

Studying the Mode Evolution within a Knife-Edge Taper- Based Spot Size Converter

Using BeamPROP

Introduction

A Spot Size Converter (SSC) is used to transition the optical mode from one device to another, typically from a waveguide with a small mode field diameter to one with a larger mode field, or vice versa. This process is crucial for efficient coupling between optical components, such as lasers, fibers, or waveguides in Photonics Integrated Circuits (PICs).

In this application note, we explore the mode profiles evolution at specific cross-sections along a knife-edge taper-based SSC structure. Understanding how the optical mode evolves allows us to optimize various parameters of the SSC, such as taper length, core size, and material properties. This helps minimize mode mismatch, reduce insertion loss, relax fabrication tolerances, and enhance device integration in PICs.

SSC devices are generally longer because a gradual transition is needed to effectively change the optical mode size from one waveguide to another. For such a longitudinally extended spot size converter, BeamPROP BPM is the most effective simulation approach, providing much faster results than FullWAVE FDTD. Because of minimal reflection, BeamPROP BPM is nearly as accurate as FDTD [2].

Design Description

1. Build the Geometry

A conventional spot size converter includes a Silicon adiabatic taper that gradually narrows in width towards the end, coupled with a second low-index polymer core waveguide covering the taper. However, such a design exhibits a larger difference in mode conversion loss between the TE-like and TM-like modes due to the extremely high aspect ratio termination at taper widths of ~ 50 nm [1]. To address this issue, a knife-edge taper based SSC structure with a triangular cross-section near the taper end, where the height gradually decreases, was proposed [1], as shown in Figure 1.

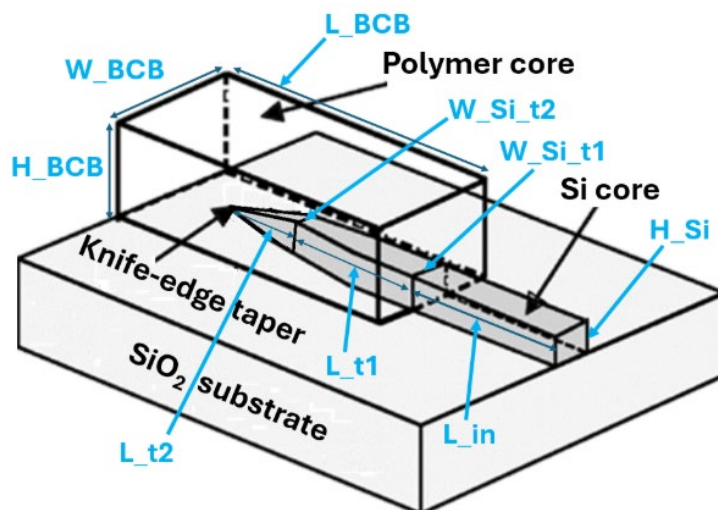


Figure 1. Schematic of the Silicon knife-edge taper based spot size converter with labeled design parameters in RSoft CAD

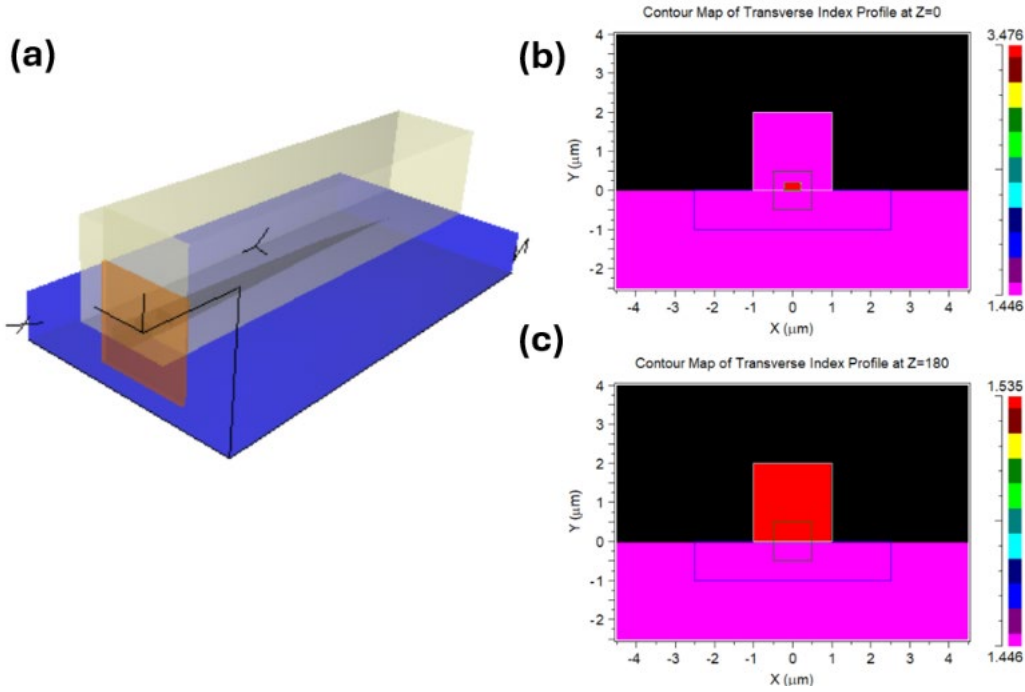


Figure 2. Layout of the spot size converter in RSoft CAD. (a) 3D view of the SSC device, (b) refractive index profile at the input port (i.e., $z=0 \mu\text{m}$), (c) refractive index profile at the output port (i.e., $z=180 \mu\text{m}$)

The layout of the spot size converter is built in RSoft CAD (Fig. 2a), with the design parameters defined as shown in Figure 1. An industry-standard Si core strip waveguide with dimensions of $0.45 \mu\text{m} \times 0.22 \mu\text{m}$ is utilized as an input waveguide port (Fig. 2b), and a polymer benzocyclobutene (BCB) material core waveguide having a cross-section of $2.0 \mu\text{m} \times 2.0 \mu\text{m}$ serves as the output port, which partially covers the inverse Silicon taper (Fig. 2c).

2. Simulation Parameters

The simulation is run for both Semi-vector mode TE and TM polarizations, respectively. The input mode for each polarization is first calculated at the input port and used as a File type launching field. The two pathway monitors are added along the structure to evaluate the overlap between the propagated field and the pre-calculated mode field at the input and output ports, providing coupling efficiency for both TE and TM polarized modes. Toward studying the mode field evolution along the propagation direction, six regular spatial field monitors are placed at $30 \mu\text{m}$ intervals along the structure in Z direction.

3. Run the Simulation and Export the Results

The simulation completes in just a few minutes. Figure 3 shows the major electric field evolution of the optical mode as it propagates along the knife-edge taper based SSC device at the various Z positions from 0 to 180 μm using BeamPROP. We can observe the mode field starting from a Silicon strip waveguide gradually coupling to the end of a larger BCB polymer waveguide core. Similar results can also be obtained for the TM polarized mode.

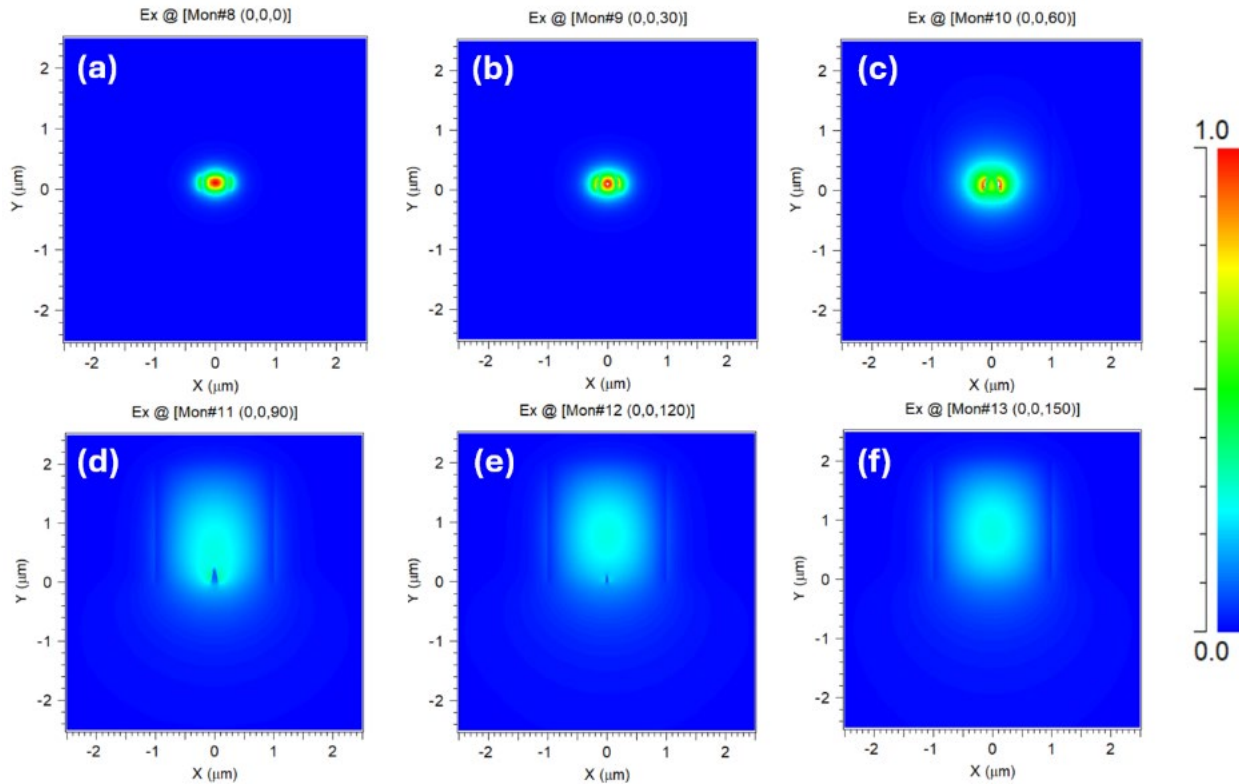


Figure 3. Major electric field evolution for the TE polarized mode in the knife-edge taper SSC at a wavelength of 1.55 μm , recorded at various Z positions of (a) 0 μm , (b) 30 μm , (c) 60 μm , (d) 90 μm , (e) 120 μm , and (f) 150 μm

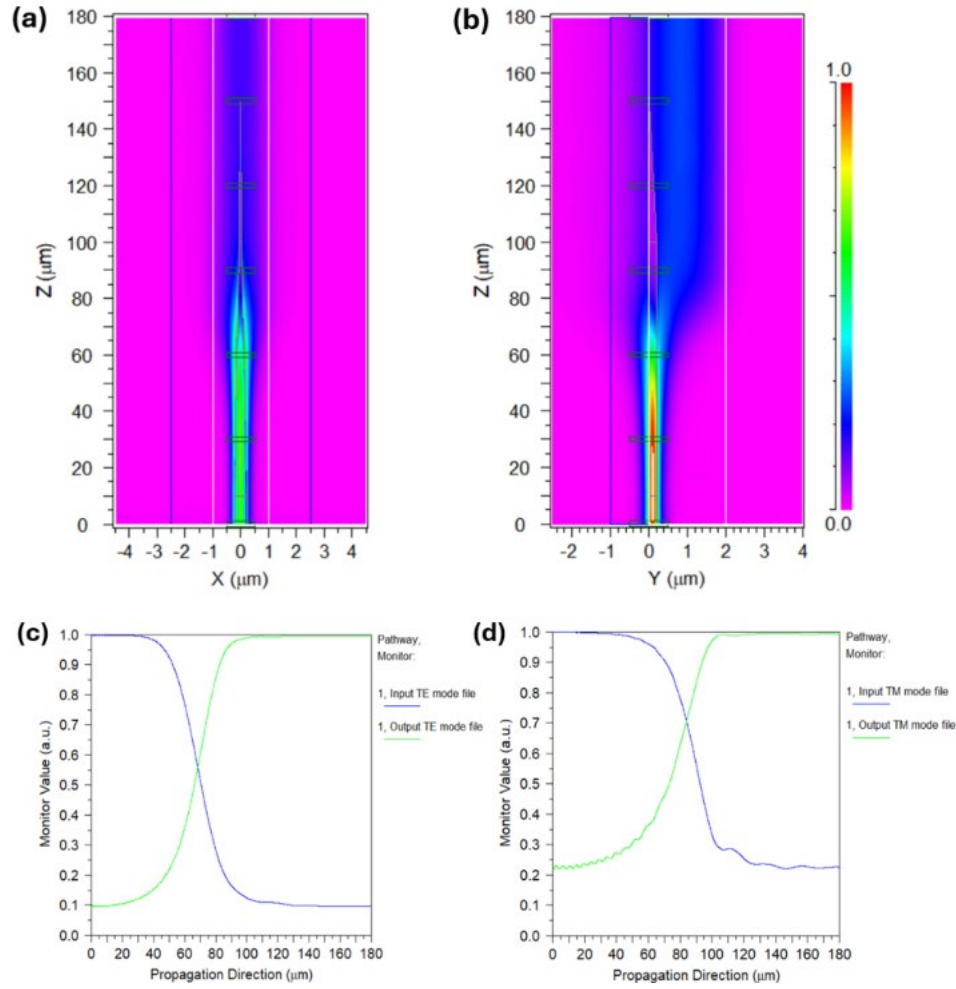


Figure 4. TE polarized mode field propagation in the SSC at the (a) XZ view and (b) YZ view. The coupling efficiency of (c) 99.2% for TE mode and (d) 99.6% for TM mode are attained through the pathway monitors.

As shown in Figure 4(a) and 4(b), the top and side views demonstrate the continuous evolution of the TE mode field along the SSC. The pathway monitors measure the coupling efficiency of 99.2% for TE input mode (Fig. 4c) and 99.6% for TM input mode (Fig. 4d), with mode conversion losses of 0.035 dB for TE and 0.017 dB for TM, respectively. This confirms that polarization-independent operation of the spot size converter is achieved with the knife-edge taper structure.

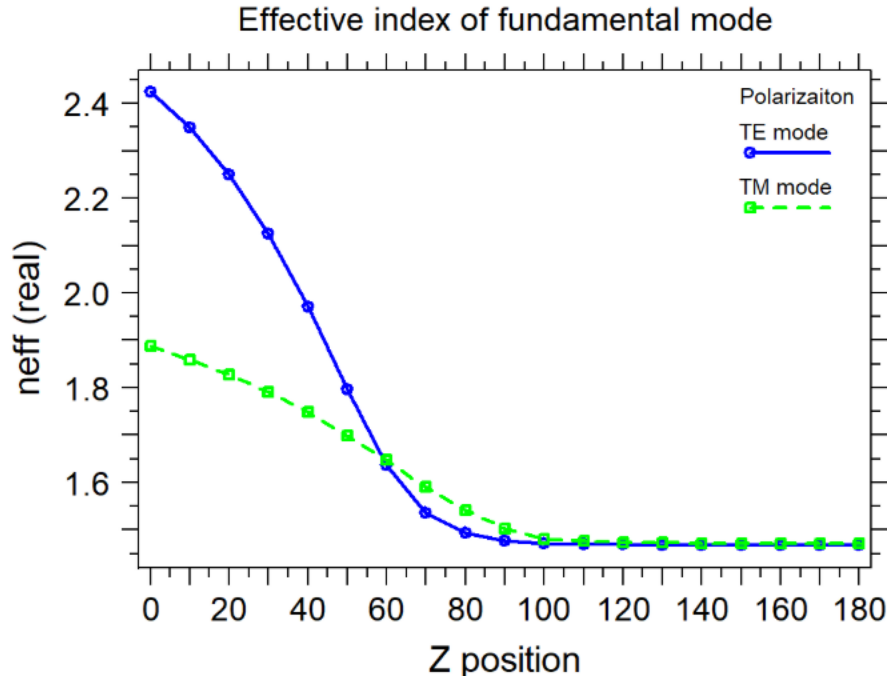


Figure 5. Calculated effective indices of TE and TM polarized modes along the Z position of the knife-edge taper based SSC.

MOST, RSoft's Multi-Variable Optimization and Scanning Tool, is used to calculate the real part of effective indices for the TE and TM polarized modes along the Z positions with a spacing of 10 μm (Fig. 5). The BP mode solver is utilized for the calculation. The results further confirm the polarization-independent mode operation starting at $Z=100 \mu\text{m}$ through to the end of the spot size converter.

Conclusion

We have demonstrated the simulation procedure for a knife-edge taper-based spot size converter by using RSoft BeamPROP tool. The mode field evolution within the SSC device was analyzed, showing that the knife-edge taper improves coupling efficiency for both TE and TM polarized modes. Compared to conventional spot size converter designs, this structure enables polarization independent mode coupling with similar mode conversion loss for TE and TM modes.

Reference

[1] R. Takei, M. Suzuki, E. Omoda, S. Manako, T. Kamei, M. Mori, and Y. Sakakibara, "Silicon knife-edge taper waveguide for ultralow-loss spot-size converter fabricated by photolithography", Applied Physics Letters, Vol.102, 101108 (2013).

[2] C.L. Xu, et.al., "Suitability of BPM simulation for Silicon photonics", TechRxiv (2021). <https://doi.org/10.36227/techrxiv.16658989.v1>.

Design Files

Supporting Files of RSoft Application Note "Studying the Mode Evolution within a Knife edge Taper based Spot Size Converter"



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