASERA

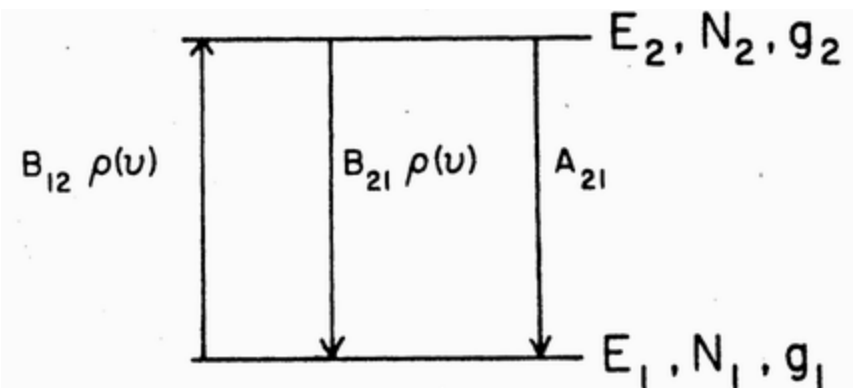
- Prema aktivnoj sredini (gasni; tečni; čvrsti).
- Prema "čestici" (atomi; joni; molekuli).
- Prema talasnoj dužini (Slika 2) IR; vidljivi; UV; itd.).
- Prema vremenskoj evoluciji "izlaza".
 - Kontinualni las.: P ; λ ($\Delta\lambda$, $\Delta\nu$); θ ; "mod"; η .
 - Impulsni las.: E ; $\Delta\tau_{1/2}$ (ms, μ s, ns, ps, fs, as); P_p ; f ; P_{sr}



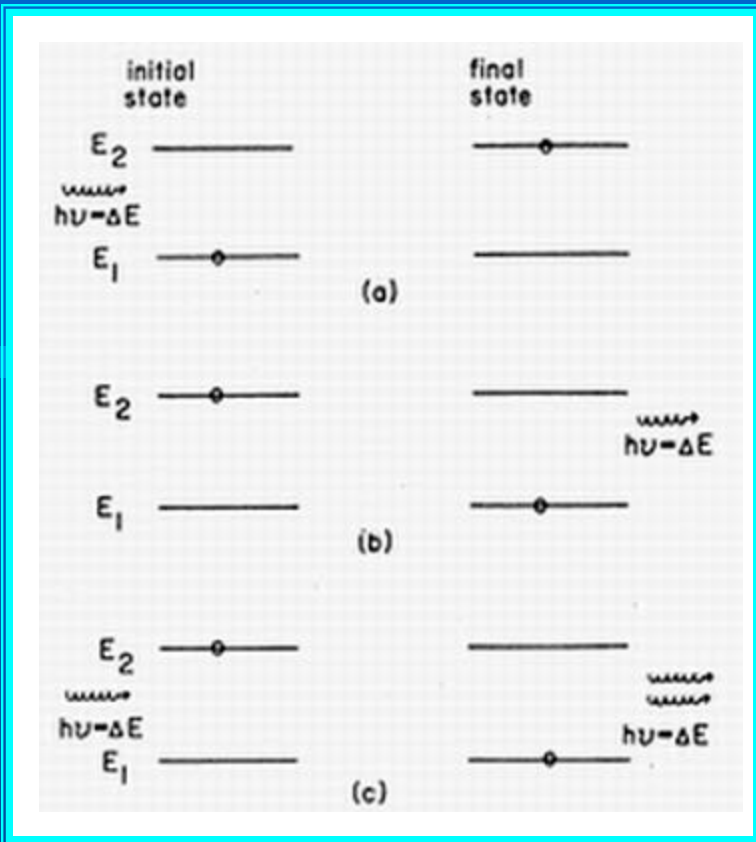


Slika 2. Elektromagnetni spektar zračenja.

- PRINCIPI RADA LASERA



Slika 3. Sistem dva nivoa.



Slika 4. Procesi apsorpcije i emisije zračenja (sistem dva nivoa).

- Apsorpcija zračenja, $P_{12} = B_{12} \cdot \rho(\nu) \cdot dt$

- Spontana emisija, $P_{21} = A_{21} \cdot dt$

- **Stimulisana emisija**, $P_{21} = B_{21} \cdot \rho(\nu) \cdot dt$

$$B_{12} = B_{21}$$

- Sistem većeg broja čestica:

$$N_2(A_{21} + \rho(\nu) B_{21}) = N_1 B_{12} \cdot \rho(\nu)$$

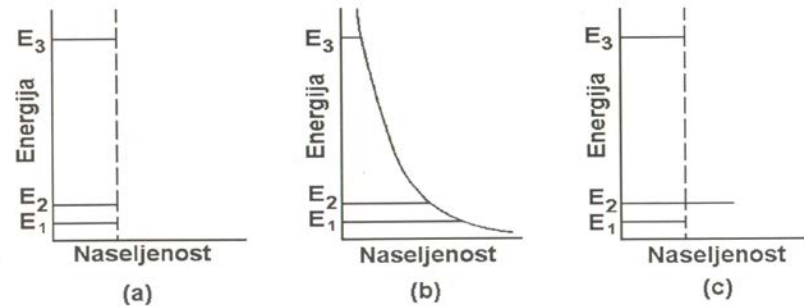
$$A_{21}/(B_{21} \cdot \rho(\nu)) = \exp(h\nu/kT) - 1,$$

Primer: Svetlosni izvor, $T = 1000 \text{ K}$, $\lambda = 500 \text{ nm}$,
 "odnos" = 10^{12} .

$N_1 > N_2$; $N_2 = N_1$; **$N_2 > N_1$** , inverzija naseljenosti.

Bolcmanov zakon:

$$N_2/N_1 = \exp(-hv/kT)$$

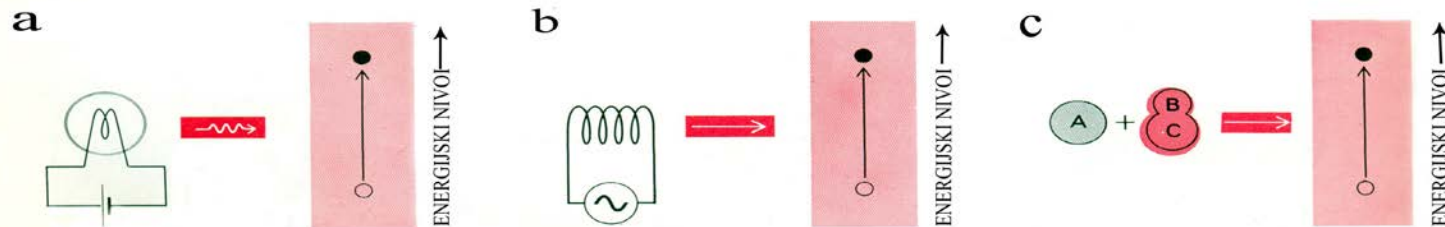


Slika 5. Dijagram energetskega nivoa.

POJAČANJE:

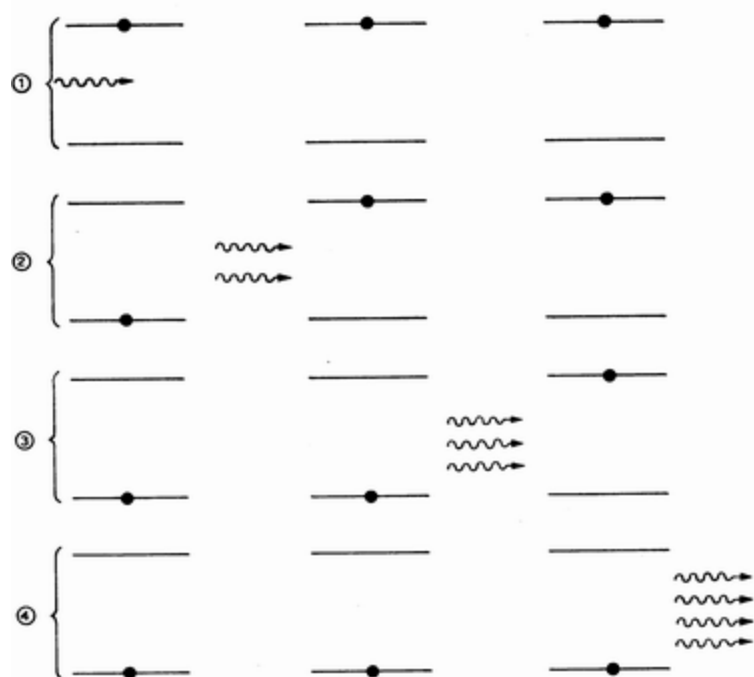
$$\rho(v)/\rho_0(v) = \exp(-\alpha \cdot l),$$

$$\alpha = (N_1 - N_2) \cdot \sigma$$

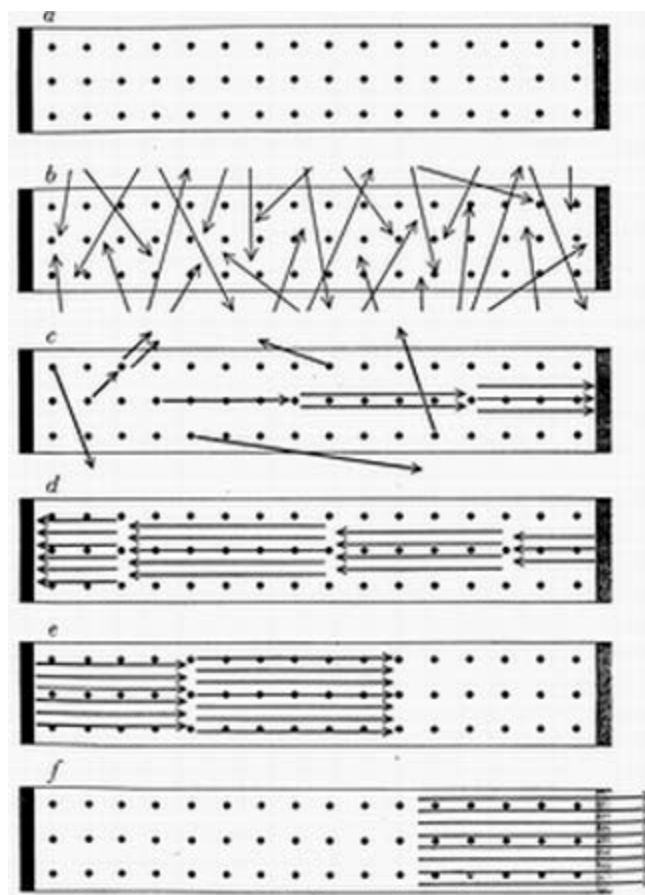


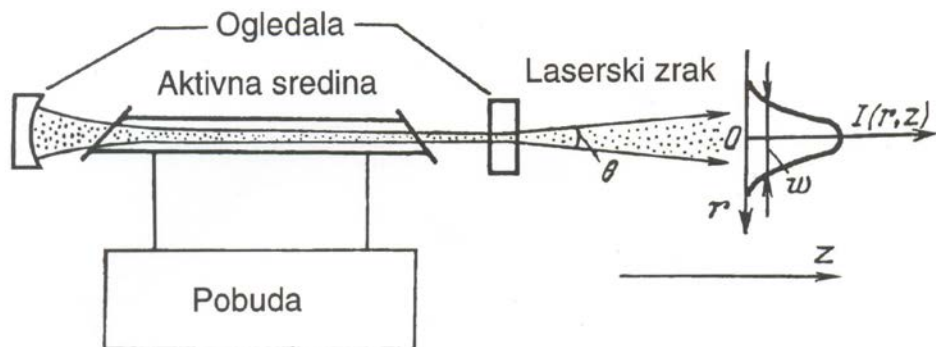
Slika 6. Tehnike kreiranja inverzije naseljenosti.

Slika 7. Proces pojačanja (sistem tri čestice).

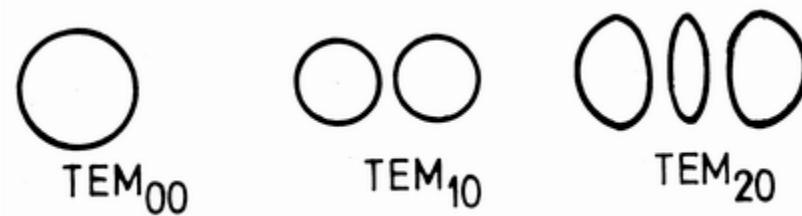


Slika 8. Procesi u laseru.





Slika 9. Dizajn lasera.



Slika 10. Modovi lasera.

- SAVREMENI IMPULSNI LASERI

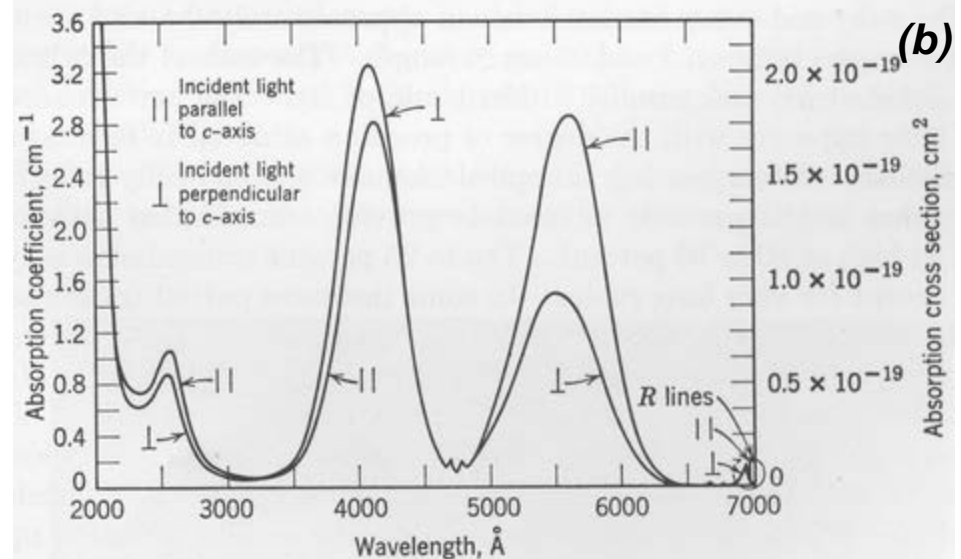
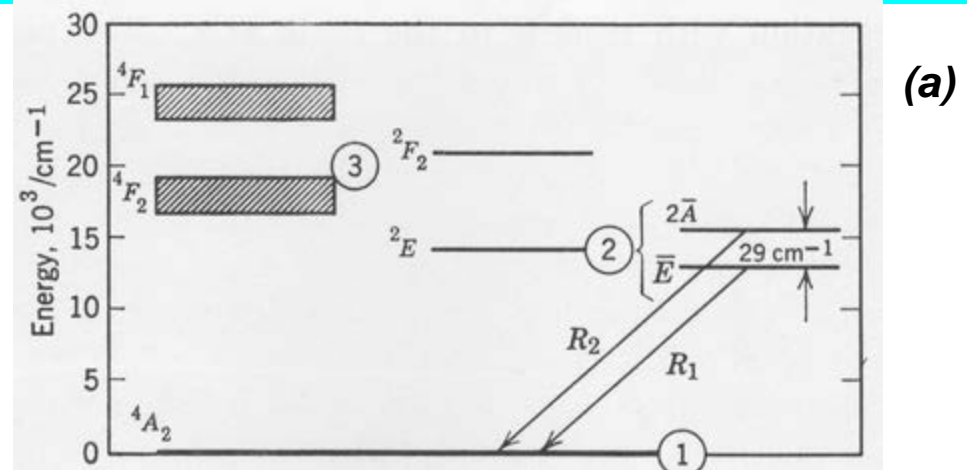
- Čvrsto-telni sistemi
- Tečni sistemi
- Gasni sistemi

- Čvrsto-telni sistemi

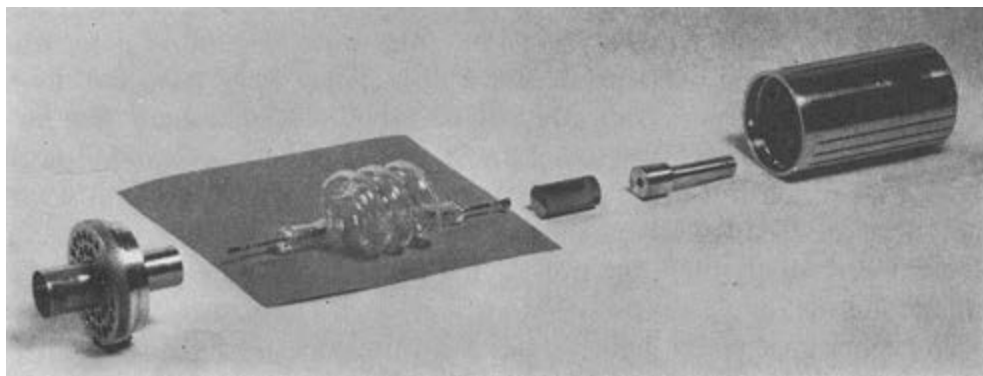
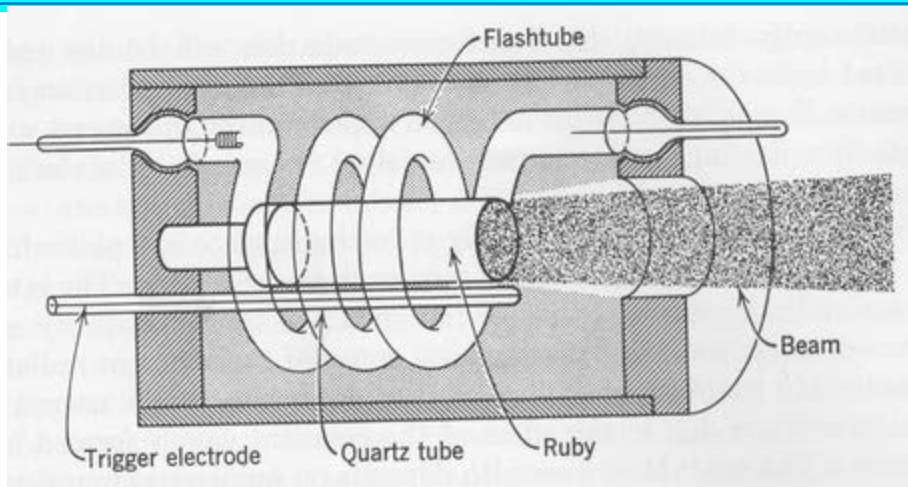
- Rubinski laser
- Nd:YAG laser
- Ti:Safirni laser

- Rubinski laser:

Al_2O_3 i 0,05% Cr_2O_3 (Cr^{3+}).



Slika 11. Energetski nivoi Cr^{3+} jona (u Al_2O_3) (a), apsorpcioni spektar rubina (b).

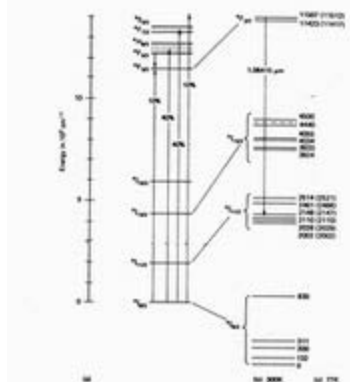


Izlazni parametri: E , 1-100 J;
 $\Delta\tau_{1/2}$, 1 ms (Q-switching, 10 ns);
 P_p , KW (MW, GW); λ , 694,3 nm;
 $\Delta\lambda$, 0,1-1 Å; θ , mrad; f , reda Hz.

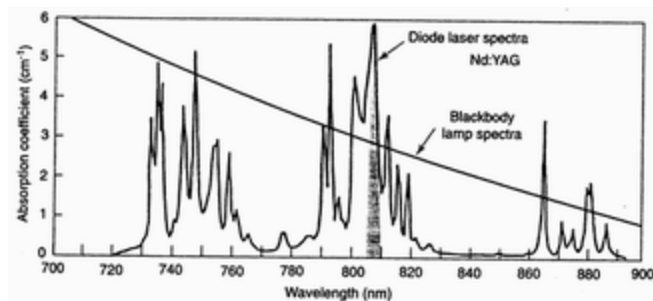
- Nd:YAG laser:

YAG i Nd_2O_3 . (Nd^{3+}).

Slika 12. Konstrukcija i fotografija rubinskog lasera.



(a)



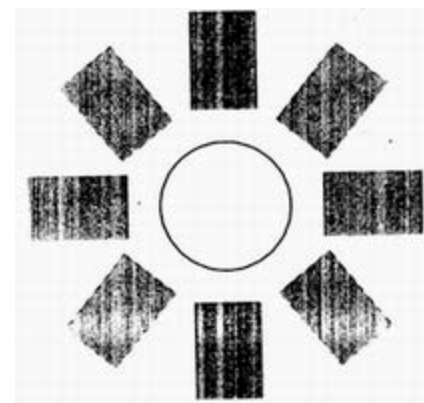
(b)

Slika 13. Energetski nivoi Nd^{3+} jona (u matrici YAG) (a), apsorpcioni spektar (b).

(a)



(b)



Slika 14. Konstrukcija Nd:YAG lasera.

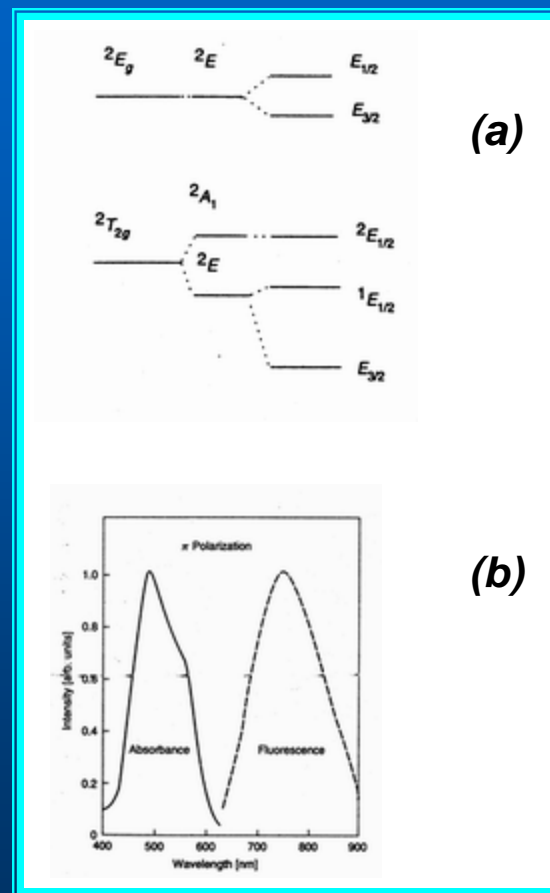
Izlazni parametri: E , 1-100 J; $\Delta\tau_{1/2}$, 1 ns (Q-switching); P_p , MW (GW); λ , 1064 nm; $1/\Delta\lambda$, 4 cm⁻¹; θ , mrad; f , nekoliko Hz.

- “mode locking”: E , 1-100 J; $\Delta\tau_{1/2}$, reda ps.

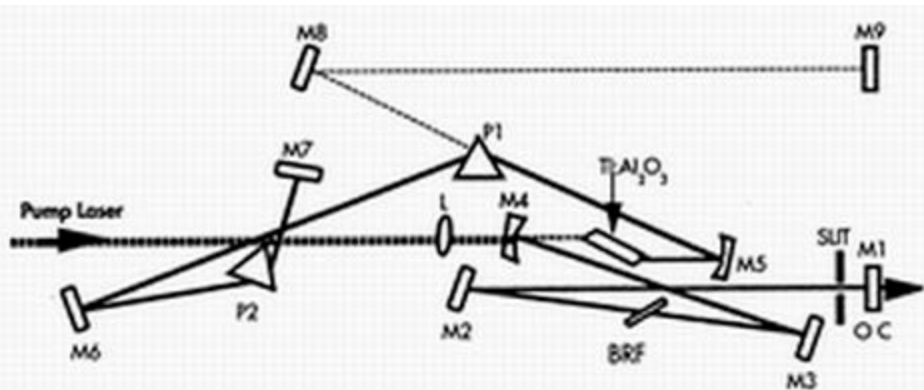
- λ , 1064 nm, 532 nm, 355 nm.

- Ti:Safirni laser:

$\text{Ti}^{3+} : \text{Al}_2\text{O}_3$ (Safir).



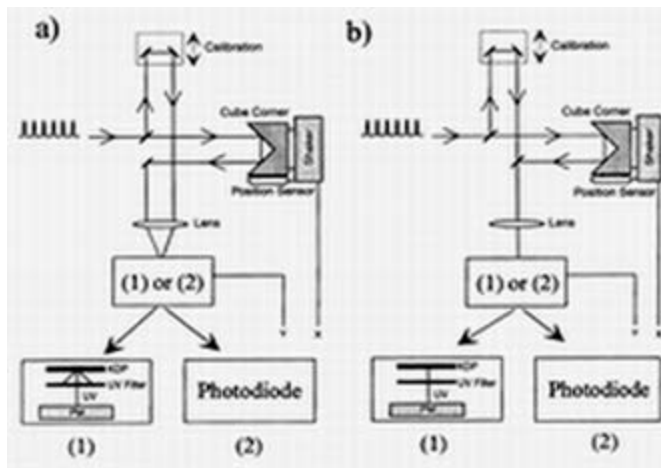
Slika 15. Energetski dijagram za Ti:safirni las. (a), apsor. i emis. spektar (b).



Slika 16. Konstrukcija Ti:Safirnog lasera.

Izlazni parametri: E , nJ do mJ; $\Delta\tau_{1/2}$, reda fs do 200 fs (mode-locking); P_p , MW (GW, TW); λ , 700 do 1000 nm; $\Delta\nu$, reda GHz; θ , mrad; f , MHz.

- pumpanje, Ar^+ laserom; “mode-locking” (“Kerr-lens” tehnika).
- merenje kratkog impulsa: vremenski auto-korelator.
- atosekundni impulsi: SRR; VH.

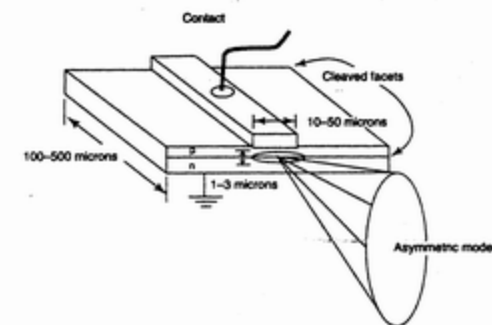


- Poluprovodnički laseri:

Slika 17. Auto-korelator.

GaAlAs, λ , 808 nm (Nd:YAG las.)

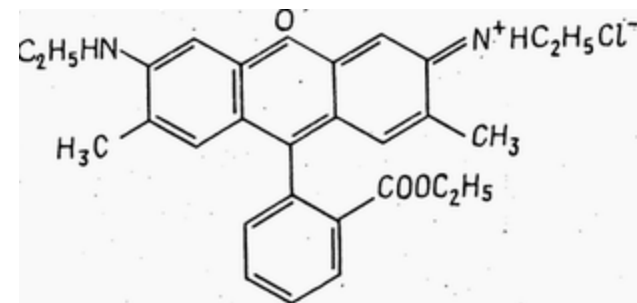
**Izlazni parametri: E, pJ do nJ; $\Delta\tau_{1/2}$, 1 ns (ps);
 **P_p , reda W; λ , 375 do 1060 nm; $\Delta\lambda$, 3 nm;
 θ , reda 10 mrad; f, do MHz.****



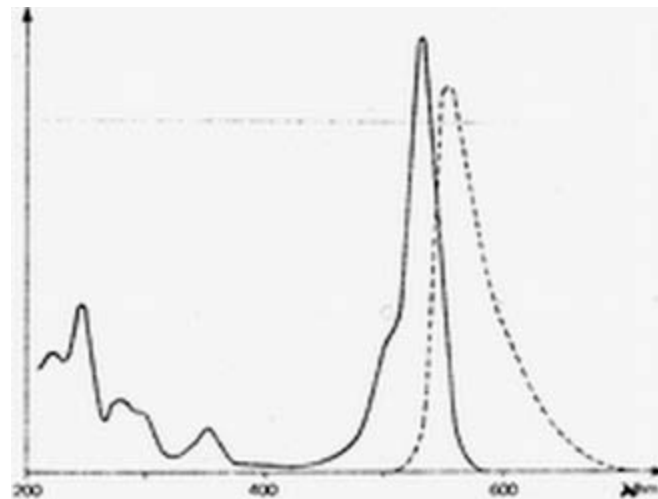
Slika 18. Izgled PP lasera.

- Tečni sistemi

- Dye: Rodamin 6G/rastvarač

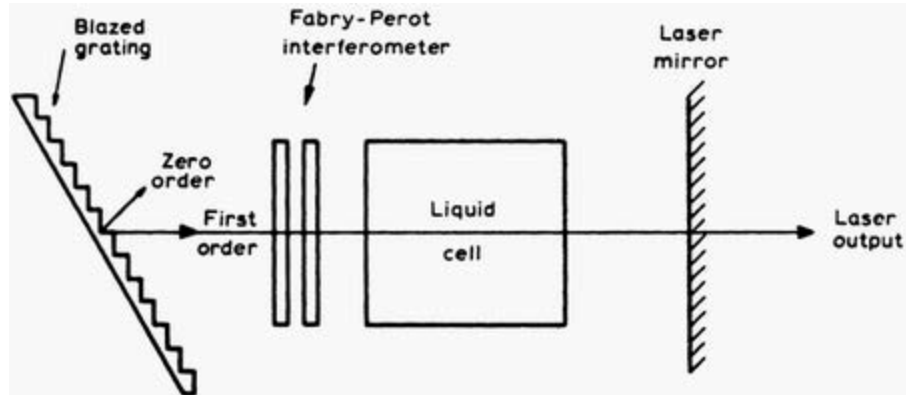


(a)



(b)

*Slika 19. Struktura Rodamina 6G (a),
spektar R 6G u etanolu (b).*



Slika 20. Konstrukcija tečnog lasera.

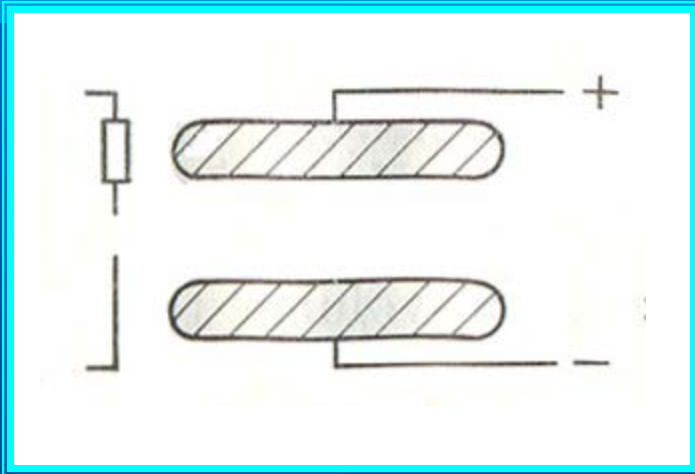
Izlazni parametri: E, reda J; $\Delta\tau_{1/2}$, 1 ns (ps, fs- domen); P_p , MW; λ , 340 do 1175 nm; $\Delta\lambda$, 0,5 do 0,01 Å; θ , mrad; f, 100 Hz.

- Gasni sistemi
 - TEA CO₂ laser
 - Excimerni laseri
 - Hemijski laseri
 - Optički pumpani laseri

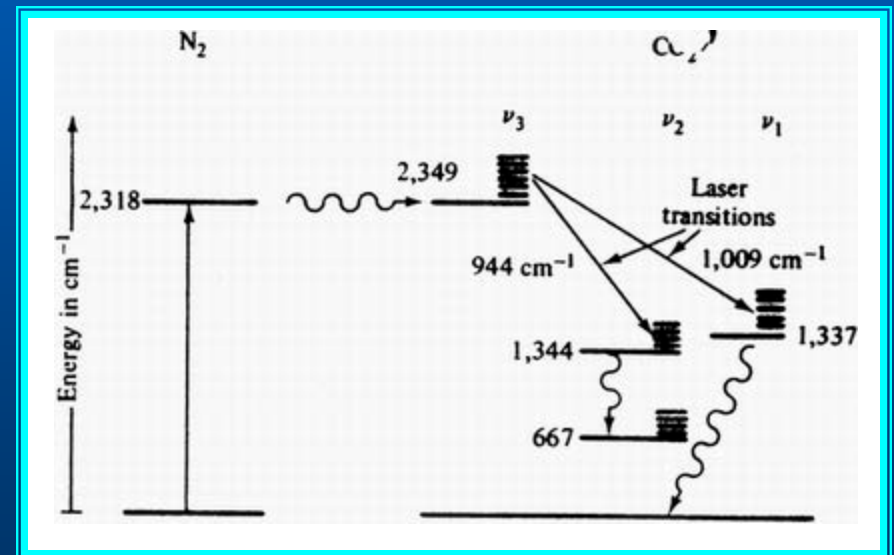
-TEA CO₂ laser:

Transversely Excited Atmospheric

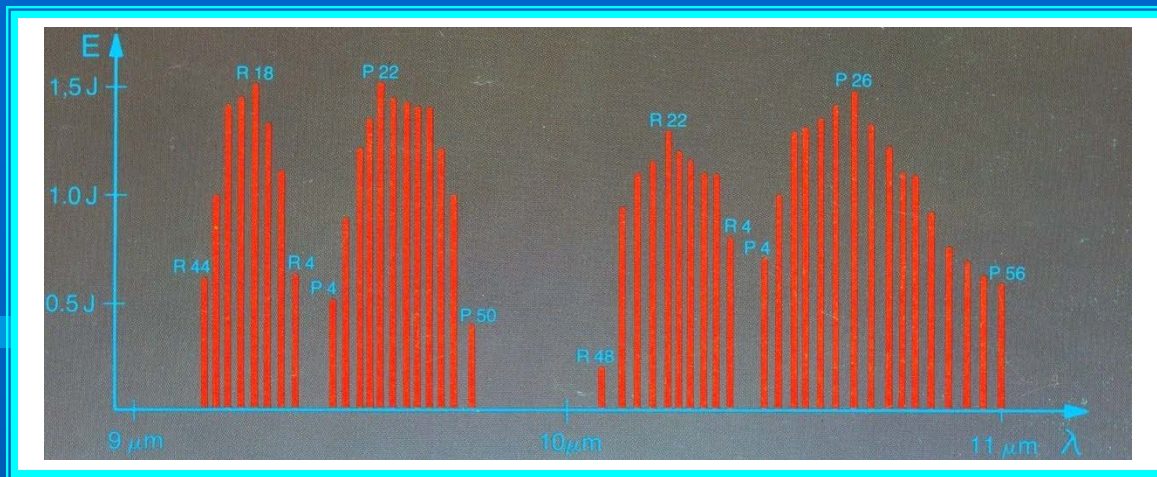
CO₂/N₂/He; 1 atm



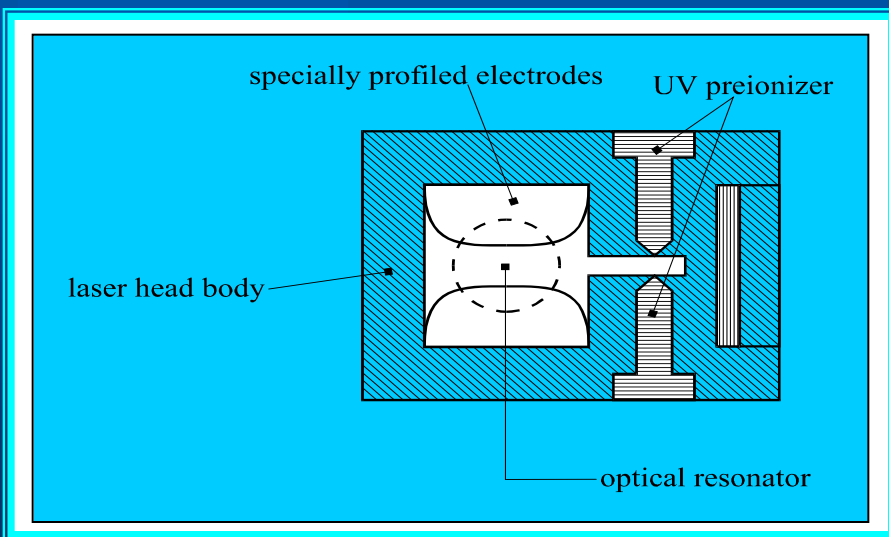
Slika 21. Šematski prikaz TEA CO₂ lasera.



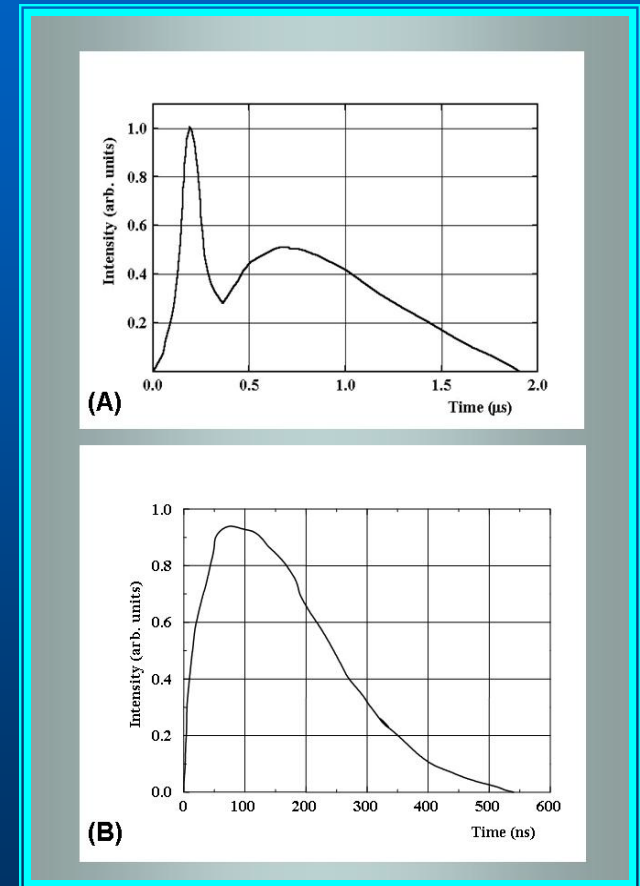
Slika 22. Energetski nivoi CO₂ molekula.



Slika 23. Opseg zračenja TEA CO₂ lasera.



Slika 24. Dizajn TEA CO₂ lasera.



Slika 25. Vremenski oblik TEA CO₂ (A) i HF (B) lasera.

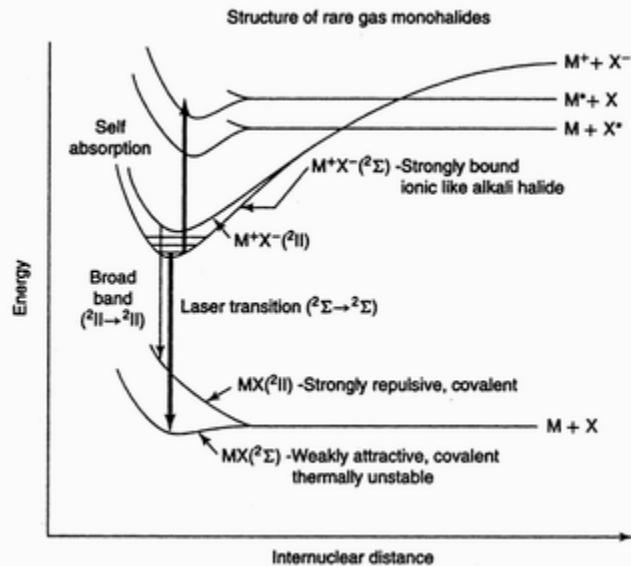


Slika 26. Foto TEA CO₂ lasera.

Izlazni parametri: E , do 100 J; $\Delta\tau_{1/2}$, reda μs , ns, ps; P_p , MW (GW);
 λ , 10,6 μm ; $\Delta\nu$, 1 GHz; θ , mrad; f , KHz.

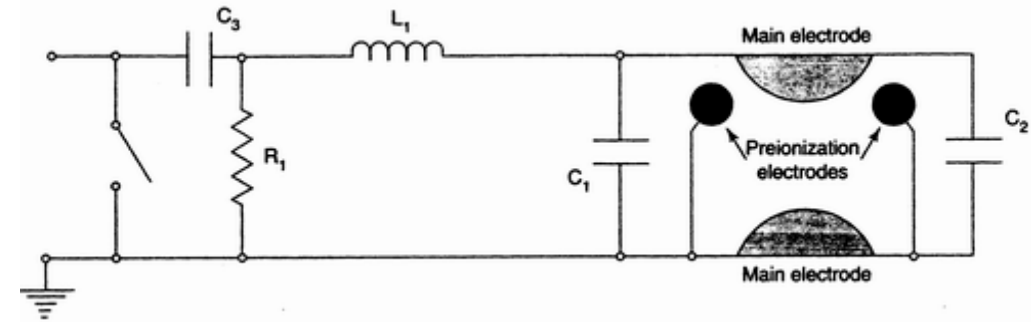
- Excimerni laseri:

- XeCl; KrF; ArF; F₂, itd.



Slika 27. Energetski nivoi excimernih molekula.

- dizajn lasera: Sl. 28; p - reda atm



Slika 28. Dizajn excimernog lasera.

Izlazni parametri: E , do J; $\Delta\tau_{1/2}$, reda ns; P_p , MW (GW); λ , 150 do 308 nm; $\Delta\nu$, GHz; θ , mrad; f , KHz.

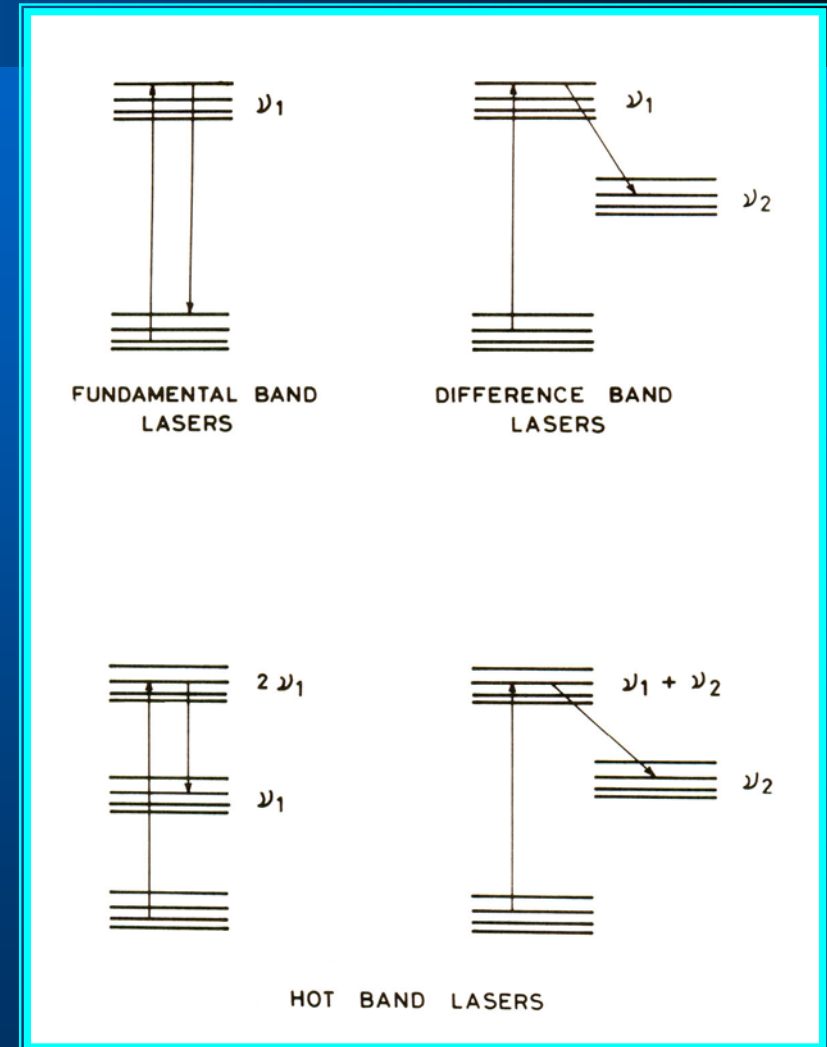
- Hemijski laser:



$\text{HCl}^*, \text{CO}^*, \text{itd.}$

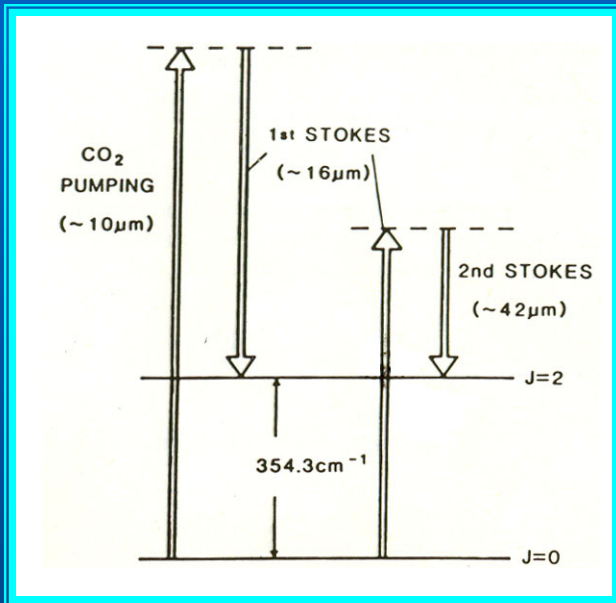
- Optički pumpani laseri:

$\text{NH}_3; \text{CF}_4; (p\text{-H}_2); \text{itd.}$
(npr. pumpanje TEA CO_2 las.).

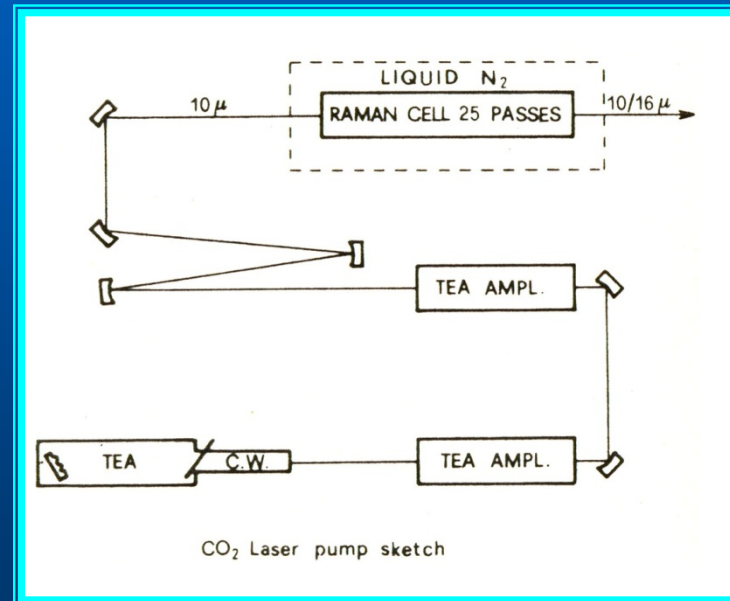


Slika 29. Šema opt. pum. lasera.

- Optičko pumpanje: $p\text{-H}_2$ laser



Slika 30. Energ. nivoi $p\text{-H}_2$.



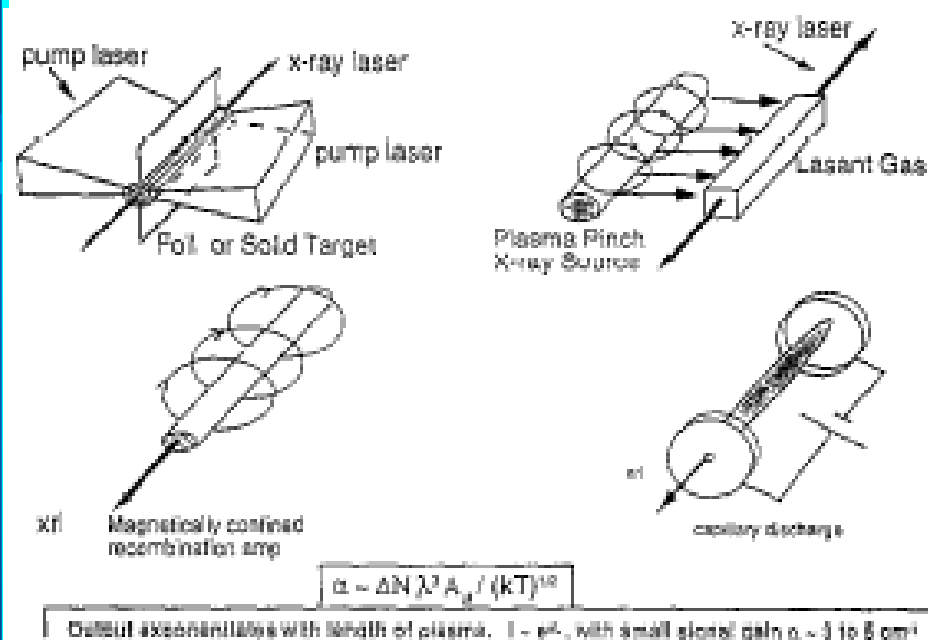
Slika 31. Dizajn opti. pumpanog $p\text{-H}_2$ lasera.

- Plazma laseri

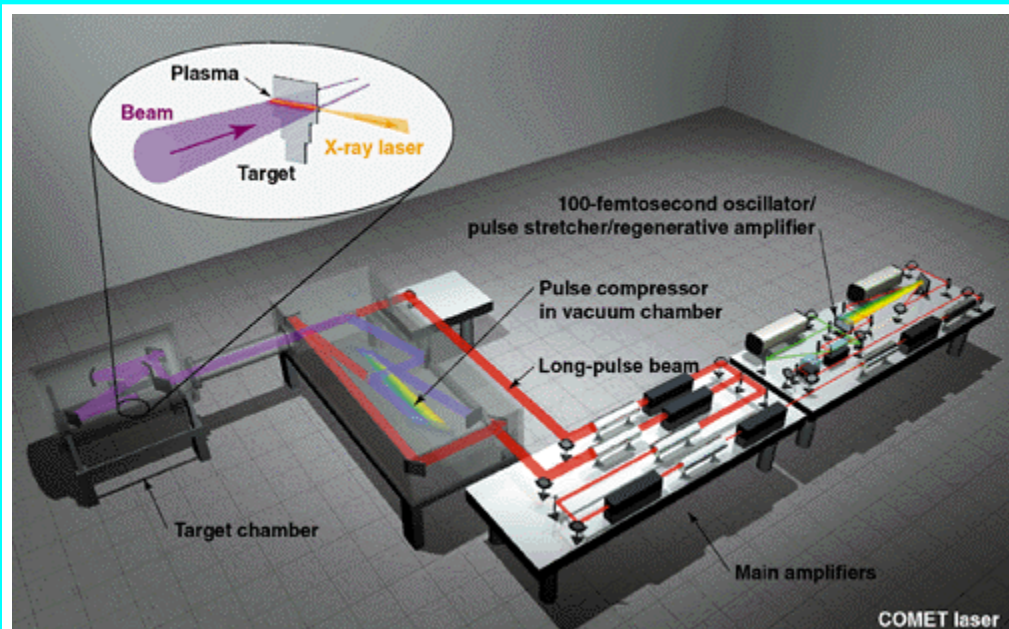
- X- laseri:

“Ne- like” Ar jon; λ , 46,68 nm.

“Ni- like” Pd jon; λ , 14,7 nm.



Slika 32. Dizajn “X-ray” lasera.



Slika 33. Šema “X-ray” lasera.

Karakter. pump. lasera: P_p , TW; λ , 1054 nm,
 $\tau_{1/2}$, 500 fs; f , 1-4 imp/min.

Izlazni parametri: E , $\mu\text{J/mJ}$; $\Delta\tau_{1/2}$, 0,02 do 3 ns; P_p , MW (GW); λ , 3,5 do 50 nm; θ , mrad; f , reda Hz.

- Jodidni laser: $\text{C}_3\text{F}_7\text{I} + h\nu_1 \rightarrow \text{C}_3\text{F}_7 + \text{I}^*$, $\text{I}^* \rightarrow h\nu_2$, 1,315 μm .
- Laseri na bazi metalnih para: Cu, Au, itd.
 - Cu laser, λ (510,5; 578,2 nm).
- “Free Electron Laser”

Lasери na bazi slobodnih elektrona

- Zaključak:

- PRIMENE IMPULSNIH LASERA u FH

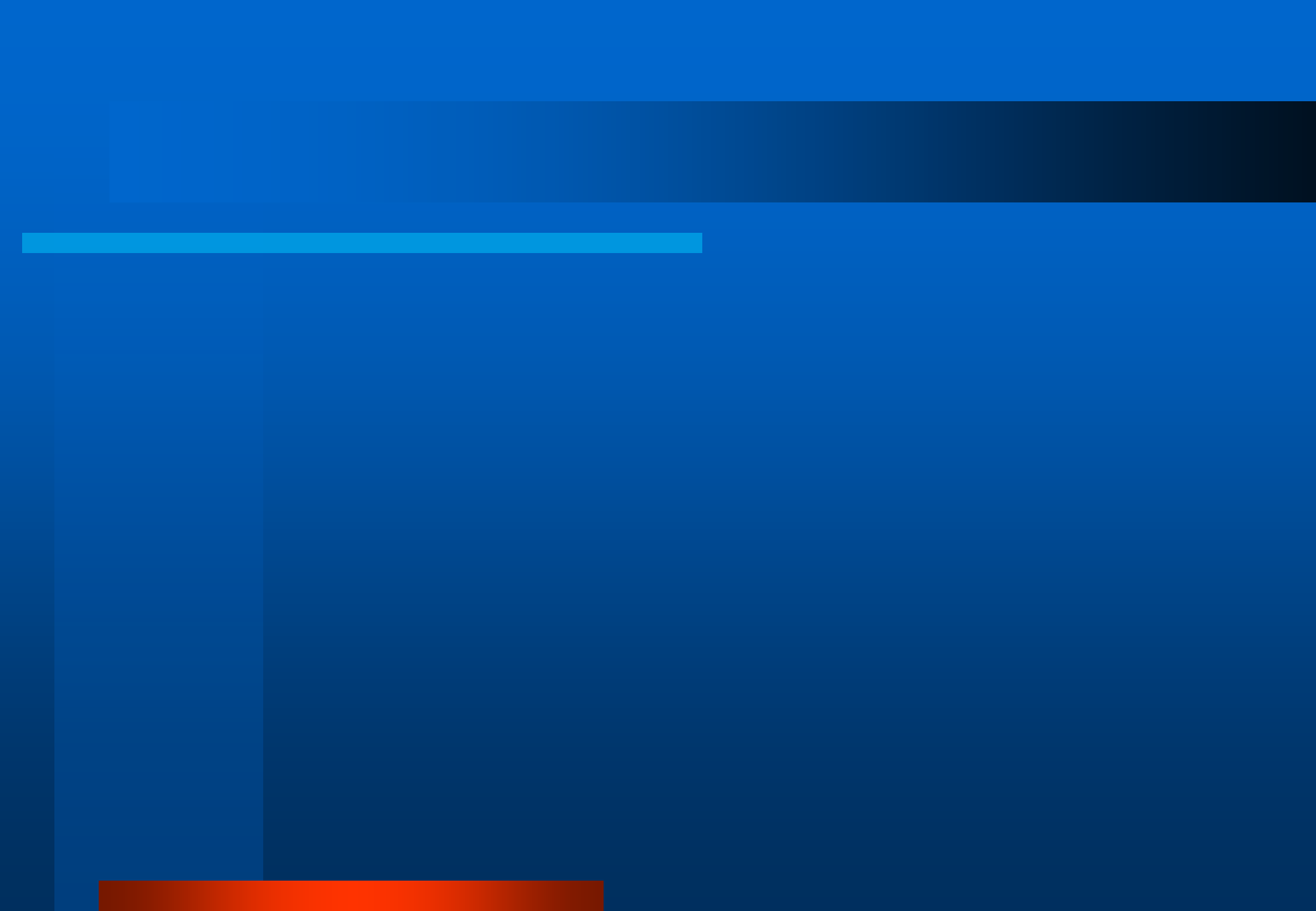
Osobine laserskog zračenja:

- Intenzivnost
- Monohromatičnost
- Usmerenost
- Koherentnost

E ; $\Delta\tau_{1/2}$ (ms, μ s, ns, ps, fs, as).

P_p (kW; MW; GW; TW; Peta-W; Exa-W).

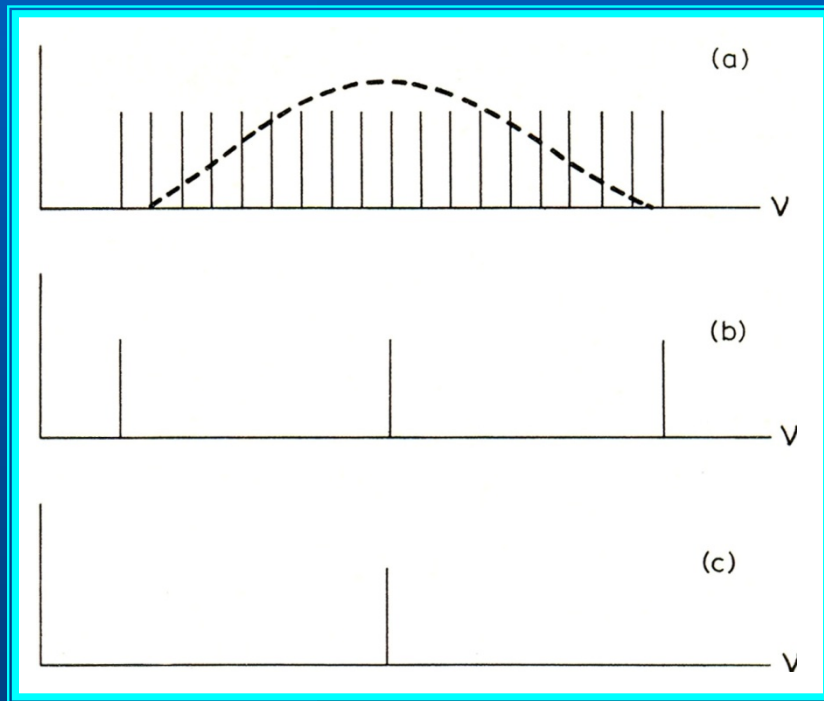
- Las. indukovanje i kontrola hem. reakcija
- Preparativna hemija
- Analitička hemija/Spektrohemijska
- Dijagnostika hemijskih procesa, itd.



Aksijalni modovi:

$$n \cdot \lambda/2 = L; \nu = nc/2L; \Delta\nu = c/2L.$$

$$(L = 50 \text{ cm}, \lambda = 0,5 \text{ } \mu\text{m}, n = ?; n = 2 \cdot 10^6).$$



Slika 34. Kriva pojačanja i aksijalni modovi.