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Principles and Applications of Laser

Laser is the abbreviation of **L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation. It is a device that creates a narrow and low-divergent beam[1] of coherent light, while most other light sources emit incoherent light, which has a phase that varies randomly with time and position. Most lasers emit nearly "monochromatic" light with a narrow wavelength spectrum. Fig.1 [1] is the spectrum of a helium neon laser, showing very high spectra purity.

1 Principle of Lasers

The principle of a laser is based on three separate features: a) stimulated emission within an amplifying medium, b) population inversion of electronics and c) an optical resonator.

Spontaneous Emission and Stimulated Emission

According to the quantum mechanics, an electron within an atom or lattice can have only certain values of energy, or energy levels. There are many energy levels that an electron can occupy, but here we will only consider two. If an electron is in the excited state with the energy E_2it may spontaneously decay to the ground state, with energy E_1, releasing the difference in energy between the two states as a photon.

This process is called spontaneous emission, producing fluorescent light. The phase and direction of the photon in spontaneous emission are completely random due to Uncertainty Principle. The angular frequency ω and energy of the photon is:

(1)

$$E_2 - E_1 = \hbar\omega$$

where ħ is the reduced plank constant.

Conversely, a photon with a particular frequency satisfying eq(1) would be absorbed by an electron in the ground state. The electron remains in this excited state for a period of time typically less than 10^{-6} second. Then it returns to the lower state spontaneously by a photon or a phonon. These common processes of absorption and spontaneous emission cannot give rise to the amplification of light. The best that can be achieved is that for every photon absorbed, another is emitted.

Alternatively, if the excited-state atom is perturbed by the electric field of a photon with frequency ω, it may release a second photon of the same frequency, in phase with the first photon. The atom will again decay into the ground state. This process is known as stimulated emission.

The emitted photon is identical to the stimulating photon with the same frequency, polarization, and direction of propagation. And there is a fixed phase relationship between light radiated from different atoms. The photons, as a result, are totally coherent. This is the critical property that allows optical amplification to take place.

All the three processes occur simultaneously within a medium. However, in thermal equilibrium, stimulated emission does not account to a significant extent. The reason is there are far more electrons in the ground state than in the excited states. And the rates of absorption and emission is proportional the number of electrons in ground state and excited states, respectively. So absorption process dominates.