Gallium Aluminum Arsenide—a new generation of infrared LEDs superior to gallium arsenide

Application Bulletin 205

The first light source for actuating an optoelectronic photosensor was the tungsten filament or incandescent lamp. It was eventually replaced by the GaAs infrared emitting diode which offered longer life, smaller size, less power to operate and less heat generated. The GaAs LED is still the workhorse of the industry and will continue to be used in steadily decreasing numbers for the next few years. It will eventually be replaced by GaAlAs as the industry standard for two major reasons: GaAlAs offer at least twice the power output at the same input current (I_F) level and significantly improved coupling efficiency.

General Description

Typically a GaAs LED mounted on a TO-46 header with a flat window can will emit 5 milliwatts total radiant flux at an I_F—100 mA. At the same I_F, a GaAlAs LED will typically emit 10 milliwatts total radiant flux. Similar increases are possible in other packages. This allows the designer some options which have not been available before.

In addition, silicon doped GaAs has a spectral emission centered at approximately 935 nanometers. GaAlAs has a spectral emission at approximately 890 nanometers which is very close to the peak response of silicon phototransistors. This improves coupling efficiency by approximately 30%.

Figure 1 graphically illustrates the improvement in photodiode collector current as a result of both the higher radiant flux and the optimized spectral emission.

The only negatives to GaAlAs are a slightly higher forward voltage (V_F) (see Figure 2) and a slightly higher initial cost. With process improvements, and higher volumes, this cost difference would eventually disappear.

FIGURE 1

Photodiode Collector Current Versus LED Forward Current With Both GaAlAs and GaAs

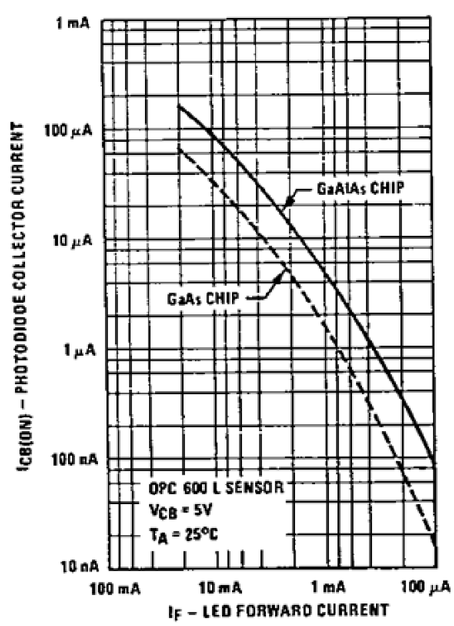
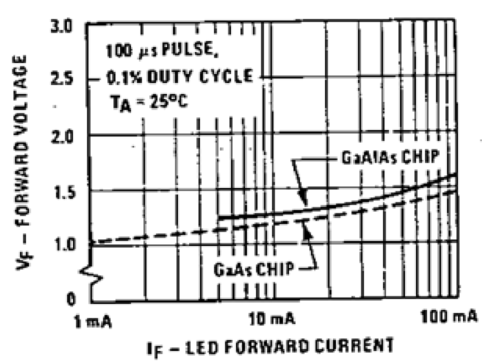


FIGURE 2

Forward Voltage Versus LED Forward Current

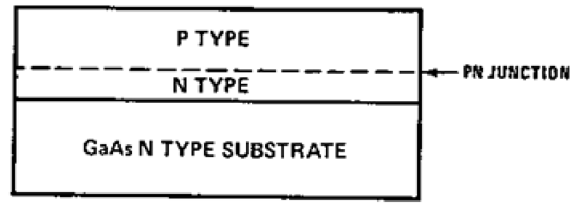


TT Electronics | Optek Technology
1645 Wallace Drive, Suite 130, Carrollton, TX, USA 75006 |Ph: +1 972-323-2300
www.ttelectronics.com | sensors@ttelectronics.com

Chip Fabrication

All Optek GaAlAs LEDs are made by means of a straightforward single step solution grown liquid phase epitaxial (LPE) preparation technique. Initially it is much the same process as making GaAs LEDs. N type GaAs substrates approximately 16 mils thick are placed in a furnace and heated to around 920°C. A melted mixture of gallium, gallium arsenide and silicon (called the "melt") is then placed on top of the substrates. In the case of GaAlAs, aluminum (Al) is added to the melt. The furnace then starts cooling, and an epitaxial N type layer begins to grow on top of the substrates. As the cooling continues, the silicon in the melt which is amphoteric changes polarity or "flips" to P type material at approximately 900°C, forming the PN junction. The growth process continues until the epi layer reaches a thickness of 7-8 mils. (See Figure 3.)

FIGURE 3
Typical Epitaxial Layer Growth

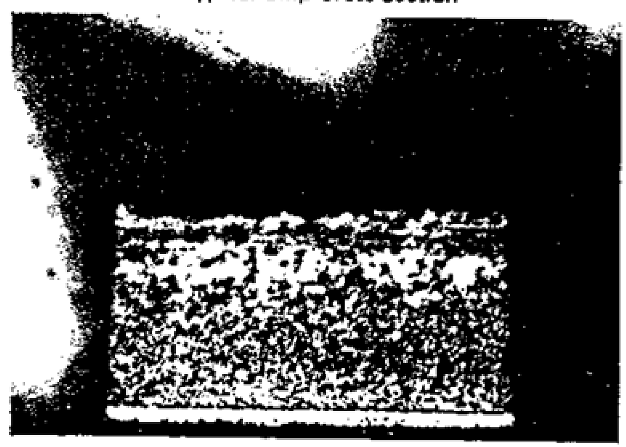


The nature of the Al in the melt is such that it is depleted or used up rapidly in the early stages of the epi growth. Concentration is virtually zero at the top of the P layer.

The substrate is then etched away with an etchant that readily dissolves GaAs. As the etchant contacts the N layer, the aluminum causes the etch rate to be slowed to 1/100th of the initial rate. This is convenient because it helps to ensure that the N layer is not materially etched.

After etching, appropriate ohmic contacts are added by evaporation techniques. A gold contact completely covers the P layer or backside, and a dot matrix contact is put on the N layer or topside. The chips are then sawed into their final size. A final etching is done to remove saw damage and the roughen the surface of the N layer which enhances light output. (Figure 4).

FIGURE 4
Typical Chip Cross Section



What makes GaAlAs superior?

The wavelength of the emitted light of an LED is related to the energy in the photons of light it emits. Also the higher the band gap energy of the semiconductor material, the higher the photon energy. Al atoms increase the band gap energy in proportion to the concentration which allows adjustment of the photon wavelength. By controlling this concentration, the wavelength can be varied to approximate the peak spectral response of a silicon phototransistor or 890 nanometers.

GaAlAs also has an improved radiation window. In order for an LED to emit more light, absorption of photons traveling through the material must be as low as possible. In other words, there must be a high probability that the photons generated at the junction will reach a surface and escape. For this to happen effectively, the photon energy must be less than the band gap energy of the material. In previous discussions, it was mentioned that Al atoms increase the band gap energy. The heaviest concentration of Al atoms is at the N layer surface with rapidly decreasing concentration toward the PN junction. Photons generated at the junction then travel a path through steadily increasing band gap energy levels until they reach the surface. This property ensures a much reduced chance of re-absorption of photons than does a material in which the band gap energy is constant from junction to surface such as GaAs.

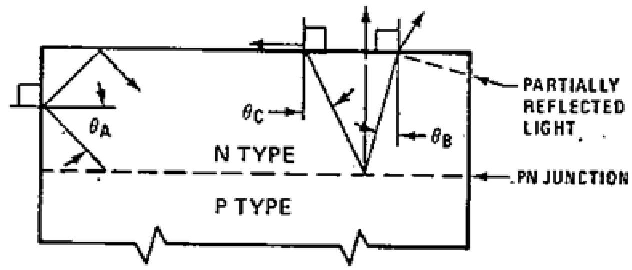
TT Electronics | Optek Technology
1645 Wallace Drive, Suite 130, Carrollton, TX, USA 75006 |Ph: +1 972-323-2300
www.ttelectronics.com | sensors@ttelectronics.com

One final plus, GaAlAs has an index of refraction which is slightly lower than GaAs. This affects the critical angle which defines the angle at which there is total internal reflection. (See Figure 5.)

At angles less than the critical angle, there is partial reflection. (See angle Θ_B in Figure 5.) At angles greater than the critical angle, there is total internal reflection. (See angle Θ_A in Figure 5.)

There are ways of improving surface emission. One, mentioned earlier, is the post-dicing etch cleanup which roughens the chip surface. This increases the likelihood of photons striking the surface at less than the critical angle. Another improvement is the addition of a clear epoxy, anti-reflective, domed lens placed over the chip which actually enlarges the critical angle to approximately 24°.

FIGURE 5
Definition of Critical Angle



The critical angle is determined by the formula:

$\sin\theta_C = \frac{n_1}{n_2}$ Where n_1 is the index of refraction of air, or 1, and n_2 is the index of refraction of the chip material.

With GaAs, $n_2 = 3.6$

$$\sin\theta_C = \frac{1}{3.6}$$
$$\theta_C = 16°$$

With GaAlAs, $n_2 = 3.4$

$$\sin\theta_C = \frac{1}{3.4}$$
$$\theta_C = 17°$$

APPLICATION

Reliability
Since GaAlAs and GaAs junctions are formed in the same manner, the chips should have the same reliability. Life tests to date indicate that this is true. Data shows that both GaAlAs and GaAs have from 5 to 8% degradation after 1,000 hours of maximum rated operation.

Drawbacks
GaAlAs has inherently high V_F. The higher the band gap energy, the higher the V_F must be to impart adequate energy to the electrons. Typical V_F for Optek's GaAs LEDs at 100 mA is 1.5 V vs. 1.75V for GaAlAs. This difference increases slightly at higher currently levels.

Conclusion
Many power-starved optical assembly packages will be helped immediately by using GaAlAs. Special optosensor assemblies such as card readers, paper tape readers, paper sensors and precision shaft encoders will become easier to design.

Electronic assemblies which operated with an LED/sensor pair will benefit immediately.

- With optocouplers, higher current transfer ratios will be available, and the LED and sensor will not need to be mounted as close to each other which will allow higher isolation voltages.
- With reflective assemblies, reflective objects will be able to be sensed at greater distances than before.
- With interrupter assemblies, precise alignment and gap width will not be as critical. Since there is more light available, aperturing can be reduced for higher resolution or photosensor gain can be reduced for better signal-to-noise ratio and improved gain-bandwidth product.
- In battery-operated applications, a GaAlAs LED can replace a GaAs LED and provide the same light output at 1/2 the current drive.
- Since the same light output can be produced at 1/2 the current drive, GaAlAs LEDs will have much longer operating life.

GaAlAs, with its superior performance, will give the designer more options and design flexibilities than were previously available.

Dean Wolfe

TT Electronics | Optek Technology
1645 Wallace Drive, Suite 130, Carrollton, TX, USA 75006 | Ph: +1 972-323-2300
www.ttelectronics.com | sensors@ttelectronics.com