Broadband Power Coupling and Splitting in Photonic Thouless Pump Systems

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Abstract: By utilizing the topological transport property of Thouless pump, we experimentally demonstrate the broadband optical power coupling and splitting on the silicon photonic platform in the telecom band. © 2021 The Author(s)
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1. Introduction
Thouless pump is a key concept in condensed matter physics. The quantized charge transport in Thouless pump is defined by the Chern number and therefore is robust against perturbations [1]. Photonic analogs of Thouless pump offer a route to robust optical interconnects due to the topological transport property [2]. In this paper, we propose and experimentally demonstrate the broadband power coupling and splitting by introducing the Thouless pump mechanism into the coupling process, which validates the robustness against wavelength variation.

2. Results and Discussions
Figure 1(a) presents the photonic analog of Thouless pump system built on the silicon-on-insulator (SOI) platform (3-μm-thick buried oxide layer, 220-nm-thick top silicon layer and 1-μm-thick silica upper cladding layer). It is formed by tuning the waveguide width \( W \) and gap width \( g \) in such a way that the waveguide array resembles a Su-Schrieffer-Heeger (SSH) lattice in the transverse direction and changes periodically along the propagation direction [3]. Figure 1(b) shows the band structure of the transverse magnetic (TM) supermodes of the system over a full pump cycle. A pair of edge states appear in the band gap between two bulk bands, which can be utilized to realize edge-to-edge transport across the waveguide lattice [4]. Figure 1(c) exhibits the power coupling device that employs the waveguide array configuration of the Thouless pump system. It can accomplish a complete power transfer from the input port to the cross port over one pump cycle, as verified by the 3D finite-difference time-domain (FDTD) simulations shown in Fig. 1(d). The Thouless pump mechanism can also be used in the design of a power splitting device, as illustrated in Figs. 1(e) and 1(f). The optical power input from the I1 port is distributed evenly to the O1 and O2 ports, which is validated by the 3D FDTD simulations shown in Fig. 1(f).

Fig. 1. (a) Photonic analog of the Thouless pump system built on the SOI platform. The waveguide width \( W \) and the gap width \( g \) vary in the range of 400 nm - 500 nm and 100 nm - 400 nm, respectively. The pump cycle is \( L = 50 \) μm. The red and white colors represent silicon and silica, respectively. (b) Band structure of the TM supermodes in the Thouless pump waveguide array. Odd (indicated in red) and even edge modes (indicated in blue) appear in the band gap between two bulk bands (indicated in black). (c) Power coupling device composed of a 4-waveguide version of the waveguide array shown in Fig. 1(a). (d) Power distribution of light when the fundamental TM mode is launched from the input port. The complete power transfer can be accomplished between the leftmost and rightmost waveguides over one pump cycle. (e) Power splitting device employing the Thouless pump mechanism. (f) Power distribution of light when the fundamental TM mode is launched from the middle I1 port. The input optical power is evenly distributed to the O1 and O2 ports.
The devices were fabricated on a SOI wafer by E-beam lithography (Vistec EBPG 5200-), inductively coupled plasma dry etching (SPTS DRIE-I) and plasma enhanced chemical vapor deposition (Oxford Plasmalab System 100). The optical microscope photos of the power coupling and splitting devices are shown in Figs. 2(a) and 2(b), respectively. The coupled waveguide array regions of the devices are magnified and displayed in the scanning electron microscope (SEM) images of Figs. 2(c) and 2(d). In the measurements, the TM-polarized light from a tunable laser (Santec TSL-710) was coupled into and out of the chip by grating couplers. An optical power meter and a photodetector (Santec MPM-210) were employed for optical calibration and receiving the transmitted power, respectively. Figure 2(e) plots the measured transmission spectra at the through and cross ports of the power coupling device, which are normalized to that of a reference grating coupler pair fabricated on the same wafer. The insertion loss of < 0.5 dB and the crosstalk of < -20 dB were measured in the wavelength range of 1.48 μm - 1.58 μm at the cross and through ports, respectively. The measured transmission spectra of the power splitting device are also normalized to that of a reference grating coupler pair and depicted in Fig. 2(f), as well as the imbalance between two output ports. The excess loss of < 0.6 dB and the imbalance of less than ±0.3 dB were achieved at the O1 and O2 ports over a 100-nm bandwidth spanning from 1.48 μm to 1.58 μm.

3. Conclusion
In conclusion, we have proposed and experimentally demonstrated the broadband power coupling and splitting in the photonic Thouless pump systems. Thanks to the robust transport of light enabled by Thouless pump, the insertion loss is lower than 0.5 dB at the cross port and the crosstalk is below -20 dB at the through port for the power coupling device, both in the wavelength range of 1.48 μm - 1.58 μm. The excess loss of the power splitting device is smaller than 0.6 dB with the imbalance less than ±0.3 dB in the same wavelength range. Our findings may open a new way of designing broadband integrated devices with concepts and methods in topological physics.

4. References