Floquet topological polaritons in semiconductor microcavities

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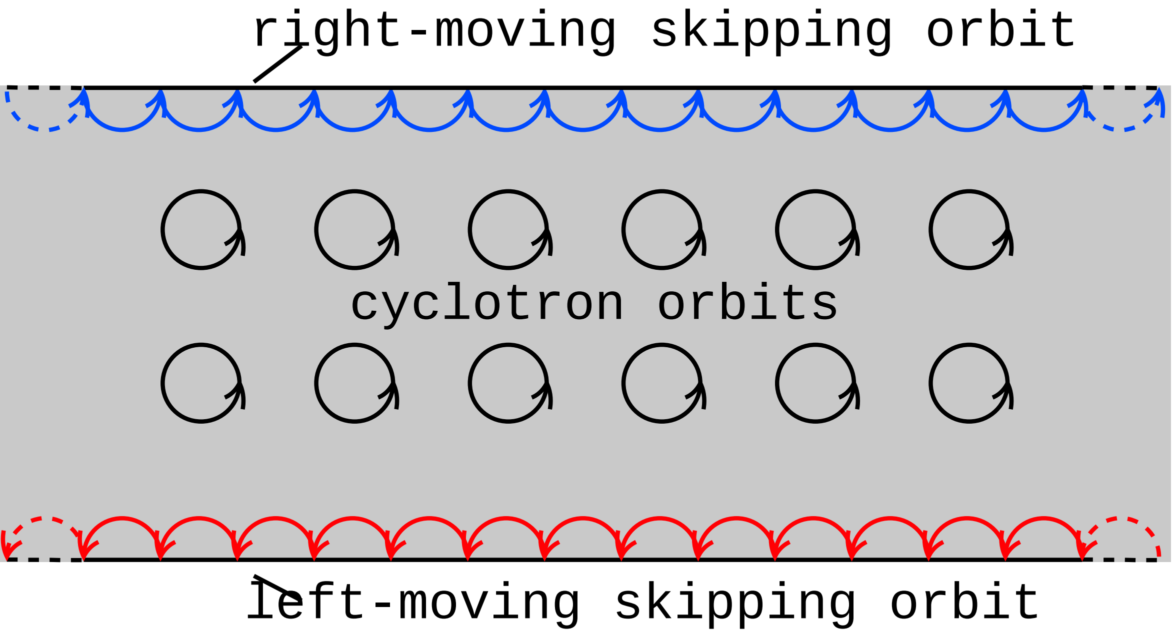
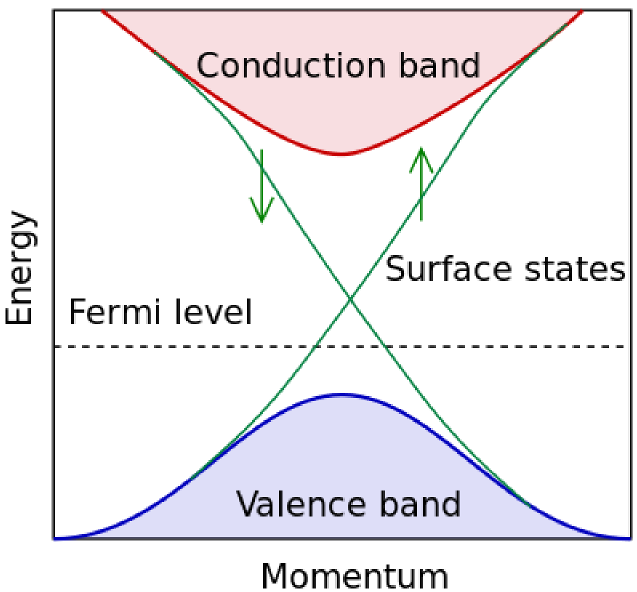
Topological polaritons

- (Exciton-)Polariton: result of EM Energy coupled to exciton
- Photonic analogue of electronic topological insulator
- Occurs upon time-reversal symmetry breaking
- Chiral edge state
- Topologically protected: Propagation backscattering immune

Quantum Hall Effect



Band Structure



Cf. Lorentz force

Electromagnetic Analog

PRL **100,** 013904 (2008) PHYSICAL REVIEW LETTERS week ending 11 JANUARY 2008

Possible Realization of Directional Optical Waveguides in Photonic Crystals with Broken Time-Reversal Symmetry

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We show how, in principle, to construct analogs of quantum Hall edge states in "photonic crystals" made with nonreciprocal (Faraday-effect) media. These form "one-way waveguides" that allow electromagnetic energy to flow in one direction only.

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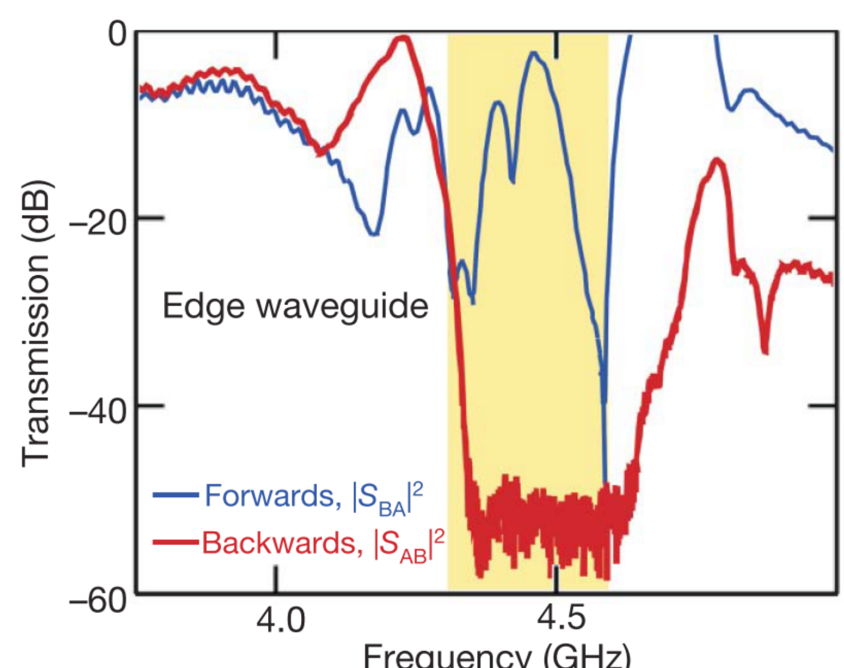
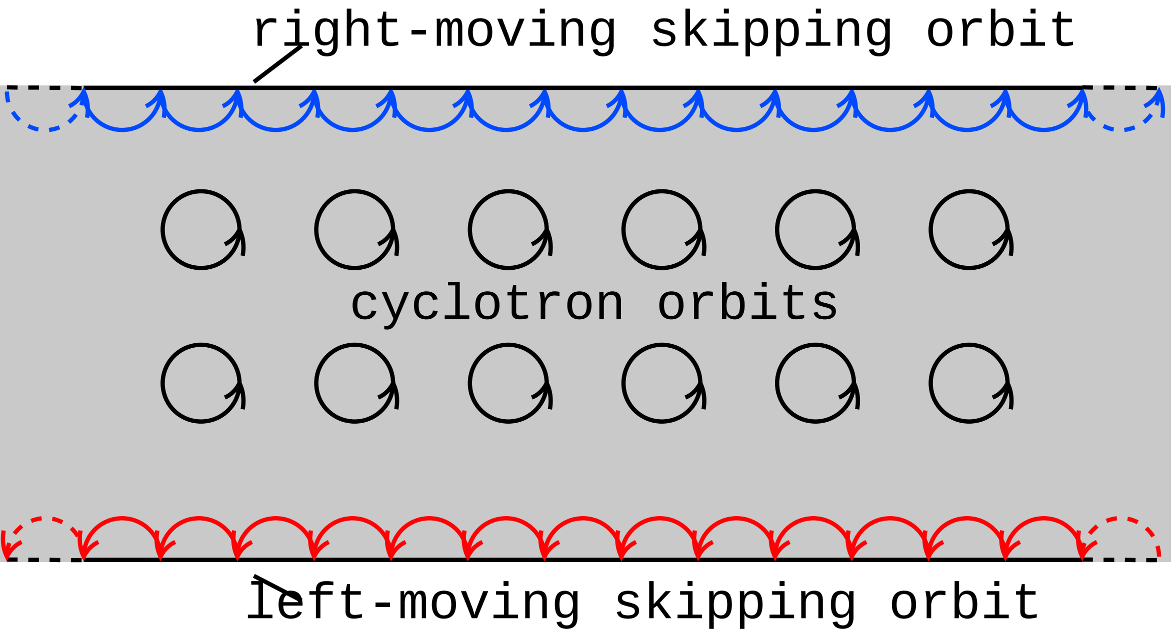
Theoretical prediction

Experimental observation:

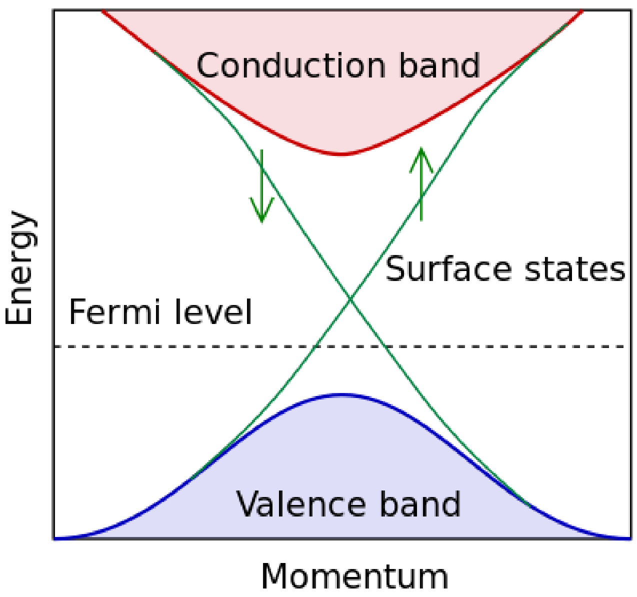


Z. Wang et al., Nature **461,** 772 (2009)

Quantum Hall Analog



Band Structure



Cf. Lorentz force ⟺ Magnetic Field?

Examples Zeeman splitting

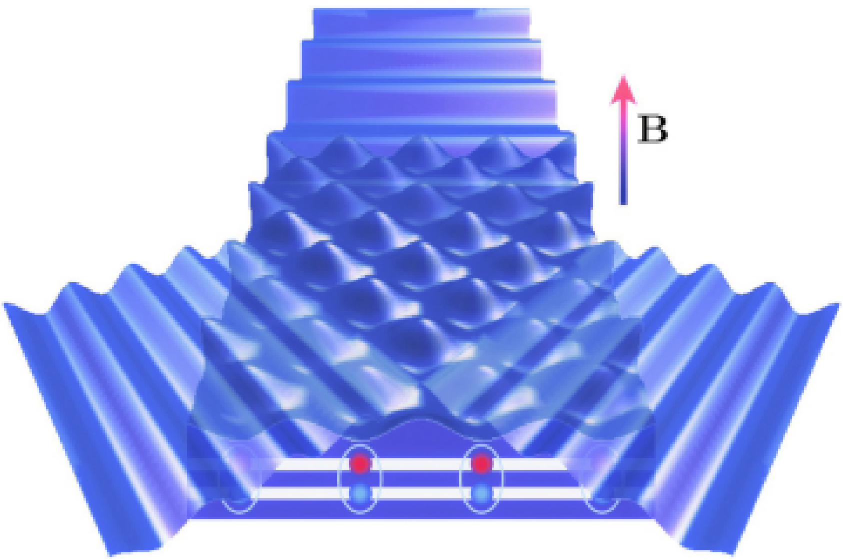
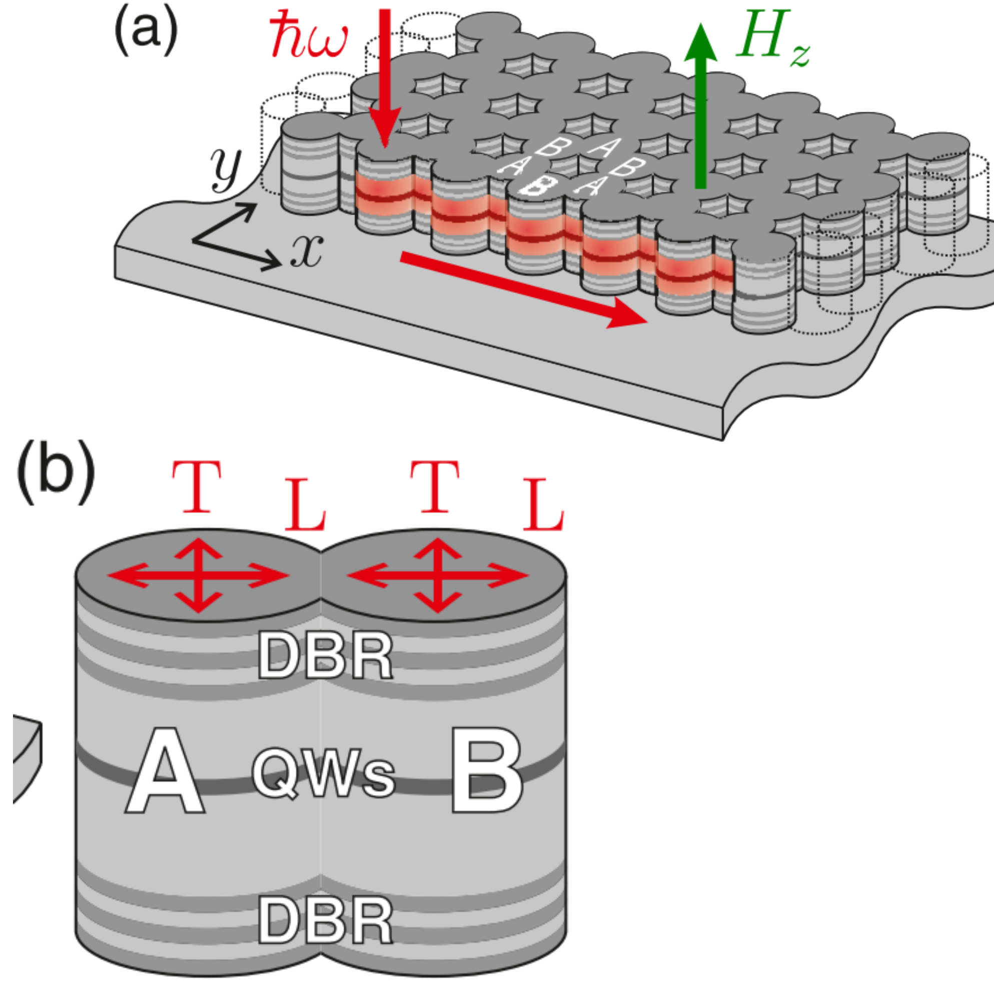


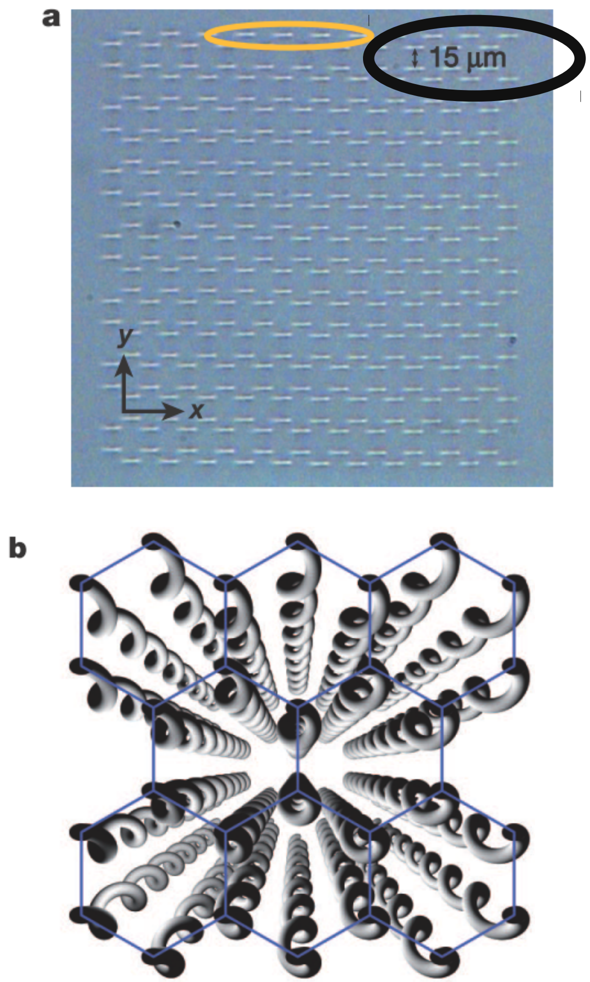
FIG. 1. (Color online) Schematic view of a typical system supporting topological polaritons or indirect excitons: Surface acoustic waves modulate the thickness of quantum wells and interfere to generate a triangular lattice potential for particles in the plane. Whether multiple quantum wells are coupled together, as in the depicted system of indirect excitons, or are strongly mixed with light inside a microcavity, combining the periodic potential with an applied Zeeman field **B** leads to topologically nontrivial bands.



Bardyn et al. PRB **91,** 161413 (2015)

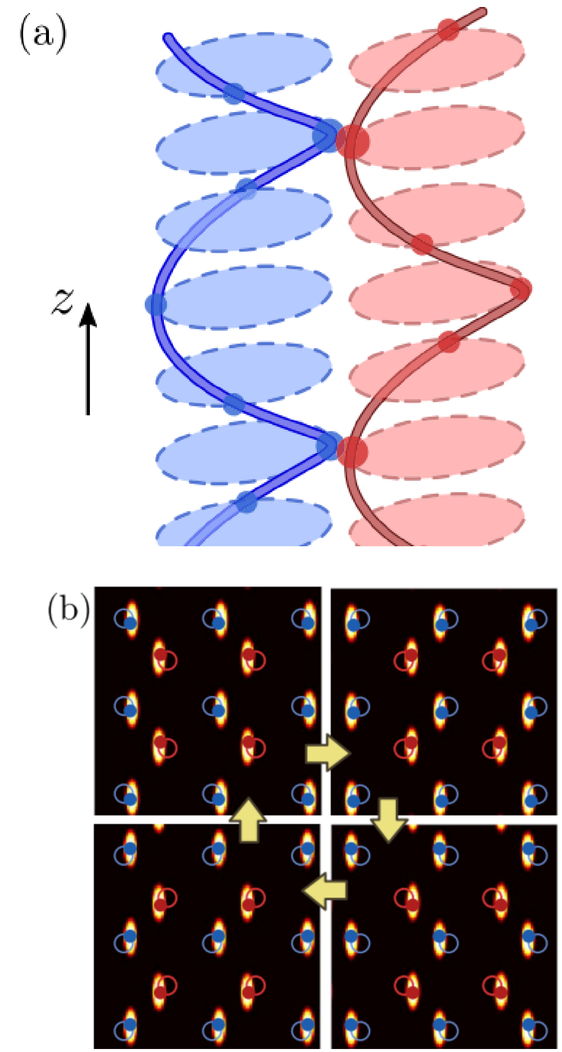
Nalitov et al, PRL **114,** 116401 (2015)

Without Magnetic Field: Helical structure



$a \approx 15\mu m$

$a \approx 20\mu m$



M. C. Rechtsman et al., Nature **496** 196 (2013)

D Leykam et al, PRL **117**, 013902 (2016)

Tight Binding Model

Linear combination

$$|\Psi(x,y,t)\rangle = \sum_{n,p,\beta} C_{np\beta}(t)|np\beta\rangle$$

Gaussian Basis:

$$\Phi_{n,p,\beta}(x,y) = \exp[-(x-x_{n,\beta})^2/L^2 - (y-y_{p,\beta})^2/L^2]$$

Coefficients

$$i\hbar\frac{\partial}{\partial t}C_{np\beta}(t) = \langle np\beta|\hat{H}(x,y,t)\sum_{n'p',\beta'}|n'p'\beta'\rangle C_{n'p'\beta'}(t)$$

if $\langle n'p'\beta'|np\beta\rangle = \delta_{n'n}\delta_{p'p}\delta_{\beta'\beta}$

ODE to be solved numerically

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Time Evolution

$$C_{np\beta}(t) = \mathcal{T}\exp\left[-\frac{i}{\hbar}\int_0^t \langle np\beta|\hat{H}(x,y,t)\sum_{n',p',\beta'} C_{n'p'\beta'}(t)|n'p'\beta'\rangle dt\right] C_{np\beta}(0)$$

with $C_{np\beta}(0) = 1$

Let $\hat{U}(t+T,t)\Psi(x,y,t) = \Psi(x,y,t+T)$

Then the quasi-energies are:

$\varepsilon_{\alpha,kx} = \frac{i\hbar}{T}\log(\eta_\alpha)$ where η_α denotes eigenvalues of $\hat{U}$

- Quasi-Energies obtained by diagonalizing $\hat{U}$
- Tight Binding Model provides Matrix Representation

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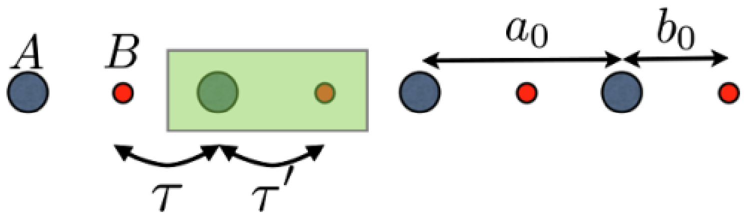
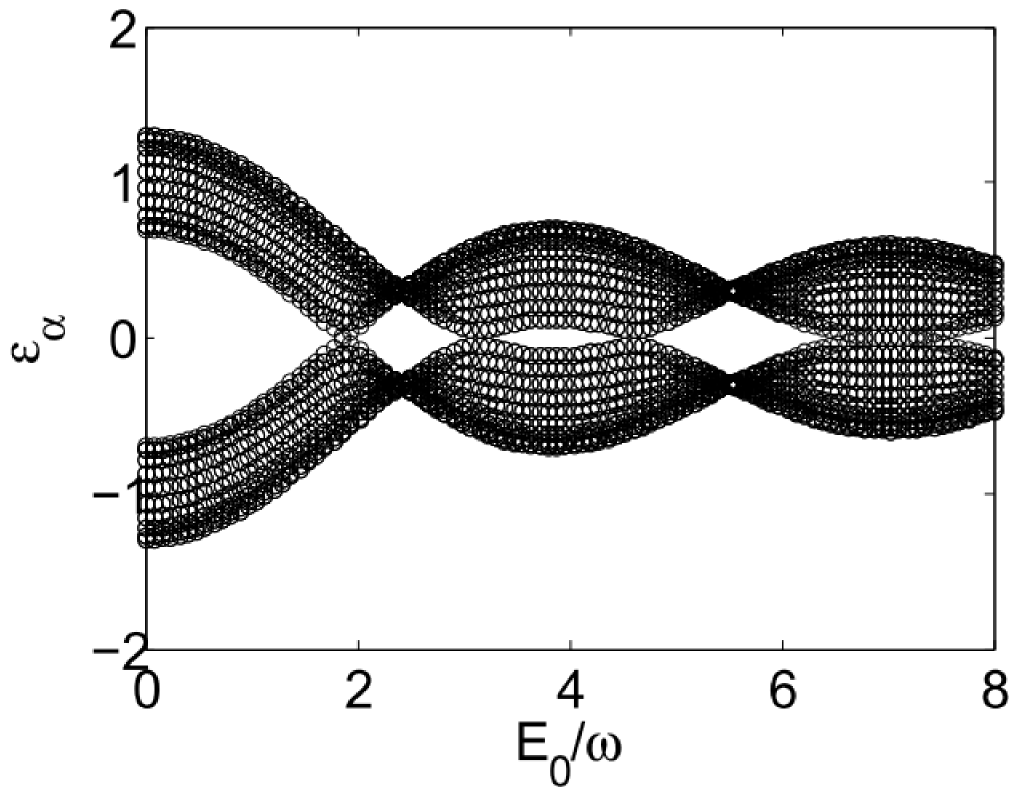
Cf. 1D dimer chain



$$H_{K(t)} = \tau \begin{pmatrix} 0 & \rho(k,t) \\ \rho(k,t)^* & 0 \end{pmatrix},$$

$$\rho(k,t) \equiv \lambda e^{-i(k+A_0 \sin(\omega t))b_0} + e^{i(k+A_0 \sin(\omega t))(a_0-b_0)}$$



Tight Binding Hamiltonian with AC Electric Field

Gomez-Leon et al. PRL **110**, 200403 (2013)

Summary and Outlook

- We have proposed a method to obtain topologically non-trivial bandstructures in a microcavity without an external magnetic field
- Determining time dependent coefficients of the tight binding model reproduces known results
- To be included: Spin dependence . Absence of magnetic field preserves spin-degeneracy