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Babylon university- Collage of Science
Chemistry Department

Laser diode wavelength adjustment setup for environment sensing

التحكم بالطول الموجي لضوء الليزر المنبعث من الثنائي الضوئي لأغراض الاستشعار البيئي

By Student

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إقرار السيد المشرف

اقرار المشرف

أشهد بان موضوع البحث الموسوم... والمنجز من قبل الطالب ....قد اجري تحت اشرافنا في قسم الفيزياء كلية العلوم جامعة بابل كمتطلب جزئي لنيل شهادة البكالوريوس في علوم الفيزياء وذلك للفترة من 2023/10/1 ولغاية 2024/4/1

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Contents

ملخص

تعد المراقبة الموثوقة والتقديرات الدقيقة للغازات السامة والملوثة للغلاف الجوي الأرضي أمرًا ضروريًا لإدارة النظام البيئي والحفاظ على نماذج نظام الأرض. حاليًا، الطريقة الأكثر مباشرة لقياس تدفق الغازات هي التباين الدوامي(EC) ،

تعتمد برامج ومعدات مسح المسار المفتوح لرصد التلوث البيئي على تطوير أجهزة استشعار التلوث سريعة الاستجابة وكذلك بتوفير فيها القابلية على تغطية نطاق واسع.. في هذه الدراسة تم استخدام طريقة التحكم الحراري بالطول الموجي المنبعث من ليزر اشباه الموصلات وذلك لتحقيق مسح طيفي ضمن مدى كافي مفتوح المسار.
فقد كانت هناك ازاحه بمقدار 7nm وبمعدل انجراف حراري مقداره 0.19 nm/C .

Abstract

The reliable observation and accurate estimates of land–atmosphere toxic and polluting gases is essential for ecosystem management and keeping of Earth system models. Currently, the most direct measurement method for gases flux is eddy covariance (EC), which depends on the development of fast-response pollution sensors. In this study, we presented an open-path H2O analyser (model: HT1800) based on the tenable diode laser absorption spectroscopy (TDLAS) technique, and investigated the ability to wavelength adjustment based on temperature control. Through the practical procedure, it was found that it is possible to control the wavelength within a limited range sufficient to perform the sensing process.

Chapter one

Basics theory of semiconductor lasers

1.1 Introduction

A laser is an optical device that creates and amplifies a narrow and intense beam of coherent, monochromatic light. LASER stands for "Light Amplification by Stimulated Emission of Radiation" [7, 14]. The invention of the laser can be dated to the year 1958, with the publication of the scientific paper Infrared and Optical Masers, by Arthur L. Schawlow and Charles H. Townes in the American Physical Society's Physical Review [7]. However, it was Albert Einstein who first proposed the theory of "Stimulated Emission" already in 1917, which is the process that lasers are based on [16].

1.2 Basic Laser Theory

The principles of a laser can be explained on the basis of photons and atomic energy levels. For simplicity we consider an atomic electron with only two energy levels separated by an energy E. When in the lower energy state, the system may be excited to the upper state by absorbing a photon with energy $E = h\nu$, where h is Planck's constant and ν is the frequency of the photon. The same atom will later return to the ground level emitting a photon with the same frequency as the one originally absorbed. This process is called spontaneous emission and will produce light of random direction and phase [23]

Lasers are based on the process of stimulated emission. In this process an electron in a higher or excited state is induced to drop to a lower energy level, stimulated by the presence of photons of the proper wavelength. This drop results in an emission of a photon. The stimulating photons have an energy of $h\nu$, the same as the energy difference between the two energy levels. Thus the radiation will be monochromatic, since all the photons will have the same energy. It will also be coherent, because all photons released will be in phase and reinforcing. The process is illustrated in figure 1 [14].

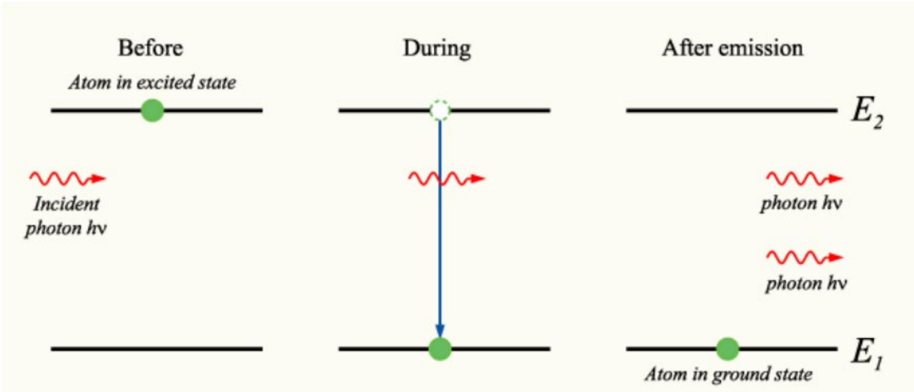


Figure 1.1: Process of stimulated emission [20].

1.3 Population Inversion

Let us assume a collection of atoms where each atom has two energy states E1 and E2. The number of atoms in each state are N1 and N2 respectively. If a beam of radiation with frequency ν12 = (E2 − E1)/h is passed through this collection of atoms then both absorption and stimulated emission processes occur. The probability of a photon being absorbed when it encounters an atom in the lower energy state, is the same as the photon causing stimulated emission when it encounters an atom in the upper energy state. This means that the photons in the beam will be lost through absorption at a rate proportional to N1, and created through stimulated emission at a rate proportional to N2. The number of photons, n, will change in time according to:

$$\frac{N_2}{N_1} = exp\frac{-(E_2-E_1)}{kT} \qquad 1.1$$

When N2 > N1 the number of photons will grow in time and laser light is produced. This condition is called population inversion. Unfortunately, when atoms are in thermal equilibrium, N1 is always greater than N2, and input of external energy, often called ’pumping’, is needed to achieve population inversion. Consider an example of a three level laser. It consists of a gain medium of ruby formed as a rod and a high power flash tube providing illumination for pumping. Ruby is actually a crystal of Al2O3 containing a small amount of Cr. It is the excitation levels of the chromium that provides the states needed for lasing. Figure 2 shows a schematic diagram of the three levels used for lasing. Levels 1 and 2 are sufficiently far above the ground state so that, in thermal equilibrium, their populations are negligible compared with that of the ground state.

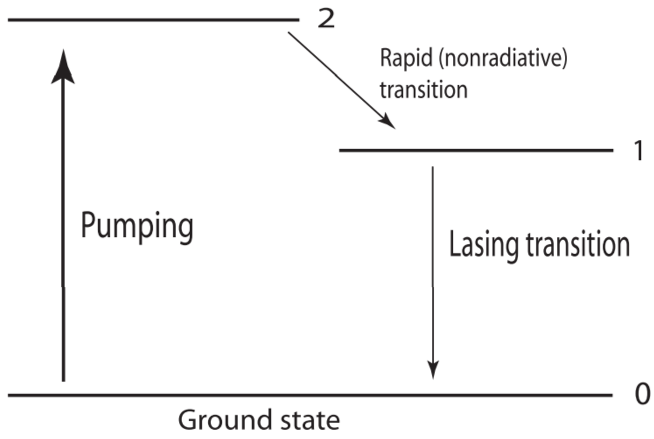


Figure 2: A schematic diagram of a three level laser showing the pumping and laser transitions.

The illumination for the pumping contains the frequency component needed to excite the atoms from level 0 to 2. The atoms in level 2 make a rapid (nonradiative) transition to level 1, which has a comparatively long lifetime. The atoms tend to pile up in level 1 and given sufficiently intense pumping, a population inversion between level 1 and 0 is created. Any light of the correct frequency will cause stimulated emission between these two levels, and laser light is created.

1.4 Physical Structure

A laser will normally consist of a gain medium with mirrors on each end (see figure 3), and some kind of external energy for pumping. The gain medium can be a solid, liquid or gas, and the beam of photons will amplify as it moves through it. Unless the pumping is extremely intense or the gain medium is very long, the beam irradiance will not be particularly strong after just one transit of the laser medium. This is why mirrors are used in each end to create optical feedback. This causes each photon to pass through the medium several times, stimulating more emissions before escaping [4].

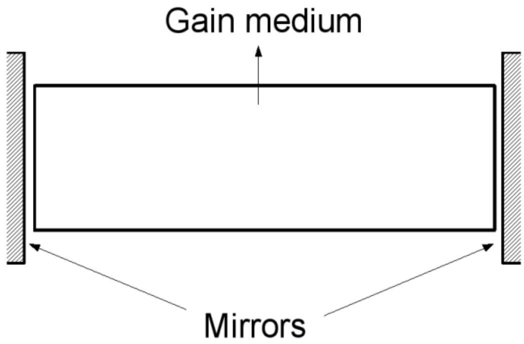


Figure 1.3: A laser with a gain medium and mirrors on each side to provide optical feedback.

The mirrors and the space between is called laser cavity (also called optical cavity). One of the mirrors is usually highly reflective while the other one will have a reflectance of around 95%, allowing the laser light to go through. One of the requirements for stable behaviour for a plane wavefront travelling back and forth within the cavity, is that the phase of the wavefront at a partic point must be the same (to within an integer multiple of 2π). That is why the laser is sometimes more accurately referred to as laser oscillator [4].

Several different methods are used for laser pumping, and optical, electrical and chemical pumping are some of the common ones. The intensity of the energy source must be higher than a certain threshold value to be able to provide enough excited atoms to exceed the ones lost by spontaneous emission and other factors. Even with high enough pumping the laser beam will not amplify indefinitely. As the irradiance in the cavity increases, the gain tend to decrease because of a reduction in the population inversion. There will inevitable be a cavity loss due to absorption and optical elements which couple light out of the cavity.

1.5 Basic Physics

In a semiconductor laser, the gain medium consists of layers of doped semiconducting material. Light is emitted at a junction between two regions of opposite doping as shown in figure 4. The mode of operation is somewhat different than that of the laser described in the previous chapter. In stead of exciting atomic electrons at separate locations in a medium by flashing light, the population inversion is created in the large number of electrons at a junction. And pumping is done by injecting carriers (electrons). Due to the crystalline nature of semiconductors, the electrons do not have discreet energy levels as the single chromium ions in a ruby, but continuous bands of available states. The lowest bands of electrons are tightly bound to the atoms and we are only interested in the uppermost completely filled valence band Ev, and the (intrinsic) empty conduction band Ec above. The lasing action will take place between the edges of these two bands and therefore the emitted light will be of a frequency proportional to the band gap Eg [14]. irradiance reaches a saturation level when the losses per transit is equal to the gain per transit [4, 18].

2 - Chapter two

Practical and design aspects of semiconductor lasers

2.1 Semiconductor Laser Materials

Semiconductor lasers have been made from many different semiconductor materials. The main aim for investigating the use of different materials is to extend the range of possible wavelengths [17]. Most semiconductor lasers are based on compounds from the III and V columns of the periodic table (figure 13). An example is gallium arsenide, which was the first semiconductor laser material. The first semiconductor lasers were made of crystals containing a junction of p- and n-type gallium arsenide. These have now been superseded by alloys containing three or four elements from columns III and V in the periodic table, called ternary or quaternary compound semiconductors. In such compounds the percentage of each component can be varied, so that different material properties can be achieved.

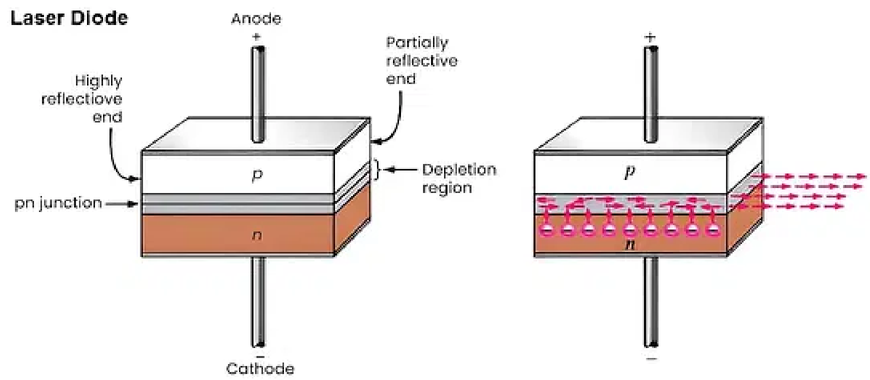


Figure 4: A simple p-n junction laser [17].

Some examples are the ternary compound Al1−xGaxAs (aluminium gallium arsenide), and the quaternary compound is In1−xGaxAs1−yPy (indium gallium arsenide phosphide). In this notationx and y are composition parameters that have values between 0 and 1. They define the exact composition of the compound. Thus, the Al1−xGaxAs system can vary continuously from AlAS, where x=0, to GaAs, where x=1 [10].

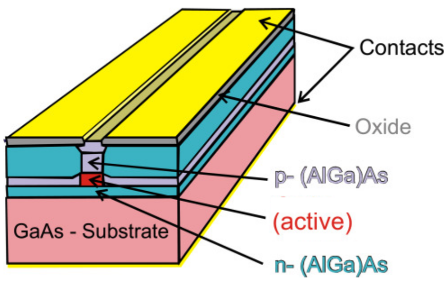
Materials used in semiconductor lasers must be efficient light emitters. The formation of p-n junctions, and in most cases also the formation of heterojunction barriers, must also be possible. Thus, some materials are simply not suitable for practical use in semiconductors. Semiconductors with indirect band gaps are examples of such materials, they are not sufficiently efficient light emitters for practical laser fabrication [14].

The II/VI compounds are generally very efficient light emitters, but junctions are formed with difficulty. Modern techniques like molecular beam epitaxy (MBE) and metal-organic vapor phase epitaxy (MOVPE) makes it possible to grow junctions in ZnS, ZnSe, ZnTe, and alloys of these materials, by the use of N as the acceptor. These materials can be used to make lasers that emit green and blue-green light [14].

2.2 Types of laser diodes:

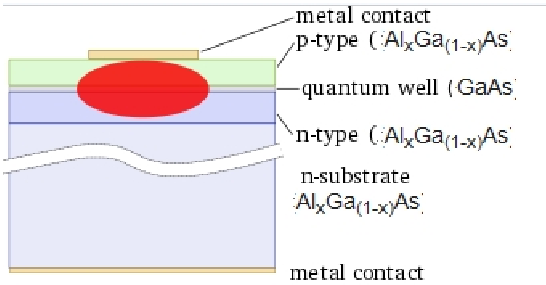
2.2.1 Double heterostructure laser diode:

Heterostructure is a material that is sandwiched between two n-type and p-type materials. Because of the presence of heterostructure material, this type of laser diode is called a double heterostructure (DH) laser diode. The main advantage of this diode is that the active region is used for better optical amplification.



2.2.2 Quantum well laser diode:

The quantum well is a very thin middle layer in the diode. The quantum energy is used for converting electrons from higher energy to lower energy and is responsible for better efficiency.



2.2.3 Separate confinement heterostructure laser diode:

There are two additional layers along with three layers. These layers have a lower refractive index and the emission of light is also improved. A separate confinement heterostructure laser device has an optical guiding region, an active region in the optical guiding region, and p-type and n-type cladding regions on opposite sides of the optical guiding region. At least one barrier layer is present within the p-type cladding region. The composition of the barrier layer is such that it has an X-minimum higher than that of adjacent parts of the p-type cladding region. The composition and/or thickness of the barrier layer is also such that it has a Γ-minimum which is higher than the X-minima of the adjacent parts of the p-type, cladding region. The thickness of the barrier layer is such as to prevent electron tunneling between the X-bands of the adjacent parts of the p-type cladding region on opposite sides of the barrier layer, and/or the compositions of the adjacent parts of the p-type cladding region on opposite sides of the barrier layer are sufficiently different from one another to prevent such tunneling.

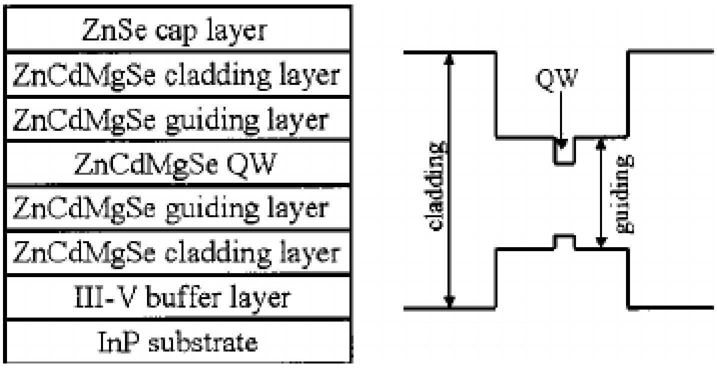


Figure 2.2 Separate confinement heterostructure laser diode

2.2.4 Vertical cavity surface-emitting laser diode:

In this type of laser diode, the optical cavity is along the axis of the current flow. A typical Vertical-Cavity Surface-Emitting Laser is made of several layers. The top is a layer in electrical contact for current injection. The next layer, i.e. the second layer, is the high-reflectivity mirror with 99% reflectivity. The next– third layer is an oxide layer that develops a light-emitting window so that the light beam can be converted into a circular beam.

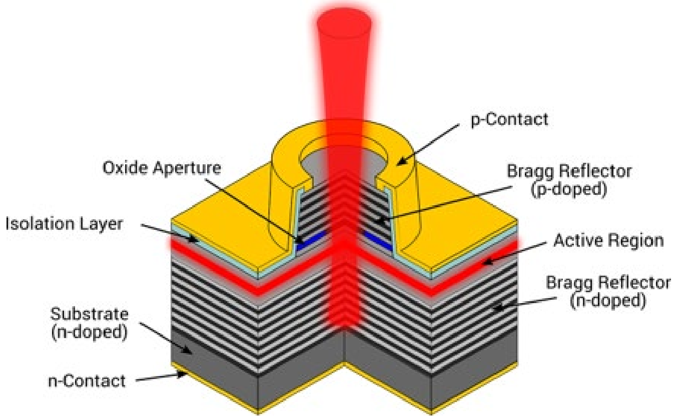


Figure 3.2 Vertical cavity surface-emitting laser diode

A typical Vertical-Cavity Surface-Emitting Laser is made of several layers. The top is a layer in electrical contact for current injection. The next layer, i.e. the second layer, is the high-reflectivity mirror with 99% reflectivity. The next– third layer is an oxide layer that develops a light-emitting window so that the light beam can be converted into a circular beam.

The next layer– the centre layer in the VCSEL is the laser cavity. It is the active gain region where lasing happens. Again there is an oxide layer below the center layer to confine the light. And the last layer is again a DBR– distributed Bragg reflector and the last– bottom layer is a reflective mirror with 99.9% reflectivity.

2.3 Characteristics of Laser Diode

The laser diode is characterized as follows:

Monochromatic: An insubstantial width of radiated narrow light containing only a single color.

Well-directed: In this type, the light will be directed into a narrow beam. It is easy to launch through an optical fibre.

Coherent: A light with a single wavelength emitted by an LED with a wide wavelength.

The important characteristic of a laser diode is its approach or the threshold. The laser diode doesn’t operate until a minimum power is applied. If the light is below its energy, then the emission is weaker than the threshold compared to the full energy.

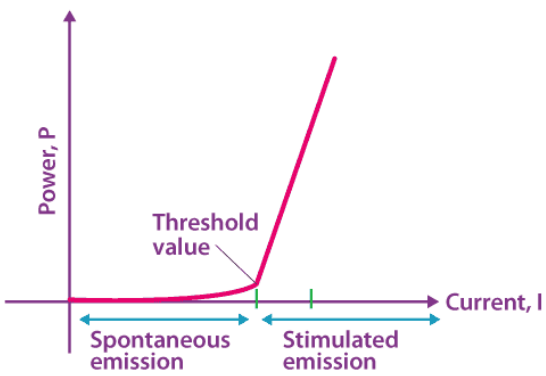


Figure 4.2 IV properties

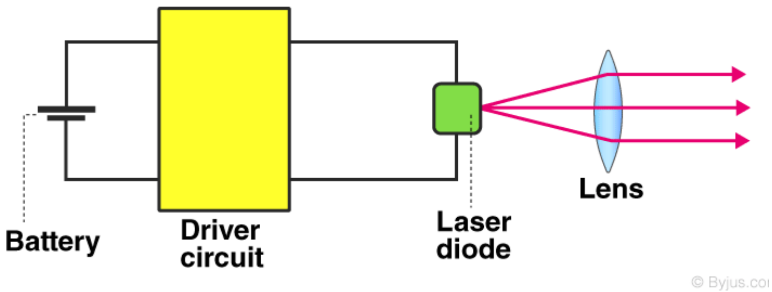


Figure 5.2 Driver circuit

Advantages and disadvantage of Laser Diode

The following are the advantages of laser diode:

When a laser diode is compared with other light-emitting devices, the operational power is less in the laser diode.

The handling of these diodes is easy as they are small.

The light generated by these diodes is of high efficiency.

The following are the disadvantages of laser diode:

These diodes are expensive when compared to other light-emitting devices.

The light generated by these diodes adversely affects the eyes.

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3 - Chapter three

Laser Diode Control

3.1 Fundamentals of Laser Diode Control

3.1.1 Laser Diode Characterization

To assess the quality, performance, and characteristics of laser diodes, manufacturers often perform exhaustive testing which requires electro-optical, spectral and spatial characterization of the laser output. A laser diode's output is dependent on its injection current and temperature. Therefore, tightly controlling these parameters using laser diode current and temperature controllers is critical for extracting important operational parameters. An example of a laser diode test and characterization set-up is shown in Figure 1. Furthermore, laser diodes are expensive and have delicate electronic loads requiring controllers to be capable of protecting these devices while ensuring their output is stable. In general, the term "driver" typically refers to a current source while a "controller" often refers to an all-in-one current source and temperature-control mechanism. Current drivers and temperature controllers are discussed separately below.

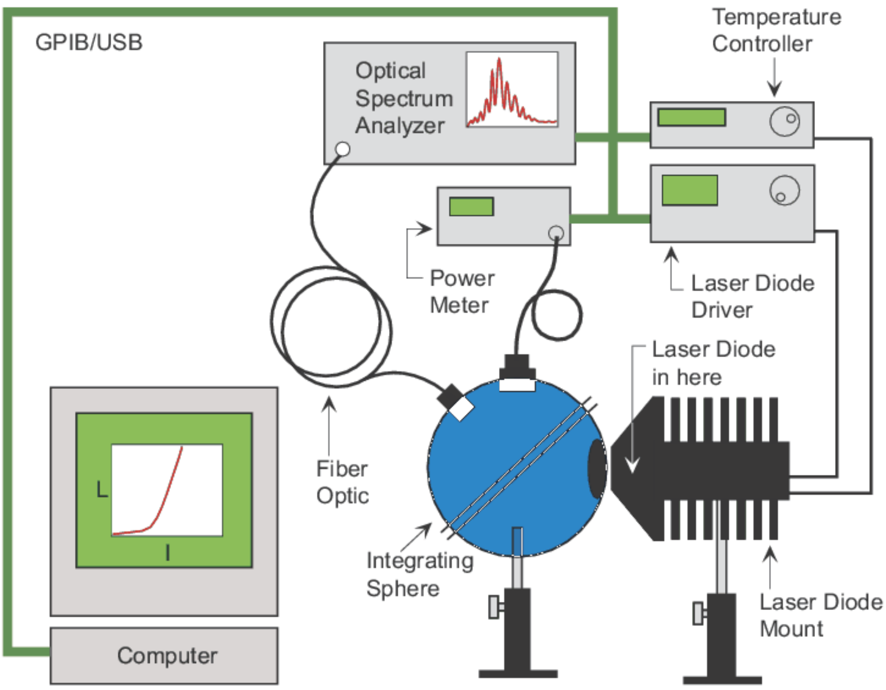


Figure 1.3 Temp. Laser diode control

3.1.2 Laser Diode Current Drivers

The most important laser diode characteristic is how its light output power (L) responds to injected current (I). This is referred to as the L-I curve (see Figure 2). This curve can be used to determine a number of significant parameters, including threshold current and threshold current density, differential responsivity, internal quantum efficiency, and external differential quantum efficiency. These values are usually listed in a laser diode's specification sheet so that a user can determine important operational parameters such as the current at which lasing begins, the drive current for a specific laser power, as well as the maximum current the device can take. Finally, the drive current can influence the laser's center wavelength (see Figure 2), so precise control of the current is also important for spectral control of the diode output.

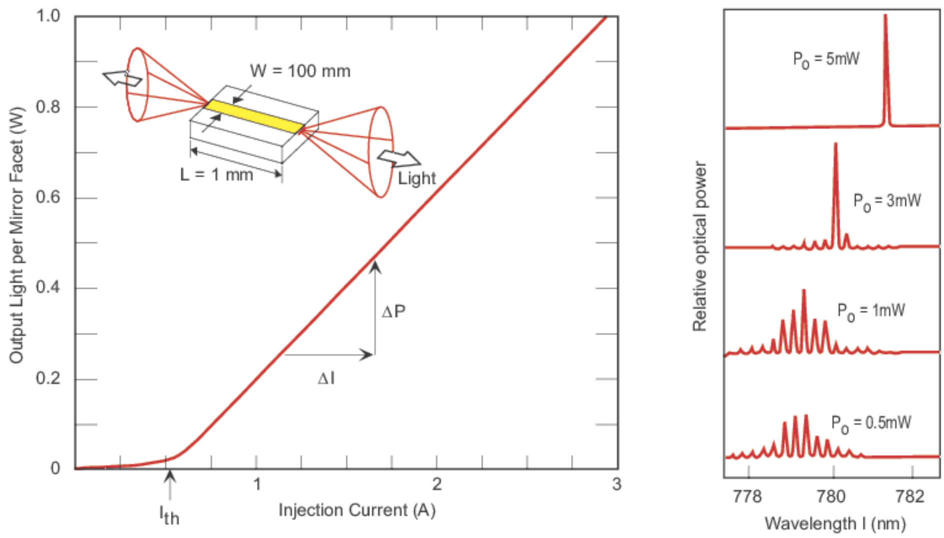


Figure 2.3 current – power

For sensing and others some applications, it is required that the wavelength (and thus the optical frequency) of a laser beam can be tuned within some range.

3.1.3 Laser Diode Temperature Controllers

Figure 3 shows that the threshold current and differential responsivity of a laser diode are strongly affected by the laser's temperature. The laser threshold will increase exponentially with temperature as exp(T/T0), where T is the laser temperature and T0 is the "characteristic temperature" of the laser (typically between 60 to 150 °C). T0 is a measure of the temperature sensitivity of the device with higher values implying that the device is more thermally stable. T0 is an important laser diode characteristic and is commonly extracted from multiple L-I curves. Changes in temperature affect the bandgap of the semiconductor junction and therefore, the peak wavelength of the gain profile. This results in a linear relationship between temperature and the center wavelength of the laser diode (see Figure 3) with typical temperature tuning coefficients of 0.3 nm/°C. As a result, a temperature controller plays a key role in determining the laser wavelength.

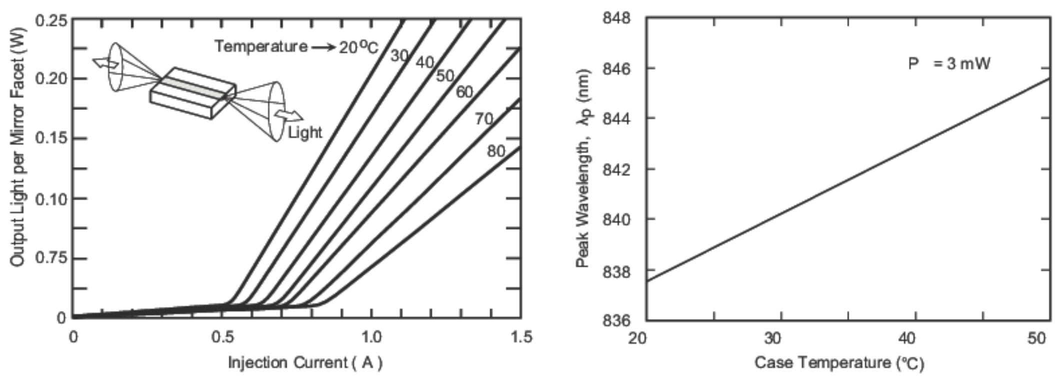


Figure 3.3 injection current/output power

Given the number of parameters that depend on laser diode temperature, it is important to set and maintain a stable temperature using a temperature controller. Most laser diode applications use thermoelectric (TE) coolers to maintain a constant temperature. TE coolers rely on the Peltier Effect, whereby driving current through p- and n-type semiconductor materials will cause them to transfer heat. The most important point to consider when using TE coolers is that they are heat pumps. In other words, they pump heat from the laser, which generates heat, to the heat sink, which dissipates heat. To achieve this heat pump action, current must be driven to the TE cooler in the proper direction. These solid-state devices can heat or cool small thermal loads to more than 60 °C from ambient and achieve temperature stabilities of better than 0.001 °C. An accurate temperature sensor attached to the laser diode allows the TE cooler to properly regulate the device's temperature. One type of sensor is a thermistor which is a resistance device that exhibits a voltage drop proportional to temperature. It is the most commonly used sensor because it is inexpensive, accurate, highly sensitive and easy to work with. It is also the smallest type of sensor, which makes it ideal for integration into laser diode packages.

Semiconductor laser can be implemented in various fields, such as for telecommunication, radar, spectroscopy and sensor. Specialized for radar application.

In some studies it has been reported that the change of temperature causes the wavelength changes linearly. In our experiment, it is proven that the increase in temperature causes a shift in the peak wavelength toward the long wavelength laser typical of 0.094 nm/°C. Theoretically, it is shown that the wavelength shift caused by the thermal expansion on the laser grating period. In addition to the shift in wavelength, it is also shown that the increase in temperature causes a decrease in the optical power at the laser output. From the experiments of mixing two lasers that we have conducted, it was found that the tenability factor of laser beat frequency versus temperature is 10.35 GHz/°C. In this paper we show that the beat frequency of the result of mixing two laser diodes can be tuned by varying the temperature of one laser by varying Peltier temperature and laser injection current and let the other laser constant. When the optical grating is used to adjust the frequency, it works according to the following relationship:

$$\lambda_B = \left(2n_{eff}\Lambda\right)m \qquad 1$$

Where m is a positive integer that describes the grating order, λ_B is the Bragg wavelength and n_{eff} is the effective refractive index when the lasing mode in the active layer [11].

3.2 Experimental results

One way to adjust the wavelength shift DFB laser is by performing temperature variation. A temperature change causes a thermal expansion change on the grating period of laser cavity. Furthermore, it causes change of the DFB laser wavelength output. Typically, the experiments show the average semiconductor has a resonant wavelength shift of about 1 Å/K [11]. The effect of wavelength change due to index refraction change is not reported, because of very small effect.

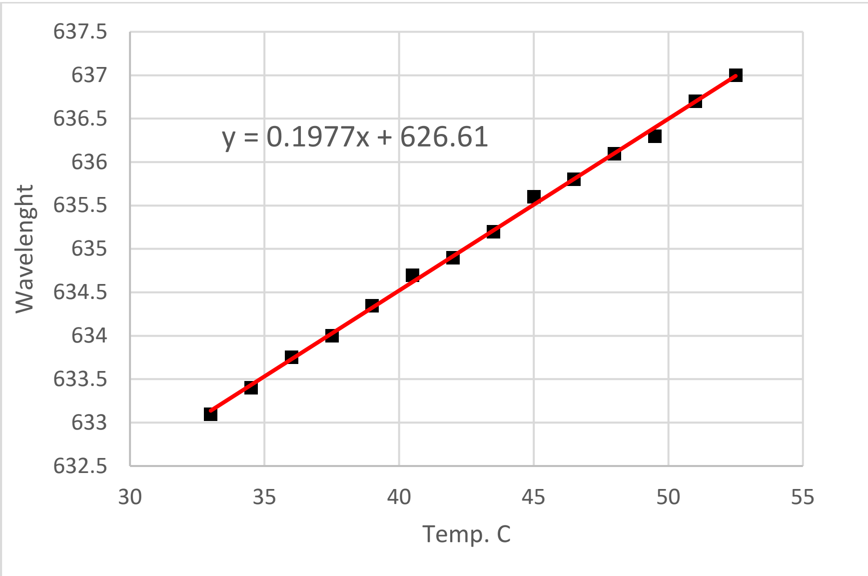


Figure 4.3. Wavelength variation versus laser temperature

The results shows that the wavelength with respect to temperature is shown in Figure 4, the graph shows a relatively linear relation. The experimental result shows that the slope in Figure 4 is 0.094 nm/°C or 0.94 Å/K. This slope is called wavelength-temperature slope (dλB/dT).

It can be seen from Eq. 1 that increasing laser temperature will cause thermal grating period expansion. In temperature variation region from 30 to 47°C, the refractive index of the resonant mode (neff) is relatively constant, hence the deviation can be ignored. Then, based on Eq. 1, the deviation of Bragg wavelength (dλB) due to grating period deviation (dΛ) can be written as following:

$$d\lambda_B = 2n_{eff}.d\Lambda \qquad 2$$

When $d\Lambda$ depends on laser temperature deviation dT. This relationship in DFB laser is written:

$$d\Lambda = C.dT \qquad 3$$

So finally:

$$C = (\frac{d\lambda_B}{dT})n_{eff} \qquad 4$$

Eq.4 shows that for typical laser, where $n_{eff} = 3.6$ and wavelength-temperature slope (dλB/dT) = 0.094 nm/°C, will have grating period expansion ratio C of 0.014 nm/°C.

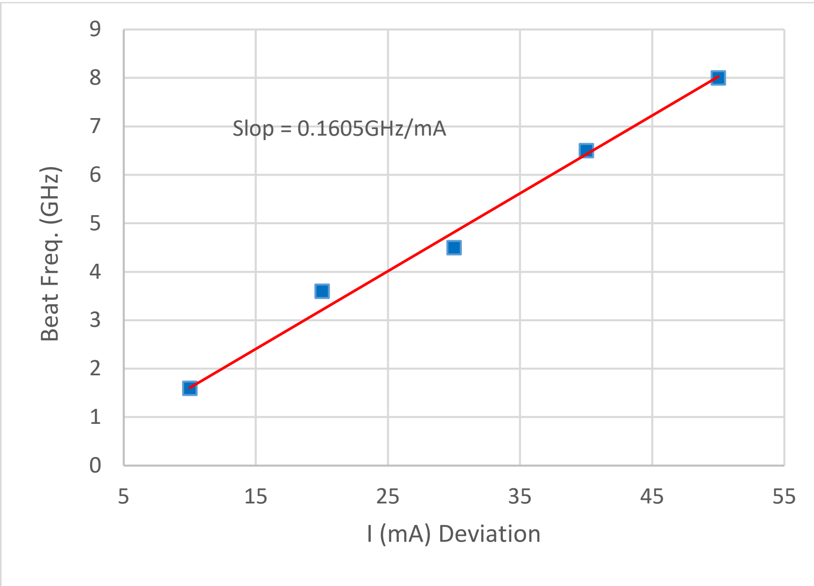
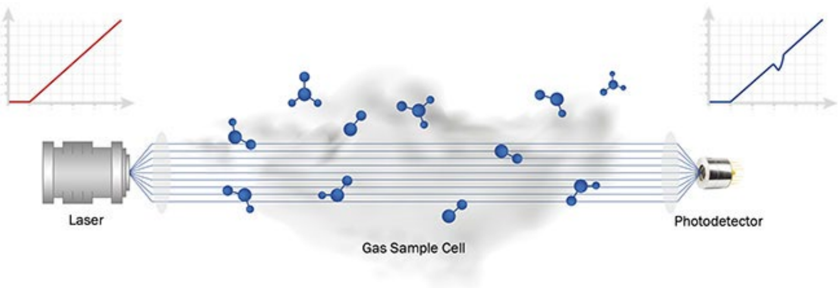


Figure 5.3. The output beat frequency versus laser injection current (Iinj) deviation (at starting temperature of 40.5°C and injection current 20 mA)

3.3 Discussion and TDL application

Tunable single-frequency diode lasers utilize a laser diode and a frequency selective element like a grating for laser frequency selection and tuning. They are available for individual wavelengths between 190 nm and 4000 nm, and deliver narrow-linewidth emission that is tunable – in some systems up to 120 nm wide without a single mode-hop.

Tunable diode laser absorption spectroscopy (TDLAS) is a technique for measuring the concentration of certain species such as methane, water vapor and many more, in a gaseous mixture using tunable diode lasers and laser absorption spectrometry. The advantage of TDLAS over other techniques for concentration measurement is its ability to achieve very low detection limits (of the order of ppb). Apart from concentration, it is also possible to determine the temperature, pressure, velocity and mass flux of the gas under observation.[2][3] TDLAS is by far the most common laser based absorption technique for quantitative assessments of species in gas phase.



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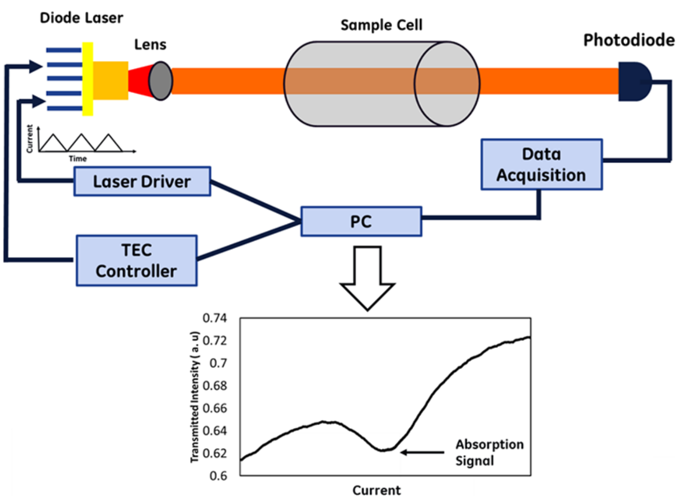
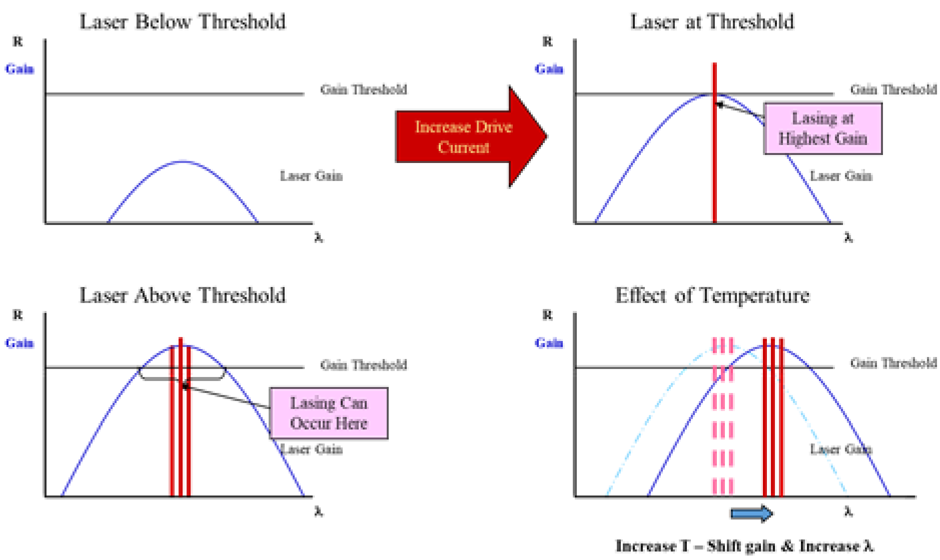


In the Laser Diode Fundamentals series, a deep dive into the underlying physical properties behind the longitudinal mode structure of laser diodes. In that blog post, we explained the advantages and disadvantages to both multi-longitudinal mode and single longitudinal mode diode lasers. In this blog post, we are going to expand on what we learned about single longitudinal mode diodes lasers and take a look at a wide range of stabilization techniques which are used to ensure that a laser maintains single mode performance during its operation. To briefly review the previous post, we established that the interplay between the gain threshold, gain bandwidth, and longitudinal mode spacing is what ultimately determines whether or not a diode operates as a single- or multi-mode device. We further went on to explain that for only one longitudinal mode to exist the gain threshold needs to be significantly high and the gain bandwidth substantially narrow to allow for only one mode to lase at a time. What we did not explain in that post is that the diodes gain curve is dependent on both the junction temperature and drive current. While a detailed analysis of why the current and temperature affects the gain curve is beyond the scope of this post, the diagram below does an excellent job of illustrating the basic principles. This figure shows that as the current in increases or decreases the height of the gain curve will increase or decreases and that as the temperature increases or decreases the curve with red shift or blue shift.



With this knowledge, it should now be evident that for a standard free running laser diode, the only way that single longitudinal mode operation can be achieved is by precisely controlling both the drive current and temperature. While this is possible, it is not only technically challenging to make, but it is also reasonably impractical because it limits the functionality of the diode. For example, it limits the environmental conditions for laser operation and prevents the user from adjusting the output power of the laser diode. Luckily there are a wide variety of techniques which have been developed for selectively modifying the gain threshold by either increasing or decreasing the cavity loss at specific wavelengths. As a result, as the current and temperature of the diode are varied and single mode operation is always maintained.

3.4 Interferometry sensing methods.

The extraordinary sensitivity of interferometry sensors is due to their operational principle which is based on the interference of two electromagnetic (EM) waves having different optical path lengths. In a typical interferometry sensor, one of the EM waves interacts with the medium (it could be named as a sensing channel), while the other one is not affected by the surrounding medium as thus serves as a 49 reference. When both waves meet and interfere, the intensity of the resulting light (I) is a periodic function of phase variation [86]:

and are the light intensities of the sensing and reference channels, respectively. This dependence is shown in Fig. 2.24 where each peak corresponds to phase shift between the sensing and reference channels. This phase variation can be related to the changes in the medium refractive index or to molecular adsorption or bio-molecular interaction in the sensing channel, [87].

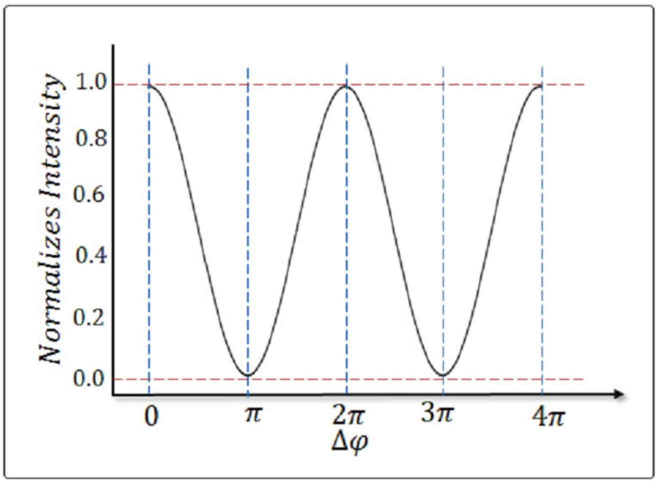


Figure 8.3. Interference pattern: the variation of the light intensity vs phase shift

A large number of interferometry methods have been developed, some of them were utilized in biosensing applications.

3.5 Polarization interferometer

This device consists of a single channel planar waveguide. The widow in the upper cladding layer exposes the core to environment. When the polarized light propagates through the core of the waveguide and pass the sensing window, its p-component (parallel to the plane of incidence) penetrate into the medium and could be affected by changes in the medium refractive index. At the same time, s-component of polarized light (perpendicular to the place of incidence) is much less affected (practically not affected) by the medium and it can serve as a reference. A phase shift between p- and s- components of polarized light can be employed as indicator of the changes in the refractive index or optical property of the medium. As illustrated in Fig. 2.31, such changes can be caused by molecular adsorption or binding of analyte molecules to bio-receptors immobilized on the surface. The output signal of polarization interferometer forms by converting changes in polarization of light to the light intensity using a linear polarizer. The resulted multi-periodic output signal is described by according to Malus‘s formula [18, 19]:

3.6 Sensing signal processing

In order to optimal performance of sensing equipment based on the use of semiconductor lasers, there is a need to process the signal for the purpose of eliminating interference and reducing noise.

In general, there are two issues that require addressing; Noise from different sources and unwanted signal interference. Therefore, spectral analysis of the signal models was required, to determine the required treatment and select the appropriate program. Results of spectroscopic analysis of the signal of systems based on laser phase interferometer show wide range frequency and law amplitude noise, it is suppressed using amplitude based filter.

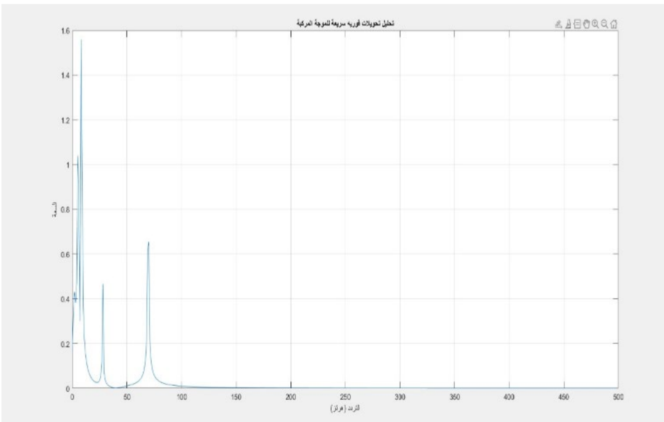


Figure 5.3 Spectrum of the output laser signal

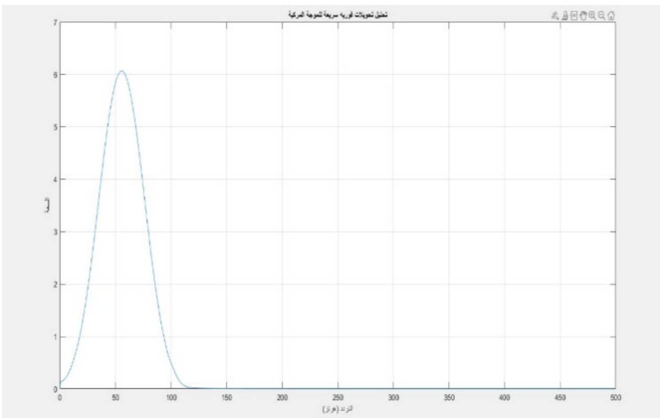


Figure 6.3 Sensing signal after MATLab. Processing

MATLAB Functions were used to build two kind of filters, the required sensitivity clear signal is obtained through them as showed in above figures. Other processing of the signal, the purpose of which was to find a reading of the sensitivity level, was done using Excel and Organ together.

4 Conclusions

From the experiment calculation, we are able to conclude that for typical DFB laser, output wavelength shift due to increasing temperature is about 0.094 nm/°C shifted to the longer wavelength and it corresponds to grating period expansion of 0.014 nm/°C. However, the increasing laser temperature affects to decrease the laser power output by 0.033 mW/°C. This condition causes microwave generation technique based on mixing two optical waves will have lower power output in corresponds to the effort to increase microwave. Furthermore, by varying the second laser temperature deviation in the range from 0 to 2.3°C, it results in output wavelength range from 1551 nm to 1554nm, as shown in Figure 8. It means that the frequency can be tuned at 10.35 GHz/°C laser temperature deviation and injection current of 0.37 GHz/mA. For the future application, we recommend to apply electronics control system to keep the microwave frequency and its power out stable.

On the other hand, the results of signal processing showed that it is possible to obtain the clear enough sensitivity signal after three treatments using the Exicl, Organ, and MATLAB program.

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