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Study of Gain Switching in Vertical Cavity Surface Emitting Laser under Different Electrical Pulse Inputs

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ABSTRACT

Vertical cavity surface emitting laser (VCSEL) is a strong candidate for short pulse generation among the other semiconductor lasers in the era of laser technology. A 1550 nm, low power VCSEL is excited under different current shapes and the chief laser parameters are found out. The concept of gain switching under various current profiles are utilised effectively to bring out maximum laser power with minimum pulse width, which are the essential factors for long haul high speed optical data transmission. For a haversine electrical current input with 3.7 I_{th} amplitude, a laser peak power of 2.2 mW at 57 ps pulse width is obtained. In the case of trapezoidal pulse, 67 ps pulse width is obtained for 2.6 I_{th} current amplitude. It is also observed that square pulse of amplitude 2 I_{th} produces short optical pulse of 0.887 mW peak power and 89 ps width which shows the best performance when compared to other forms of pulses discussed in this work at the same input condition.

Keywords: Vertical cavity surface emitting laser; VCSEL; Gain switching; Laser peak power; Full width at half maximum; FWHM; Current amplitude

1. INTRODUCTION

Vertical cavity surface emitting lasers (VCSELs) are cost effective laser sources which find applications in high speed optical communications. Many researches have contributed towards the fast growing path of VCSEL mass production. Dlamini[1], *et al.* demonstrated routing and spectral assignment in VCSEL based optical networks. In this work, the proposed technique reduced the number of transceivers, switches and optical transmission links in the network, thereby increasing the number of satisfied bandwidth requests. Their technique also optimised an optical fibre transport network that can be used in high capacity cloud based applications. Sezgin[2], *et al.* tested oxide based VCSEL with different aperture sizes on ultra-high speed sigma-delta modulation over fiber communication links. They also pointed out that larger the size of the aperture higher will be the bias current needed thereby reducing the energy efficiency. They concluded their findings by making a statement that for carrier frequency beyond 10 GHz, communication links can be realised with ultra-high speed Sigma modulation Delta over Fibers. With this sort of motivation in this field, our research work[3] also focused on long wavelength VCSELs. Our work was based on transmitting data at different gigabit rates from 1550 nm VCSEL over a hybrid architecture comprising of Single mode fiber and free space optic links. The FSO link performances were obtained under various atmospheric conditions.

VCSEL can also be operated under gain switched conditions. This technique is meant for generating short optical pulses excited either electrically or optically, when the device is biased below threshold. RF- gain switching was used for pulse generation in 1550 nm VCSEL and pulse parameters were characterised[4]. Gain switching femtosecond laser equipped with Yb-doped fiber linear amplifier was designed with very strong pumping to generate ultrashort highly controllable optical pulses[5]. Optical Frequency Combs were generated by injecting external light into a gain switched VCSEL. These frequency combs are characterised by free spectral range, high optical carrier to noise ratio, low phase noise and low relative intensity noise as portrayed[6]. To produce very narrow optical pulses with good extinction ratio, step rectangular electrical signals are used for modulation finds applications in optical time domain reflectometry as presented[7]. Also it was evident that by increasing RF power and bias current until self-heating sets in laser diode, very narrow optical pulses were generated. For simultaneous transmission of Gigabit digital data as well as for remote millimeter wave generation, gain switched VCSEL was analysed[8]. Moreover, gigabit transmission and millimeter wave generation are two important techniques for modern wired and wireless communication. When both are implemented in a single transmission link, it draws attention to the field for investigators to develop cost effective schemes. Only a single mode fiber and simple gain switching technique are utilised in our approach to build these hybrid applications.

The efficient gain switching in quantum cascade lasers (QCLs) was investigated under different electrical pulses[9].

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Both Golden Section search and parabolic interpolation techniques are used to obtain an optimum FWHM and maximum peak power in QCL characteristics. The work showed when using tangential hyperbolic inputs, laser emits an optical pulse of recorded FWHM and peak power with QCL.

Ashok & Ganesh Madhan[10] made use of particle swarm optimisation to obtain the reduced pulse width with high peak power. The work highlights among various electrical pulses like square, haversine and tangential hyperbolic, the tangential hyperbolic shape yields the expected output from gain switching technique applied in dual wavelength QCLs.

Free space optics (FSO) is an emerging technology which employs direct line of sight optical link as the basis for communication. Hence, VCSEL based FSO links offer a cost efficient solution for point to point wireless data transfer. In this work, various electrical excitation waveforms for VCSEL at different amplitudes are investigated for gain switched optical pulses generation. The analysis helps to find out, the optimum source of excitation for given current amplitude to obtain maximum peak power and minimum pulse width at half maximum (FWHM).

2. RATE EQUATIONS OF VCSEL

The VCSEL taken for our study is 1550 nm single transverse mode Raycan fiber pigtailed laser. The VCSEL structure comprises of top and bottom DBR mirrors based InAlAs/InAlGaAs material that are alternatively used, an air gap aperture, a tunnel junction and the main part which is the active region (quantum well) made of seven pairs of strain compensated 7 nm thick InAlGaAs compound. Using metal organic chemical vapor deposition (MOCVD) technique, the VCSEL structure is monolithically grown on InP substrate. To dissipate heat and to reduce device's resistance, the quantum well is sandwiched between two n-InP plates. The laser intrinsic parameters are given[11]. The longer emission wavelength (1550 nm) for laser was selected in order to propagate optical pulses in optical fiber or free space with minimum attenuation. Due to the cylindrical symmetry of VCSEL structure, the emitted light has polarisation anisotropy to a lesser extent only. But due to various effects, linear polarisation takes place in the emission of laser light. The factors bringing out this polarisation in transverse[11] plane carriers spin relaxation processes, line-width enhancement factor and birefringence. To extract the polarisation parameters from VCSEL, Spin Flip Model is utilised. To obtain rate equations for a linearly polarised single-mode VCSEL, SFM model equations are simplified with standard two level laser rate equations by assuming linear polarisation in y direction alone. Mathematically simplified, laser rate equations Eqns. (1)-(5) without taking polarisation properties into account considered in this work are,

$$\frac{\partial N}{\partial t} = \gamma\mu(N_{th} - N_t) - \gamma(N - N_t) - G_N(N - N_t)S \tag{1}$$

$$\frac{\partial S}{\partial t} = \frac{\beta_{SF} N \gamma^2}{2\kappa} + 2\kappa S\left(\frac{(N - N_t)}{(N_{th} - N_t)} - 1\right) \tag{2}$$

$$P = \frac{eS}{\tau_p F} \tag{3}$$

Here, $$\mu = \frac{\tau_n}{\tau_e}\left(\frac{\left(\frac{I}{I_{th}} - 1\right)}{1 - \frac{I}{I_{th}}}\right) + 1 \tag{4}$$

and $$\kappa = \frac{1}{2\tau_p} \tag{5}$$

N refers to carrier number; *S* denotes photon number; *P* represents optical power and *I* denotes injection current. These coupled laser rate equations are numerically solved using fourth order Range Kutta method in MATLAB.

3. SIMULATION RESULTS AND ANALYSIS

The simulation is carried out using haversine, trapezoidal and square pulse excitation signals at 1.25 GHz frequency for a 1550 nm VCSEL. The current amplitude is fixed in terms of device's threshold current (I_{th} = 1.602 mA). VCSEL is biased below threshold for initiating gain switching operation. The pulse characteristics are based on the value of FWHM measured lesser than 400 ps and maximum peak power. Figure 1 reveals three types of excitation signals with current amplitude of 2.6 I_{th}, used in this simulation. The VCSEL exhibits gain switching and produce short

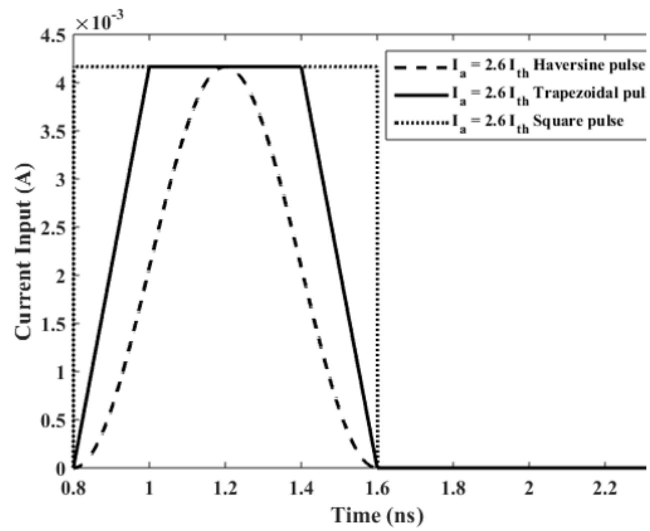

Figure 1. Current input *vs* time.

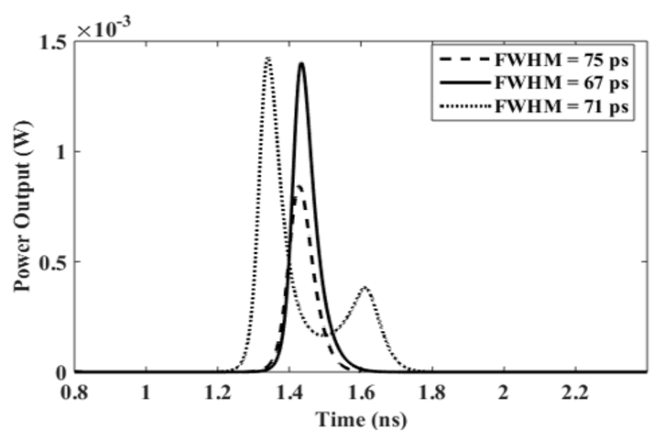

Figure 2. Power output *vs* time.

pulses in pico second range for the different excitation waveforms, as shown in Fig. 2. For square excitation, the onset of second spike arises for the specified current amplitude. Hence, for single short pulse generation with the chosen excitation type, I_a should be less than 2.6 I_{th}.

Laser Peak power and FWHM are calculated for the given simulation conditions and plotted in the Figs. 3 and 4. From the simulation results, to avoid large optical pulse width and onset of secondary peak, the optimum I_a in terms of I_{th} is chosen for each excitation type and results are computed accordingly. As I_a increases, peak power increases but FWHM decreases, for the given frequency of current signal (namely 1.25 GHz).

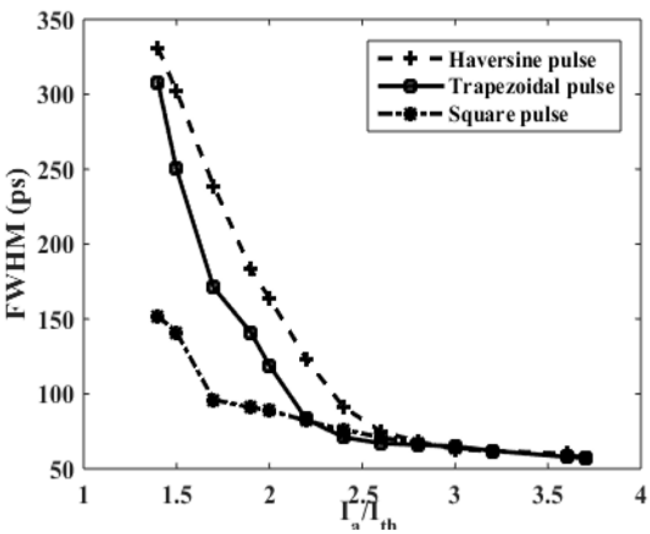

Figure 3. FWHM *vs* normalised current.

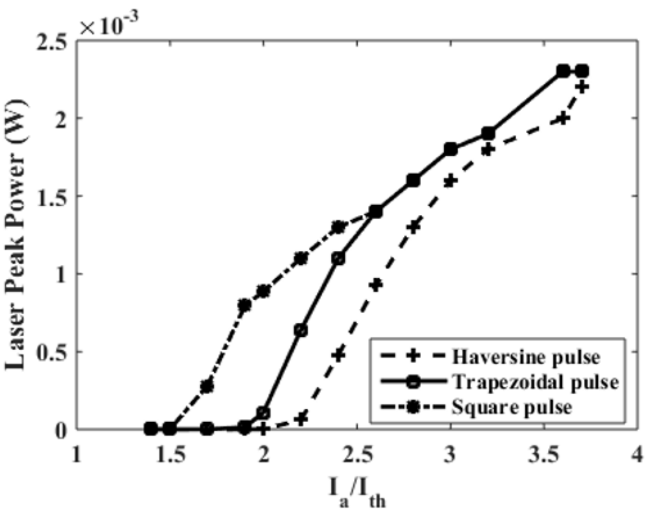

Figure 4. Peak power *vs* normalised current.

4. CONCLUSIONS

For different excitation waveforms used in the simulation, the current amplitude is varied from I_a = 1.4 to 3.7 I_{th}. The control parameter for the simulation is FWHM. Based on the pulse width of the optical pulse, the initial and final I_a values are fixed. The condition is set with output pulse width less than half of the input pulse width and no secondary peak is allowed. Following these criteria, under haversine excitation at 3.7 I_{th}, optical pulse with peak power of 2.3 mW and 57 ps pulse width is generated. In the case of trapezoidal excitation, 2.6 I_{th} amplitude provides peak power of 1.4 mW and 67 ps pulse width. Similarly, for square pulse excitation, a maximum peak power of 0.89 mW at minimum FWHM of 89 ps are obtained.

REFERENCES

1. Dlamini, P.P.; Isoe, G.M.; KiboiBoiyo, D.; Leitch, A.W.R. & Gibbon, T.B. All-optical VCSEL-to-VCSEL injection based on cross gain modulation for routing in multinode flexible spectrum optimization in optical fibre transmission links. *Int. J. Optics,* 2019, 2987652, 1-11. doi: 10.1155/2019/2987652
2. Sezgin, I.C.; Gustavsson, J.; Lengyel, T.; Eriksson, T.; He, Z.S. & Fager, C. Effect of VCSEL characteristics on ultra-high speed sigma-delta-over-fiber communication links. *J. Lightwave Technol.,* 2019, **37**(9), 2109-2119. doi: 10.1109/JLT.2019.2898270
3. Murali Krishna, K. & Ganesh Madhan, M. Vertical cavity surface emitting laser based hybrid fiber-free space optic link for passive optical network applications. *Optik*, 2018, **171**, 253-265. doi: 10.1016/j.ijleo.2018.06.079
4. Consoli, A.; Esquivias, I; Lopez Hernandez, F.J.; Mulet, J. & Balle, S. Characterization of Gain-Switched Pulses from 1.55-µm VCSEL. *IEEE Photonics Technol. Lett.,* 2010, **22**(11), 772-774. doi: 10.1109/LPT.2010.2045648
5. Ito, T.; Nakamae, H.; Hazama, Y; Nakamura, T; Chen, S; Yoshita, M; Kim, C; Kobayashi, Y; Akiyama, H. Femtosecond pulse generation beyond photon lifetime limit in gain-switched semiconductor lasers. *Commun. Phys.,* 2018, **1**(42),1-8. doi: 10.1038/s42005-018-0045-0
6. Hammad, M.N.; Martin, E.P.; Lakshmijayasimha, P.D, Anandarajah, A.K; Landais, P. & Anandarajah, P.M. Optimum optical frequency comb generation via externally injection of a gain switched VCSEL. *In* 01 July 2019 Conference on Lasers and Electro-Optics (CLEO), *IEEE*, 2019, 18863977, 1-3. doi: 10.1364/CLEO_SI.2019.SM4N.6
7. Li, B.; Sun, C; Ling, Y; Zhou, H. & Qiu, K. Step-Pulse Modulation of Gain-Switched Semiconductor Pulsed Laser. *Appl. Sci,* 2019, **9**(3), 1-8. doi: 10.3390/app9030602
8. Murali Krishna, K. & Ganesh Madhan, M. Performance evaluation of remote millimeter wave generation in a digital optical link incorporating a gain switched vertical cavity surface emitting laser. *J. Optoelectronics Adv. Mate.,* 2019*,* **21**(1-2), 54-63. https://joam.inoe.ro/articles/performance-evaluation-of-remote-millimeter-wave-generation-in-a-digital-optical-link-incorporating-a-gain-switched-vertical-cavity-surface-emitting-laser/fulltext (Accessed on 25 March 2019)
9. Ashok, P. & Ganesh Madhan, M. Optimum electrical pulse characteristics for efficient gain switching in QCL. *Optik,* 2017, **146**, 51-62. doi: 10.1016/j.ijleo.2017.08.071

10. Ashok, P. & Ganesh Madhan, M. Particle Swarm Optimization approach to identify optimum electrical pulse characteristics for efficient Gain Switching in Dual Wavelength Quantum Cascade Lasers. *Optik,* 2018, **171**, 786-797.
doi: 10.1016/j.ijleo.2018.06.137
11. Perez, P.; Valle, A.; Noriega, I. & Pesquera, L. Characterization of the working parameters of a long-wavelength VCSEL. *In* Proc SPIE, Semiconductor Lasers and Laser Dynamics VI*,* 2014, **9134,** 91341Q1-12.
doi: 10.1117/12.2051538

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In the current work, he has carried out the detailed study on VCSEL model with different input current pulses, performed the simulation work and prepared the manuscript.

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In the current study, he has given the idea, reviewed the work, validated the results, continuously provided the guidance and given many valuable inputs.

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