Designing photonic topological insulators with quantum-spin-Hall edge states using topology optimization

Designing photonic topological insulators (PTIs) is highly non-trivial because it requires inversion of band symmetries around the band gap, which was so far done using intuition combined with meticulous trial and error. Here we take a completely different approach: we consider the design of PTIs as an inverse design problem and use topology optimization to maximize the transmission through an edge mode past a sharp bend. Two design domains composed of two different but initially identical $C_{6v}$-symmetric unit cells define the geometrical design problem. Remarkably, the optimization results in a PTI reminiscent of the shrink-and-grow approach to quantum-spin-Hall PTIs but with notable differences in the crystal structure as well as qualitatively different band structures and with significantly improved performance as gauged by the band-gap sizes, which are at least 50% larger than in previous designs. Furthermore, we find a directional $\beta$-factor exceeding 99% and very low losses for sharp bends. Our approach allows the introduction of fabrication limitations by design and opens an avenue towards designing PTIs with hitherto-unexplored symmetry constraints.