1060 nm Vernier-Tuned Distributed Bragg Reflector (VT-DBR) Laser for Swept-Source OCT

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Abstract: We report the first wavelength-tunable 1060nm VT-DBR laser for use in SS-OCT applications. Electrical measurements demonstrate 1-3 nanosecond step response times for wavelength tuning. Optical linewidths less than 10 MHz are measured using self-homodyne interferometry.
OCIS codes: (170.4500) Optical Coherence Tomography; (140.3600) Lasers, tunable; (140.5960) Semiconductor lasers.

1. Introduction to the 1060nm VT-DBR laser.

Vernier-Tuned Distributed Bragg Reflector (VT-DBR) lasers have recently been demonstrated at center wavelengths of 1310nm and 1550nm in swept-wavelength applications such as Optical Coherence Tomography (OCT), spectroscopy, and remote sensing. In this paper we present the first electrically-tuned single-chip 1060nm VT-DBR for applications in OCT. The VT-DBR laser has five semiconductor sections in a planar structure using the GaAs material system. The front mirror and back mirror sections enable coarse wavelength selection using the Vernier tuning effect [1]. The phase section allows fine wavelength tuning. The gain section provides optical amplification for the laser. The Semiconductor Optical Amplifier (SOA) section amplifies the output for shaping of the power profile across the tuning range of the laser to a flat, Gaussian, or custom power profile.

2. Optical spectrum at a discrete operating point.

Figure 2 shows a CW VT-DBR spectrum while lasing at 1064.97 nm. CW output power was 3 dBm. In other devices, we have measured fiber-coupled output power of up to 50 mW. The Side Mode Suppression Ratio (SMSR) is 27 dB in Figure 1. SMSR greater than 40 dB is achievable over a wide range of FM, BM and Phase currents. The CW linewidth was measured with a self-homodyne measurement technique [2]. An optical linewidth measurement of 2.4 MHz (-3dB electrical) is shown in Figure 2.

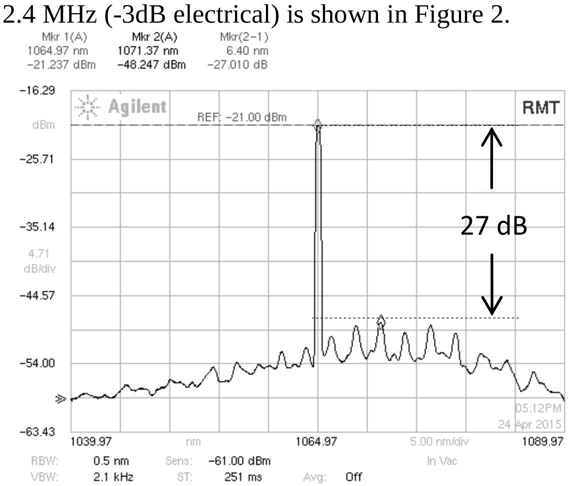

Figure 1 - Optical spectrum of 1060nm VT-DBR laser operating at 1064.97nm with a SMSR of 27 dB.

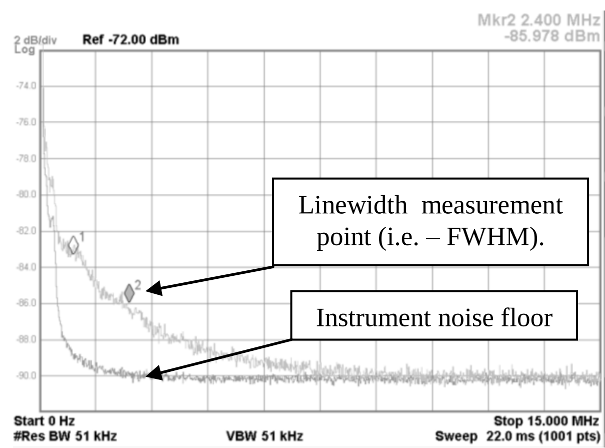

Figure 2 - Linewidth measurement of 1060nm laser using delayed self-homodyne method; a linewidth of 2.4 MHz is observed.

3. Frequency tuning transition speeds of each segment.

Akinetic tuning is a key advantage of the VT-DBR design; because there are no moving parts, customized tuning patterns, very short sweep times, and near-100% frequency-sweep duty-cycles are possible [3]. A consideration for the optical transition time is the electrical response time of each laser section. The dynamic resistance and effective capacitance of each segment are measured versus bias current. Response times are calculated from the resulting RC time-constant, τ_{RC}.

The wavelength step response time of each laser section is measured in both the time and frequency domains using a 9 GHz vector network analyzer [4]. The electrical model of the laser sections was found by matching s-parameter measurements with the circuit model shown in Figure 3. An example time domain reflectometry (TDR) step-response of the back mirror segment is shown in Figure 4. The step response settles to its final value in less than 1 ns. Table 1 shows the bias current, example equivalent circuit elements, and worst-case step response times for all 5 VT-DBR sections.

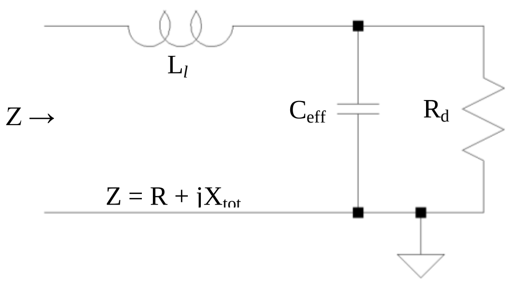

Figure 3 – Simplified circuit model of each laser segment including the lumped series inductance from the laser packaging (e.g. – bond wires), effective capacitance, and dynamic resistance from the PN junction.

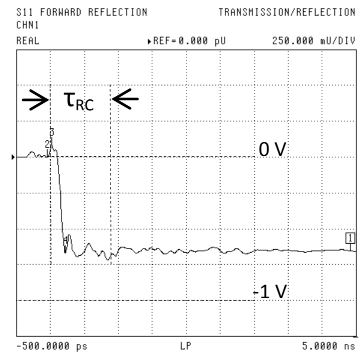

Figure 4 - Fast TDR response of 1060 nm laser's back-mirror biased at 45 mA. Less than 1 ns transition time observed.

4. Equations

The following equations reduce the raw impedance data from the frequency domain reflectometry (FDR) measurements to arrive at bias-dependent transition time estimates. Equation 1 estimates the capacitor's contribution to the total measured reactance, X_{tot}. The lead inductance 'L_l' from the laser's packaging contributes a reactance 'X_L' to the total reactance 'X_{tot}'; X_L is estimated using the largest positive reactance measured. Equation 2 converts the RC impedance to frequency-dependent susceptance.

$$X_C = X_{tot} - X_L \qquad (1)$$

$$B_c = \frac{-X_c}{|Z|^2} = \frac{-X_c}{(R_d^2 + X_c^2)} \qquad (2)$$

Equation 3 calculates the effective capacitance at the diode junction. All FDR data were collected at 10 MHz; therefore, f = 10MHz for the calculations. Equation 4 estimates the tuning response time based on the bias dependent C_{eff} and its charge/discharge resistance (i.e. - the parallel combination of the dynamic resistance and the current source's impedance of 50 ohms).

$$C_{eff} = \frac{B_c}{2\pi f} \qquad (3)$$

$$\tau_{RC} = (R_d \parallel 50)) \cdot C_{eff} \qquad (4)$$

Table 1 - Maximum tuning response times of each diode segment.

Laser Segment	Bias (mA)	R_d (Ω)	C_{eff} (pF)	τ_{RC} (ns)
FM	0.6	247	28	1.2
BM	200	6	454	2.4
Phase	0.9	159	42	1.6
Gain	1.5	105	68	2.3
SOA	1.2	122	61	2.2

5. Summary:

The electrical and optical properties of a 1060nm VT-DBR laser are presented. To our knowledge, this is the first demonstration of such a device. The electrical transition times for all sections of the laser allow for fast wavelength sweeping, suitable for SS-OCT at sweep repetition rates up to 400 kHz. The narrow CW optical linewidth should allow for the very long coherence lengths required for OCT.

5. References

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