Tailoring of laser output

- Polarization is selected using polarizer or Brewster windows (for gas laser e.g. CO\textsubscript{2})
- Transverse mode is selected using apertures
- Selection of laser line can be done using a prism

Resonant condition for cavity: \( L = n\lambda \)

Energetic electrons in a glow discharge collide with and excite He atoms, which then collide with and transfer the excitation to Ne atoms, an ideal 4-level system.
Pulsed lasers

• To date we considered only CW laser

• Pulsed laser have a wide range of applications
  – Photochemistry
  – Solid state physics
  – Generation of ultra-short electron beam (photoemission)
Modelocking: introduction

- A laser can oscillate on many longitudinal modes with frequency separated by $\nu_f = c/2d$
- These modes usually oscillate independently (free running modes)
- External means can be used to couple these modes and phase lock them, this is the concept of modelocking.
Modelocking: description I

- Consider each of the mode to be a plane wave (this is an approximation). The total complex amplitude is

\[ U(z,t) = \sum_q A_q \exp \left[ 2\pi i \nu_q \left( t - \frac{z}{c} \right) \right] \]

where \( \nu_q = \nu_0 + q \nu_f \)

- So

\[ U(z,t) = \sum_q A_q \exp \left[ 2\pi i q \nu_f \left( t - \frac{z}{c} \right) \right] \exp \left[ 2\pi i \nu_0 \left( t - \frac{z}{c} \right) \right] \]

\[ = a \left( t - \frac{z}{c} \right) \exp \left[ 2\pi i \nu_0 \left( t - \frac{z}{c} \right) \right] \]

- rewrite

\[ a(t) = \sum_q A_q \exp \left[ \frac{2\pi i q t}{T_f} \right] \]
Modelocking: description II

- \( a(t) \) is a periodic function of \( t \) and \( z \)
- If the phase and amplitude of \( A_q \) are properly chosen \( a(t) \) may be made to take the form of periodic narrow pulses

- Example: consider all the \( A_q \) to be the same for \( M \) modes (q=0, ±1, ±2,…). Then

\[
a(t) = A \sum \exp \left[ \frac{2\pi i q t}{T_f} \right] = A \sum x^q = A \frac{x^{s+1/2} - x^{s-1/2}}{x^{1/2} - x^{-1/2}}
\]

\[
= A \frac{\sin(M \pi t / T_f)}{\sin(\pi t / T_f)}
\]

and the optical intensity

\[
I(z,t) = I_0 \frac{\sin^2 \left( M \pi (t - z / c) / T_f \right)}{\sin^2 \left( \pi (t - z / c) / T_f \right)}
\]

Separation=\( T_f, 2d \)
width=\( \frac{T_f}{M}, 2d/M \)
Modelocking

[Graphs and diagrams related to modelocking]

Credit: Cundiff, UCB

P. Piot, PHYS 630 – Fall 2008
How to implement modelocking I

- Active modelocking
  - Introduce a modulation using
    - Acousto-optic modulator
    - Electro-optic modulator
How to implement modelocking II

- Passive modelocking
  - Introduce an absorber
  - The most popular technique in short pulse laser oscillators
Q-Switching

- Used to obtain energetic laser pulse
- Cannot beat modelocking as far as generating ultra-short laser pulse
- Keep high resonator losses, so that lasing cannot occur, pumping continuously increase population inversion
- Losses are suddenly reduced to a small value
- Laser radiation build up (many cavity round trips) until gain saturate
Pulse compression and stretching

Blue travel along a longer path than red

Red travel along a longer path than blue

FIG. 3. Schematic diagrams of (a) a pulse stretcher and (b) a pulse compressor.

## Pulse compression and stretching

### Table 1

<table>
<thead>
<tr>
<th>Order</th>
<th>Material</th>
<th>Grating pair compressor/stretcher</th>
<th>Prism pair</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVD</td>
<td>( \frac{d^2 \phi_m(\omega)}{d\omega^2} = \frac{\lambda^2 L_m}{2 \pi c^2} \frac{d^2 n(\lambda)}{d\lambda^2} )</td>
<td>( \frac{d^3 \phi_r(\omega)}{d\omega^3} = \frac{\lambda^3 L_r}{2 \pi c^2} \left[ 1 - \left( \frac{\lambda}{d} \sin \gamma \right)^2 \right]^{-3/2} )</td>
<td>( \frac{d^2 \phi_p(\omega)}{d\omega^2} = \frac{\lambda^3}{2 \pi c^2} \frac{d^2 P}{d\lambda^2} )</td>
</tr>
<tr>
<td>TOD</td>
<td>( \frac{d^3 \phi_m(\omega)}{d\omega^3} = -\frac{\lambda^4 L_m}{4 \pi^2 c^3} )</td>
<td>( \frac{d^3 \phi_r(\omega)}{d\omega^3} = -\frac{6 \pi \lambda}{c} \frac{d^2 \phi_r(\omega)}{d\omega^2} \left( 1 + \frac{\lambda}{d} \sin \gamma \sin^2 \gamma \right) )</td>
<td>( \frac{d^2 \phi_p(\omega)}{d\omega^2} = -\frac{\lambda^4}{4 \pi^2 c^2} \left( \frac{3 \frac{d^2 P}{d\lambda^2} + \frac{d^2 P}{d\lambda^2}}{d\lambda^2} \right) )</td>
</tr>
<tr>
<td>FOD</td>
<td>( \frac{d^4 \phi_m(\omega)}{d\omega^4} = \frac{\lambda^5 L_m}{8 \pi^3 c^4} )</td>
<td>( \frac{d^4 \phi_r(\omega)}{d\omega^4} = \frac{6 d^2 \frac{d^2 \phi_r(\omega)}{d\omega^2}}{d\omega^2} )</td>
<td>( \frac{d^4 \phi_p(\omega)}{d\omega^4} = \frac{\lambda^5}{8 \pi^3 c^4} \left( \frac{12 \frac{d^2 P}{d\lambda^2} + 8 \lambda \frac{d^2 P}{d\lambda^2} + \lambda^2 \frac{d^2 P}{d\lambda^2}}{d\lambda^2} \right) )</td>
</tr>
</tbody>
</table>

\[
P(\lambda) = L_x \cos \beta(\lambda)
\]
\[
\beta(\lambda) = -\arcsin(\eta_p(\lambda) \sin \alpha(\lambda) + \arcsin[\eta_p(\lambda) \sin \alpha(\lambda)])
\]
\[
\alpha(\lambda) = \xi
\]
\[
-\arcsin[\sin \theta_p(\lambda)] / \eta_p(\lambda)
\]
\[
\theta_p(\lambda) = \arctan[\eta_p(\lambda)]
\]
Chirp pulsed amplification (CPA)

- To be able to amplify a short pulse.

Oscillator → **Stretcher** → Amplifier (Regen/multipass + power) → Compressor

Fs - ps → ps - ns → ps - ns

**Courtesy of Yuelin Li, APS/ANL**