Optodevice Data Book

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ODE-408-001I

Rev.9
Mar. 2003
Opnext Japan, Inc.

Section 1 Operating Principles

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

1.1.1 Emitting Principles

Each electron in an atom or molecule has a specific discrete energy level, as shown in figure 1-1. 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

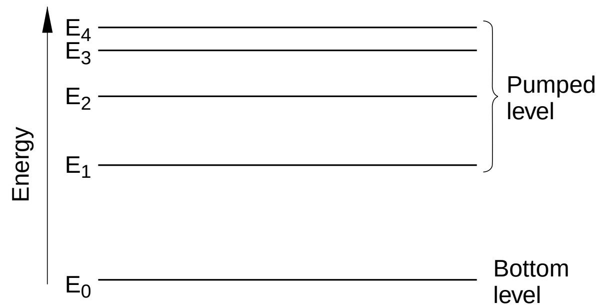

Figure 1-1 Energy Level

There are three types of electron transitions, as shown in figure 1-2.

The first type of transition, shown in figure 1-2 (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 1-2 (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.

Section 1 Operating Principles

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 1-2 (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 1-2 (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.

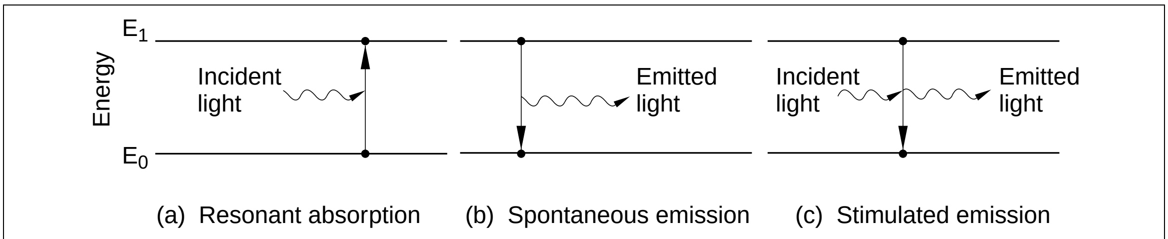

Figure 1-2 Transition Processes

Figure 1-3 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 1-3, 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.

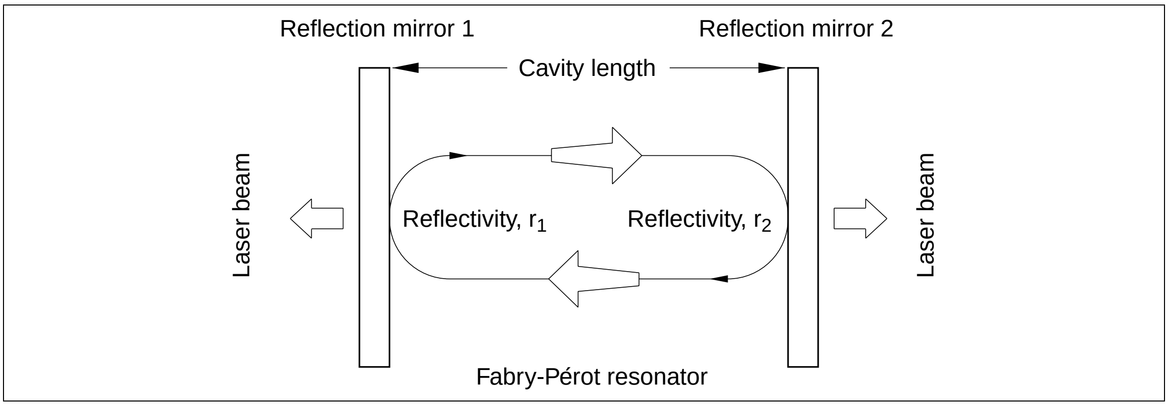

Figure 1-3 Fundamental Structure of Fabry-Pérot Resonator

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%.

1.1.2 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 1-4). 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.

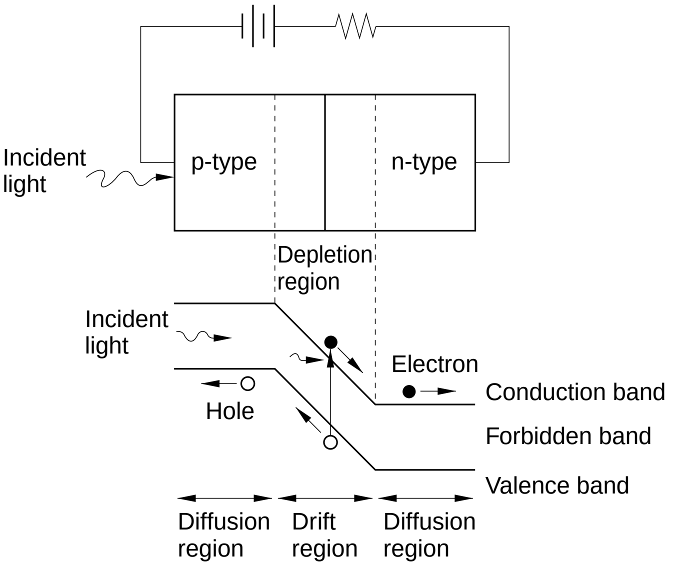

Figure 1-4 Photo-detection Principles

Section 2   Chip Structures

2.1   Laser Diodes Structures

2.1.1   AlGaInP LD Structure

The p-type active layer, in which stimulated emission enforces optical amplification (figure 2-1 (a)), is processed first. The p-n junction is made here for injecting minority carriers (the p-n heterojunction). With forward current applied to the junction, electrons in n-type region are injected into p-type region. With a p-type semiconductor of wide band gap on the other side of the p-n junction (heteroisolation junction), the injected carriers are mostly confined within the p-type active layer. This carrier confinement makes population inversion occur easily, increasing the light emission intensity.

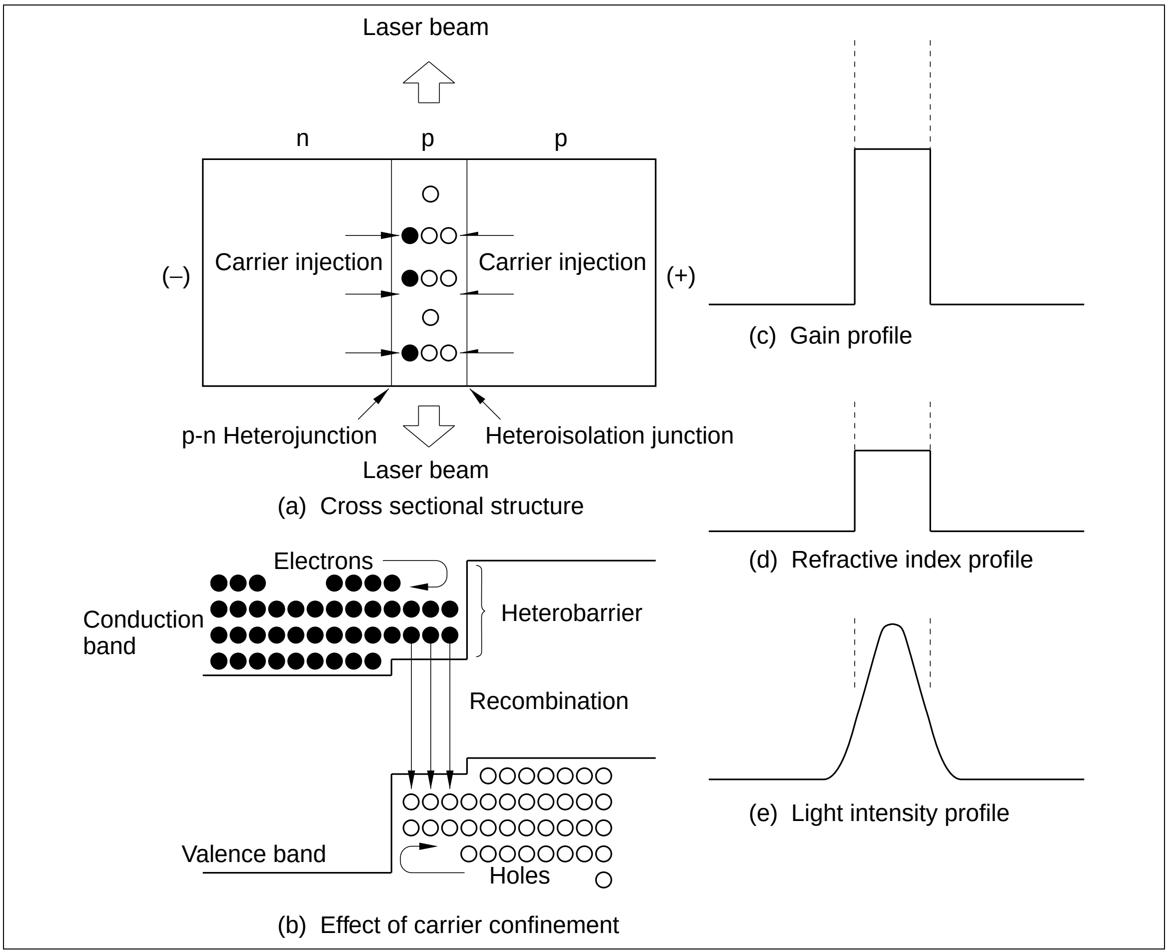

Figure 2-1   Operation Principles of Double-heterojunction LD

Section 2   Chip Structures

The active layer of the AlGaInP LD is made of $In_zGa_{1-z}P$ (figure 2-2). The thickness of the layer is approximately 0.05 µm. P-type and n-type $(Al_xGa_{1-x})_yIn_{1-y}P$ (the cladding layers) sandwich the active layer (x, y, and z here are the mixture ratio). When x, y, and z are 0.7, 0.5, and 0.5, respectively, the band gap of the cladding layers is 2.4 eV, and there is a balance of 0.6 eV against 1.8 eV of the active layer. When forward bias is applied here, the heterobarrier confines carriers within the active layer. In addition, carrier population is inverted and the gain increases. The refractive index of the active layer is higher by some percent than those of the cladding layers, which confine the generated light within the active layer. Therefore, laser oscillates effectively there (figure 2-1). A thinner active layer (called multiple quantum well structure) can make do with less threshold current density to achieve laser oscillation. At present, a threshold current density of as low as 1 to 2 kA/cm^2 can be achieved, realizing a stable continuous oscillation (CW) at room temperature.

2.1.2 LD Lasing Modes

Under laser oscillation, a light standing wave created with its wavefront parallel to the mirror facets while light is traveling back and forth within the laser cavity. This standing wave consists of a longitudinal mode and a transverse mode (figure 2-3). The longitudinal mode expresses the condition of the standing wave in the direction of cavity length (z direction). The transverse mode expresses the condition of the axis perpendicular to the cavity length direction. The transverse mode is divided into a perpendicular transverse mode which is perpendicular to the active layer, and a parallel transverse mode which is parallel to the layer.

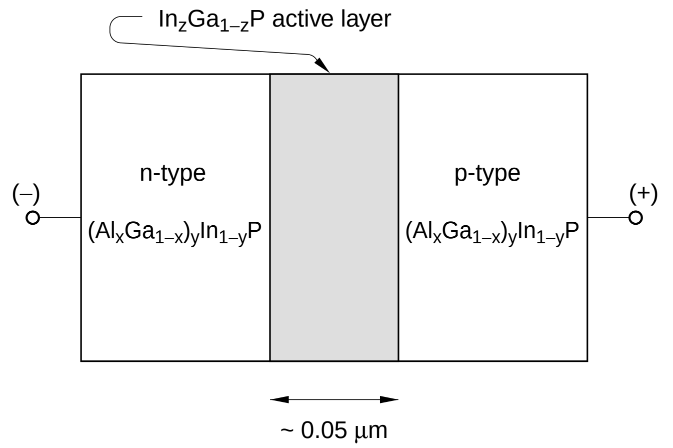

Figure 2-2   AlGaInP DH Structure LD

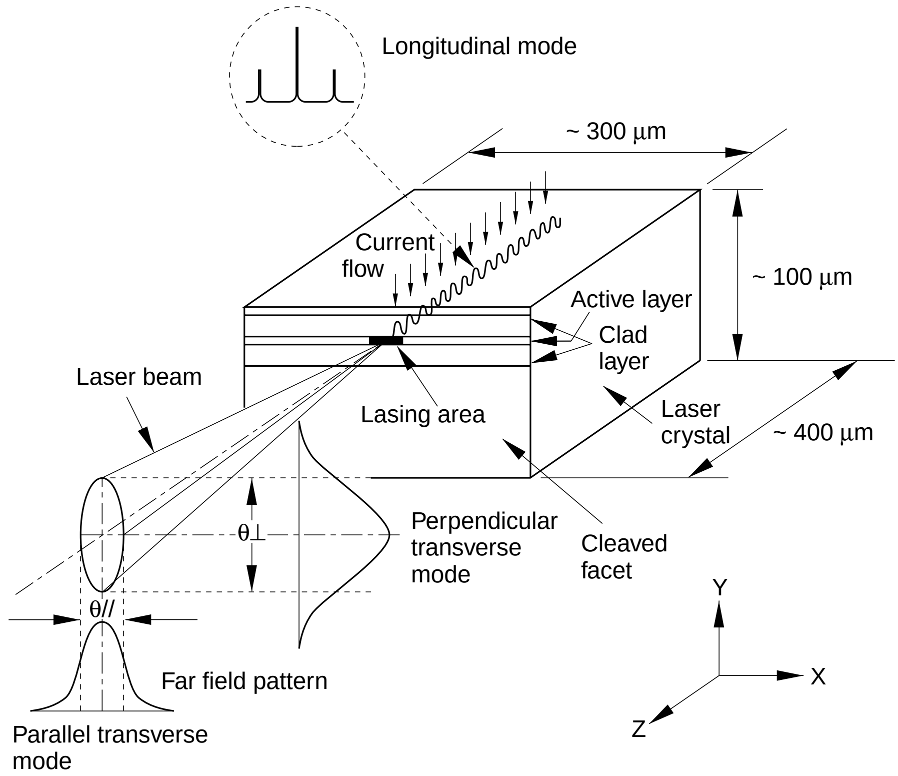

Figure 2-3 Lasing Mode of LD

1. Longitudinal mode

   Figure 2-4 (a) shows that a half-wavelength standing wave multiplied by an integer, q, forms in the direction of the laser cavity length (z direction). When the refractive index of the medium is n and the wavelength in a vacuum is λ, the wavelength of light λ' in the medium is expressed as:

   $$\lambda' = \lambda / n$$

   So the half wavelength is expressed as:

   $$\frac{1}{2}\lambda' = \frac{\lambda}{2n}$$

   As described above, the half wavelength multiplied by an integer, q, equals to the cavity length, L:

   $$q \cdot \frac{\lambda}{2n} = L$$

   For a semiconductor laser diode, when λ is 670 nm, n is 3.5, and L is 400 µm, q is about 4200. This q is referred as the mode number.

   When the mode number, q, changes by 1, the wavelength change Δλ, is expressed as:

   $$|\Delta\lambda| = 0.16 \text{ nm}$$

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Section 2 Chip Structures

Since a cavity length is incomparably longer than a wavelength, cavity resonance can take place at multiple wavelengths. The particular wavelength in which the cavity gain becomes maximum will then produce a stable standing wave.

In a semiconductor laser diode, when the temperature changes, the band gap energy changes causing the wavelength where the maximum gain is achieved to change. As for the AlGaInP DH structure laser, this temperature coefficient is about 0.20 nm/°C. Therefore, the temperature rise makes the oscillation wavelength jump upward at intervals of $\Delta\lambda$ ($\approx$ 0.16 nm). The same phenomenon takes place because of temperature rise in the active layer when the injection current increases to achieve higher optical output power under continuous operation (CW).

A long wavelength laser diode for long haul fiberoptic communication systems needs to have a dynamic single mode oscillation. Figure 2-4 (b) shows a DFB (distributed feedback) structure for dynamic single mode oscillation. The incident light to the grating formed in the device is selected to have a single wavelength by the Bragg reflection. The formula is as below, where Λ is the pitch of the grating.

$$\Lambda = \frac{\lambda}{2n}$$

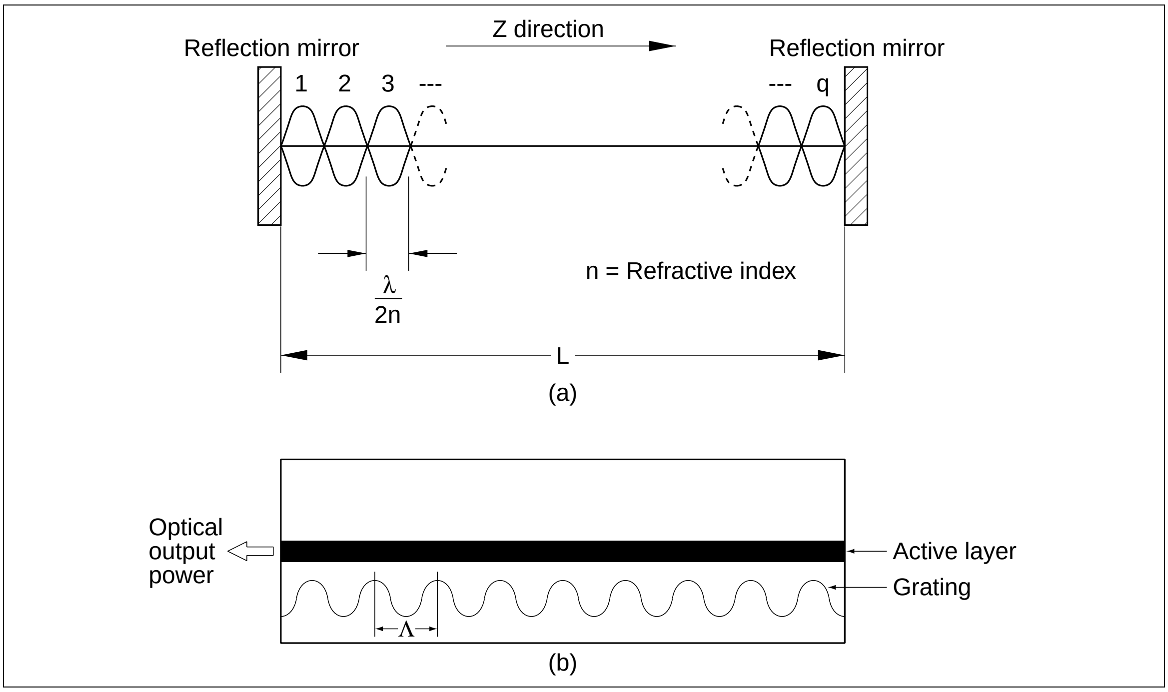

Figure 2-4 Longitudinal Mode of LD

2. Perpendicular transverse mode

In a AlGaInP laser diode, the active layer is sandwiched by heterojunctions (figure 2-5). Light is confined within the active layer because of the higher refractive index inside the layer than that of the outer AlGaInP layers. The amount of light confined within the active layer depends on its thickness. A thicker layer confines more light. Also, light penetrates into the outer layers when the active layer is too thin. The width of laser beam divergence depends on the thickness of the active layer, and when it is 0.3 to 0.4 µm, the width becomes narrowest. At this width, the radiation angle of laser beam emitted from the cleaved facet becomes widest (figure 2-6). In general, in a semiconductor laser, the radiation angle of the laser beam becomes very wide because the laser beam profile width in the device is the same as or less than the lasing wavelength. This is very different from what occurs in a conventional gas laser or solid state laser.

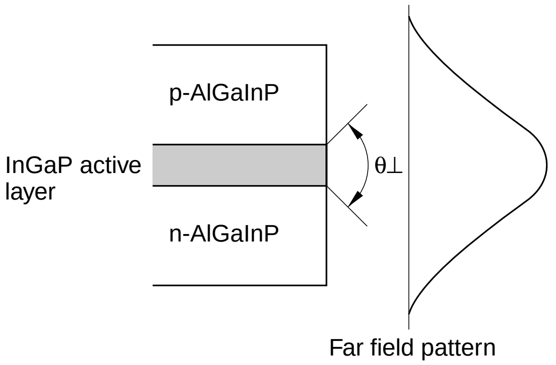

Figure 2-5 Perpendicular Transverse Mode

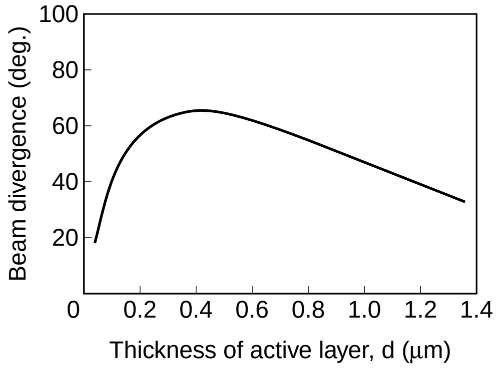

Figure 2-6 Thickness of Active Layer vs. Beam Divergence

3. Parallel transverse mode

   A waveguide must be formed by some means because there is nothing to guide light in the active layer in a direction parallel to the junction. When current injection is limited to a narrow enough region with a full cavity length, laser oscillation can then take place in the region (figure 2-3). Figure 2-7 shows the basic stripe structure which can limit current pass only.

   In order to control the transverse mode more effectively, the refractive index profile or the optical loss profile should also be built into the stripe structure. Figure 2-8 shows examples of this structure.

   Figure 2-8 (a) describes a ridge laser. The light penetrated from the active layer is absorbed in the blocking layer. Therefore, the refractive index profile is built into the stripe area. Figure 2-8 (b) describes a BH (buried heterostructure) laser. In both the perpendicular and parallel directions, the double-heterostructure is made.

   These structural waveguides stabilize the single fundamental transverse mode.

   A structure to realize a dynamic single mode is shown in figure 2-9. A LD with a dynamic single mode has a DFB (distributed feedback) structure integrated with an EA (electro-absorption) modulator.

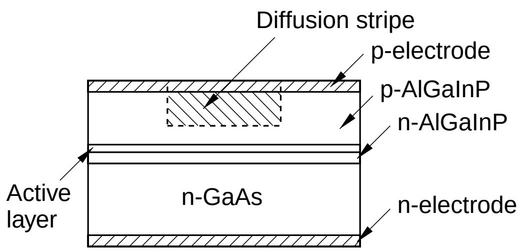

Figure 2-7 Basic Stripe LD

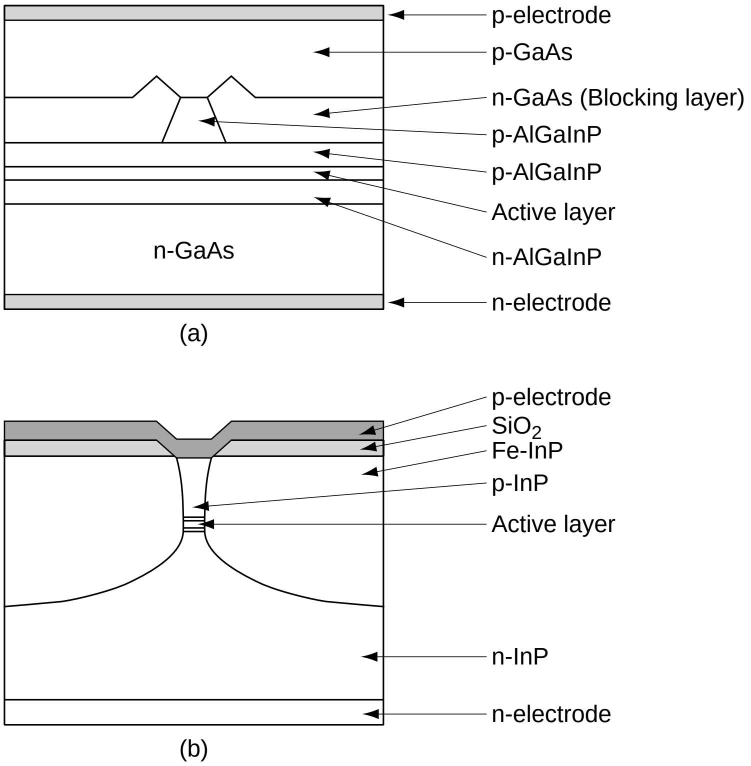

Figure 2-8   Stripe Lasers with Built-in Waveguide

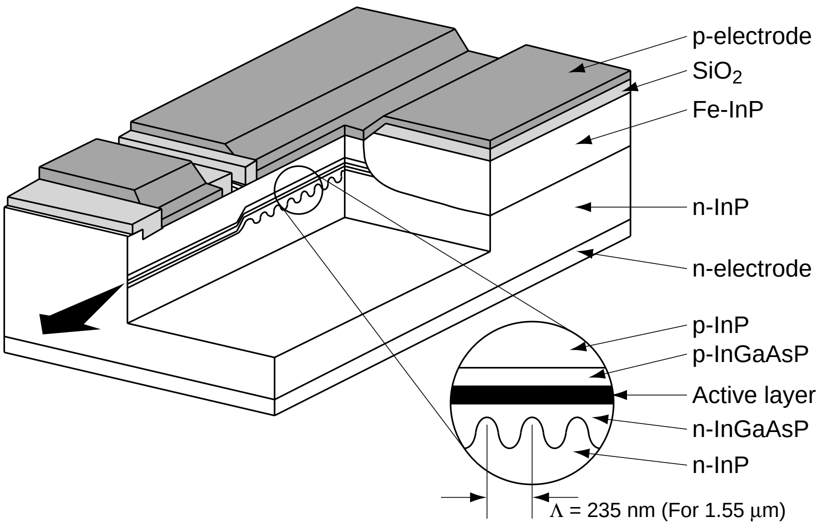

Figure 2-9   Dynamic Single Mode LD

2.2 IRED Structures

2.2.1 Heterostructure

The p-n junction barrier of the diode confines the injected current to the active layer. The heterojunction (figure 2-10 (a)) consists of p-type and n-type whose band gap energy are different from each other. This heterojunction structure increases the confinement effect and realizes high-power output and high speed. Practically, $Ga_{1-x}Al_xAs$ is used the band gap energy is controlled by changing the mixture ratio, x.

Opnext provides two types of IRED: SH (Single Hetero) structure which has only one heterojunction and DH (Double Hetero) structure which has two heterojunctions (figure 2-10 (b)) capable of realizing high-power output and high speed. Table 2-1 shows the structure of each type.

High efficiency of current-light conversion is achieved using GaAs crystal, which is a direct transition material. The chip surface is hemispherically shaped to best utilize the emitted light out of a chip (figure 2-11).

Table 2-1 IRED Structures

Part No.	Structure
HE8807 series	SH
HE7601SG	DH
HE8404SG	DH
HE8812SG	DH
HE8811	DH

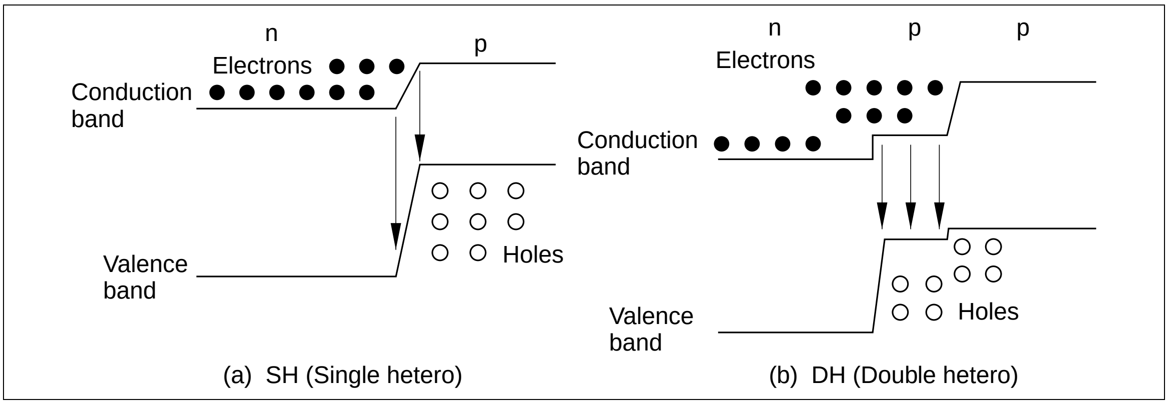

Figure 2-10 Junction Structure

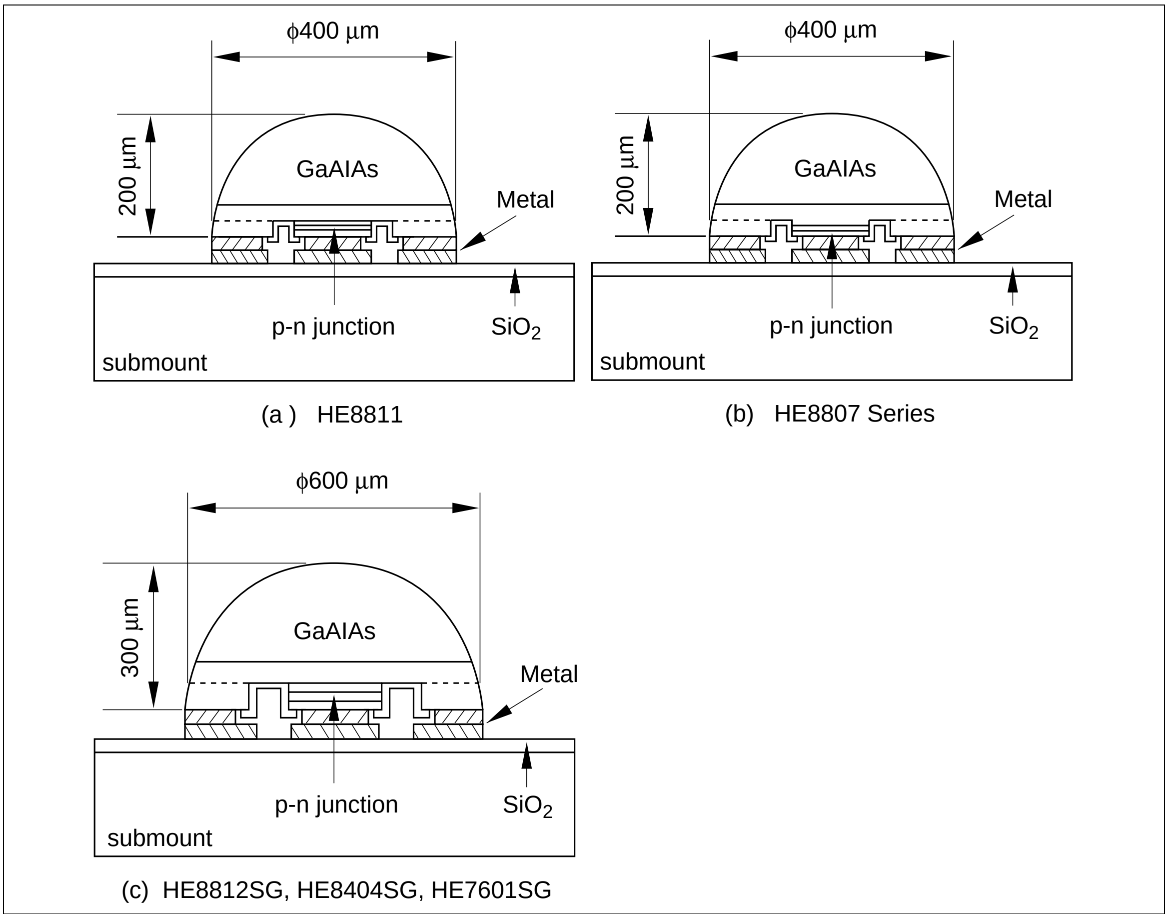

Figure 2-11 IRED Structures

2.2.2 Dome Shaped Chip

Refraction at the outer surface of the dome must be taken into account when considering light emission efficiency. Since the refractive index of GaAlAs is about 3.4, light projected to the surface of a flatshaped chip is unable to pass out at angles above 17 degrees and is reflected inside the chip, as shown in figure 2-12. Therefore, by making the chip dome-shaped, light from the center of the chip will hit the surface perpendicularly no matter what the angle and will almost all emit from the chip, as shown in figure 2-13. As a result, light hitting around the dome periphery is refracted forward, increasing the amount of utilizable light.

Table 2-2 Dome Diameter and Junction Diameter of Each Part Number

Part No.	Dome Dia. (µm)	Junction Dia. (µm)
HE7601SG	600	160
HE8404SG	600	160
HE8812SG	600	160
HE8807 series	400	100
HE8811	400	100

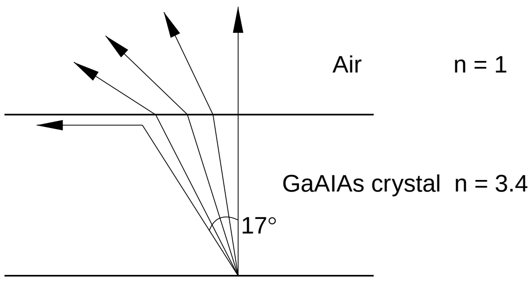

Figure 2-12 Light Refraction at Boundary Layer

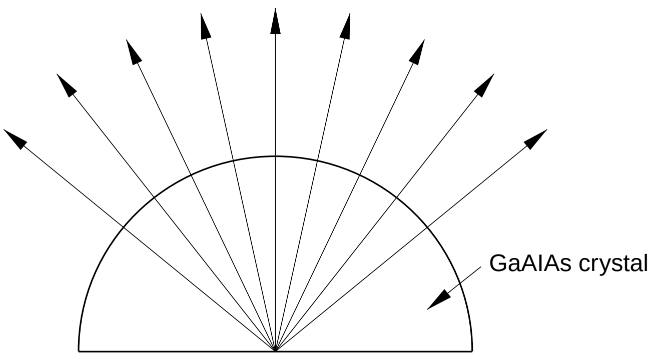

Figure 2-13 Hemispherical Shaped Light Radiation

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