Pulsed Laser Behavior

Desirable: * pulsed pump
* Q-switching
* mode-locking

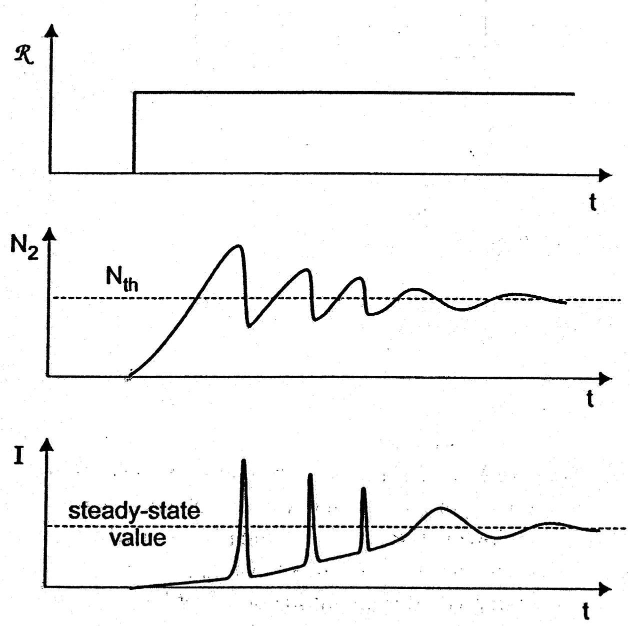
Undesirable: spiking

Basic equations:

$$\frac{dN_2}{dt} = \mathcal{R} - N_2\left(\frac{I\sigma}{h\nu} + \frac{1}{\tau_2}\right) \qquad (1)$$

$$\frac{dI}{dt} = \left(c\sigma N_2 - \frac{1}{\tau_c}\right) I \qquad (2)$$

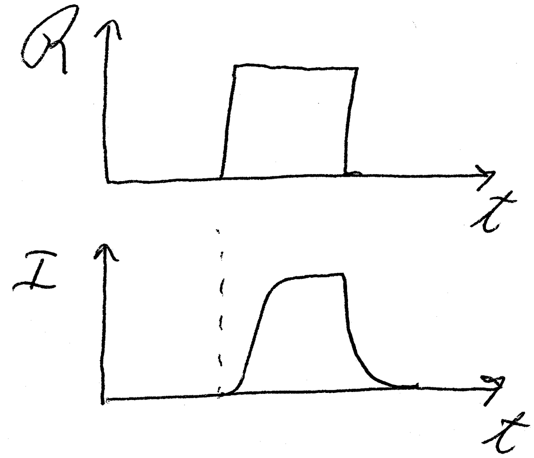
For a step input pump



Some lasers (e.g. ruby) do not reach steady-state, but instead exhibit spiking, a series of randomly spaced pulses.

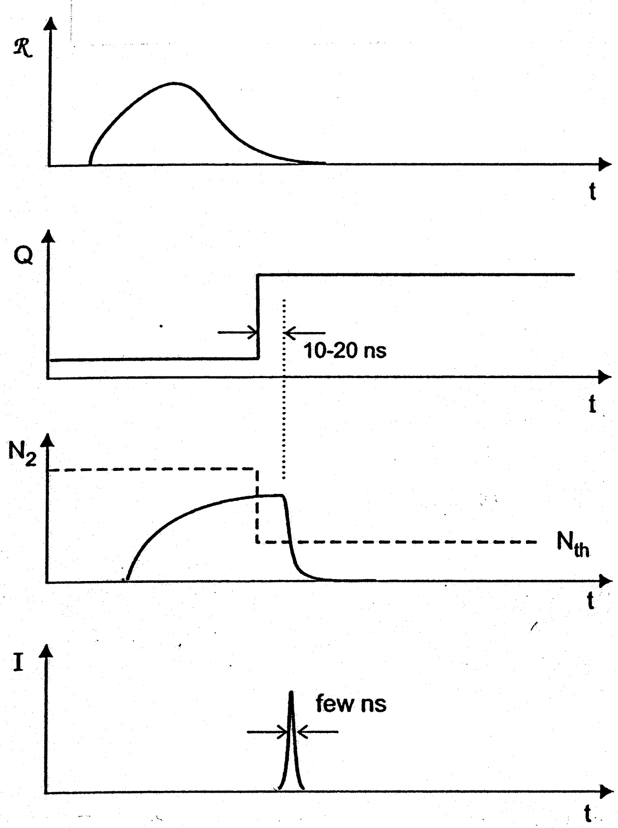
Time scale 1–10 μs

Pulsed pump



* common for semiconductor lasers
* difficult to get short pulses with optical excitation
* often used in combination with Q-switching and mode-locking

Q-switching



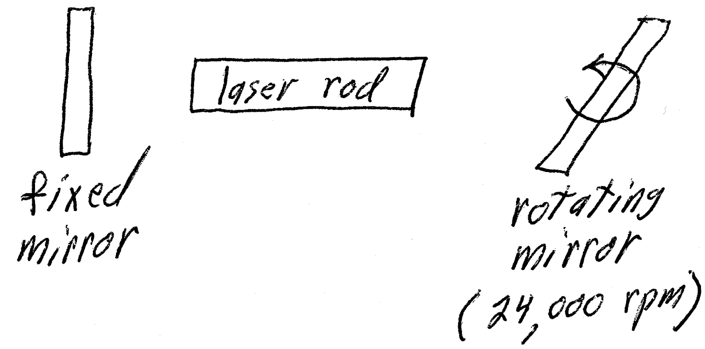
$$Q = \frac{\nu_0}{\Delta\nu_{1/2}} = 2\pi \nu_0 \tau_c$$

$$N_{th} = \frac{1}{c\sigma\tau_c} = \frac{2\pi\nu_0}{c\sigma Q}$$

* Must switch Q within ~10 ns
* stored energy is quickly channeled into single pulse.
* pulse width ~ few ns
* can also repetitively Q-switch with cw pump.

Methods of Q-switching

1. Rotating mirror



$\Delta\theta \simeq \frac{d}{L} \approx 10^{-3}$ rad

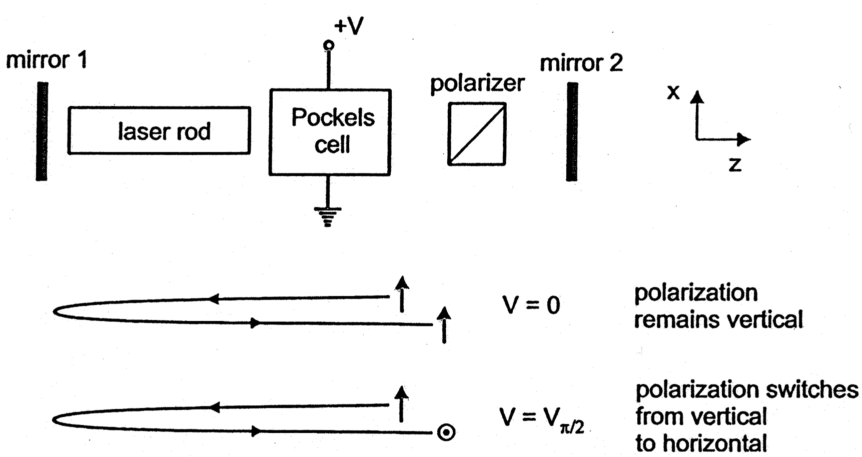
$\omega t_{sw} = \Delta\theta$

$t_{sw} = \frac{10^{-3} \text{ rad}}{2500 \text{ rad/s}}$

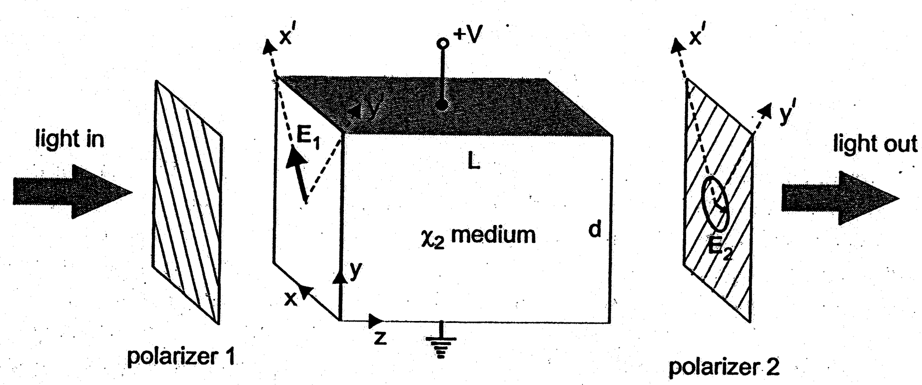
$t_{sw} = 400$ ns

"slow" switch (μs time scale)

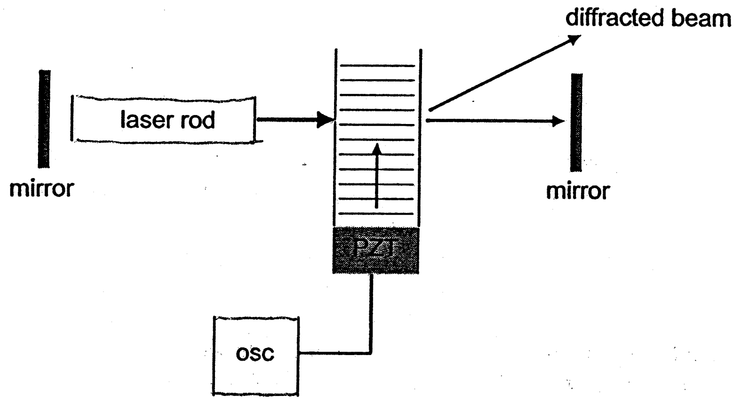
2. Electro-optic shutter

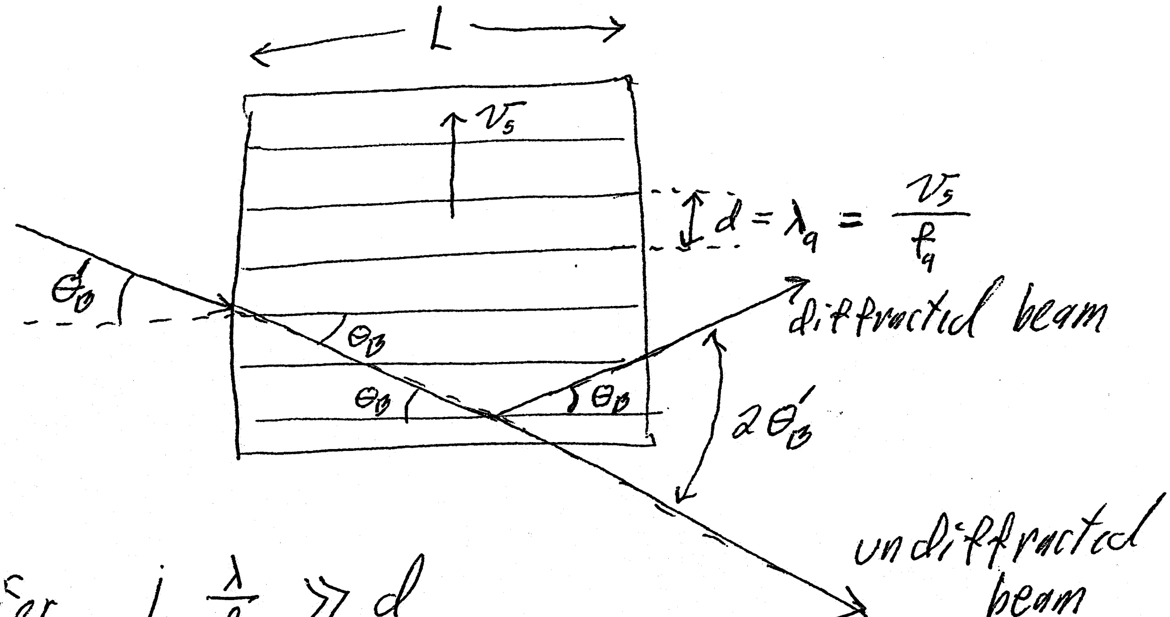


- * Pockels effect-induced birefringence
- * Need high voltage (kV)
- * can be fast ($\lesssim 20$ ns)



3. Acoustooptic shutter





for $L \frac{\lambda}{d} \gg d$

have Bragg condition

$$\theta_B = \frac{\lambda/n}{2d} \qquad (\text{small } \theta_B)$$

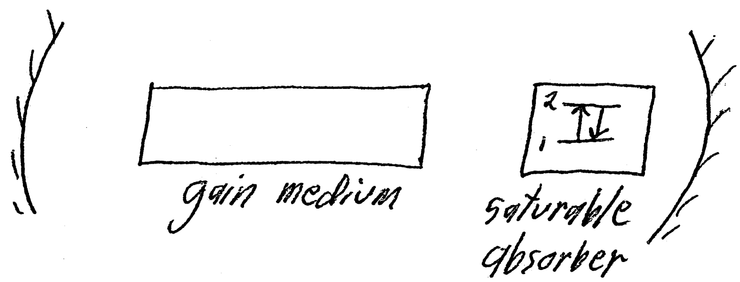
For small θ, using Snell's Law, $\theta_B' = n\,\theta_B$

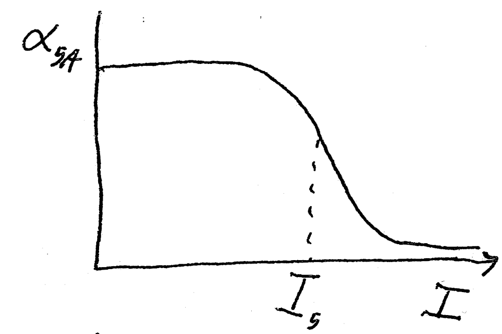
So

$$\boxed{\theta_B' = \frac{\lambda}{2d}}$$

λ is free-space wavelength

Passive Q-Switching



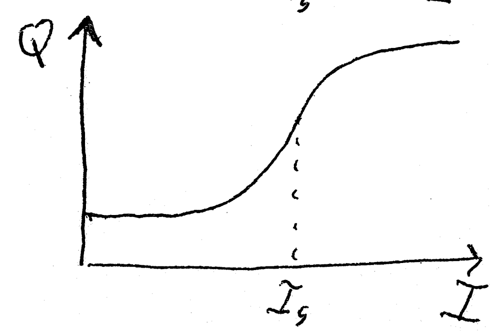


loss in saturable absorber

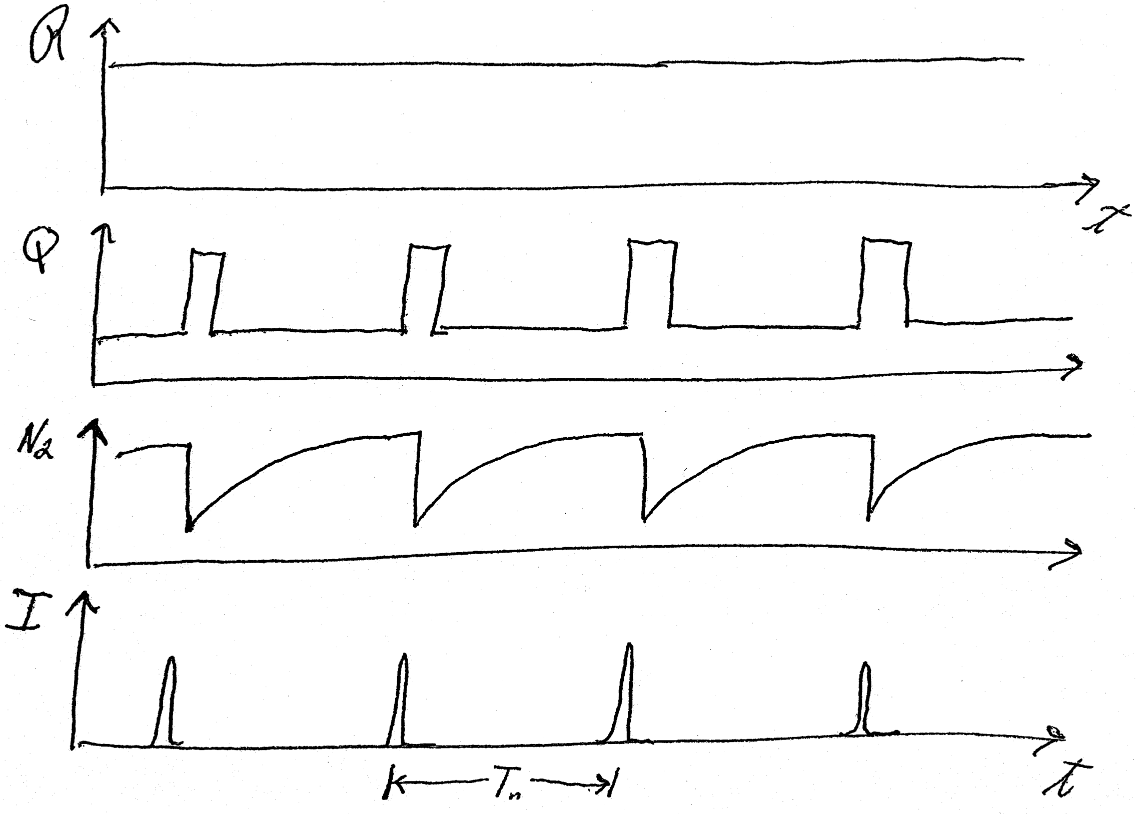
$$\alpha_{SA} = (N_1 - N_2)\,\sigma_{SA}$$

As I increases, $(N_1 - N_2)$ decreases

$$\alpha_{SA} = \frac{\alpha_0}{1 + I/I_s}$$



Repetitive Q-Switching



optimum

$T_p \simeq \tau_2$

$\Delta t_p \sim$ few ns