Probing the band structure of topological silicon photonic lattices in the visible

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SUPPLEMENTAL INFORMATION

Sample fabrication

Silicon nanopillars were fabricated on 10-nm-thick free standing Si_3N_4 membranes (Norcada, Fig. S1). We start with epitaxial liftoff of a 200-nm-thick single-crystalline intrinsic Si film from a silicon-on-insulator (SOI) wafer in 52% HF solution[1,2,3]. The SiO_2 layer was etched (lateral etching rate ~ 300 nm/s), leaving the silicon film floating on top of the HF solution. The Si film is then transferred from the HF solution to water (this process was repeated until the HF was cleaned away) and subsequently placed onto a 10-nm-thick Si_3N_4 membrane, which was surface-cleaned by a Nanostrip solution (90% sulfuric acid, 5% peroxymonosulfuric acid, <1% hydrogen peroxide, 5% water). The wet transferred film and the membrane substrate were then left to dry at an inclined angle, followed by Nanostrip cleaning of the Si film surface. A 100-nm-thick layer of electron beam resist (Diluted ZEP-520A; Zeon chemicals; anisole:ZEP520 volume ratio 1.3:1) was then spin-coated on the Si film (4000 rpm) to produce a 100-nm-thick film.

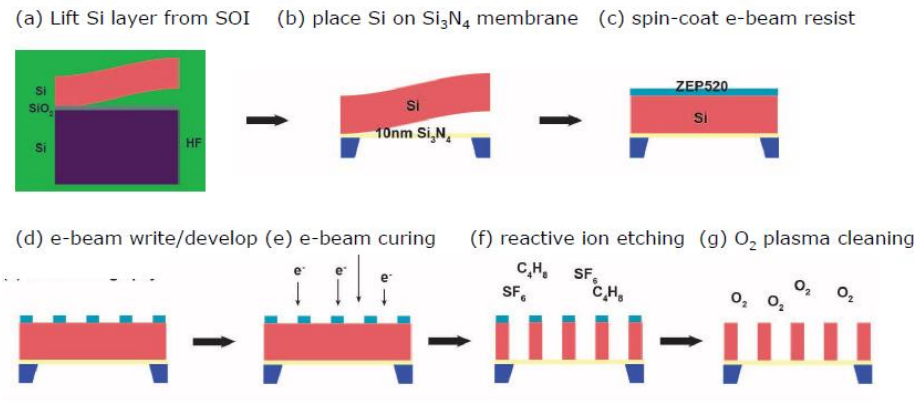

Figure S1. Schematic of preparation of photonic lattices composed of Si nanopillars on a 10-nm-thick free-standing Si_3N_4 membrane.

After lithographically defining a pattern using a 100 keV electron beam (Raith EBPG5200), the electron beam resist was developed (ZED-N50, Zeon Chemicals); the remaining resist was treated by electron beam irradiation at 2 keV with a dose of 500 C/m^2. This step is essential for high-quality pattern transfer during reactive ion etching, since cross-linking of the resist on the pattern edge is significantly improved. Then the pattern was transferred into the Si layer via reactive ion etching (Oxford Instruments System 100 ICP 380, mixture of C_4F_8 and SF_6 gases; 23 W RF generator forward power, 1200 W ICP generator forward power, 27 sccm SF_6, 52 sccm C_4F_8) and the remaining etch mask was removed by O_2 plasma cleaning. SEM images of the fabricated structure are shown in Fig. 1c,d. Since we are using a positive resist, an inverse pattern with hole diameter of 118 nm was written. The final pillars dimensions are 90 nm in diameter and 200 nm in height for electron beam dose of 260 µC/cm^2. For electron beam dose of 250 µC/cm^2, the pillars are 85 nm in diameter and 200 nm in height.

There are several advantages of our fabrication method. Firstly, a 10-nm-thick membrane has minimal influence on the dielectric environment of the dielectric resonator, preserving its intrinsic optical properties. Secondly, the free standing 10-nm-thick Si_3N_4 membrane is almost transparent for the electron beam, therefore reducing both charging and incoherent defect luminescence compared to a thick substrate, making it an ideal platform to study subtle photonic features by electron excitation.

Band structure dispersion

In Fig. S2a the dispersion data derived from Fig. 2b are overlaid with the simulations and show good agreement. A broad collection of low-*Q* guided modes is observed with high-*Q* flat bands within the Dirac cone representing the Mie resonances. In Fig. S2b we plot the (zone-folded) dispersion bands of TM

surface modes with an effective mode index n=1.05 (obtained by fitting Fig. 2b with $k=nk_0$); they correspond well to the simulated data.

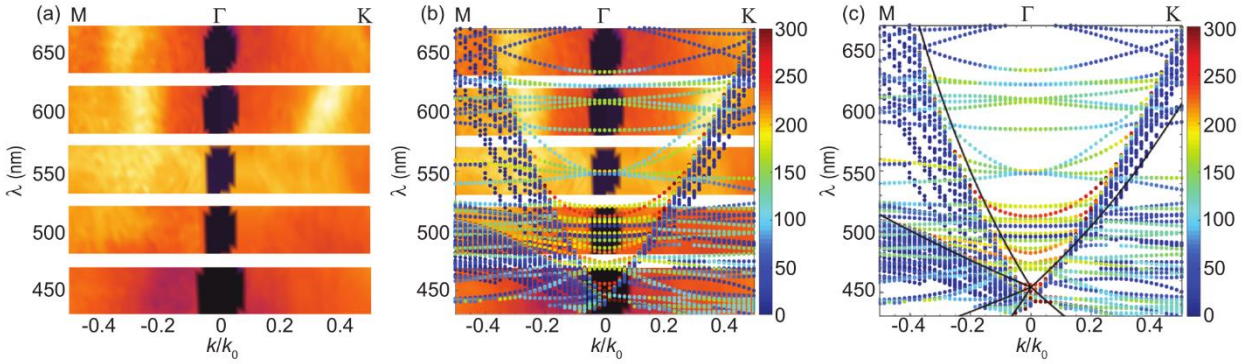

Figure S2. Band structure dispersion. (a) Experimental angle-resolved CL data. (b) Same as (a), overlaid with numerically simulated band diagram for the photonic lattice with two hexagonal pillars for the unit cell in Fig. 2 (colored dots). The quality factor Q of the modes is indicated by the color scale. (c) Same simulated data as in (b) with fit to experimental data from diffractive outcoupling model using a TM surface mode with mode index n=1.05 (black lines).

Cathodoluminescence

Cathodoluminescence spectroscopy was carried out using a 30 keV electron beam in a ThermoFisher Scientific/FEI Quanta 650 SEM equipped with a Delmic SARC system for cathodoluminescence collection and analysis. Light emitted by the sample was collected by a half-parabolic mirror placed between the sample and the electron column, with a focus on the sample of ~20 μm. Collected light was either guided to a spectrometer for spectral analysis to make spatial maps, or projected onto a CCD imaging camera for angular analysis (see Fig. 1b). The parabolic mirror contains a hole for the electrons to go through. This hole spans an angle of 6.9°. For a horizontally placed sample, this hole hinders collection of light emitted along the Γ-point. To probe the bandgap of the topological photonic crystals at the Γ-point, we put the sample under an angle of 7.5° for the data presented in Fig. 4 of the main text. Light emitted normal to the sample can then be collected. To avoid electron-induced background CL from the sample holder, we drilled a hole through the sample holder underneath the sample.

Confocal microscopy measurements

Confocal transmission measurements were performed using a WiTec α300 confocal microscope. A fiber-coupled tungsten broadband light source (Thorlabs SLS202L) was used to illuminate the sample from the bottom. A 10× objective (Zeiss, numerical aperture: 0.2) was used to weakly focus the light into a

homogeneous spot larger than the patterned area. Light transmitted by the sample was collected with a 50× objective (Zeiss, numerical aperture: 0.7) and coupled into a 25 μm core collection fiber that functioned as the confocal pinhole, and analyzed using a spectrometer (300 lines/mm, spectral resolution of 0.27 nm). The signal was normalized to the transmission of an uncovered Si_3N_4 membrane.

Numerical simulations

First-principle simulations were performed using full-wave finite-element-solver COMSOL Multiphysics (RF Module). For bulk band structure calculations in Figs. 3, the periodic boundary conditions were imposed along the boundaries of the unit cell, and perfectly matched layer (PML) boundary conditions were applied perpendicular to the surface of the sample. Dimensional sizes of the structure are the same as the ones used for the fabricated sample. Optical constants for Si were taken from Ref. 4.

References

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