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THz and mid-infrared solitons in semiconductor ring lasers

THz and mid-infrared soliton generation in an electrically pumped gain medium could enable compact sources of highly coherent pulses with frequency comb spectra, suitable for high-sensitivity spectroscopy and free-space communication. Recently, we have shown such gain solitons can be generated from mid-infrared ring quantum cascade lasers[1]. In a medium with saturable gain, the electric field amplitude is governed by the Complex Ginzburg-Landau Equation (CGLE), which has a rich set of solutions depending on both initial conditions and the system parameters.[2] We explore these solutions numerically by solving a normalized CGLE

$$\frac{\partial \mathcal{E}}{\partial \tau} = \mathcal{E} - (1 + \mathrm{i}\alpha)|\mathcal{E}|^2\mathcal{E} + (1 + \mathrm{i}\beta)\frac{\partial^2 \mathcal{E}}{\partial \Theta^2}$$

which depends only on three laser parameters; the linewidth enhancement factor through α, the dispersion through β, and the number of modes N inside the gain bandwidth, which gives the periodicity in Θ. In the case of gain-only solitons analytical solutions exists and resemble the typical sech^2 solutions of externally driven microcavities[3-5]. Though these solutions are unstable, they resemble the stable numerical solutions in terms of their widths and spectra.

Simulation results for N=6 modes with positive gain are summarized in Fig. 1. For experimentally attainable parameters, single-mode operation (white areas), solitons with strong amplitude modulation (1)-(2), chaotic light states (3), and breather-like solitons (4) can form. By designing the quantum well structure of semiconductor lasers and varying experimental conditions such as driving current and temperature, these predicted light states could be utilized in compact devices for a range of applications.

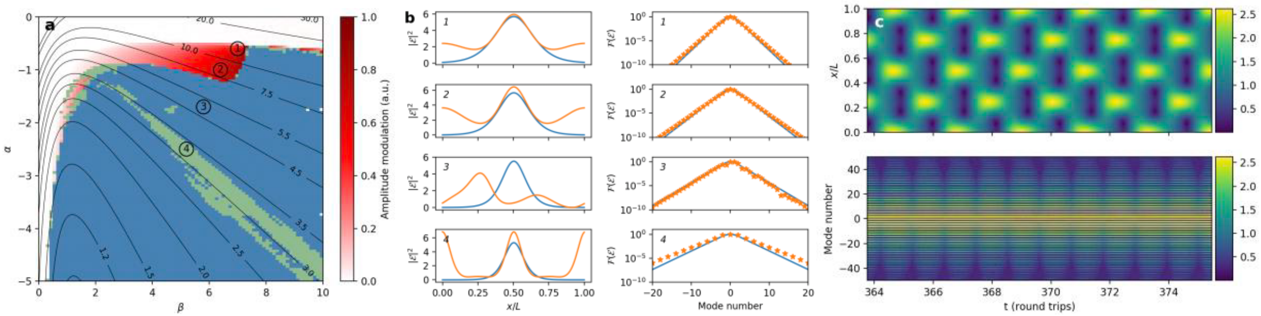

Figure 1: a) Phase diagram of the solutions the CGLE with single-mode (white), amplitude-modulated (red), breather solitons (green), and chaotic solutions (blue) indicated. Contour lines show the widths of the analytic solutions to the CGLE. b) Intensity profile on the left and the corresponding Fourier transforms on the right. Both analytic (blue) and numerical (orange) solutions are shown. c) Time-evolution of the breather-like soliton (4).

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