# Diode Laser

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In this lad a diode laser is studied looking at its man region of operation and how this laser can be controlled and tuned. The transition form LED to laser is observed and we study how the current and temperature play a role in the emission spectra of the laser. A measurement of the divergence of the diode was also done which showed a deviation form what was specified by the manufacture.

## I. INTRODUCTION

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of light [3]. The laser diode is a particular semiconductor device which core structure is a heavily doped p-n junction. To have a lasing mode, the p-n junction is forward-biased, with enough injected current to provide optical gain.

Laser diodes have a numerous advantages with respect to other types of lasers. They can achieve high power and high efficiency with a size small enough to be compatible with electronic components.

Additionally, laser diodes have a wide range of uses that include fiber optic communications, bar-code readers, laser pointers, CD's reading and recording, laser printing, laser scanning and light beam illumination.

## II. DIODE LASER CHARACTERISTICS

### Structure

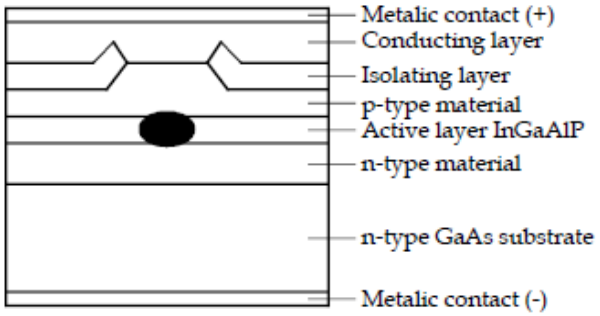



FIG. 1: The core structure of a diode laser is a p-n junction with quantum wells in its active region. Other layers such as substrate layer, and the isolating and conducting layer are added to have a complete functioning device. Figure taken from: [1]

As mentioned before, the core structure of the diode is a p-n junction, however, the overall composition consist on several layers of materials to form the contacts, to have conduction and isolation and of course, the active layer for the optical modes (Fig. 1).

The active layer consist on several quantum wells. It is known that two-dimensional confinement leads to a steps-like density of state [4], this enhances the carrier concentration and as a result, the threshold current goes down, the maximum modulation range is increased and the frequency stability improved [1].

### Modes

The confinement in the active layer leads to the existence of standing waves. As in any cavity, the allowed wavelengths is given by

$$2d = N\frac{\lambda}{n}, \tag{1}$$

where $d$ is the distance between end surfaces, $n$ is the refractive index of the semiconductor material at wavelength $\lambda$ and $N$ is an integer number.

Since the active layer walls are wider than the wavelength of the laser light, there can be more than one standing waves, or longitudinal modes, with different wavelengths, at the same time. The wavelength difference between neighbouring modes is

$$\Delta\lambda = \frac{\lambda^2}{2nd}. \tag{2}$$

Depending on the gain profile, the lasing can be one single mode or several (multiple) modes. The single/multi mode profile will be discussed later in section IV.

### Divergence

A laser diode with an active layer of dimensions $d$ (the one mentioned in the previous subsection) and $w$ (width of the active layer) will emit light with far-field angular divergence $\approx \lambda_0/d$ in the plane perpendicular to the

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junction and $\approx \lambda_0/w$ in the plane parallel to the junction. Since the active layer has a small size compared to the wavelength, the diode laser usually has a large divergence. The two divergence angles are defined, perpendicular to and parallel to the active layer, as the angle where the intensity has dropped to 50%. The angle of divergence perpendicular to the active layer can vary between 20° and 50°, while the parallel divergence angle is always smaller.

#### Electrical properties

Regarding the electrical characterization of a laser diode, one the most important concepts is the threshold current. The threshold current is the smallest current needed for laser action; below this current, the spontaneous emission dominates and diode will be in LED mode. When the current exceeds the threshold, the stimulated emission dominates and diode is in laser mode.

## III. METHOD

### A. Radiation pattern and Power-Voltage characteristics

To measure the power-voltage characteristics we used a laser diode coupled to a voltage-current controller and a thermoelectric cooler. The laser aligned orthogonal to a screen set at 10.6cm in front of the diode. The illumination pattern on the screen was recorded (live) with a CCD camera and the footage was later analyzed to extract its intensity distribution.

The measurements shown in section IV corresponding to the divergence of the radiation pattern were taken at a temperature of 25°C and at a current around 40 mA. To analyze the power-current characteristics and its dependence with temperature, we measured the power from the diode sweeping the current from 0 to 50 mA for temperatures in the range of $15 - 25.1$°C.

### B. Spectrum of emitted light and its current-temperature dependence.

To observe the spectrum of the laser diode and its dependence with power and temperature an identical laser diode and its power-current controller and temperature controller were used, mounted in a Michelson-like interferometer, calibrated with a He-Ne laser.

The interferometer allows us to measure the intensity of light emitted at a certain energy or wavelength, *i.e.* the spectral characteristics. Setting a constant power ($\sim 5\ mW$, lasing mode) we studied how the spectra evolves from LED mode at low currents (below the threshold current) to multi-mode laser and finally to single-mode laser. Additionally, it was possible to observe how the emission wavelength changes with temperature.

## IV. RESULTS AND DISCUSSION

An overview of the recollected data for this experiments is shown and discussed in this section. There were three main task for this experiment. First we measured the LED lasers radiation pattern, then we studied output power as function of the current, voltage and temperature. The final task was to look at the emission spectrum and see how it changes with temperature and current.

### A. Laser beam radiation pattern and divergence

With a CCD camera we recorded an image of the transverse profile, the intensity profile transverse to the direction of propagation, of the laser and with a software we could recollect the intensity spectrum of the data collected by the CCD. The transverse profile is shown in Fig.2 from this we can take the intensity spectrum versus distance, as seen in Fig.3.

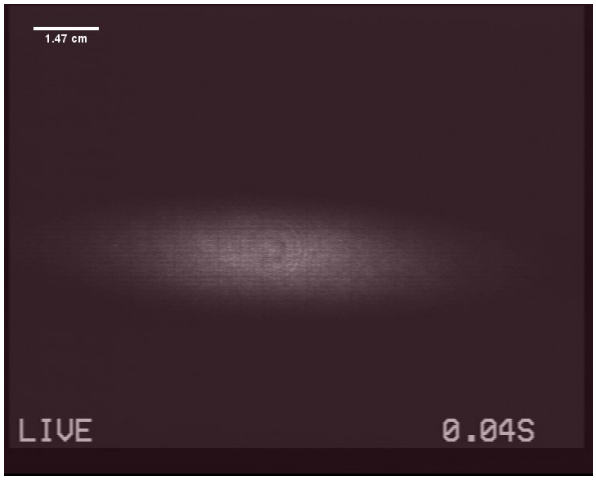



FIG. 2: Transverse profile of a LED laser recollected with a CCD camera. The parallel direction is the vertical component of the spectrum and the orthogonal direction is the horizontal component.

Following the definition for the parallel and orthogonal directions for the emission profile [3] [1] we can find that the FWHM is $d_\perp = 4.48cm$, $d_{//} = 1.26cm$. Knowing that the distance between the laser and the screen was 10.6 cm we can find that the divergence of the laser profile is $\theta_\perp = 25.0°$, $\theta_{//} = 6.83°$.

Comparing with given values of the data sheet we have that divergence angels should be in the following range $\theta_{//} = [5 - 11]$, $\theta_\perp = [25 - 37]$. We fall into the expected

value of the divergence given in specified in the data sheet in both of the components.

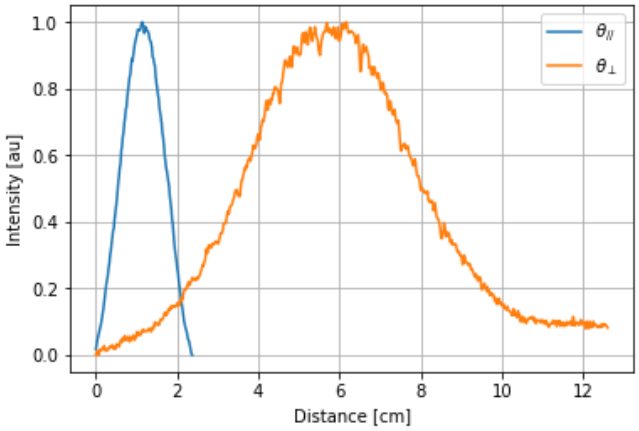



FIG. 3: Intensity normalized average for the orthogonal and parallel components of the transverse profile.

### B. Laser power as a function of current and voltage and it's depends on temperature

Scanning the laser power vs current for different temperatures we recollect the data shown in Fig.4. From the data a general trend can be observed, when increasing the temperature of the laser a higher current is required to reach the same power. Lasing is also achieved at higher temperatures; by controlling the temperature we can then have a laser that produces a power output at lower temperature, achieving lasing earlier.

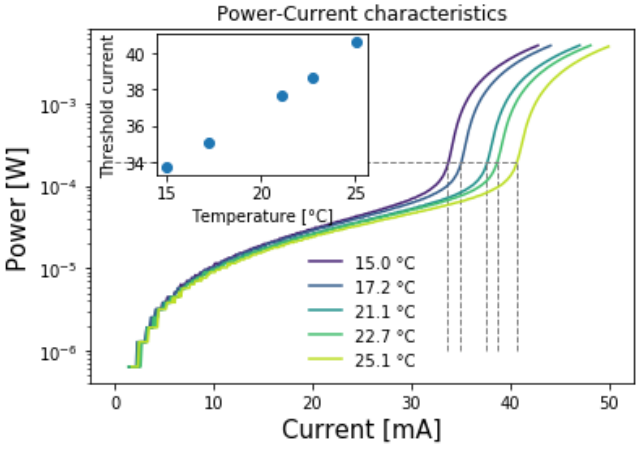



FIG. 4: The power output vs current for different temperatures. A linear dependence between threshold current and temperature is clear.

The difference of 10° C gives a current change of approximately 8 mA which is a 20% reduction over the current fed to the laser. A linear depends between the temperature and the current is noticeable from the experiment. This is to be expected since for higher temperatures the Fermi level is displaced to higher energise requiring more current to achieve population inversion in the system, giving of a proportional relation between the threshold current and temperature. The voltage has the same tendency as the power since for this type of lasers, power, current and voltage have a linear relation.

### C. Light spectrum and its dependence with current and power

When increasing the current and collecting the spectrum of the signal we can observe when the diode transitions between LED to laser. Fig.5 shows how when increasing the current we go from a broadband incoherent light source to a single mode laser when the threshold current is reached around 38.2 $mA$, as was expected from the recollected data in Fig.4. Its worth mentioning that the secondary peak is the He-Ne laser in the FTS which is the same intensity in all the measurements but since the laser power its much large than the He-Ne laser then it vanishes.

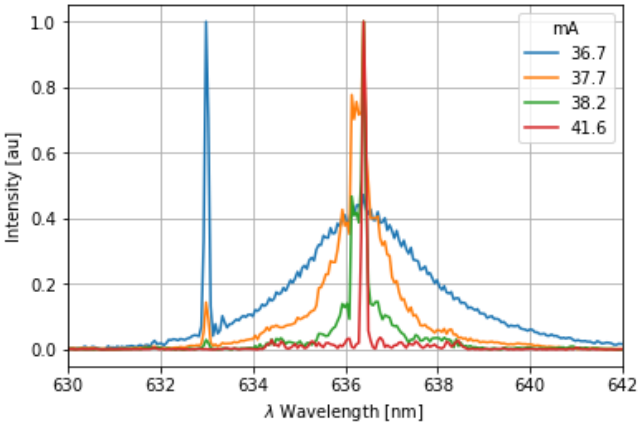



FIG. 5: Spectrum of the diode laser at 21.1° $C$ for different currents where lasing is being archived at higher currents where the transition from LED to laser is clear by the bandwidth change.

Now if the power is set to be constant then we can scan the temperature and measure how the wavelength spectrum changes as shown in Fig.6. We can see that for higher temperatures the wavelength also increases, one can also see that there is a reduction in the bandwidth of a single wave length spectrum, this is similar to the effect for incriminating current for constant power the wave length spectrum got reduce in bandwidth. .

There is tunability in the wavelength when controlling the temperature of the diode for a change in tem-

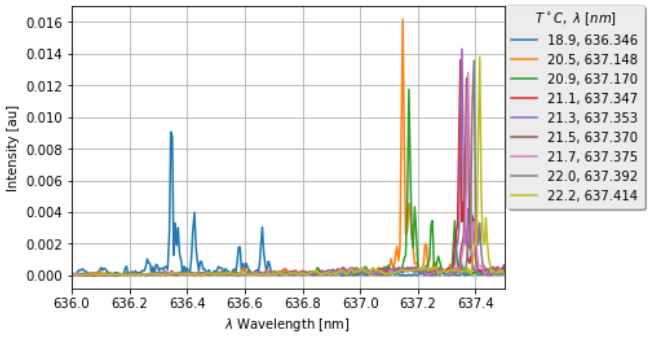



FIG. 6: Diode emission spectrum for different temperatures at constant power output.

perature of $\Delta$T=0.2° C there is a wavelength change of $\Delta\lambda$=0.011 nm. Since temperature is connected with current when the system receives a change in the internal energy state this displaces the Fermi energy levels, this displacement is corresponds to a wider or smaller energy gap between Fermi levels which, is also a change in wavelength.

## V. CONCLUSIONS

In general we observed how a diode can transition form a LED mode where there is no coherence in the light and its also a broadband light source to a single mode laser with a narrow band of emission. We also observed how there is tunability in this system by changing the temperature and the current we can control the power and the wavelength of the laser. An interesting thing to notice is that the divergence of the laser was actually smaller than the one specified in the data sheet which is unexpected but it is also in a since beneficial since we can have a better coupling of the laser since its not diverging as fast.

[1] Optoelectronics and optical communication (FFFN25), "Diode Laser", Laboratory guide 2018.
[2] Le Nguyen Binh, Advanced Digital Optical Communications, Second Edition, 2nd Edition.
[3] B.E.A. Saleh and M.C. Teich, *Fundamentals of Photonics*, 2nd Edition. Wiley-Interscience.
[4] John H. Davies. *Physics of Low-Dimensional Semiconductors*. Cambridge University Press, 1998.