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High speed data transmission through optical fiber of 1550 Nm InGaAsP/InP MQW semiconductor laser

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Abstract
High speed lasers are usually used as data transmitter on fiber optic communication [3-7]. High power lasers are used in materials processing, nuclear fusion, medical field, defense etc. VCSELs are also used in fundamental researches. This is the main reason that's why semiconductor lasers are projected to grow at annual rate of 9 to 10% [8]. The effects of variation of injection current on the characteristics of a 1550 nm InGaAsP/InP MQW VCSEL have been presented in this work with the aim of obtaining high speed performance.

Keywords: InGaAsP/InP MQW Semiconductor, High Speed Data Transmission, Optical Fiber

Introduction
The Vertical Cavity Surface Emitter Laser (VCSEL) is the latest technology of light source whose importance is increasing linearly in our optical communication system. Due to the development of advance semiconductor material, a remarkable change has been made in our communication engineering such as; using semiconductor laser sending high data transmission through single mode optical fiber. The VCSEL is a low-cost light source with attractive performance characteristics such as low power consumption, high speed capabilities [1, 2].
High speed lasers are usually used as data transmitter on fiber optic communication [3-7]. High power lasers are used in materials processing, nuclear fusion, medical field, defense etc. VCSELs are also used in fundamental researches. This is the main reason that's why semiconductor lasers are projected to grow at annual rate of 9 to 10% [8]. The effects of variation of injection current on the characteristics of a 1550 nm InGaAsP/InP MQW VCSEL have been presented in this work with the aim of obtaining high speed performance.

Structure of a Semi-Conductor Laser

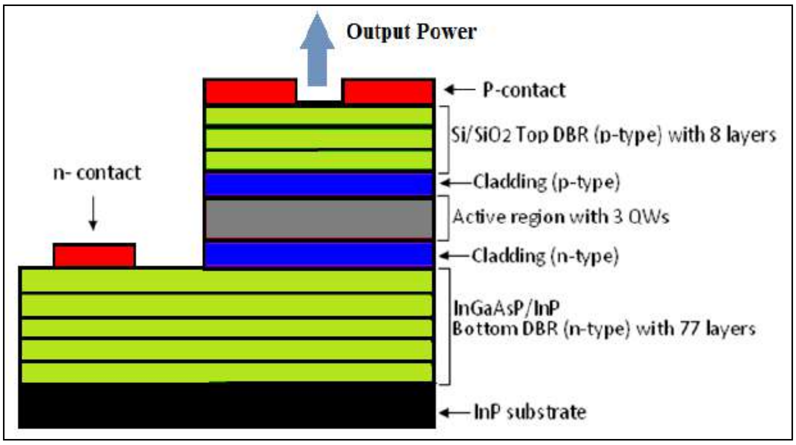

Fig 1: The Structure of a 1550 nm Top Emitting InGaAsP/InP MQW VCSEL.

The structure of a 1550 nm top emitting MQW VCSEL is presented in Figure 1. The active region of the device consists InGaAsP based 3QWs of 195 Å each, which are separated by InP barrier layers. The active layers are guided by p-type and n-type GaInP cladding layers in the VCSEL cavity.

There are two Distributed reflector (DBR) mirrors which are parallel to the wafer surface with an active region. In the top DBR stack there are eight layers of Si/SiO2 and 77 layers of InGaAsP/InP materials in the bottom DBR stack. This type of designed VCSEL is considered for achieving a high reflectivity of 99.9% which is required for the emission because of short cavity length of the VCSEL. Current is injected through the top p-contact of the device and the InP substrate is connected with the lower n-contact as shown in the figure.

Simulation Results and Discussions

The rate of change of carrier density of a laser is written as [9].

$$\frac{dN}{dt} = \frac{\eta_i I}{qV_a} - \frac{N}{\tau_c} - \frac{v_g a(N-N_{tr})S}{(1+\varepsilon S)} \tag{1}$$

where, N is the carrier density, S is the photon density, I is the injection current, q is the electron charge, V_a is the volume of the active region, η_i is the injection efficiency, τ_c is the carrier life time, v_g is the group velocity, a is the differential gain, N_{tr} is the transparency carrier density and ε is the gain compression factor.

The rate of change of photon density of a laser is written as [9].

$$\frac{dS}{dt} = \frac{\Gamma v_g a(N-N_{tr})S}{(1+\varepsilon S)} + \Gamma \beta_{sp} \frac{\eta_i I_{th}}{q} - \frac{S}{\tau_p} \tag{2}$$

where, β_{sp} is the spontaneous emission coefficient, Γ is the confinement factor, τ_p is the photon life time and I_{th} is the threshold current of a laser.
Using the following Eq. (3), the confine factor is calculated as 0.0607

$$\Gamma = 2 \times \frac{L_{active}}{L_{eff}} \times 0.9 \tag{3}$$

where, L_{active} is 5.85x 10^{-6} cm and L_{eff} is 1.735x10^{-4} cm.
The threshold current of a laser can be written as [9, 10].

$$I_{th} = \frac{qV_a N_{th}}{\eta_i \tau_c} \tag{4}$$

By using the above equation the threshold current is calculated by 0.78 mA.
At steady-state the photon density of a laser can be expressed as [9].

$$S = \eta_i \frac{(I-I_{th})}{qv_g g_{th} V_a} \tag{5}$$

where, g_{th} is the threshold gain.
At steady-state the output power of a laser can be calculated as [9].

$$P_{out} = v_g \alpha_m h \nu S V_p \tag{6}$$

where, α_m is the mirror loss coefficient, $h\nu$ is the photon energy and V_p is the cavity volume.

Using MATLAB solution of the above Eqs. (1) to (6), the characteristics of carrier density, photon density and output power of 1550 nm laser are obtained by varying injection current 10 to 20 times of the threshold current and the obtained results are presented as shown in Figures 2, 3 and 4.

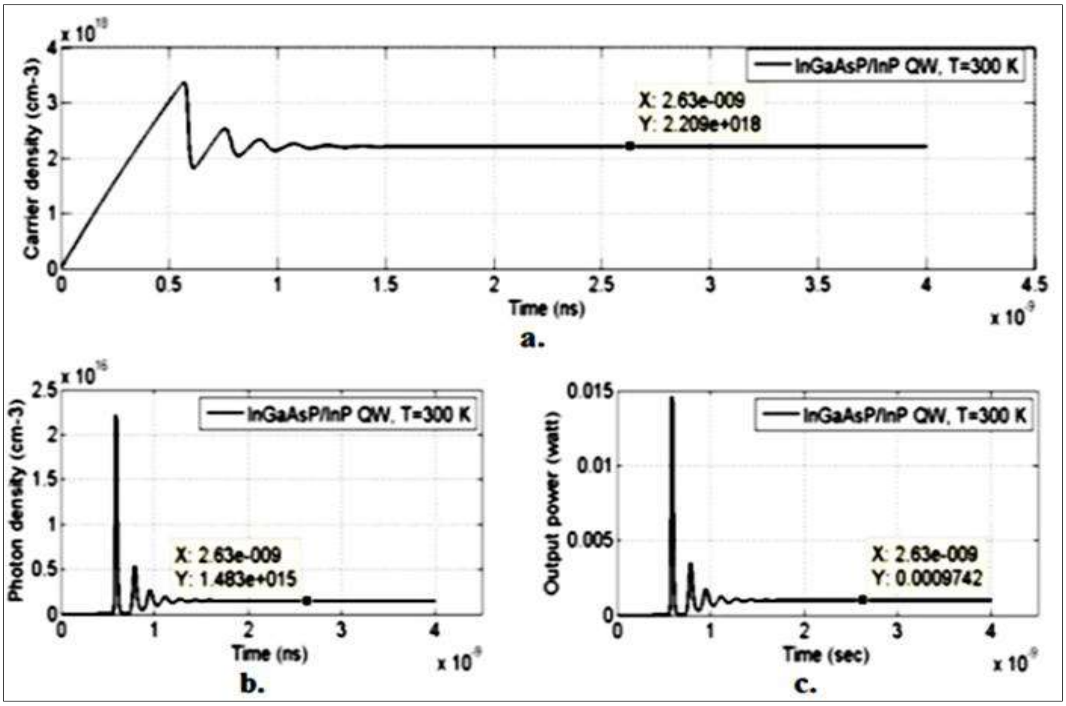

Fig 2: Plots of (a) Carrier Density vs. Time, (b) Photon Density vs. Time and (c) Output Power vs. Time of a 1550 nm InGaAsP 195 Å QW VCSEL at 300 K, where the Injection Current is 7.8mA.

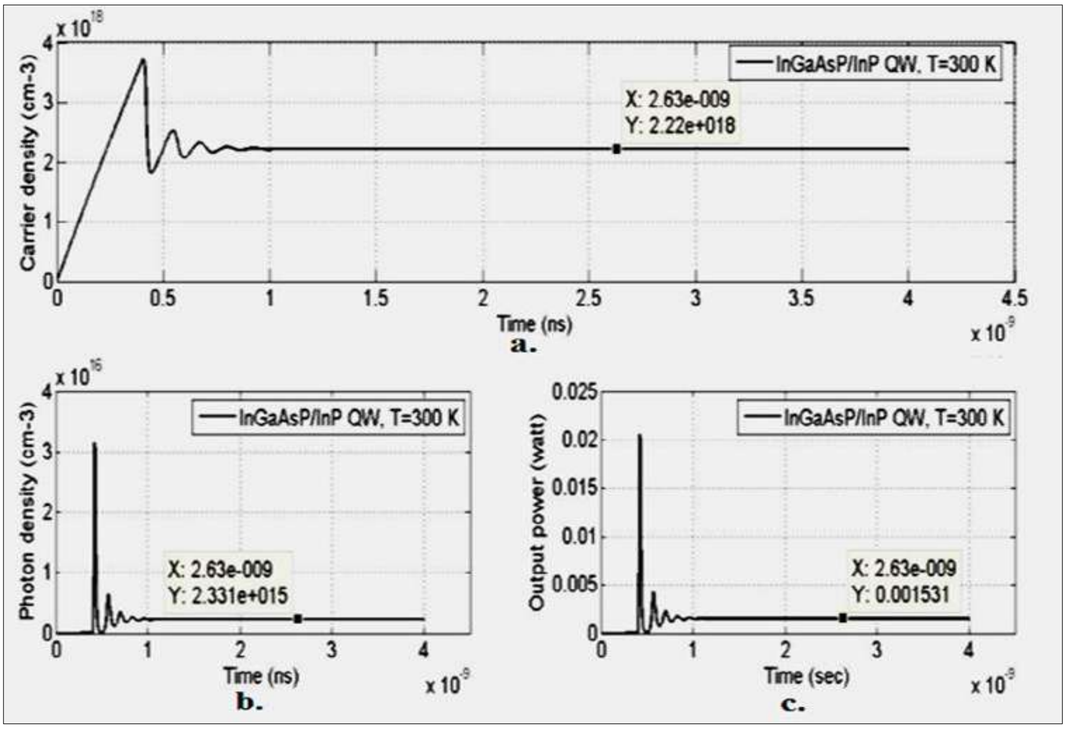

Fig 3: Plots of (a) Carrier Density vs. Time, (b) Photon Density vs. Time and (c) Output Power vs. Time of a 1550 nm InGaAsP 195 Å QW VCSEL at 300 K, where the Injection Current is 11.7mA.

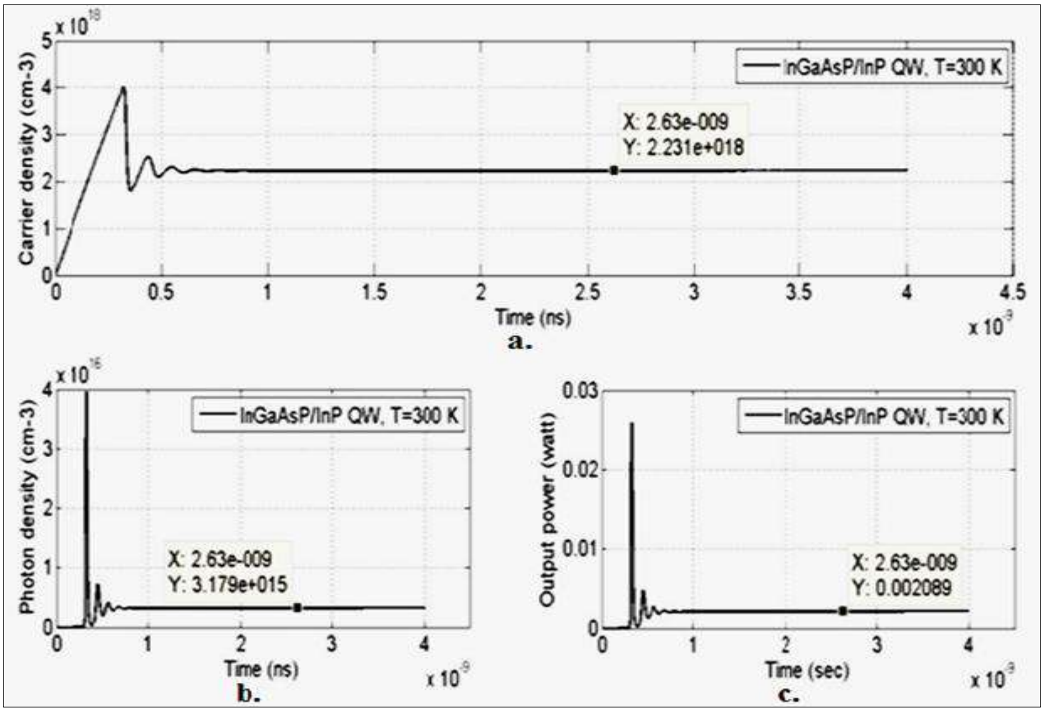

Fig.4: Plots of (a) Carrier Density vs. Time, (b) Photon Density vs. Time and (c) Output Power vs. Time of a 1550 nm InGaAsP 195 Å QW VCSEL at 300 K, where the Injection Current is 15.6mA.

It is found that with the increase of injection current, the steady state carrier density, photon density and output power of the laser increases. The values are obtained and listed in the Table 1 for $I = 10I_{th}$, $I = 15I_{th}$ and $I = 20I_{th}$.

Table 1: Carrier Density, Photon Density and OutputPower by Varying Injection Current.

Injection current, I (mA)	**Carrier density, N (cm^{-3})**	**Photon density, S (cm^{-3})**	**Output power, P_{out}(mw)**
I=10I_{th}=7.8	2.209×10^{18}	1.483×10^{15}	0.9742
I=15I_{th}=11.7	2.22×10^{18}	2.331×10^{15}	1.531
I=20I_{th}=15.6	2.231×10^{18}	3.179×10^{15}	2.089

By varying injection current upto 15.6 mA a maximum output power of the laser is obtained as 2.089 mw.
For analyzing the performance of the laser the material gain is calculated as [9, 10].

$$g(E) = \left(\frac{q^2 \pi \hbar}{\varepsilon_0 m_0^2 ncE}\right) |M_T|^2 \rho_r (f_2 - f_1) \quad (7)$$

where, q is the electron charge, ε_0 is the free-space permittivity, c is the vacuum speed of light, n is the refractive index of laser structure, E is the transition energy, m_0 is the mass of electron, $|M_T|^2$ is the transition momentum matrix element, ρ_r is the reduced density state, $\hbar$ is the plank's constant divided by 2π, f_2 and f_1 are the electron quasi-Fermi functions in the conduction band and valance band, respectively.
The material gain g is referred to as the threshold material gain at the threshold condition and it corresponds to the situation where, the gain equals the losses. The output power from the mirrors of a laser is related to the material gain as [9, 10].

$$P_{out} = \frac{\alpha_m h \nu \eta_i}{qg\Gamma} (I - I_{th}) \quad (8)$$

where, h is the Planck's constant, ν is the lasing frequency.

Using Eq. (8), for 7.8mA (10I_{th}) injection current, the output power is calculated by varying wavelength and the results are plotted as shown in the Figure 5. The peak intensity of output power is obtained at 1505 nm wavelength.It is possible to reach the wavelength close to 1550 nm by adjusting the material concentration with considering thermal effect.

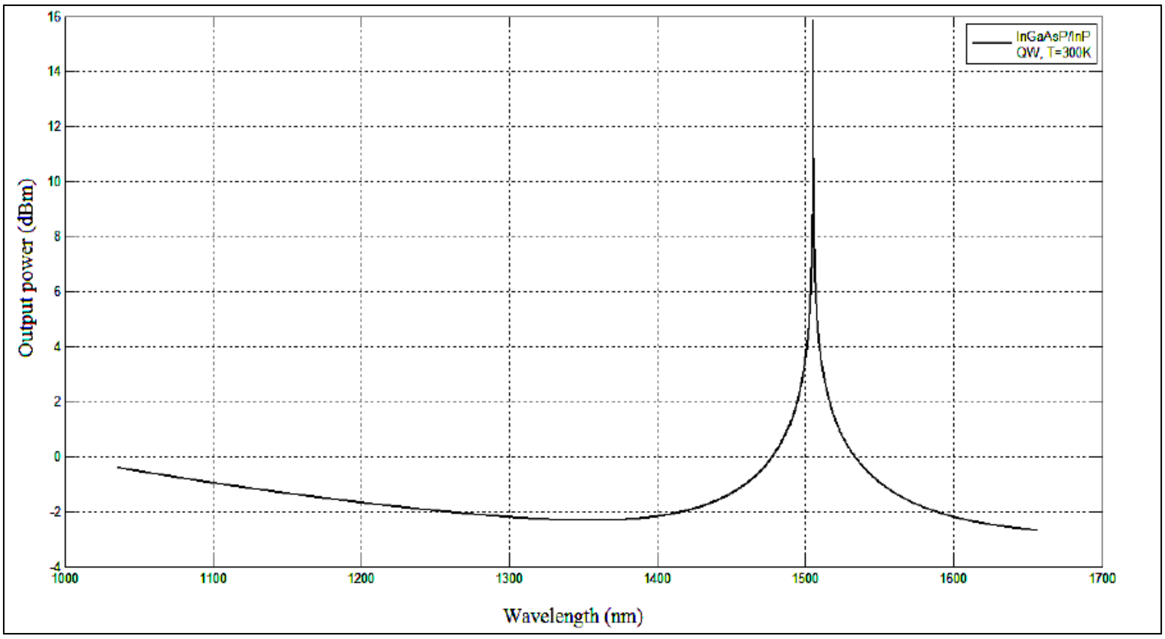

Fig 5: Plot of Output Power vs. Wavelength of a 1550 nm InGaAsP 195 Å QW VCSEL at 300 K, Where the Injection Current is 7.8 mA and the Peak Intensity of the Output Power is gained at 1505 nm Wavelength.

Modulation response of a laser depends on its resonance frequency and damping parameter. The modulation transfer function H(f) is written as [9, 10].

$$H(f) = \frac{f_R^2}{f_R^2 - f^2 + j\frac{f}{2\pi}\gamma} \tag{9}$$

where, f_R is the resonance frequency and γ is the damping parameter.

By varying injection current the obtained results of relative response vs. frequency of a 1550 nm InGaAsP/InP laser are plotted as shown in Figure 6. It is found that the resonance frequency and modulation bandwidth of the laser increases with the increase of injection current. The values are obtained and listed in the Table 2 for $I = 10I_{th}$, $I = 15I_{th}$ and $I = 20I_{th}$.

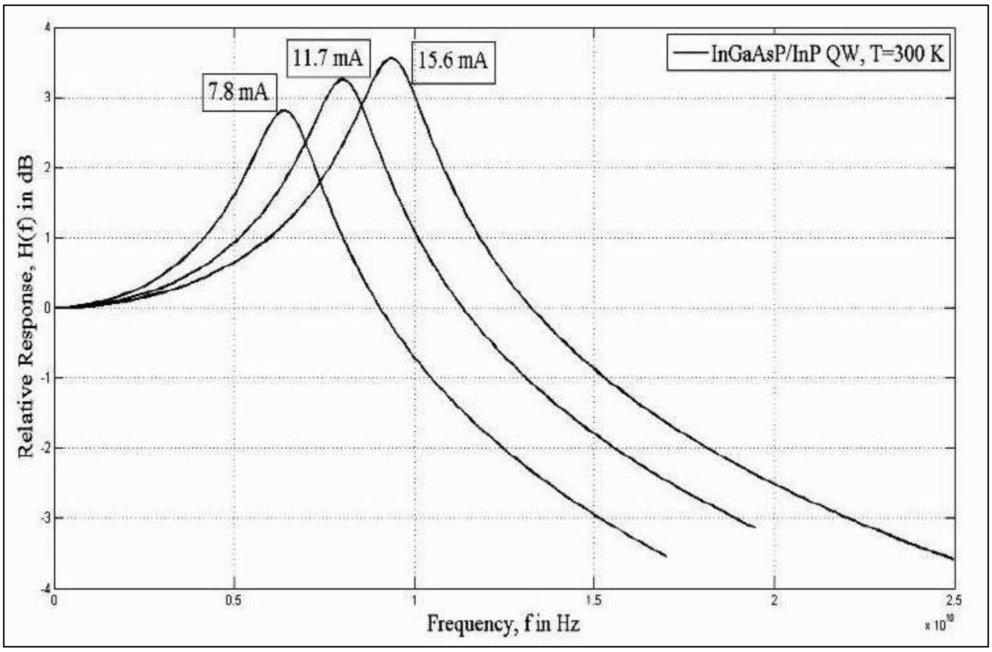

Fig 6: Plots of Relative Response vs. Frequency of a 1550 nm InGaAsP/InP MQW VCSEL for different Values of Injection Current at 300 K

By varying injection current up to 15.6mA a maximum resonance frequency of 9.43 GHz and the maximum modulation bandwidth of 22.2 GHz of the VCSEL are obtained. The high modulation bandwidth obtained in this work, makes the VCSEL suitable for transmitting data at high speed through optical fiber.

Table 2: Resonance Frequency and -3 dB cut off Frequency (i.e. Modulation Bandwidth) by Varying Injection Current.

Injection current, I (mA)	Resonance frequency, f_R (GHz)	-3dB cut off frequency,f-3dB GHz
7.8	6.5	15.2
11.7	8.10	18.9
15.6	9.43	22.2

Conclusion

For high-speed data transmission through optical fiber the characteristics of a 1550 nm InGaAsP/InP MQW semiconductor laser has been presented in this work, At 300 K, the threshold current is obtained as 0.78 mA. The effects of variations of injection current on the performance characteristics of the laser are obtained with the aim of obtaining high speed performance for transmitting data through optical fiber. For 15.6 mA (20I_{th}) injection current a maximum output power of 2.089 mW, a maximum resonance frequency of 9.43 GHz and a maximum modulation bandwidth of 22.2 GHz are obtained which makes the laser as high speed data transmitter.

References

1. Djafar Mynbaev K, Lowell Scheiner L. Fiber-Optic Communications Technology, Published by Addison Wesley Longman (Singapore) Pte. Ltd, India First Indian reprint, 2001, 1-7.
2. Iga K. Vertical-Cavity Surface-Emitting Laser: Its Conception and Evolution. Japanese Journal of Applied Physics, 2008;47(1):1-10.
3. John Senior M. Optical Fiber Communications, Prentice-Hall of India Private Limited: 2nd Ed., India, 2001, 294-350.
4. Gerd Keiser. Optical Fiber Communications, Published by Tata McGraw Hill Education Private Limited: 3rd Ed., India, 2000, 113-152.
5. Govind Agrawal P. Fiber-Optic Communication System, John Wiley & sons:3rd Ed., New York, 2002, 105-106.
6. Ajoy Ghatak, Thyagarajan K. Introduction to Fiber Optics, Cambridge University Press India Pvt. Ltd: India, 1999; 209-235.
7. Adams MJ, Steventon AG, Devlin WJ, *et al.* Semiconductor Laser for Long-wavelength Optical-fibre Communication Systems, 1st Ed., London, United Kingdom, 1987, 62-69.
8. Pallab Bhattacharya, Semiconductor optoelectronic Devices, Prentice-Hall of India Private Limited: 2nd Ed. M-97, Connaught circus, New Delhi-110001, 1997, 2.
9. Coldren LA, Corzine SW. Diode Lasers and Photonic Integrated Circuits, John Wiley and Sons: New York, 1995, 1-261.
10. Rinku Basak, Saiful Islam. Performance Analysis of a 980 nm $In_{0.2}Ga_{0.8}As/GaAs$ MQW VCSEL Considering Thermal Effect, The AIUB Journal of Science and Engineering (AJSE). 2011;10(1):9-14.