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Characterization of a 808 nm High power Diode Laser module

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Abstract

A complete characterization for the diode laser module operating at 808 nm is required for different applications; such as developing an efficient Nd^{3+} doped solid state laser, industrial and medical applications. In this paper a complete characterization for a high power diode laser module with fiber pigtail is presented. Up to 6.6 Watt output optical power was measured. The electrical characterization of the diode laser module was examined by measuring the dependence of the laser driving current on the operating voltage. The optical characterization was investigated at different temperatures; these included the laser output power versus the driving current, the output optical power versus electrical input power and the laser output spectrum. The measured diode laser parameters at 25°C were (1.3A) threshold current, (42%) overall slope efficiency and (807.96nm) central wavelength with line width of (3.59nm) at FWHM. The variation of the above mentioned parameters with temperature are presented.

1. Introduction

Developing TEM_{00} laser mode with high efficiency, high output power, good spatial beam profile and good stability is highly desired. This will make it suitable for using in material processing and other scientific applications such as pumping other laser crystals (Diode-Pumped-Solid-State Laser "DPSSL"). Using novel technique such as High power Diode Laser modules for pumping solid state lasers is a promising technique in developing TEM_{00} laser output [1-3].

Diodes fabricated from (A1Ga)As with different percentages of A1 and Ga emit at wavelengths in the vicinity of 800 nm ranging from approximately 700nm to 900nm[1],[5]. These emission wavelengths coincide well with strong absorption bands of several currently and potentially important solid-state lasing ions, like; Nd^{3+} [1]. These diode lasers modules are preferable due to their advantages over the other traditional pumping methods (flashlamps) these include ; high conversion slop efficiency, good overlap with the solid state active medium (rods), compact and small size, low consumption power and in addition to their ability to control the diode laser temperature.

The emitting wavelengths of the laser diode module can be adjusted by varying the diode material composition during wafer growth. And by controlling the operating temperature; the emitting wavelength can be precisely matched to be coincide with the peak absorption line(s) [2-3].

Diode pumps cause less undesirable heating and produce no damage that occurs when high energy photons are presented in the pump light. Moreover; because the partially coherent laser output characteristic; the diode output beam can be efficiently focused and adjusted to spatially match the solid-state laser mode.

In this paper; the brief discussion in Section (2) is focused on the diode lasers with a fiber pigtail and emphasis on their applications as practical pumping units. In section (3) we measured the dependence of the operating current versus operating voltage at different temperatures, showing the diode electrical consumption power. In section (4) we discussed the optical characterization for the high power diode module, measuring the laser output power versus the electrical input one, showing the laser threshold and calculating the overall slope efficiency. Dependence of the laser threshold and overall slope efficiency on the temperature variations has been discussed. And finally; in Section (5) the laser output spectrum was measured illustrating the temperature effect on the output wavelength.

2. Fiber-Coupled diode lasers overview

Conventional (A1Ga)As diode laser pumps emit from a very thin area of the laser facet on the order of 1 µm[5]. In modern diode lasers, the laser emission is generally produced in very thin layers less than 20 nm thick, called quantum wells [5]. Recently, crystal growth by Molecular Beam Epitaxy (MBE) and Organometallic Vapor Phase Epitaxy (OMVPE) together with using quantum-well (QW) structure technique have led to Lasers with lower threshold current, high slope efficiency, high output powers and longer lifetimes which increased the interest in developing Diode-pumped solid state lasers [4].

Fibers coupled techniques are quite differ according to the diode lasers manufacturing and construction [6]. The simplest case is that of a VCSEL (Vertical Cavity Surface Emitting Laser); which usually emits a beam with high beam quality, moderate beam divergence, no astigmatism, and a circular intensity profile. A simple spherical lens is sufficient for imaging the emitting spot to the core of a single-mode fiber. As the coupling efficiency can be of the order of 70-80%. Small edge-emitting laser diodes also emit in a single spatial mode, allowing an efficient coupling to a single-mode fiber. However, the coupling efficiency can be significantly degraded by the ellipticity of the beam if a simple spherical lens is used. With output powers of up to a few hundred milliwatts; fiber-coupled gain-guided LDs can be used for pumping erbium-doped fiber amplifiers. For diode bars (diode arrays); the outputs of individual emitters coupled into separate fibers of a fiber bundle. The fibers are arranged in a linear array on the side of the diode bar and a circular array on the output end. Coupling of 30 W laser o/p into a fiber with 200µm (or even 100µm) core diameter and an NA of 0.22 can be used for pumping a Nd:YAG or $Nd:YVO_4$ laser. For diode stacks, fibers with larger core diameters are used. It is possible to couple hundreds of watts of optical power into a fiber with 600-µm core diameter and NA=0.22.

Diode arrays are limited by waste heat and the maximum packaging density determined by the mounting plate. Physically separated the diode bars and optically couple the pumped light from diodes via fiber bundles can give a facility of waste heat removal, overcome the problem of packing density restriction with effortless handling, controlling and guiding. The optical brightness is reduced significantly from the diode after propagating through some length of fiber [1], using micro optics for coupling between the Diode module and the fiber bundle is so important to minimize that effect and increasing the coupling efficiency.

3. Electrical characterization of the fiber coupled Diode module

A. Experimental setup

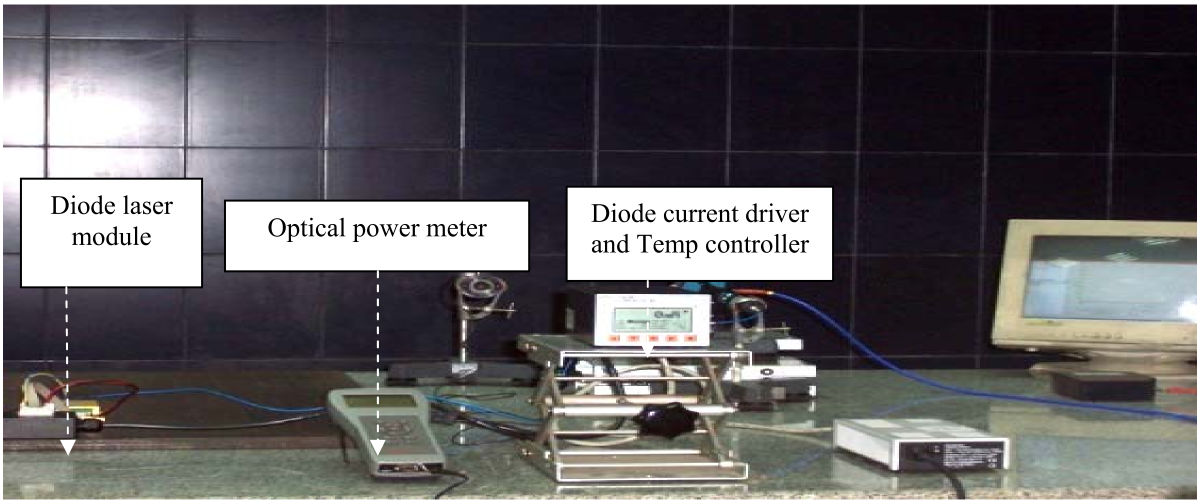

Figure (1) shows the experimental setup with its different instruments.

The experimental setup shown in figure (1) consists of; laser diode driver with a temperature controller, power supply (output 24V, 10.5A), high power diode laser module (fiber coupled), optical power meter and laser optical detectors.

A laser diode driver (UM DiTec 60/8000 Benchtop) with an integrated highly precise temperature controller (TEC) used for driving diode lasers in cw and pulsed mode as it has an On-Board Oscillator which can be freely configure for pulsation the laser. The driver is completely controllable by RS232 serial interface; where the current, voltage and temperature can freely set, as it will be used to measure the electrical and optical characterization of the high power Diode laser module.

Our high power Diode laser module is a fiber coupled @ 808 ± 3 nm (model VDM00013); this Diode has a maximum cw output power up to 7.80 Watt under maximum input driving current at 6.02 Amp. The highest brightness is achieved by transforming the asymmetric radiation from the laser diode into a symmetrical beam, using micro optics and finally this beam can be coupled into 100μm fiber (under NA 0.20) with a high efficiency.

While the optical power meter system (PM213) provided by THORLABS with two different detectors; (S120B) silicon sensor has spectral ranging from 400:1100nm measuring an optical power ranging form 50:500mW and the other (S213A) Thermal sensor has spectral ranging from 250:1064nm measuring up to 30W. Using the silicon sensor at low power measuring since its response is a wavelength dependent.

B. Measurements results

By adjusting the laser diode driver to a different voltages and obtaining the driving input current to the diode module (measured and viewed through the driver's LCD) at different operating temperature (12, 25 and 36^{o}C); the measured (I-V) diode characteristic curve is shown in figure(2).

Figure (2) shows the input diode module current (A) Vs. the driver controlling voltage (V) for temperatures of 12, 25 and 36^{o}C.

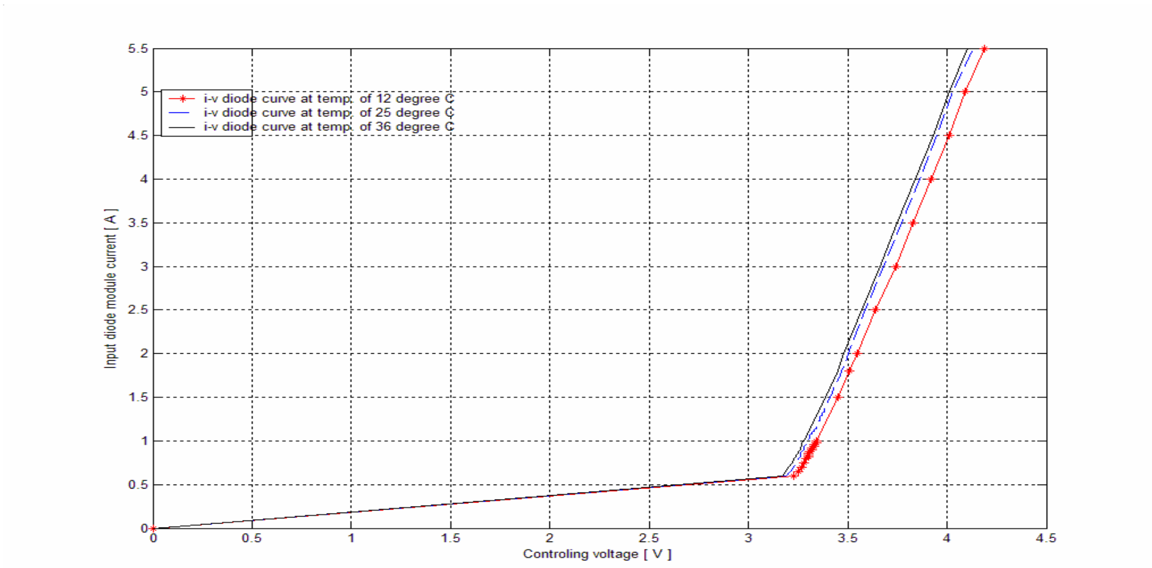

Figure (2) The (I-V) curve measured at 3 different temperatures (12, 25, 36 C^o).

From Fig.(2) one can notice that; the maximum consumption electrical power was measured at temperature of 12^{o}C provided the lowest electrical to optical slope efficiency in this case.

4. Optical characterization of the fiber coupled Diode module

The experimental setup was shown in previously section.

A. Principles and concepts of the measurements

The light emitted by one facet of the semiconductor (Diode) laser was measured as a function of the deriver input current (I); and the measuring curve is referred to as the Light-Current (L-I) curve which is strongly temperature dependent. The form of the (L-I) curve is typical the same as in any lasers; the turning point at which the laser output abruptly start to increase corresponds to the threshold lasing point. The threshold current (I_{th}) or equivalently threshold current density (J_{th}) is an important device parameter and its minimization is desirable. It is well known that when the input current $I < I_{th}$; light output mainly consists of spontaneous emission.

B. Optical characterization measurements results

The output laser power at a constant operating temperature (25°C) is measured using the optical power meter and the laser detectors; corresponding to the change in the driving input current to the Diode laser module. As the optical characteristics (L-I) curve can be investigated.

diode output laser power (Watt) Vs. the diode input driving current (A); measured at temperature 25°C.

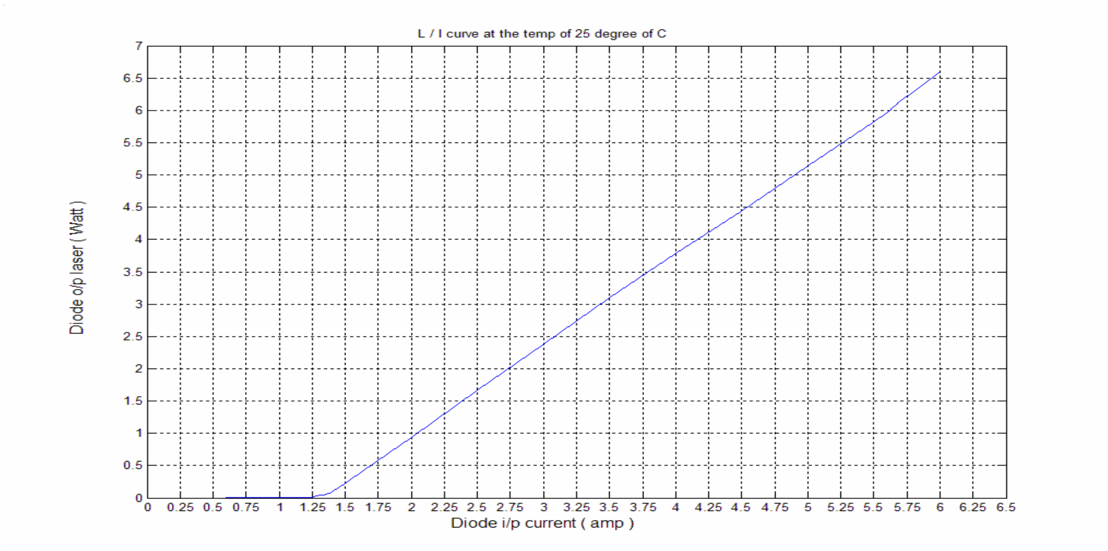

Figure (3) The Optical characteristics (L-I) curve of the high power diode module at operating temperature of 25°C.

Output measured threshold laser was 45.42 mW at input driving current of 1.3A (using S120B photo detector for measuring such low output power).

The (L-I) characteristic curve will be measured at different temperatures showing the temperature effect on the threshold lasing point and the slope efficiency shown in the next section.

Figure (3) shows the clearly linear relation between the output laser power and the input driving current behind threshold point, as the laser is shown to operate continuously without any indication of heating or failure.

The maximum output measuring power from the pigtail fiber coupled diode module was 6.6W; i.e. we have conversion efficiency around 85%[4]; which is considered as high conversion efficiency between the Diode module and the fiber pigtail.

From the previous Electrical and Optical characterization measurements; we got the important relation between the output optical power and the input electrical one shown in figure (4).

Figure (4) shows the relation between the optical output power and the electrical input one in the above curve; while the lower one shows the electrical to optical slope efficiency.

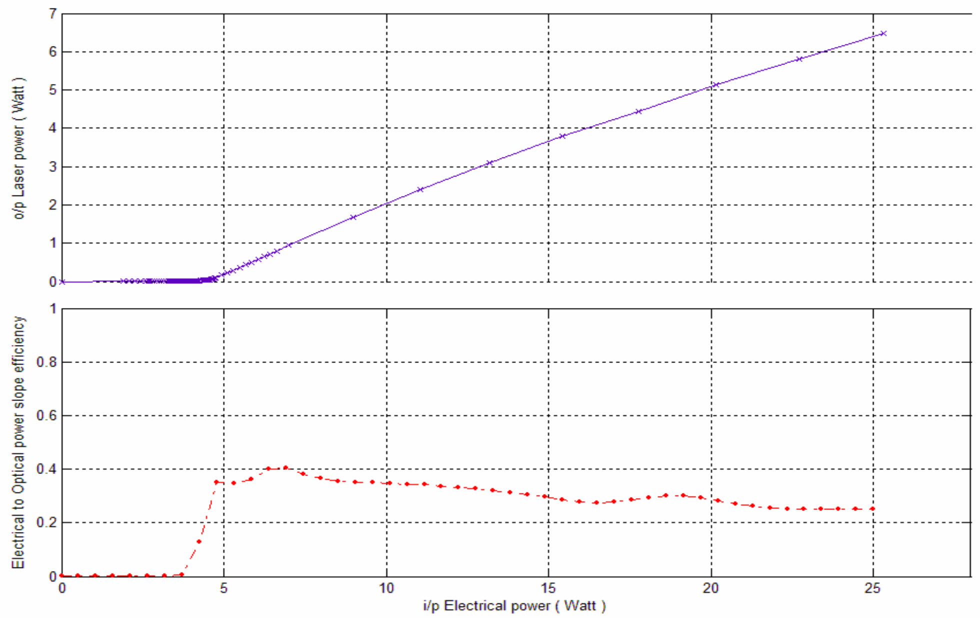

Figure (4) The High power diode measuring optical characteristics.

From our measurements shown in figure (4); we have maximum slope efficiency around 42% with a final electrical to optical conversion efficiency of 28%.

The decreasing in the measured efficiency with increasing pumping current shown in figure(4) occurs because of the ohmic losses in the diode laser increasing with the square of the current [1]; where the output power is in linear relation with the driving current as shown in figure(3).

5. The Temperature effects on the Output diode laser characteristics

A. Temperature effect on the lasing threshold point

Using the previous experimental setup; with changing the diode operating temperature to be 12, 25 and 36^{o}C; and measuring the (L-I) curve in each case, the temperature effect on the output threshold laser can be examined.

Figure (5) shows the laser diode output Vs. the driving input current at temperatures (12, 25 and 36^{o}C), the result illustrates that; the laser threshold output is an increasing function of temperature; this is because of the reduction in the diode gain and increasing in the leakage current as well as the increasing in Auger recombination [7].

From these experimental results; it is obviously clear that at temperature of 36^{o}C the (L-I) curve has the highest threshold value; with the lowest conversion electrical to optical slope efficiency in this case.

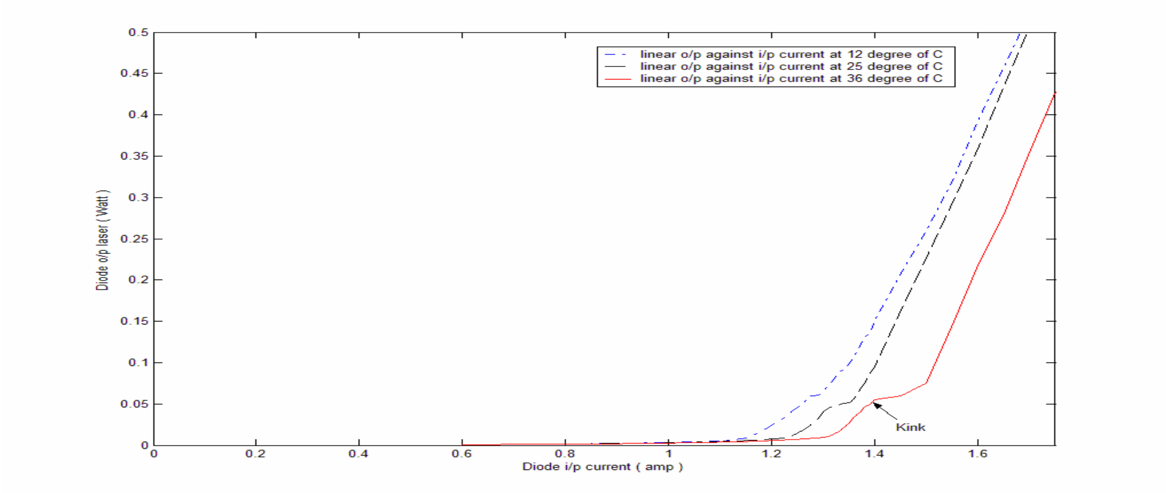

Figure (5) The Temperature effect on the (L-I) characterization curve with a kink appears at the threshold point

Concerning with the temperature effect on both of threshold lasing and the conversion slope efficiency; and taking into account the measuring results of the electrical characterization shown in fig.(2); we notice that; operating the high power Diode module at the room temperature (25^{o}C) is the best condition. It gives higher slope efficiency with lower consumption electrical power and lower threshold lasing which considered to be an optimum condition producing a maximum output performance.

B. Temperature effects on the Wavelength measurements

Temperature variation has an important effect on the output laser wavelength; that the later will directly be changed as the temperature changes.

This important effect appeared in the next experimental work; showing a novel technique to control the Diode laser wavelength to be perfectly coincident with the solid state absorbed bands (Nd^{3+} doped materials) [8].

[4] Maximum output laser for the Diode module was 7.8W given by manufacture datasheet.

i) Experimental setup

The experimental setup shown in figure (6) consists of; high resolution Spectrometer, fiber optic integrating spheres, collimated optics, optical density lens, high power pigtail diode module and

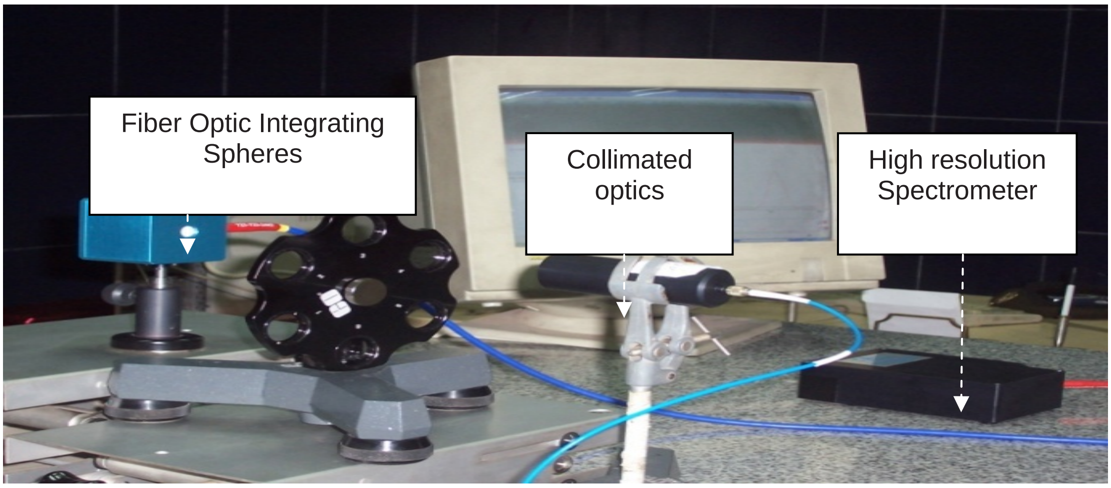

Figure (6) shows the experimental setup of the wavelength measuring and at the right the spectromete ranging from 200:1100 nm is shown.

"SpectraSuite" computer software.

The high resolution Spectrometer (HR4000CG) with a 3648-element linear-array CCD detector that provides better optical resolution produced by "Ocean Optics Inc." shown in figure (11); providing 200:1100 nm wavelengths ranging with 0.75nm optical resolution (FWHM) is used in our experimental work. "SpectraSuite" spectrometer software is used in analyzing and viewing our measurements.

ii) Experimental results

Firstly; we investigate the temperature effect on the laser output wavelength; we measure the diode wavelength at different operating temperatures controlled by the laser diode driver and temperature controller (within the diode operating temperature acceptance 0:40^{o}C) with a constant driving current 3500 mA.

Figure (7) shows the wavelength of the laser output at different temperatures (12, 20, 25 and 30^{o}C) at constant driving current (3.5A).

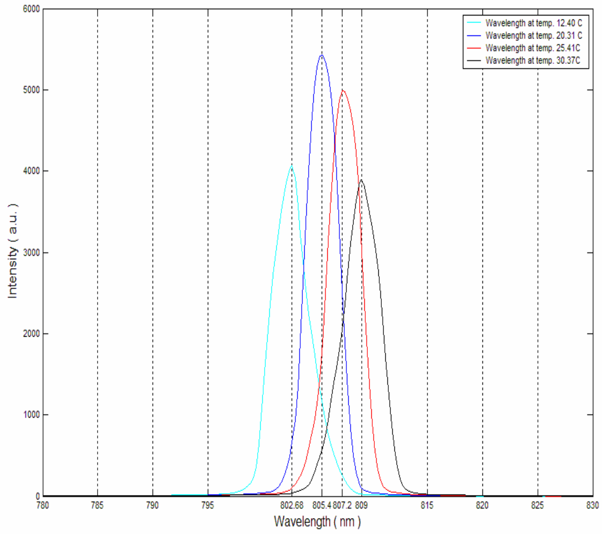

Figure (7) The wavelength variation according to temperature changed under constant driving current (3.5 A).

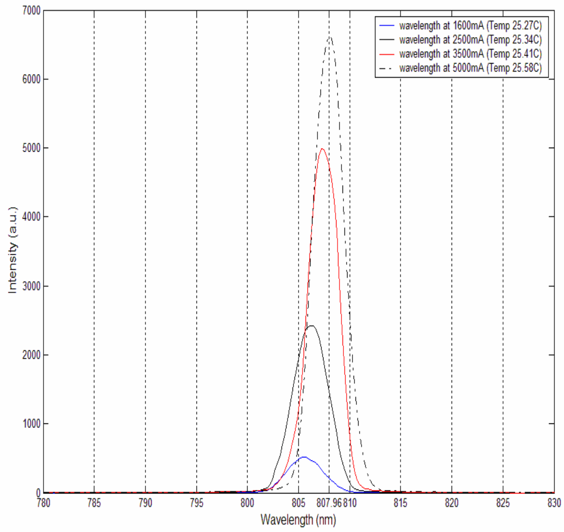

Figure (8) The diode wavelength o/p; with its peak insignificant shift according to increasing i/p currents at constant temperature (25°C).

We notice that the emitted laser wavelength is affected by the temperature increasing; and for a good approximation; Diode wavelength will increase by 0.35nm/C[5]; which agrees with the published results shown in [1]. This will lead to a suitable technique for controlling the output diode laser wavelength to be typically coincident with the absorbed band for Nd^{3+} doping materials [8].

From figure (7) the maximum diode output power obtained at the room temperature (20:25°C); which proves that; the ideal temperature for the diode operation is the room temperature.

Furthermore; the best useful wavelength band for pumping Nd^{3+} doped materials was given at the same temperature ranging (20:25°C).

Secondly; we measure the wavelength of the diode o/p at different i/p driving currents; nearly at constant temperature.

Figure (8) shows the output wavelength measured at different driving current (1600, 2500, 3500 and 5000mA) for a constant temperature (25°C).

From our measurements; one can observe that the peak wavelengths for the diode laser are nearly constant for different i/p driving currents (1600, 2500, 3500 and 5000mA); showing a slightly shift towards higher wavelength according to increasing the driving current causes a little increased in the diode temperature.

Typical 808nm laser o/p is obtained with different driving i/p current at constant temperature of 25°C with line width of 3.59 nm measured at FWHM.

6. CONCLUSIN

In this paper; the temperature effect on both of threshold lasing and the conversion slope efficiency was measured. Based on the Electrical and Optical characterization measuring results; operation of the high power Diode module at the Room temperature (25^{o}C) gave a higher slope efficiency with low consumption electrical power and low in lasing threshold; which is considered as an optimum condition that gives the maximum output performance.

Maximum slope efficiency around 42% with a final electrical to optical conversion efficiency of 28% was measured.

The emitted laser wavelength was affected by the temperature increasing; and for a good approximation; diode wavelength was increased by 0.35nm/C.

Moreover; the appropriate wavelength that useful for pumping Nd^{3+} doped materials (around 808nm) was obtained at the temperature range of (20:25^{o}C).

The peak wavelengths for the diode laser were found to be nearly constant for different i/p driving currents.

Typical 808nm diode laser o/p was obtained with different driving i/p current at constant temperature of 25^{o}C with line width of 3.59 nm at FWHM.

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[5] All wavelengths measuring data ware averaged to 5 readings.