Optical switching of topological phase in a perovskite polariton lattice

Rui Su1*†, Sanjib Ghosh1†, Timothy C. H. Liew1,2*, Qihua Xiong3,4*.

Strong light-matter interaction enriches topological photonics by dressing light with matter, which provides the possibility to realize active nonlinear topological devices with immunity to defects. Topological exciton polaritons—half-light, half-matter quasiparticles with giant optical nonlinearity—represent a unique platform for active topological photonics. Previous demonstrations of exciton polariton topological insulators demand cryogenic temperatures, and their topological properties are usually fixed. Here, we experimentally demonstrate a room temperature exciton polariton topological insulator in a perovskite zigzag lattice. Polarization serves as a degree of freedom to switch between distinct topological phases, and the topologically nontrivial polariton edge states persist in the presence of onsite energy perturbations, showing strong immunity to disorder. We further demonstrate exciton polariton condensation into the topological edge states under optical pumping. These results provide an ideal platform for realizing active topological polaritonic devices working at ambient conditions, which can find important applications in topological lasers, optical modulation, and switching.

INTRODUCTION

Topological insulators represent a new class of materials that are insulating in the bulk but show the hallmark property of topological conducting edge states, which are endowed with topological robustness against disorder, as a consequence of the nontrivial topology of the bulk (1). Early demonstrations of topological insulators date back to the discovery of quantum Hall effect in condensed matter in 1980s (2), and the concept of topology was later advanced to various fields including microwaves (3, 4), photonics (5, 6), cold atoms (7), acoustics (8), and mechanics (9). In particular, initially proposed by Haldane and Raghu (3), the extension of topology into photonics has revolutionized the design principle of novel optical devices, which allow robust edge transport with strongly suppressed backscattering loss (4, 10, 11), robust lasing (12–14), and harmonic generation (15), as well as robust propagation of single photons in the quantum regime (16, 17). Despite the remarkable success of introducing topology into photonics for robustness, the properties of the topological photonic structures are usually fixed once fabricated. To develop a broader range of applications, the realization of reaching distinct topological phases in a single system is highly demanded (18–21). In condensed matter, several strategies have been experimentally used to gain access to distinct topological phases via spin–orbit coupling (22) and electrical field (23), which lay the foundation for realizing topological transistors. Similar achievements have also been experimentally demonstrated with microwaves (18), mechanics (24), and electric circuits (25, 26). However, this access to distinct phases without changing the topological structure remains experimentally nontrivial in the optical frequency, particularly the visible spectral range, which demands subwavelength architectures (27).

Recently, microcavity exciton polariton systems have emerged as a unique platform for topological photonics (11, 12, 28–34), representing a linking bridge between photonics and condensed matter. Exciton polaritons are half-light, half-matter quasiparticles, which result from the strong coupling between cavity photons and excitons. Compared with pure photonic systems, the light–matter hybridization provides them strong nonlinearity and enhanced response to external stimuli. Topological exciton polaritons have been experimentally demonstrated in GaAs microcavities (11, 12, 35) and the more recent monolayer WS2 (33) but demanded cryogenic temperatures, and their topological phase is usually fixed. With the recent demonstration of polariton condensation in lattices (36, 37), the halide perovskite system (38–42) emerges as a promising candidate for room temperature active topological insulators with exciton polaritons. Exciton polariton topological insulators with polarization-dependent phases were theoretically proposed before (30), while they have not been experimentally realized yet.

Here, we demonstrate an exciton polariton topological insulator with polarization-dependent phases in a one-dimensional (1D) perovskite lattice at room temperature, which is based on the Su–Schrieffer–Heeger (SSH) model by coupling the s-orbital type polariton modes with a zigzag chain of nanopillars. By using the anisotropy and strong photonic spin–orbit coupling from the halide perovskite microcavity (36, 40, 41), we demonstrate the emergence of topological polariton edge states locating inside a large topological gap of ~10 meV, which is essential for nonlinear devices that seek to use energy shifts to realize switches and information processing while remaining topological (32). In the meantime, it allows distinct topological phase switching between topologically nontrivial phase and topologically trivial phase by means of polarization switching. Furthermore, we show the topological robustness of the polariton edge states in the presence of structural imperfections with onsite energy variations, and exciton polaritons can condense into the topological edge states under optical pumping at room temperature.
RESULTS
Mechanism of polarization-dependent topological phases in the perovskite zigzag lattice

In our experiment, the CsPbBr₃ perovskite active medium is grown by a vapor-phase deposition technique as discussed before (38, 43, 44), with excellent optical properties and flat surface (see the Supplementary Materials). Robust exciton polariton condensates have been previously demonstrated in this type of perovskite microcavity at room temperature (36, 39). Here, we fabricate an active SSH zigzag chain with a perovskite microcavity consisting of 40 identical coupled nanopillars (20 unit cells) with a diameter of 0.5 μm and a center-to-center distance of 0.475 μm (Materials and Methods), which is schematically shown in Fig. 1A. The zigzag chain is created by patterning the spacer layer of poly(methyl methacrylate) (PMMA) inside the cesium lead bromide perovskite planar microcavity (Fig. 1B) with a cavity detuning of ~140 meV. Our halide perovskite system is known to exhibit birefringent behavior at room temperature due to the orthorhombic structure of the perovskite, leading to the intrinsic anisotropy along different crystalline axes (36). Unlike previous demonstrations of topology by using p-orbital type polariton modes with a limited topological gap and a fixed phase at 4 K (12), here, we create the topology with s-orbital type polariton modes with a substantially large topological gap and allow topological phase switching at room temperature, as a consequence of the intrinsic anisotropy and strong photonic spin-orbit coupling of the perovskite system. As shown in Fig. 1A, we intentionally align the zigzag chain at an angle of 45° with respect to one of the perovskite crystalline axes (fig. S2). In this case, the polariton hopping directions inside the lattice are exactly along the major crystalline axes. In the SSH model, the unit cell is composed of two sites, and the Hamiltonian can be written in the tight binding limit as

$$\hat{H} = \sum_{\mu \nu}(t_{\mu\nu} \hat{b}_{\mu}^\dagger \hat{b}_{\nu} + t_{\nu\mu}^* \hat{b}_{\nu}^\dagger \hat{b}_{\mu} + h.c.)$$

where $\hat{a}_{\mu}(\hat{a}_{\mu}^\dagger)$ and $\hat{b}_{\nu}(\hat{b}_{\nu}^\dagger)$ are the polariton annihilation (creation) operators in the sublattices $a$ and $b$ in the $n$th unit cell, respectively; $t$ and $t'$ represent the intracell and intercell hopping strengths, respectively. The Hamiltonian reveals two topologically distinct phases for the cases of $t > t'$ (trivial) and $t < t'$ (topologically nontrivial), and the difference can be directly distinguished by the topological invariant, i.e., the winding number $w$ of phase $\phi(k)$ across the Brillouin zone

$$w = \frac{1}{2\pi} \int \frac{\partial \phi(k)}{\partial k} dk$$

$w = 1$ for the topologically nontrivial phase ($t < t'$) and $w = 0$ for the trivial phase ($t > t'$). In our perovskite system, because of the intrinsic anisotropy and strong photonic spin-orbit coupling (36), the polariton effective mass is strongly polarization dependent and $30$ of $8$
direction dependent. As shown in Fig. 1 (C and D), the dispersions from a perovskite planar microcavity exhibit distinct curvatures under different polarizations and directions (along X and Y), suggesting different effective masses that are linked to the polariton hopping strengths (Materials and Methods). From the fitting of the dispersions, we extract distinct effective masses of $m_{xx} = 1.5188 \times 10^{-5} m_e$ (X direction in X polarization, blue line in Fig. 1C), $m_{xy} = 2.2335 \times 10^{-5} m_e$ (X direction in Y polarization, red line in Fig. 1C), $m_{yy} = 1.5188 \times 10^{-5} m_e$ (Y direction in Y polarization, red line in Fig. 1D), and $m_{yx} = 2.1094 \times 10^{-5} m_e$ (Y direction in X polarization, blue line in Fig. 1D), respectively. In this scenario, the hopping strength ratios between intracell and intercell appear to be different with X and Y polarizations, where $t_Y/t_Y' = 0.68$ for Y polarization and $t_X/t_X' = 1.39$ for X polarization. This suggests that the system exhibits a topologically nontrivial phase with Y polarization ($w = 1$), while it shows a trivial phase with X polarization ($w = 0$). Figure 1 (E and F) show the calculated band structures for a zigzag chain of 40 sites with X and Y polarizations. Topological gaps open in both X and Y polarizations, while the most notable difference is that topological states exist in the latter case inside the topological gap and spatially localize at the two end sites of the zigzag chain. The localization nature is strongly determined by the hopping strength ratio, where the calculated wave function distribution of the topological state exhibits an exponential decay behavior of $(t_Y/t_Y')^n$ along the pillars as highlighted in the inset of Fig. 1F.

**Experimental demonstrations of polarization-dependent topological phases**

To experimentally demonstrate the emergence of topological polariton edge states and polarization-dependent topological phases, we directly probe the band structure of the zigzag chain by mapping the energy-resolved momentum-space photoluminescence spectra. The zigzag chain is nonresonantly excited with a continuous-wave laser of 457 nm (2.713 eV) at room temperature. Figure 2 (A and B) show the emission collection schemes from the edge and body center of the lattice, which cover around 10 unit cells, respectively. Figure 2C shows the experimental photoluminescence mapping in X polarization collected from the edge. Because of the subwavelength size of the nanopillars, the coupling between s-mode polaritons gives rise to the s band ranging from 2.24 to 2.30 eV, representing the

![Fig. 2. Experimental demonstrations of polarization-dependent phases in a perovskite zigzag lattice.](http://advances.sciencemag.org/)

(A and B) Schematic diagrams of excitation and emission collection from the edge and the body center, covering 10 unit cells, respectively. The red dashed line represents the emission collection area for the energy-resolved spatial images in (G) and (H). (C and D) Energy-resolved momentum-space polariton dispersions of the perovskite zigzag lattice collected from the edge in (A) for X and Y polarizations, respectively. The gray dashed lines highlight the topological gap opening inside the s band. Topological polariton edge states only exist inside the topological gap in Y polarization. (E and F) Theoretically calculated momentum-space polariton dispersions collected from the edge for X and Y polarizations, respectively. (G and H) Energy-resolved spatial images collected along the red dashed lines in (A) for X and Y polarizations, respectively. It shows localized emission at the end site with some decay to nearby pillars in Y polarization. Inset to (H): Typical real-space image at the edge energy, showing localized emission at the end site. (I and J) Energy-resolved momentum-space polariton dispersions of the perovskite zigzag lattice collected from the body center in (B) for X and Y polarizations, respectively.
major band in the dispersions. At higher energies above 2.32 eV, the $p$ band arising from $p$-mode polaritons can also be seen. Within the $s$ band, the anisotropic hopping of polaritons results in a large topological gap opening of $\sim 8$ meV as highlighted with gray dashed lines, which is in good agreement with the theoretically calculated dispersion shown in Fig. 2E. The spatial image collected along the red dashed line (Fig. 2A) further elucidates the topological gap opening nature, where no emission is observed inside the topological gap, but the emission from the pillars can be observed outside the topological gap within $s$ band. As a notable comparison, the emission collected from the edge in $Y$ polarization (Fig. 2D) exhibits distinct features, where a similar topological gap opening of $\sim 10$ meV exists inside the $s$ band but with the additional emergence of discrete states inside the topological gap at $k = 4.5$ $\mu$m$^{-1}$ (highlighted with gray dashed lines). These discrete states correspond to the emergence of topological polariton edge states in $Y$ polarization, which is in good agreement with theory (Figs. 1F and 2F). The large topological gap opening of $\sim 10$ meV is at least five times larger than previous demonstrations with polaritons (11, 12). The nontrivial nature can be further experimentally clarified by the real-space image at the edge state energy and energy-resolved spatial image (Fig. 2H), which exhibits strongly localized emission at the end site. Because of the limited difference between intracell and intercell hopping strength ($t_Y/t_Y' = 0.68$), the edge state wave function exhibits some decay to nearby pillars along the red dashed lines (Fig. 2A). Similar results can also be realized at the other end of the zigzag chain as shown in fig. S3. To further confirm the emergence of topological states localized at the edge, as shown in Fig. 2 (I and J), the energy-resolved emission mappings collected from the body center (Fig. 2B) exhibit similar topological gaps inside the $s$ band but without any discrete states inside the topological gap in both $X$ and $Y$ polarizations. These results together unambiguously suggest that the perovskite zigzag lattice works as a topologically trivial insulator in $X$ polarization but as a topologically nontrivial insulator in $Y$ polarization, which can be switched by changing the linear polarization.

One of the most crucial features of topologically nontrivial states is their robustness against fabrication imperfections and deformations, which provide the promising future in real-world applications.

**Fig. 3. Topological edge states in the presence of structural deformations.** (A and B) Experimental energy-resolved momentum-space polariton dispersion and spatial image of an inhomogeneous perovskite zigzag lattice in $Y$ polarization. The arrow in (A) shows the topological edge state that locates at the upper limit of the topological gap. The dashed lines in (B) highlights the onsite polariton energy variations in the pillars. The intensity of spatial dispersion from 2.22 to 2.275 eV in (B) is magnified by two times for visibility. (C) Theoretical photon potential variations in the pillars compared with a homogeneous photon potential system. (D and E) Theoretically calculated energy-resolved momentum-space polariton dispersion and spatial image of an inhomogeneous perovskite zigzag lattice in $Y$ polarization by including the photon potential variations in (C). The arrow in (D) shows the topological edge state that locates at the upper limit of the topological gap. (F) Theoretically calculated energy-resolved momentum-space polariton dispersion of a homogeneous perovskite zigzag lattice in $Y$ polarization, showing topological edge states exactly in the middle of the topological gap.
In the SSH model, the topological edge states are protected by the chiral symmetry to ensure that topological modes always appear in the middle of the topological gap and localize in the edges. Disorder in hopping strengths will not break the chiral symmetry and only changes the size of the topological gap; thus, edge states are robust against this type of disorder (12, 45, 46). One of the most sensitive perturbations to the topological edge states is the onsite energy variations that could break the chiral symmetry and shift the topological edge modes toward trivial bulk states (12, 46). It is known that more significant disorder exists in perovskite systems than in the previous GaAs system. Here, we demonstrate this topological robustness protected by the topological gap in the presence of certain structural deformations, which lead to onsite energy variations in the pillars. As shown in Fig. 3A, with an inhomogeneous perovskite polariton lattice (high-resolution atomic force microscopy image as shown in fig. S4), the polariton dispersion in Y polarization still exhibits a typical topological gap with edge states inside, while the edge states are not in the middle of the topological gap but locate at the upper limit of the topological gap, suggesting the existence of perturbations that effectively breaks the chiral symmetry. From the energy-resolved spatial image in Fig. 3B, we observe clear onsite energy variations as highlighted by the dashed line and the edge state still remains more localized in the edge, suggesting the topological robustness in the presence of these perturbations in the system. Theoretically, as shown in Fig. 3C, we include photon potential variations in the pillars within the range of ±17 meV into a homogeneous system and couple them with perovskite excitons, leading to onsite polariton energy variations within the range of ±4 meV in the pillars (Fig. 3, B and E). The theoretically calculated polariton dispersion and energy-resolved spatial image agree well with our experimental observations, as shown in Fig. 3 (D and E). Without any onsite energy variations that break the chiral symmetry, the topological edge states will remain as zero energy modes exactly in the middle of the topological gap, as theoretically shown in Fig. 3F.

**Exciton polariton condensation into topological polariton edge states**

An interesting feature for exciton polaritons in the strong coupling regime is that they are able to show nonequilibrium condensation at high temperatures, accompanied by laser-like emission. Because of the driven-dissipative nature of polaritons, in which the steady state is fixed by the interplay between gain and loss, polaritons can condense to nonground states (11, 12, 39), which has been shown in perovskite lattices recently (36). To achieve polariton condensation into the topological edge states, we select a sample with exciton photon detuning of $\sim -140$ meV, in which polaritons favor relaxation into the edge state mode. The system is nonresonantly pumped with a pulsed laser to reach the condensation regime. As shown in Fig. 4A, under low excitation power of 0.5 $P_{th}$, where $P_{th}$ is the threshold pump fluence, the perovskite lattice exhibits a typical dispersion in...
Y polarization with edge states in accordance with Fig. 2H, while under strong excitation power of 2.0 $P_{th}$, polaritons tend to condense into selected states with maximum gain. As shown in Fig. 4B, the emission is mainly from the edge states at $k = 4.5$ μm$^{-1}$ with much more intense intensity, suggesting the emergence of condensation into the polariton edge states. Polariton edge state condensation could be further revealed by the real-space image (Fig. 4D), where it shows localized emission at the end site with some decay to nearby sites. It is worth noting that we also observe much weaker emission from a higher state, corresponding to the state at the top of s band at $k = 6.2$ μm$^{-1}$, which could be confirmed from the wave vector and also the real-space image (Fig. 4C). The simultaneous condensation into this state could be due to the overlapping of the large pump spot with the bulk mode, which provides the gain to condense. To characterize the transition quantitatively, we demonstrate the evolution of emission intensity, linewidth, and peak energy at the edge state as a function of pump fluence. As shown in Fig. 4E, with the increase in pump fluence, the emission from the edge state exhibits a clear nonlinear increase by three orders with a threshold of $P_{th} = 10$ μl/cm$^2$. Correlatively, the linewidth of the polariton edge state displays a clear drop by around three times from 7.2 to 2.6 meV across the threshold. In the meantime, the energy of the polariton edge state emission exhibits a clear continuous blueshift trend by increasing the pump fluence (Fig. 4F) as a consequence of repulsive interaction of polaritons and reservoir. All the above evidence together shows the emergence of polariton condensation into the edge states.

**DISCUSSION**

We have unambiguously demonstrated a 1D exciton polariton topological insulator in a perovskite zigzag chain at room temperature. By using the anisotropy and strong photonic spin-orbit coupling of halide perovskite microcavities, we demonstrate that the phase of the zigzag chain could be switched between topologically nontrivial and topologically trivial phase by means of polarization switching. In the topologically nontrivial phase, the topological polariton edge states remain robust against structural imperfections with onsite potential variations and protected by the topological gap. In addition, we also demonstrate that exciton polaritons could condense to this particular topological edge state with optical pumping at room temperature. Our work reveals a new avenue to reach distinct topological phases in a single structure by photonic spin-orbit coupling, and we anticipate that more degrees of freedom to reach distinct phases can be achieved with synthetic photonic spin-orbit coupling (47). Our results represent an important step toward not only exploring fundamental topological polaritonics but also developing switchable optical devices with robustness.

**MATERIALS AND METHODS**

**Perovskite lattice fabrication**

A total of 20.5 parts of titanium oxide (54.6 nm) and silicon dioxide (87.6 nm) were deposited using an electron beam (e-beam) evaporator as the bottom distributed Bragg reflector (DBR). The 80-nm-thick cesium lead bromide perovskite was grown with a vapor-phase deposition method as described in our previous reports (43, 44). In detail, CsPbBr$_3$ powders (0.15 g) as the source and muscovite mica as the substrate were respectively put in the middle and downstream of a quartz tube, which was mounted in a zone furnace (Lindberg/Blue MTF55035C-1). The quartz tube was pumped down to a base pressure of 50 mtorr and then continuously flowed with 30 sccm (standard cubic centimeters per minute) high-purity N$_2$. The temperature and pressure inside the quartz tube were maintained at 600°C and 40 torr, and the whole synthesis time was set to 20 min to obtain high-quality perovskite crystals on mica substrates. The perovskite crystal was then transferred onto the bottom DBR by a dry-transfer process with Scotch tape. A thin layer of PMMA spacer with a thickness of 60 nm was spin-coated onto the perovskite layer and patterned into a zigzag chain with a standard e-beam lithography process (36). Another 10.5 pairs of silicon dioxide (87.5 nm) and tantalum pentoxide (60.2 nm) were deposited onto the structure by the e-beam evaporator, acting as the top DBR to complete the fabrication process.

**Optical spectroscopy characterizations**

The energy-resolved momentum-space and spatial photoluminescence mappings were conducted using a homebuilt angle-resolved photoluminescence setup by imaging the Fourier plane and real-space plane as described in previous reports (38, 42). A linear polarizer and a half-waveplate were used to select the emission linearly polarized along the X or Y direction of the perovskite zigzag lattice. A 50× objective [numerical aperture (NA), 0.75; Mitutoyo] was used to collect the emission from the perovskite lattice, which was sent to a 550-mm focal length spectrometer (HORIBA iHR550) with a grating of 600 lines/mm and a liquid nitrogen–cooled charge-coupled device of 256 pixels × 1024 pixels. In the linear region, a continuous-wave laser (457 nm) with a pump spot of ~10 μm was used to pump the perovskite lattice. In the real-space plane, a spatial filter was used to select the emission area of the lattice. In the nonlinear regime, the perovskite lattice was pumped nonresonantly with a pulsed laser (400 nm, pulse duration of 100 fs, repetition rate of 1 kHz) with a pump spot of ~15 μm.

**Theoretical calculations**

We consider an anisotropic model for photons to describe the polaritons in perovskite. The anisotropy is considered in the form of different effective masses along two perpendicular directions to the crystal axis

$$i\hbar \frac{\partial \Phi}{\partial t}(\vec{r}, t) = \left[ -\hbar^2 \frac{\partial^2}{2m_y \partial y^2} - \hbar^2 \frac{\partial^2}{2m_x \partial x^2} + V(\vec{r}) \right] \phi(\vec{r}, t) + \frac{g_0}{2} \chi(\vec{r}, t)$$

(1)

where the photon Hamiltonian is given by $H_p = -\hbar^2/(2m_p) \partial_r^2 - \hbar^2/(2m_x) \partial_x^2 + V(\vec{r})$. The potential $V(\vec{r})$ defines the lattice as the
zigzag chain (section S5). We diagonalize the Hamiltonian to obtain the modes $\varphi_n$ and the energy eigenvalues $\varepsilon_n$. We calculate the dispersion from the formula

$$I(E, k) = \frac{1}{\pi \Delta_k \Delta E} \sum q \langle \varphi_q | \varphi_k \rangle^2 \exp \left[ -\frac{(E - \varepsilon_q)^2}{\Delta E} - \frac{k^2 - q^2}{\Delta k^2} \right]$$

(4)

where $\Delta_k$ and $\Delta E$ are the energy and momentum resolutions in the dispersion. $\langle \varphi_q | \varphi_k \rangle$ is the Fourier transform of the eigenfunction $\varphi_q (r)$. Experimentally, we find that for one polarization $m_1/m_2 > 1$, while for the other one it is the opposite $m_2/m_1 < 1$. For our numerical simulation, we considered $E_{\text{ex}} = 2407.7$ meV and $g_0 = 120$ meV. For topological phase in Y polarization, $m_1/m_2 = 0.68$, $m_2 = 2.2335 \times 10^{-5} m_e$, and $m_1 = 1.5188 \times 10^{-5} m_e$. For trivial phase in X polarization, $m_1/m_2 = 1.3889$, $m_1 = 1.5188 \times 10^{-5} m_e$, and $m_2 = 2.1094 \times 10^{-5} m_e$ (the electron mass).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/7/2/eabf8049/DC1

REFERENCES AND NOTES

1. M. Z. Hasan, C. L. Kane, Colloquium: Topological insulators. Rev. Mod. Phys. 82, 3045–3067 (2010).
2. K. V. Klitzing, G. Dorda, M. Pepper, New method for high-accuracy determination of the fine-structure constant based on quantized hall resistance. Phys. Rev. Lett. 45, 494–497 (1980).
3. F. D. M. Haldane, S. Raghu, Possible realization of directional optical waveguides in photonic crystals with broken time-reversal symmetry. Phys. Rev. Lett. 100, 013904 (2008).
4. Z. Wang, Y. Chong, J. D. Joannopoulos, M. Soljačić, Observation of unidirectional backscattering-immune topological electromagnetic states. Nature 461, 772–775 (2009).
5. M. C. Rechtsman, M. J. Zeuner, Y. Plotnik, Y. Lumer, D. Podolsky, F. Dreisow, S. Nolte, M. Segev, A. Szameit, Photonic Floquet topological systems. Nature 496, 196–200 (2013).
6. M. Hafezi, S. Mittal, J. Fan, A. Migdall, J. M. Taylor, Imaging topological edge states in silicon photons. Nat. Photonics 7, 1001–1005 (2013).
7. G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, T. Esslinger, Experimental realization of the topological Haldane model with ultracold fermions. Nature 515, 237–240 (2014).
8. Z. Yang, F. Gao, X. Shi, X. Lin, Z. Gao, Y. Chong, B. Zhang, Topological acoustics. Phys. Rev. Lett. 114, 114301 (2015).
9. R. Süssstrunk, S. D. Huber, Observation of phononic helical edge states in a mechanical topological insulator. Science 349, 47–50 (2015).
10. A. B. Khanikaev, S. Hossein Mousavi, W. K. Tse, M. Kargarian, A. H. MacDonald, G. Shvets, Photonic topological insulators. Nat. Mater. 12, 233–239 (2013).
11. S. Kembhavi, T. H. Harder, O. A. Egorov, K. Winkler, R. Ge, M. A. Bandres, M. Emmerling, L. Warschew, T. C. H. Liew, M. Segev, C. Schneider, S. Höfling, Exciton-polariton topological insulator. Nature 562, 552–556 (2018).
12. P. St-Jean, V. Goblot, E. Galopin, A. Lemaître, T. Ozawa, L. Le Gratiet, I. Sagnes, J. Bloch, A. Amo. Lasing in topological edge states of a one-dimensional lattice. Nat. Photonics 11, 651–656 (2017).
13. B. Bahari, A. Ndao, F. Vallini, A. el Amili, Y. Faïman, B. Kanté, Nonreciprocal lasing in topological cavities of arbitrary geometries. Science 358, 636–640 (2017).
14. M. A. Bandres, S. Wittek, G. Harari, M. Parto, J. Ren, M. Segev, D. N. Christodoulides, M. Kajavikhan, Topological insulator laser: Experiments. Science 359, eaar4005 (2018).
15. S. Kruk, A. Podubdyy, D. Smirnova, L. Wang, A. Slobodziany, A. Sharokhov, I. Kravchenko, B. Luther-Davies, Y. Kivshar, Nonlinear light generation in topological nanostructures. Nat. Nanotechnol. 14, 126–130 (2019).
16. S. Barik, A. Karasahin, C. Flower, T. Cai, H. Miyake, W. DeGottardi, M. Hafezi, E. Waks, A topological quantum optics interface. Science 359, 666–668 (2018).
17. S. Mittal, E. A. Goldschmidt, M. Hafezi, A topological source of quantum light. Nature 561, 502–506 (2018).
18. X. Cheng, C. Jouyavd, X. Ni, S. H. Mousavi, A. Z. Genack, A. B. Khanikaev, Robust reconfigurable electromagnetic pathways within a photonic topological insulator. Nat. Mater. 15, 542–548 (2016).
Acknowledgments

Funding: Q.X. gratefully acknowledges the funding support from the National Natural Science Foundation of China (no. 12020101003) and Tsinghua University Start-up Grant. T.C.H.L. acknowledges the support from the Singapore Ministry of Education via AcRF Tier 3 Programme "Geometrical Quantum Materials" (MOE2018-T3-1-002), AcRF Tier 2 grants (MOE2018-T2-2-068 and MOE2019-T2-1-004). S.G. acknowledges the support from the Singapore Ministry of Education via AcRF Tier 2 grant (MOE2017-T2-1-001). R.S. acknowledges the support from the Singapore Ministry of Education via grants (MOE2018-T3-1-002 and MOE2017-T2-1-040). Author contributions: R.S. conceived the idea, fabricated the device, and performed all the experiments. S.G. performed the theoretical calculations. R.S., S.G., T.C.H.L., and Q.X. analyzed the data and wrote the manuscript, with input from all the authors. T.C.H.L. and Q.X. supervised the whole project. Competing interests: The authors declare that they have no competing interests. Data and materials availability: All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. The experimental data are available at Zenodo (DOI: 10.5281/zenodo.4649934).
Optical switching of topological phase in a perovskite polariton lattice
Rui Su, Sanjib Ghosh, Timothy C. H. Liew and Qihua Xiong

Sci Adv 7 (21), eabf8049.
DOI: 10.1126/sciadv.abf8049

ARTICLE TOOLS
http://advances.sciencemag.org/content/7/21/eabf8049

SUPPLEMENTARY MATERIALS
http://advances.sciencemag.org/content/suppl/2021/05/17/7.21.eabf8049.DC1

REFERENCES
This article cites 45 articles, 9 of which you can access for free
http://advances.sciencemag.org/content/7/21/eabf8049#BIBL

PERMISSIONS
http://www.sciencemag.org/help/reprints-and-permissions

Use of this article is subject to the Terms of Service

Science Advances (ISSN 2375-2548) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title Science Advances is a registered trademark of AAAS.
Copyright © 2021 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).