Semiconducting Light-emitting Devices

James A. Johnson

Abstract—Semiconducting light-emitting devices are continually being improved for power and radiance efficiency. Upon examining the fundamental structure and physics of light-emitting devices, device packaging will be examined in reference to expanding applications and efficiency.

Index Terms—Light-emitting diodes, Optoelectronics, Semiconductor Lasers, Semiconductor Materials.

I. INTRODUCTION

Semiconducting light-emitting devices are unique types of semiconductor diodes that include light-emitting diodes and laser diodes. In order for semiconducting light-emitting devices to be effective at radiating light for any application, they must be manufactured using specific materials and constructs to achieve the highest efficiency possible. Direct bandgap semiconductors provide the most efficient means creating a photon during electron-hole recombination. The minimum energy of the conduction band of a semiconductor lies directly above the maximum energy level of the valance band. This allows electrons from the conduction band and holes from the valence band to recombine while conserving momentum [1]. A prime example of a direct gap semiconductor used in light-emitting devices is gallium arsenide (GaAs).

Fig. 1. Energy band diagram of a direct gap semiconductor.

The conduction band minimum is not directly above the valence band maximum in indirect gap semiconductors such as Silicon (Si).

Fig. 2. Energy band diagram of an indirect gap semiconductor.

In order for the electrons of the conduction band to recombine with holes from the valance band, they must travel across the k-vector. During recombination, conservation of energy and conservation of momentum must be observed. Typically phonons are created in order to accommodate the conservation laws. Phonons, which are quantized modes of vibration occurring in the rigid lattice structure of solids, do not radiate when they are created. Thus, indirect gap semiconductors do not emit light efficiently [1], [2].

II. LIGHT-EMITTING DEVICES

A. Edge-Light-Emitting Devices

Two common structures exist in production of light-emitting devices: edge emitting device structure and surface emitting device structure. Edge emitting structures consist of a minimum of three semiconductor layers forming a double heterostructure and a substrate layer.

Fig. 3. Typical edge emitting device structure.

The bottom layer is a substrate, commonly n-type silicon (Si), n-type gallium arsenide (GaAs), or sapphire [3], [4]. The first semiconductor layer is typically an n-type semiconductor layer, followed by the active region. The active region is commonly doped to be a p-type semiconductor. This is the
region that emits the photons resulting from the electron-hole recombination. The top and final semiconductor layer is a p'-type semiconductor [5].

The device begins to operate when an appropriate forward bias voltage is applied. The forward bias voltage causes the holes in the p'-layer and the electrons in the n-layer to diffuse into the active region. Once in the active region, the electrons “fall” to a new energy level when they recombine with the holes. The electron-hole pair is annihilated and a photon is created in order to preserve conservation of energy. The photon is emitted from exposed edges of the active region.

The surrounding semiconductor materials act as waveguides for the photons until they are emitted from the device.

The semiconductor layers act as waveguides because the device was designed as a double heterostructure. With a heterostructure junction, the index of refraction is greatly increased and light energy is not lost into the semiconducting layers [3].

### B. Surface-Light-Emitting Devices

The physics of surface emitting devices is the same as that for edge emitting devices. The challenge with light emitting devices is that they do not lend themselves to easy fabrication as edge emitting devices do. An example of the surface emitting device structure can be seen in Figure 5.

Figure 5 shows a dual wavelength diode laser, which provides an advantage over the simpler edge emitting devices. Multiple wavelengths can be fabricated into a single device. This opens the opportunity to create coherent and white light in a single device by fabricating the appropriate materials into the device [6].

Rather than “sandwiching” the active region between uniform layers of semiconductors, the metal contact pads must be placed on the same side of the device with the other. Another option is to fabricate a similar structure to the edge emitting device, except a ring is used to create an aperture on one side of the device.

![Double heterostructure device diagram](image1.png)

**Fig. 4.** Double heterojunction device (left). Index of refraction for respective materials found in double heterojunction (right).

### III. APPLICATIONS OF LIGHT-EMITTING DEVICES

Light-emitting devices have applications in all segments of industry. LED’s are commonly available for mounting on printed circuit boards (PCB), which are integrated into consumer products. They are also commonly found in traffic lights, motorcycle lights, railroad crossing bars, remote controls, and more recently in Christmas decoration lights. Laser diodes are frequently found in laboratory settings. They are also used for fiber optic interconnects and they drive consumer products such as laser pointers [7], [3].

The application has a great impact on the type of packaging that is used to encase the semiconducting structure. Wire ledged and PCB surface mount edge-emitting LED’s are typically placed inside a reflective cup to improve directionality of the emitted light.

![Dual wavelength surface emitting laser structure diagram](image2.png)

**Fig. 5.** Dual wavelength surface emitting laser structure diagram (bottom). Plan view photograph of device (top).

![Edge emitting LED in reflective cup](image3.png)

**Fig. 6.** Edge emitting LED in reflective cup.

Some researchers are experimenting with redesigning the light emitting devices altogether to accommodate new and innovative methods of packaging in order to improve device efficiency. For example, through a process called epitaxial...
Epitaxial lift-off involves removing the device’s optically absorbing substrate and replacing it with a thin, transparent or reflective substrate. The fabrication process had to be carefully customized because the light-emitting device is mechanically weak without its substrate [8].

IV. CONCLUSION

Light-emitting devices are sound devices that continue to be improved. Fundamental structure and physics of semiconducting light-emitting devices was discussed. The general structures of edge-emitting and surface-emitting devices were presented. A brief discussion of applications and packaging of light-emitting devices was included.

REFERENCES