Nanosecond lasers

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Types of pulsed lasers

1) Long pulse lasers (typically* $\mu$s – ms range)

*Except for laser diodes and excimer lasers.

*The laser output is pulsed because the ‘pump’ is pulsed.

Examples: flash lamp, high pressure discharge, pulsed electrical current.

Alternative laser name: free running laser

2) Q-switched lasers (ns – $\mu$s range)

*The laser output is pulsed because a high amount of ‘inversion’ is suddenly released.

Alternative laser name: nanosecond laser

3) Mode-locked lasers (fs – ps range)

*The laser output is pulsed because many laser modes are oscillating simultaneously in the cavity and are coherently superposed.

Alternative laser name: femtosecond laser

*Except for laser diodes and excimer lasers.
Q-switched lasers: Working principle

- **Q-switching**
  - Flash lamp pumped q-switched laser
  - Working principle:
    - Laser output pulse
    - Q-switch
    - Cavity loss
    - Gain \( \propto \dot{N}(t) \)
  - Pulse output interval
  - Pumping interval

- **Spiking**
  - Q-switching phenomenon
  - Interval between pulses
  - Peak power

**Equations and Graphs**
- \( Q(t) \)
- \( N(t) \)
- \( n(t) \)
- \( T_b \)
- \( \tau_p \)
- \( N_f \)

**Key Concepts**
- Q-switched lasers
- Working principle
- Flash lamp pumped
- Q-switching
- Spiking

Q-switched lasers: switching devices

- Rotating mirror: Hardly used
- Electro-optic: The usual method: Pockels-cell (EOM) and polarizer
- Acousto-optic: Acousto-optic modulator (AOM)
- Saturable absorber: Very compact, but less control over the pulse
- Thin-film absorber
Q-switched lasers: mode competition 1

Lasing starts from spontaneous emission (quantum noise)

Due to high inversion, many modes have enough gain to start oscillating.

The different modes have arbitrary phase relation (different in each pulse)

Interference between modes: mode beating: ps-duration intensity spikes

For a reasonable budget measurement is not possible (>15 GHz bandwidth).
In average the peak intensity is two times higher than for the mono-mode pulse.
Q-switched lasers: mode competition 2

The only way to get a high-power single longitudinal mode (SLM) output from a q-switched laser is to give the best starting conditions to the most amplified mode.

Keyword: injection seeding  (The reliability depends on the laser manufacturers.)

Schematics of an injection-seeded laser:

Seed laser:
cw, spectrally fine

Mirror on piezo:
stabilize one longitudinal laser resonator mode at the frequency of the seed laser.

The pulse build-up time is reduced when the laser is seeded.

https://www.rp-photonics.com/injection_seeding.html
Q-switched lasers: Peak power

Is much higher than the average power of the same laser without q-switch.

A continuous wave laser

Energy of the beam during a certain time.

Average power \(P_{\text{moy}}\)

\(P\) vs. time \(t\)

A pulsed laser emitting a pulse train

Peak power \(P_{\text{max}}\)

\(P_{\text{max}} = \frac{E_P}{\tau_p}\)

Energy per pulse \(E_p\)

(measured in J)

Pulse duration \(\tau_p\)

Time between two pulses = \(1/(\text{pulse repetition rate})\)

Not exactly the same average power in q-switched mode compared to cw or free running mode: higher fluorescence losses.
Q-switched lasers: continuous pumping

Giant pulse suppression avoids damage during switch-on.

Maximum pulse repetition rate depends on the host material:

- **Nd:YAG**: 25 kHz
- **Nd:YVO\textsubscript{4}**: 200 kHz

Maximum average power:

- **Nd:YAG**: 150 W
- **Nd:YVO\textsubscript{4}**: 200 W
Q-switched lasers: typical applications

Nonlinear optics, material processing, ...

Capacitor trimming

Marking, engraving

Medical skin treatment
Q-switched lasers: application movies

Capacitor trimming

Marking, engraving