Inverse Design in Silicon Nitride Photonics

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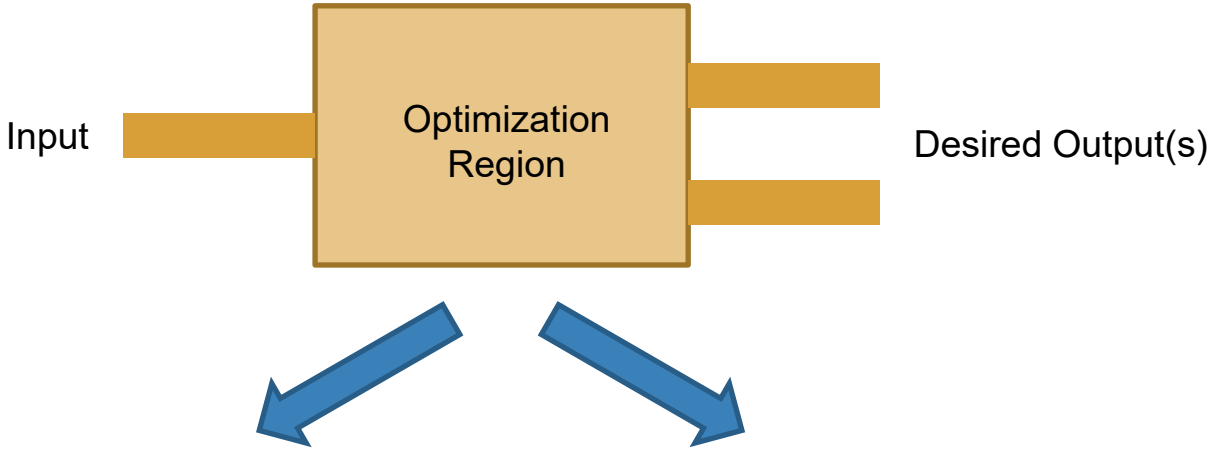
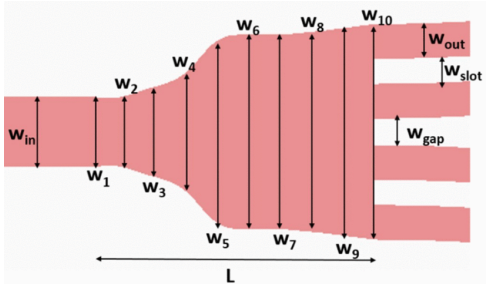
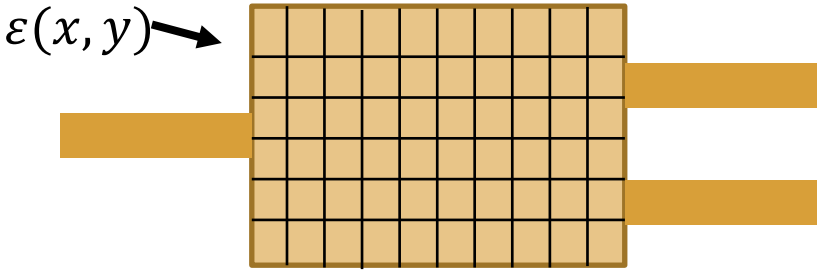
Background—Inverse Design



Parametric (contour) Optimization



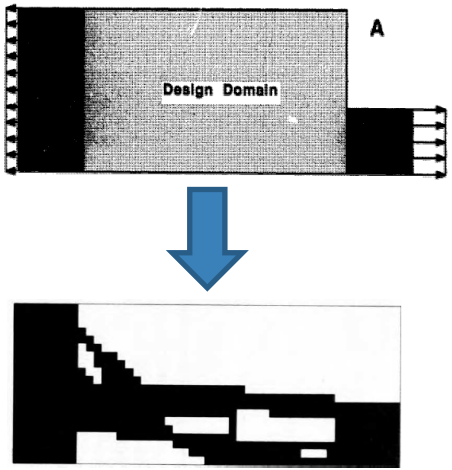
Density Topology Optimization



D. P. Nair & M. Ménard, *IEEE Photonics Journal*, vol. 17, #1, Art no. 6600208

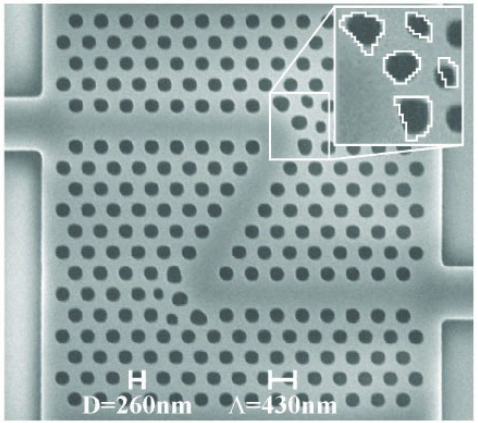
Density Topology Optimization

Mechanical Design



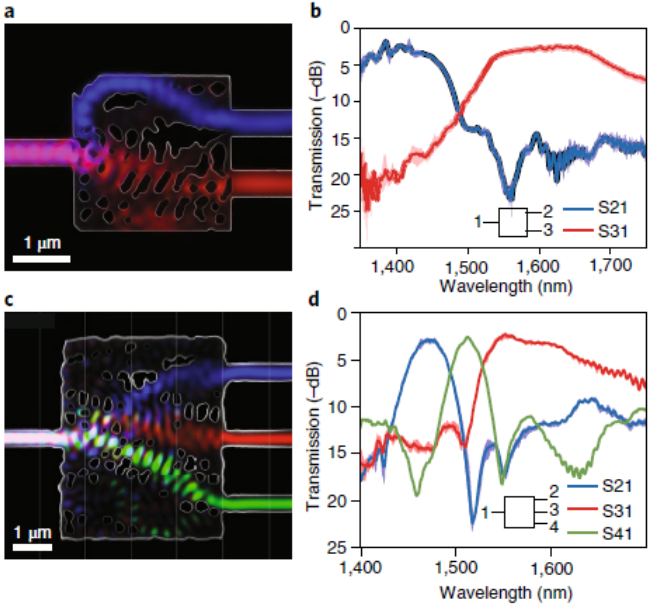
M. P. Bendsøe & N. Kikuchi, CMAME vol. 71 # 2, pp. 197-224 (1988)

1st Demonstration in Integrated Photonics



P. I. Borel et. al. Opt. Express vol. 12, pp. 1996-2001 (2004)

General Formulation



S. Molesky, Z. Lin, A.Y. Piggott, et al. Nature Photon vol. 12, pp. 659–670 (2018)

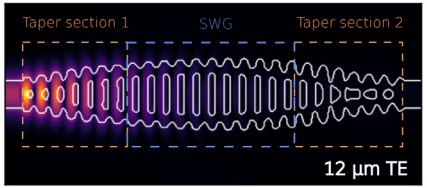
J. Vuckovic Proc. SPIE PC1360109 (2025)

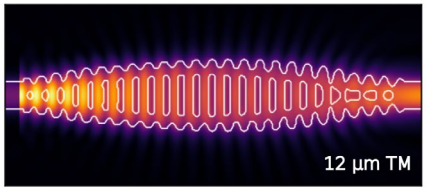
Topology Optimization in Silicon Nitride

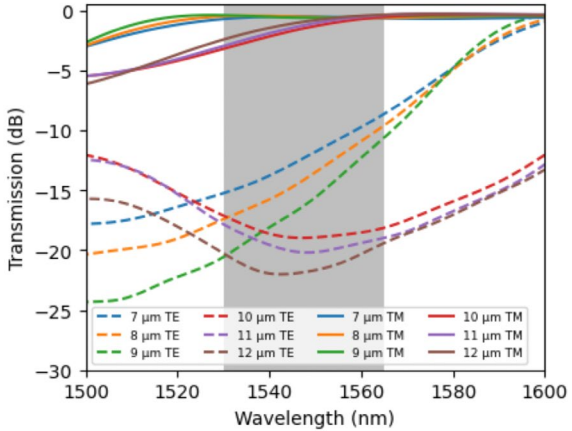
- Can we obtain compact high performance devices in SiN?
  - Polarizer
  - Coarse Wavelength Division Multiplexer (CWDM)
  - Spatial Mode Division Multiplexer (MDM)
  - Bimodal Mode Converter
  - Multi-mode Edge Coupler

TM-Pass Polarizer

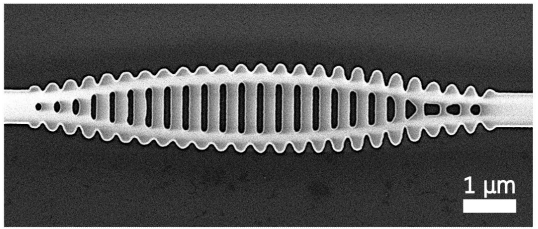
Simulations

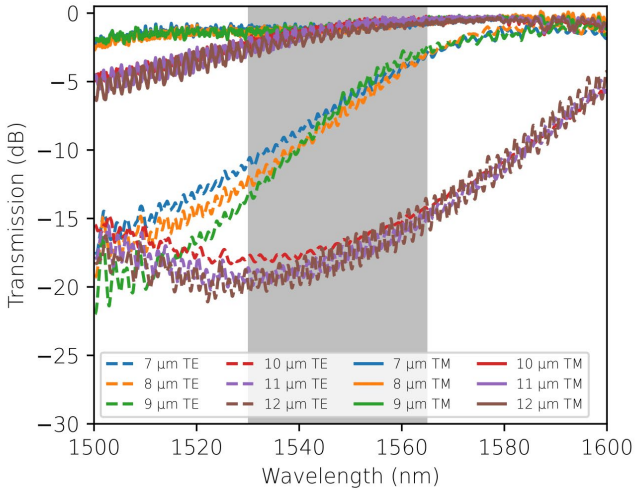






Experiment



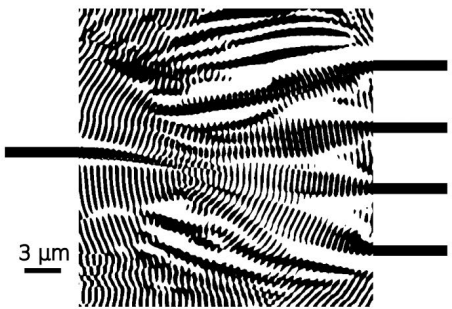


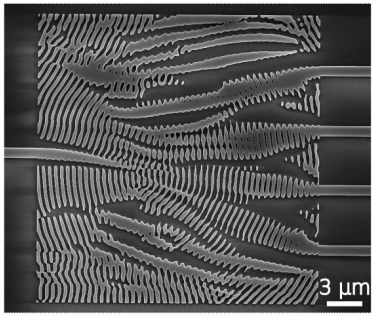
Best device (11 µm × 2 µm):

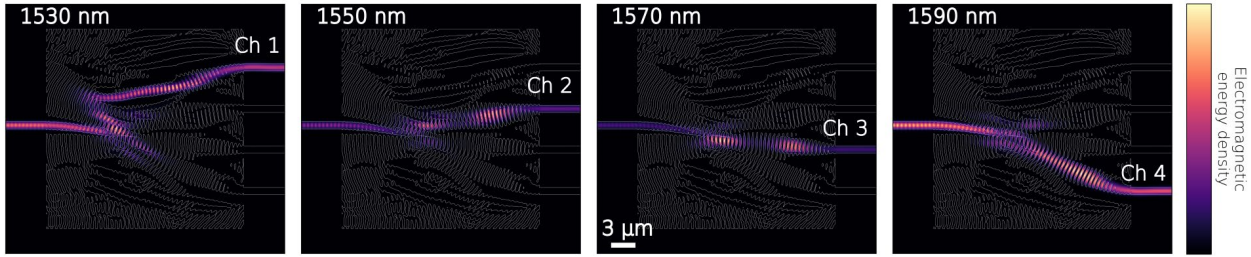
- TM insertion loss = **0.28 dB**
- PER = **18.2 dB**
- 3-dB bandwidth > 80 nm
- **Device area only 22 µm²**, record-compact for SiN polarizers.
- Fabricated by Applied Nanotools on a 400 nm SiN platform

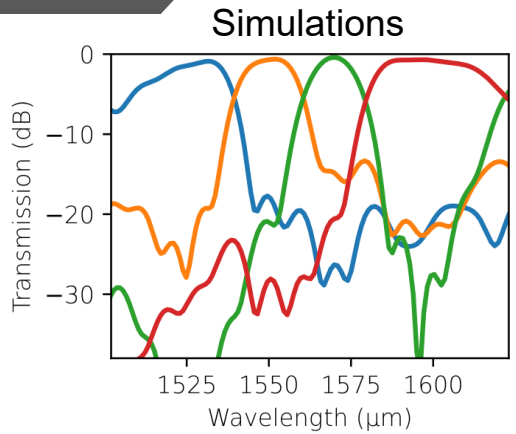
J. L. Pita Ruiz, F. Nabki, and M. Ménard, "Silicon nitride TM-pass polarizer using inverse design," Opt. Express 31, 37892-37899 (2023)

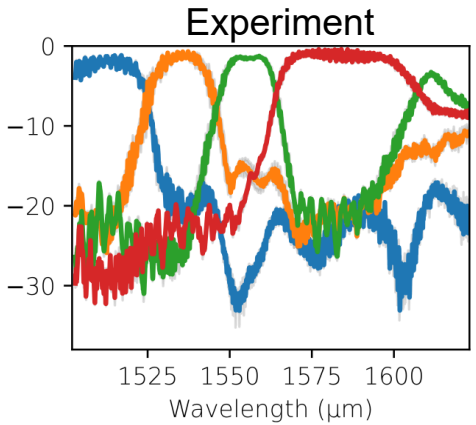
Coarse Wavelength Division Multiplexer (CWDM)







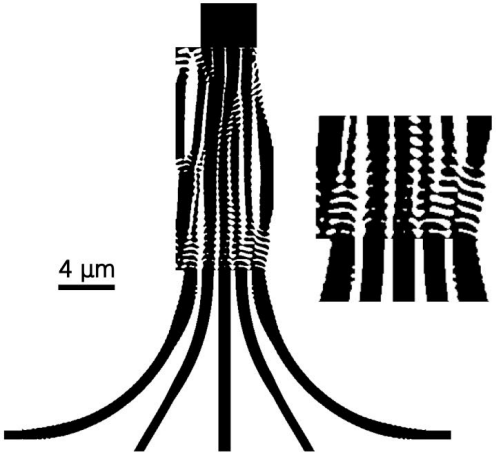


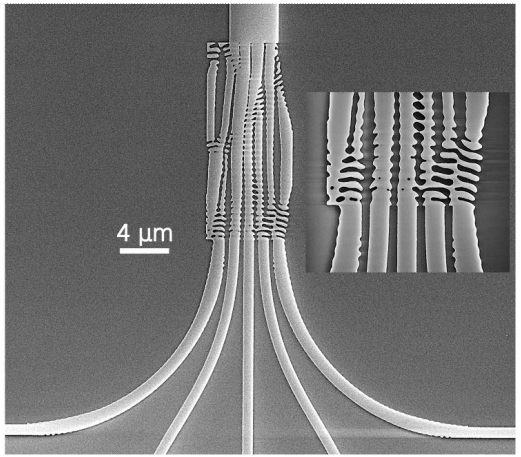


- Footprint 24×24 µm²
- Efficiency ≈ **–1 dB** per channel
- Crosstalk < **–19 dB**

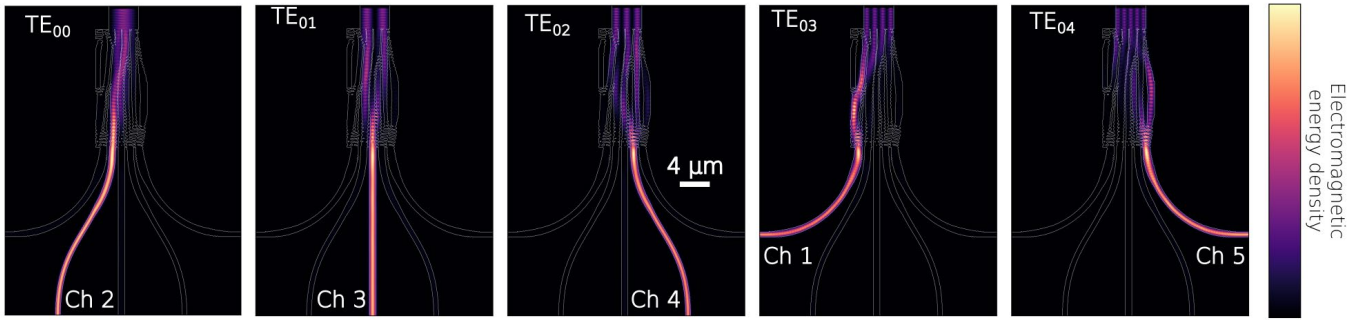
Pita Ruiz, N. Dalvand & M. Ménard "Integrated silicon nitride devices via inverse design." *Nat Commun* vol. 16, article 9307 (2025)

1 x 5 Spatial Mode Division Multiplexer (MDM)





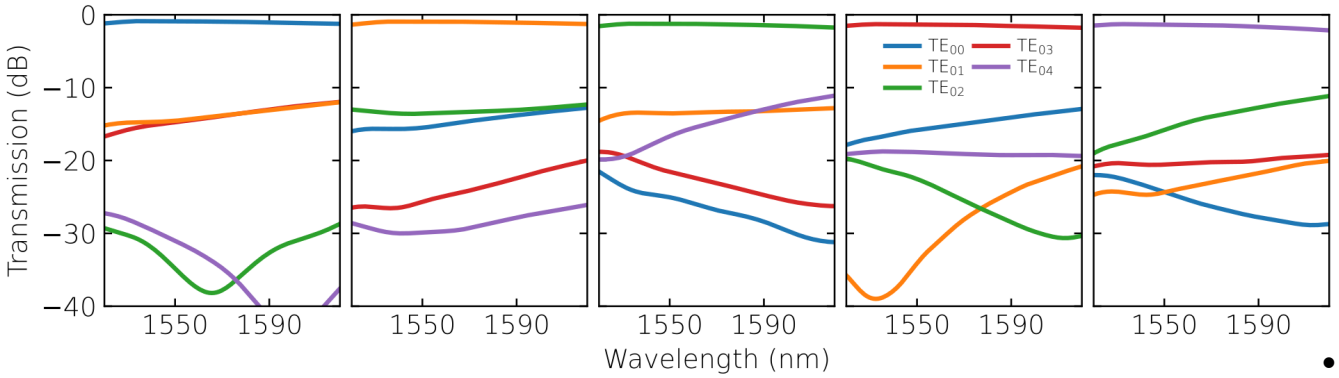
- Footprint 16×7 µm²
- Convert between TE_{00}–TE_{04} modes:



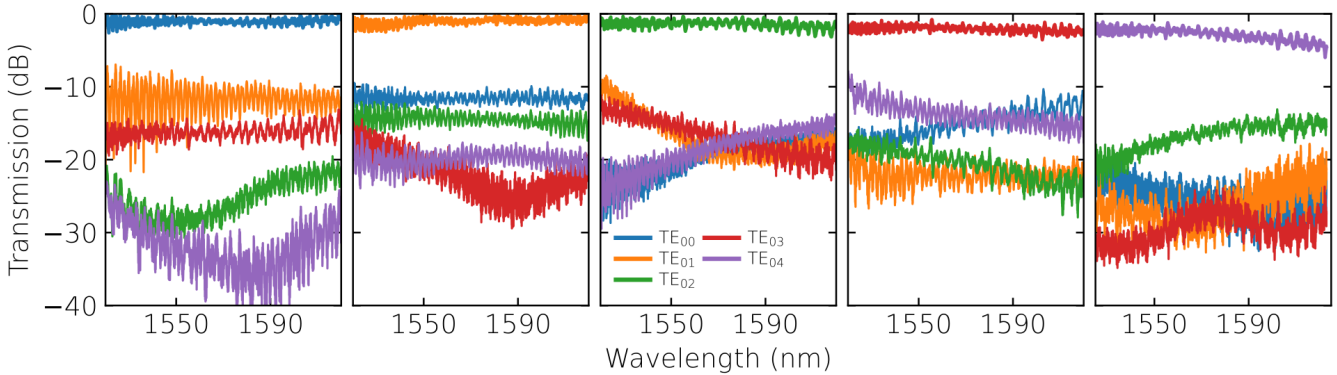
Pita Ruiz, N. Dalvand & M. Ménard "Integrated silicon nitride devices via inverse design." *Nat Commun* vol. 16, article 9307 (2025)

MDM Results

Simulations



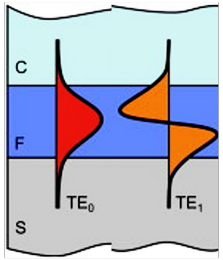
Experiment

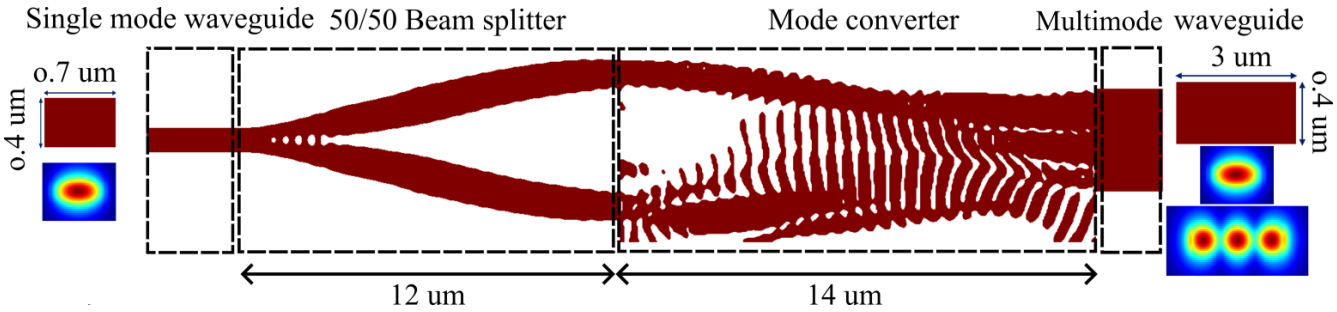


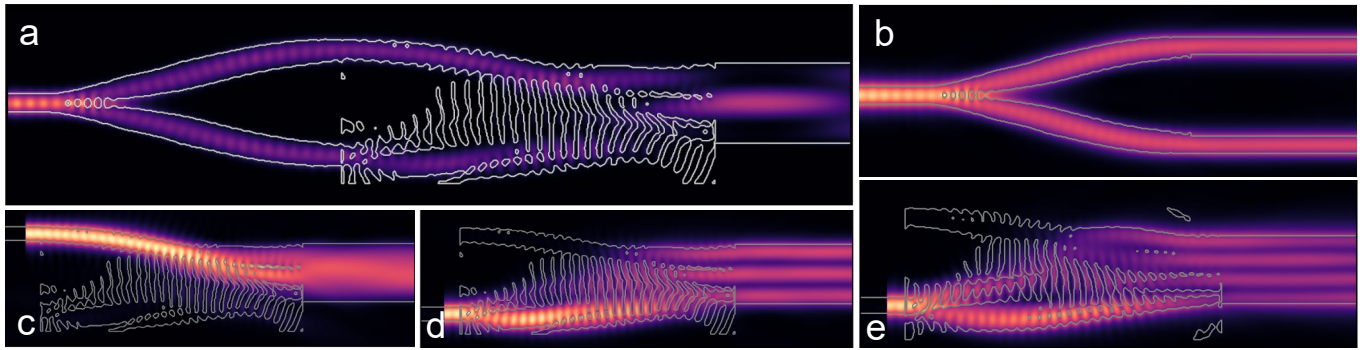
- Transmission: **–1 to –2.3 dB**
- Crosstalk: **–11 to –16 dB**

Bimodal Mode Converter (BiMC)

Bimodal Interferometer







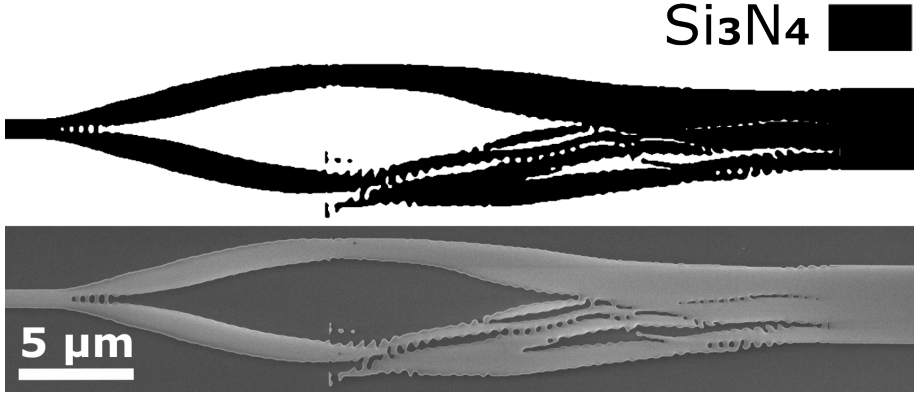
Electric field profile at 1550 nm:

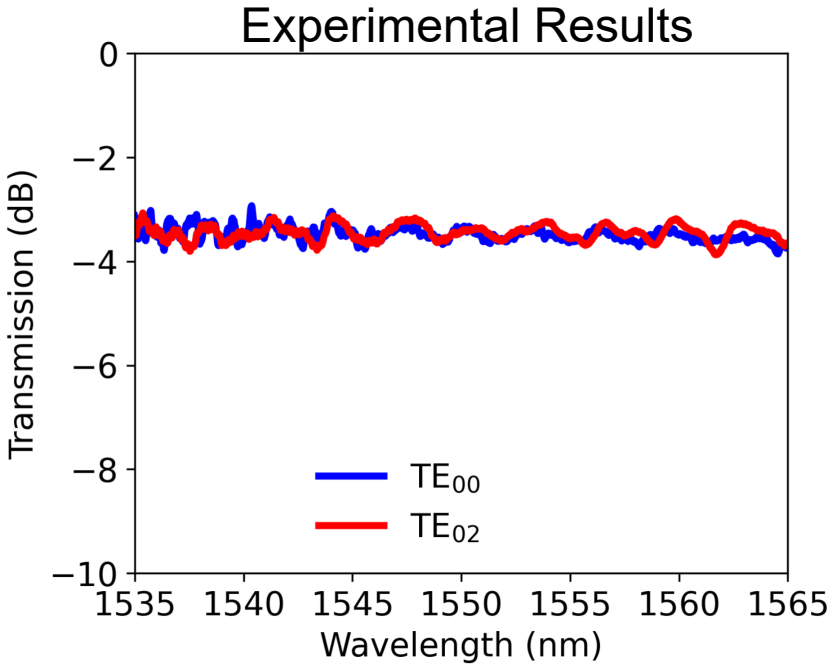
a. Whole structure
b. Beam splitter
c. Mode converter: fundamental mode
d. Mode converter : 2nd high order mode
e. Mode converter : 3rd high order mode

N. Dalvand, J.L. Pita Ruiz & M. Ménard “Inverse-Designed Silicon Nitride Arbitrary Mode Splitters for Interferometric Optical Sensors.” Optica Advanced Photonics Congress, Marseille, France, 2025

BiMC—Results

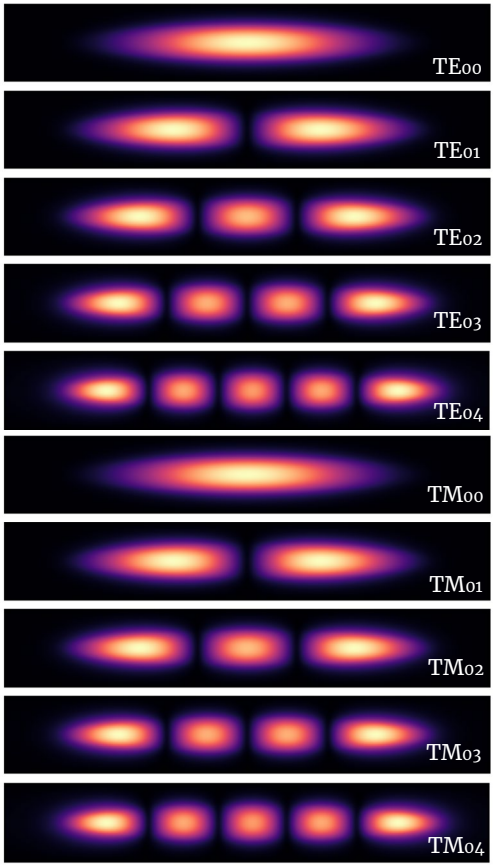
■ —• **Results for BiMC TE_{00} : TE_{02}**

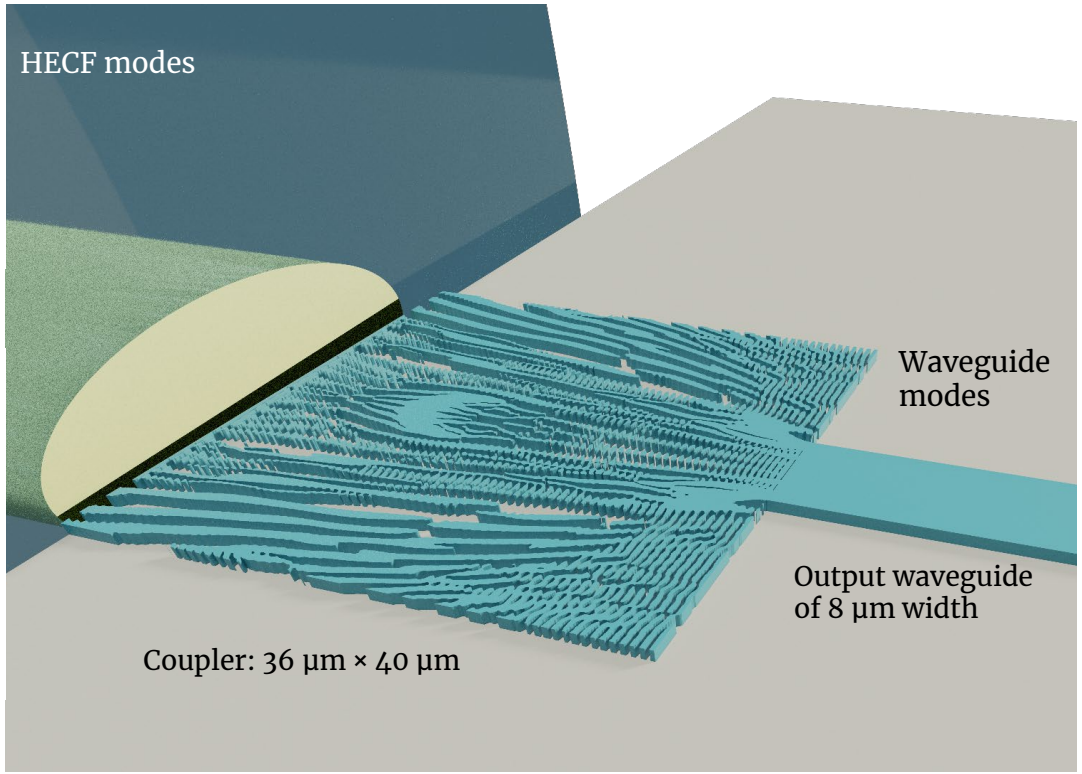


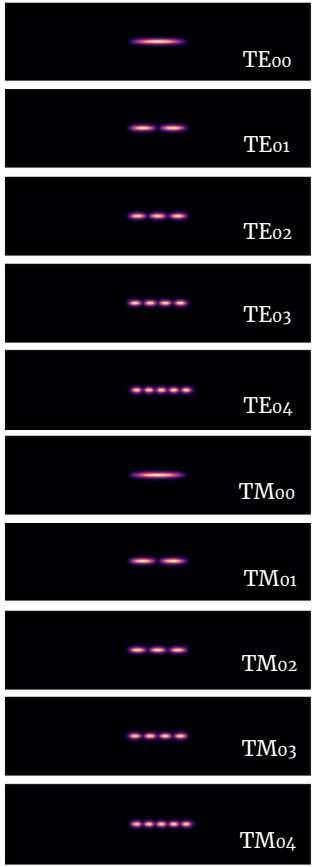


Average transmission	
TE_{00}, TE_{02}	$-3.6\ dB, -3.7\ dB$

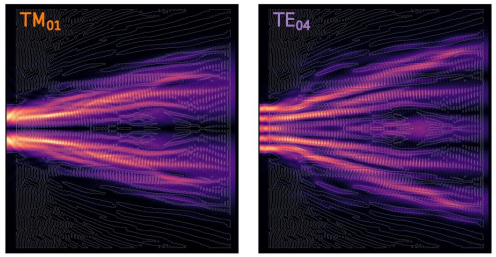
10-mode Fiber-to-chip Coupler

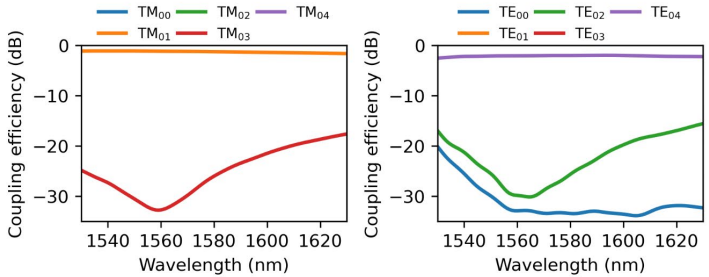


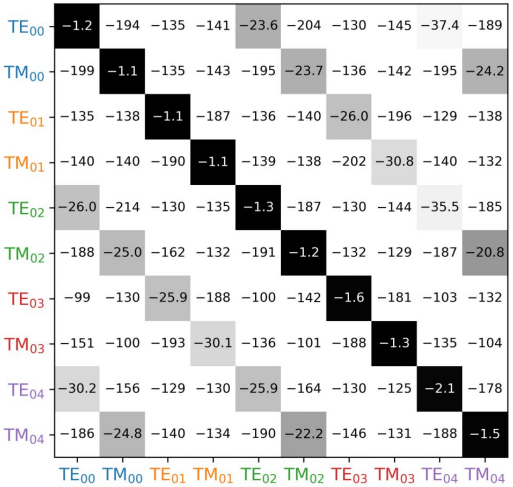


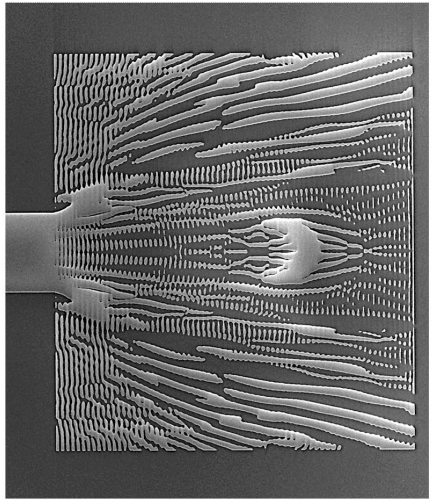


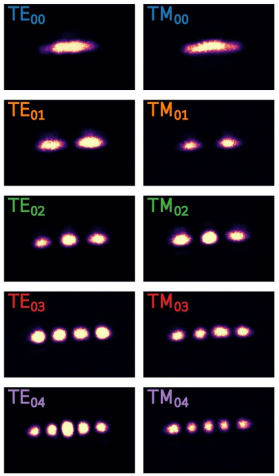
10-mode Fiber-to-chip Coupler—Simulations











- Simulated efficiencies: **−1.1 to −2.1 dB**
- Modal crosstalk: < −20 dB
- Broadband response: Flat across the C–L bands.
- Measured profiles: Strong mode fidelity

Conclusions

- Topology optimization can be applied to SiN platforms
- Inverse design mitigates low index contrast limitations.
- In some cases, it can achieve Si-like compactness.
- What are the optimal parameters to get the best devices?

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Thank you for your attention!

Any questions?

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