Single Frequency free-runing low noise compact External-Cavity VCSELs at high power level (50mW)

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Abstract

We present a highly coherent semiconductor device formed by a ½-VCSEL and an external concave mirror. The low noise single-frequency TEM00 laser exhibits 50mW output power with a linewidth <1kHz.

Laser technology is maturing rapidly and is finding applications in areas such as high resolution spectroscopy, medicine, optical telecoms, metrology, where highly coherent tunable low noise sources are required. Single frequency tunable high-power solid-state lasers rely on intracavity filtering. A more compact design can be achieved using a simple External-cavity VCSELs (VECSELs), to develop high power highly coherent laser. VECSELs exhibit single-frequency operation in the 0.8-2.5µm range and wide mode-hope-free tuning range. They offer cw 300 K operation at high output power with a TEM00 beam [1,2].

Device Design & Single Frequency Operation

Here, we present a GaAs-based VECSEL emitting at 1 µm formed by a ½-VCSEL (fig. 1), a 10-25mm air gap to stabilize single longitudinal mode operation, and a commercial concave mirror (99% of reflectivity). The ½-VCSEL structure is composed of a HR AlAs/GaAs Bragg Miror, 6 InGaAs/GaAs(P) strain compensated quantum-wells (QWs) and a SiN antireflection coating on top. The substrate back side was polished with a wedge and gold covered.

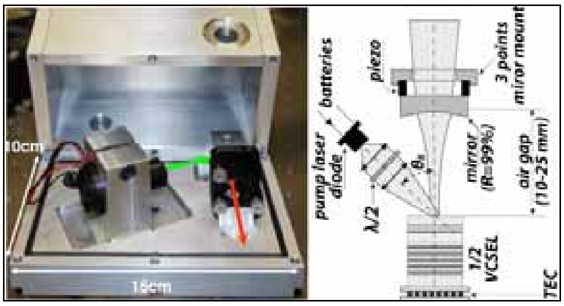

Figure 1 : VECSEL device and Schematic view.

The external mirror is held by an ultra-stable mirror mount (New Focus 9882). A low noise 200mW single transverse mode 800 nm commercial pump laser diode (Sanyo DL-LS2075, battery biased) is focused on a 30µm spot size at 65° incidence angle. The components are glued on the breadboard and inserted in a metallic box. The threshold density is ~2 kW/cm^2. The external cavity enforces TEM$_{00}$ beam operation (M^2<1.2).

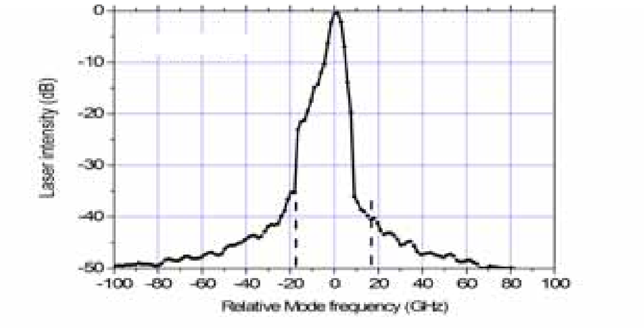

Figure 3 : Experimental laser spectrum showing single frequency operation (FSR≈16.5GHz).

Single frequency operation (SMSR>40 dB) is obtained up to 50 mW output power (pump power limited, 35% slope efficiency) at 295K, without any intracavity spectral filter thanks to the QW homogeneous gain [1]. The VECSEL was linearly polarized along the [110] crystal axis due to QW gain dichroïsm. A continuous tunability ~40 GHz was obtained by moving the mirror with a PZT.

Intensity and Phase Noise

The free running single frequency VECSEL was studied in terms of RIN (Relative Intensity Noise) and linewidth. The RIN (fig. 2) reached the quantum limit below the VECSEL cavity cut-off frequency, in spite of a highly super-poissonian pump.

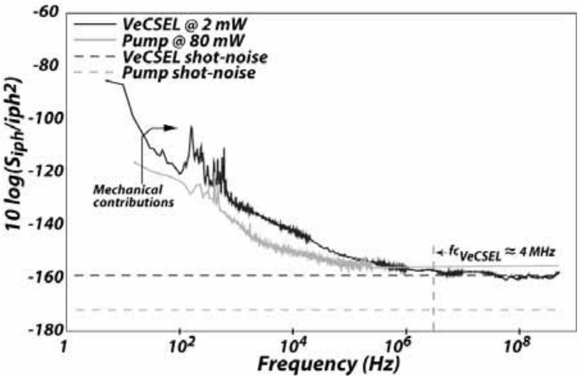

Figure 2 : Pump & VECSEL RIN versus frequency.

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The linewidth properties shown in fig. 3 are obtained with a delayed self-homodyne technique, using two fiber time delays τ=5µs and 125µs between the two paths. The photo-detected signal is then Fourier-transformed by a FFT Analyser. For the longest delay (fig.2-a) the linewidth exhibits a 1.2kHz technical FM-noise induced broadening @ -3 dB for 400µs measuring time, two order of magnitude narrower than commercial External-Cavity Laser Diodes. For the shortest delay (fig. 2) the measurements are fitted with an FFT-transformed autocorrelation function taking into account both white and 1/f FM noise contributions [3]. This treatment leads to a classical behavior for the white FM noise originated linewidth (fig. 2) with a 0.127 Hz.W slope and a 10 Hz limit at 10 mW emitted power. An optical power independent 1/f FM noise contribution (5.10^5 Hz^2/Hz at 1Hz) is also observed. All these parameters are 5 to 6 orders of magnitude smaller than usual values for conventional integrated semi-conductor lasers [3].

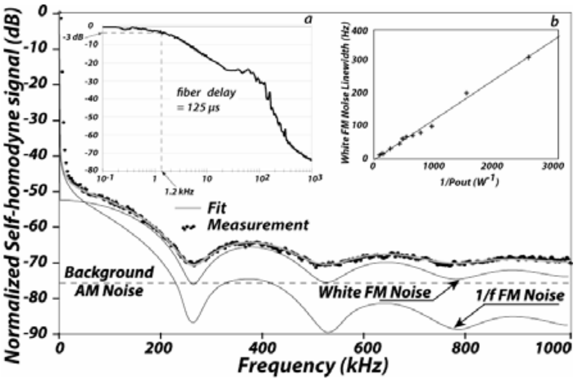

Figure 3 : Fitted and measured self-homodyne signal @ τ=5μs. (a) : Self-homodyne τ=125 μs (b) : White FM noise linewidth versus 1/Pout.

Influence of cavity dispersion on single mode stability

In order to investigate the influence of mode phase dispersion in the ½-VCSEL structure on single longitudinal mode stability, we tuned the laser wavelength (with temperature) around the Bragg centre wavelength (λ=1010nm) in a structure designed to exhibit a relatively strong dispersion (>10^4 s^{-1}) around this spectral position. We observed strongly multimode operation for large positive or negative cavity dispersion and stable single longitudinal mode operation near zero dispersion (Fig.5). We believe that this behaviour can be explained by the interplay between four-wave-mixing induced population pulsation in the quantum-well gain [1] and mode phase dispersion after one reflection in the structure. We simulated the non-linear dynamics of this multimode laser system [1] but taking into account the cavity dispersion.

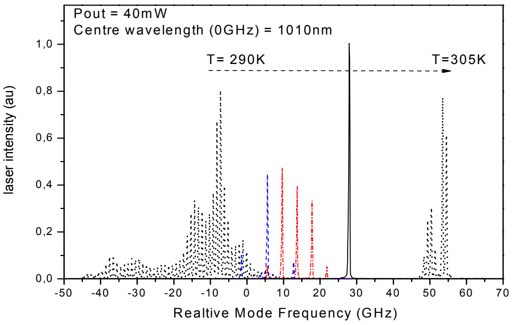

Figure 5 : Steady state Laser spectra taken at different temperatures, showing single mode stable operation at a wavelength ~1010nm where the 1/2-VCSEL structure phase dispersion is close to zero.

We obtained a strongly multimode non-linear dynamics during the transient after the laser start-up, for large positive or negative cavity dispersion (Fig.6). In contrast, stable single longitudinal mode operation is obtained after the transient near zero dispersion as in the experiment. These dynamics behaviours are still under study.

This shows that for single frequency applications, the dispersion value has to be as low as possible in the VECSEL cavity design to avoid any unstable deterministic non-linear dynamics.

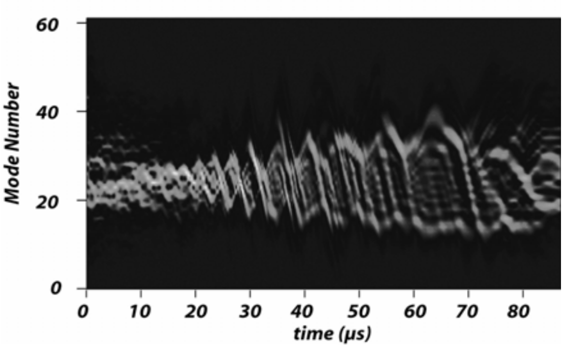

Figure 6 : Simulated VECSEL transient non-linear dynamics (electric field amplitude) for a cavity dispersion ~10^4 s^{-1} after start-up.

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