Discrete Mode Laser Diodes with Ultra Narrow Linewidth Emission < 3kHz

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Abstract: Ex-facet, free-running ultra-low linewidth (< 3 kHz), single mode laser emission is demonstrated using low cost, regrowth-free ridge waveguide Discrete Mode Fabry Pérot laser diode chips.

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1. Introduction

Attainment of very narrow spectral linewidth emission using monolithic semiconductor lasers with the least associated level of device complexity and low component cost are critical for realising many single wavelength laser applications in optical coherent communications systems, sensors, and clocks. The free-running line-width reported for ordinary DFB and DBR laser devices is typically in the 1-5 MHz range, which restricts their use in those applications. The lowest monolithic single mode DFB laser diode emission line-width of 3.6 kHz reported to date was achieved in a 'hero' demonstration using a highly complex device structure specially tailored for narrow linewidth emission and emitting at very high powers [1].

In this paper we report the lowest linewidth (< 3kHz) achieved to date with a 350 μm cavity length monolithic semiconductor laser structure operating at fibre coupled powers in the 1 to 6mW range. The discrete mode laser used in this study is hermetically sealed in a 14-pin butterfly package, which contains a thermoelectric cooler, thermistor and optical isolator.

2. Device Operation

Discrete Mode laser diodes (DMLDs) [2] are simple, regrowth-free ridge waveguide Fabry-Pérot (FP) lasers. Single wavelength operation in DMLDs is achieved by introducing index perturbations in the form of etched features positioned at a small number of sites distributed along the ridge waveguide

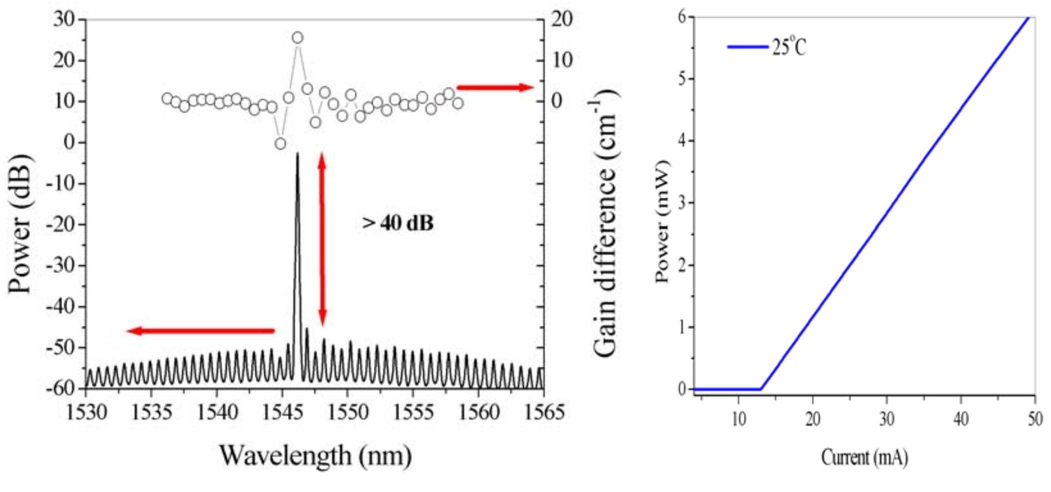

Fig. 1 (a). Upper curve: Calculated gain difference Vs wavelength for a DMLD. Lower curve: measured emission spectrum of a DMLD at a bias current of 40 mA showing a high side mode suppression ratio. (b) LI curve at 25 °C.

laser cavity. The features manipulate the FP cavity mirror loss spectrum by enhancing one FP mode and suppressing the others (Fig. 1(a), upper curve). The resulting optical power spectrum shows high

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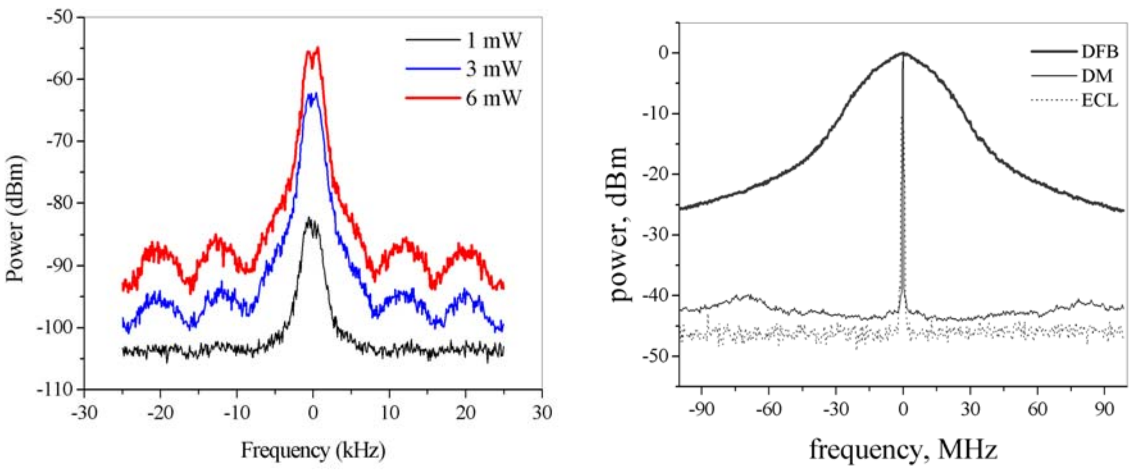
side-mode suppression ratio (SMSR) between the selected ‘discrete mode’ and all other FP modes (Fig. 1 (a), lower curve). Fig 1 (b) depicts the light-current, characteristic at 25^{o}C. Threshold current is 13mA, and the operating current giving a fibre coupled output power of 5mW is 40mA. DMLDs exhibit stable single mode operation over temperatures of -40 °C ≤ T ≤ 85 °C and modulation rates up to 10Gbs^{-1} [3-4].

3. Results & Discussion

The delayed self-heterodyne (DS-H) technique [5-6] was used to measure the DM linewidth, the fibre delay length in one arm of the set-up is 25 km corresponding to a time delay τ of 125 μs and system resolution of *(c/nL)/2* where *c* is the speed of light *n* is the refractive index of the fibre and *L* is the fibre length. This delay time corresponds to a 4 kHz resolution. Light propagating in the short arm of the set-up is modulated using a $LiNbO_3$ phase modulator to frequency shift the detected heterodyne beat signal to 1 GHz to enhance measurement accuracy. This technique offers the highest resolution, but requires that the delay length of fibre be much longer than the coherence length of the laser. The shape of the DS-H spectrum depends on the noise spectrum and ratio of the fibre delay time to the coherence time of the laser. If the frequency noise spectrum is white and the delay time of the fibre is much larger than the coherence time of the laser, the phase between the optical fields travelling in the two paths becomes totally de-correlated. In this case the DS-H spectrum is a true Lorentzian profile where the HWHM corresponds to the laser linewidth. Fig 2(a) plots the DS-H power spectrum of the DMLD at bias currents from 20-50 mA, which corresponds to emission power levels in the 1-6 mW range. The power spectra show clear interference fringes indicating that the coherence length of the laser is considerably longer than the 25 km of fibre even at low power levels. The oscillation period in the spectra is equal to 8 kHz, corresponding to 1/τ in agreement with a time delay for 25 km of fibre. Since the coherence length of the DMLD is longer than the fibre delay line of 25 km, we cannot immediately use the Lorentzian lineshape to extract the laser linewidth.

Fig. 2 (b) illustrates an overlapped DFB, DMLD and external cavity laser (ECL) laser line-width spectra measured using the DS-H set-up with the 25 km of fibre now replaced with 37 km of fibre (τ=185μs) in order to fully resolve the DM line-width. For comparison the plot shows the linewidth of a commercial DFB with Δν = 12.75 MHz; an ECL laser with Δν = 500 kHz; and a DMLD with Δν = 2.7 kHz operating at the same fibre coupled emission power level of 3 mW. Fig. 3 shows the measured DMLD DS-H spectrum, which was curve fitted to a Lorentzian function to extract the laser linewidth of 2.7 kHz. These DMLD linewidths are the narrowest reported from any monolithic laser.



diode.

Fig. 2 (a). Delayed self-heterodyne spectra for a DM laser with a fibre delay length of 25 km where the phase modulated frequency shift has been subtracted off (b) Measured delayed self-heterodyne spectra where the offset modulation frequency 1GHz has been subtracted. Three spectra are shown (i) a commercial DFB LD, (ii) a DMLD and (iii) an ECL.

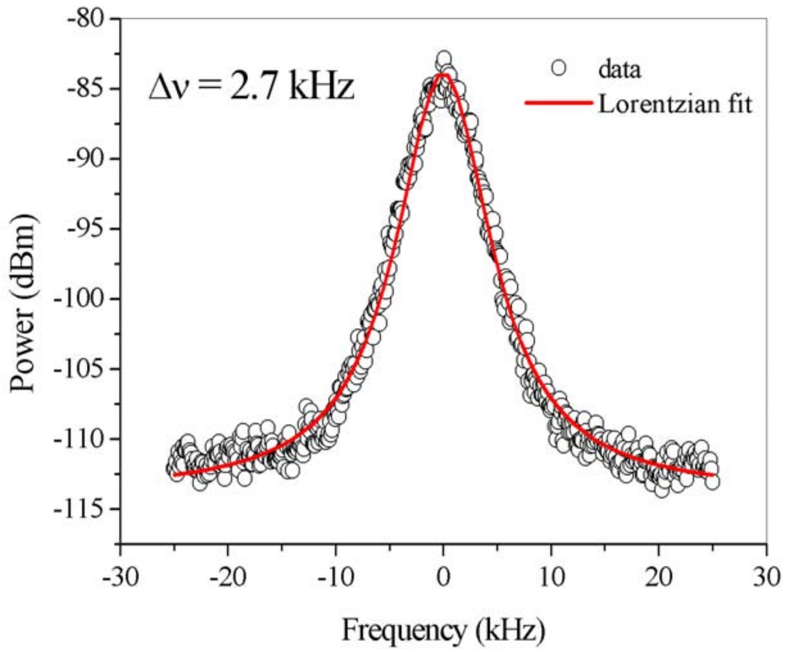


Fig. 3. Self-heterodyne spectrum of a DMLD at a bias current of 30mA curve fitted with a Lorentzian lineshape to extract a laser linewidth of 2.7 kHz. Ex-facet output power estimated to be 7mW.

The question then arises as to the origins of the ultra narrow DMLD linewidths in comparison to DFB's. One factor is that for DMLDs such as those used here with Lcav=350μm and high facet reflectivity's ($\sqrt{R_1}\sqrt{R_2} \cong 0.5$), the cold cavity linewidth is $\Delta\nu_{cavity} \cong 28$ GHz. Zero detuning of the laser emission from the gain peak (gain peak $\lambda = 1546$ nm) was measured as the laser emission was not designed to reduce the α parameter ($\Delta\nu \propto 1 + \alpha^2$), the DM multiple quantum well active region was fabricated in the InGaAlAs material system where due to its higher differential gain, α is about 2-3 compared to 5 for an InGaAsP-based DFB. Other potential factors are currently under investigation

4. Summary

In this paper we have presented measurements on the spectral line-width characteristics of a DMLD. This is the lowest linewidth reported with a monolithic laser structure. The fact that it has been achieved with a low cost, easily manufacturable laser device bodes well for more widespread deployment for coherent communications systems. A minimum emission linewidth of 2.7 kHz was measured for the DMLD, which is a factor of 1000 less than standard commercial DFB laser diodes at equivalent emitted powers.

5. References

[1] M. Okai, M. Suzuki and T. Taniwatari. "Strained multiquantum-well corrugation-pitch-modulated distributed feedback laser with ultranarrow (3.6kHz) spectral linewidth" *Electron. Lett., vol 29, no 19, pp 1696-1697. 1993*

[2] J. Patchell, D. Jones, B. Kelly, J. O'Gorman, "Specifying the wavelength and temperature tuning range of a Fabry-Perot laser containing refractive index perturbations," *in Proc. SPIE.* vol. 5825, pp. 1-13*, 2005 (and references therein).*

[3] http://www.eblanaphotonics.com/news.html

[4] B. Kelly, R. Phelan, D. Jones, C. Herbert, J. O'Carroll, M. Rensing, J. Wendelboe, C. B. Watts, A. Kaszubowska-Anandarajah, P. Perry, C. Guignard, L. P. Barry and J. O'Gorman. "Discrete Mode Laser Diodes with Very Narrow Linewidth Emission *" Accepted for publication Electronic Letters Oct 2007*

[5] T. Okoshi, K. Kikuchi, and A. Nakajama, "Novel method for high resolution measurement of laser output measurements", *Electon. Lett., vol. 16, pp630-631, 1980.*

[6] M. O. van Deventer, P. Spano, and S. K. Nielsen, "Comparison of DFB laser linewidth measurement techniques results from COST 215 round robin," *Electron Lett*, vol. 26, pp. 2018-2020, 1990.

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