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Heat Effects on Spectrum Shift by Laser Diode (780 and 808 nm) in High Frequency for Optical Communication Systems

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Abstract— **Laser Diode are vastly used in fields of free space optical and fiber optical communication systems, which become needful devices in the systems and equipment making up the infrastructure of our society. In this paper a laser diode power supply with controller oscillator had be designed and operated with different frequencies (50 kHz – 2 MHz) with tunable pulse width, Different laser diodes with (780nm and 808 nm), An optical spectrum analyzer with spectrum range (200 – 1050 nm) had been used to test the output spectrum, A digital thermometer to measure the temperature and thermo electric cooler (TEC) to controller the device temperature (20 – 50 Co) was also employed. All optical sources had be operated with different frequencies (50 kHz – 2 MHz). The device temperature had increased proportionally and the trigger width was the main factor. The best spectrum stability was at a trigger (10%) of pulse duration. With temperature increase, the output spectrums showed Red-shift and expansion in spectrum width, via temperature controller with TEC and metallic heat sink. The instability was controlled in output spectrum the for a laser diode (780 nm) the spectrum shift was (1.18 nm to 2.94 nm). While, for a laser diode (808 nm) the spectrum shift was (6.12 nm to 9.19 nm).**

Index Terms— Laser Diode, High Frequency Optical Communication Systems, Temperature Effects on Laser Diode.

I. GENERAL INTRODUCTION

Since the mid-20th Century the electronics industry has enjoyed phenomenal growth and is now the largest industry in the world. The foundation of the electronics industry is the semiconductor device.

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To meet the tremendous demand of this industry, the semiconductor-device field has also grown rapidly. Coincident with this growth, the semiconductor-device literature has expanded and diversified. For access to this massive amount of information, there is a need for a book giving a comprehensive introductory account of device physics and operational principles [1].

Another significant development was the development of laser-diode is arrays multiple lasers by a single device. Even though the beam generated by this diode array device is of doubtful quality for numerous applications, the output power is much more than that obtained from a single laser. Also, high-power arrays applications like as solid-state lasers optical pumping not needs a high beam quality. For some cases, it can be locked the optical phase of adjacent lasers, the result is improved in beam stability and quality. Even it can be obtained a greater power by put a one-dimensional arrays on each other. It is actually two-dimensional array in essence. Many manufacturers made a stacks “high-power laser-diode” that the output power exceeds 100 Watt. Even though the quality of beam from such stacks is somewhat poor, stacks are1 ideally suitable for some applications that needs high power efficient delivery like many medical and industrial applications and optical pumping of other lasers [2].

II. SPECTRAL CHARACTERISTICS OF LASER DIODES

- *Optical Spectrum*

The optical spectrum of laser diodes depends on the particular characteristics of the laser’s optical cavity. Most conventional gain or index-guided devices have a spectrum with multiple peaks, while distributed feedback (DFB) and distributed Bragg reflector (DBR) types of devices display a single well-defined spectral peak. Fig. 1 shows a comparison between these two spectral behaviors [3].

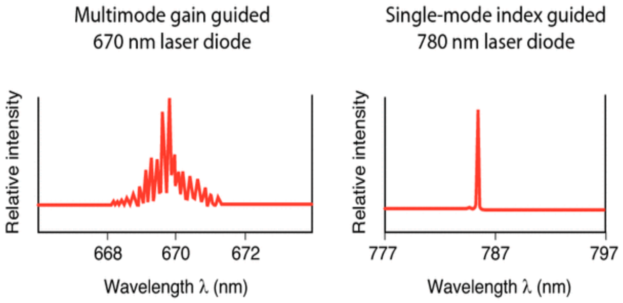


Fig. 1. Multimode versus single-mode spectra [3]

The number of spectral lines that a laser is capable of supporting is a function of the cavity structure, as well as the operating current. The result is that multimode laser diodes exhibit spectral outputs with multiple peaks around their center wavelength. The optical wave propagating through the laser cavity forms a standing wave between the two mirror facets of the laser. The distance L between the two mirrors determines the period of oscillation of this curve. This standing optical wave resonates only when the cavity length L is an integer number m of half wavelengths existing between the two mirrors. In other words, a node must exist at each end of the cavity. The only way this can take place is for L to be exactly a whole number multiple of half wavelengths $\lambda/2$. This means that $L = m(\lambda/2)$, where λ is the wavelength of light in the semiconductor matter and is related to the wavelength of light in free space through the index of refraction n by the relationship $\lambda = \lambda o/n$. As a result of this situation, there can exist many longitudinal modes in the cavity of the laser diode, each resonating at its distinct wavelength of $\lambda m = 2L/m$. From this you can note that two adjacent longitudinal laser modes are separated by a wavelength of $\Delta\lambda = (\lambda o)2/2nL$ [4,5].

Even single-mode devices can support multiple modes at low output power as shown in Figure 1. As the operating current is increased, one mode begins to dominate until, beyond a certain operating power level, a single narrow line width spectrum appears [5].

- *Temperature Control for Laser Diodes*

Since many parameters depend on the temperature of the laser diode, it is important to set and maintain a stable temperature using a thermo-electric temperature controller. Most laser diode applications use Thermoelectric (TE) coolers based on the Peltier Effect to maintain a constant temperature. TE modules are semiconductor “heat pumps” that move heat from one side of the device to the other. Depending on the direction the current flows through the TE cooler, you can either heat or cool a laser diode. Several types of temperature sensors are used: thermistors, I.C. sensors, and platinum resistive temperature devices (RTDs).

The most commonly used is the thermistors because of its small size and fast response time. Thermistors and RTDs are nonlinear resistance devices. Both require a small accurate current source to bias them. Changes in temperature result in resistance changes, with the voltage drop across the device proportional to temperature. Each device has a characteristic equation that converts resistance to temperature. The Steinhart-Hart equation is used to convert a thermistors resistance to temperature and uses two or three constants depending on the accuracy required [6].

The Steinhart–Hart equation is a model of the resistance of a semiconductor at different temperatures. The equation is often used to derive a precise temperature of a thermistors since it provides a closer approximation to actual temperature than simpler equations, and is useful over the entire working temperature range of the sensor. Where Steinhart–Hart coefficients are not available, they can be derived. Three accurate measures of resistance are made at precise temperatures, then the coefficients are derived by solving three simultaneous equations. The equation is [6]:

$$\frac{1}{T} = A + B\ln(R) + Z[\ln(R)]^3 \qquad (1)$$

Where:
T: is the temperature (in Kelvin's)
R: is the resistance at T (in ohms)
A, B, and Z: are the Steinhart–Hart coefficients which vary depending on the type and model of thermistors and the temperature range of interest. (The most general form of the applied equation contains a $[ln(R)]$^2 term, but this is frequently neglected because it is typically much smaller than the other **coefficients**, and is therefore not shown above.)

III. METHODOLOGY

The experiment includes parts and devices that used to measure the wave shifting for the two type of laser diode when used with high frequency as a result to increasing its temperature with increasing the frequencies. A circuited has been designed to provide high frequencies for LD with range from (100 KHz up to 2MHz). Laser diode (LD) has been used with wavelength (780, and 808nm). An oscilloscope has been used to monitor the change of frequencies as a result to changed resistors and capacitor values. A Spectrometer has been used to monitor the wave shifting when increased the frequency of light source. All specification of equipment and devices in addition to circuit design has been described.

- *Experimental Results*

In this parts, the maximum frequency of (50 kHz up to 2MHz) we have been used a waveform function generator to get a higher frequency as shown in Table I.

Table I

Gained frequencies from waveform function generator

	Frequency Gained (KHz)		Frequency Gained (KHz)		Frequency Gained (KHz)		Frequency Gained (KHz)
1	50 KHz	5	400 KHz	9	800 KHz	13	2000 KHz
2	100 KHz	6	500 KHz	10	900 KHz		
3	200 KHz	7	600 KHz	11	1000 KHz		
4	300 KHz	8	700 KHz	12	1500 KHz		

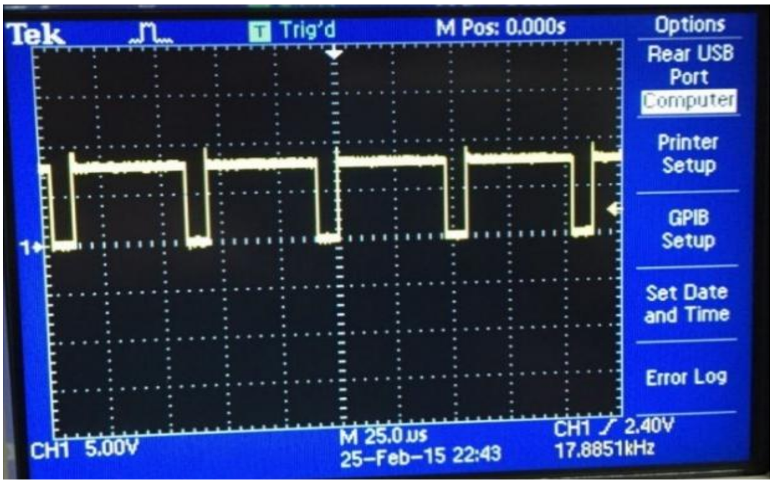


Fig. 2. Waveform function generator

- *Spectrum Analyzer Results*

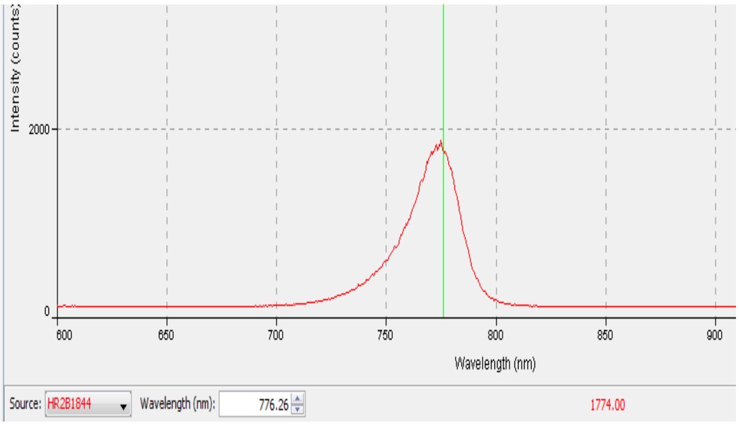
\- *Laser Diode (780nm)*

The laser diode 780nm has been connected to waveform function generator (RIGOL "DG1022") and the optical signal has been measured by spectrum analyzer (HR2000spectrometer), first we measure the wavelength of laser in steady state (λ_0) then we have been applied a range of high frequencies on it to measure wavelength shifting as a result to increase of frequency. Fig. 3 shows the spectrum of 780nm laser diode in steady state.

Table II shows the shifting value for multi frequencies. As shown in Fig. 3, the steady state wavelength measured by spectrometer are (776nm), then we calculated the shifting value for each frequency and for 10% pulse duration.

$$Shift(\Delta\lambda) = \lambda nm - \lambda_0 nm$$

Where:
$\lambda_0 nm$: thermal wavelength,
λnm: experiment wavelength,
$\Delta\lambda$: shift wavelength



Source: HR2B1844
Wavelength (nm): 776.26

Fig. 3. Laser diode 780nm spectrum in steady state

Table II
Laser diode 780 nm shifting value as a result to applied multi values of high frequencies

Frequency (kHz)	Pulse duration (%)	λnm	($\lambda_0 nm$)	Shift ($\Delta\lambda$)	Spectrum bandwidth
50	10%	776nm	774.05nm	2.05nm	5.37nm
100			774.50nm	2.50nm	5.50nm
200			774.94nm	2.94nm	5.61nm
300			775.32nm	1.32nm	5.28nm
400			775.50nm	1.50nm	5.32nm
500			775.82nm	1.82nm	6.24 nm
600			775.97nm	1.97nm	6.37nm
700			776.30nm	0.30nm	6.44nm
800			776.65nm	0.65nm	6.56nm
900			776.90nm	0.90nm	6. 63nm
1000			777.10nm	1.10nm	7.98nm
1500			777.18nm	1.18nm	8.08 nm
2000			777.18nm	1.18nm	8.08 nm

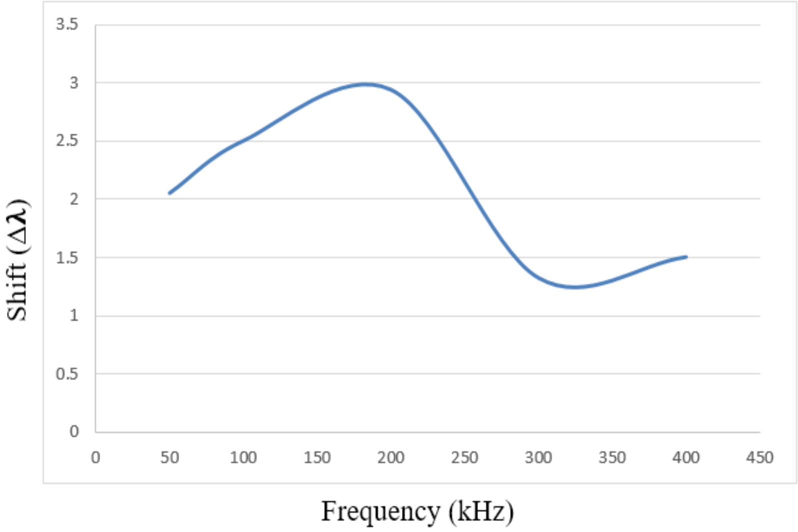
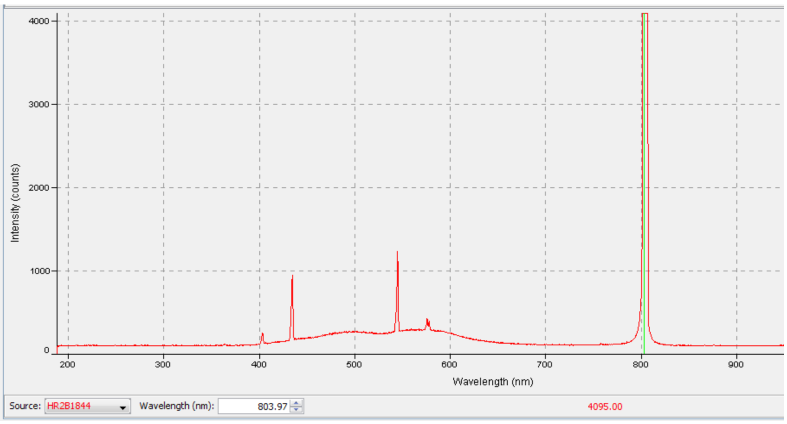


Fig. 4. Laser diode 780nm shifting

- *Laser Diode (808nm)*

The laser diode 808nm has been connected to waveform function generator (RIGOL "DG1022") and the optical signal has been measured by spectrum analyzer (HR2000spectrometer), first we measure the wavelength of laser in steady state (λ_0) then we have been applied a range of high frequencies on it to measure wavelength shifting as a result to increase of frequency. Fig. 5 shows the spectrum of 808nm laser diode in steady state. Table 3 shows the shifting value for multi frequencies. As shown in figure 5, the steady state wavelength measured by spectrometer are (811), then we calculated the shifting value for each frequency and for 10% pulse duration.



Source: HR2B1844

Wavelength (nm): 803.97

Fig. 5. Laser diode 808nm spectrum in steady state

Table III

Laser diode 808nm shifting value as a result to applied multi values of high frequencies

Frequency (kHz)	Pulse duration (%)	λnm	$\lambda_0$nm	Shift(Δλ)	Spectrum bandwidth
50	10%	811nm	817.12nm	6.12nm	6.32nm
100			817.56nm	6.56nm	6.54nm
200			818.00nm	7.00nm	6.89nm
300			818.44nm	7.44nm	7.07nm
400			818.62nm	7.62nm	7.36nm
500			818.88nm	7.88nm	7.49nm
600			819.19nm	8.19nm	7.66nm
700			819.31nm	8.31nm	7.94nm
800			819.57nm	8.57nm	8.35nm
900			819.75nm	8.75nm	8.60nm
1000			819.99nm	8.99nm	8.80nm
1500			820.19nm	9.19nm	8.92nm
2000			820.19nm	9.19nm	8.92nm

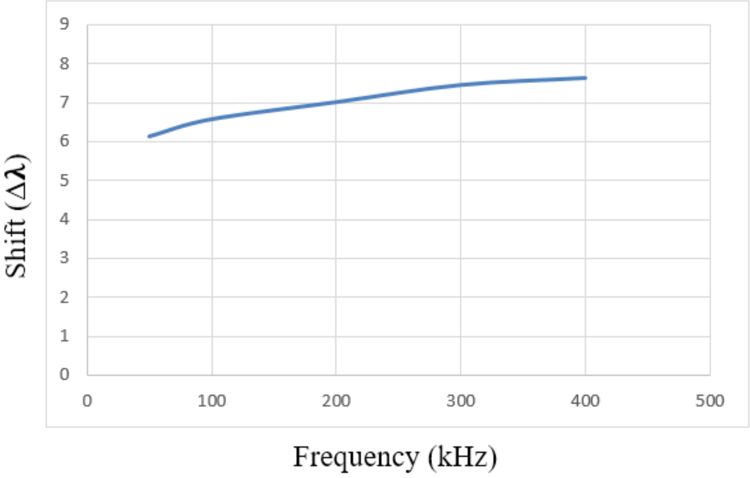


Fig. 6. Laser diode 808nm shifting

IV. MEASUREMENT THE LASER DIODE TEMPERATURE

- *Laser Diode (780nm)*

The laser diode 780nm has been connected to Digital Multimeter (Pro'sKit“MT-1232”) to measure LD temperature at each frequencies. Table IV. shows the temperature readings for LD for each applied frequency.

$$\Delta T = T(^\circ C) - T_0(^\circ C)$$

Where:
$T_0(^0C)$: is the thermal temperature,
$T(^0C)$: is the experiment temperature,
ΔT: is the difference temperature.

Table IV
Laser diode780nm temperature as a result to applied multi values of high frequencies

Frequency (kHz)	Pulse duration (%)	$T_0(^\circ C)$	$T(^\circ C)$	ΔT
50	10%	27	27,2	0,2
100			27,9	0,9
200			29,5	2,5
300			30,3	3,3
400			33,3	6,3
500			37,1	10,1
600			39	12
700			41,1	14,1
800			42,6	15,6
900			45,4	18,4
1000			46,8	19,8
1500			48,2	21,2
2000			49,6	22,6

- *Laser Diode (808nm)*

The laser diode 808nm has been connected to Digital Multimeter (Pro'sKit“MT-1232”) to measure LD temperature at each frequencies. Table V. shows the temperature readings for LD for each applied frequency.

Table V
Laser diode 808nm temperature as a result to applied multi values of high frequencies.

Frequency (kHz)	Pulse duration (%)	T_0(°C)	T(°C)	ΔT
50	10%	27	27,5	0,5
100			27,9	0,9
200			28,8	1,8
300			30,6	3,6
400			34,1	7,1
500			38,3	11,3
600			40,3	13,3
700			42,2	15,2
800			44,8	17,8
900			45,6	18,6
1000			47,9	20,9
1500			49	22
2000			50,3	23,3

In second part we have been used thermoelectric cooler to control temperature for laser diode in rang (from 25 to 50C^{o}). Table VI and VII shows the shifting of laser diodes 780nm, and 808nm. Operating voltage 5 Volt and frequency 1000 kHz pulse width (10%) of the wave time.

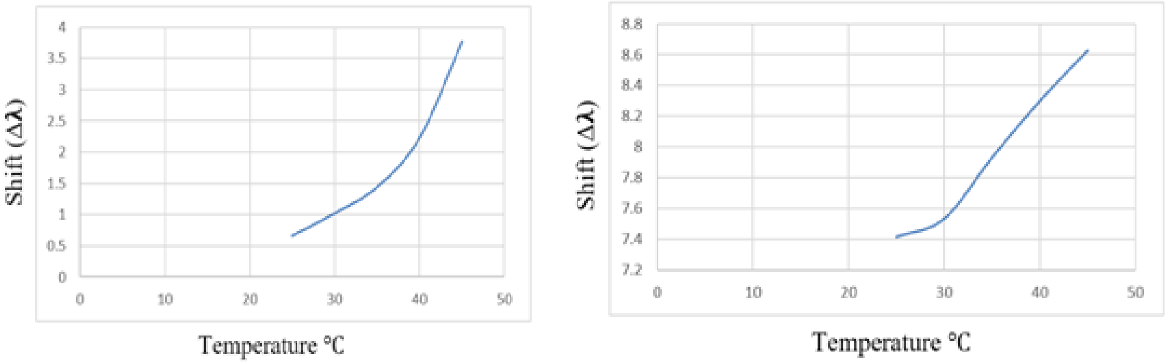
Table VI
Laser diode 780nm shifting as an increased of temperature

T(°C)	$\lambda_0$nm	λnm	Shift(Δ λ)nm	Spectrum bandwidth
25	776	776.26	0.26	5 nm
30	776	776.34	0.34	5,18 nm
35	776	776.52	0.52	5,35 nm
40	776	776.76	0.76	5,80 nm
45	776	776.90	0.9	6,84 nm
50	776	777,1	1.1	7,98 nm

Table VII
Laser diode 808nm shifting as an increased of temperature

T(°C)	**λnm**	**$\lambda_0$nm**	Shift(Δ λ)nm	Spectrum bandwidth
25	811	818.41	7.41	6 nm
30	811	818.53	7.53	6,7 nm
35	811	818.93	7.93	6,9 nm
40	811	819.30	8.3	7,4 nm
45	811	819.63	8.63	7,9 nm
50	811	819.99	8.99	8,8 nm

From the results, the spectrum laser diode shown unstable behavior with high frequency. At higher operating frequency, as frequency increased it leads to a rise in device temperature that is the main reason to spectrum shift and expansion. Fig. 7 laser diode shifting as an increased of temperature for: (a) 780nm laser diode, (b)808nm laser diode.



(a) (b)

Fig. 7. Laser diode shifting as an increased of temperature for: (a) 780nm laser diode, (b)808nm laser diode

V.CONCLUSION

The emphasis of this paper is to steady the effects of heat on spectrum shift by laser diode at high frequency. From the results, the spectrum laser diode shown unstable behavior with high frequency. At higher operating frequency, as frequency increased it leads to a rise in device temperature that is the main reason to spectrum shift and expansion. By used cooling techniques, the laser diode give the system more stability but add more cost. Furthermore, the result appeared that lasers diode with metallic case has a higher heat capacity and lead to increases the temperature Study the ability of spectrum controller for laser diode temperature.

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