Chip Structures

1. Laser Diodes Structures

1.1 AlGaInP LD Structure

The p-type active layer, in which stimulated emission enforces optical amplification (figure 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.

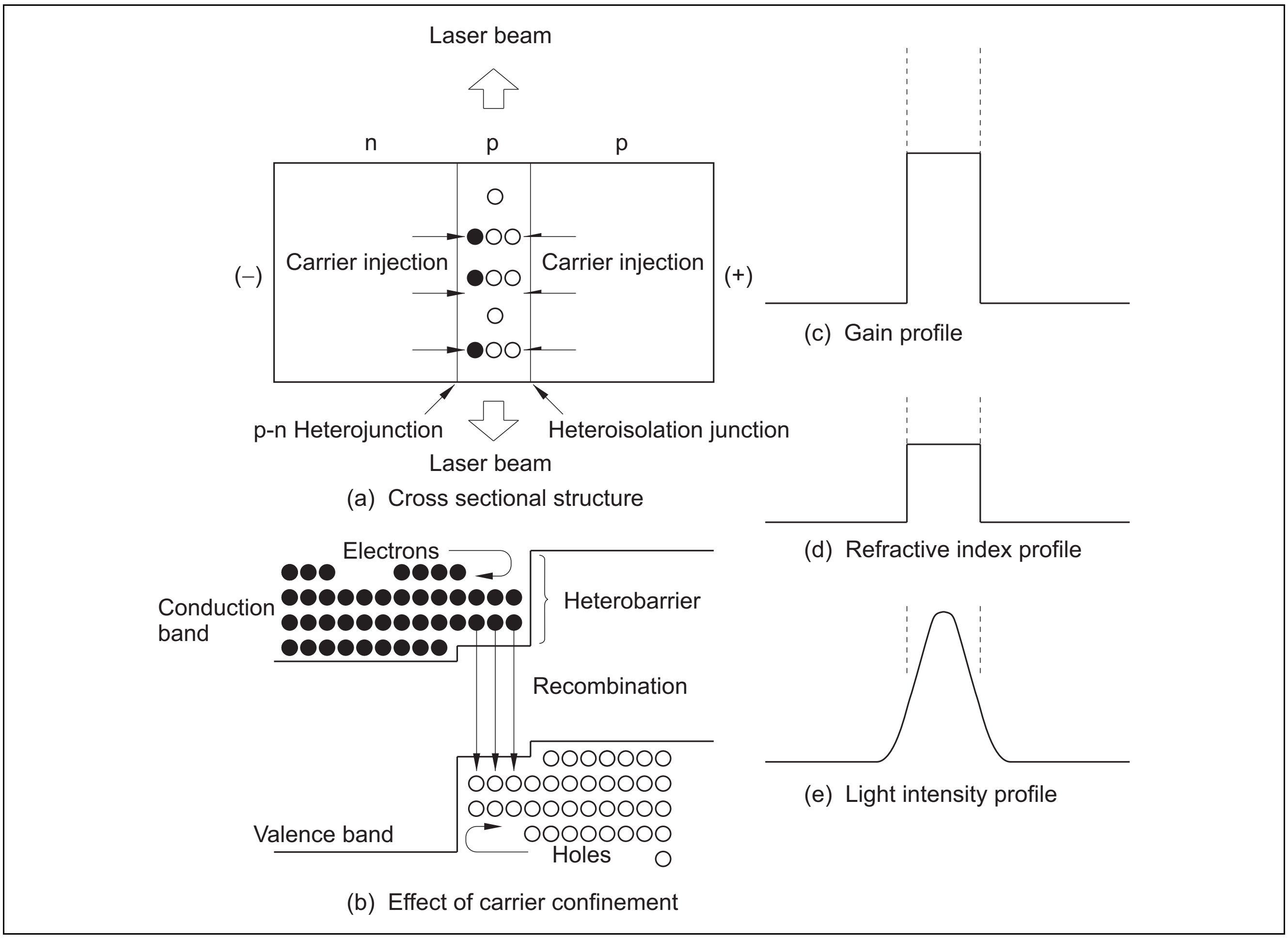


Figure 1 Operation Principles of Double-heterojunction LD

The active layer of the AlGaInP LD is made of $In_zGa_{1-z}P$ (figure 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 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.

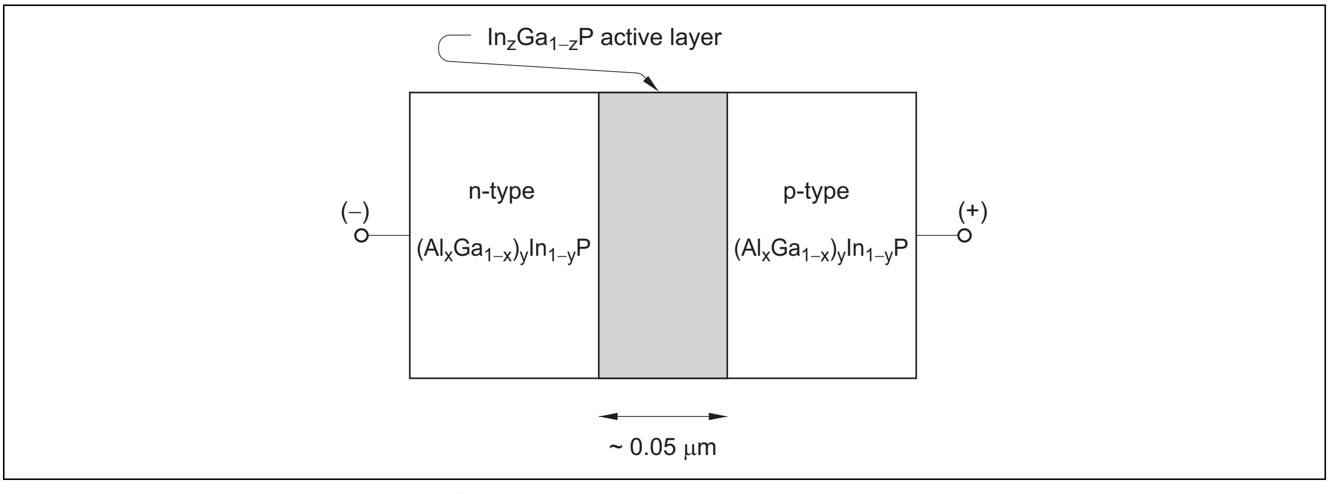


Figure 2 AlGaInP DH Structure LD

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 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.

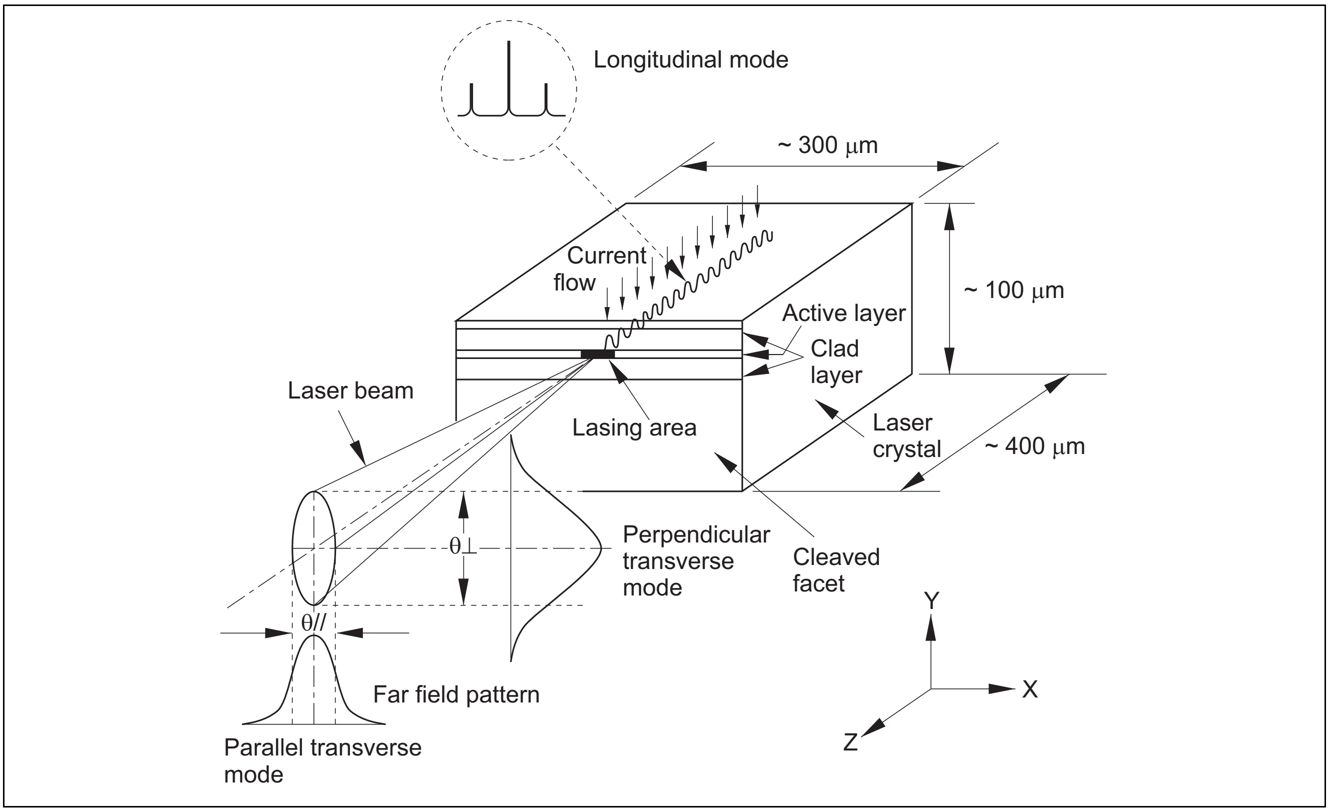


Figure 3 Lasing Mode of LD

1.2.1 Longitudinal Mode

Figure 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 635 nm, n is 3.5, and L is 400 µm, q is about 4400. This q is referred as the mode number.

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

$$|\Delta\lambda| = 0.144 \text{ nm}$$

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 Δλ (≈ 0.144 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).

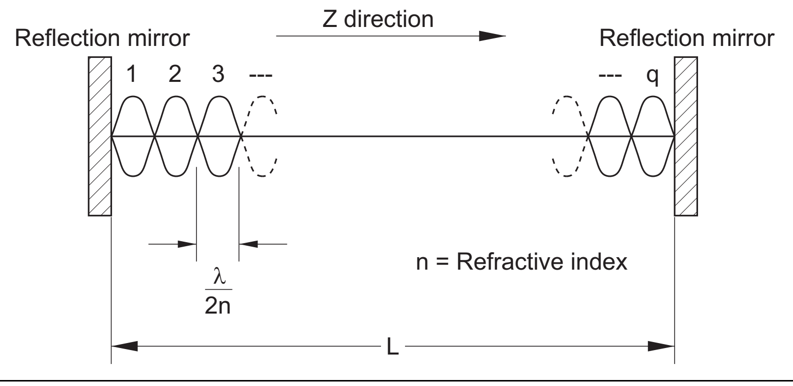


Figure 4 Longitudinal Mode of LD

1.2.2 Perpendicular Transverse Mode

In a AlGaInP laser diode, the active layer is sandwiched by heterojunctions (figure 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 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.

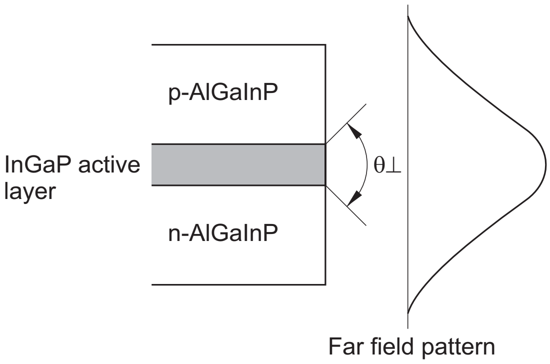


Figure 5 Perpendicular Transverse Mode

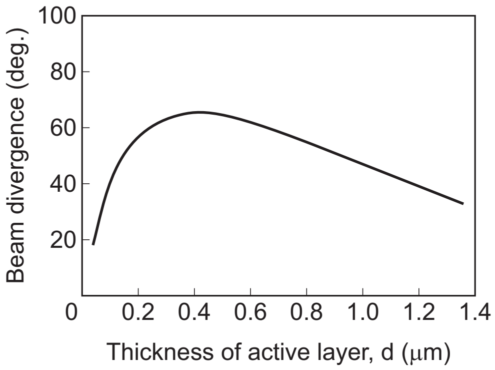


Figure 6 Thickness of Active Layer vs. Beam Divergence

1.2.3 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 3). Figure 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 8 shows examples of this structure.

Figure 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 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.

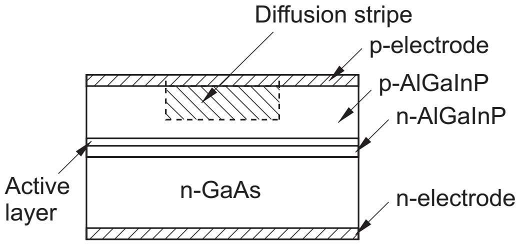


Figure 7 Basic Stripe LD

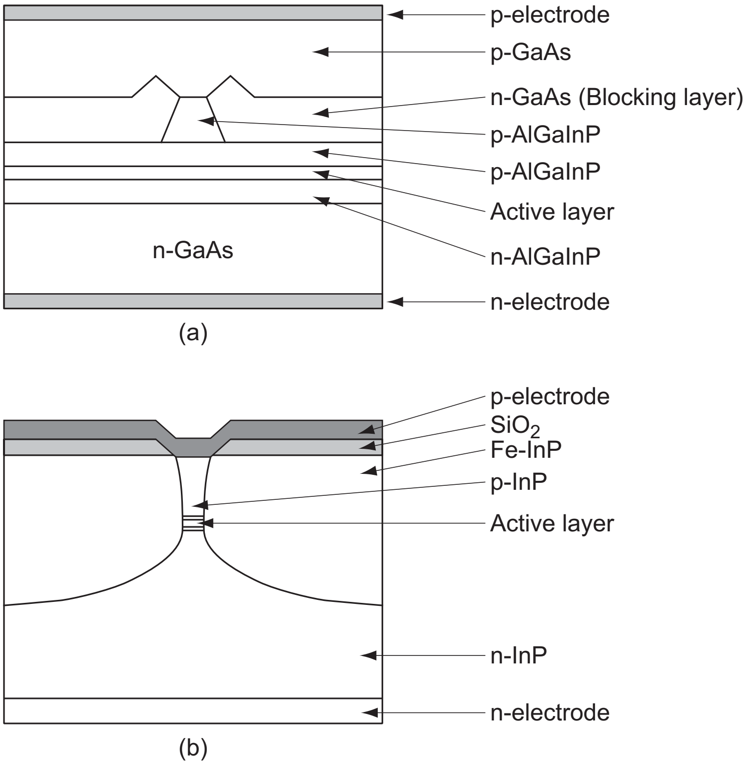


Figure 8 Stripe Lasers with Built-in Waveguide

2. IRED Structures

2.1 Heterostructure

The p-n junction barrier of the diode confines the injected current to the active layer. The heterojunction (figure 9 (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 9 (b)) capable of realizing high-power output and high speed. Table 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 10).

Table 1 IRED Structures

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

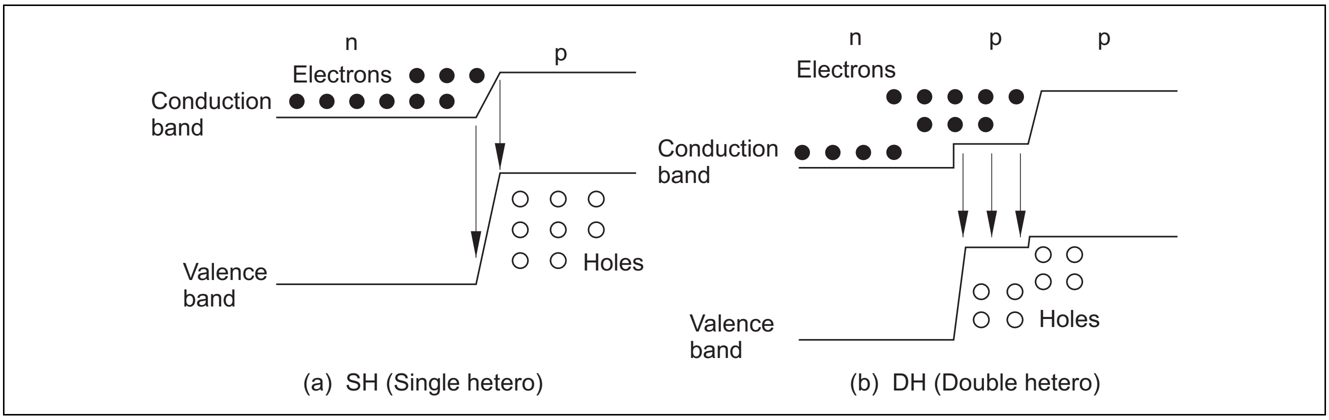
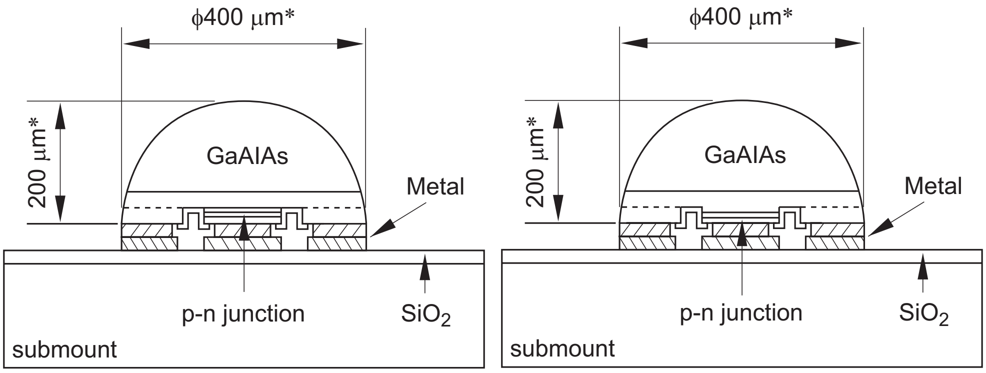
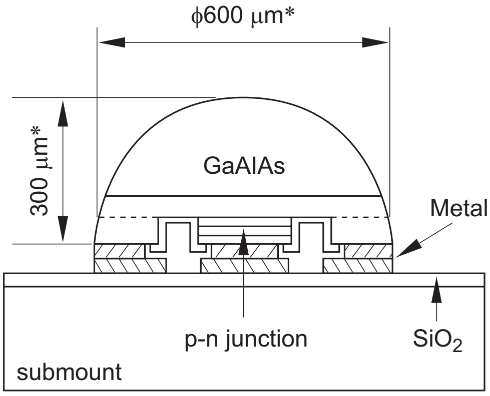


Figure 9 Junction Structure



(a) HE8811 (b) HE8807 Series



(c) HE8812SG, HE8404SG, HE7601SG

Note: * The dimensions are for reference.

Figure 10 IRED Structures

2.2 Dome Shaped Chip (Reason of High Optical Output Power of IRED)

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 11. 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 12. As a result, light hitting around the dome periphery is refracted forward, increasing the amount of utilizable light.

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

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

Note: Dome diameter and Junction diameter are for reference.

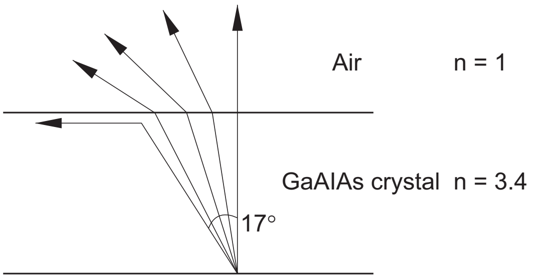


Figure 11 Light Refraction at Boundary Layer

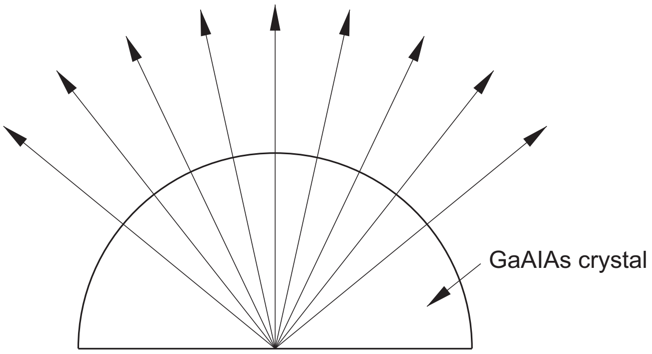


Figure 12 Hemispherical Shaped Light Radiation