Photonic Topologic Insulator

Shugayev Roman

Lecture Notes S3,

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A photonic topological insulator, like an ordinary solid state insulator, has an energy gap separating the highest occupied electronic band from the lowest empty band. The surface (or edge in two dimensions) of a topological insulator, however, necessarily has electronic states corresponding to the Dirac points with zero bandgap which are protected by time reversal symmetry. Like the integer Quantum Hall State, which has unique gapless chiral edge states, the surface (or edge) states of a topological insulator are topologically protected and exhibit a conducting state with properties that are unlike any other known 1D or 2D electronic systems.

By analogy with electronic phenomena these surface states may be understood in terms of the skipping orbits that photons undergo as their “cyclotron-like” orbits bounce off the edge. Importantly, the states responsible for this motion are *chiral* in the sense that they propagate in one direction only along the edge. These states are insensitive to disorder because there are no states available for backscattering—a fact that underlies the perfectly quantized electronic transport in the quantum Hall effect. The existence of such “one way” edge states is deeply related to the topology of the bulk quantum Hall state.

In the first part of his presentation Mikael Rechtsman describes the theory and experimental observation of surface state created Floquet-like topological insulator [1]. Originally, proposed Floquet insulator was thought to be able to take advantage of externally induced temporal variations [2]. However in the presented approach helicity, necessary to achieve z-reversal symmetry was achieved using arrays of helical waveguides.

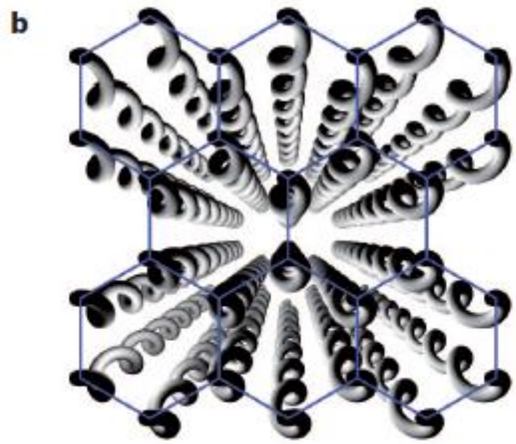

Figure1. Array of helical waveguides

In order to predict characteristic of Floquet states necessary simulation were performed. Band structure of the system was calculated using mix of periodic and finite boundary conditions. One particular feature that distinguishes surface states is their apparent lack of counter propagating surface states for a particular edge having nonzero group velocity

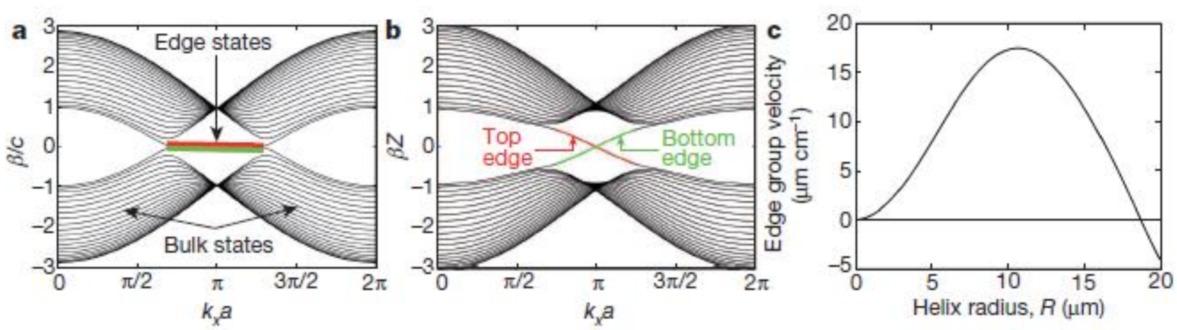

Figure 2 Simulation results for the waveguide array band structure (a,b) and group velocity of the edge state (c)

For experimental observation the fabricated structures were illuminated with the helical beam to couple to point- like edge state. The propagation was monitored at the array output facet Snapshots taken at different z locations confirm the motion of the state along the edge. Most importantly, when the surface state has encountered a strong defect (corner of the waveguide array) no scattering was observed – as

the backscattering is suppressed and there are no available states in the bulk to scatter to. This confirms the original hypothesis concerning Floquet state being immune to defects and irregularities.

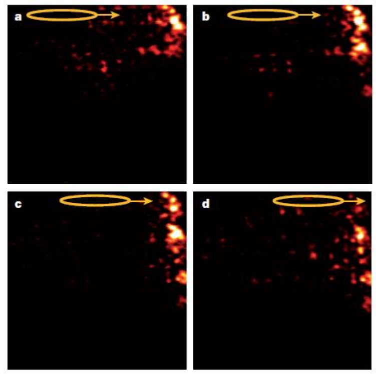

Figure 3 Experimental observations of topological states. Yellow arrow indicates position of the launched beam

Additionally since the side edge of the array has an armchair profile which should not allow surface states for the straight waveguides now confines light. This also serves as a confirmation of the helical nature of the waveguide states and their topological character.

In the second part of his talk Mikael Rechtsman described his work on strain induced magnetic field [3].

Hexagonal photonic lattices can be regarded due to their 2D+ geometry as a direct analogy of grapheme for photonics. Hence it is expected to exhibit similar effects related to their band structure and symmetry breaking as a graphene. One would also expect to see effects related to Quantum Hall effects discovered during early work in graphene. Furthermore the light propagating along the uniform direction of the photonic lattice diffracts in the same way as electrons in p orbitals of graphene evolve in time.

Magnetic fields in the strained graphene were demonstrated more than a decade ago [4]. Particularly it has been shown that for a specific distribution of a strain tensor vector potential corresponding to a constant magnetic field along with a complete absence of the electric field can be achieved.

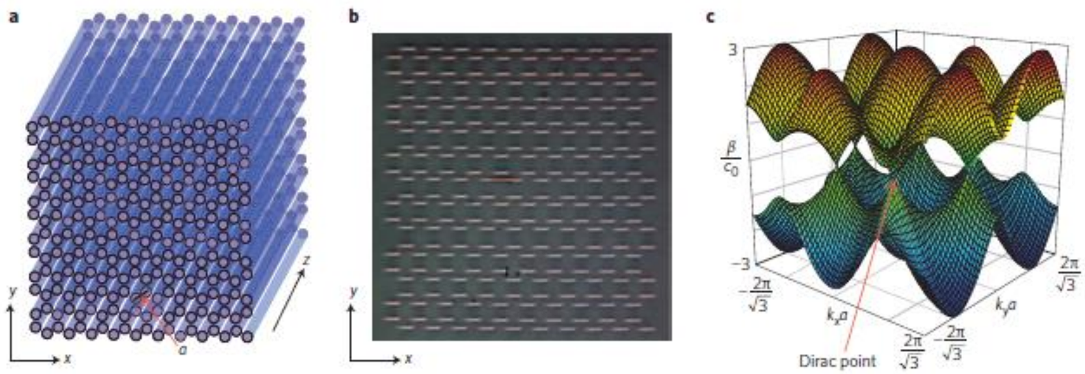

Fig.4 (a)Ideal honeycomb photonic lattice (b) fabricated structure (c) computed energy bands

In this work it was experimentally and theoretically shown that such affects can indeed be realized in the photonic lattice structures.

When magnetic fields are introduced in the wave equation Landau levels emerge in the spectrum. The available states congregate to a few discrete energy levels creating characteristic plateaus

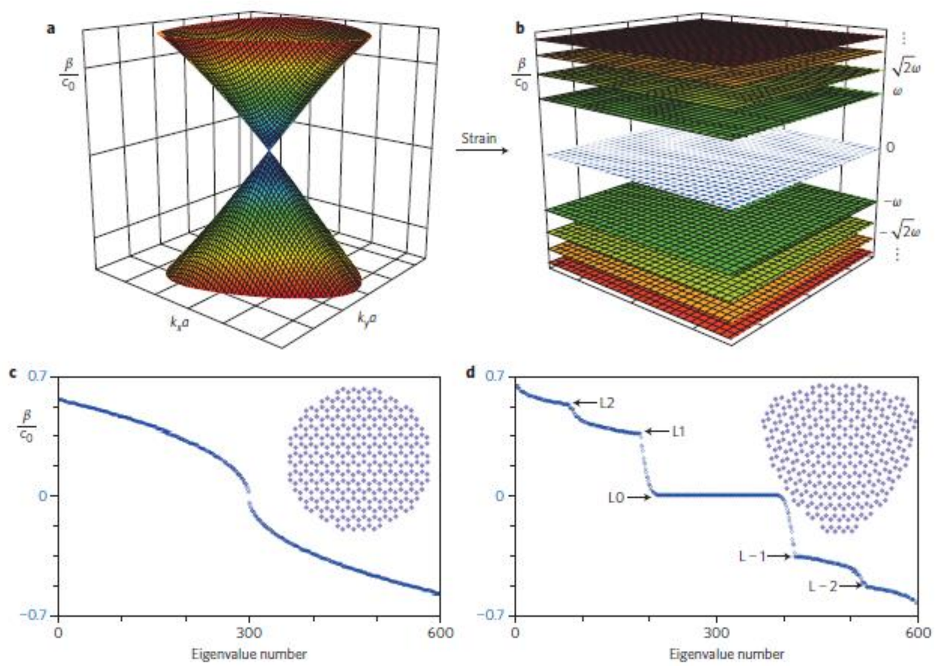

Fig. 5 Band structure of unstrained lattice (a) and lattice under strain (b)

The waveguides were fabricated using direct femtosecond writing technique. Instead of directly inducing the strain effect of strain-induced shift in lattice spacing is emulated by physically writing the waveguide with a “strained” spacing. The structure with various amount of emulated strain was probed with a laser source localized to the surface states. The results show strong correlation with degree of surface localization and the strain induced in the structure. Existence of discrete localized states, characteristic of quantum Hall effect, gives a strong indication of Landau level splitting and creation of bandgaps.

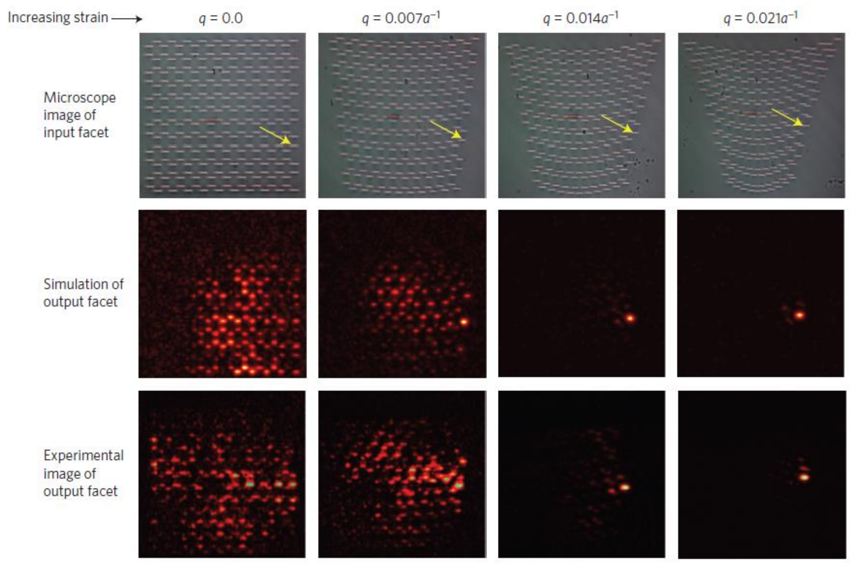

Fig.6 Experimental study of surface field localization as a function of induced strain

It was further verified that the effects are not induced by the leaky modes but a true strain induced effects. For this purpose a defect state corresponding to single waveguide with a changing refractive was introduced. By varying the refractive index of the defect state it was demonstrated that the leaky effects are indeed separate from the strain induced localization.

References:

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[4] "Shape, and low energy electronic structure of carbon nanotubes" Kane, C. L. & Mele, E. J. Size, *Physics. Review. Letters*. **78**,(1997).