Non-Hermitian synthetic lattices with light-matter coupling

Amir Rahmani, Mateusz Kedziora, Andrzej Opala and Michał Matuszewski

Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, 02-668

Warsaw, Poland

Corresponding author. email: rahmani@ifpan.edu.pl

Introduction

- Lattice models are ubiquitous in physics with applications ranging from approximations of real physical systems to efficient tools in theoretical research. The formation of different lattice configuration may be realized by using the internal degree of freedoms [1-3]. Light-matter coupling may provide an advantage in investigations of non-Hermitian physics duo t exchange of energy or particle with surrounding environment [4-5].
- Here we explore how light-matter coupling can provide an additional degree of freedom for creating a synthetic lattice. We study a simple model of a one-dimensional lattice in which the light-matter coupling can be manipulated [6].
- We analyze band structures and steady state solutions in three regimes: (1) manipulating the light-matter coupling strength; (2) manipulating the decay rate; (3) manipulating the pumping rate. Our results show the emergence of Flat-band and exceptional points (EPs) in our analysis.

Model

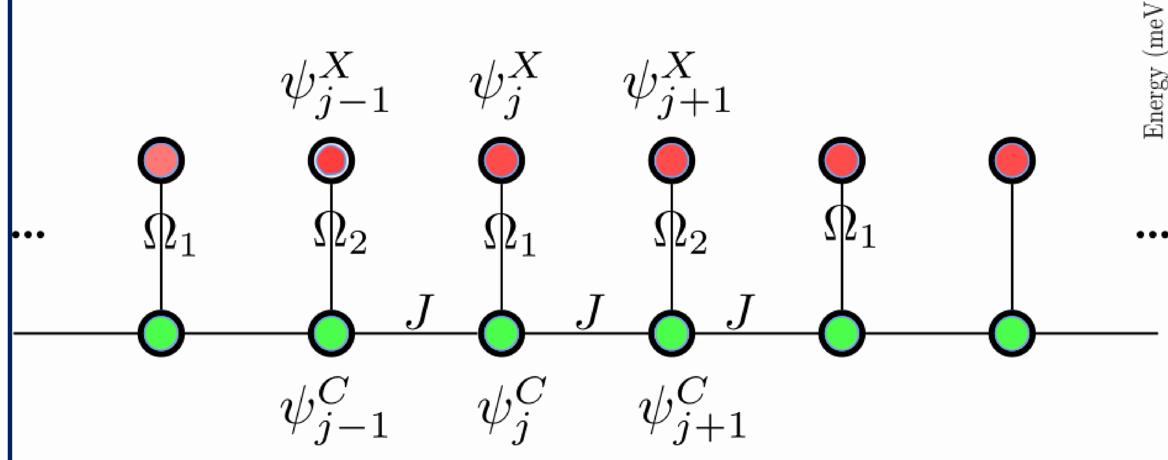


Fig.1. Schematic of our model.

$$i\partial_t\psi_j^C = -i\gamma_C\psi_j^C + J(\psi_{j-1}^C + \psi_{j+1}^C) + \Omega_j\psi_j^X$$

$$i\partial_t\psi_j^X = -i\gamma_X\psi_j^X + g\hbar^{-1}|\psi_j^X|^2\psi_j^X + \Omega_j\psi_j^C$$

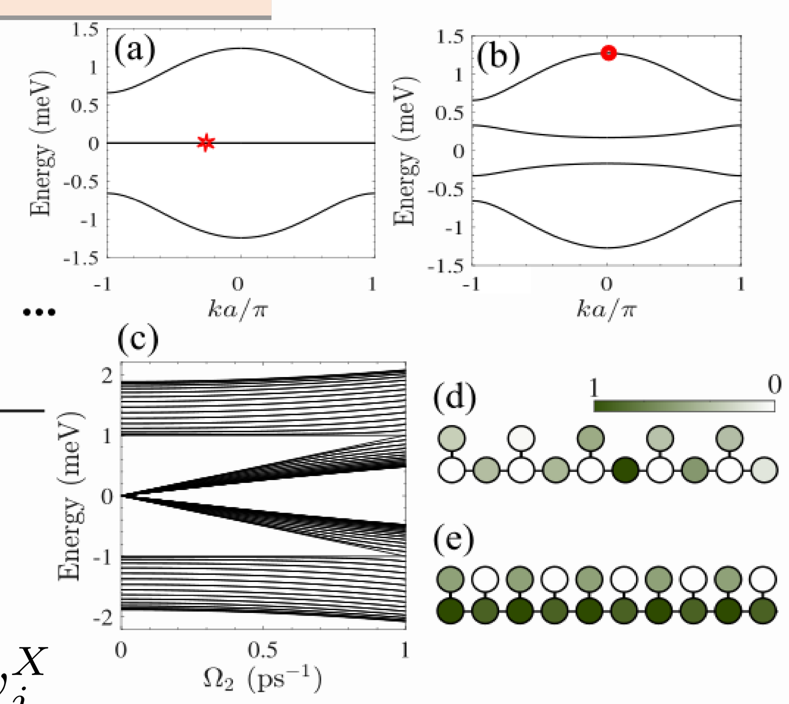
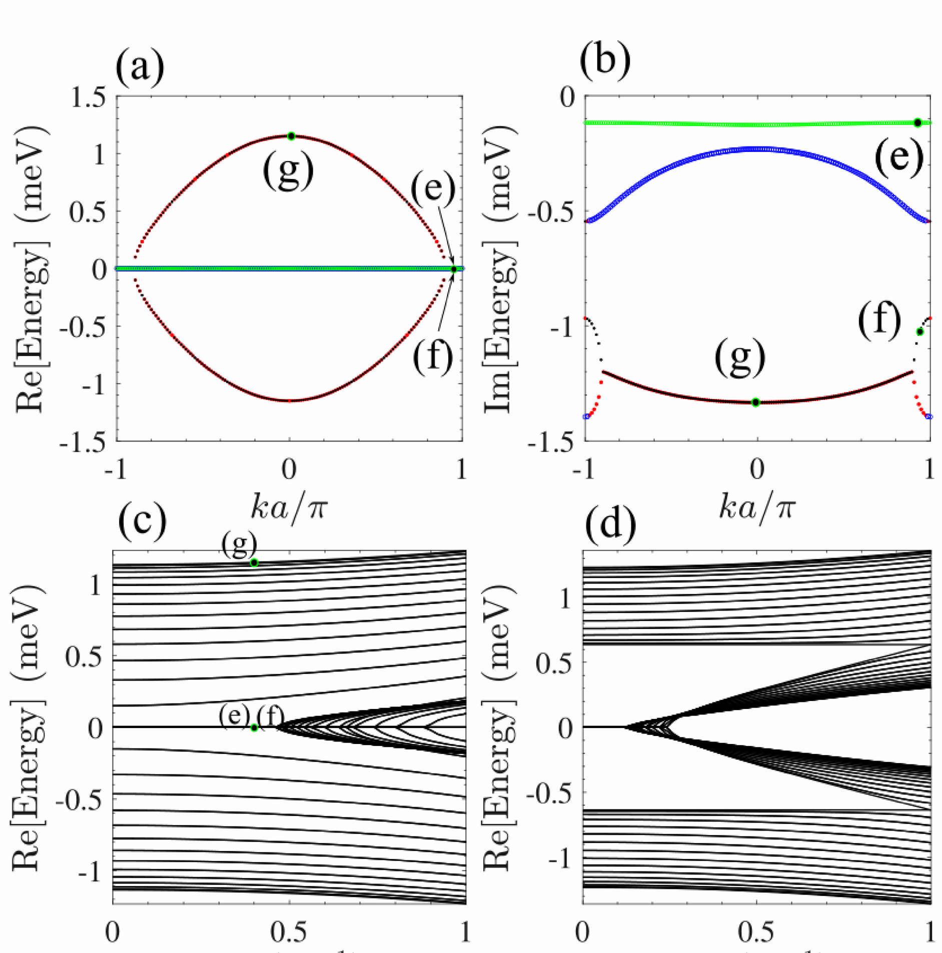


Fig.2. Examples of spectra and eigenstates in the linear Hermitian case. (a) and (b) Energy spectra in momentum space for an infinite system. Panel (c) shows an eigenenergy spectrum in function of 2 in a finite system with N = 30. (d) and (e) Examples of density distributions for eigenstates corresponding to the flat band in (a) and dispersive band in (b), respectively.

Flat-band and EPs

❖ With changing the coupling strength



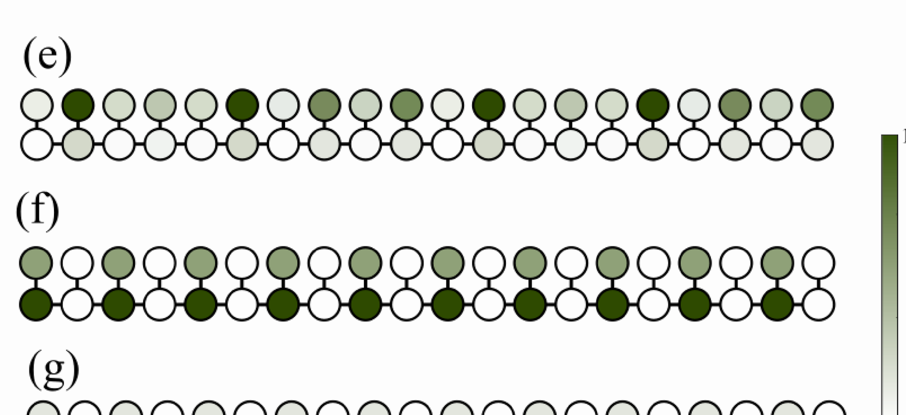


Fig. 3. Linear non-Hermitian case. In (a) and (b) we show the real and imaginary parts of eigenvalues in a function of quasimomentum for the same parameters as in Fig. 2. but with nonzero decay. In contrast to the Hermitian case, flat bands are present in the system for a nonzero coupling. Exceptional points are marked with a black open circle. In (c) and (d) we show real parts of eigenvalues in function of . The eigenstates corresponding to the points marked in panels (a) and (b) are shown in panels (e)–(g).

❖ With changing the loss

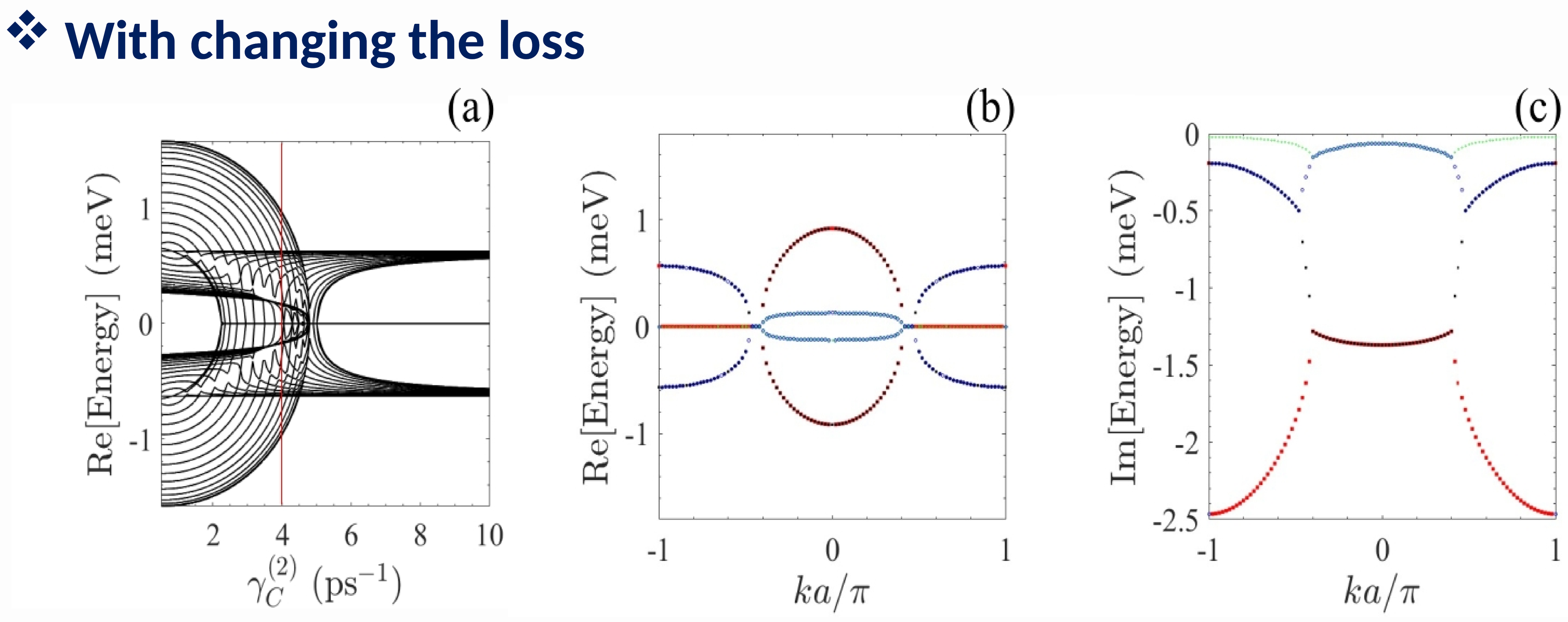


Fig. 4. **(a)** An example of a spectrum (real part) in the non-Hermitian case is presented. In this regime, the loss in one of the photonic sites is varying while all other parameters (including the coupling strength and gain) remain constant. When the loss is set to the value indicated by the red line, the resulting dispersion is illustrated in panels (b) and (c). This marks the onset of the lasing regime, beyond which the linear becomes unstable.

Flat-band and EPs

❖ With changing the gain

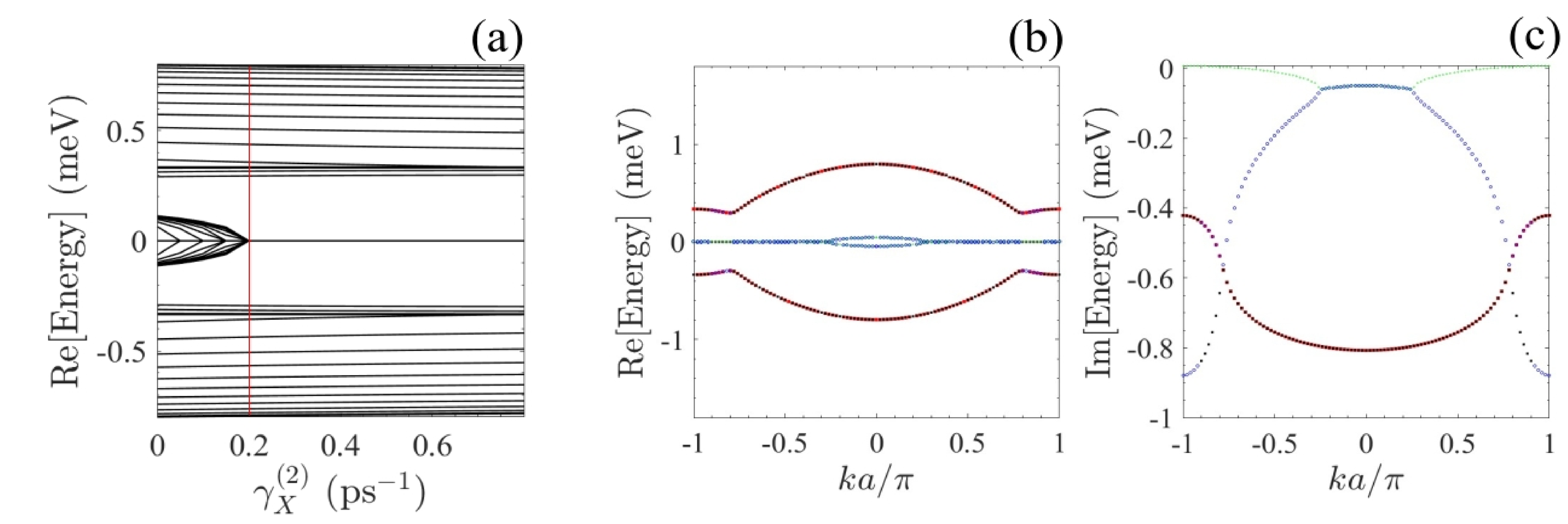


Fig. 5. **(a)** An example of a spectrum (real part) in the non-Hermitian case is presented. In this regime, the gain in one of the excitonic sites is varying while all other parameters (including the coupling strength and decay) remain constant. When the gain is set to the value indicated by the red line, the resulting dispersion is illustrated in panels (b) and (c). This marks the onset of the lasing regime, beyond which the linear becomes unstable.

Lasing and zero Energy

❖ With changing the coupling strength

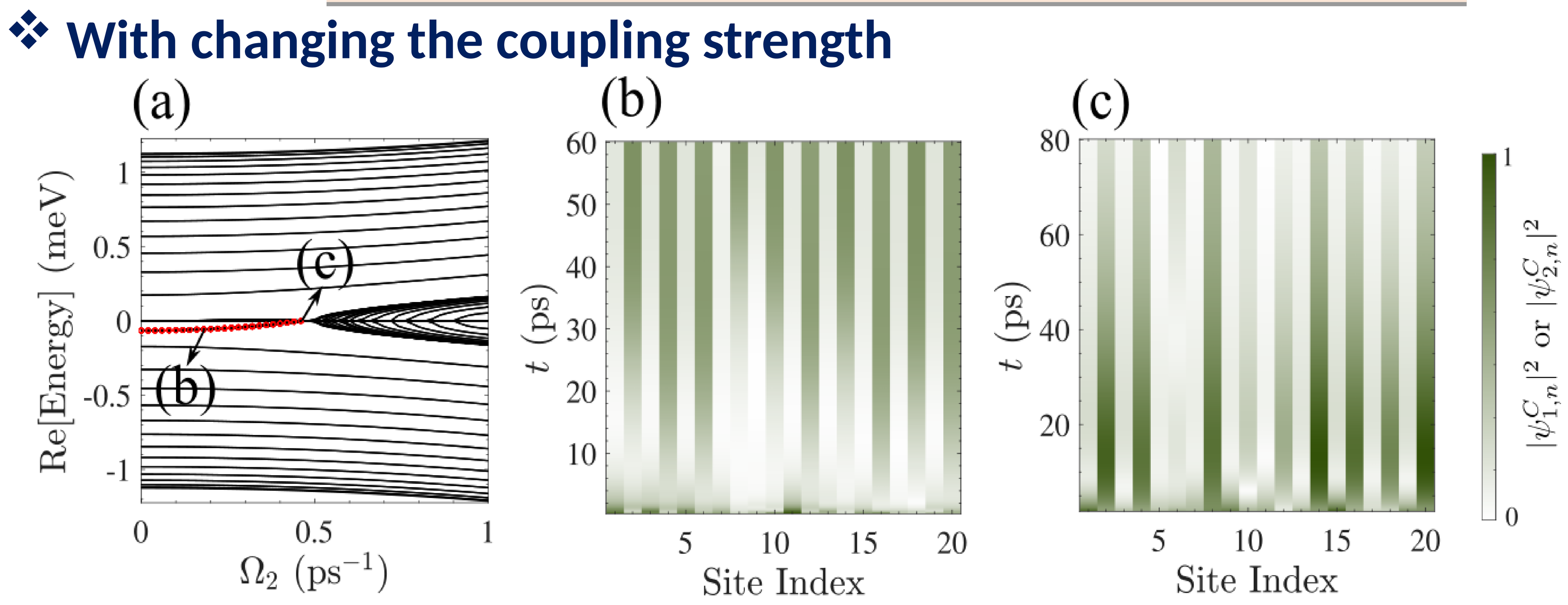


Fig. 6. **(a)** Taking into account non-linearity may lead to emergence of the lasing regime . Panel (a) shows the spectrum considering non-linearity. A comparison can be made with Fig. 3, panel (c) which display the linear spectrum. Red points show the solutions with zero imaginary part. Panels (b) and (c) provides the densities at photonic sites for two distinct selections of Ω_2 .

❖ With changing the loss

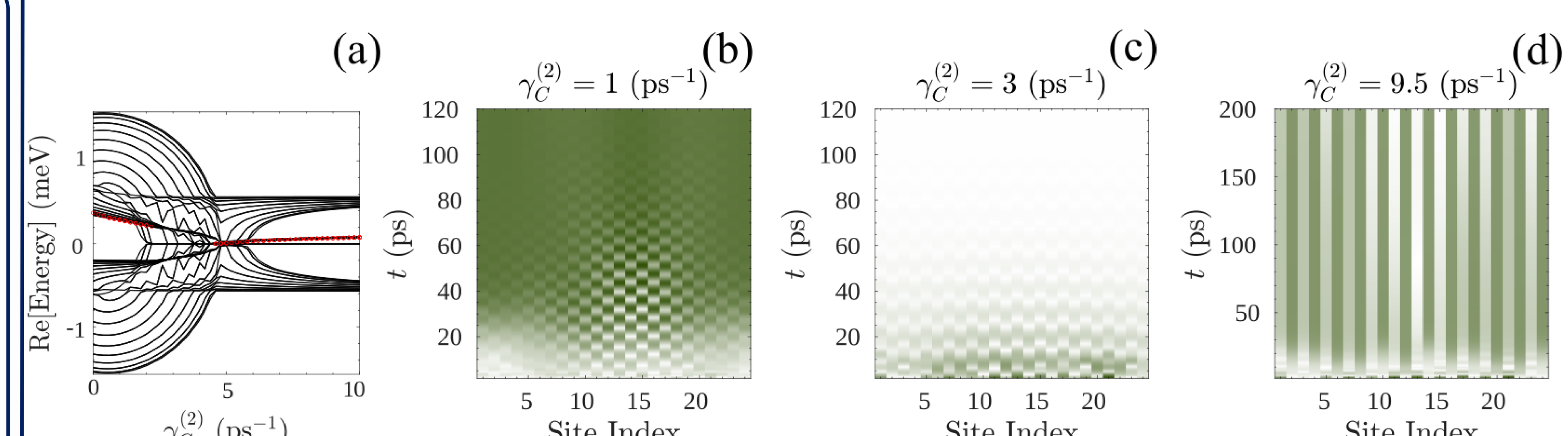


Fig. 7. Examples of lasing with varying the decay rate. Panel (a) shows the spectrum. A comparison can be made with Fig. 4, panel (a) which shows the linear spectrum. Panels (b-d) show the steady state solutions at photonic sites, showcasing the revival of the lasing for larger decay rates.

❖ With changing the gain

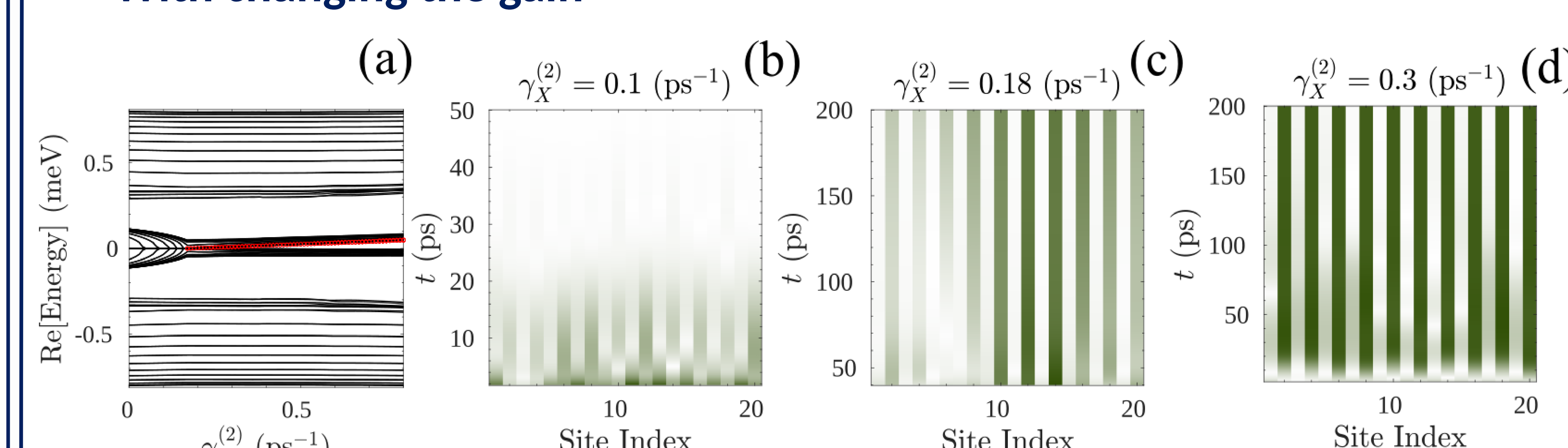


Fig. 8. **(a)** Examples of lasing with varying the gain. Panel (a) shows the spectrum. A comparison can be made with Fig. 5, panel (a) which display the linear spectrum. Panels (b-d) show the steady state solutions at photonic sites for three distinct selections of gain rates.

Conclusions

We demonstrated that local engineering of light-matter coupling provides a way to explore a dissipative phase transition between the regimes of dispersive and flat-band phases. The transition is accompanied by the appearance of exceptional points (EPs) in the spectrum.

- Our analysis involved examining the system while manipulating the decay rate and/or gain rate. Despite the fundamental differences in the band structure, both exceptional points (EPs) and Flat-band phenomena may arise as a result of varying loss and gain within the system.
- We showed that the existence of a flat band has a profound effect on the states of the system after long evolution in the regime of lasing, enabling a straightforward experimental observation. By manipulating decay the suppression and revival of lasing was shown.

References

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Acknowledgments

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