Pumping

Mechanism depends on gain medium
- solid state (ion-doped host crystal/glass), dye
  → optical (lamp or laser-pumped)
- gas
  → collisional (discharge or e-beam)
- semiconductor
  → electrical

others: chemical, gas dynamic, x-ray.

We'll concentrate on optical pumping of solid-state lasers.

Pumping issues dominate the practical performance/cost of the laser:

- what is the efficiency?
  > wall plug: $\frac{\text{optical out}}{\text{power in}}$

	~ 75%	laser diodes
	~ 50%	Diode pumped solid state
	~ 1-2%	lamp-pumped solid state.
	< 10^{-5}	X-ray laser.

- how to handle thermal load?
  > cool crystal, still get power in/out.

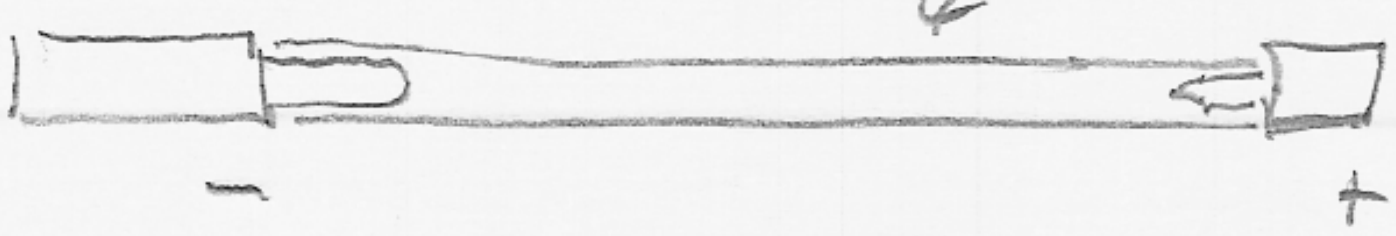
- pump spatial distribution → beam quality.

All these considerations → overall cost + size of the system.

Lamp pumping:

- flashlamp - pulsed 10 μs - 1 ms typ ~100 μs
- arc lamp ~ CW

Flash lamp: ↙ 500 - 1500 Torr Xe or Kr.



sequence: HV spark to initiate discharge.
low simmer current to maintain
dump current pulse through gas.
collisions drive emission

power supply:

- slow charge of capacitor to selected voltage.
- trigger to discharge capacitor
- LC pulse-forming network → critically-damped pulse.

Coupling of lamp light to gain medium:

1-2 lamps focusing ellipse
close-coupled.

cooling: water flows along rod, lamp

others: zig zag slab (difficult to cool)
brewster plates (air cooled, single-shot)

Spectral overlap:

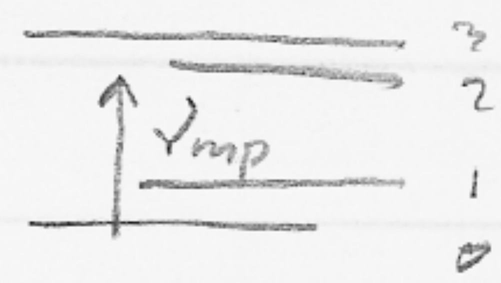
- line emission of Xe, Kr overlaps w/ some pump bands.
- filter to block UV to prevent solarization damage.

Pump efficiency:

For a given pump rate R_p

$$\eta_p = \frac{P_m}{P_p} = \frac{\text{pumping power}}{\text{electrical input power}}$$

$$P_m = \left(\frac{dN_2}{dt}\right)_p \cdot V h\nu_{mp}$$



→ net rate $0 \to 1 = R_p$

if pumping is not uniform, integrate over volume.

pulse-pump: integrate over time (or use $R_p(t)$)

breakdown: η_p is product of efficiencies

η_r · electrical to radiative, including spectral overlap w/pump bands

η_t transfer effic: pump light thru surface of rod.

η_a absorption effic.

η_{pq} once absorbed, fraction → level 2

nominally $\lambda_{pump} / \lambda_{laser}$

also includes effects of non-radiative channels

Laser pumping:

- disadvantages cost (usually).
- advantages: - more effic. absorption
  - tune closer to λ_{laser}, less heating.
  - pump only laser mode volume, focus tight
  - higher pump fluence: can use gain media w/ short storage time.

laser diode pumping

- limited wavelengths, stabilize temperature to stabilize λ
- very efficient
- typically CW pumped.
- high aspect ratio for beam size
  - > gaussian, but diff't widths
  - → cyl. lenses or anamorphic prism pair.
  - also use multimode fiber.

end-pumping

transverse pumping.

Effective pump rate

mode-averaged rate

$|u(r,z)|^2$ = intensity of mode w/in crystal

$R_p(r,z)$ = pump rate w/in crystal

$$\rightarrow \langle R_p \rangle = \frac{\int R_p |u|^2 \, dV}{\int |u|^2 \, dV}$$

longitudinal pump:

if $|u|^2 \propto e^{-2r^2/w_0^2} \cos^2 kz$ standing wave.

$$\rightarrow \langle R_p \rangle = \eta_r \eta_t \frac{P_p}{h\nu_p} \frac{2(1-e^{-\alpha l})}{\pi(w_0^2 + w_p^2) l}$$

smaller pump is best