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# Non-linear broad spectral tuning of a semiconductor laser and application to coherent dual frequency source

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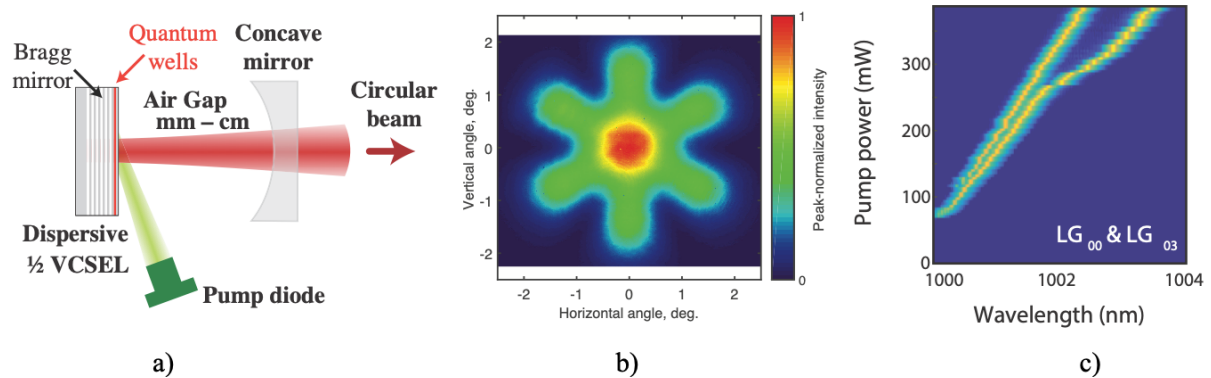
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Laser technology is finding applications in areas such as high-resolution spectroscopy, radar-lidar, velocimetry, or atomic clock where highly-coherent tunable high-power light sources are required. Offering such performances in the Near- and Middle-IR range, III-V semiconductor-based Vertical-external-Cavity Surface-Emitting Lasers (VeCSEL) technologies seem to be a well-suited path to meet the required specifications of demanding applications [1].

As an example, we demonstrate that a dual-frequency VeCSEL based on the coexistence of two Laguerre-Gauss (LG) transverse modes was suitable to provide coherent and tunable THz emission using photomixing techniques [2], the coherence being verified in terms of longitudinal modes, transverse modes and polarization (linear state). The typical optically-pumped laser structure is shown in Fig. 1a, and the resulting output beam that consists of the superimposition of  $LG_{00}$  and  $LG_{03}$  modes is shown in Fig. 1b. In this two-modes laser, the frequency difference between the two transverse modes could be tuned by the optical pump power from 50 GHz to about 900 GHz, but this outstanding tuning range could not be solely explained by linear thermal effects ruled by the pump beam. Therefore, a fundamental study of the non-linear multimode laser dynamics was carried out to explore phase-amplitude dynamic instabilities [3], by taking into account combined key physical effects such as cavity dispersion and diffusion, four-wave mixing and light-matter-interaction-induced phase-amplitude coupling.



**Fig. 1 a)** Diode-pumped VeCSEL device design. **b)** Transverse modes ( $LG_{00}$  &  $LG_{03}$ ) superimposition observed at the laser output. **c)** Non-linear broad spectral tuning map as a function of intracavity pump power for dual-mode operation involving  $LG_{00}$  &  $LG_{03}$  transverse modes, the  $LG_{00}$  mode operates at the higher wavelength.

We report experimentally and theoretically the existence of deterministic dynamics of the laser field, with a route to robust single-frequency operation exhibiting broad non-linear spectral tuning far above the thermally-assisted conventional tuning range [3]. This study provides physical explanations for the beat-frequency shift observed in the dual-frequency VeCSEL as shown in Fig. 1c, with a linear shift driven by thermal effects at low pump power ( $< 275$  mW), and a non-linear shift at higher pump power characterized by a low intracavity bifurcation threshold intensity of typically  $10^5$  kW/cm<sup>2</sup>.

These results pave the way to frequency-tuning management in such coherent lasers, either for robust single-frequency operation or dual-frequency operation.

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