Broadband Back-Excitation Suppressor with On-chip Asymmetric Metasurface

Heijun Jeong, Yahui Xiao, Zi wang, and Tingyi Gu
Electrical and Computer Engineering, University of Delaware, Newark, DE 19711 USA
Corresponding author e-mail address: tingyigu@udel.edu.

Abstract: We demonstrated an insertion loss of 2.2 dB and a back-excitation suppression of 5.1 dB over the 35 nm bandwidth with on-chip asymmetric metasurface.

1. Introduction

The exploration of metasurfaces, characterized by superimposed periodic structures, has opened new avenues in the study of diverse physical phenomena. Geometric manipulations, such as twists, offsets, and rotations, have been leveraged to enhance sensing capabilities, achieve light localization, and form intricate photonic moiré lattices [1]. Multi-layer meta-structures with design variations have paved the way for the construction of complex photonic topological isolator metacrystals, Hofstadter butterflies, and topological edge states, revolutionizing integrated photonics [2]. In response to the escalating data transmission demands in modern optical communication systems, there is a burgeoning interest in achieving broadband unidirectional transmission. Traditional unidirectional devices primarily focused on suppressing backward reflection [3], but we introduce the meta-backward excitation suppression (BES) concept—a meta-blocker designed to selectively block the coupling between multiple laser excitations in photonic integrated circuits (Fig. 1a, b). This innovation holds promise for simplifying circuit designs in applications like ion trapping, recurrent photonic neuron networks, and high-power RF photonic systems. The study also delves into the realm of flipped gradient metasurfaces, aligning with the concept of unidirectional guided resonances [4]. Through numerical demonstrations, the text showcases the emergence of topological charges in the polarization field, resulting in unidirectional guided resonance with significant transmission contrast and low insertion loss. The implementation of a compact broadband metalens BES in silicon photonics, achieved through subwavelength engineering, is highlighted as a crucial development, offering a passive, low-loss solution that operates across a broad range of wavelengths. This research signifies a significant stride towards addressing the evolving challenges in optical systems and photonics applications.

2. Design and Numerical Analysis

The double flipped taper slot (DFTS) meta-unit is designed on the 250 nm SOI substrate. When light propagates in free space and encounters into the DFTS, it creates a vortex current flow due to asymmetric velocity changes. This induces strong electric field coupling at the taper edge, leading to the BES. The insertion loss, phase shift, and asymmetric transmission can be engineered through a few critical parameters in the unit cell of DFTS, including the width of the small taper pair, inter-taper gap, and the length of the longer taper. Based on the unit cell, fully embedded BES in the taper between a grating coupler and single-mode waveguide is simulated. With forward excitation, the

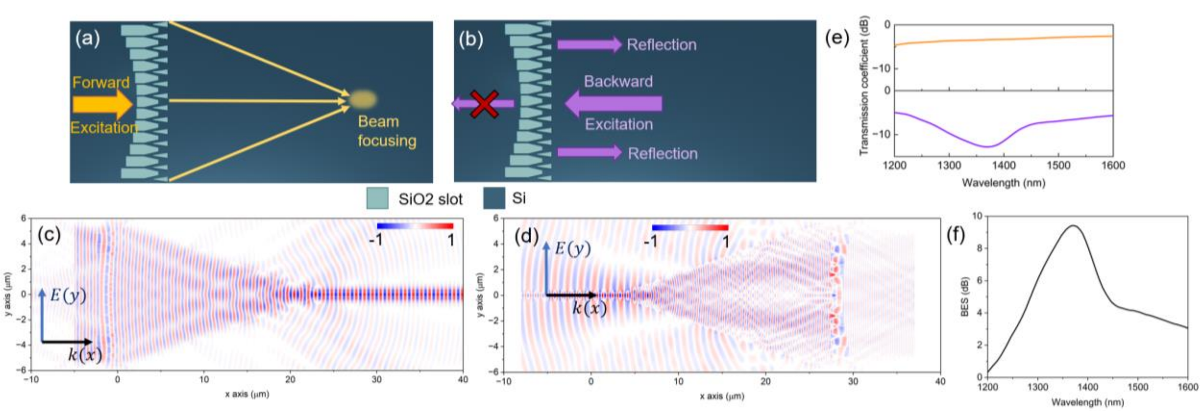

Fig. 1 Illustration of the proposed asymmetric metasurface. (a) Beam focusing function on forward excitation and (b) BES on backward excitation. Simulations of fully embedded BES in a grating coupler taper. Electric field intensity in E_y plane for (c) forward excitation and (d) backward excitation. (e) Transmission spectra for forward (top) and backward (bottom) excitation, resulting in calculated (f) BES performance.

incident light converges into the single mode waveguide (Fig. 1c). It shows higher-order modes, which are generated from unit cells are eliminated toward the outer part of the taper structure, allowing only the single fundamental mode to be transmitted into the output waveguide. With backward excitation we confirmed that the incident light from the waveguide is reflected at the metalens before reaching the grating coupler (Fig. 1d). After embedded metalens in a grating coupler taper, forward transmission coefficient of -3dB and backward transmission coefficient of -12.5 dB at 1380 nm, resulting in the highest BES of 9.5 dB (Fig. 1e, f). Moreover, due to the metalens structure, BES provides provides a single mode in the waveguide within much shorter taper length. Here we select a metalens design with the focal length of 20 μm [5]. The metalen BRS only has a footprint of 11 μm × 2.8 μm (30.8 μm²).

3. Device Fabrication and Measurement

All the structures (waveguides, grating couplers, tapers, and BES) are fabricated on 250 nm-thick SOI substrate (Fig. 2a, b). The fabrication process involved the utilization of a Vistec EBPG5200 electron beam lithography equipment, followed by resist development and a single step dry etch method. A silicon dioxide protective layer with a thickness of 900 nm is applied onto the device layer using plasma-enhanced chemical vapor deposition. Patterns with a set of geometric offsets (in the step of 10 nm, considering the minimum resolution of 7 nm of the E-beam lithography equipment) are included in the layout to compensate fabrication variations. Continuous wave laser sources were generated using the ANDO AQ4321A tunable laser source meter. The output power was measured using the NEWPORT InGaAs photodiode (818-IG-L-FC/DB) and 1830-R optical power meter. After completing forward transmission measurements, we carefully swapped the coupling of the input fiber and output fiber by utilizing angled physical contact connectors without adjusting the excitation position of the SMF or controlling the polarization controller. This was done to maintain the same measurement environment, including alignment and polarization, and enable the measurement of backward transmission signals. Finally, forward transmission of -2.2 dB and a backward transmission of -7.3 dB. 3 dB BES wavelength ranges of 1480 to 1516.8 nm are experimentally achieved, which can extend to lower wavelength range, but the measurement is limited by the laser scanning system (Fig. 2c). We also measured the power dependence of the device for verifying the wide dynamic range. This result confirms that the proposed BES maintains its performance from -10 dBm to 8 dBm of input power from the tunable laser (Fig. 2d).

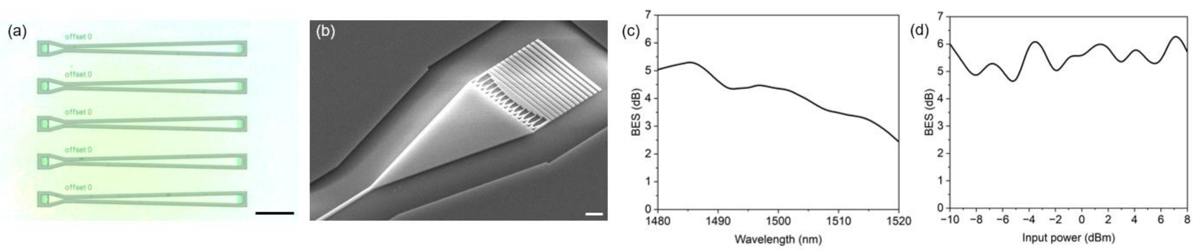

Fig. 2 Device fabrication and experimental results. (a) Microscope image of arrays of fabricated grating couplers with integrated isolators (scale bar: 50 μm). (b) Scanning electron microscope image of metalens integrated with grating coupler and inverse taper structure (scale bar: 2 μm). (c) Measured BES spectra with 10nm geometric offset. (d) BES over a wide range of input power levels from the laser at wavelength of 1480 nm.

References

1. P. Wang, Y. Zheng, X. Chen, C. Huang, Y. V. Kartashov, L. Torner, V. V. Konotop, and F. Ye, "Localization and delocalization of light in photonic moiré lattices," Nature **577**, 42–46 (2020).
2. X. Cheng, C. Jouvaud, X. Ni, S. H. Mousavi, A. Z. Genack, and A. B. Khanikaev, "Robust reconfigurable electromagnetic pathways within a photonic topological insulator," Nat Mater **15**, 542–548 (2016).
3. Q. Du, C. Wang, Y. Zhang, Y. Zhang, T. Fakhrul, W. Zhang, C. Gonçalves, C. Blanco, K. Richardson, L. Deng, C. A. Ross, L. Bi, and J. Hu, "Monolithic On-chip Magneto-optical Isolator with 3 dB Insertion Loss and 40 dB Isolation Ratio," ACS Photonics **5**, 5010–5016 (2018).
4. X. Yin, J. Jin, M. Soljačić, C. Peng, and B. Zhen, "Observation of topologically enabled unidirectional guided resonances," Nature **580**, 467–471 (2020).
5. Z. Wang, T. Li, A. Soman, D. Mao, T. Kananen, and T. Gu, "On-chip wavefront shaping with dielectric metasurface," Nat Commun **10**, (2019).