Laser Pulsing Techniques

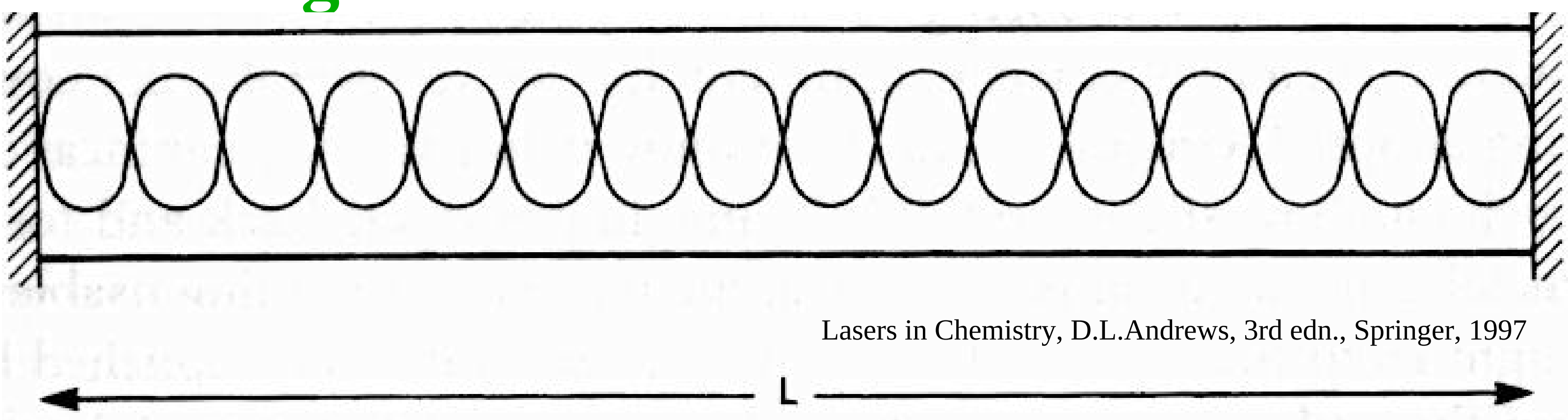
modes, mode locking, cavity dumping,pulse compression, grating pairs, femtosecond pulses

Energy and Power

- **energy of a photon: $\varepsilon = h\nu$**
- **h, plank's constant in J s photon^{-1}, ν in s^{-1}**
- **i,e. energy is Joules per photon**
- **photon beam passes unit area per unit time, or energy area^{-1} time^{-1}**
- **power is energy time^{-1}**
- **energy is power area^{-1}, or watts m^{-2}**

Standing Wave between Mirrors

- **nodes at ends of cavity - coherence**
- **integer # of half-wavelengths gives constructive interference**
- **$m\lambda/2 = L$**
- **several million half λ's**
- **range restricted by gain bandwidth of lasing medium**



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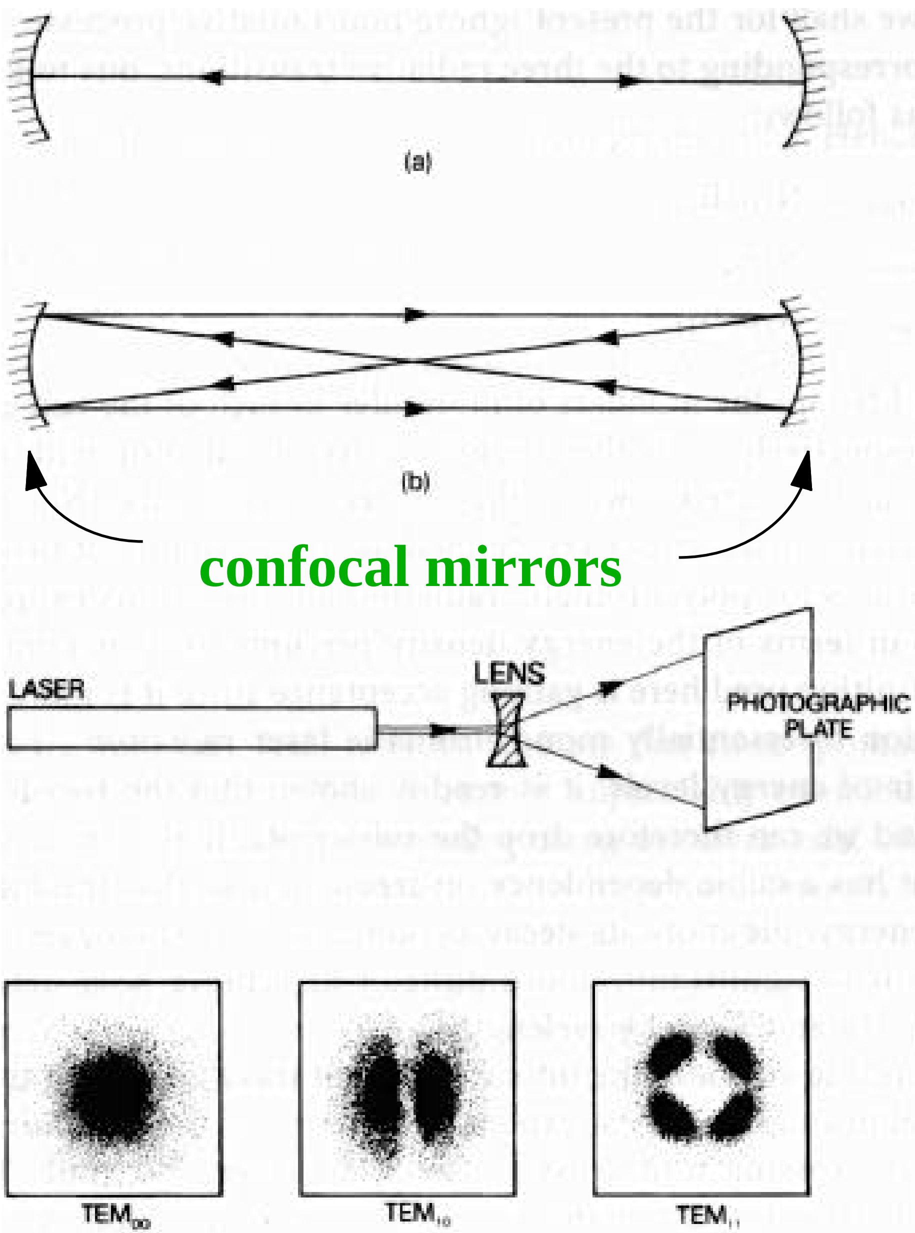
TEM modes



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a) on axis TEM_{00}*

b) off axis TEM_{10}

- **(TEM_{pq}) confocal**
- **p, q, # intensity min.**

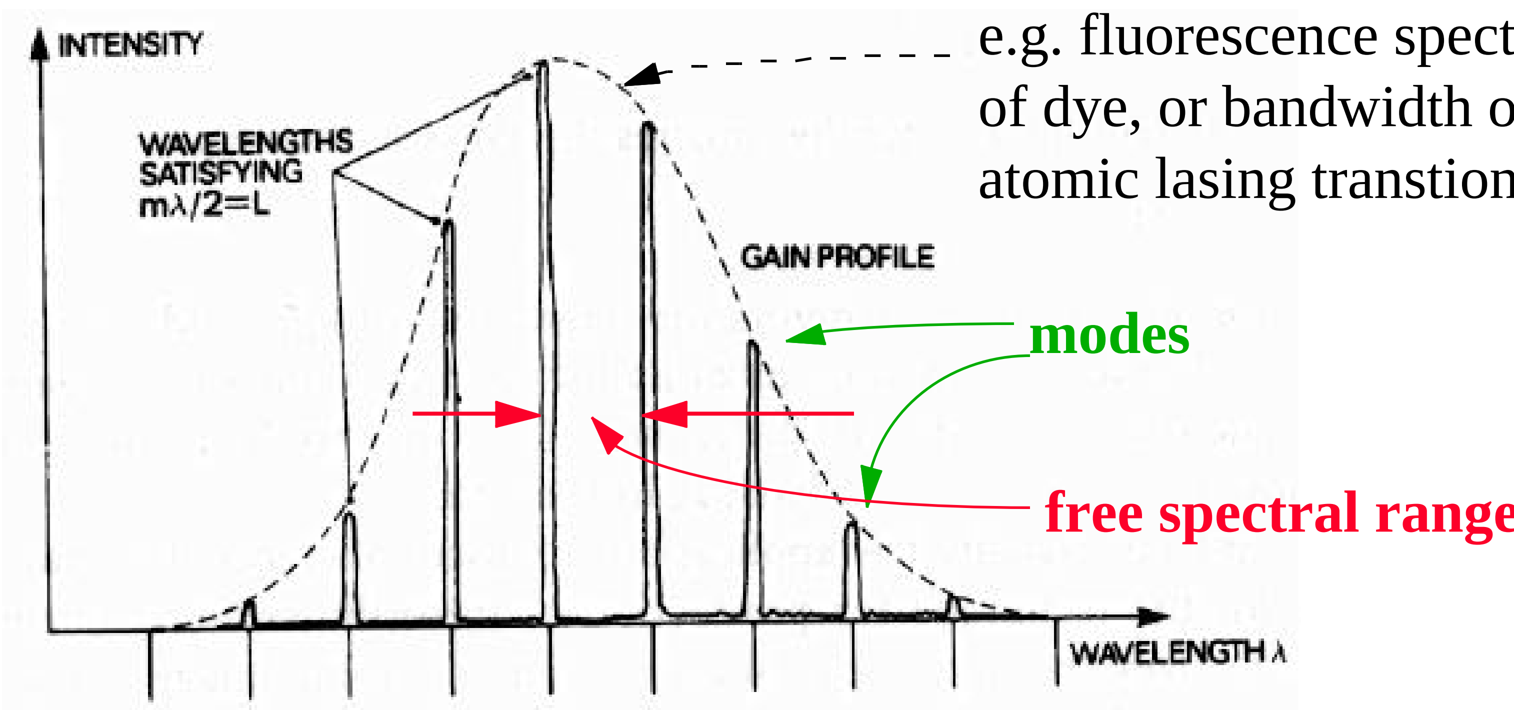
multimode - less coherence

narrow cavity $\Rightarrow$ TEM_{00}

*transverse electromagnetic mode

Laser Gain Profile

- **modes - different wavelengths, $m\lambda/2 = L$**



e.g. fluorescence spectrum of dye, or bandwidth of an atomic lasing transtion, etc.

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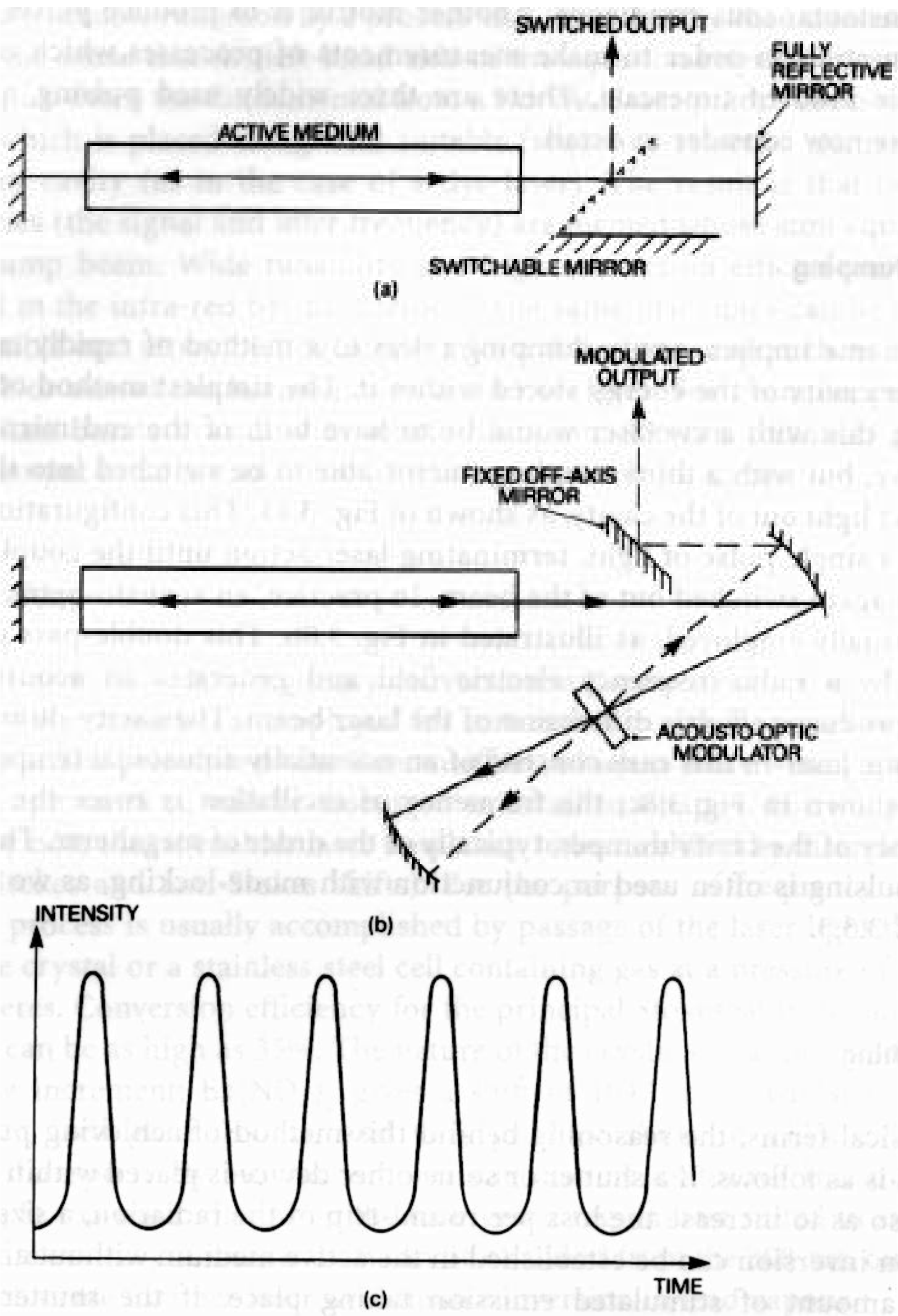
monochromaticity

- **gratings and etalons - isolate modes**
- **linewidth e.g. 1 cm^{-1}**
  - **wavenumber $\Rightarrow$ $1/\lambda = \tilde{\nu}$**
- **Quality factor, $Q = \nu / \Delta \nu$,**
- **$\nu \Rightarrow$ frequency, $\Delta \nu \Rightarrow$ spectral linewidth**
  - **can be 10^8**
  - $\Delta \lambda = \lambda / Q$
  - $\Delta \tilde{\nu} = \Delta \lambda / \lambda^2$



Cavity Dumping

- fully reflective mirrors + switchable mirror to give single pulse
- diffraction at AOM modulated at MHz ns pulses
- sinusoidal output

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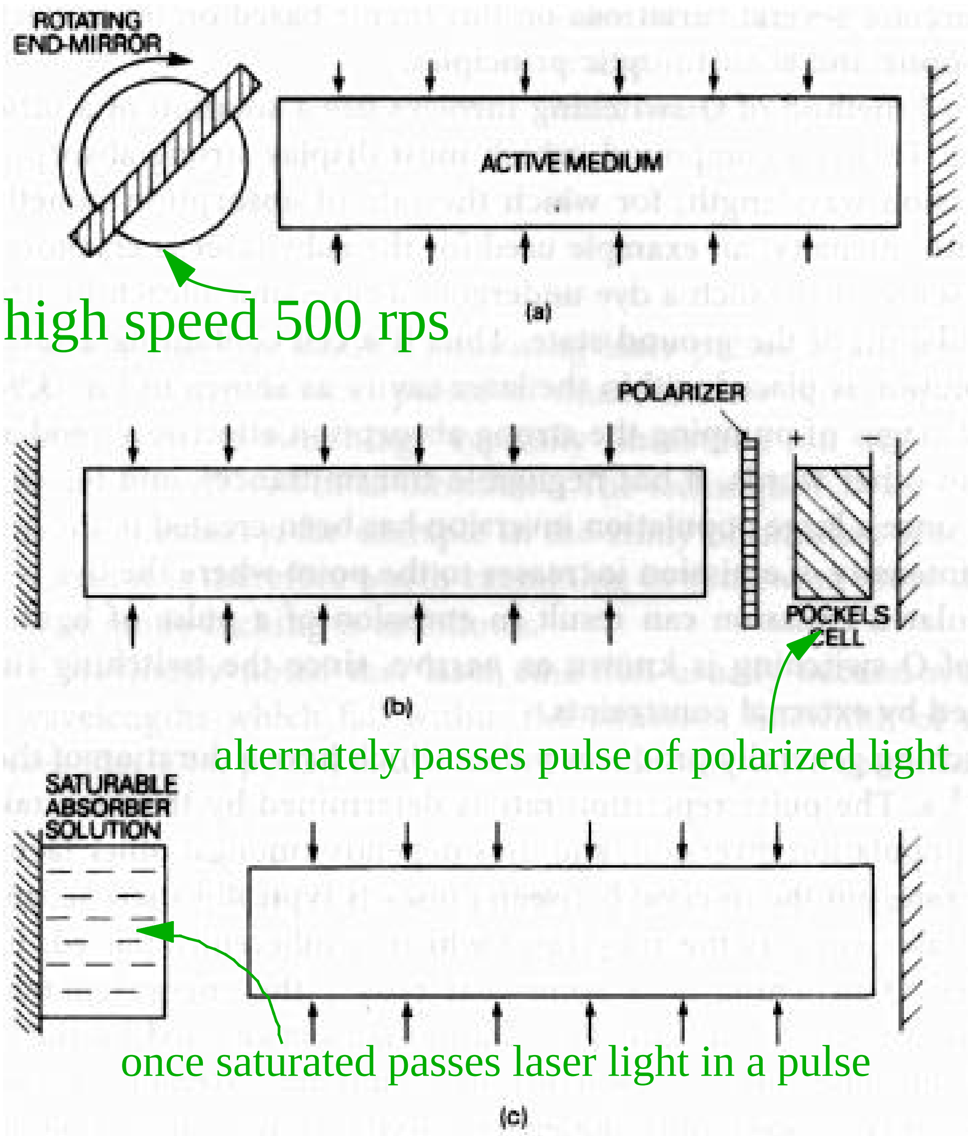
$$Q = \frac{2\pi \times \text{energy stored in cavity}}{\text{energy stored per optical cycle}}$$



Q switching

- **shutter increases losses (reduces Q) to give inversion w/o stimulated emission**
- **losses switched out to produce pulse**

optical cycle ⇒

inverse of resonant frequency

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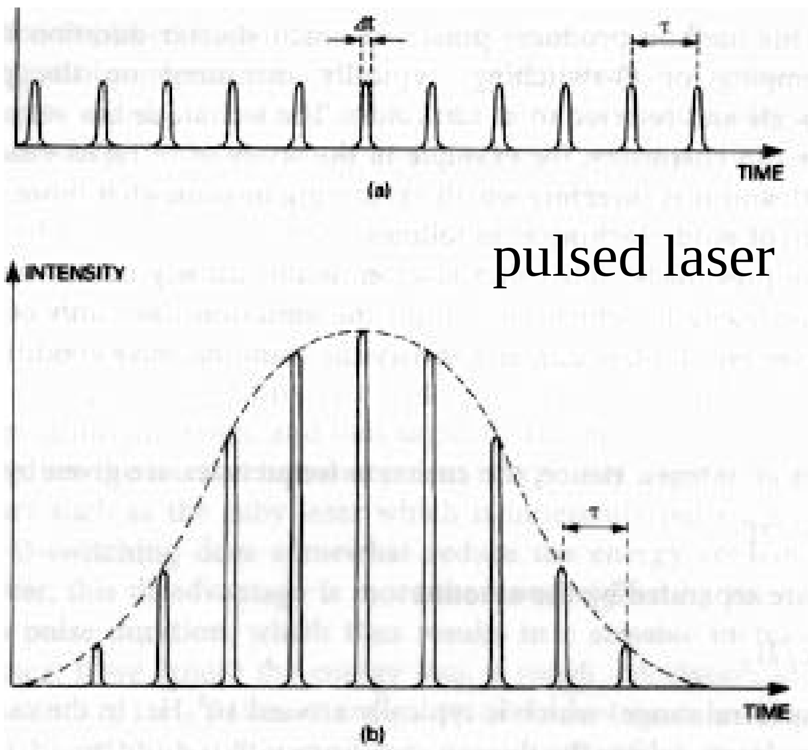
Q-switching

- pulse repetition rate determined by time to re-establish inversion
- depends on many factors including pumping rate
- interval between pulses usually seconds
- often reduces pulse width, e.g. ruby laser but increases peak irradiance
- e.g. 1 ms pulse at 10 J average 10kW becomes 10 ns with average power of 1GW (assuming no other losses)

Mode-Locking (ps)

cw laser



pulsed laser

- $m\lambda / 2 = L$
- $\nu = mc' / 2L$
- separated by $\Delta\nu = c / 2L$ (free spectral range)
- dye laser up to 10^4 modes - no grating etc, no phase coherence, intensity varies
- electro-optic switch, saturable absorbers, etc create "in-phase" at one point only - train of pulses

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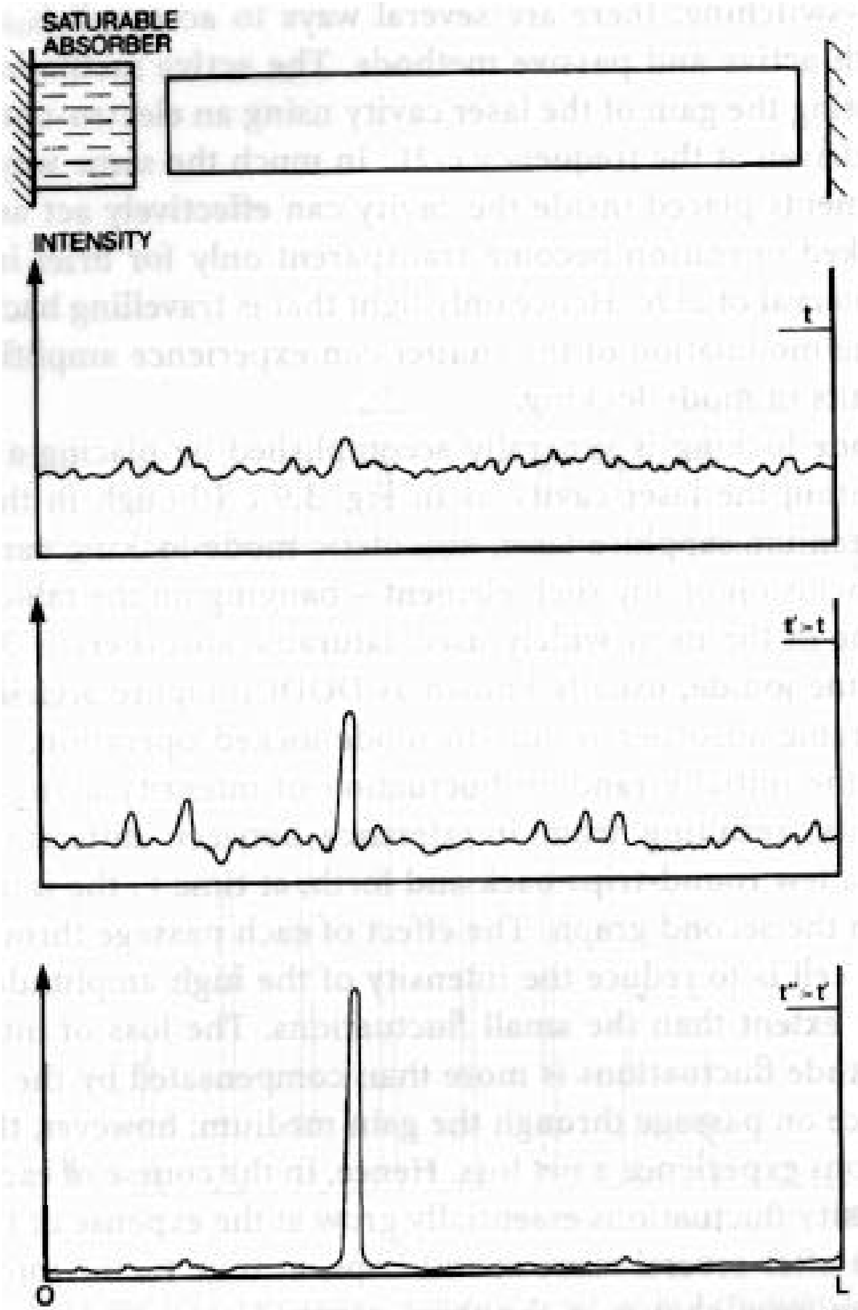
Mode-locking Theory

- pulse duration (width of pulse at half power) can be shown to be:
  - $\Delta t = 4\pi L / (2N + 1)c'$
- interval between pulses is round trip time
  - $\tau = 2L / c'$
- ns between pulses and duration 1-10 ps
- greater the number of modes, N, shorter pulse length
- energy same before and after mode locking, so increased "power" in ps pulse (energy per unit time)



Mode Locking Method

random fluctuations of laser output
no phase relationships between modes

saturable absorber e.g. DODCL
3,3' - diethyloxadicarbocyanine iodide

more intense pulses reduced less
than smaller pulses

builds up single mode pulse via
amplication in gain medium
(gain is non linear) creates phase
relatonship

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Mode locking methods

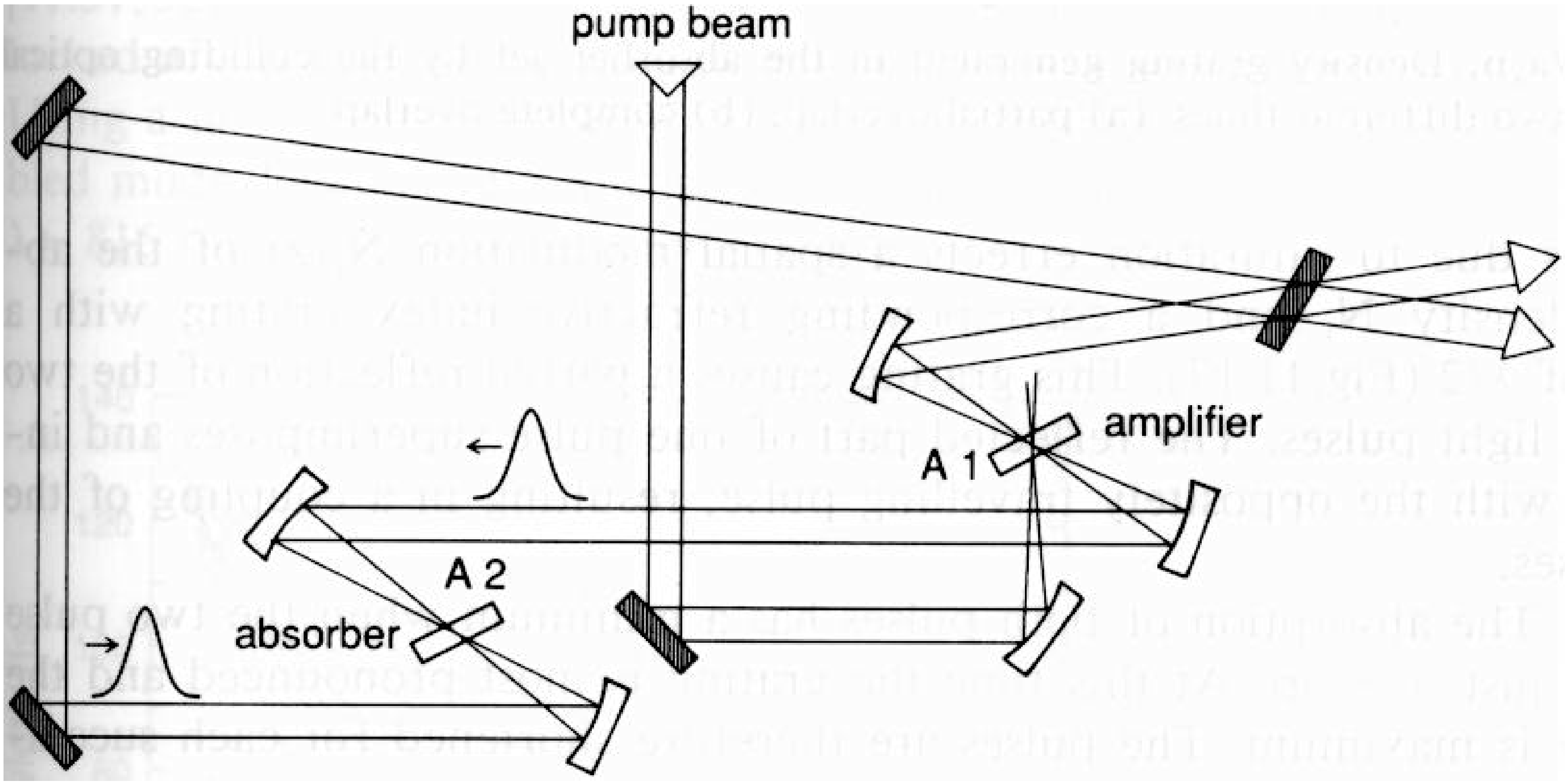
- saturable aborber method is passive mode-locking
- active methods use modulation of the gain with electro-optic devices
- very similar to Q-switching
- light travelling in phase with modulation will amplify

Other pulse compression methods

- **By use of other pulse compressoin methods, in conjunction with mode-locking, can obtain ps and fs pulses**
- **duration of pulses less than 10^{-4} s are only a few optical cycles**

  $\Delta\upsilon\ \Delta\tau \geq 1/2\pi$ (**time/frequency uncertainy principle)**
- **broad range of frequencies in short pulses**

Colliding Pulse Mode-locked laser



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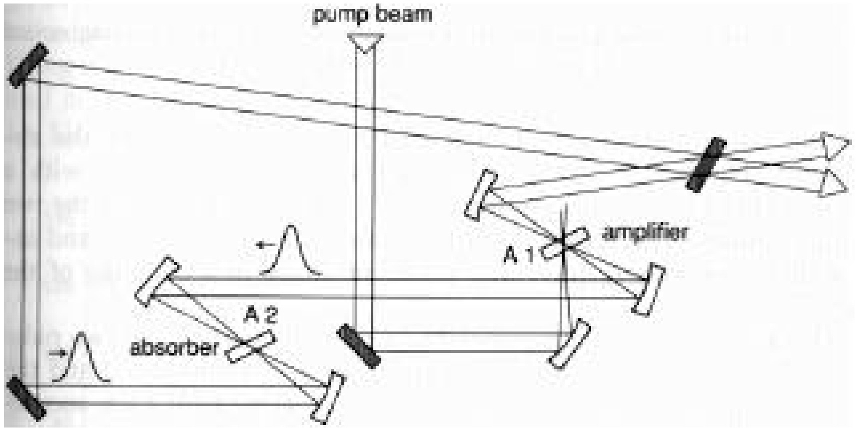

- **ring dye laser**
- **A1, A2, thin dye jets**
- **path length A1-A2 is 1/4 of total ring length L**
- **pulses travel in both directions, collide in absorber with maximum gain**
- **max time for amplifier to recover inversion after depletion by prior pulse**
- **pulse intensity at pulse collision is 2x**
- **larger sat^{n} less absorption at absorber**

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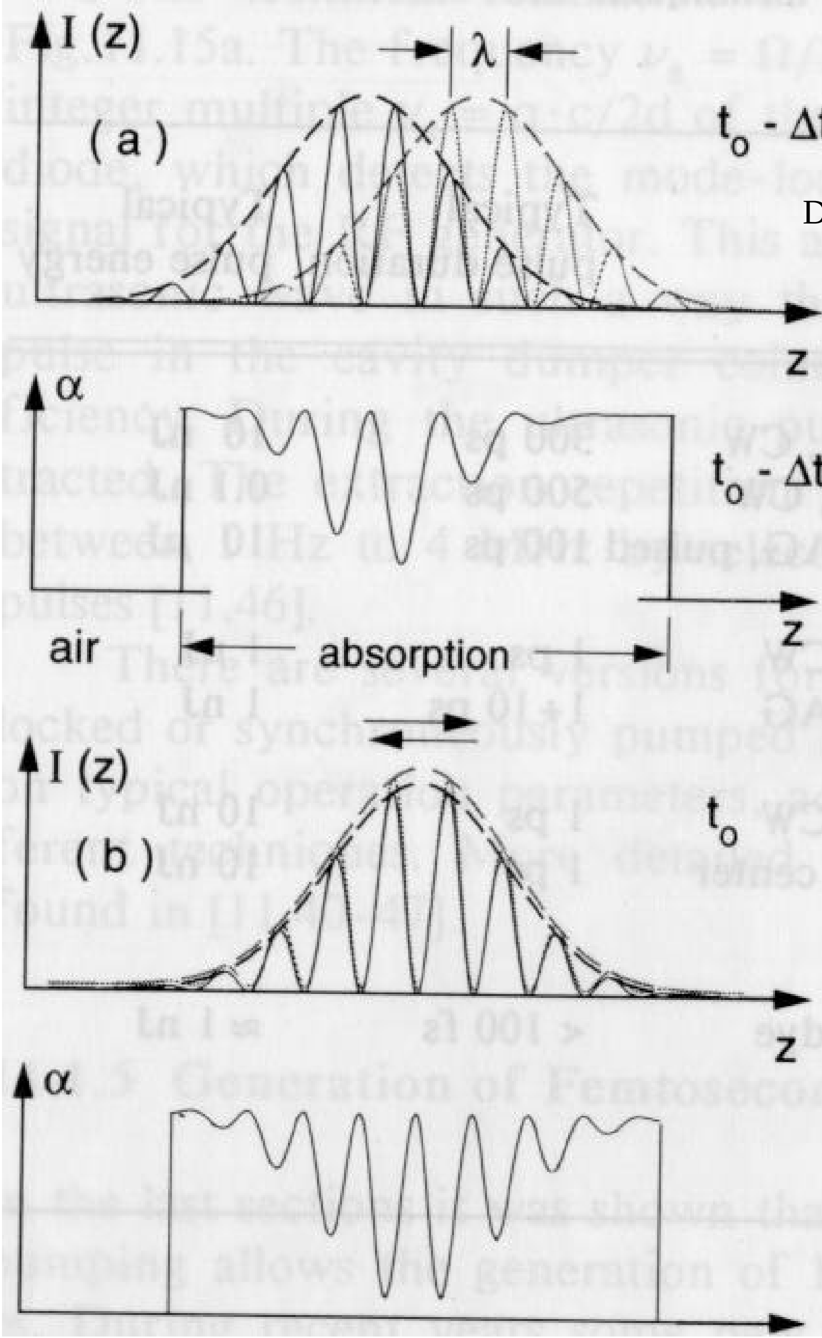

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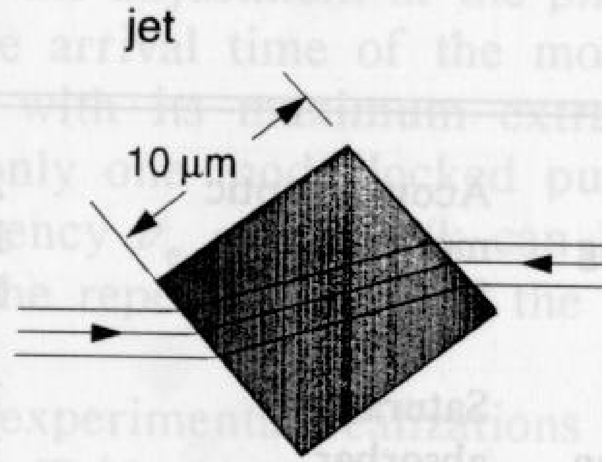

Density grating in CPM laser

- **a) partial overlap**
- **b) complete overlap**
  - **shortening ~ 50 fs**

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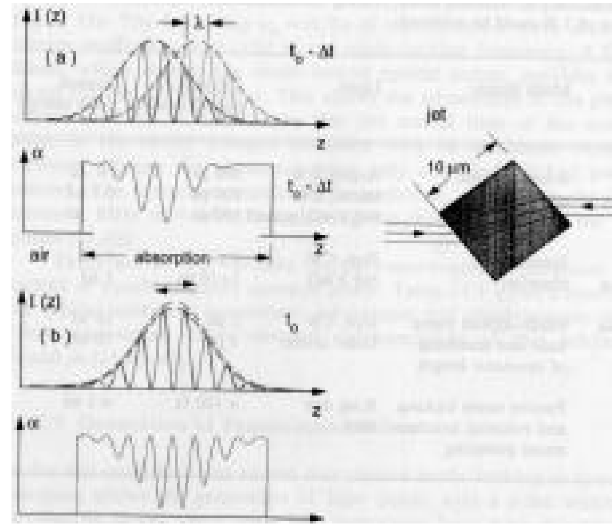
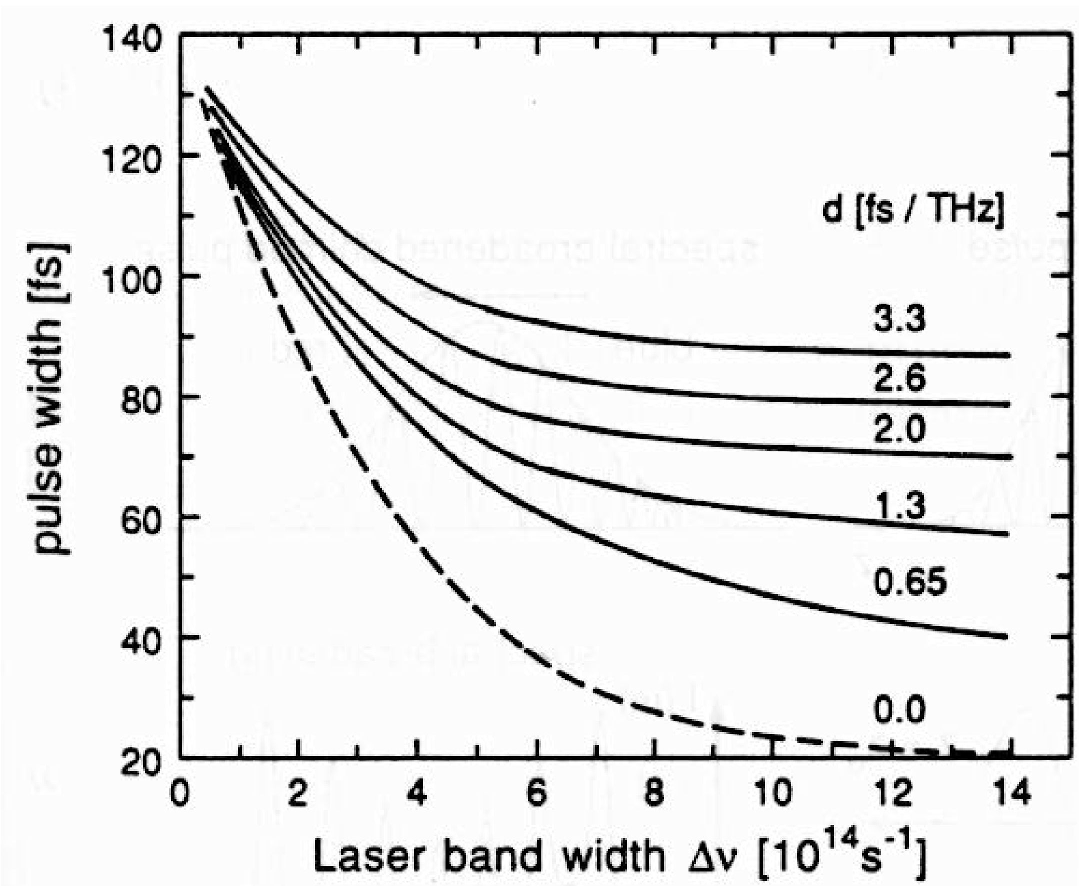


- **time in jet (<100 μm) ~ 400 fs**
- **two colliding pulses form standing wave**
- **spatially modulated saturation occurs**
- **forms refractive index grating period λ/2**
- **partial reflection of two opposite pulses, interfere with each other and couple**
- **absorption of pulses at a min. at overlap**
- **pulses shorter with each round trip**
- **limited by spectral broadening (dispersion at dielectric mirror surfaces - diff. λ's in light)**



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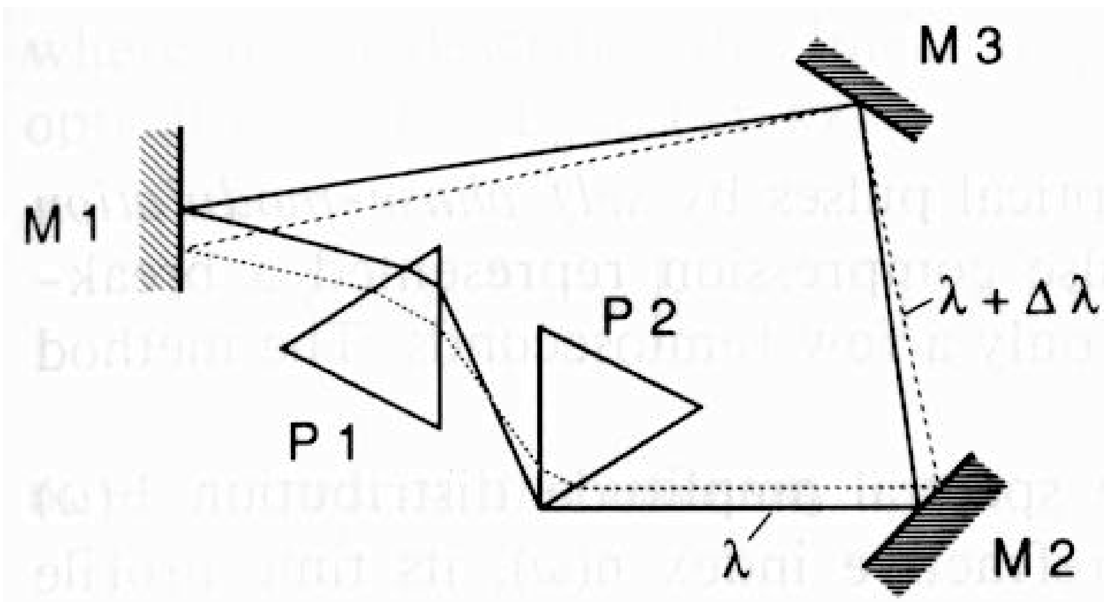

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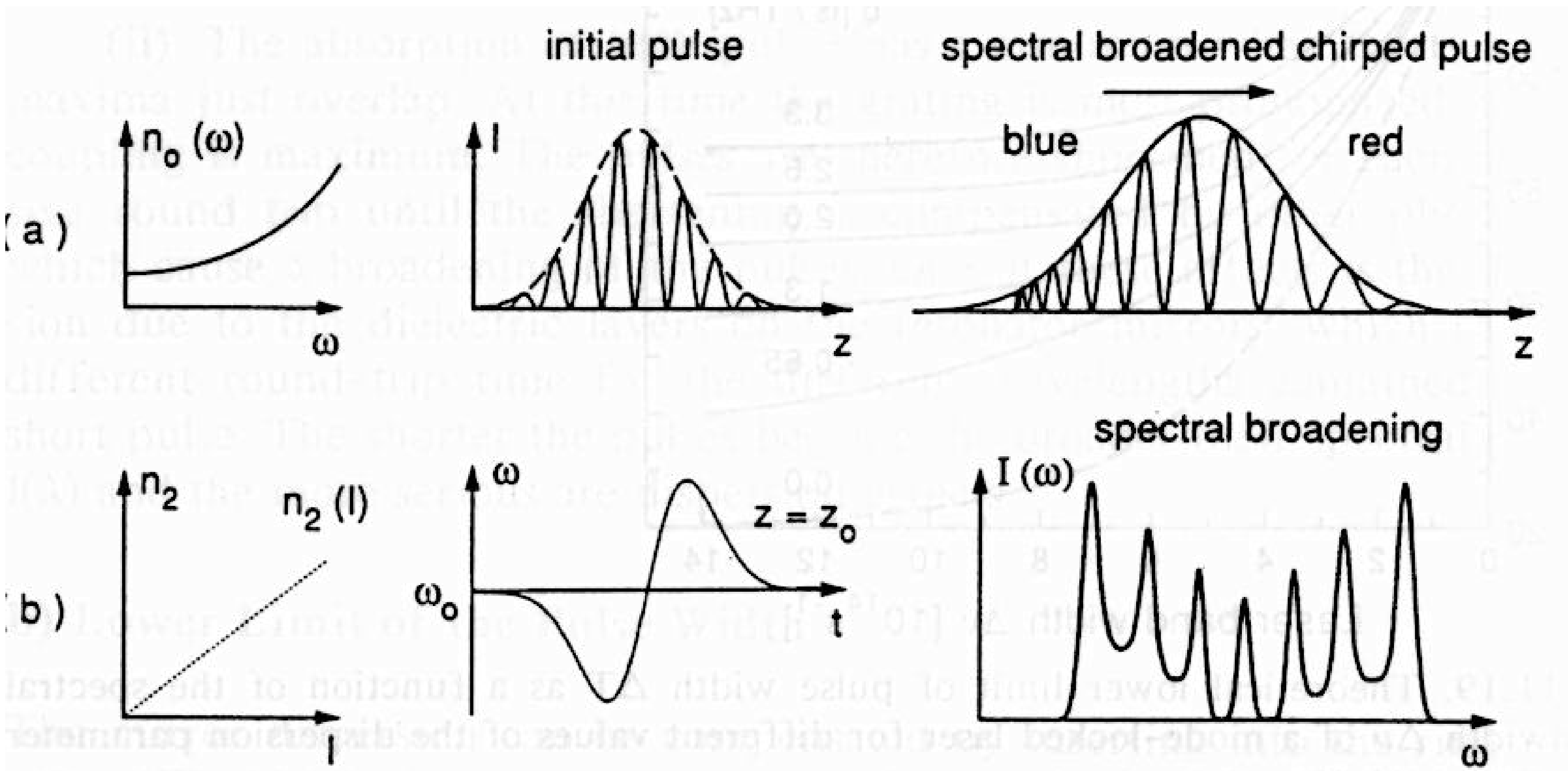

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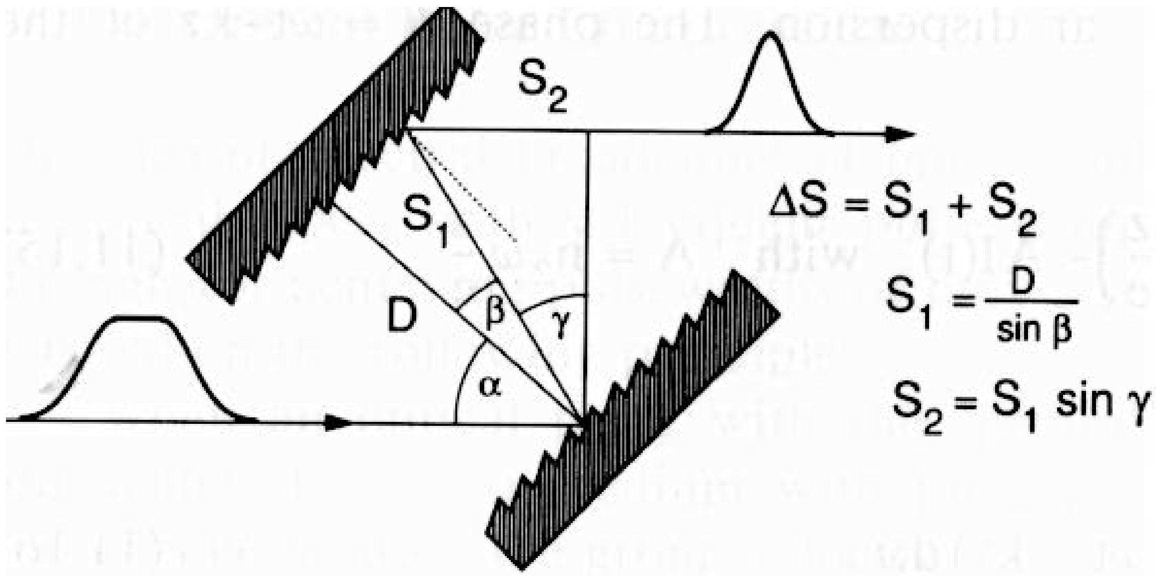

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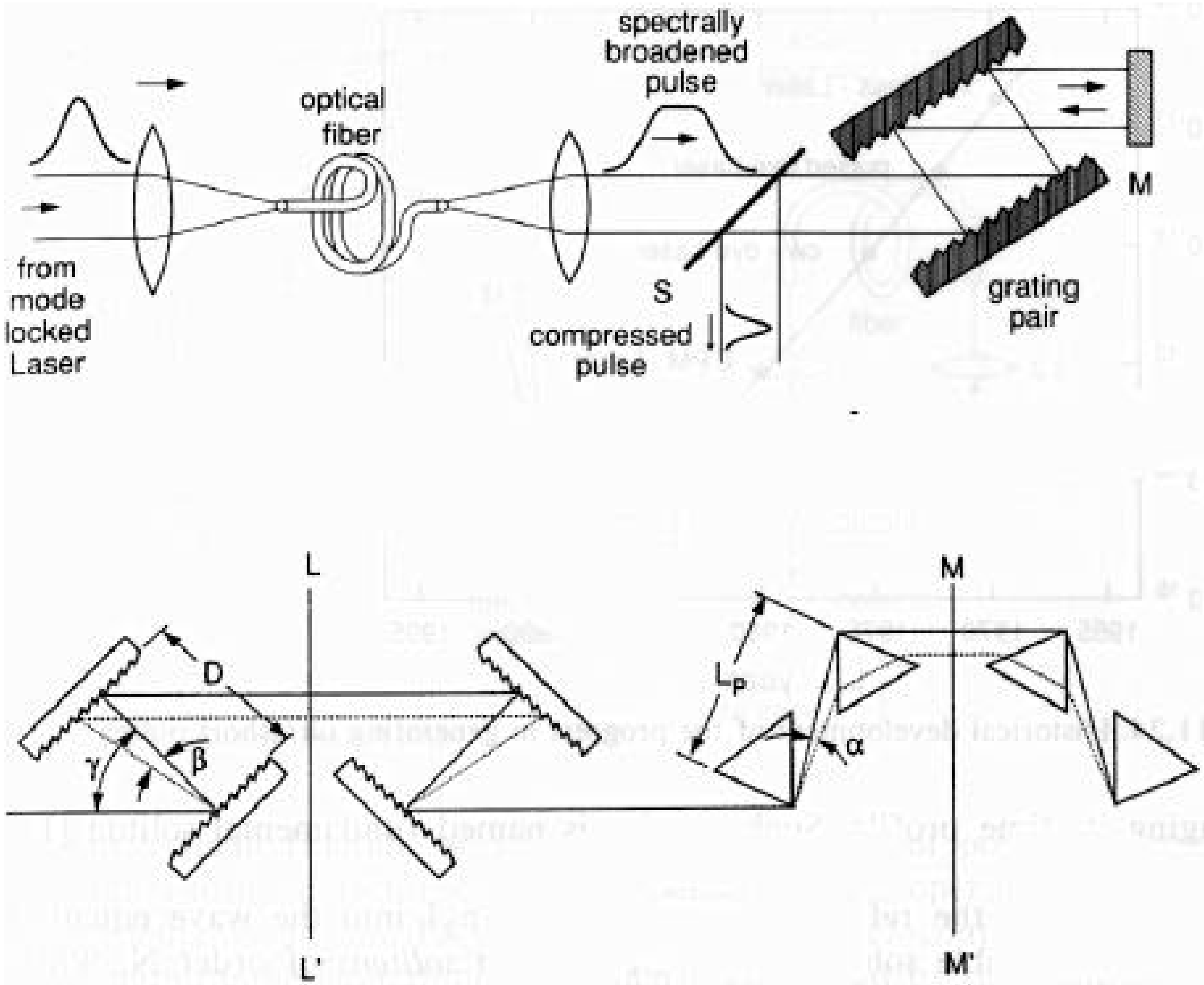

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