Non-Hermiticity and dynamics in coupled VCSEL arrays


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An optical system with nontrivial gain/loss profile is inherently a non-Hermitian system in analogy to the non-Hermiticity in quantum mechanics [1-4]. The non-Hermiticity in photonics, especially parity-time (PT) symmetry, has been studied extensively recently, and novel applications have been demonstrated including unidirectional reflection, improved single-mode lasing, and enhanced sensing sensitivity [1, 3, 4]. One realization of this non-Hermitian optical system is coherently coupled vertical cavity surface emitting laser (VCSEL) arrays [2]. Probing the non-Hermiticity of this electrically injected diode laser system has enabled applications such as high data rate modulation [5, 6] and high speed electronic beam steering [7].

A top view of our photonic crystal 2x1 VCSEL array is shown in Fig 1. The photonic crystal pattern creates the index-confined dual optical cavities (labeled A and B); stacked ion implantation is used to define two independent gain regions with electrically isolated independent contacts [6]. Hence the gain/loss profile can be dynamically controlled. Tuning of the coupled mode is shown in Fig 2, with Fig 2(a) showing the far-field beam steering due to relative phase tuning between cavities, and Fig 2(b) showing tuning of the near field intensities. The relative phase tuning and intensity tuning are results of non-Hermiticity in the array, with co-existing gain/loss contrast and frequency detuning between cavities. The control of the gain/loss contrast and frequency detuning is through the injected currents, and we recently found that this control is dominated by the nonlinearities that are inherent to semiconductor lasers, including carrier density pinning and the amplitude-phase coupling. Coupled rate equation analysis is necessary to study this tuning behavior and interesting physics is revealed as there is net energy transfer between cavities through optical coupling [8].

In addition to the steady-state mode tuning, we also observe that the dynamical behavior of the array is strongly influenced by the coupling. This includes the tuning (enhancing) of modulation bandwidth [5] and the change in relative intensity noise.

In summary, we have observed non-Hermitian analogs in the optical characterization of coherently coupled microcavity laser arrays. The degree of non-Hermiticity is tuned by injection currents, and nonlinearities play critical roles as shown by coupled rate equation analysis. Dynamics of the coupled array, including modulation response and intensity noise, are also strongly influenced by the coupling. This research is an important step to leverage the researches of non-Hermitian photonics into practical applications.

References