Temperature Dependence of 980 nm VCSEL Dynamics

Rashid Safaisini[1], John R. Joseph[1], Duane Louderback[2], Xiaojun Jin[2], and Kevin L. Lear[1]
[1]Electrical and Computer Engineering Department
Colorado State University, Fort Collins, CO 80523-1373, USA
[2]Opticomp Corporation
215 Elks Point Road, Zephyr Cove, NV 89448, USA

***Abstract*-Resonance frequencies and damping rates extracted from noise spectra measurements on flip-chipped VCSELs indicate temperature dependence is dominated by output power and associated photon density reduction with minimal indications of differential gain decrease.**

I. Introduction

Advances in local area network data rates beyond those for 10 Gigabit Ethernet as well as shorter distance board-to-board and chip-to-chip interconnects demand higher speed vertical cavity surface emitting lasers (VCSELs). Prior work on the fastest 850 nm directly modulated VCSELs indicated significant increases in bandwidth at reduced temperatures [1]. That experimental observation motivates the investigation of temperature dependent laser dynamics presented here.

II. Experiment

Resonant optical frequency and damping rate have been studied as a function of temperature from 10 to 70C and current bias from 2 to 4 mA in a 980 nm, bottom-emitting VCSEL. The lasers were fabricated from molecular beam epitaxy layers grown on an n-type GaAs substrate with three InGaAs quantum wells, a 23 period n-type lower mirror and a 27 period p-type upper mirror. The device reported here had a 7 μm diameter oxide aperture in a 10 μm diameter mesa that was coated with silicon nitride and plated over with 2 μm of copper before being flip-chip bonded by indium solder to a copper on GaAs heatspreader. The laser's 25C threshold current was 1.3 mA, and its slope efficiency was 0.14 W/A. The device operated primarily in the fundamental mode but with a limited side-mode suppression ratio of approximately 5 dB at currents up to 4 mA. Single mode operation was useful for obtaining well defined resonance frequency. The laser's measured thermal resistance was 880 C/W.

The resonant frequency and damping rate as functions of temperature were obtained from noise spectra under DC bias. The use of noise spectra rather than current modulation response reduces non-linear large signal effects, simplifies electrical probing requirements, and eliminates convolution with electrical effects due to parasitic circuit elements and impedance matching. Measured noise spectra at 3 mA for 15, 35, and 60C are shown in Fig. 1 along with curve fits described by the magnitude of the conventional damped oscillator response, $N(\omega)=(a+b\omega^2)/((\omega^2-\omega_r^2)^2+\gamma^2\omega^2)$, where a and b are constants, ω_r and γ are angular resonance frequency and damping factor respectively.

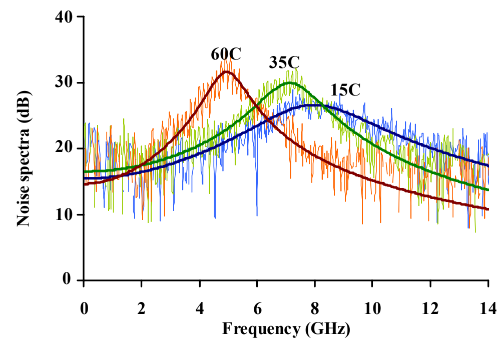

Fig. 1. Noise spectra at different temperatures and a current bias of 3 mA along with curve fits.

III. Analysis

The measurements indicate resonance frequency decreases with increasing temperature due to reduced photon density in the gain region. Fig. 2 summarizes the change in resonance frequency and damping rate with temperature at selected bias currents.

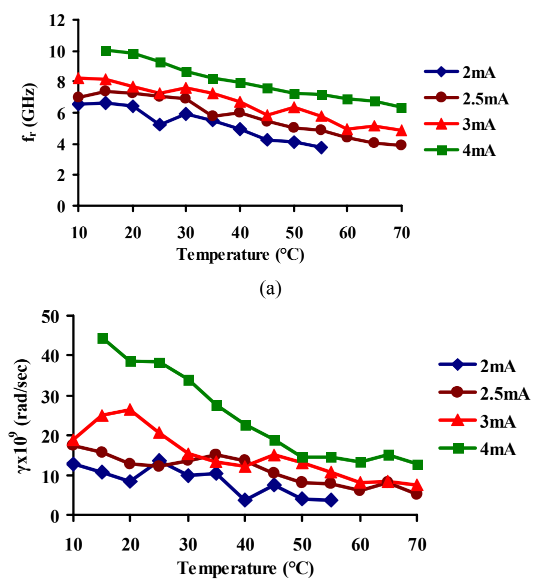

Fig. 2. Change in (a) resonance frequency and (b) damping with temperature for multiple bias currents.

1-4244-0925-X/07/$25.00 ©2007 IEEE

Rate equation theory shows resonance frequency is proportional to the square root of optical power, $f_r = DP^{1/2}$, where D is a proportionality constant only dependent on temperature through the differential gain, dg/dn, and P is the optical output power. D is given by $D=[(dg/dn)(\alpha_{oc}v_g/4\pi^2\tau_{ph}A_m)(\lambda/hc)]^{1/2}$, where α_{oc} is mirror loss, v_g is group velocity, τ_{ph} is photon lifetime, A_m is effective mode area, λ is wavelength, h is Planck's constant, and c is the speed of light. Since P decreases with increasing temperature as shown in Fig. 3 for a range of currents, it is useful to plot the squared resonance frequency normalized by output power, $f_r^2/P=D^2$, in Fig. 4.

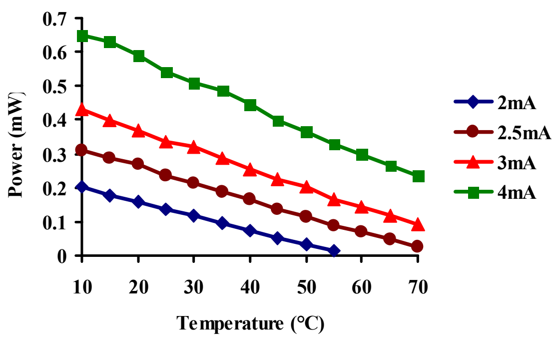

Fig. 3. Optical power as a function of temperature.

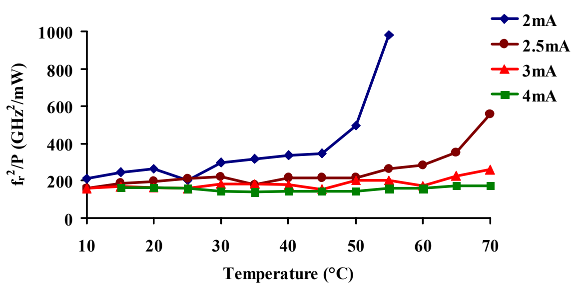

Fig. 4. Squared resonance frequency for different temperatures.

At higher currents, the plots are flat with temperature indicating the D coefficient and thus differential gain is relatively temperature independent across this range. At lower currents, there is a notable *increase* in D at the highest temperatures which is still under investigation. However, this may be related to approaching threshold under these conditions. The appearance of constant D factor vs. temperature may be due to increasing gain offset balancing decreasing dg/dn.

Expressing the damping factor as a function of resonance frequency, $\gamma = \gamma_0 + Kf_r^2$, the γ vs. f_r^2 data plotted in Fig. 5 can be fit to extract K-factors used to estimate maximum intrinsic -3dB frequency. While the data in Fig. 5 contains some scatter, fits indicate that the K-factor for this device is relatively temperature independent.

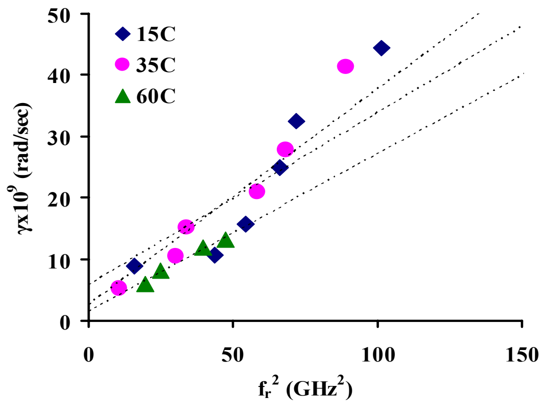

Fig. 5. Damping versus squared resonance frequency.

K-factors are plotted in Fig. 6 for temperatures from 10 to 70C. This plot shows a relatively flat K at different temperatures for the device. However, lasers fabricated from the same wafer using other methods have shown an increase in K at the highest temperatures.

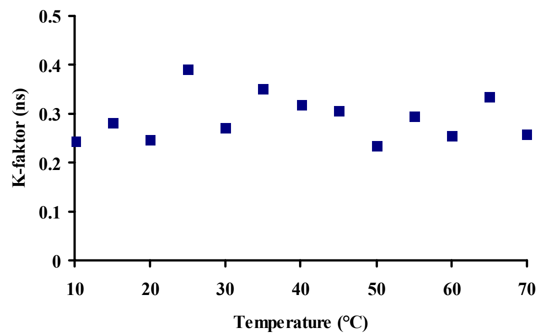

Fig. 6. Changing K with temperature.

IV. Conclusion

Variations in dynamics of 980 nm flip-chip bonded VCSELs over a temperature range of 10 to 70C have been studied. The results show an effectively constant D^2 coefficient at higher currents and relatively flat K-factor with temperature. These findings indicate that power reduction is the dominant temperature dependent effect on VCSEL dynamics.

Acknowledgment

The authers gratefully acknowledge the support of DARPA under contract DAAD19-03-1-0059.

References

[1] K.L. Lear, V.M. Hietala, H.Q. Hou, J. Banas, B.E. Hammons, J. Zolper, S.P. Kilcoyne, "High-speed 850 nm oxide-confined vertical cavity surface emitting lasers," Ultrafast Electronics and Optoelectronics in series OSA Trends in Optics and Photonics, Washington, D.C., 1997.