



Dublin Institute of Technology

School of Electronic and
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Optical Communications Systems

Laser Fundamentals

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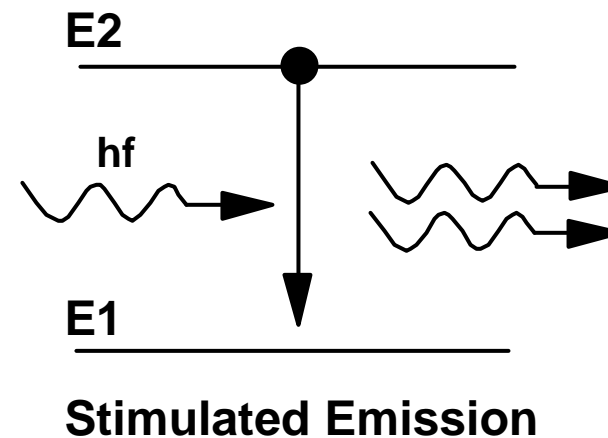
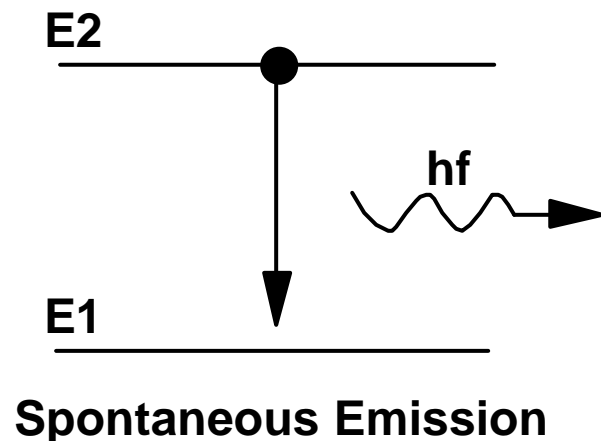
- **Wide variety of lasers have developed, including those based on:**
 - ▶ **Solid Crystals: Ruby laser, Neodymium.Yttrium-Aluminium-Garnet (YAG) laser**
 - ▶ **Gas: Helium-Neon, Carbon Dioxide.**
 - ▶ **Dye lasers.**
 - ▶ **Semiconductor diodes (most important for optical communications).**
 - ▶ **Glass fibre lasers.**
 - ▶ **X-ray lasers.**

- **Basic principles are the same for all types of laser, these will be considered first, before moving on to semiconductor lasers.**



Stimulated Emission

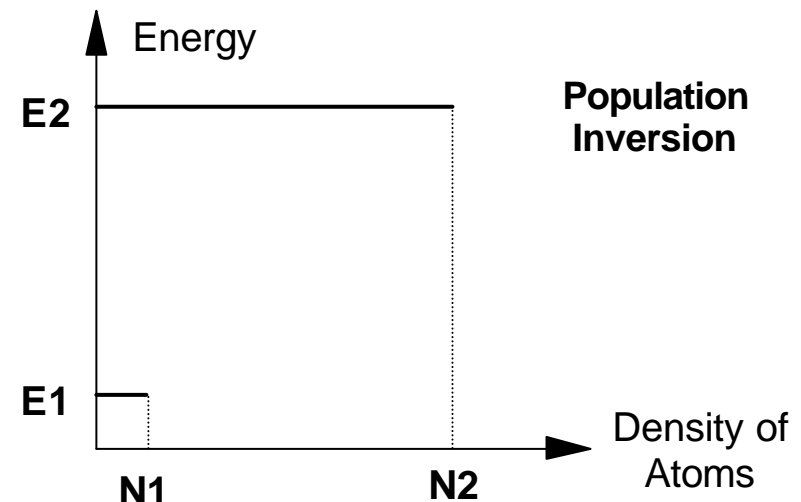
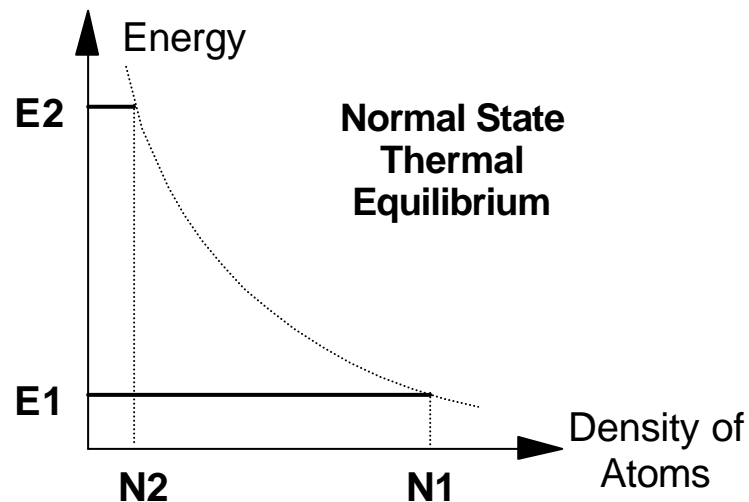
- Spontaneous emission: electron makes a transition from high energy state E2 to lower energy state E1, resulting in the emission of a photon
- Stimulated Emission: Photon, with an energy equal to E2-E1 interacts with an atom in the upper energy state, causing it to return to the lower state with the emission of a second photon
- Second photon has the same phase, frequency and polarization as the first
- It is stimulated emission which gives the Laser its special properties, such as narrow spectral width and coherent output radiation.





Conditions for Stimulated Emission

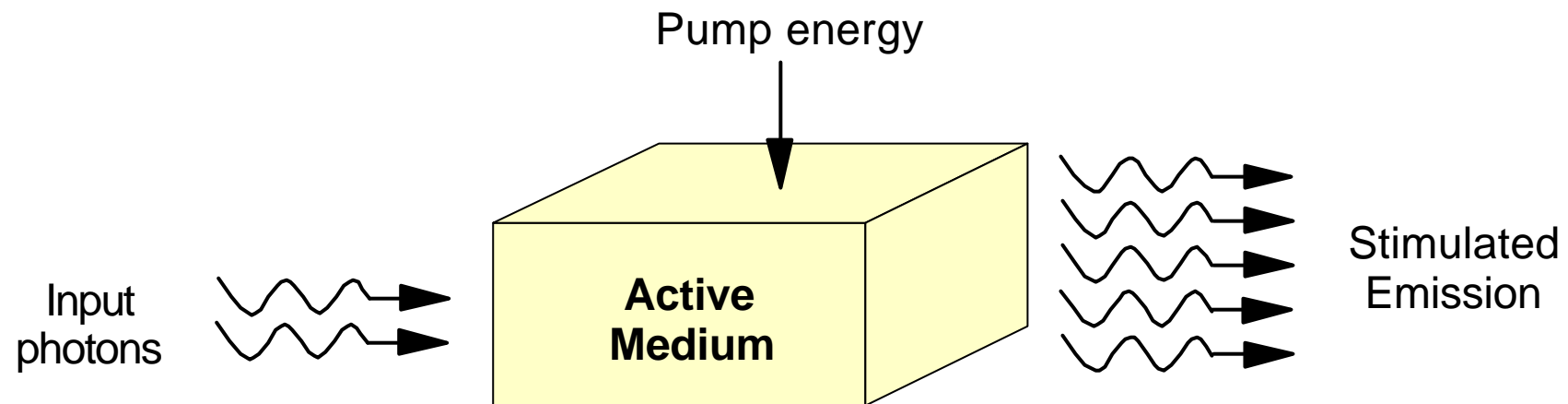
- Stimulated emission takes place in many optical sources but is normally too small to be detected (eg. ratio of stimulated to spontaneous emission in a light bulb is $<10^{-12}$!)
- Einstein demonstrated that for stimulated emission to dominate it was necessary that the photon radiation density and the population density N_2 of the upper energy level must be increased relative to the lower level (E_1 and N_1)
- When $N_2 > N_1$ this is known as population inversion and is a fundamental condition for stimulated emission.





Achieving Stimulated Emission\

- To achieve population inversion it is necessary to excite atoms into the upper energy level E_2 . This process is called pumping.

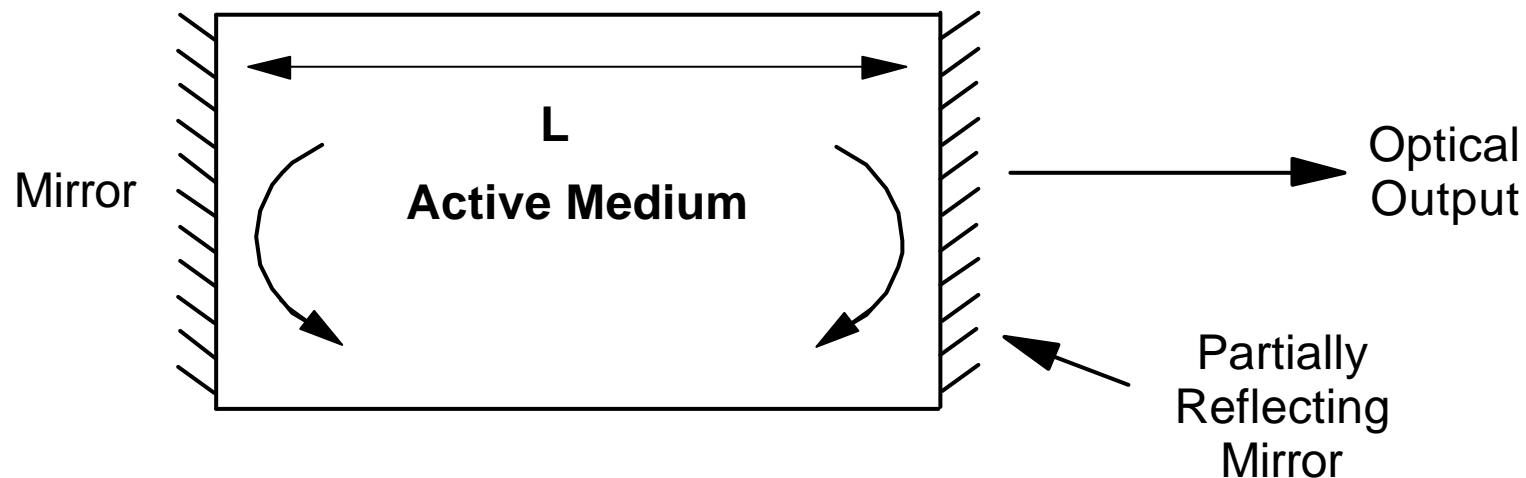


- Pumping takes many forms, including flash tubes, light from other lasers and electrical current
- Stimulated emission can be seen as optical gain, in that the number of photons out of the pumped medium exceeds the number entering
- ***Pumping alone will not produce lasing. For lasing to occur population inversion and stimulated emission must take place in the presence of optical feedback***



Optical Feedback

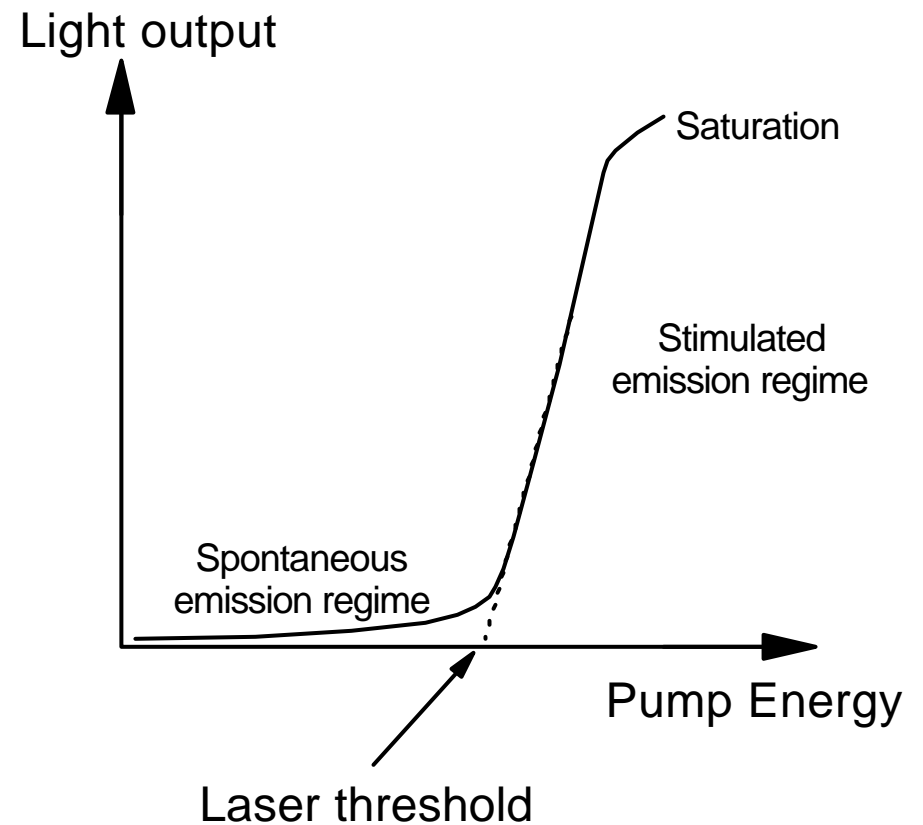
- If the gain which stimulated emission produces is to provide a continuous output then optical feedback must be present.
- Feedback is normally achieved using plane mirrors at both ends of the active medium. This resonant cavity is called a **Fabry-Perot** cavity
- Within the cavity stimulated emission gives gain and with feedback continuous oscillation takes place, analogous to an electrical amplifier with positive feedback.
- It is the combination of stimulated emission and feedback that gives a continuous output





Laser Threshold

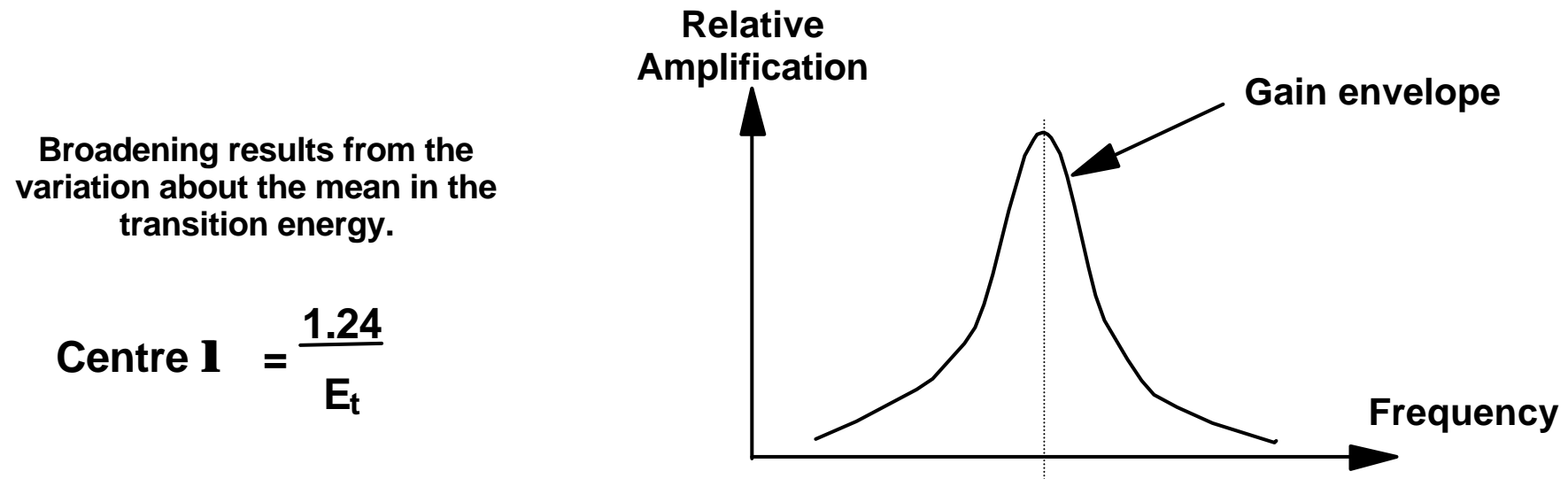
- To start stimulated emission photons must be present, normally provided by spontaneous emission
- However lasing does not take place at all pump energies, because cavity loss can reduce net gain below 1.
- Cavity losses include absorption and scattering in the active material and at the mirrors, as well as light output from the mirrors
- To overcome this the pump energy must reach a threshold, the so-called laser threshold





Lasing Action and Frequency

- Ultimately as stimulated emission and gain build up in the Laser a saturation point is reached and the optical output is constant.
- Saturation is reached when the gain in the medium exactly equals the losses in the medium (such as absorption etc.) .
- Gain only occurs over a narrow range of frequencies, centred on the stimulated energy transition energy E_t , also called the broadened laser transition (see diagram).



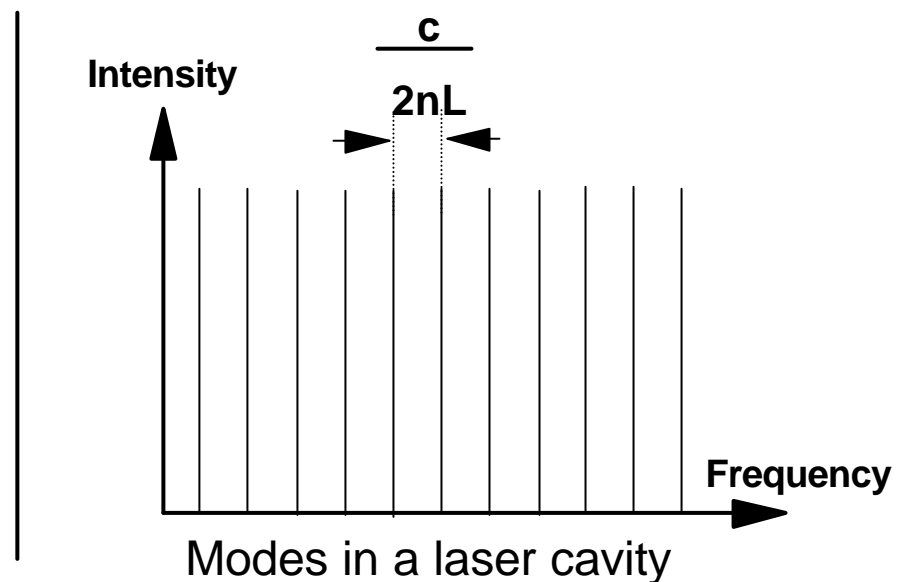


Longitudinal Modes

- Standing waves build up between the mirrors in the cavity
- To exist a standing wave must have a frequency such that the optical path length between the mirrors is an integer number of half wavelengths.
- The optical path length is nL , where L is the physical path length and n is the cavity refractive index
- These standing waves, called cavity longitudinal modes, are at frequencies derived from the relationship between L and the wavelength given by:

$$nL = q \frac{\lambda}{2} \quad \text{thus} \quad f = \frac{qc}{2nL}$$

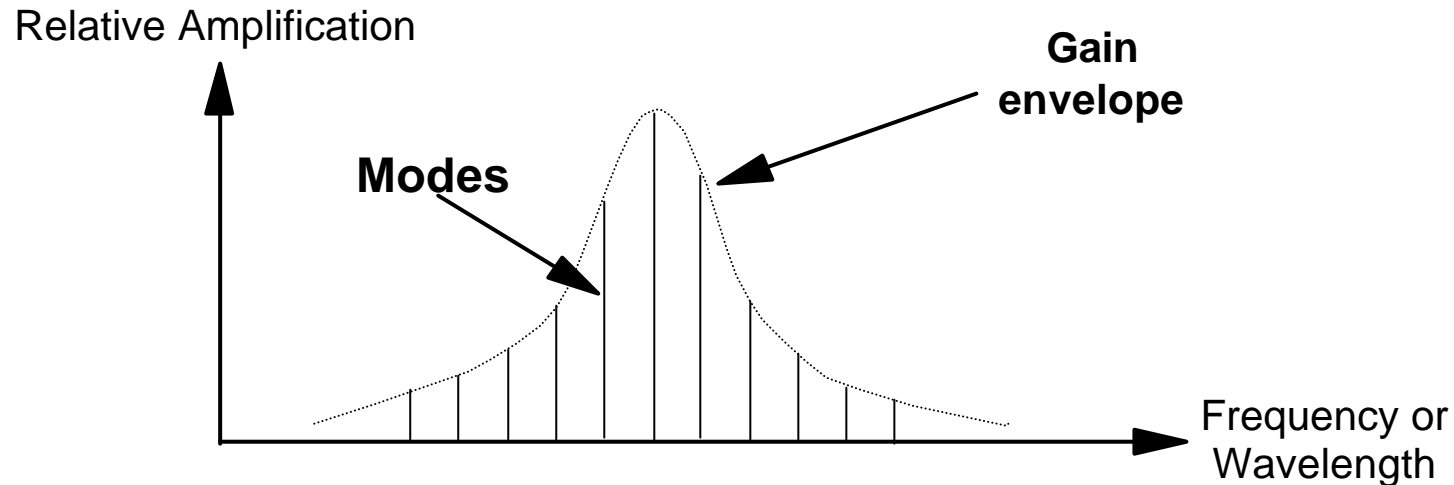
Where q is an integer





Complete Laser Spectrum

Longitudinal mode amplitude is dictated by gain curve, resulting in the curves below



Actual laser optical spectrum span 1600 to 1620 nm

Self-pulsating laser diode

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