Topologically Protected Wavelength Conversion in a Photonic Valley Hall Insulator

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Abstract: We explore nonlinear effects in a topological photonic valley Hall insulator with a Kagome system at telecommunications wavelengths, we achieve topologically protected -12dB parametric conversion with sub-milliwatt input and 7dB enhancements at slow light region.

1. Introduction

Valley photonic crystal (VPC) waveguides, which support valley-dependent modes, exhibit robust transmission as long as strong perturbations or defects that break the symmetry and induce valley flipping are absent. Light traveling through these waveguides remains locked in a specific valley and propagates unidirectionally [1-3]. These valley-dependent modes are facilitated by the interface between VPCs with different valley Chern numbers, making VPCs a promising choice for designing waveguides with sharp bends. This immunity to backscattering is invaluable for various applications, including directional couplers and lasing. Beyond linear phenomena like transmission and directional couplers, numerous papers have delved into the theoretical exploration of nonlinear behavior within valley Hall topological states of light, including phenomena such as second harmonic generation [4,5]. This paper, however, takes an experimental approach to investigating nonlinear occurrences within a topologically protected valley Hall boundary state. Specifically, we demonstrate topologically protected optical parametric wavelength conversion within a valley Hall photonic crystal. Additionally, we present observations supporting the existence of slow light enhancement at the edge of the boundary state.

2. Results

The honeycomb unit cell, consisting of three circular holes, serves as the fundamental building block for creating the topological valley insulator, as depicted in Fig. 1(a). The distance between near blocks, *b,* can be modified by either reducing or increasing it. This adjustment leads to the breaking of inversion symmetry when b differs from b_0==$a/(2\sqrt{3})$ and change of topological Chern number. We have introduced a domain wall between two valley surface-wave photonic crystals. The upper domain has a parameter value of b=0.9b_0, while the lower domain has b=1.1b_0. The band diagram shown in Fig. 1(b) reveals the presence of valley-polarized topological edge states, indicated by the red line within the band gap. These edge states propagate exclusively in the K and K' valleys. The black lines in Figure 1(b) represent the bulk states of the system. The grey region in Figure 1(b) corresponds to the light cone within the cladding for a slab in the z-direction. The mode shape for the boundary state fixed at K and K' is confined to the domain wall. photonic valley Hall insulator with straight and zig zag interfaces is implemented using ultra-silicon-rich nitride which has a high Kerr nonlinearity of 2.8×10^{-13} cm^2/W [6].

The transmission is measured as shown in Fig. 2(a) for the Kagome photonic crystals featuring both straight (blue line) and zigzag (magenta line) interfaces. It is evident from the graph that both devices exhibit similar transmission spectra, encompassing a band gap within the wavelength range of 1511 nm to 1528 nm. The parametric wavelength conversion is measured on the sample with a straight boundary as shown in Fig. 2(b), which varies as the peak pump power is increased from 0.48W, 0.60W, 0.75W to 0.93W. Within these spectra, the pump wavelength is fixed at 1526 nm, and the signal wavelength is set at 1528 nm. Figure 2(c) is the experimentally measured conversion efficiency for various input pump wavelengths. The blue star in the graph represents a pump wavelength of 1528 nm, while the red circles and black squares correspond to 1526 nm and 1524 nm, respectively.

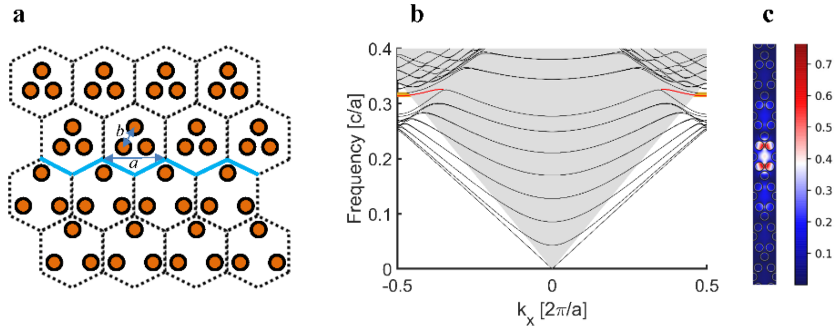

Fig. 1. Topologically protected domain wall between two different valley photonic crystals. (a) Schematical design for the sample with the topological boundary (b) Energy bands (c) Eigen mode for the boundary state.

At a pump wavelength of 1528 nm, the measured conversion efficiency is -18dB at a peak pump power of 0.9W (average power of 90μW). In contrast, for pump wavelengths of 1526nm and 1524nm, the conversion efficiency is -25dB under the same peak power conditions. The enhanced conversion efficiency observed at 1526nm arises from the slow light effect as the pump wavelength approaches the red band edge. The blue and black stars in Fig. 2(c) respectively correspond to the straight and zigzag type respectively; The conversion efficiencies are similar, indicating that the sharp edge existence does not reduce the nonlinear conversion efficiency on the topological boundary wall states as a result of topological protection. In conclusion, the device's CMOS-compatibility combined with its efficient, low-power operation at telecommunication wavelengths, holds significant implications towards their application in topologically protected light sources and nonlinear optical information processing.

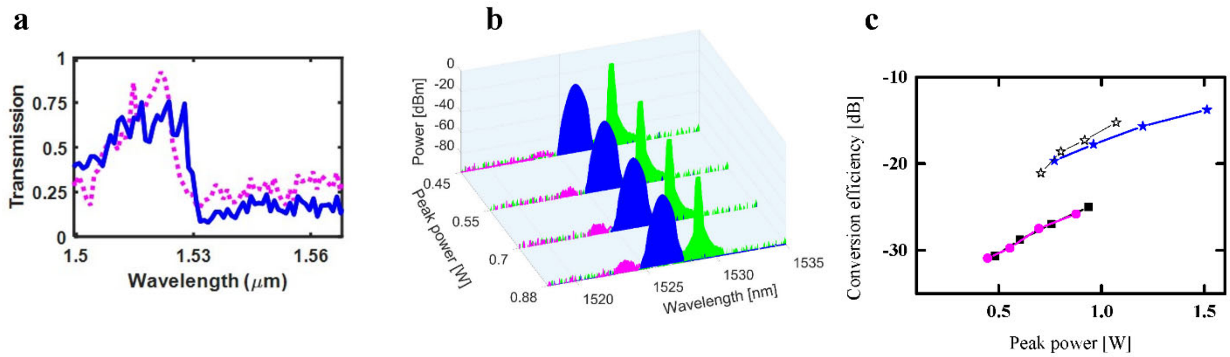

Fig. 2. Topologically protected nonlinear parametric wavelength conversion. (a) Transmissional spectrum for straight interface(blue) and zigzag type(red) (b) Four wave mixing for pump(blue), signal(green), and idler(red) (c) Retrieved conversion efficiency for the straight interface (solid points: star (1528nm), square(1526nm), circle(1524nm)) and zigzag interface (blank stars).

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