Topological Delay Lines

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Delaying optical pulses in a compact footprint is of crucial importance for integrated photonics, but technologically challenging. Slow light waveguides, for example, are susceptible to disorder-induced backscattering (reducing transmission) and, due to momentum mismatch, require large adiabatic transition regions (increasing the overall footprint). In this talk, we will discuss our recent results in the context of non-reciprocal metamaterials based on magnetic bias and on time-varying elements supporting robust topological signal transport, with significant impact in the realization of compact, inherently robust, non-reciprocal waveguides with slow-light over broad bandwidths.

We start by studying the dynamics of nonreciprocal cavities. One might expect that using nonreciprocity one can excite a cavity over a broad bandwidth, while making it impossible for the cavity to decay, enabling large delay times [Tsakmakidis et al., Science 356, 1250 (2017)]. However, we develop a self-consistent coupled-mode theory for linear, time-invariant nonreciprocal cavities, and demonstrate that nonreciprocal cavities do not offer advantages over their reciprocal counterparts. Broadband fields cannot be forced into cavities, even if the feeding waveguide is unidirectional: these fields will be stored at the cavity entrance.

We then apply nonreciprocity in the form of magnetic bias or time-varying circuit elements to design topologically robust delay lines: we study immediate transitions into slow light waveguides, which due to nonreciprocity yield unity transmission over a large bandwidth, despite extreme momentum mismatch. As a result, adiabatic transitions are no longer required and footprints are reduced. We use our aforementioned nonreciprocal coupled-mode theory to derive concise analytical formulas for the group delay of such structures, and unearth interesting new phenomena, such as unidirectional Fabry-Pérot resonances enabled by the evanescent coupling of two nearby waveguide junctions. We connect these results to a broad class of topological photonic crystals, and show that this framework enables a better understanding of the dynamics of a series of sharp corners, and opportunities for robust, broadband delay lines.

Finally, we discuss the opportunities offered by time modulation in large circuit arrays to realize topological propagation and broadband slow light going beyond the delay-bandwidth limits in linear time-invariant systems.