# Dynamical and Thermal Properties of 850 nm Vertical Cavity Surface Emitting Laser (VCSEL)

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## Abstract

*Vertical cavity surface emitting laser diodes (VCVSELs) are widely used in different areas especially in telecommunications because of their unique properties compared to other types of lasers. In the present work, we explain the dynamical and thermal properties of 850 nm VCSELs. Specifically, we determine the threshold current, output power for a continuous wave operation and pulsed operation for different pulse durations, the wavelength as a function of (injected current/ dissipated power/ temperature).*

***Keywords:*** *VCSEL, CW operation, pulsed operation*

## Introduction

In vertical cavity surface emitting, laser (VCSEL) light propagates in a direction that is parallel to the growth direction. Single-longitudinal mode of light can be emitted in a VCSEL. The active layer of a VCSEL is composed of a quantum well (QW) or a quantum dot (QD) structures (Takahiro, 2004). Typically, the active region is composed of several QWs with a thickness of only a few nanometers (nms). The most common emission length lies in the range 750-980 nm spectral length. VCSELs are usually electrically pumped, either in a continuous wave (CW) operation or in a pulsed operation.

Compared to edge emitting laser (EEL) or other conventional semiconductor lasers (SCLs), VCSELs possess a lot of favorable properties, namely, they are cheaper and easier to test on wafer. Also, they have a lower threshold current and a high modulation bandwidth. For low-power VCSELs, the beam profile is symmetric with high quality and low divergence (Iga, 2000) (Larsson, 2011). Because of these properties, VCSELs are widely used in different applications, especially in optical fiber communication systems, optical information processing and high-speed parallel network applications (A Haglund, J S Gustavsson, J Vukusic, P Modh, A Larson, 2004) (WEI Si-Min, XU Chen, DENG Jun, ZHU Yen-Xu, MAO Ming-Ming, XIE Yi-Yang, XU Kun, CAO Tian, LIU Jiu-Cheng, 2012) (Osinski, 1995).

Single-mode -850 nm VCSELS are extensively studied because of their unique properties and their wide range of applications. They have smaller size, lower threshold current, lower consumption power superior output power and tighter focused beam compared to other VCSELs and SCLs (Szweda, 2006).

In this article, we present the dynamical and thermal properties for 850nm VCSEL. Specifically, we obtain the output power as a function of injected current in both CW and pulsed operations. Also, we obtain the wavelength as a function of temperature, injected current, pulse amplitude and pulse duration in pulsed operation. It is of vital importance to study the dynamical and thermal properties of the VCSEL to avoid any noise or disturbance of the laser during operation. Thus, we need to know the regime in which the laser operates with the best functionality when we use it in different applications. The VCSEL that we used in our experiments was manufactured at Thorlabs (Thorlabs, n.d.).

## Dynamical Properties

In this section, we present the power as a function of injected current in the lasing regime in both CW and pulsed operations. The temperature is maintained at 25° during the experiments. Measurements are done for pulsed operation (for different pulse durations) at low duty cycle of 1%. From figure 1. We notice that the threshold current ($I_{th}$) is 1 mA in CW operation. In addition, there is a strong linear increase in power. At a certain stage, thermal rollover occurs due to the heating of the device, resulting in the saturation and eventual decrease in power. The maximum power of 4.34 mW is reached at 22.5 mA-injected current (I).

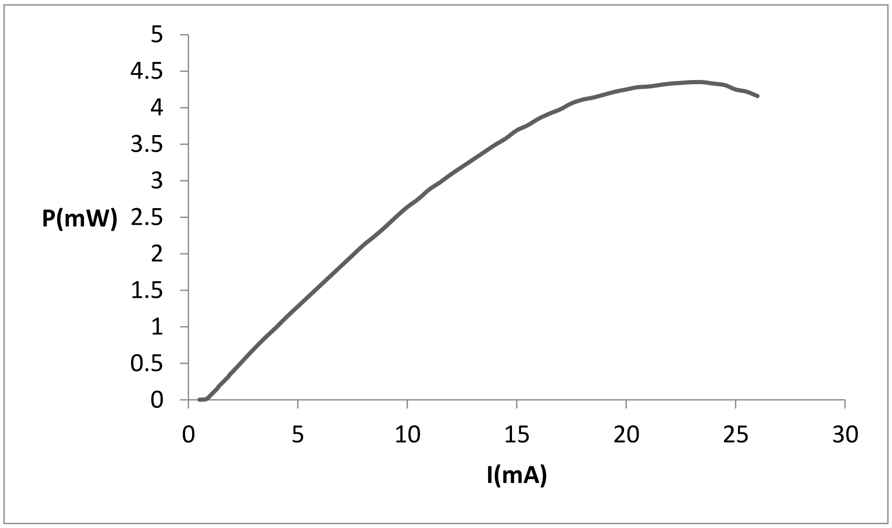

**Figure 1. Optical power as a function of injection current for CW operation.**

Figure 2 shows the voltage as a function of I in pulsed operation. The voltage can be approximated by a linear function of the injection current as in the following equation:

$$V_{VCSEL} = V_{th} + aI = 1.6175 + 36.2I, \qquad (1)$$

Where a is the VCSELs differential resistance.

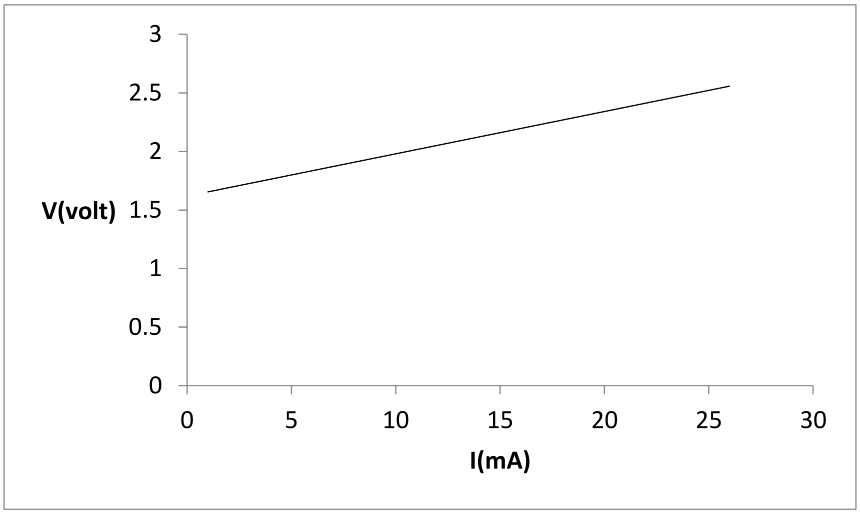

**Figure 2. The potential difference across the VCSEL as a function of the injection current.**

**$V_{th}$ = 1.6175 volt, R= 36.2 Ω (slope of VI graph).**

Figure 3 shows the output power as a function of voltage in pulsed operation for different pulse durations ranging from 0.1 µs to 10 µs.

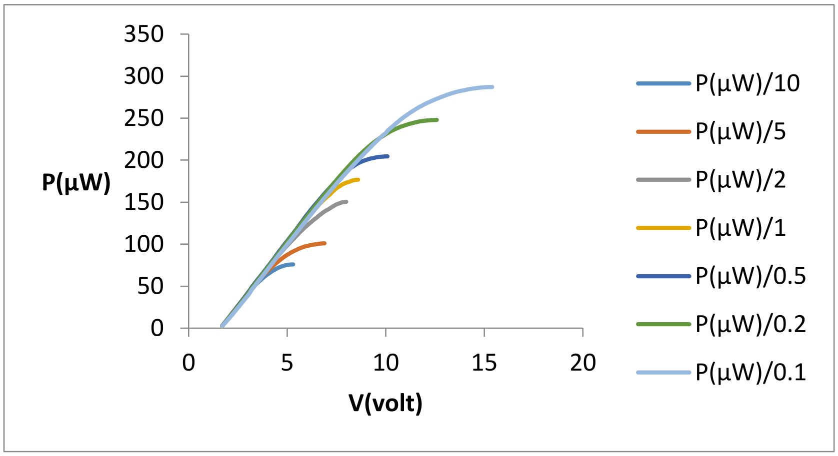

**Figure 3. Optical power as a function of potential across the VCSEL' S for pulsed operation.**

To compare the output power in pulsed operation with that in CW operation, we need to convert the voltage into injected current. Given that the resistance of the deriver is 50 Ω, the set voltage ($V_{set}$) is related to $V_{VCSEL}$ by the following equation:

$$V_{set} = V_{VCSEL} + 50I. \quad \text{in units of volt} \qquad (2)$$

Equations (1) and (2) implies that:

$$I = \left(V_{set} - 1.607\right)/80.32. \quad \text{in units of A} \qquad (3)$$

By using equation (3) and taking into account the duty cycle (peak power during the pulse = 100 x measured power) ,we convert the voltage into current and we obtain a graph for the output power versus injected current in pulsed operation (figure 4).

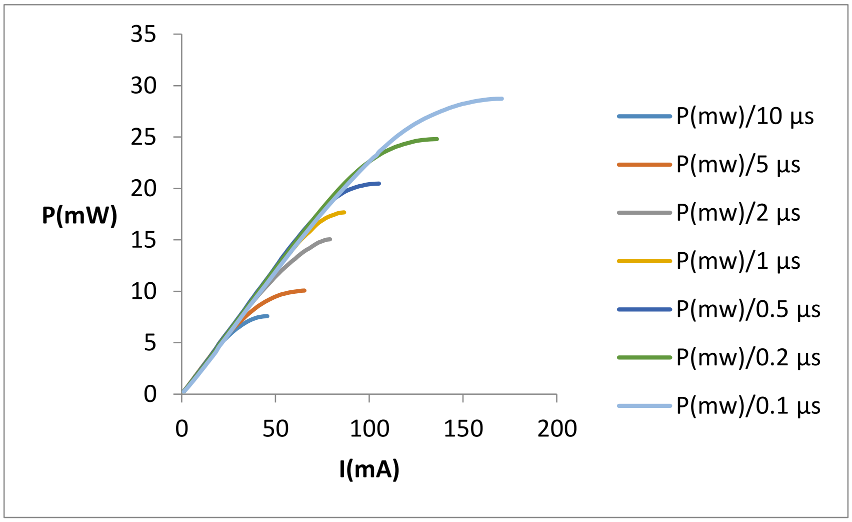

**Figure 4: Optical power as a function of injected current for pulsed operation.**

Figures (1) and (4) show the output power in both CW operation and in pulsed operation for different pulse durations ranging from 0.1 µs to 10 µs, we notice that the output power in pulsed operation is much larger than that in CW operation. For example, at 0.1 µs pulses the peak output power is 28.72 mW which is nearly 7 times the output power of CW operation. This is because the thermal roll-over point occurs at higher current amplitude for a decreasing pulse duration.

## Thermal properties

A spectral analysis is performed by coupling the laser light into an optical fiber to study the influence of the injected current, temperature, and pulse duration on the VCSEL' S lasing wave length. Figure 5 shows the wavelength as a function of I in the CW operation. It is clear that the function is parabolic and we address that to the parabolic relation between the dissipated power and the injected current and the linear dependence of the wave length on the dissipated power (figure 6).

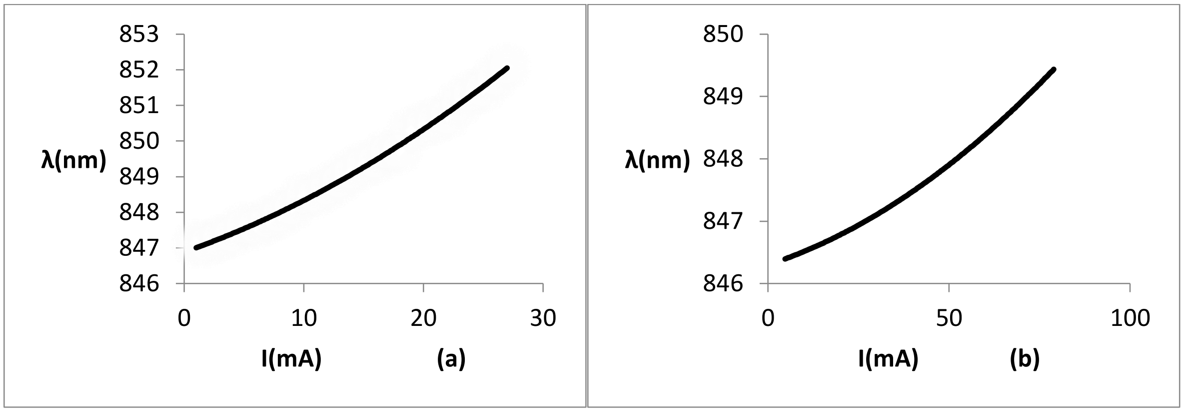

**Figure 5. Wavelength as a function of injected current. (a) CW operation (b) 0.1 us pulsed operation.**

The resulting parabolic graph can be explained as follows:

Δλ (wavelength shift) is proportional to $P_{diss}$ (dissipated power).

$$P_{diss} = V_{VCSEL} I - P_{out} = 1.6175 I + 0.05 I^2 - P_{out}, \text{ in units of mW} \tag{4}$$

where $P_{out}$ is the output laser power. $P_{out}$ is linearly dependent on the current for small injected current (as shown in figure (1), slope of the linear part = ΔP/ΔI= 0.256 w/A).

$$P_{out} = c(I - I_{th}), \tag{5}$$

where c is constant. By substituting equation (5) in equation (4)

$$P_{diss} = (1.6175 - c) I + 0.05 I^2 + c, \tag{6}$$

where $I_{th}$ = 1 mA.

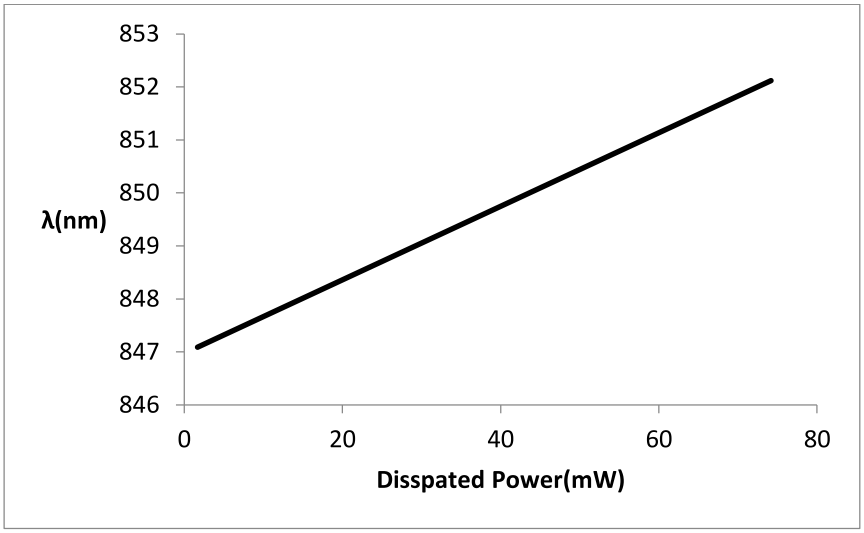

**Figure 6. Wavelength as a function of dissipated power.**

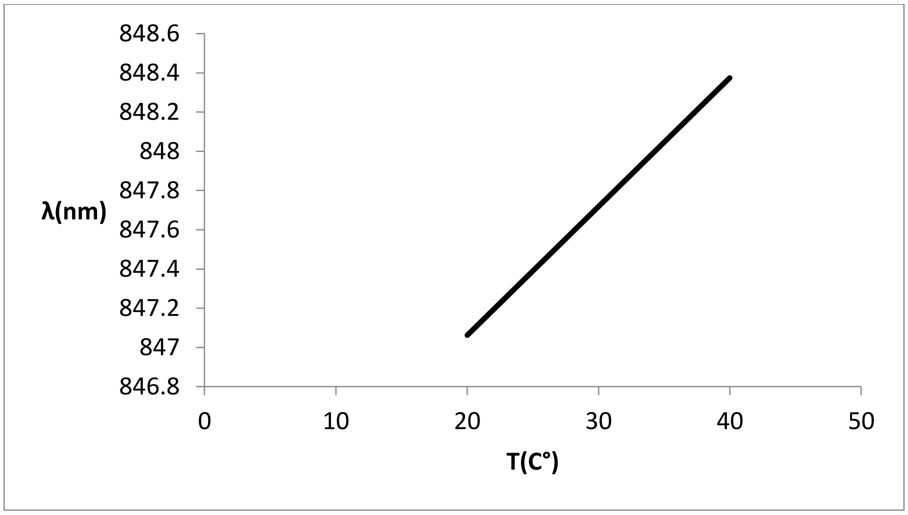

**Figure 7: Wavelength as a function of temperature. I = 5 mA**

Figure 7 shows that the wavelength increases linearly as the temperature increases. The increase of temperature increases the cavity length and as a result the wavelength of the emitted light increases.

## Conclusions

For 850 nm VCSEL, the threshold current at room temperature in CW operation is very small compared to other VCSELs. By reducing the pulse duration, much higher output power could be achieved in pulsed operation compared to CW operation because the thermal roll-over point occurs at higher current.in pulsed operation. In CW operation, the peak power is 4.34 mW while it is 28.72 mW in pulsed operation for 0.1 µs pulse duration. The increase of temperature increases the cavity length and as a result the wavelength of the emitted light increases. Thus, the wavelength increases lineally with temperature. Also, the wavelength increases lineally with dissipated power while the wavelength as a function of injected current is parabolic because the dissipated power is a function of the square of the injected current.

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# الخصائص الديناميكية والحرارية لـ " الليزر ذي الانبعاث السطحي الرأسي التجويفي بطول موجة 850 نانومتر"

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## ملخص

*يستخدم الليزر ذو الإنبعاث السطحي الرأسي التجويفي بشكل واسع، وفي عدة مجالات، وبشكل خاص في مجال الاتصالات؛ لأنه يمتلك خصائص فريدة مقارنة مع الأنواع الأخرى من الليزرات. في هذا البحث نوضح الخصائص الديناميكية والحرارية لـ " الليزر ذي الانبعاث السطحي الرأسي التجويفي بطول موجة 850 نانومتر". على وجه التحديد، سنحدد قيمة تيار العتبة والقدرة الناتجة عن عملية انتاج الليزر بشكل متواصل، أو على شكل نبضات ذات فترات زمنية متعددة. كما سنوضح علاقة طول موجة الليزر الناتج مع كل من التيار والقدرة المبددة ودرجة الحرارة.*

***الكلمات الدالة:*** *الليزر ذو الانبعاث السطحي الرأسي التجويفي، الليزر ذو الانبعاث المستمر، الليزر ذو الانبعاث على شكل ومضات.*