Wavelength, Polarization and Beam Profile

- Stimulated emission produces photons which are coherent. In order to choose output parameters such as polarization, extra elements are added to the laser resonator. For e.g. a polarizer in the resonator will determined the output polarization. The resonator, also called laser cavity, described above can support several modes which slightly different frequencies (wavelength). In order to have single wavelength operation it is necessary to add an element called an etalon which is a device that uses interference to create a narrow transmission band centered around a single cavity mode. This ensures single wavelength operation with high spectral purity.

Operation Contd

- In addition to single mode operation, typically the beam profile of laser output is gaussian shaped as described in previous slides. Beam divergence is quite low and laser beams can be easily focused to diffraction limited spots for applications such as imaging.

Pulsed and CW Operation

- As pointed out earlier, lasers can be operated in a pulsed mode, where the output consists of bursts of radiation at fixed intervals of time, or in continuous (wave) mode (CW), where output is continuous in time. CW operation is achieved by maintaining a constant population inversion rate that keeps the gain in the medium equal to the cavity losses attaining a steady power output.
- Pulsed operation can be achieved in several different ways. The simplest would be to pulse the pumping source which would create gain only for intermittent periods of time thus causing a pulsed output.

- There are also other methods to create pulsed lasers which we will describe in later slides. In fact some of these methods can be used to create pulses that are as small as tens of femto-seconds (10^{-15} s). As we will see later lasers capable of producing such small pulses, called ultra-fast lasers have opened up new ways of probing matter.

Q Switching

- As we mentioned before, the simplest way to produce a pulsed laser is to use a pulsed pump. Another way to create pulsed output is called Q switching, i.e. modulating the quality factor of the cavity actively or passively. In active Q-switching, an element such as an acousto-optic (AO) or electro-optic (EO) modulator, described in a later lecture. By switching the modulators on and off, the gain in the cavity is modulated producing pulsed output.

Passive Q Switching

- Passive Q switching is done using materials that are called saturable absorbers. These are materials where the absorption coefficient decreases with increasing intensity. When this happens, output can only be emitted from the laser cavity after a sufficiently large number of round trips (amplification factor) inside the cavity. Then the intensity is high enough for the gain to offset the losses and the output is dumped out. The intensity goes down again and losses dominate until intensity come up to a level where losses are dominated. Q switching can produce pulse widths around a nanosecond

Mode locking: Ultra-fast Lasers

- In order to produce even shorter pulses, a technique called mode-locking can be used. As we mentioned during the discussion on diffraction gratings, the width of the mth diffracted order is inversely proportional to number of 'slits' or modulations in the grating. A similar effect happens here. As we mentioned earlier, the cavity supports a number of modes. If we are able to lock the phase of all the modes to a single value, the output is the resultant of modes with different frequencies and same phase. In time domain the resultant output is a compressed pulse with pulse width which is the ratio of round-trip time to the number of modes.

Ultra-fast Lasers

- As the number of modes is proportional to the bandwidth (spectral region where laser gain is possible), one can produce small pulses by using gain media which have large bandwidths. For e.g. using Titanium doped Sapphire (Al_2O_3), one can create pulses less than 10 fs.

- Ultra-fast lasers consists of femto-second (fs) pulses with repetition rates of the order of MHz. The average pulse power is defined as the pulse energy of each pulse times the repetition rate. The instantaneous power is defined as pulse energy per pulse divided by the pulse width. This value can be extremely large due to the small pulse width.

- The extremely large instantaneous power implies an extremely large number of photons that are squeezed into a small time window. Such high photon densities enable many non-linear optical processes that are not possible with low powers.

- The other useful aspect of ultra-fast lasers is that even though the instantaneous power is very large, the average power level can be quite low. Therefore it is possible to use these light sources for various biological applications without causing damage to living tissue.

Some Common Lasers

- Commercial lasers available today cover a wide range of operating wavelengths and output power levels. A few of the important ones are summarized below.
- Gas lasers such as,
  - Helium-Neon (He-Ne), 632.8 nm, various applications
  - Argon-ion, 488/514 nm, useful for fluorescence excitation
  - CO2 laser, 10.6 µm, laser cutting , cosmetic surgery
- Dye lasers covering range from 400 nm to 800 nm capable of producing nanosec pulses.
- Nd-YAG laser operating at 1064 nm, frequency doubled operation (described later) produces 532 nm output.
- Ti-Sapphire laser, tunable from 690 nm to 1000 nm. Wide bandwidth capable of producing ultra-short pulses.

Diode Lasers

- Another important class of lasers is the diode lasers which are made with semiconducting materials. In a forward biased pn junction, electron hole recombination produces photons. The production rate can be controlled by the injection current. Beyond a certain threshold, stimulated emission takes place and laser output is produced.

- Diode lasers are generally not very tunable, but they provide a compact and economic laser source and has enabled several technologies such as optical data storage, optical communication links and laser printing.

Laser Applications

- Lasers find applications in a large number of areas, too numerous to list in a single slide. Some important applications are given below. Applications requiring long temporal or spatial coherence, diffraction limited focusing, non-linear optics using ultra-fast pulses etc. require the use of lasers
  - Laser based imaging techniques
  - Optical data storage
  - Optical sensors
  - Biomedical, surgical applications
  - Optical communication links
  - Study of non-linear optical phenomena