Laser Cavity Modes

• All lasers produce light over range of frequencies, known as the gain bandwidth.
• For example, a HeNe laser has a gain bandwidth of approximately 1.5 GHz (a wavelength range of about 0.002 nm at a central wavelength of 633 nm), whereas a Ti:Sapphire has a bandwidth of about 128 THz (a 300 nm wavelength range centered around 800 nm).
Mode Locking

• In lasers with only a few oscillating modes acting independently, interference between the modes can cause beating effects in the laser output, leading to random fluctuations in intensity.

• In lasers with many thousands of modes, these interference effects tend to average to a near-constant output intensity, and the laser operation is known as a c.w. or continuous wave.

• If each mode operates with a fixed phase between it and the other modes, the modes of the laser will periodically all constructively interfere with one another, producing an intense burst or pulse of light.

• The minimum possible pulse duration $\Delta t$ is given by

$$\Delta t = \frac{0.441}{N \Delta \nu}.$$
Concepts of Mode Locking

Mode locking is a method to obtain ultrafast pulses from lasers, which are then called mode-locked lasers.

![Diagram showing irradiance vs. time with waves in phase and out of phase.](chrome://newtabhttp://www.youtube.com/watch?v=efxFduO2Yl8)
Basic principles of ultrafast lasers

Bandwidth vs Pulsewidth

\[ \Delta \nu \Delta \tau = \text{const.} \]

For the HeNe laser with a 1.5 GHz spectral width, the shortest Gaussian pulse consistent with this spectral width would be around 300 picoseconds; for the 128 THz bandwidth Ti:sapphire laser, this spectral width would be only 3.4 femtoseconds.
Active Mode Locking

• When driven with an electrical signal, AOM produces a sinusoidal amplitude modulation of the light in the cavity.

• The amplitude modulator acts as a weak shutter to the light bouncing between the mirrors of the cavity, attenuating the light when it is "closed", and letting it through when it is "open".

• Considering this in the frequency domain, if a mode has optical frequency $\nu$, and is amplitude-modulated at a frequency $f$, the resulting signal has sidebands at optical frequencies $\nu - f$ and $\nu + f$.

• If the modulation rate $f$ is synchronised to the cavity round-trip time $\tau$, then these sidebands correspond to the two cavity modes adjacent to the original mode.

• Since the sidebands are driven in-phase, the central mode and the adjacent modes will be phase-locked together.

• As a result, a single pulse of light will bounce back and forth in the cavity.

www.olympusmicro.com/primer/java/lasers/ndylf/index.html
Types of Laser Output

- **cw**
- **Q-switch**
- **cw ML**
- **Q-sw.ML**