Introduction

The optical source is often considered to be the active component in an optical fiber communication system. Its fundamental function is to convert electrical energy in the form of a current into optical energy (light) in an efficient manner which allows the light output to be effectively launched or coupled into the optical fiber. Three main types of optical light source are available. These are:

- ✓ wideband ‘continuous spectra’ sources (incandescent lamps)
- ✓ monochromatic incoherent sources (light-emitting diodes, LEDs);
- ✓ monochromatic coherent sources (lasers).

To aid consideration of the sources currently in major use, the historical aspect must be mentioned. In the early stages of optical fiber communications the most powerful narrowband coherent light sources were necessary due to severe attenuation and dispersion in the fibers. Therefore, gas lasers (helium-neon) were utilized initially. However, the development of the semiconductor injection laser and the LED, together with the substantial improvement in the properties of optical fibers, has given prominence to these two specific sources

LEDs

Spontaneous emission of radiation in the visible and infrared regions of the spectrum from a forward-biased *p–n* junction was discussed. The normally empty conduction band of the semiconductor is populated by electrons injected into it by the forward current through the junction, and light is generated when these electrons recombine with holes in the valence band to emit a photon. This is the mechanism by which light is emitted from an LED, but stimulated emission is not encouraged, as it is in the injection laser, by the addition of an optical cavity and mirror facets to provide feedback of photons.

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The LED can therefore operate at lower current densities than the injection laser, but the emitted photons have random phases and the device is an incoherent optical source. Also, the energy of the emitted photons is only roughly equal to the band gap energy of the semiconductor material, which gives a much wider spectral line width (possibly by a factor of 100) than the injection laser. The line width for an LED corresponds to a range of photon energy between 1 and 3.5KT, where K is Boltzmann's constant and T is the absolute temperature.

This gives line widths of 30 to 40 nm for GaAs-based devices operating at room temperature. Thus the LED supports many optical modes within its structure and is therefore often used as a multimode source, although the coupling of LEDs to single-mode fibers has been pursued with success, particularly when advanced structures are employed. Also, LEDs have several further drawbacks in comparison with injection lasers.

These include:

- ✓ generally lower optical power coupled into a fiber (microwatts)
- ✓ usually lower modulation bandwidth
- ✓ harmonic distortion.

However, although these problems may initially appear to make the LED a less attractive optical source than the injection laser, the device has a number of distinct advantages which have given it a prominent place in optical fiber communications:

***Simpler fabrication*.** There are no mirror facets and in some structures no striped geometry.

***Cost*.** The simpler construction of the LED leads to much reduced cost which is always likely to be maintained.

***Reliability*.** The LED does not exhibit catastrophic degradation and has proved far less sensitive to gradual degradation than the injection laser. It is also immune to self-pulsation and modal noise problems.

***Generally less temperature dependence*.** The light output against current characteristic is less affected by temperature than the corresponding characteristic for the injection laser. Furthermore, the LED is not a threshold device and therefore raising the temperature does not increase the threshold current above the operating point and hence halt operation.

***Simpler drive circuitry*.** This is due to the generally lower drive currents and reduced temperature dependence which makes temperature compensation circuits unnecessary.

***Linearity*.** Ideally, the LED has a linear light output against current characteristic, unlike the injection laser. This can prove advantageous where analog modulation is concerned.

The planar LED is the simplest of the structures that are available and is fabricated by either liquid- or vapor-phase epitaxial processes over the whole surface of a GaAs substrate. This involves a *p*-type diffusion into the *n*-type substrate in order to create the junction illustrated in Figure 3.1. Forward current flow through the junction gives Lambertian spontaneous emission and the device emits light from all surfaces. However, only a limited amount of light escapes the structure due to total internal reflection, and therefore the radiance is low.

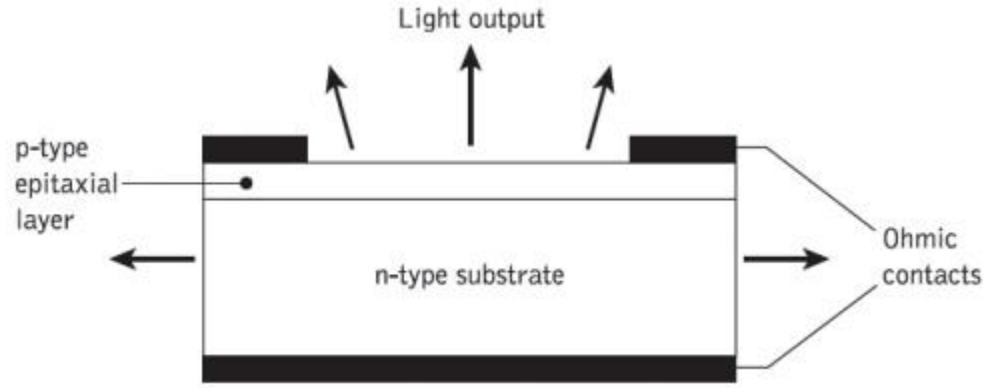

Figure 3.1 The structure of a planar LED showing the emission of light from all surfaces

[Source: htpp://img.brainkart.com]

The absence of optical amplification through stimulated emission in the LED tends to limit the internal quantum efficiency (ratio of photons generated to injected electrons) of the device. Reliance on spontaneous emission allows non-radiative recombination to take place within the structure due to crystalline imperfections and impurities giving, at best, an internal quantum efficiency of 50% for simple homojunction devices. However, as with injection lasers, double-heterojunction (DH) structures have been implemented which recombination lifetime measurements suggest give internal quantum efficiencies of 60 to 80%.

The power generated internally by an LED may be determined by consideration of the excess electrons and holes in the *p*- and *n*-type material respectively (i.e. the minority carriers) when it is forward biased and carrier injection takes place at the device contacts. The excess density of electrons Δn and holes Δp is equal since the injected carriers are created and recombined in pairs such that charge neutrality is maintained within the structure.

LED STRUCTURES

1. Surface Emitting LEDs

A method for obtaining high radiance is to restrict the emission to a small active region within the device. The technique pioneered by Burrus and Dawson with homostructure devices was to use an etched well in a GaAs substrate in order to prevent heavy absorption of the emitted radiation, and physically to accommodate the fiber. These structures have a low thermal impedance in the active region allowing high current densities and giving high-radiance emission into the optical fiber. Furthermore, considerable advantage may be obtained by employing DH structures giving increased efficiency from electrical and optical confinement as well as less absorption of the emitted radiation.

This type of surface emitter LED (SLED) has been widely employed within optical fiber communications. The structure of a high-radiance etched well DH surface emitter* for the 0.8 to 0.9μm wavelength band is shown in Figure 3.2. The internal absorption in this device is very low due to the larger bandgap-confining layers, and the reflection coefficient at the back crystal face is high giving good forward radiance. The emission from the active layer is essentially isotropic, although the external emission distribution may be considered Lambertian with a beam width of 120° due to refraction from a high to a low refractive index at the GaAs–fiber interface. The power coupled *P*c into a multimode step index fiber may be estimated from the relationship:

$$P_c = \pi (1 - r) A R_D (NA)^2 \tag{3.1}$$

where r is the Fresnel reflection coefficient at the fiber surface, A is the smaller of the fiber core cross-section or the emission area of the source and RD is the radiance of the source.

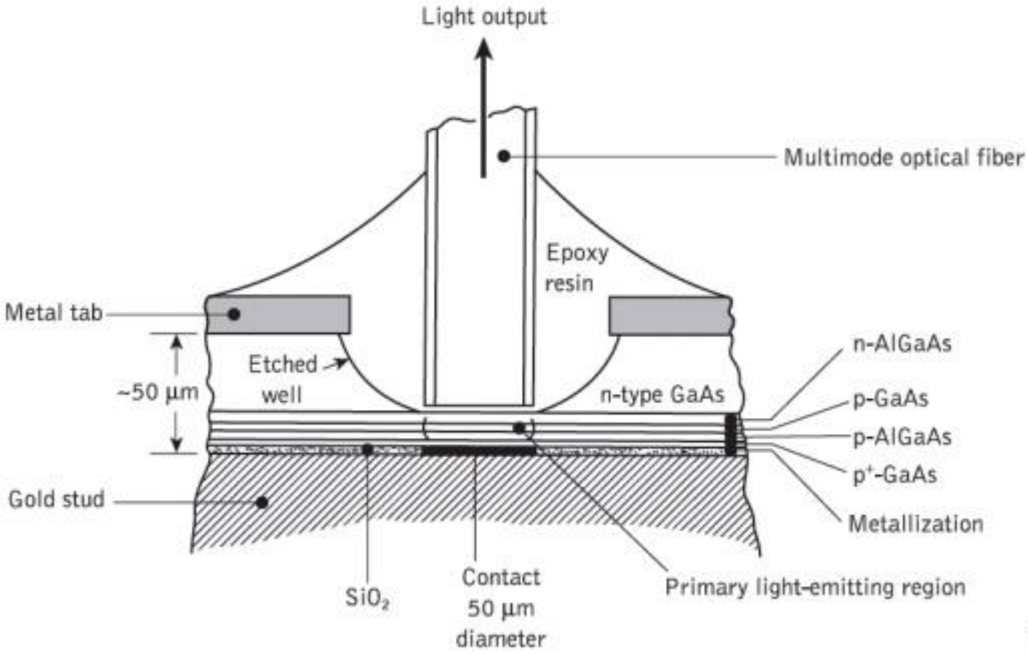

Figure 3.2 The structure of an AlGaAs DH surface-emitting LED (Burrus type).

[Source: htpp://img.brainkart.com]

However, the power coupled into the fiber is also dependent on many other factors including the distance and alignment between the emission area and the fiber, the SLED emission pattern and the medium between the emitting area and the fiber. For instance, the addition of epoxy resin in the etched well tends to reduce the refractive index mismatch and increase the external power efficiency of the device. Hence, DH surface emitters often give more coupled optical power than predicted by Eq. (3.1).

However, for graded index fiber optimum direct coupling requires that the source diameter be about one-half the fiber core diameter. In both cases lens coupling may give increased levels of optical power coupled into the fiber but at the cost of additional complexity. Other factors which complicate the LED fiber coupling are the transmission characteristics of the leaky modes or large angle skew rays. Much of the optical power from an incoherent source is initially

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coupled into these large-angle rays, which fall within the acceptance angle of the fiber but have much higher energy than meridional rays. Energy from these rays goes into the cladding and may be lost.

Hence much of the light coupled into a multimode fiber from an LED is lost within a few hundred meters. It must therefore be noted that the effective optical power coupled into a short length of fiber significantly exceeds that coupled into a longer length. The planar structure of the Burrus-type LED and other nonetched well SLEDs allows significant lateral current spreading, particularly for contact diameters less than 25 µm. This current spreading results in a reduced current density as well as an effective emission area substantially greater than the contact area.

2. Edge Emitting LEDs

Another basic high-radiance structure currently used in optical communications is the stripe geometry DH edge emitter LED (ELED). This device has a similar geometry to a conventional contact stripe injection laser, as shown in Figure 3.3. It takes advantage of transparent guiding layers with a very thin active layer (50 to 100 µm) in order that the light produced in the active layer spreads into the transparent guiding layers, reducing self-absorption in the active layer. The consequent waveguiding narrows the beam divergence to a half-power width of around 30° in the plane perpendicular to the junction. However, the lack of waveguiding in the plane of the junction gives a Lambertian output with a half-power width of around 120°, as illustrated in Figure3.3.

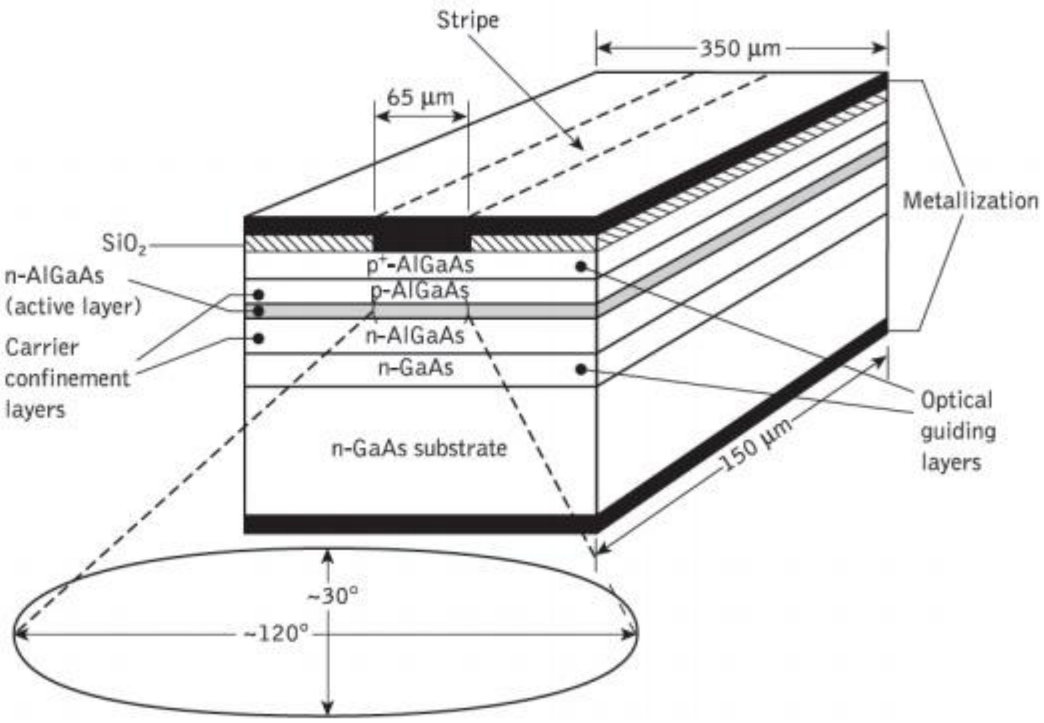

Figure 3.3 Schematic illustration of the structure of a stripe geometry DH AlGaAs edge-emitting LED

[Source: htpp://img.brainkart.com]

Most of the propagating light is emitted at one end face only due to a reflector on the other end face and an antireflection coating on the emitting end face. The effective radiance at the emitting end face can be very high giving an increased coupling efficiency into small-*NA* fiber compared with the surface emitter. However, surface emitters generally radiate more power into air (2.5 to 3 times) than edge emitters since the emitted light is less affected by reabsorption and interfacial recombination. Comparisons have shown that edge emitters couple more optical power into low *NA* (less than 0.3) than surface emitters, whereas the opposite is true for large *NA* (greater than 0.3).

The enhanced waveguiding of the edge emitter enables it in theory to couple 7.5 times more power into low-*NA* fiber than a comparable surface emitter. However, in practice the increased coupling efficiency has been found to be slightly less than this (3.5 to 6 times). Similar coupling efficiencies may be achieved into low-*NA* fiber with surface emitters by the use of a lens. Furthermore, it has been found that lens coupling with edge emitters may increase the coupling efficiencies by comparable factors (around five times).

The stripe geometry of the edge emitter allows very high carrier injection densities for given drive currents. Thus it is possible to couple approaching a milliwatt of optical power into low-*NA* (0.14) multimode step index fiber with edge-emitting LEDs operating at high drive currents (500 mA).

Edge emitters have also been found to have a substantially better modulation bandwidth of the order of hundreds of megahertz than comparable surface-emitting structures with the same drive level. In general it is possible to construct edge-emitting LEDs with a narrower linewidth than surface emitters, but there are manufacturing problems with the more complicated structure (including difficult heat-sinking geometry) which moderate the benefits of these devices.

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