10.2: Types of Lasers

There are many different types of lasers built on many different principles and techniques of creating population inversions. A population inversion can be induced in a system through the fast absorption of light, a chemical reaction that creates a non-equilibrium distribution of molecules, “zapping” a system with electrons, or many other ways. We will consider several of them in this section.

Two-level laser

The simplest type of laser is a two-level laser, although many argue that a true two-level laser cannot exist[1]. None the less, it is instructive to consider a simplified system with only two levels, in which a population inversion has been introduced. Once the population inversion has been achieved, light of a frequency that matches the resonance between the two levels is passed through the sample. This can “tickle” a molecule into dropping to the lower level by giving off a photon. If this happens, the stimulated emission will be coherent (in phase and of the same frequency) as the stimulating photon. If many molecules are stimulated to emit, the gain will be substantial and a strong beam of coherent, monochromatic light will be produced.

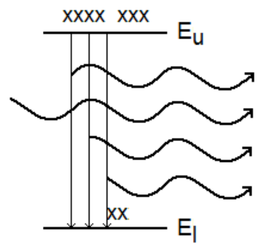

Figure 10.2.1

Naturally as laser output is achieved, the upper-level population will deplete and that of the lower level will grow. When a Maxwell-Boltzmann distribution is established, laser output will cease. So in order to keep the laser operating, the upper state must be repopulated or the lower state must be depopulated. The nature of the laser is defined by the manner in which these population/depopulation events occur. The manner in which the light is manipulated can also define the nature of the laser and how it operates.

Three-level lasers

There are several examples of three-level lasers. In these systems, a third level is introduced in order to either populate the upper level of the laser transition or depopulate the lower level. This difference defines two types of three-level laser systems.

In the case that the third level (E_1) lies above the upper level of the laser transition (E_u), the following schematic energy level diagram will result.

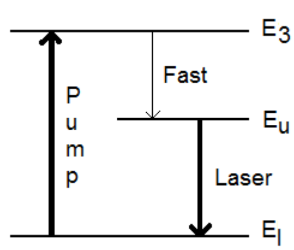

Figure 10.2.2

In this system, The level E_3 is populated by the absorption of light (which is what is depicted in the diagram above) or some other method. The transition between E_1 and E_u is much faster than the transition between E_u and the lower level of the laser transition, E_l. As such E_u will be populated quickly and a population inversion will be established. As this laser operates, E_u will be depopulated, so a fresh supply of molecules in this level must be provided by the pump source cycling molecules out of E_l and back to E_3.

An example of this type of three-level laser is the ruby laser[2], in which the gain medium is a ruby crystal. The pump exciting molecules from E_l to E_3 is provided by a flash lamp. Since the flash lamp is pulsed, this system produces pulsed laser output. The wavelength of the ruby laser output is 694.3 nm. The helium-neon (HeNe) laser (Microwave Determination of Average Electron

Energy and Density in He–Ne Discharges, 1964) is another example of this type of laser. The HeNe laser is a continuous wave laser (meaning it is not pulsed like the ruby laser) that produces red light at 632.8 nm.

A second type of three-level laser is one on which the third level (E_3) lies below the lower level (E_l) of the laser transition. In this system, the upper level of the laser transition is populated either by a chemical or electrical pump or by a chemical reaction. The lower level is depopulated by a fast transition (or a chemical reaction). Since this depopulation happens faster than the population of E_l through the laser transition, a population inversion is maintained easily.

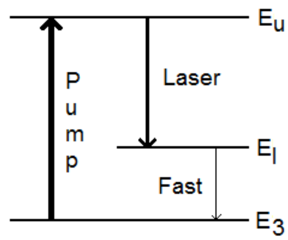

Figure 10.2.3

An example of this type of laser is the chemical laser in which the upper level of the laser transition is populated through a chemical reaction which creates vibrationally excited molecules (Spencer, Jacobs, Mirels, & Gross, 1969) (Kasper & Pimentel, 1965) (Hinchen, 1973). Such lasers typically produce output in the infrared.

Four-level lasers

A four-level laser incorporates elements of both types of three-level lasers by having an energy level above the upper level of the laser transition that rapidly populates E_u and one below the lower state of the laser transition that rapidly depopulates the lower level, E_l.

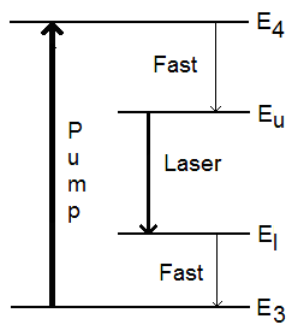

Figure 10.2.4

Briefly, a pump (usually supplied by a flash lamp) excites molecules from E_3 to E_4. A fast transition from E_4 to E_u populates the upper state of the laser transition. A fast transition from E_l to E_3 then depopulates the lower level of the laser transition, maintaining a population inversion between E_u and E_l until E_4 is no longer able to populate E_u.

The Nd:YAG (Geusic, Marcos, & Van Uitert, 1964) (neodymium YAG) laser is an example of a four level laser. In this laser, neodymium (III) ions entrained in a yttrium aluminum garnet crystal provide the four energy levels. The laser produces a polarized pulsed output at 1064 nm.

Q-switching

One of the important devices that makes a Nd:YAG laser (and many others) is a **Q-switch**. A Q-switch is a polarized filter that changes direction fo polarization when an electrical potential is applied to it. In one orientation, the switch blocks laser output light (preventing stimulated emission amplification) and in the other orientation, it allows for this light to pass.

The Q-switch is used to limit laser gain (which would deplete the upper level of the laser transition) until an optimal population inversion is achieved. The Q-switch is then “opened” and laser output is generated until the population inversion is relaxed. The timing is critical and must be tuned for each laser (and usually re-optimized several times a day while the laser is in operation, as changes in temperature can change the characteristics of the YAG crystal dramatically.

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1. Others argue that excimer lasers and dye lasers are two-level lasers. The difference depends on what is considered a “level”.

2. There are actually two levels in a ruby laser that act as E 3. For a complete description, see (Maiman, 1960)