Thermo-optic control of a topological zero mode

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Abstract: We explore the thermo-optic-induced delocalization of a topological mode in a Su-Schrieffer-Heeger (SSH) system featuring a domain wall, and demonstrate modulation of the idler signal generated via nonlinear parametric wavelength conversion, governed by thermo-optic effects. © 2025 The Author(s)

1. Introduction

Dimerized systems described by the Su-Schrieffer-Heeger (SSH) model exhibit non-trivial topological properties for larger inter-cell coupling coefficients(w) than intra cell coupling coefficients(v). A localized topological boundary state exists between the two different bulk topology distributions with Zak phase π and $-\pi$. It is a zero mode with center point energy state [1].The nonlinear Kerr effect can be interpreted as an effective on-site disorder that depends on the peak power of the incident light. This effect may break the chiral symmetry, thereby influencing the transmission properties of a topological waveguide [2]. The chiral symmetry breaking induced by Kerr nonlinearity disrupts the condition of zero amplitude in the odd-numbered waveguides, a hallmark of topological protection. The existence of the topological boundary mode relies critically on preserved chiral symmetry. However, the mode can persist even in the presence of symmetry-breaking perturbations, provided that the energy of the zero mode does not surpass the topological bandgap introduced by the defect. We experimentally observe the thermo-optic modulation of a topological mode in a Su-Schrieffer–Heeger (SSH) waveguide system featuring a domain wall. Our measurements reveal modulation in the optical transmission of the SSH waveguide upon application of a thermo-optic signal. Furthermore, four-wave mixing (FWM) experiments demonstrate that the generated idler also exhibits sensitivity to thermo-optic perturbations. These results may form the foundation for a new class of optical modulators and switches based on topologically engineered nonlinear photonic systems. Thermal energy can alter the structural properties of condensed matter systems, leading to variations in the material's refractive index. Typically, the refractive index change due to thermal effects surpasses that caused by Kerr nonlinearities, which require several watts of optical power to achieve a comparable index shift. In the context of a Su-Schrieffer-Heeger (SSH) topological boundary system, this allows for substantial on-site perturbations at lower powers—sufficient to overcome the forbidden band barrier ($w-v$) through thermal effects.

2. Experimental observations of thermo-optic control of the optical transmission

The SSH device integrated with a nanoheater was fabricated by first depositing 300 nm of ultra-silicon-rich nitride (USRN) using chemical vapor deposition. Electron-beam lithography followed by inductively coupled plasma etching was used to pattern the waveguide structures. A 1.6 µm layer of SiO_2 was deposited as an overcladding. The nanoheater and contact pads were defined through photolithography, followed by platinum (Pt) deposition using electron beam evaporation and subsequent liftoff. Platinum contact pads were connected to the nanoheater, and wire bonding was used to connect the device to an external current source for thermal modulation as shown in Fig. 1(a).

We investigated the thermo-optic response of the SSH device by applying heat via the Pt nanoheater. A continuous-wave laser at a wavelength of 1563 nm (CL band) was coupled into the waveguide using tapered lensed fibers. A square RF signal at 30 Hz was used to drive the nanoheater, inducing localized heating at the domain wall. This modulation frequency is significantly lower than the thermal equilibrium time of the structure ($\tau \approx 7.5$–1.1 ns), ensuring sufficient time for the domain wall to reach thermal equilibrium.

The transmitted optical signal was measured using a high-speed InGaAs photodiode with a 5 GHz bandwidth. An RF signal with a voltage swing from 0 to 57 V was used to modulate the nanoheater, consuming approximately 0.47 W. As the RF voltage increases, the local temperature—and thus the refractive index—at the domain wall increases via the thermo-optic effect, leading to chiral symmetry breaking and topological mode delocalization. Fig. 1(b) shows that the transmission initially decreases as the topological mode approaches the bulk bands and increases again once the mode surpasses the bulk states, indicating re-localization. The increasing RF voltage leads to stronger modulation in transmission, directly correlating with increased thermal-induced refractive index changes. This behavior confirms that the topological mode can be thermally tuned, with delocalization and re-localization governed by the induced refractive index profile and resulting chiral symmetry breaking.

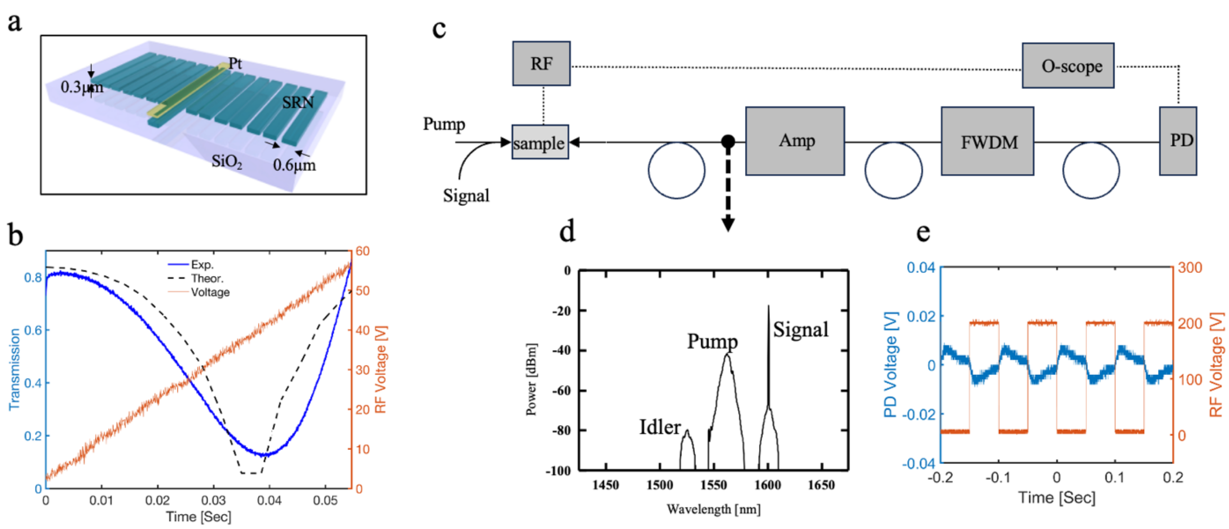

Fig. 1. (a) Schematic design of the SSH device with a Pt microheater above the domain wall. (b) Experimental (blue) and theoretical (black) transmission variation for the applied RF saw voltage (red). (c) Experimental setup used for nonlinear experiment. (d) Measured spectrum for the arrow position. (e) Oscilloscope measurement for PD signal of idler beam and RF trigger.

3. Thermo-optic control of four-wave mixing

To explore the influence of the thermo-optic effect on nonlinear optical performance, we performed four-wave mixing (FWM) experiments. FWM occurs when degenerate pump and signal photons co-propagate in a nonlinear medium, generating an idler (and signal) photon via third-order nonlinearity. The experimental setup is illustrated in Fig. 1(c). A 1 ps pulsed pump centered at 1562 nm and a continuous-wave (CW) signal at 1600 nm are combined using a 3 dB coupler and launched into the SSH device using tapered lensed fibers. The output spectrum is captured by an optical spectrum analyzer (OSA) as shown in Fig. 1(d), and an idler is observed at 1525 nm, satisfying energy and momentum conservation. The FWM output is amplified using an optical amplifier. An FWDM is used to isolate the idler wavelength for further study. As shown in Fig. 1(c), we measured the filtered idler power while applying an RF voltage to the nanoheater to induce localized heating. Fig. 1(e) shows that the idler power exhibits a clear modulation in response to temperature changes caused by the RF signal.

Compared to linear transmission experiments, the rise time of the nonlinear modulation is measured to be 0.07 seconds—approximately four times slower. This delay is likely due to the slower thermal response of the nonlinear optical interaction. Specifically, while the 1 ps pump pulses contribute minimal heating due to their low average power, the CW signal induces gradual heating of the waveguide core via optical phonon interactions. This process is slower than direct electrical heating due to the inherently sluggish thermal relaxation dynamics of amorphous silicon materials, which is similar in nature to USRN.

We have experimentally observed thermo-optic control of a topological zero mode. The transmission and four-wave mixing dynamics are observed to vary based on a thermal input through a Pt microheater above the domain wall and may form a new mechanism for modulation or switching of light.

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4. References

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