Introduction to Diode Lasers and Laser Diodes

Note: Throughout this document, we will use the terms 'laser diode' and 'diode laser' somewhat interchangeably although we will tend to use the term 'diode laser' when referring to a complete system or module. When a device is called a 'laser diode', this generally refers to the combination of the semiconductor chip that does the actual lasing along with a monitor photodiode chip (for used for feedback control of power output) housed in a package (usually with 3 leads) that looks like a metal can transistor with a window in the top. These are then mounted and may be combined with driver circuitry and optics in a 'diode laser module' or the common (red) laser pointer. A Variety of Small Laser Diodes shows some examples.

Diode lasers use nearly microscopic chips of Gallium-Arsenide or other exotic semiconductors to generate coherent light in a very small package. The energy level differences between the conduction and valence band electrons in these semiconductors are what provide the mechanism for laser action. This is not the sort of laser you can build from scratch in your basement as the required fabrication technology costs megabucks or more to set up. You will have to be content with powering a commercial laser diode from a home-made driver circuit or using a pre-packaged module like a laser pointer. Fortunately, laser diodes are now quite inexpensive (with prices dropping as you read this) and widely available.

The active element is a solid state device not all that different from an LED. The first of these were developed quite early in the history of lasers but it wasn't until the early 1980s that they became widely available - and their price dropped accordingly. Now, there are a wide variety - some emitting many *watts* of optical power. The most common types found in popular devices like CD players and laser pointers have a maximum output in the 3 to 5 mW range.

A typical configuration for a common low power edge emitting laser diode is shown below:

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                        o                                    o
            ____________|____________               _________|_________
   Laser |  P type semiconductor    |  Laser       |     P type      |
    beam |                          |  beam        |                 |
<========|::::::::::::::::::::::::::|=======>      |ooooooooooooooo  |
         |        Junction---^      |              |                 |
   End ->|  N type semiconductor    |<- End        |     N type      |
  facet  |__________________________|   facet      |_________________|
                        |                                    |
                        o                                    o
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              -                                    -

           (Side view)                         (End view)

   |<--------------------- 1 mm ---------------------->|
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This configuration above is called a 'homojunction' since there is only one P-N junction. It turns out there are benefits to using several closely spaced junctions formed by the use of layers of P and N type materials. These are called 'heterojunction' laser diodes. There are many many more advanced structures in use today and new ones are being developed as you read this! For example, see the section: Vertical Cavity Surface Emitting Laser Diodes (VCSELs) for a description of one type that has the potential to have a dramatic impact in many areas of technology.

The 'end facets' are the mirrors that form the diode laser's resonant cavity. These may just be the cleaved surfaces of the semiconductor crystal or may be optically ground, polished, and coated.

For these types of integrated laser diodes, everything takes place inside the chip. Therefore, the output wavelength is fixed and determined by the properties of the semiconductor material and the device's physical structure. Or, at least that's the way it is supposed to work though with some, reflection of the laser light back into the chip can cause stability problems or even be used to advantage to frequency stabilize the output. There are also tunable diode lasers using external cavity optics to provide a continuous and in some cases, quite wide range of wavelengths without mode hopping.

There are also pulsed laser diodes requiring many amps to to reach threshold and providing watts of output power but only for a short time - microseconds or less. Average power is perhaps a few mW. These are gallium arsenide (GaAs) heterojunction laser diodes. They are not that common today but some surplus places are selling diodes like these as part of the Chieftain tank rangefinder assembly. They mention the high peak power output but not the low average power. :(Modern devices with similar specifications are also available from manufacturers like OSRAM Opto Semiconductors. Go to "Products", "High Power Laser Diodes", "Product Catalog...", "Pulsed Laser Diodes in Plastic Packages".

Electrical input to the laser diode may be provided by a special current controlled DC power supply or from a driver which may modulate or pulse it at potentially very high data rates for use in fiber optic or free-space communications. Multi-GHz transmission bandwidth is possible using readily available integrated driver chips.

However, unlike LEDs, laser diodes require much greater care in their drive electronics or else they *will* die - instantly. There is a maximum current which must not be exceeded for even a microsecond - and this depends on the particular device as well as junction temperature. In other words, it is not sufficient in most cases to look up the specifications in a databook and just use a constant current power supply. This sensitivity to overcurrent is due to the very large amount of positive feedback which is present when the laser diode is lasing. Damage to the end facets (mirrors) can occur very nearly instantaneously from the concentrated E/M fields in the laser beam. Closed loop regulation using optical feedback to stabilize beam power is usually implemented to compensate for device and temperature variations. See the sections on CD and visible laser diodes later in this document before attempting to power or even handle them. Not all devices appear to be equally sensitive to minor abuse but it pays to err on the side of caution (from the points of view of both your pocketbook and ego!).

In their favor, laser diodes are very compact - the active element is about the size of a grain of sand, low power (and low voltage), relatively efficient (especially compared to the gas lasers they replaced), rugged, and long lived if treated properly.

In fact, high power laser diodes - those outputting WATTs of optical power - are without a doubt the most efficient light emitter - not just lasers - in existence. Some have electrical to optical efficiencies (DC W in to light W out) of greater than 50 percent! In other words, put 2 watts of DC power in and get out 1 W of light. And, research is in progress to improve this to 80 percent or beyond. The common incandescent lamp is only 5 percent, fluorescent lamps are 15 or 20 percent efficient, high intensity discharge lamps are somewhat better, but even the best can't match the laser diodes in existence now. Just think: If those super high efficiency high power laser diodes could be mass produced in visible wavelengths and were used to replace all light bulbs, the World's electicity usage would be cut way down, not to mention hobbyist access to high power lasers! (Which is of much more significance!) OK, back to reality. :)

Laser diodes do have some disadvantages in addition to the critical drive requirements. Optical performance is usually not equal to that of other laser types. In particular, the coherence length and monochromicity of some types are likely to be inferior. This is not surprising considering that the laser cavity is a fraction of a mm in length formed by the junction of the III-V semiconductor between cleaved faces. Compare this to even the smallest common HeNe laser tubes with about a 10 cm cavity. Thus, these laser diodes would not be suitable light sources for high quality holography or long baseline interferometry. But, apparently, even a $8.95 laser pointer may work well enough to experiment in these areas and some results can be surprisingly good despite the general opinion of laser diode performance.

Even if not as good as a helium-neon laser in the areas of coherence and stability, for many applications, laser diodes are perfectly adequate and their advantages - especially small size, low power, and low cost - far outweigh any faults. In fact, these 'faults' can prove to be advantageous where the laser diode is being used simply as an illumination source as unwanted speckle and interference effects are greatly reduced.

As noted, not all laser diodes have the same performance. See the section: Interferometers Using Inexpensive Laser Diodes for comments that suggest some common types may indeed have beam characteristics comparable to typical HeNe lasers. And, for short range applications, see: Can I Use the Pickup from a CD Player or CDROM Drive for Interferometry?. Also see the section: Holography Using Cheap Diode Lasers.

The following sites provide some relatively easy to follow discussions of the principles of operation, construction, characteristics, and other aspects of laser diode technology:

- Power Technology, Inc. Go to "Resource Library". Diode laser characteristics, artifacts, corrections.
- Edmund Industrial Optics. Go to "Technical Articles", "Lasers". Includes laser diode modules, beam expanders, spatial filters, more.
- Eurotechnology's Blue Laser Homepage. Includes info on GaN blue/viodlet/UV LEDs and laser didoes.
- Photon, Inc. Application Notes. Free info may be requested on a variety of topics related to laser diode characteristics, profiling, and correction.
- Lumex. Go to "Tehcn Notes". Articles on a variety of topics including laser diode construction.
- Fiber-Optics.Info Laser Diode. A summary article on laser diode types, applications, drivers, etc.

Here's a link to a historical look at the early days of laser diodes:

- The Diode Laser: The First Thirty Days Forty Years Ago