Operating Principles

1. Operating Principles of Laser Diodes (LDs) and Infrared Emitting Diodes (IREDs)

1.1 Emitting Principles

Each electron in an atom or molecule has a specific discrete energy level, as shown in figure 1. The transition of electrons between different energy levels is sometimes accompanied by light absorption or emission with the wavelength, λ, expressed as:

$$\lambda = \frac{C}{f_0} = \frac{C}{|E_2 - E_1| / h} = \frac{1.2398}{|E_2 - E_1|}$$

C : Light velocity

E_1 : Energy level before transition

E_2 : Energy level after transition

h : Planck constant (6.625×10^{-34} joul. sec.)

f_0 : Emission frequency

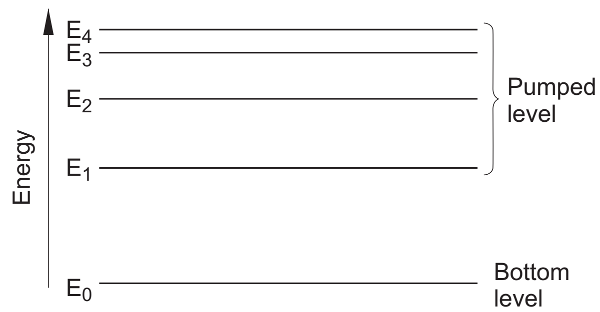

Figure 1 Energy Level

There are three types of electron transitions, as shown in figure 2.

The first type of transition, shown in figure 2 (a), is known as resonant absorption. An electron transits from the stable low energy level, E_0, to the higher energy level, E_1, by absorbing light.

Figure 2 (b) shows spontaneous emission. An electron transits from the high energy level, E_1, to a more stable low energy level, E_0. Simultaneously, the energy balance of $|E_1 - E_0|$ is released in the form of light. Since each electron at level, E_1, transits independently, light is emitted at random and out of phase. Such light is referred to as incoherent light and is one of the typical characteristics of spontaneous emission. The light from an IRED is an example of such spontaneous emission light.

Under thermal equilibrium, the probability of an electron to exist in the lower level, E_0, is higher than that in the higher energy level, E_1. Therefore, electron transition to a higher energy level ($E_0 - E_1$) by light absorption is more likely to occur than light emission as shown in figure 2 (a). To emit light, electrons must exist at E_1 with high probability, which is referred to as inversed population.

The third type of transition, shown in figure 2 (c) is stimulated emission. The electrons in the higher energy level, E_1, are forcibly transferred to the lower energy level, E_0, by incident light. The light generated this time is referred to as stimulated emission light. Its phase is the same as that of incident light, because stimulated emission light is emitted resonant to the incident light. Such stimulated emission light is referred to as coherent light.

Similarly to an electric circuit, laser oscillation requires a feedback function in addition to a gain which exceeds its loss. A laser beam is oscillated by amplification of stimulated emission and positive feedback with mirrors.

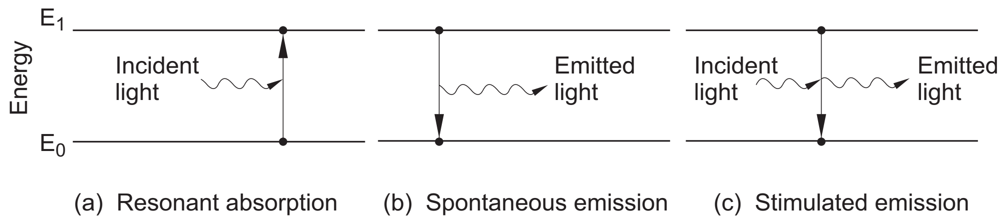

Figure 2 Transition Processes

Figure 3 shows a Fabry-Pérot resonator which is the most fundamental optical resonator.

The structure of an LD, in principle, is the same as shown in figure 3, which uses cleaved facets to make the reflection mirrors of both surfaces. Incident spontaneous emission light heading to the reflection mirror is amplified by stimulated emission and comes back to the initial position after reflection. This process is subject to losses resulting from light passing through or diffracting at the reflection mirrors and scattering or absorption within the cavity. When the loss is higher than the amplification gain, the light attenuates. Injected current strengthens amplification gain in an LD and when the gain and the loss are balanced, initial light intensity becomes equal to returned light intensity. This condition is referred to as threshold. A laser oscillates above the threshold when the gain is high enough.

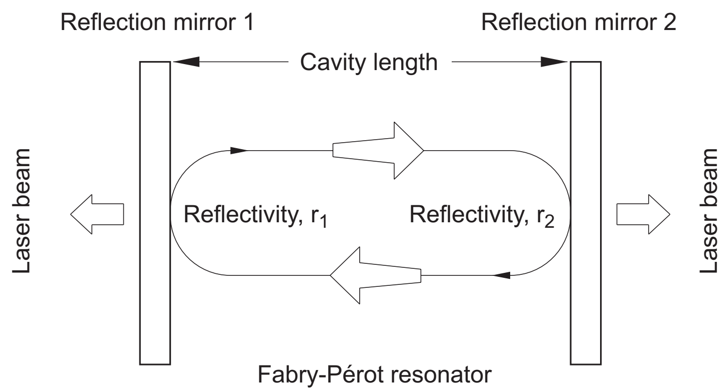

Figure 3 Fundamental Structure of Fabry-Pérot Resonator

Injection pumping mainly takes place at the p-n junction in a semiconductor laser diode. A semiconductor crystal can obtain higher gain than a gas laser (HeNe for example) due to the higher density of atoms available within the cavity. Therefore, a laser can oscillate with a short resonant cavity of 300 µm and low reflectivity of 30%.

1.2 Photo-detection Principles

Some laser diodes are assembled with a photodiode for monitoring their optical output power. Photodiodes make use of a photovoltaic effect resulting from the application of voltage to both ends of a p-n junction when light exposes the junction. Under reverse-voltage conditions, a depletion region is generated to which an electric field has been applied (see figure 4). Incident light with the same energy as the bandgap energy is absorbed in the depletion region. This absorption of light produces electron-hole pairs. The electrons and holes then drift, under electric field action, in opposite directions across the depletion region. Electrons move forward to the cathode electrode, and holes move to the anode. As a result, a current flows through the load resister, and light signals are converted to electric signals. Carriers produced in the depletion region move at high speeds due to acceleration caused by the electric field. Carriers generated in the diffusion region, however, move slowly under the influence of diffusion in accordance with the concentration gradient.

In optical fiber or information-terminal equipment systems, a high-speed response and high quantum efficiency are essential photodiode capabilities. Accordingly, Opnext has been employing PIN structures for photodiodes to achieve higher quantum efficiency and reduce junction capacitance for a faster response. “PIN” signifies a structural configuration whereby an intrinsic layer with high resistance is sandwiched between p-type and n-type semiconductors. The electric field is applied to the intrinsic region, and most incident light is absorbed in this region, producing a great many electron-hole pairs.

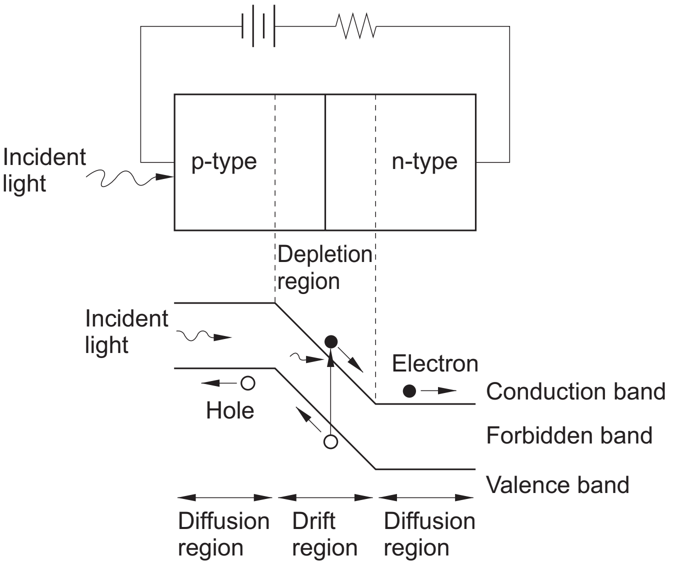

Figure 4 Photo-detection Principles