In this experiment, you will learn the characteristics and the operation of one of the most commonly used and increasingly popular lasers (Light Amplification by Stimulated Emission of Radiation) in chemical instruments: a semiconductor laser.

Introduction

This is the first and most fundamental experiment of a series of semiconductor laser based chemical analyses to be implemented in this department. The emphases are on the operation of the laser itself and on how to use lasers in practical applications. Therefore, in addition to the laser itself, you will also be required to master the use of a few other optical components such as gratings and mirrors.

Safety Issues:

Never look directly into a laser beam, and never let a laser beam that is reflected, refracted, scattered or diffracted by any objects go directly into your or anyone’s eyes. Keep your eye level well above the beam height. Use a paper card to locate the laser beam paths and block them going out the experimental area. When lasers are on, do not let others walk into the laser experimental area. Use caution when operating lasers. Do not hold a mirror in your hand while aligning it. Mount it on the table first.

Although the intensities from a single diode laser (< 50 mW, and < 10 mW in our case) are classified as Class II to Class IIIa lasers, they are very dangerous if not properly handled. Their beams can damage your and others’ eyes if being viewed directly. Always use caution when operating lasers. Always block the direct beam path before you turn on any lasers. Securely block all possible beam paths before removing the screen blocking the main beam. When using gratings, many diffraction beams exist in different directions. It is absolute necessary to make sure that each and every beam is blocked, and the materials used for blocking are securely fastened to the optical table.

When adjusting mirrors, gratings and lasers, make sure that the refracted, reflected, and diffracted beams are all contained by paper screens. Always mount the optical components on the table before directing laser beams onto them. If injuries occur, contact instructor immediately.

Theory: How does a laser work

Atoms and molecules consist of electrons and nuclei. When no bonds exist between atoms, electrons are on discrete energy levels called orbitals: those levels where electrons reside at zero degree Kelvin are called ground states, and those above them are called excited states. Hydrogen spectrum (Balmer experiment) reveals the energy levels in hydrogen atoms, and the results from the dye absorption experiment indicate that large molecules also have energy levels, though they may not be discrete anymore.

Question #1: Why does the Balmer series have sharp lines, and dyes have a broad absorption peaks?

The total number of electrons on a specific level or orbital is defined as the population of that level. Under normal conditions, the population at a higher (electronic) energy level is smaller than that at a lower one. More precisely, the population is known to follow the Boltzmann distribution. Therefore, there is no lasing under normal conditions unless a population inversion is achieved, meaning a higher level actually has more electrons on it.
Lasing occurs due to interactions of photons with population inverted medium. The medium can absorb photons and cause electrons to jump from lower states to higher states. It can also emit spontaneous emission in which photons are released when electrons jump from an upper state to a lower state without any external disturbance. More importantly, it can also emit stimulated radiation. In this case, one or more photons are emitted when electronic transitions from an upper level to a lower level are triggered by another photon.

Laser works because of the existence of population inversion and stimulated emission. In a well-constructed cavity, photons from spontaneous emission are reflected off the two mirrors sandwiching the laser medium. When these photons pass through the medium again, they can induce a large amount of stimulated radiation, which can be subsequently amplified again after passing through the medium.

Lasers share the following characteristics not available from conventional light sources:

1. **Monochromaticity:** Most lasers emit light with a very narrow spectral width.
2. **Directionality:** Laser beams diverge very slowly or can be corrected with lenses without losing much of their power.
3. **Coherence:** All the photons resemble each other by their physical properties.

### Semiconductor lasers

Like dye molecules, semiconductors are made from materials consisted of bands of energy levels (many particles in a small box). The energy difference between the band whose levels are usually occupied (valence band) and that whose levels are unoccupied (conduction band) is called bandgap. The bandgap changes as a function of the temperature of the semiconductor. Since the laser photons carry the same amount of energy as the bandgap, the laser wavelength also changes if the temperature of the diode laser is changed. This wavelength tunability gives us an upper hand when carrying out chemical analyses. The laser you are going to use is an InGaAlP diode laser. It emits light at 650 nm wavelength at 25 °C, and this wavelength is adjustable for the amount which you will determine in this experiment.

### Apparatus

1. **Diode lasers**

These lasers use electron collisions to produce population inversion in semiconductors. Different dopings are used to tailor the electrical and optical properties of these diodes to minimize heating, increase thermal conductivity, and enhance optical quality. The cavity (the two mirrors and the lasing medium) of semiconductor lasers is very compact since the two mirrors are the two ends of the semiconductor material of high refractive index.

2. **Gratings**

Those are dispersive elements which direct light of different colors to different directions. Another way to achieve a similar result is through the use of prisms. The former is based on diffraction, and the latter by refraction. The rays going into and coming out of a grating can be predicted using the following equation:
\[ d(\sin \theta + \sin \phi ) = n\lambda \]

where \(d\) is a constant (distance between the nearest grooves in the grating, 1200 grooves/mm in our case), \(\theta\) is the incident and \(\phi\) diffraction angles, respectively. \(\lambda\) is the laser wavelength, and \(n\) is the order of the diffraction. You will use this equation to estimate the change of laser wavelength.

**Component list (quantity in parenthesis)**

1. Semiconductor laser (1) (emitting at different wavelengths at different temperatures) TOLD9442M
2. Power supply for the diode laser (1) LDC 500
3. Temperature control for the diode (2) TEC 2000
4. Laser diode mount module (1) TCLDM9
5. Post holders (4)
6. Posts (6)
7. Mirrors (3)
8. Mirror mounts (4)
9. Clamps (6)
10. Grating (1)
11. Grating mount (1)
12. Screens (2)

Count all the components before you start. If there is any item(s) missing, report to TA immediately. Failing to do so may cause you points.

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**Experimental**

Note: The wristband is for mounting and dismounting laser diodes. You should not open the TCLDM9 yourself. If diodes fail during your experiment, report to TA immediately.

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**Operation of the lasers**

After the laser head (TCLDM9) is securely mounted on the ½ inch post and the post in the post holder, you should make sure that all possible beam paths are blocked by screen papers. Please also make sure that the current (controlled by the largest knob on LDC 500 laser driver) on the diode driver is set to minimum (the farther point turning counterclockwise. Do not force the turn, use the fraction between finger tips and the knob). Do not adjust the similar knob on the temperature controller TEC 2000. Turn on the power supply for the diode driver and the temperature controller. Adjust the temperature to the desired value (between 20 and 50 C) by first toggling the display to Tset (lower middle panel) and then slowly dialing the big knob on TEC 2000 while observing the change of reading on the LCD display panel. When the desired temperature is set, press ENABLE on TEC 2000 to activate the temperature setting for the diode. Toggle the display on LDC 500 to ILD (lower middle panel). Make sure that the current setting knob on LDC 500 is turned counterclockwise to the extreme and then press ENABLE. Slowly turn the current setting knob clockwise to increase the current to ~35 mA or until a very bright spot appears on the paper screen. Gradually increase the current again to 45 mA. Remove the screen
and observe the laser beam path. Use a non-reflecting surface such as a piece of paper to follow the beam. Slightly loosen the locking bolt on the post holder below the diode module TCLDM9 while holding the module with the other hand. Rotate the mount and adjust the height if necessary so that the beam hits the grating near the edge next to the second reflecting mirror (see Figure 1). Make sure the whole beam is on the grating.

**Grating alignment**

Adjust the whole grating mount and then use the turning knobs on the grating mount to bring the beam to the first mirror (the one below TCLDM9 in Fig. 1). The laser spot on the first mirror should be close to the edge next to the third mirror without clipping the beam. **Make sure that all the possible diffraction beams are either blocked or projected on the wall.** Mount a chart paper on the wall where the zeroth order of diffraction is located.

**Question #2:** How do you know which order is the zeroth order?

Choose the most intense diffraction beam (is this +1 or –1 order of diffraction?) in this application (which happens to be a non-zeroth order diffraction, see Equation \ref{1}). The beam should also be leveled with respect to the table.

**Mirror alignment**

Align the other two mirrors so that the laser beam is both leveled vertically (by observing the scattering from these mirrors) and their spots on both mirrors are evenly distributed horizontally (as shown in Figure 1). This is only the first of a series of adjustments. The last beam coming out of the third mirror should clear the second mirror by 5-10 mm. Place a chart paper on the wall so that the laser spot is on the center of the paper. You may want to adjust the second and third mirrors so that the laser spots on the second and the third mirrors have similar distances between them and the horizontal edges of these mirrors.

**Change the current and temperature**

Caution: never adjust the temperature to the outside of the safe region, which is between 20 and 50°C. Doing so will cause irreversible damages to the diode laser. In this experiment, you will determine the wavelength change as a function of temperature. Make sure the green dot is next to Const P (lower right corner) on LDC 500. If it is not correctly set, reduce the current to zero, press ENABLE button once to disengage the driver, and then press Const P. Toggle display to PLD and press ENABLE to set the power to between 1-2 mW by dialing the current setting knob. Set the temperature at 5-degree increment from 20 to 50 °C, and record the position of the laser spot on the screen. Wait 3-5 minutes after each adjustment or until the current and power of the diode laser stop changing. **Repeat the measurement three times.** You may have to realign the beam (many times) so that the laser spot appears on the chart at all the temperatures you will choose.

**Determine the difference of laser wavelengths**

Use Equation \ref{1} to calculate the wavelength change as a function of temperature adjustment.
Shut down procedure

Reduce the current or power of the diode to zero. Press ENABLE on LDC 500 to disengage the driver. Press ENABLE on TEC 2000 to disengage the temperature controller. Power off both units. You do not need to change the temperature setting on TEC 2000.

Lab Report

Draw the beam path of your setup, including distances between each optic. Explain why the laser spot on the wall disappears when the wavelength change is too big. Record the optimal alignment routine to carry out this experiment. Plot the position of the spot (ordinate) as a function of temperature (abscissa).

You will need to use Equation \( \text{(1)} \) to estimate the wavelength change as a function of temperature. Use triplicate measurements at each temperature, and calculate only the wavelength change based on the distance between the grating and the screen and that between the laser spots moved after each temperature adjustment. Hint: You will need some basic knowledge of trigonometry and to make some simplifications/manipulations to Equation \( \text{(1)} \) in order to calculate the wavelength change. (You may need to estimate the diffraction angle before you can proceed to complete the calculations). Show the mathematic procedure to TAs before the second period of the experiment.

Contributors

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