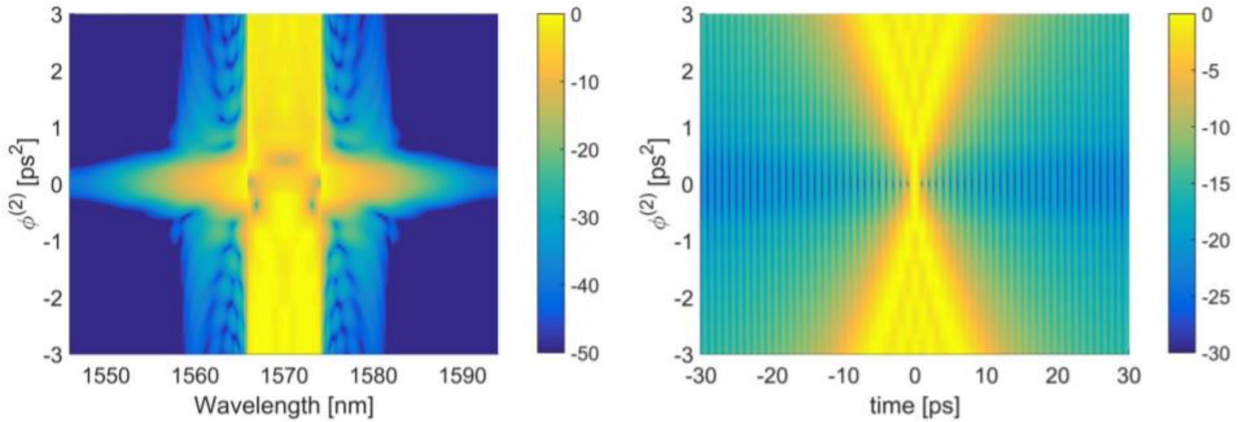
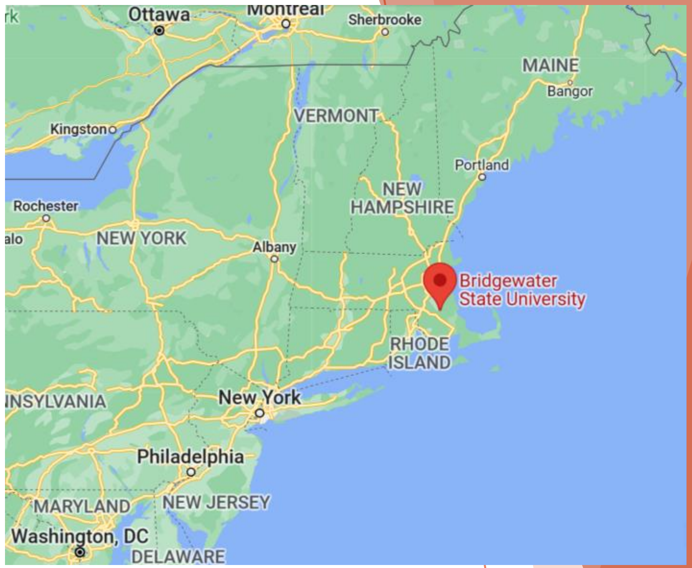
The Massachusetts LEAP network: Building a template for a hands-on advanced manufacturing hub in integrated photonics

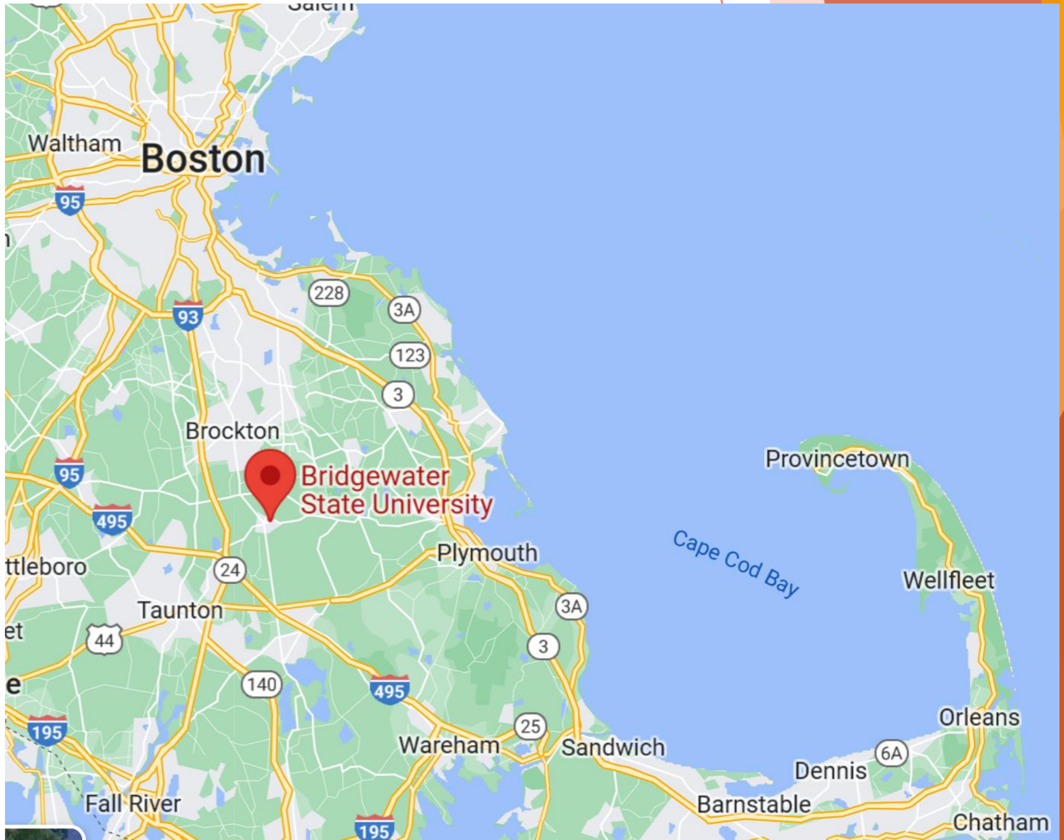
Samuel Felipe Serna-Otálvaro
Bridgewater State University
Massachusetts Institute of Technology
CHIRP research group



Bridgewater State University

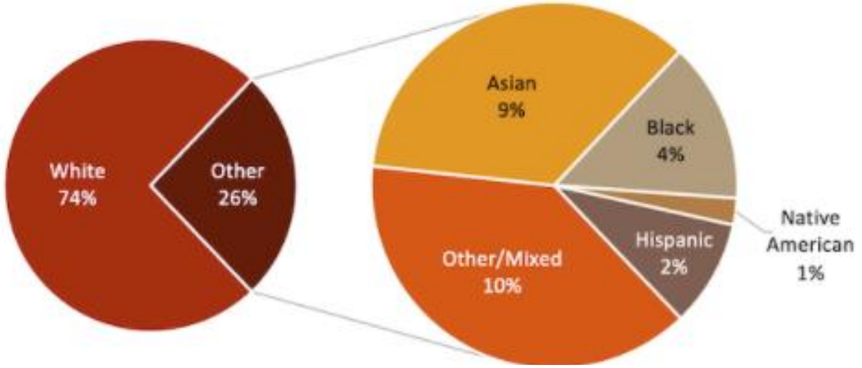
- **Founded in 1840**
  - Bridgewater State University was founded by Horace Mann, the father of American education, driven by his belief in education as the great equalizer for all citizens. Today, Bridgewater State University has over 10,000 current students and over 70,000 alumni in all 50 states.
- **Located in Bridgewater, Massachusetts:**
  - **39 buildings** on **278 acres**
  - **10th largest** four-year college or university in Massachusetts (out of 77)
  - **11 residence halls** and **1 student apartment** on campus. (Housing available for undergraduate, graduate and continuing studies students.)
  - **We have our own T stop**





Some numbers at BSU

Our Faculty



Demographics

Total Enrollment

- **Undergraduate students:** 9,463
- **Graduate students:** 1,418
- **Total Enrollment:** 10,881

**Fall 2019 numbers*

18:1	22	361	93%	6:7
student/faculty ratio	average students per class	full-time faculty	full-time faculty holding a doctoral or other terminal degree	average male/female faculty ratio

BSU is also named one of the top Fulbright-producing institutions -

https://www.bridgew.edu/sites/bridgew/files/media/pdf_document/2019-2020_Factbook_BSU.pdf

The Bartlett College of Science and Mathematics

- https://www.youtube.com/watch?v=iWNpYlmcTpA

Outline

1. Introduction
2. LEAP – Laboratory for Education and Applications Prototyping
3. Photonics and Optical Engineering BSc Program at BSU
4. Some ongoing research Projects

BRIDGEWATER
STATE UNIVERSITY

CHIRP

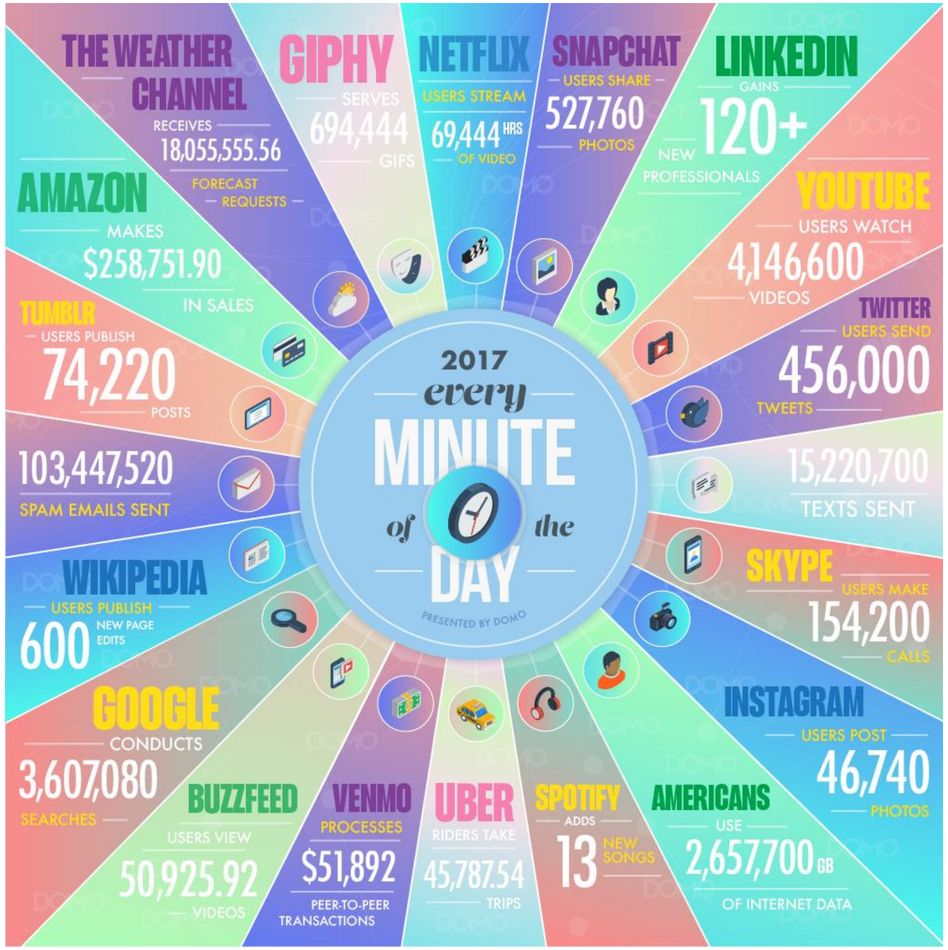
Optics, photonics, light…?

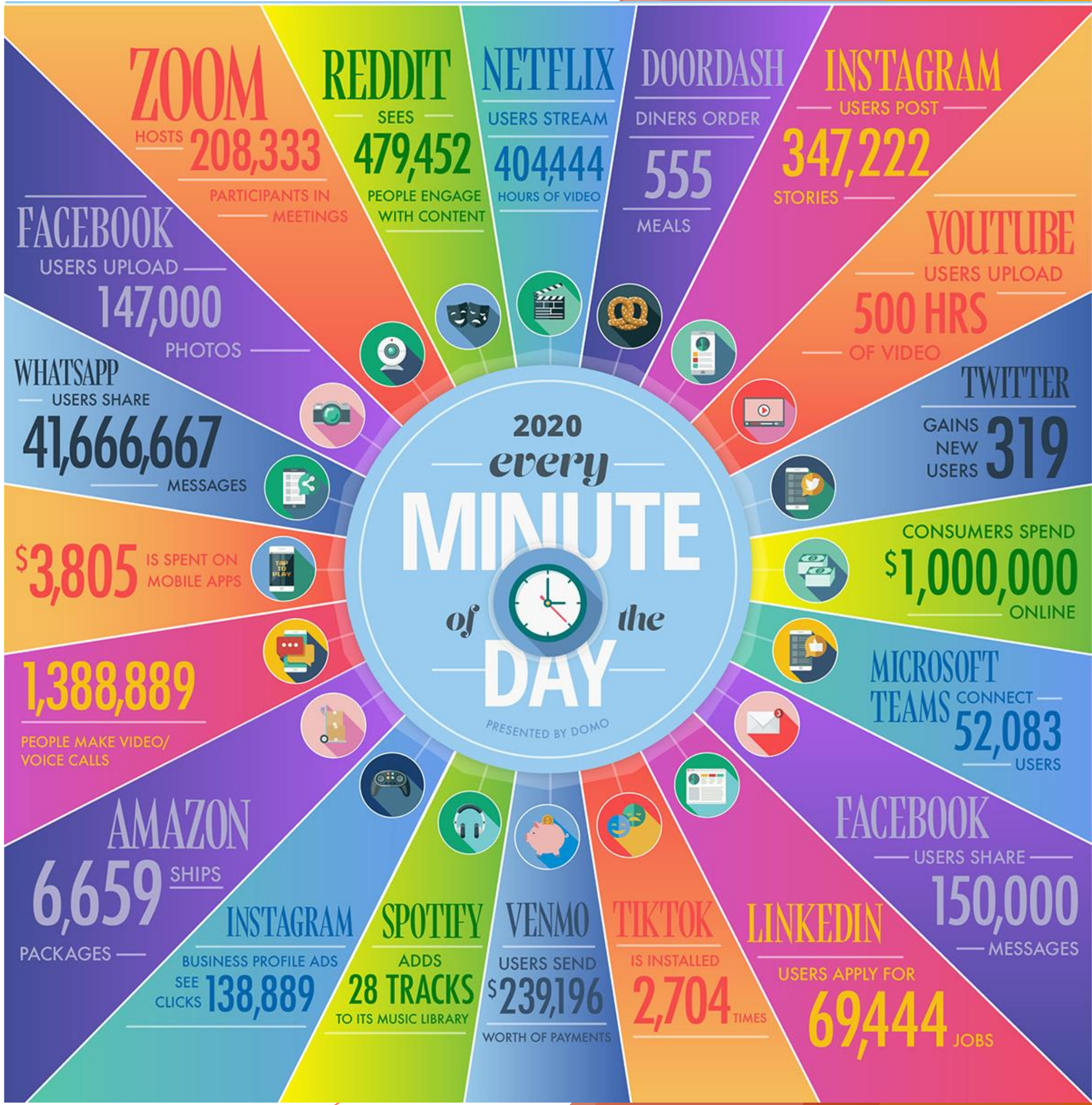
D.J. Lovell, Optical Anecdotes

UNDOUBTEDLY, NEARLY ALL WHO READ THIS BOOK HAVE, at one time or another, pondered the question, "What is light?" To answer, "Light is that which permits vision," begs the question, for such an answer provides us with no understanding of the nature of light. It says no more than "light is light."

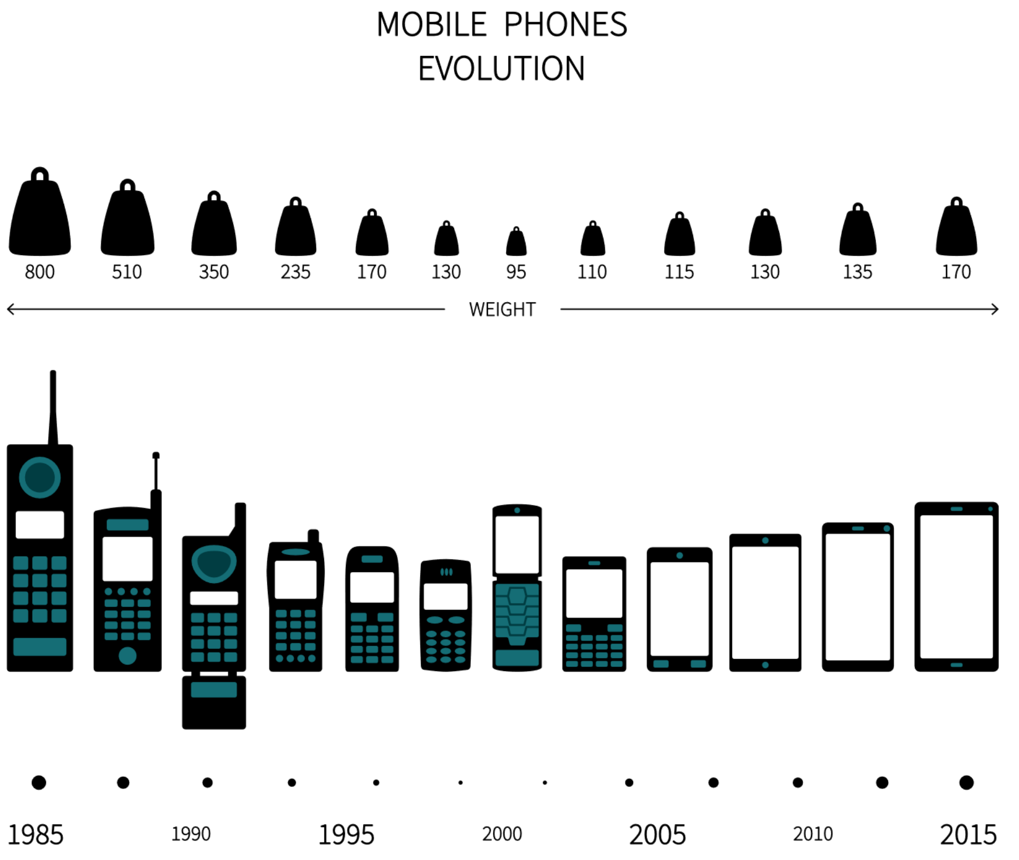
Data around the world

More than 90% of the world's data was created in the last two years alone.

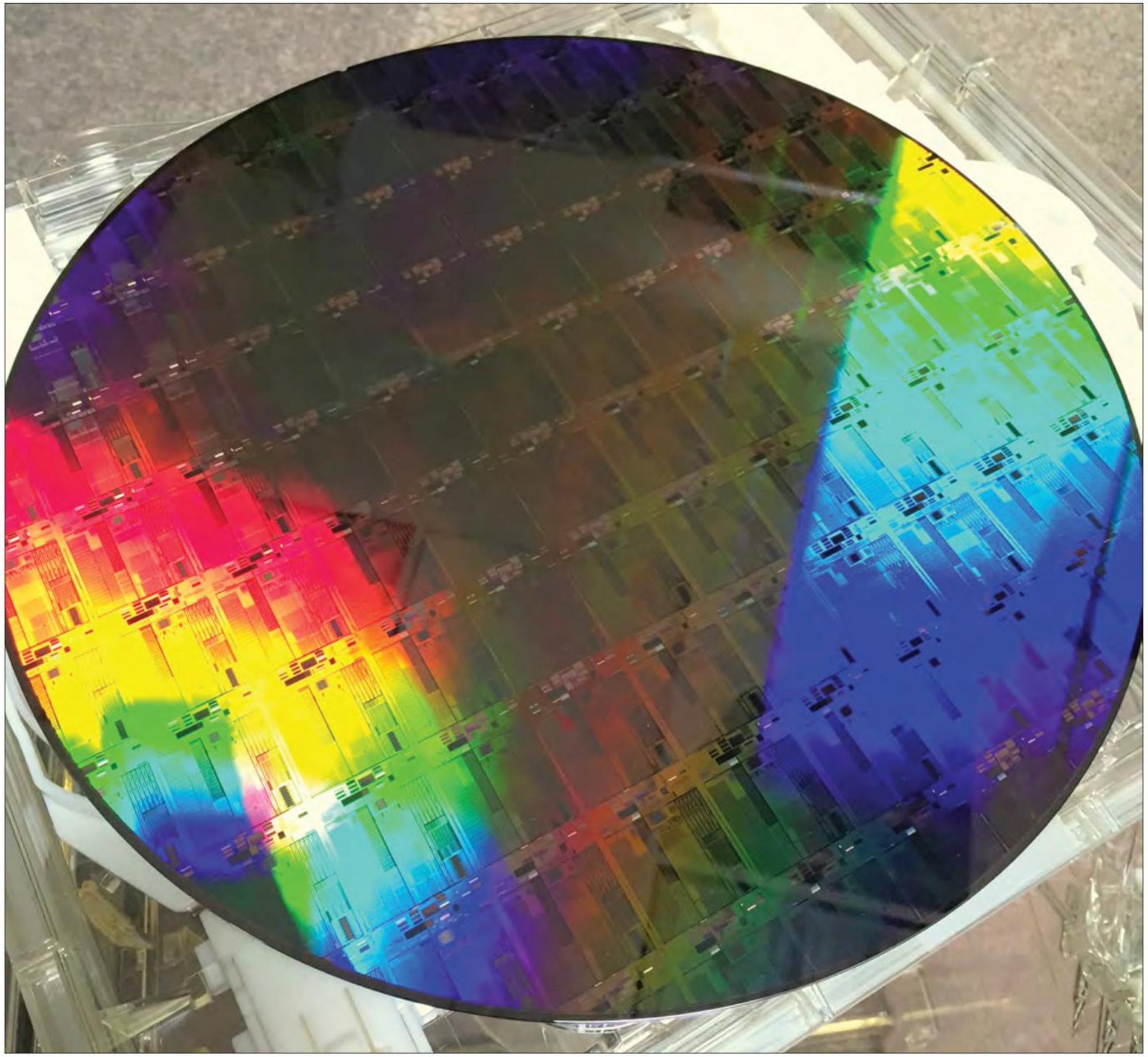




How does the future looks "light"?



CREDIT: Shutterstock/Alex Oakenman.



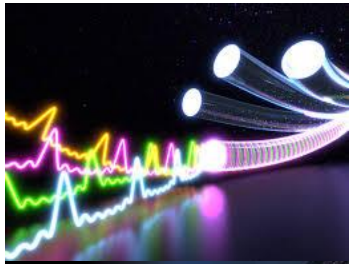
Replacing copper with light: a silicon photonics wafer. CREDIT: Wikimedia Commons.

Some Applications of Photonics

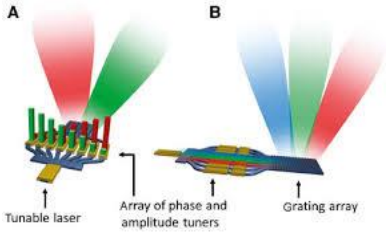
Four major areas of interest:

- telecom/datacom
- RF analog applications
- chemical sensors
- LIDAR imaging

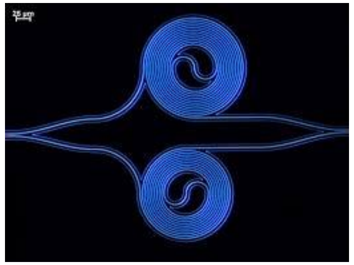
Datacom

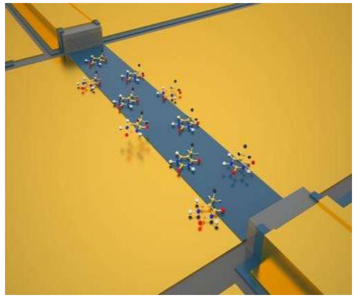


RF

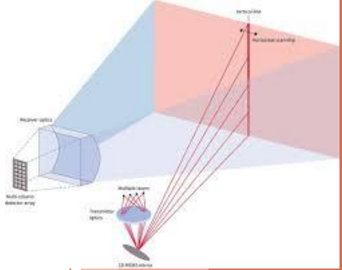


Sensing





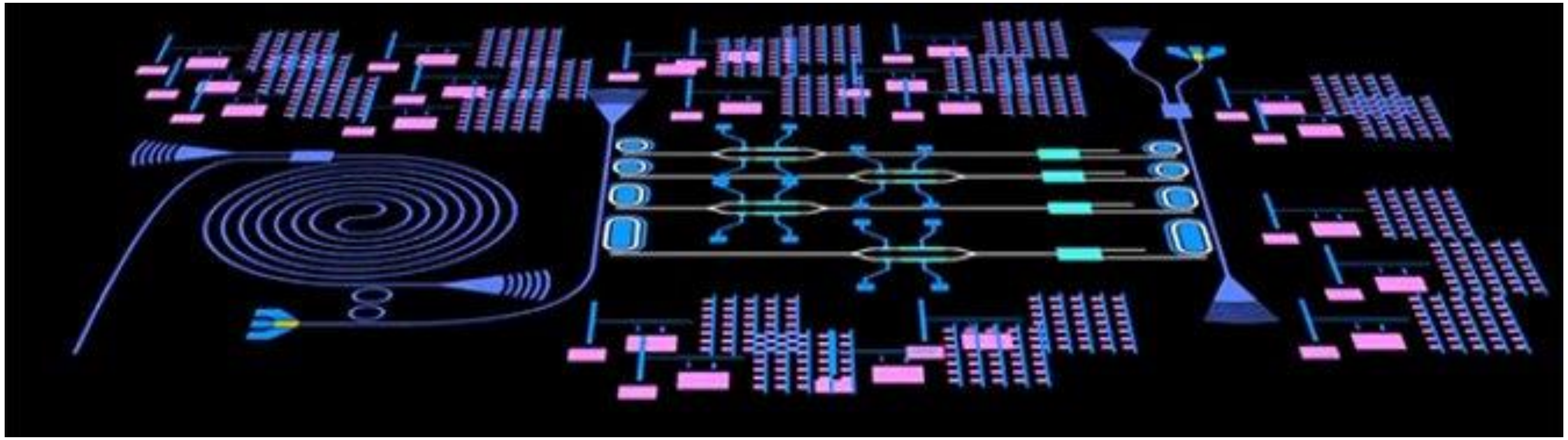
LIDAR

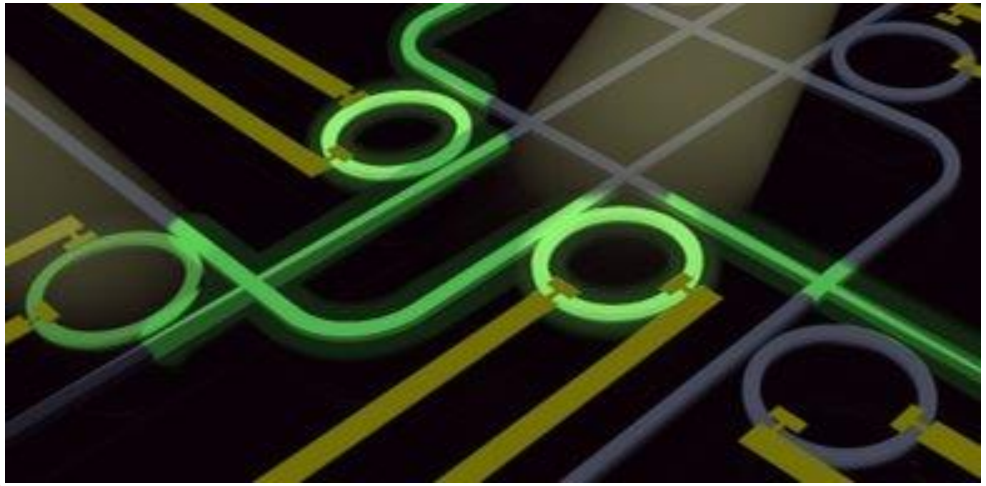


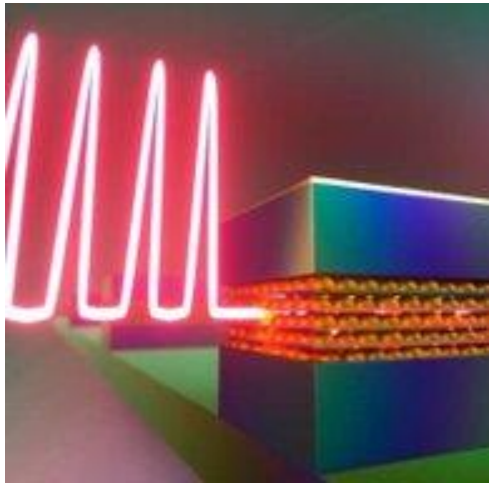
Application areas include

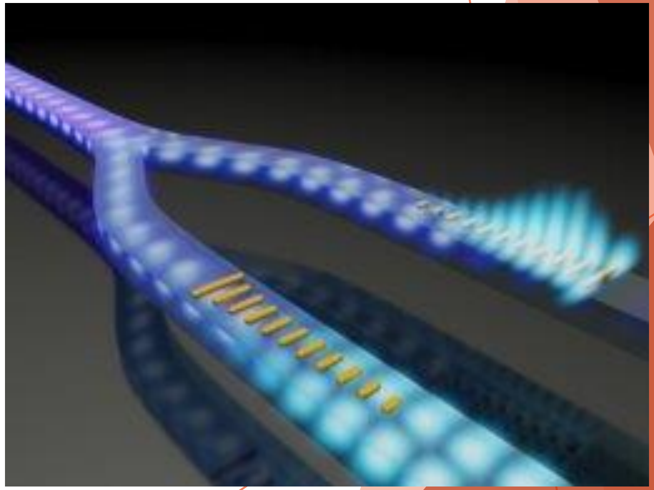
- **Data Centers**: high speed optical communication directly on chip surface
- **Advanced Equipment like Drones**: precision using integrated photonic circuits
- **Food Safety and Medical Sensors**: pathogen detection and biological sensing
- **Autonomous Vehicles**: navigation driven by photonics-based LIDAR
- *Think also about robotics, curved displays, augmented reality, communications…*

Photonic Integrated Circuits (PICs)





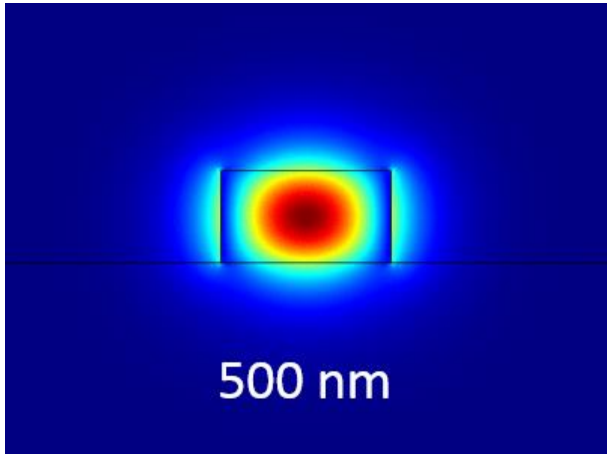


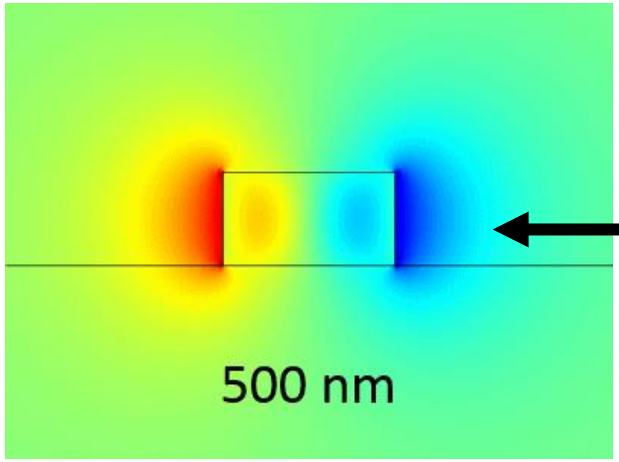


Nanophotonics

CHIRP

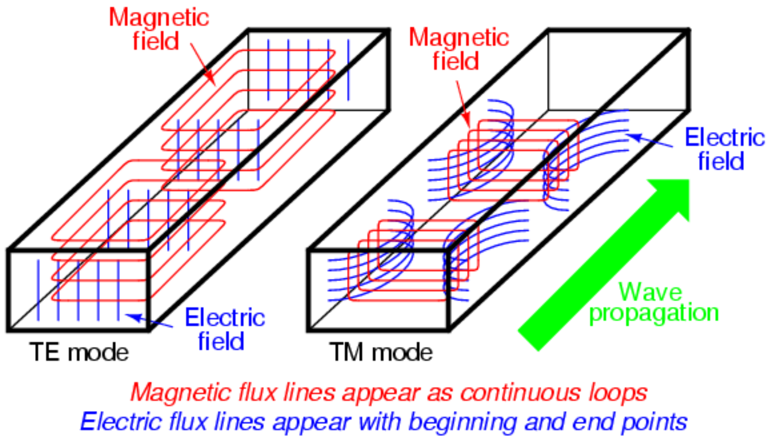
Guided modes depend on waveguide dimensions

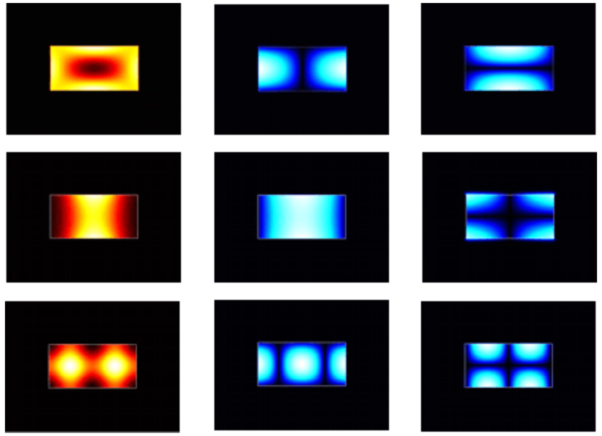




Evanescent Field

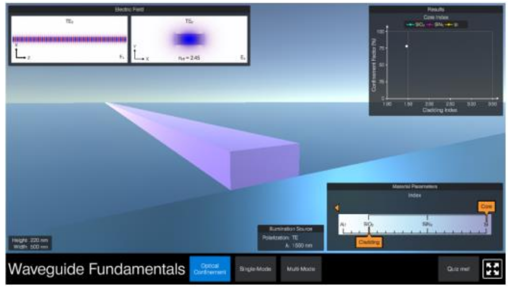
Electric and magnetic fields extend beyond the waveguide!



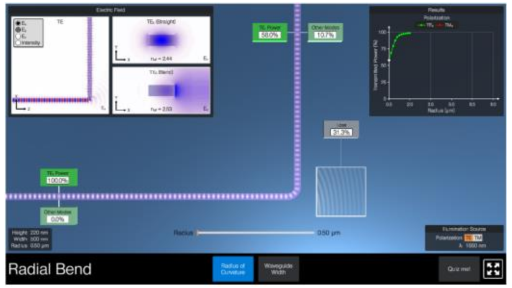


Virtual Labs Tools

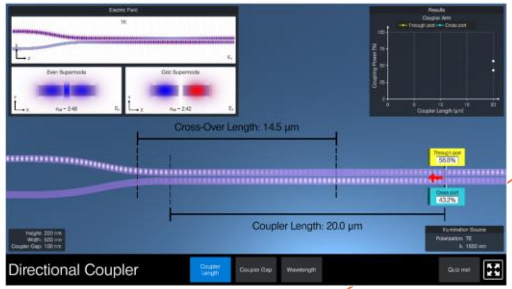
- https://s3.amazonaws.com/virtual-lab-silicon-waveguide/index.html



- https://s3.amazonaws.com/virtual-lab-radial-bend/index.html



- https://s3.amazonaws.com/virtual-lab-directional-coupler/index.html



Outline

Introduction

LEAP – Laboratory for Education and Applications Prototyping

Photonics and Optical Engineering BSc Program at BSU

Some ongoing research Projects

Where are the LEAP's ?

LEAP Network: LEAPs in MA and the nearby community colleges they can serve:
Teaching with the educational kit from AIM Photonics Academy

Photonics and Optics recognition and related Awards

2018 Award: MIT Office of Naval Research Grant subcontract for Photonics technician training program: **$200k**

2019 Award: M2I2 MA capital equipment Grant establishes LEAP @ BSU for Photonics and Optics-based cutting-edge equipment to support Industry and Research collaborations toward additional work force development: **$1.4M**

Massachusetts Institute of Technology

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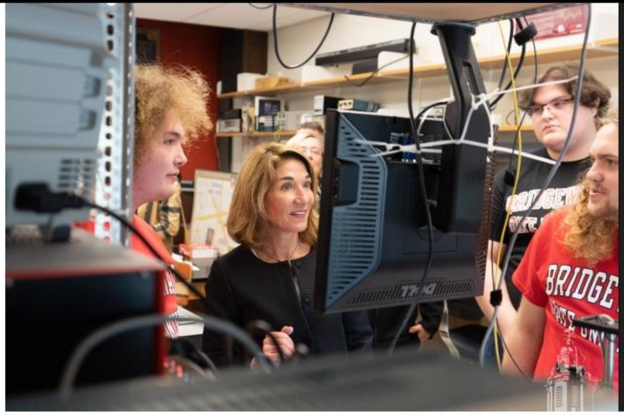
MIT News

ON CAMPUS AND AROUND THE WORLD

Browse or Search



Massachusetts Lieutenant Governor Karyn Polito tours a lab at Bridgewater State University.

Professional societies fund future photonics technicians

IEEE, SPIE, and OSA will support students within a new program launched in collaboration with MIT's Initiative for Knowledge and Innovation in Manufacturing.

Lt. Governor Karyn Polito visiting BSU Deveney laser lab after announcing $1.4 million grant MassTech award

LEAP @ BSU joins:
LEAP @ MIT
LEAP @ WPI/QCC
LEAP @ Stonehill
LEAP@STCC

Integrated Photonics Bootcamp BSU – MIT 2022

CHIRP

AIM ACADEMY photonics

LEAP @MIT M2I2 LEAP BRIDGEWATER STATE UNIVERSITY

Integrated Photonics is an emerging field.

A proliferation of new technologies in low-power cloud computing, ultra-high-speed wireless, smart sensing, and augmented imaging have begun to leverage the synergy of photonic and electronic devices working in tandem within an integrated circuit package.
As a result, critical curricular gaps are now becoming apparent in the training of engineers for these emerging industries.

INPHO-BOOT 2022
Hands-On Integrated Photonics Bootcamp

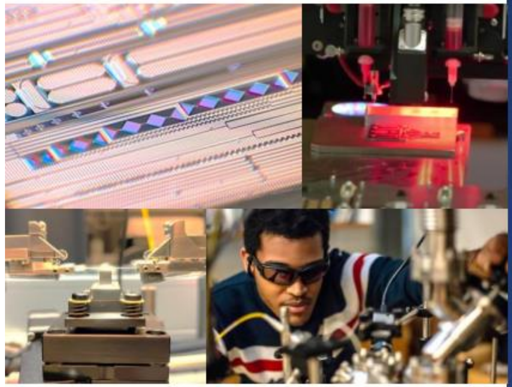
Passive integrated photonics bootcamp based on problem-based learning, to create a skilled workforce of independent thinkers who can meet practical challenges.

WHERE

Massachusetts Institute of Technology (LEAP@MIT).
Bridgewater State University (LEAP@BSU).

WHEN

March 22-24, 2022.



REGISTER!

Visit the AIM Photonics Academy website and save your spot.

ikim.mit.edu/bootcamps

*Space is extremely limited to only 12 registrants.

Organizers

MIT BRIDGEWATER STATE UNIVERSITY

YOU WILL LEARN

Basic concepts in photonic devices
TE/TM propagation modes, light confinement, evanescence, on-chip guiding, and applications

Prototyping using integrated circuit packaging
Die-bonding of surface-mounted components, X-ray inspection, and reflow soldering

Characterizing integrated photonic devices
Collect data from on-chip straight waveguides, ring resonators, and Mach-Zehnder interferometers, and analyze

Chip to fiber coupling
Couple light into an SOI chip using edge coupling

Photonic engineering tools
Laser beam characterization and fiber splicing

Data analysis
Software to characterize devices based on real test data

Virtual Lab simulations
Game-based learning to build intuition about on-chip light propagation and advanced manufacturing

YOU NEED

Laptop and lab notebook.

YOU GET TO KEEP

Manual with detailed descriptions of integrated photonics experiments and exercises.

COST

$6000 for three days of blended learning in integrated photonics.

Organizers


Prof. L.C. Kimerling
Director of
MIT Microphotonics
Center & Initiative for
Knowledge and
Innovation in
Manufacturing (IKIM)
Dr. Anu Agarwal
Pr. Res. Scientist, MIT
Prof. Samuel Serna
Bridgewater State University
Bootcamp
Creators
Meet the INPHO-BOOT
visionaries, instructors
and technical
contributors
Prof. Juejun Hu
Luigi Ranno
Graduate student
Drew Weninger
Graduate student
Dr. Kenan Cicek
Fulbright scholar
Dr. Sajan Saini
Prof. Kazumi Wada
Dr. Erik Verlage
Dr. Jeffrey Bertrand
Trevor Morrisey
Christian
Gabbianelli
Yue Yuan
Samuel Bechtold
Peyton Brown
Juan Jose Arango
Uribe
Camilo Hurtado
Ballesteros
Julian Andres
Laverde Preciado
Pablo Bedoya
Rios
BRIDGEWATER
STATE UNIVERSITY
MicrophotonicsCenter
IKIM
AIM ACADEMY

BRIDGEWATER STATE UNIVERSITY

Some pictures from the bootcamp

CHIRP

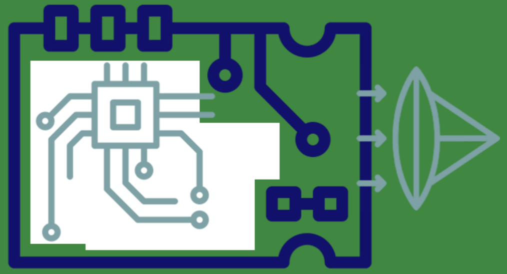
BRIDGEWATER STATE UNIVERSITY

Massachusetts Institute of Technology

Our project

https://mrl.mit.edu/article/team_creates_high-performance_microchip_technologies

Technology

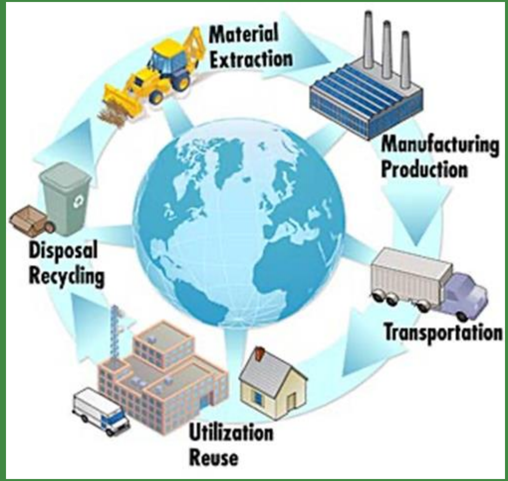


Repairable Technology Demonstrator

Workforce

Educate using Green Innovation Tool Kit

Ecology



Life Cycle Analysis

FUTUR-IC

Outline

- Introduction
- LEAP – Laboratory for Education and Applications Prototyping
- Photonics and Optical Engineering BSc Program at BSU
- Some ongoing research Projects

What is Photonics and Optical Engineering?

- Photonics: Light, not electrons, on semiconductor integrated chips. Less power consumption and higher bandwidth.

- Engineers: The design and development of devices using laser light in sensors, LIDAR, telecommunications, processor chips, and other applications.

- A fast-growing sector of

New England's light-based economies.

- State's only Photonics and Optical

Engineering Program degree

program started officially in Sept 2021!

CAN YOU DO A PHOTONICS AND OPTICAL ENGINEERING MAJOR IN 4 YEARS AT BSU? YES!

Year One		Year Two		Year Three		Year Four	
Fall		***Fall***		***Fall***		***Fall***	
PHYS 243 Gen Phys 1	4	PHYS 211 Machine Shop	1	PHOE 403 Semiconductor Devices	3	PHOE 455 Advanced Optics	3
MATH 161 Calculus 1 with MATH 143	5	PHYS 416 Modern Theory	3	PHOE 330 Fiber Optic Communication	4	Senior Photonics Elective	3
ENGL 101 Writing 1	3	PHOE 301 Foundations of Photonics & Optical Eng.	4	PHYS 438 Electricity and Magnetism	3	Senior Photonics Elective	4
COMM 102 or THEA 210	3	MATH 261 Multivariable Calculus	4	CHEM 141 Gen Chem 1	4	PHOE 483 Senior Design I	3
		CORE (CHUM, CWRT)	3	CORE (CHUM; CUSC)	3	CORE (CSOC; CGCL)	3
Totals	15		15		17		16
Spring		***Spring***		***Spring***		***Spring***	
PHYS 244 Gen Phys 2	4	PHOE 323 Optical Engineering	4	PHOE 450 PIC Design	3	Senior Photonics Elective	4
MATH 162 Calculus 2	4	PHOE 342 Digital Electronics	4	PHOE 420 Laser Engineering	4	PHOE 484 Senior Design II (CWRT)	3
First Year Seminar (CFPA)	3	PHYS 403 Mathematical Methods	3	CORE (CHUM; CMCL)	3	CORE (CSOC; CGCL)	3
ENGL 102 Writing 2	3	Second Year Seminar (CFPA; CSPK)	3	CHEM 142 Gen Chem 2	4	Major Elective / CORE	3
PHIL 111 Logical Reas. (MATH 180/COMP 111)	3	PHYS 422: Computational Methods	3				
Totals	17		17		14		13

Major Requirements in Photonics and Optical Engineering: 44-47 Credits

Cognate Requirements in Physics, Mathematics and Chemistry: 41 Credits

Core Requirements or Electives outside Science & Mathematics: 36 Credits

BSU's growing list of partners, supporters, connections and collaborators:

BRIDGEWATER STATE UNIVERSITY

Industry

- IPG PHOTONICS
- MIT Lincoln Laboratory
- Plymouth Grating LABORATORY
- angiodynamics
- HOLOGRAPHIX LLC — Creating a Spectrum of Optical Solutions
- IRADION — Ceramic Core CO_2 Lasers
- FORWARD PHOTONICS
- Optikos
- mks
- DRAPER | APOLLO 50

Federal and State

- Manufacturing USA
- AIM photonics — AMERICAN INSTITUTE for MANUFACTURING INTEGRATED PHOTONICS
- U.S. DEPT OF DEFENSE
- MASSACHUSETTS TECHNOLOGY COLLABORATIVE
- NATIONAL PHOTONICS INITIATIVE
- ARM — ADVANCED ROBOTICS FOR MANUFACTURING
- Office of Naval Research — ONR — Science & Technology
- H.R.6227 - National Quantum Initiative Act — 115th Congress (2017-2018)

National Lab and Academics

- MIT
- SUNY POLYTECHNIC INSTITUTE
- Worcester Polytechnic Institute
- MIT Lincoln Laboratory
- STONEHILL COLLEGE (LUX ET SPES)
- QUINSIGAMOND Community College
- WESTMORELAND COUNTY COMMUNITY COLLEGE
- AIM photonics ACADEMY
- DRAPER | APOLLO 50
- UMass Amherst
- UMass Boston
- UMass Dartmouth
- UMass Lowell

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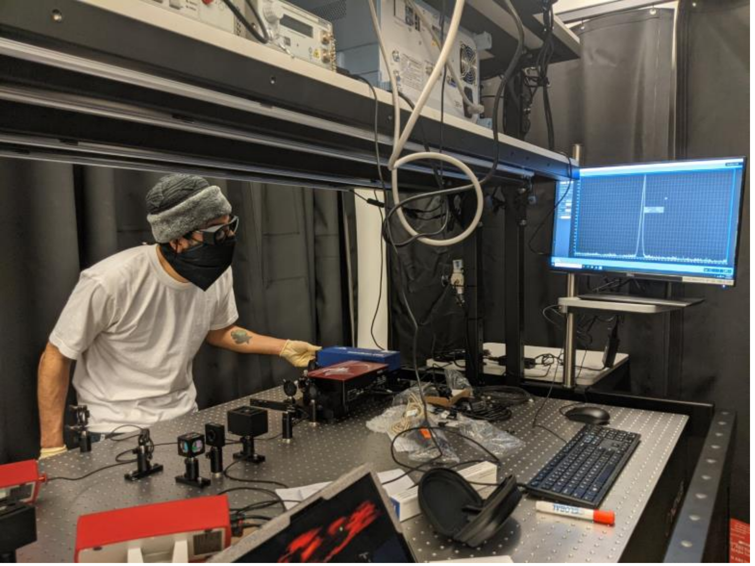
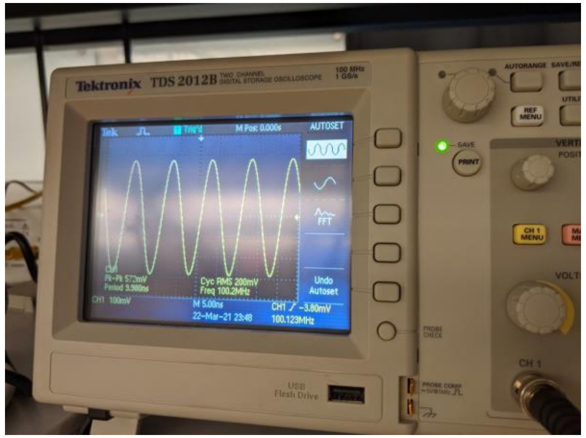




Set-up for dispersion, ultrafast and nonlinear characterization at 1550 nm

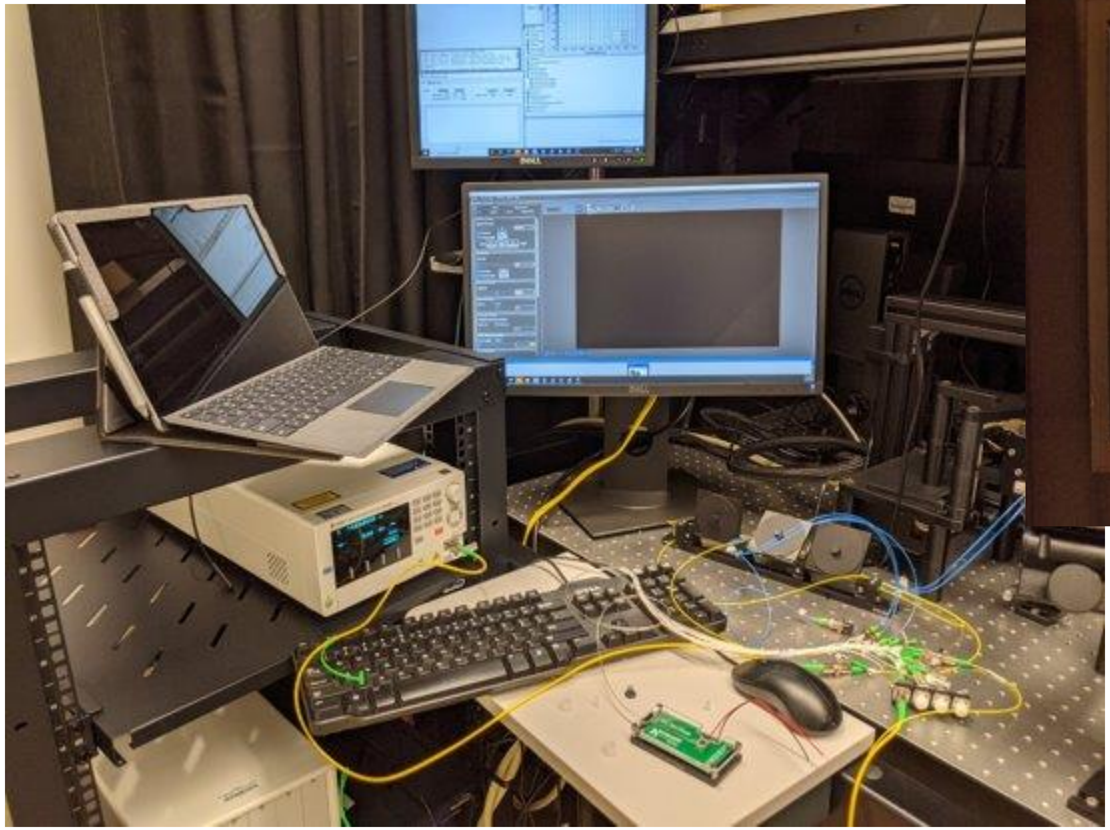
Chromacity laser, picosecond
~5 ps @100 MHz
OPA Pump 1040 nm
From 1.4 um up to 4 um

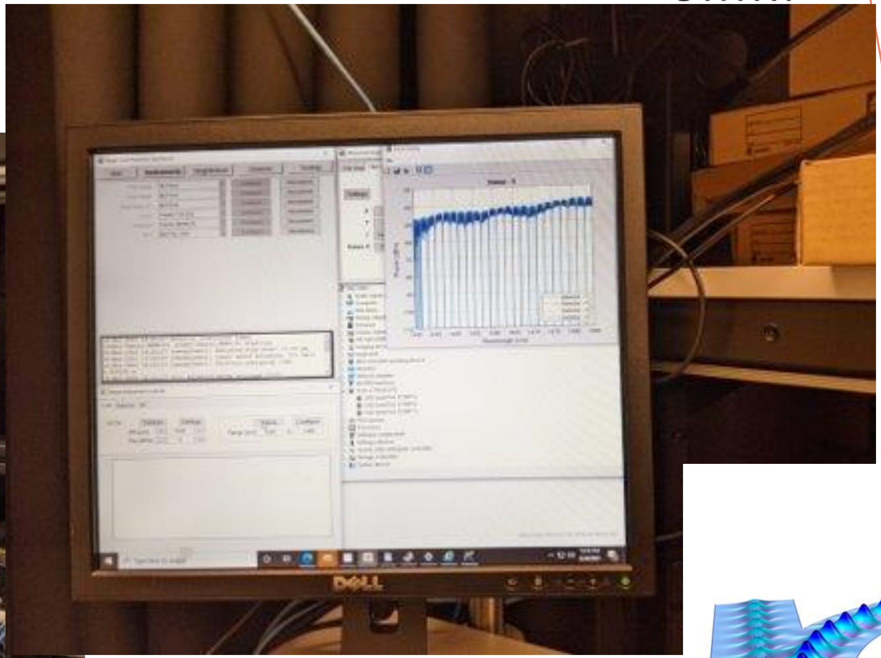
Dr. Serna's Group @ BSU

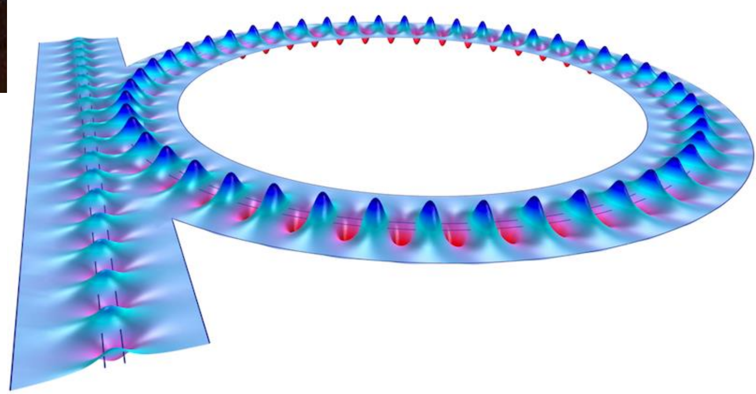
Nonlinear and Ultrafast Photonics

Angelo – 21'
Now Field Engineer at Kratos

Optical characterization of on-chip ring resonators







Comsol

Dr. Serna’s Group @ BSU

Nonlinear and Ultrafast Photonics

Brahmin and Jon – 21'

Use of an inspection IR camera Xenics adapted with the MapleLeaf Photonics system

Publications

Journal of Optics

PAPER

Enhancing SiN waveguide optical nonlinearity via hybrid GaS integration

Skylar Deckoff-Jones[5,1,2], Vincent Pelgrin[2], Jianhao Zhang[2], Christian Lafforgue[2], Lucas Deniel[2], Sylvain Guerber[4], Rebeca Ribeiro-Palau[2], Frédéric Boeuf[4], Carlos Alonso-Ramos[2], Laurent Vivien[2], Juejun Hu[1] and Samuel Serna[5,3] − Hide full author list

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Journal of Optics, Volume 23, Number 2
Citation Skylar Deckoff-Jones *et al* 2021 *J. Opt.* **23** 025802

− Hide article information

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Dr. Serna's Group @ BSU

Third-order nonlinear optical susceptibility of crystalline oxide yttria-stabilized zirconia

Guillaume Marcaud, Samuel Serna, Karamanis Panaghiotis, Carlos Alonso-Ramos, Xavier Le Roux, Mathias Berciano, Thomas Maroutian, Guillaume Agnus, Pascal Aubert, Arnaud Jollivet, Alicia Ruiz-Caridad, Ludovic Largeau, Nathalie Isac, Eric Cassan, Sylvia Matzen, Nicolas Dubreuil, Michel Rérat, Philippe Lecoeur, and Laurent Vivien

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Photonics Resea

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Suppl. Mat. (4)
Tables (4)
Equations (7)
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ultrafast signal
need to be
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stalline oxide family
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talline YSZ. Via self-
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omparable with the
promising results
optical
f on-chip optical

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Neetesh Singh, *et al.*
Photon. Res. 8(12) 1904-1909 (2020)

US 20210109290A1

(19) **United States**

(12) **Patent Application Publication**

KIMERLING et al.

(10) **Pub. No.: US 2021/0109290 A1**

(43) **Pub. Date: Apr. 15, 2021**

(54) **SIMULTANEOUS ELECTRICAL AND OPTICAL CONNECTIONS FOR FLIP CHIP ASSEMBLY**

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(72) Inventors: **Lionel C. KIMERLING**, Concord, MA (US); **Jurgen MICHEL**, Arlington, MA (US); **Anuradha M. AGARWAL**, Weston, MA (US); **Kazumi WADA**, Lexington, MA (US); **Drew Michael Weninger**, Cambridge, MA (US); **Samuel Serna**, Somerville, MA (US)

(21) Appl. No.: **16/989,448**

(22) Filed: **Aug. 10, 2020**

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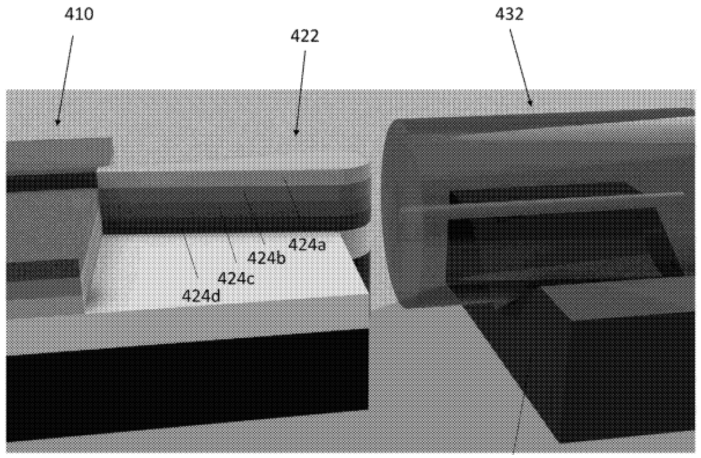
Publication Classification

(51) **Int. Cl.**
G02B 6/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/305*** (2013.01)

(57) **ABSTRACT**

Optical interconnects can offer higher bandwidth, lower power, lower cost, and higher latency than electrical interconnects alone. The optical interconnect system enables both optical and electrical interconnection, leverages existing fabrication processes to facilitate package-level integration, and delivers high alignment tolerance and low coupling losses. The optical interconnect system provides connections between a photonics integrated chip (PIC) and a chip carrier and between the chip carrier and external circuitry. The system provides a single flip chip interconnection between external circuitry and a chip carrier using a ball grid array (BGA) infrastructure. The system uses graded index (GRIN) lenses and cross-taper waveguide couplers to optically couple components, delivers coupling losses of less than 0.5 dB with an alignment tolerance of ±1 μm, and accommodates a 2.5× higher bandwidth density.



Free-form micro-optics enabling ultra-broadband low-loss fiber-to-chip coupling

Shaoliang Yu[1†], Luigi Ranno[1†], Qingyang Du[1], Samuel Serna[1,2*], Colin McDonough[3], Nicholas Fahrenkopf[3], Tian Gu[1,4*], and Juejun Hu[1,4]

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[2] *Department of Physics, Photonics and Optical Engineering, Bridgewater State University, Bridgewater, MA, USA*

[3] *The Research Foundation for State University of New York, State University of New York Polytechnic Institute, Albany, NY, USA*

[4] *Materials Research Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA*

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ABSTRACT

Efficient fiber-to-chip coupling has been a major hurdle to cost-effective packaging and scalable interconnections of photonic integrated circuits. Conventional photonic packaging methods relying on edge or grating coupling are constrained by high insertion losses, limited bandwidth density, narrow band operation, and sensitivity to misalignment. Here we present a new fiber-to-chip coupling scheme based on free-form reflective micro-optics. A design approach which simplifies the high-dimensional free-form optimization problem to as few as two full-wave simulations is implemented to empower computationally efficient design of high-performance free-form reflectors while capitalizing on the expanded geometric degrees of freedom. We demonstrated fiber array coupling to waveguides taped out through a standard foundry shuttle run and backend integrated with 3-D printed micro-optics. A low coupling loss down to 0.5 dB was experimentally measured at 1550 nm wavelength with a record 1-dB bandwidth of 300 nm spanning O to U bands. The coupling scheme further affords large alignment tolerance, high bandwidth density and solder reflow compatibility, qualifying it as a promising optical packaging solution for applications such as wavelength division multiplexing communications, broadband spectroscopic sensing, and nonlinear optical signal processing.

BRIDGEWATER STATE UNIVERSITY

Bridgewater Review

Volume 39 | Issue 1 Article 5

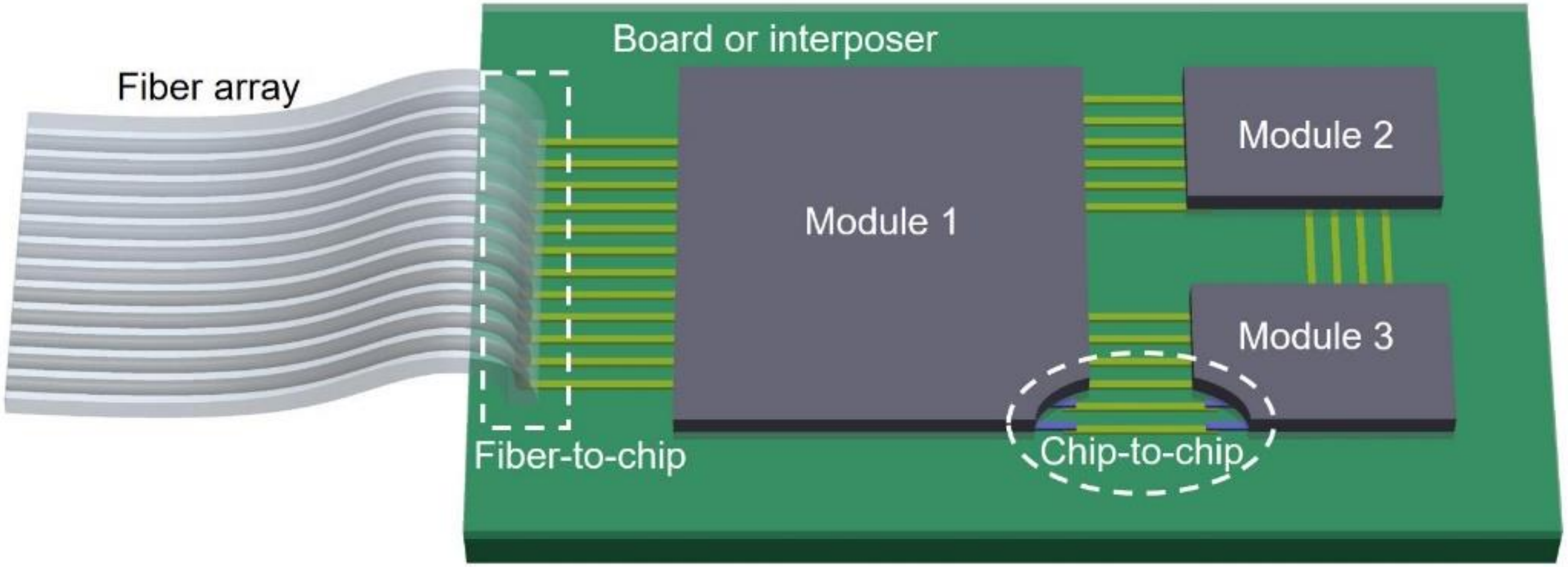
4-2020

The Responsibility of Scientists in Public Policy

Samuel S. Otálvaro
Bridgewater State University

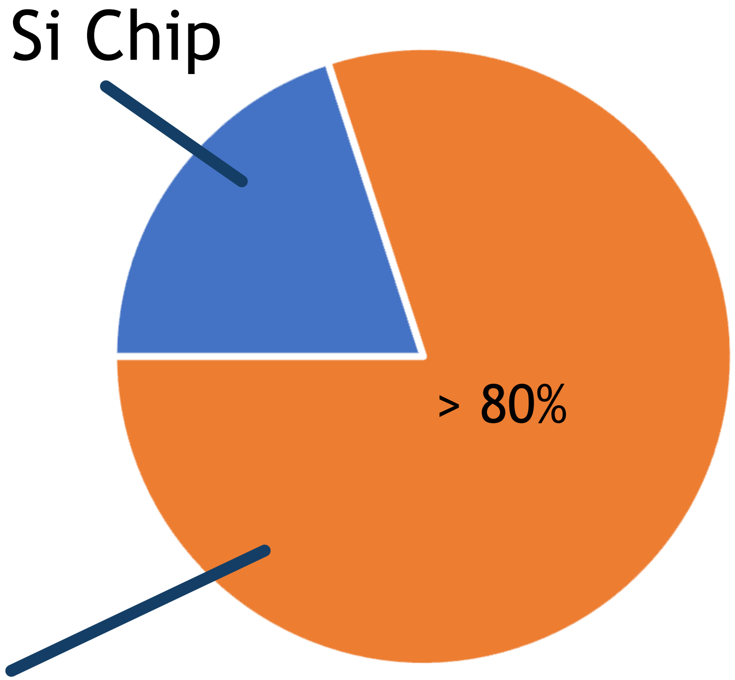
Dr. Serna’s Group @ BSU

Problem Statement

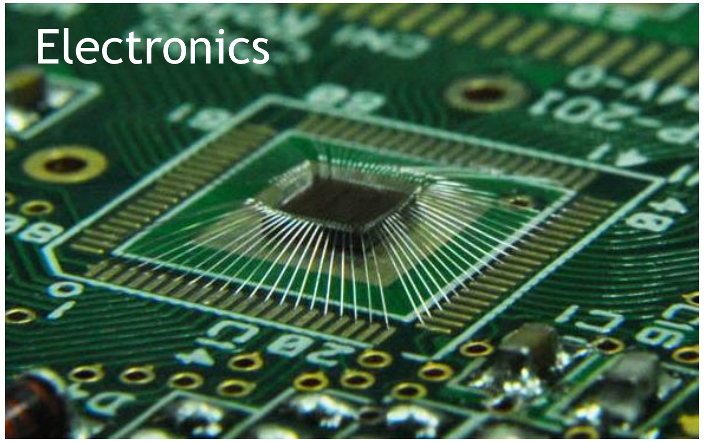


Optical coupler requirements: **low loss, broadband, high-density & good alignment tolerance**

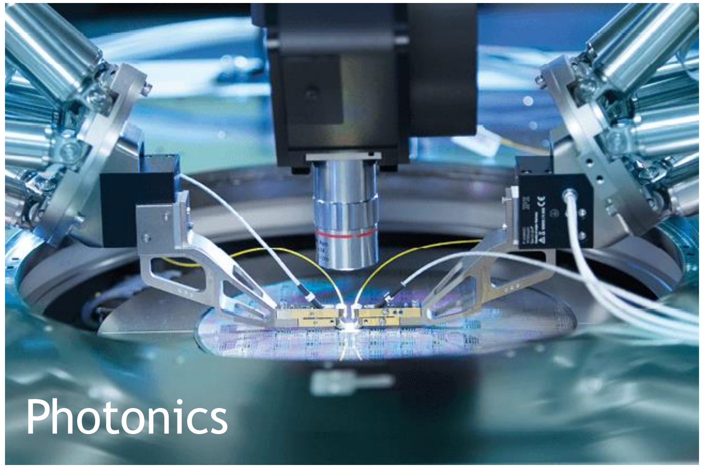
The packaging bottleneck



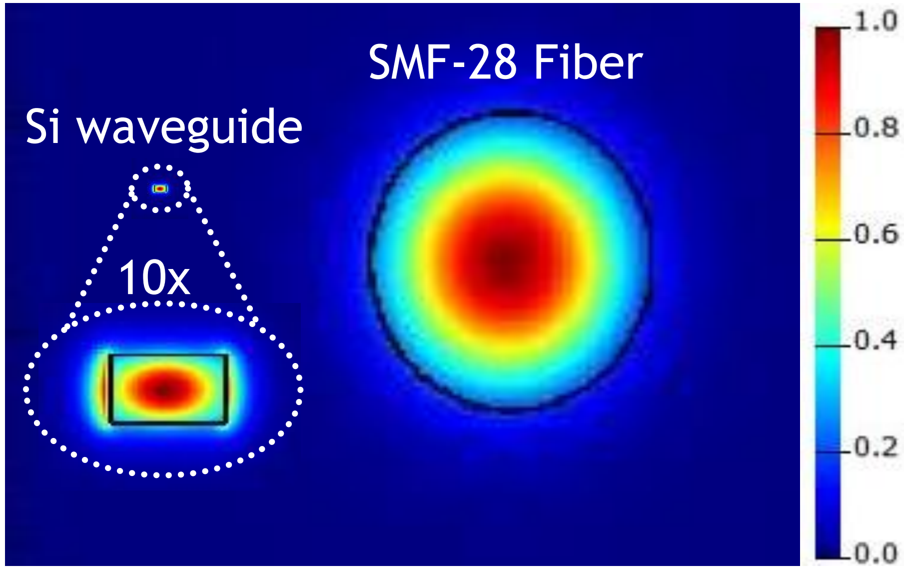
- Fiber Connector(s)
- Assembly
- Testing
- …



Rocket PCB Inc.



FormFactor Inc.

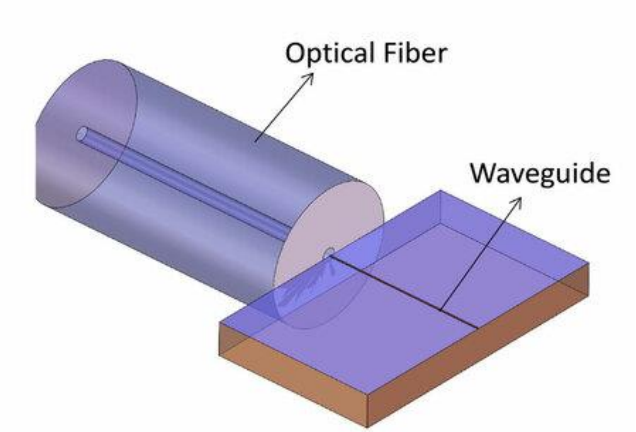


Modal fields of a Si waveguide (left) and optical fiber (right)

30

Coupling to a PIC: The Present

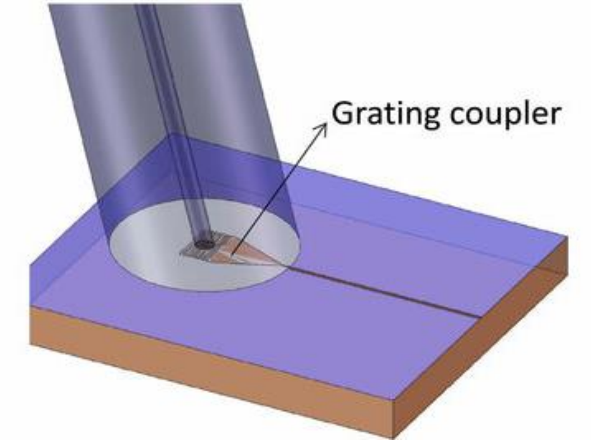
Edge coupling



IEEE Access, vol. 8, pp. 188284-188298, 2020

- X Limited Bandwidth density
- X Wafer-level testing incompatible
- X Low alignment tolerance

Grating coupling



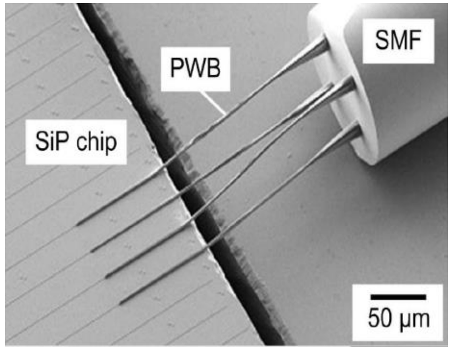
IEEE Access, vol. 8, pp. 188284-188298, 2020

- X High Insertion Loss (~ 3dB)
- X Low Bandwidth (~ 30 nm)
- X Polarization dependent

Each method has heavy downsides

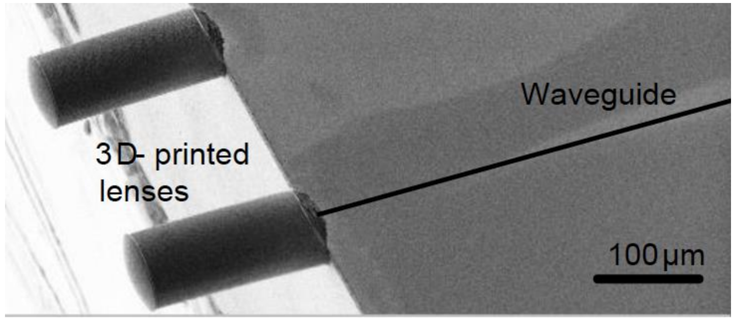
Coupling to a PIC: A promising direction

Photonic Wire



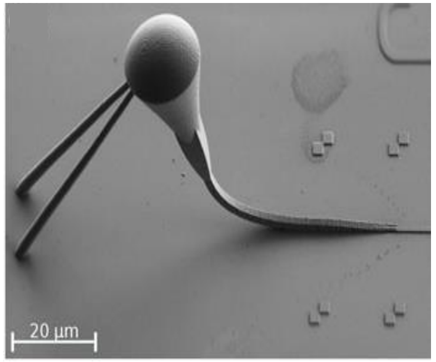
J. Lightwave Technol. 33, 755-760 (2015).

Edge coupling beam-shapers



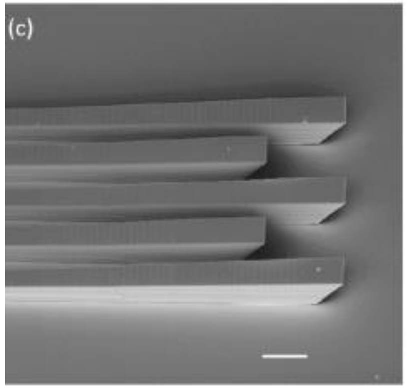
Nat. Phot. 12, 241-247 (2018).

Lensed 3D coupler



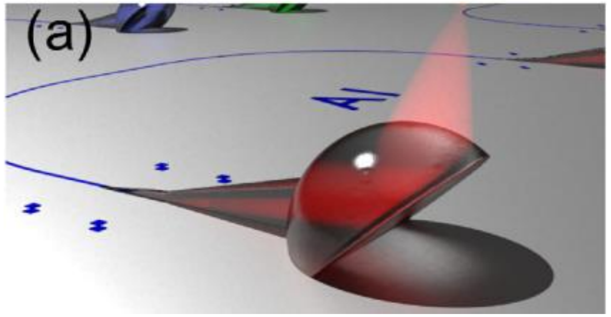
APL Photonics 4, 010801 (2019)

Multi-channel coupler



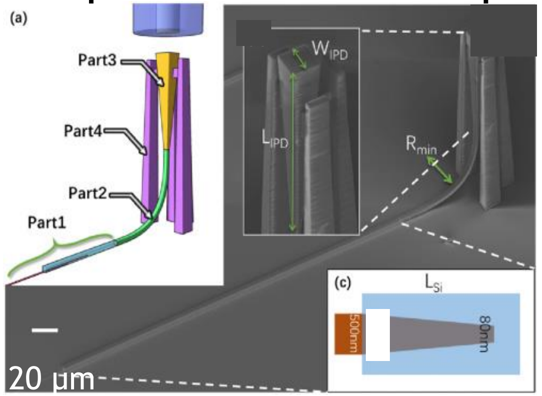
Opt. Lett. 46, 4324-4327 (2021).

Lensed reflective plane



Opt. Lett. 44, 5089-5092 (2019).

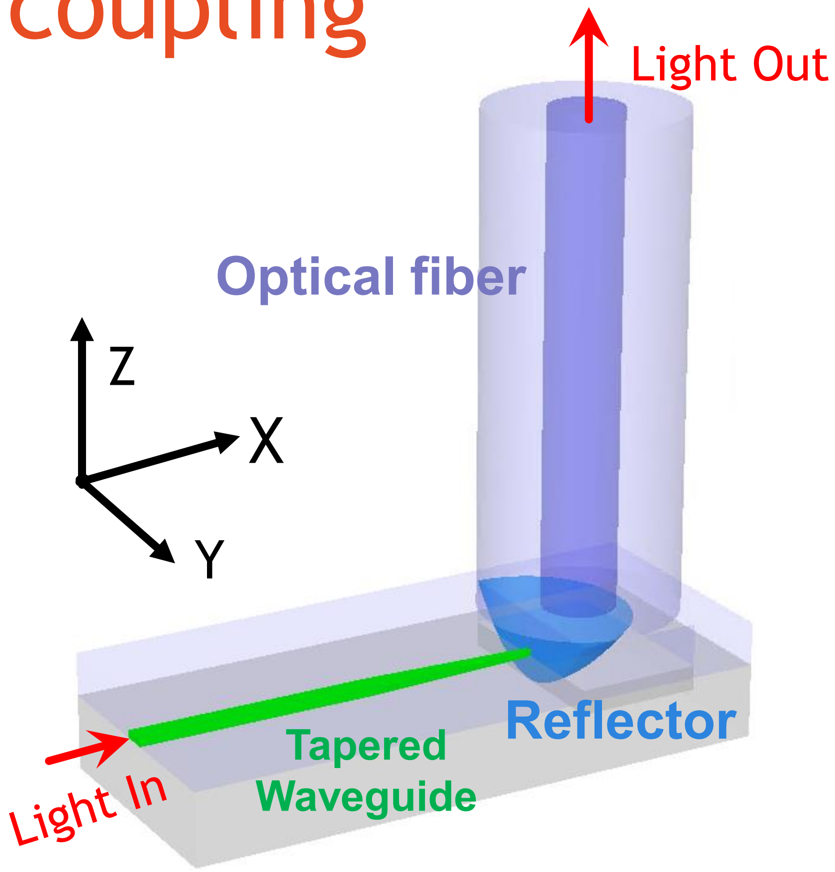
Tapered vertical coupler

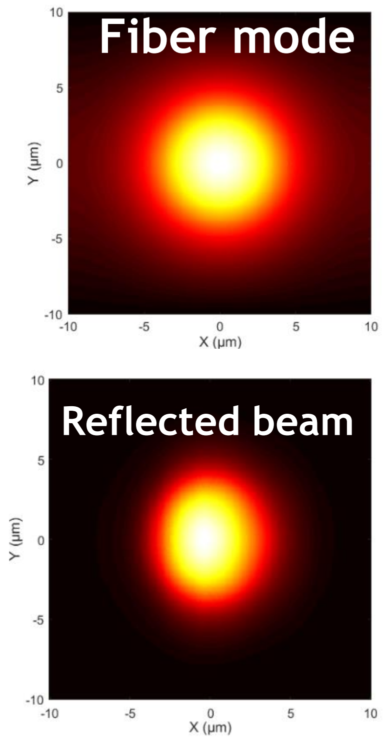


Opt. Lett. 45, 1236-1239 (2020).

Proposed designs already caught up to the state-of-the-art

Micro-reflector for chip-to-fiber coupling



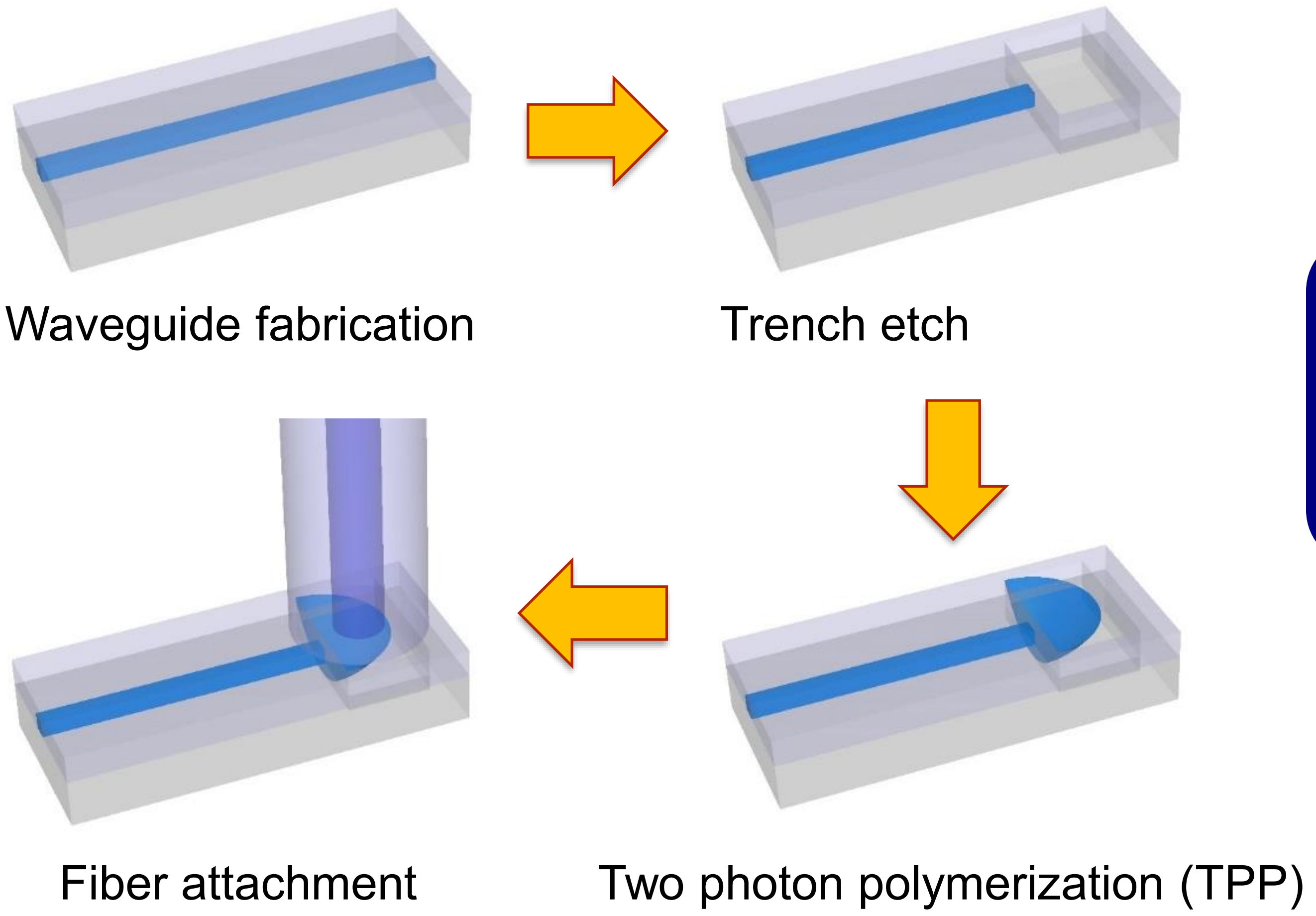


Free-form reflector offering compact beam reshaping and redirectioning

33

Proposed fabrication route

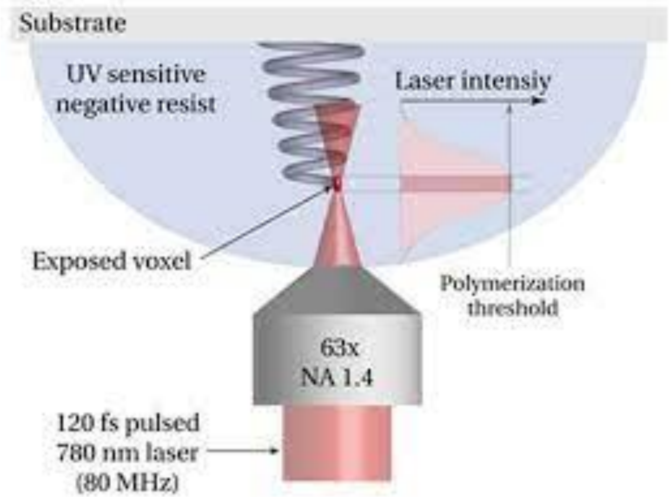
Fabrication Steps

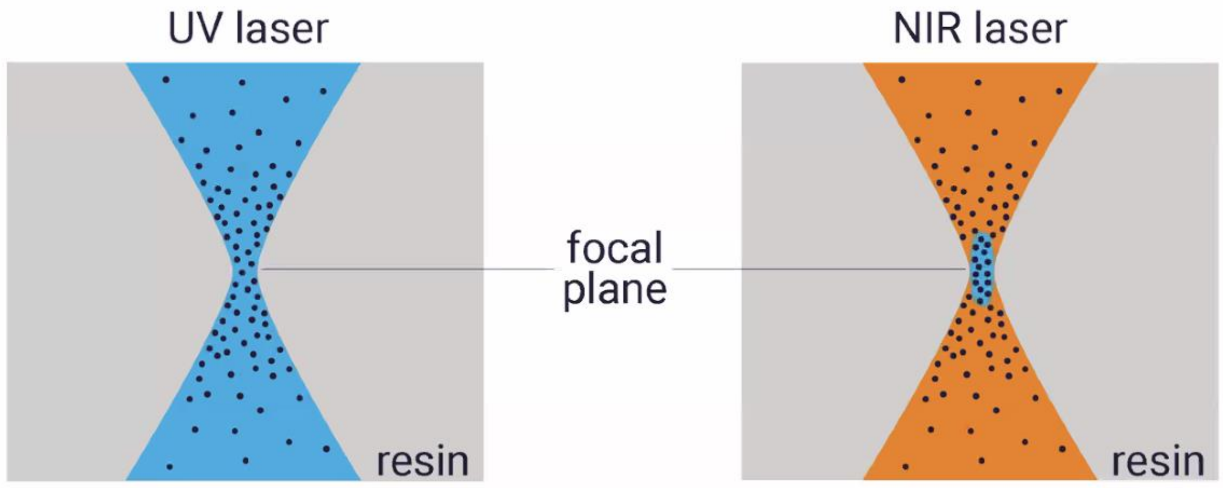


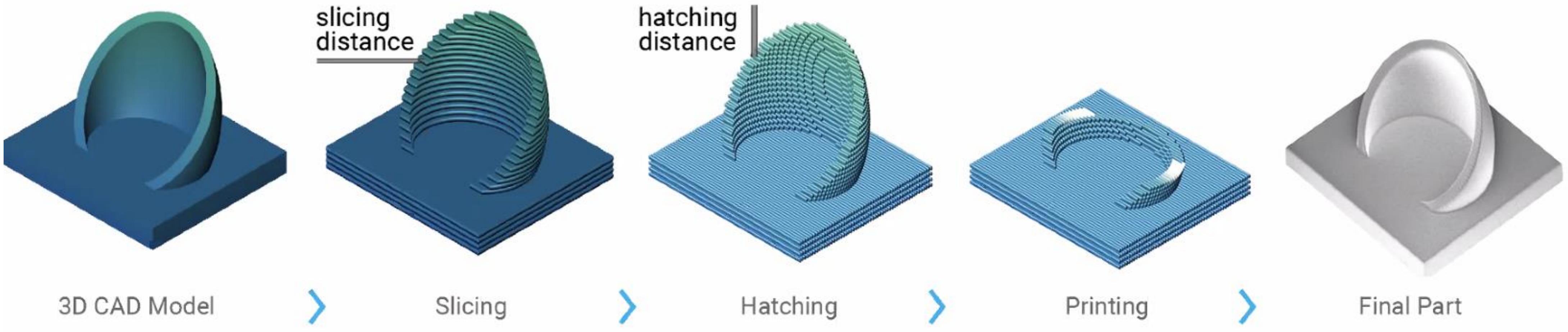
Simple and foundry-compatible back-end fabrication

34

Two Photon Polymerization

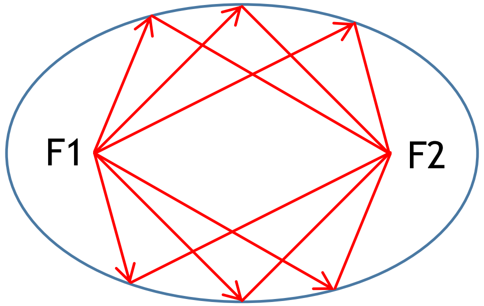






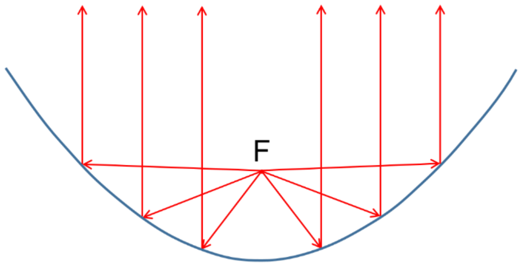
Proposed Solution

Elliptical reflector

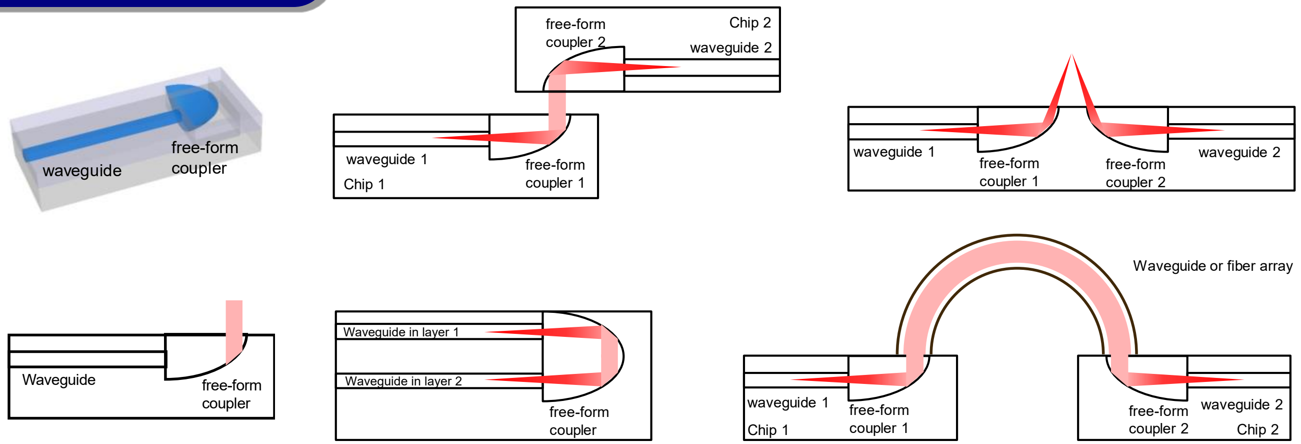


Couples focused light from one point to another

Parabolic reflector

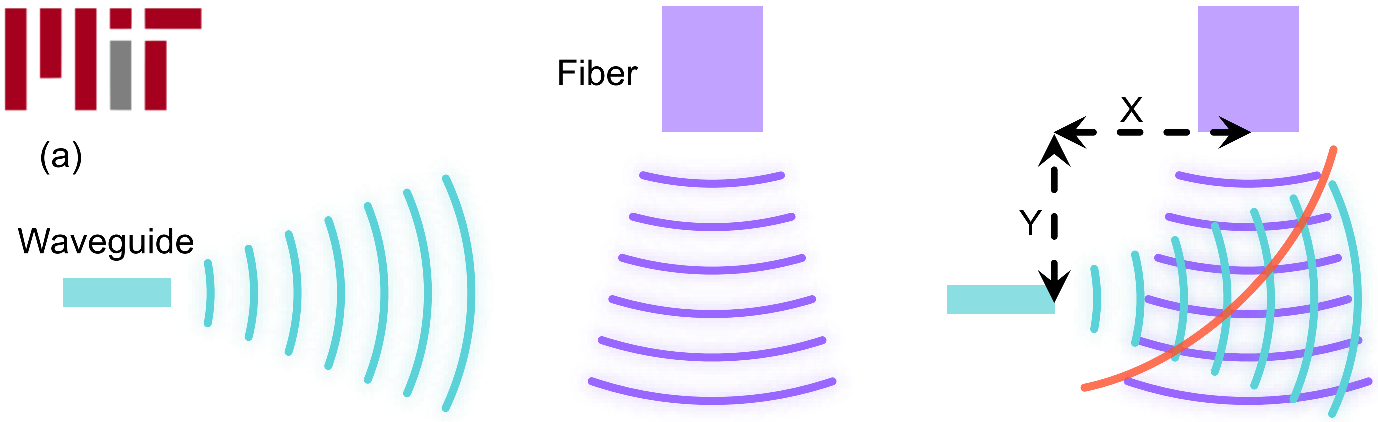


Transforms focused light into a collimated beam

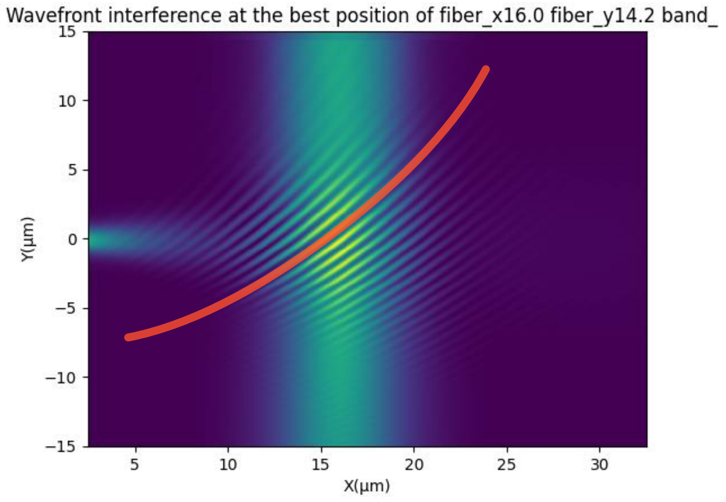


Freeform Design rule

(a)

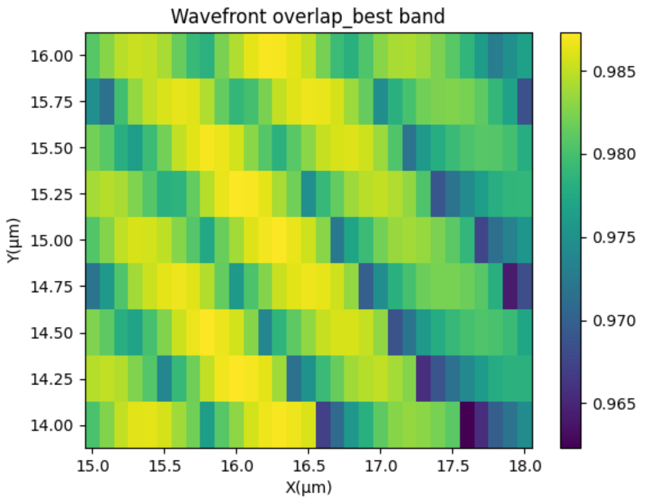


(b)



Wavefront interference

(c)

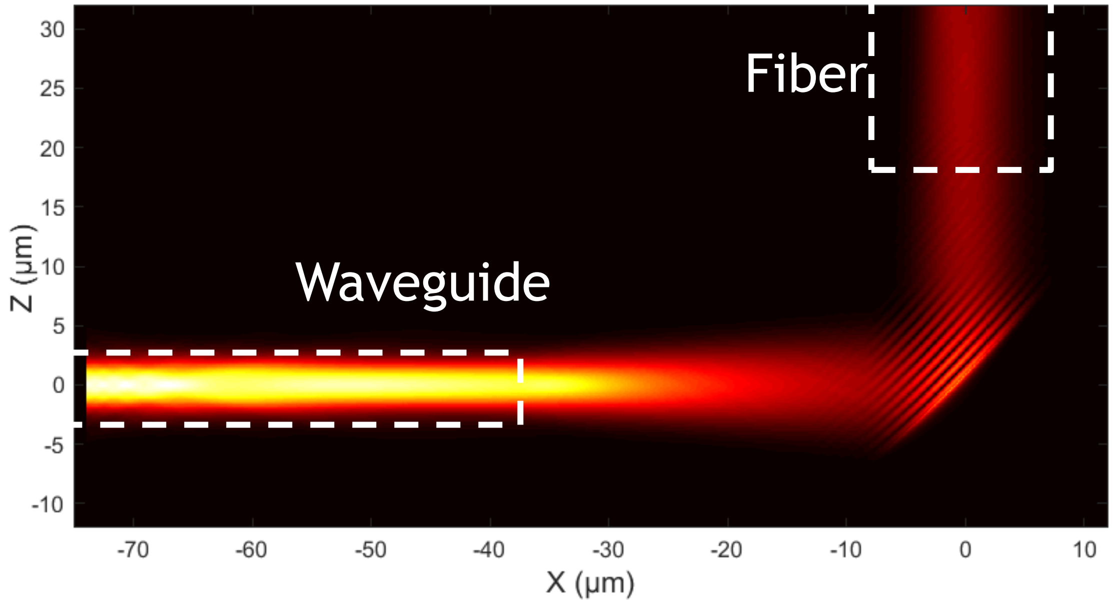


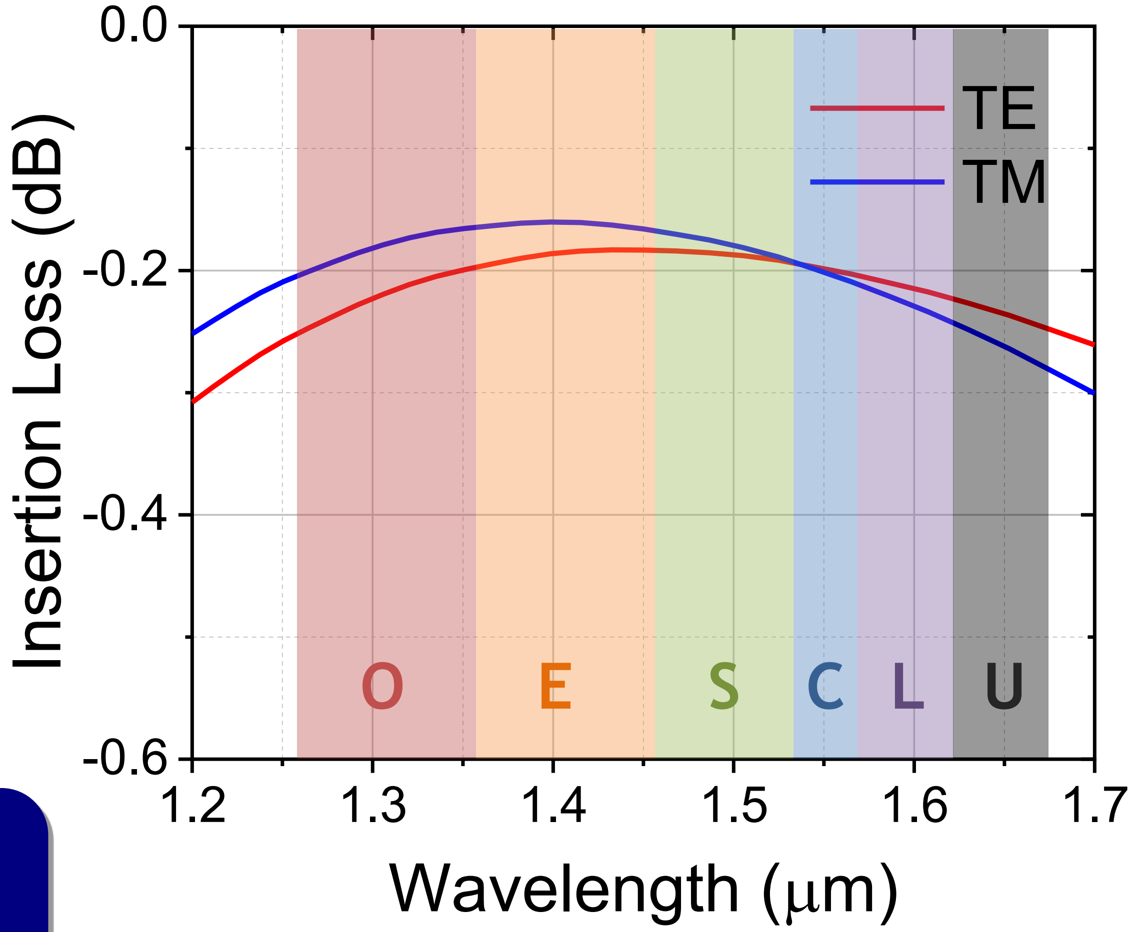
Mode overlap vs. XY scan

Steps

I. Propagate Fiber
II. Propagate waveguide + backprop. fiber
III. Find loci of maximum intensity
IV. Use EM field values on reflector surface to find modal overlaps

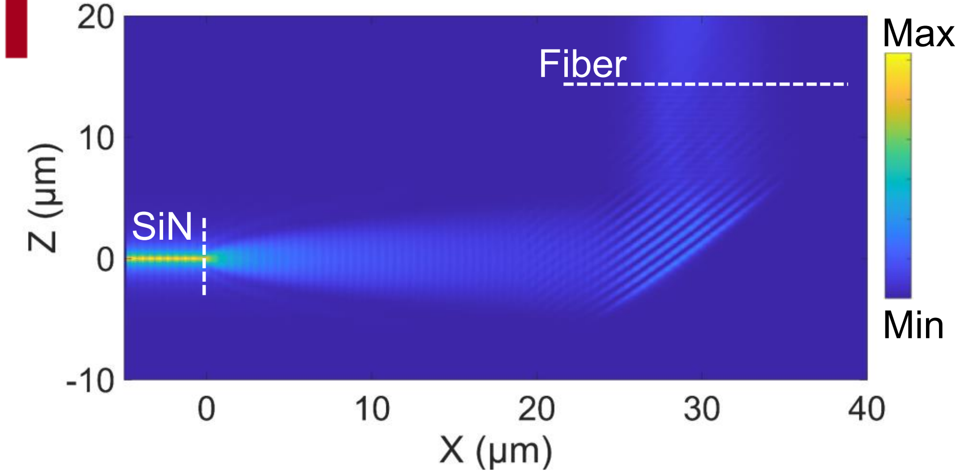
Fiber-to-chip couplers SiN: Broadband, low loss

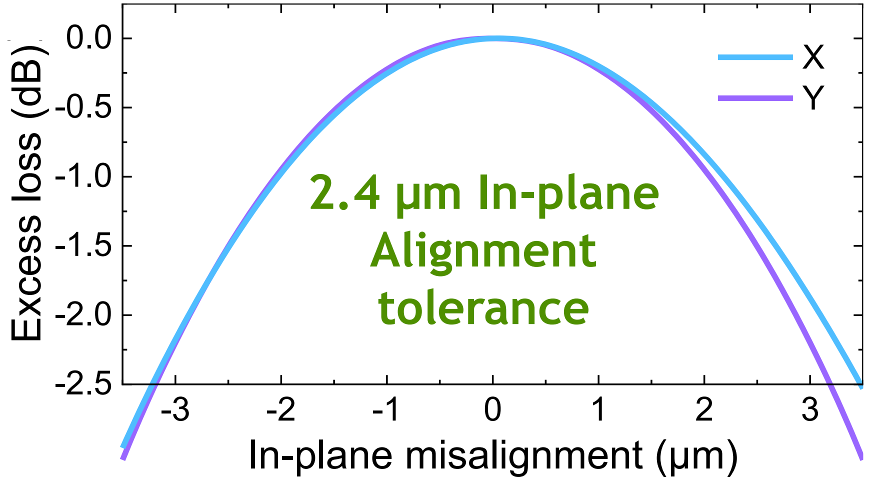


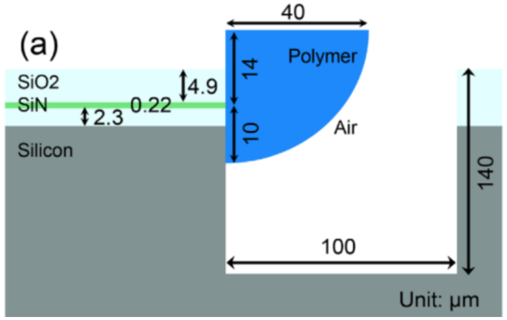


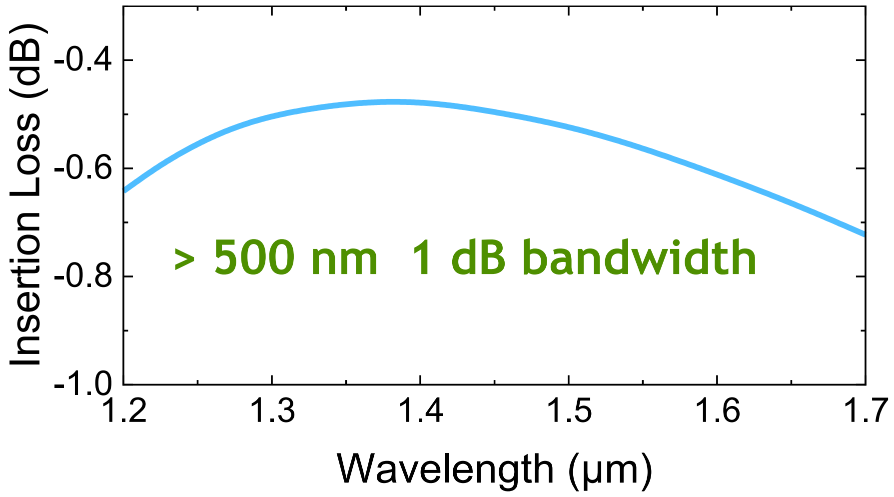
Low loss (< 0.27 dB) for both polarizations across the entire telecom band for SiN

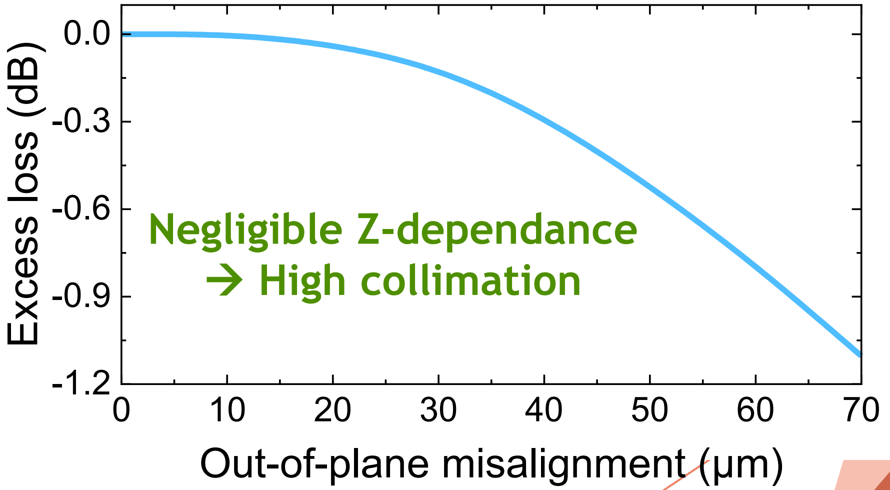
Chip-to-fiber coupling: Simulation results











Luigi Ranno

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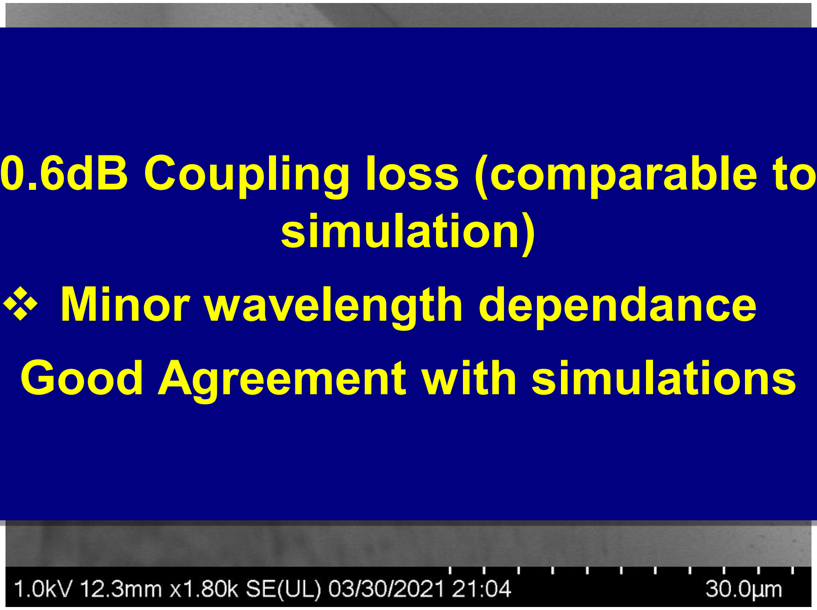
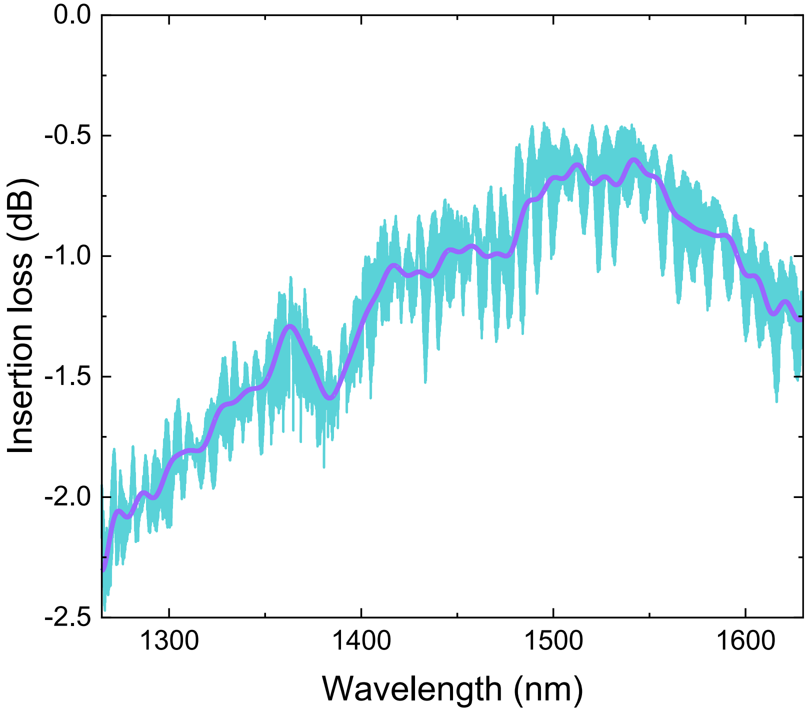
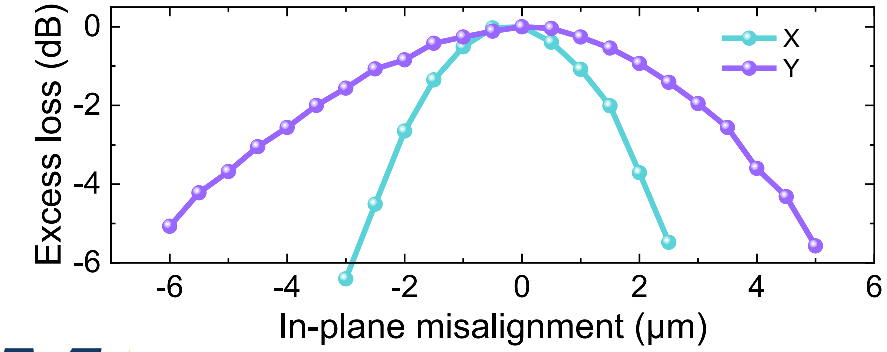
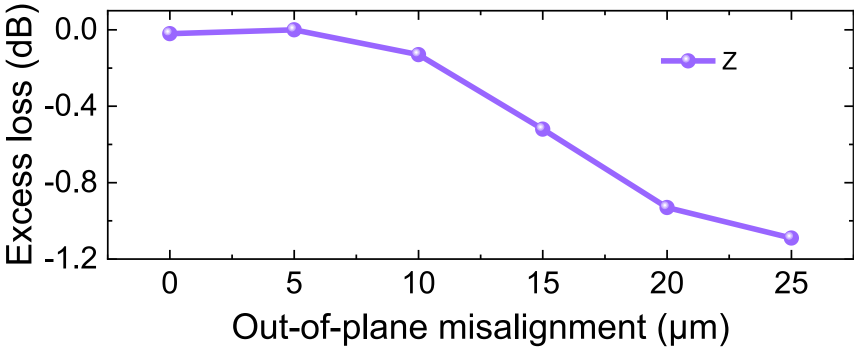
Experimental performance: Nitride taper

- **0.6dB Coupling loss (comparable to simulation)**
- **Minor wavelength dependance**
- **Good Agreement with simulations**



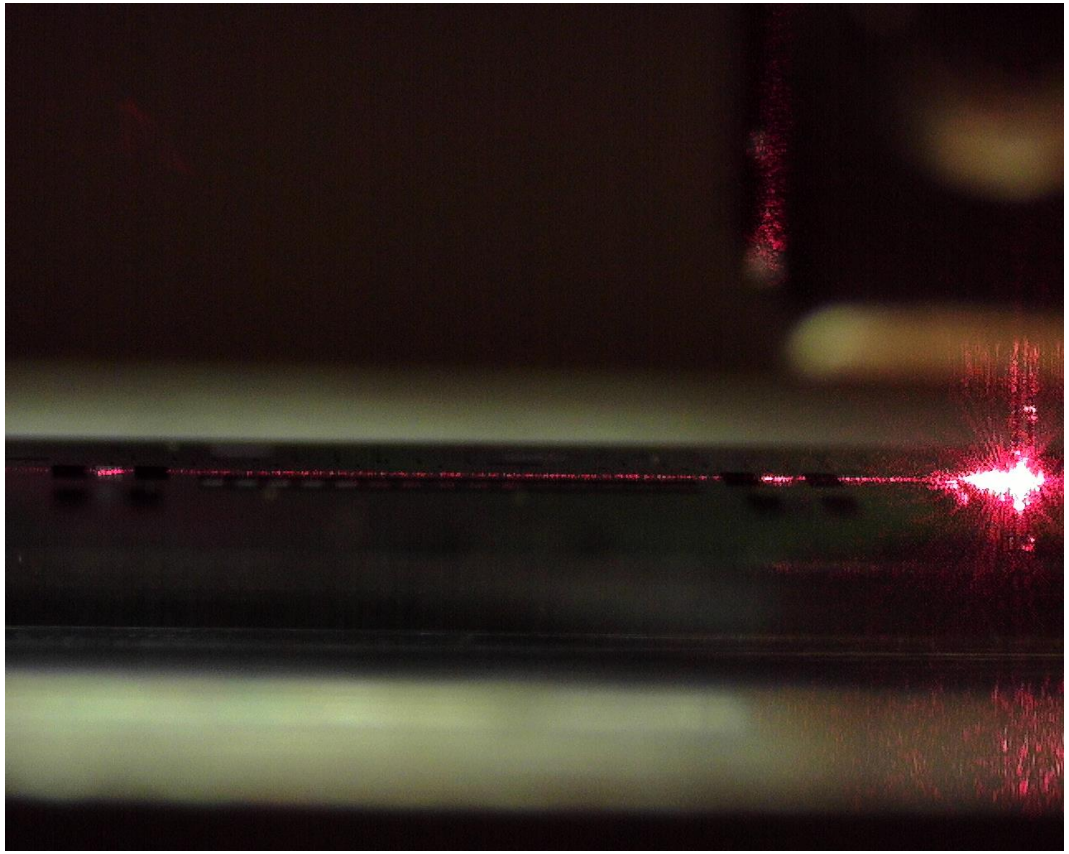


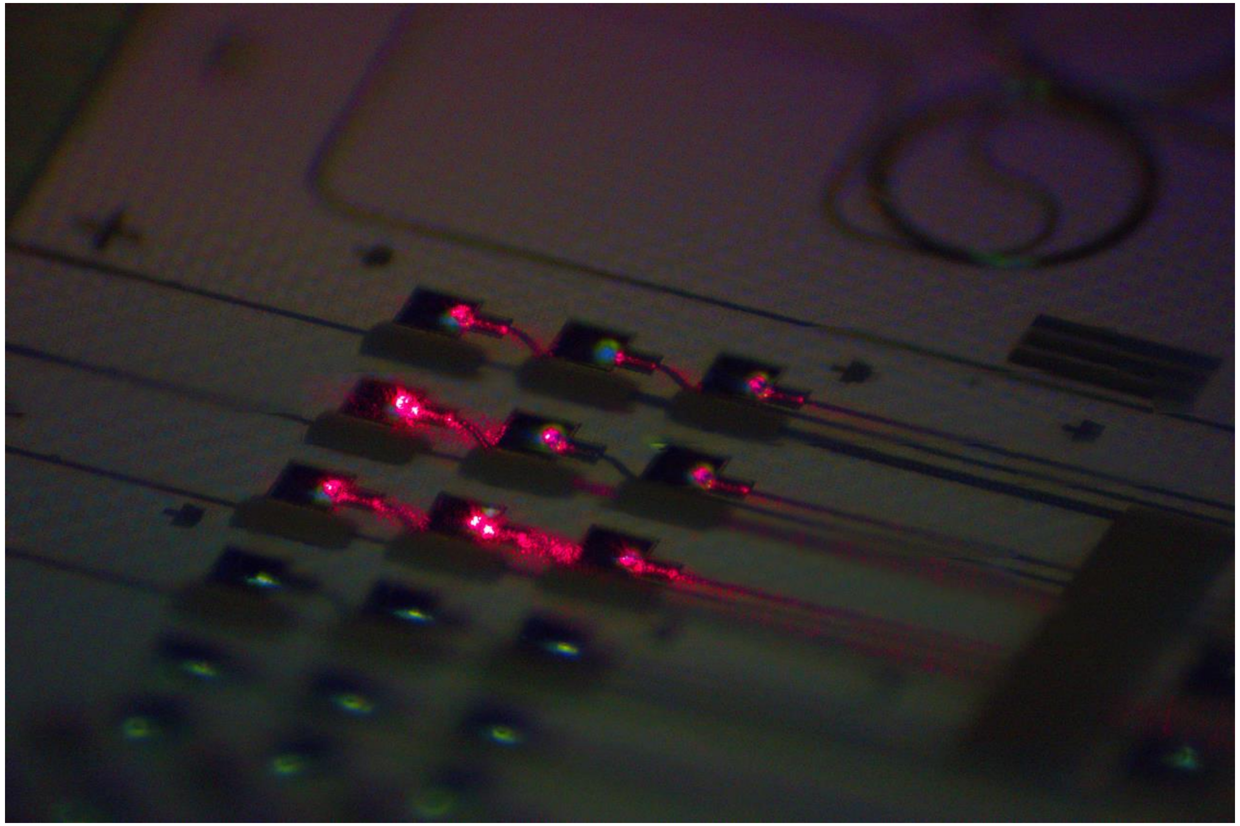




Yu, S., Ranno, L., et al. (2023). Free-Form Micro-Optics Enabling Ultra-Broadband Low-Loss Off-Chip Coupling. *Laser & Photonics Reviews*, 2200025.

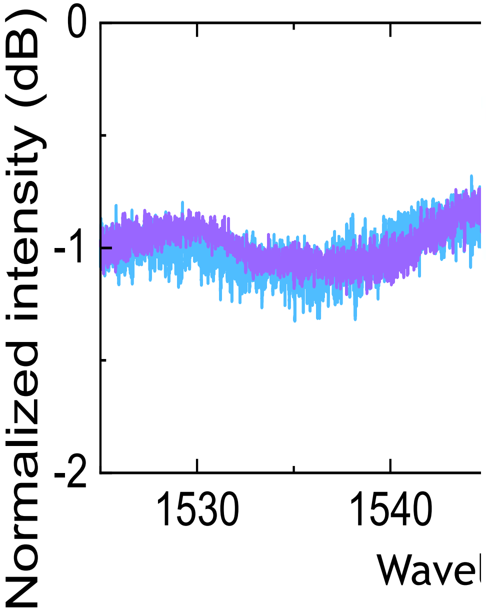
Fiber-to-chip couplers: Experimental Verification

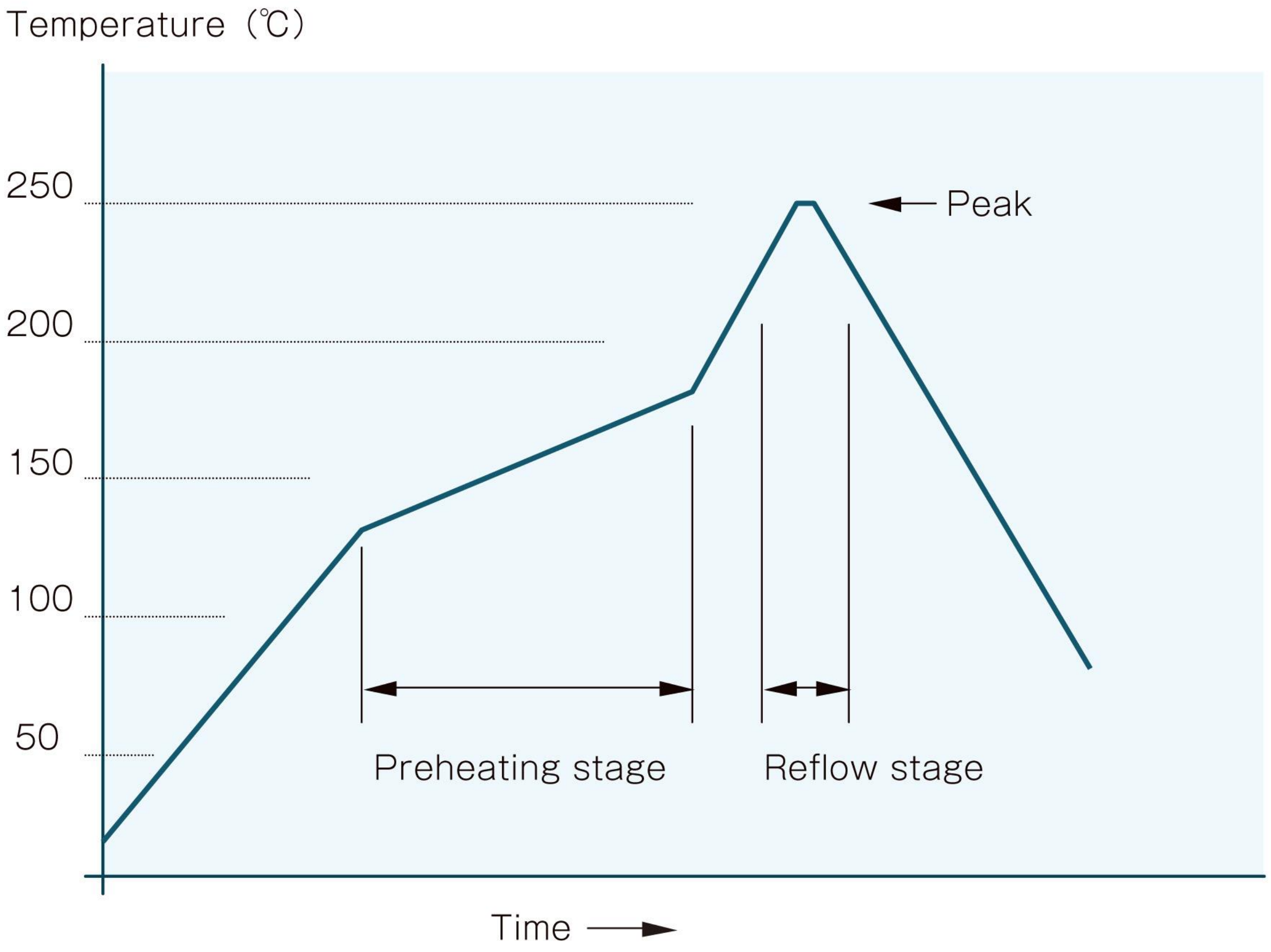




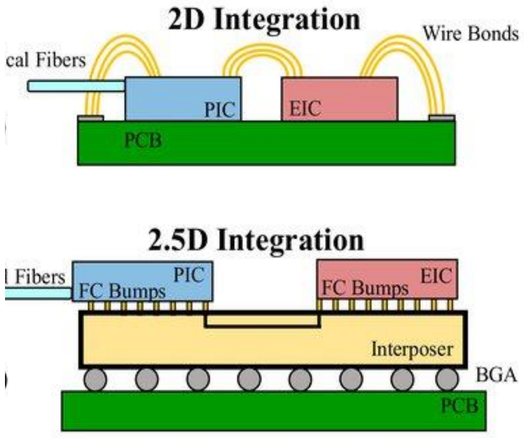
Opto-electronic co-packaging of SiN

High temperat





ɔ-integration strategies

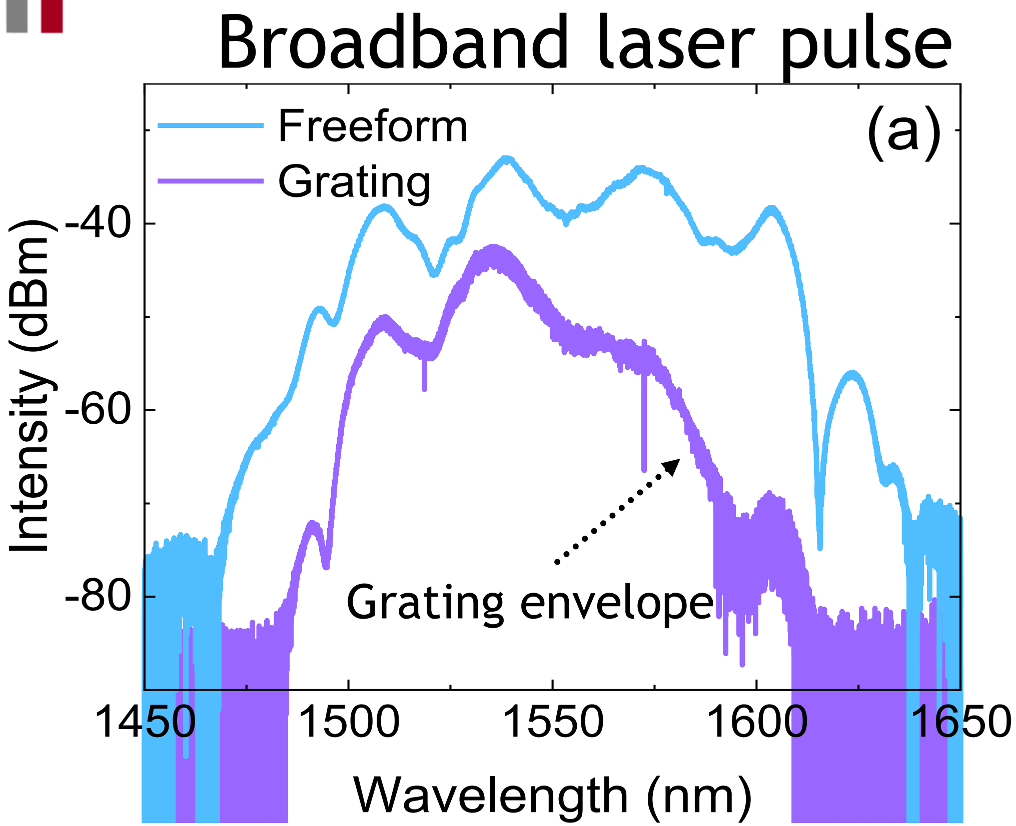


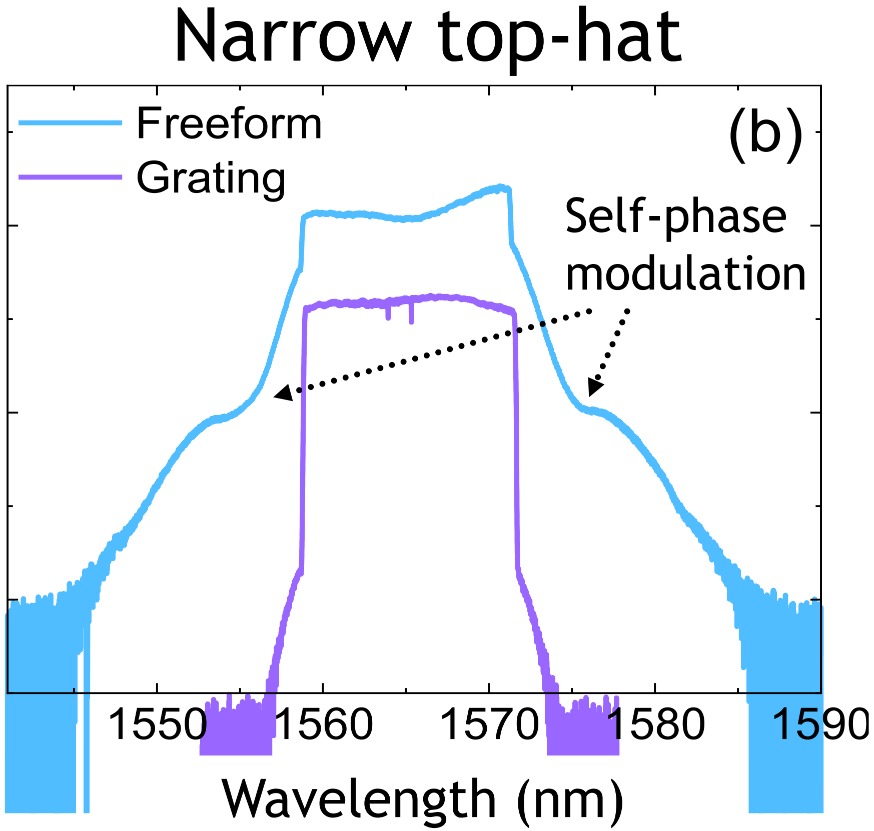
ɔlogy, 38, 3346-3357.

Compatibili

-integration

Chip-to-fiber coupling: Applications





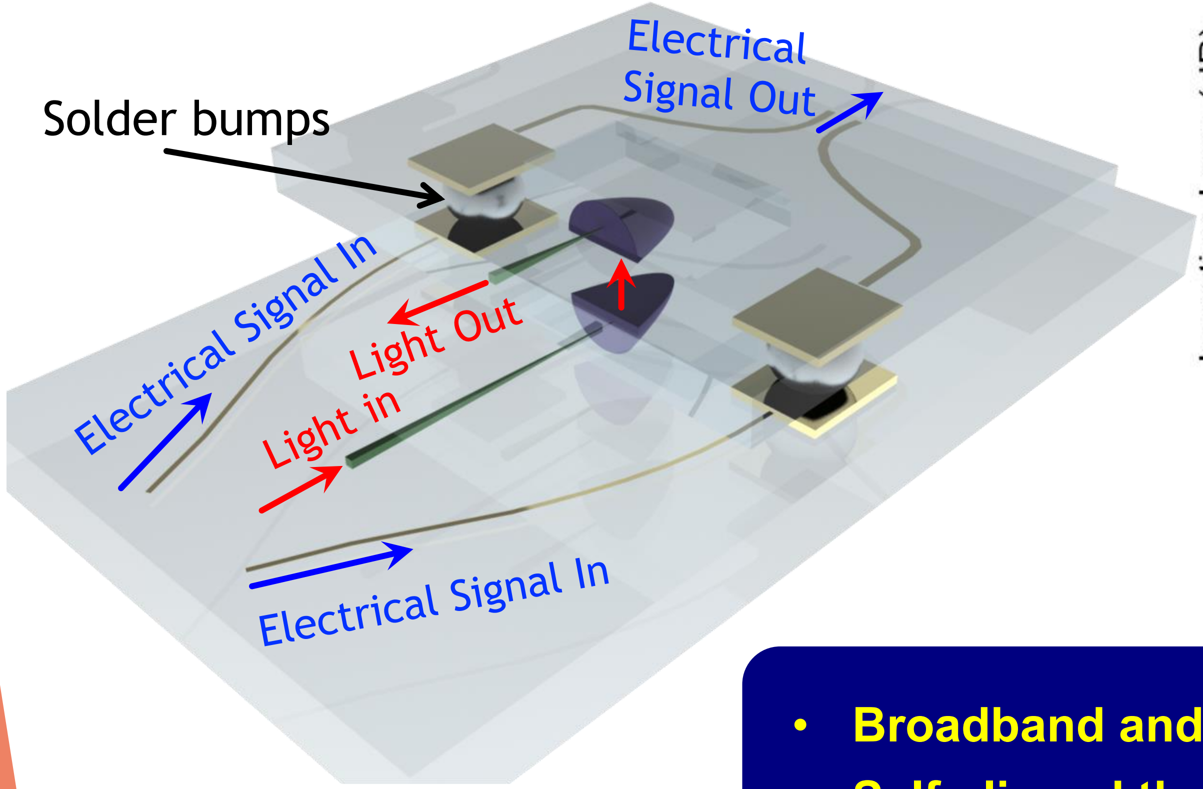
100 MHz, 80 fs
Menlo Systems
>8 kW coupled peak power

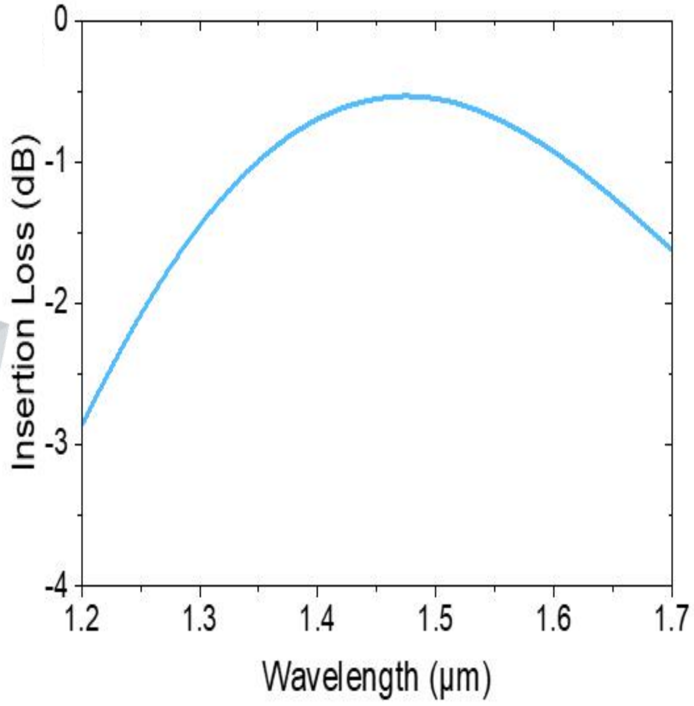
Pulse shaping
~2 ps pulse duration

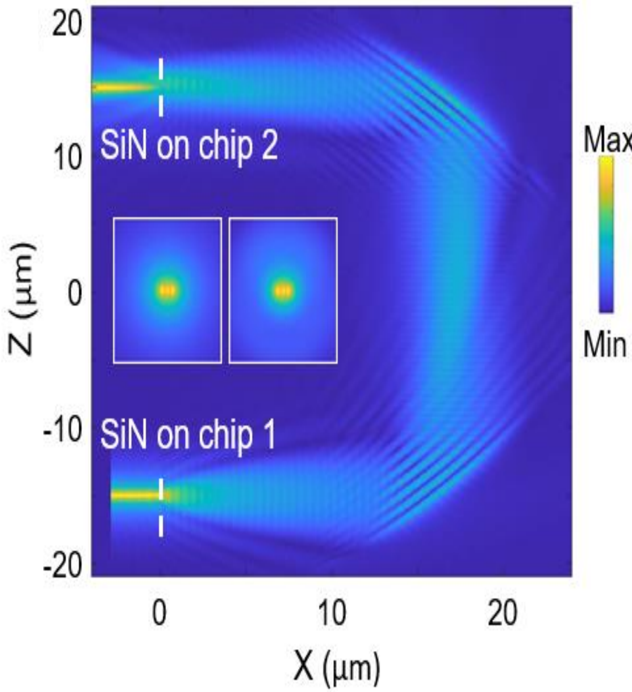
Minimal losses and high bandwidth make the couplers ideal for non-linear applications.

Yu, S., Ranno, L., et al. (2023). Free-Form Micro-Optics Enabling Ultra-Broadband Low-Loss Off-Chip Coupling. *Laser & Photonics Reviews*, 2200025.

Ideal chip-to-chip coupling interface





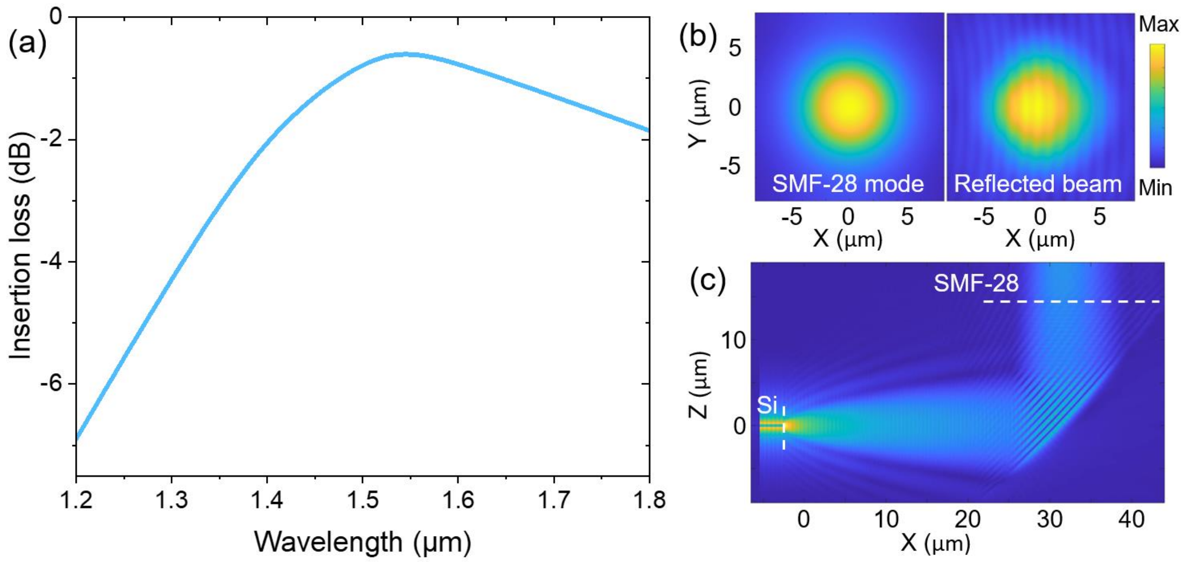


- **Broadband and efficient chip-to-chip or chip-to-interposer coupling**
- **Self-aligned thanks to the solder surface tension forces**

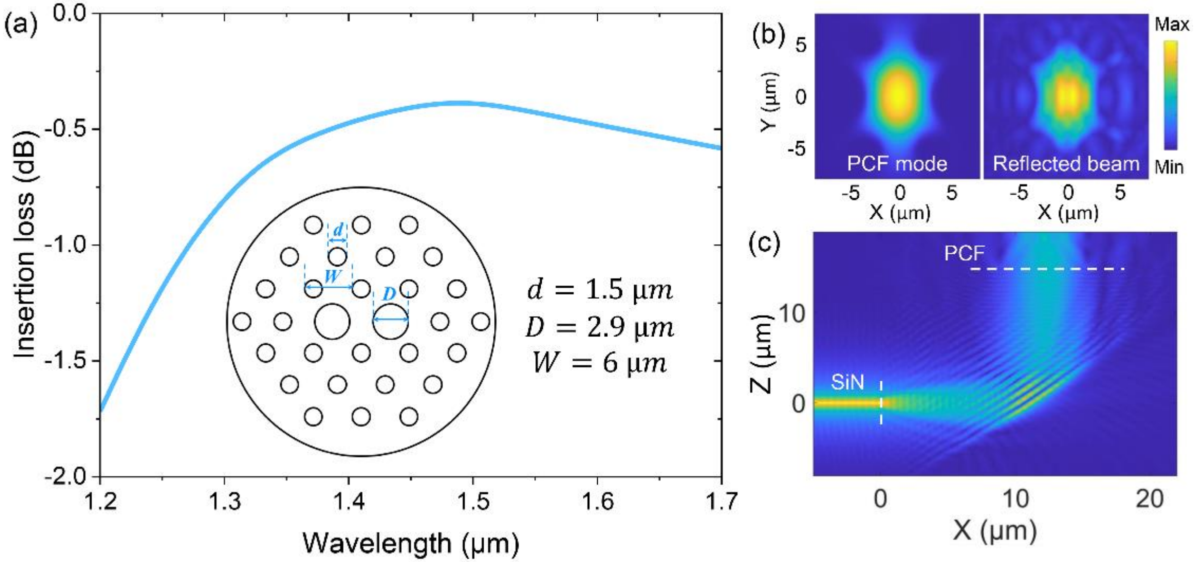
❖ **~85% Coupling efficiency**

Chip-to-fiber coupling: Universal platform

Si waveguide



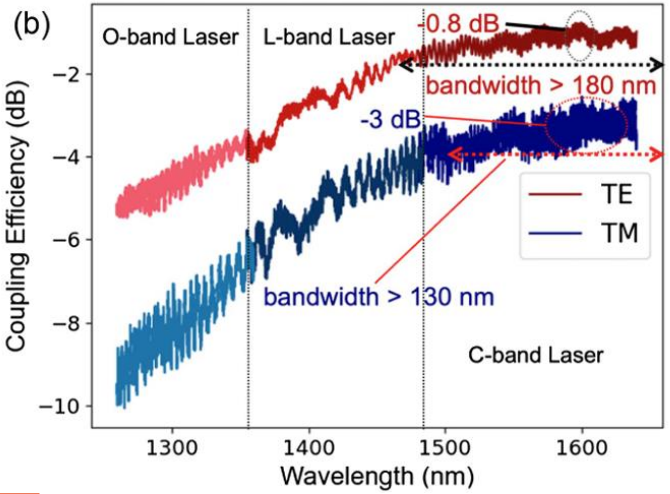
Photonic Crystal Fiber

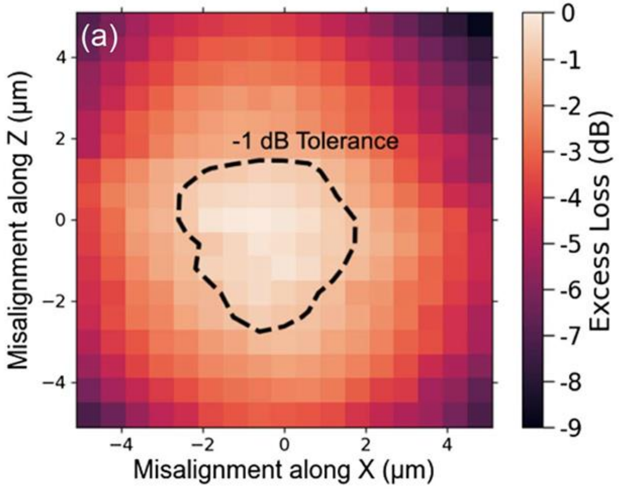


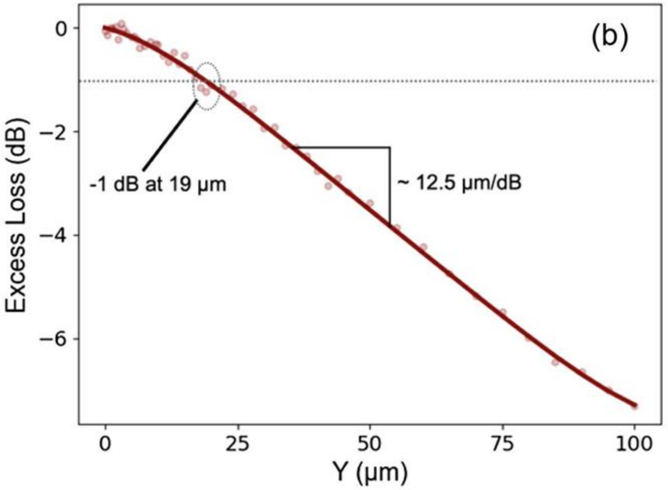
Universal solution applicable to devices with complex mode geometries

The case of silicon waveguides

- The coupler achieves a low coupling loss of 0.8 dB for the fundamental TE mode, along with 1 dB bandwidth exceeding 180 nm.
- Broadband and polarization-agnostic.
- Perfectly vertical fiber coupling implies compatibility with standard alignment tools used in electronic packaging.







Ranno, L., Sia, J. X. B., Popescu, C., Weninger, D., Serna, S., Yu, S., ... & Hu, J. (2024). Highly efficient fiber to Si waveguide free-form coupler for foundry-scale silicon photonics. *Photonics Research*, *12*(5), 1055-1066. Editor's pick

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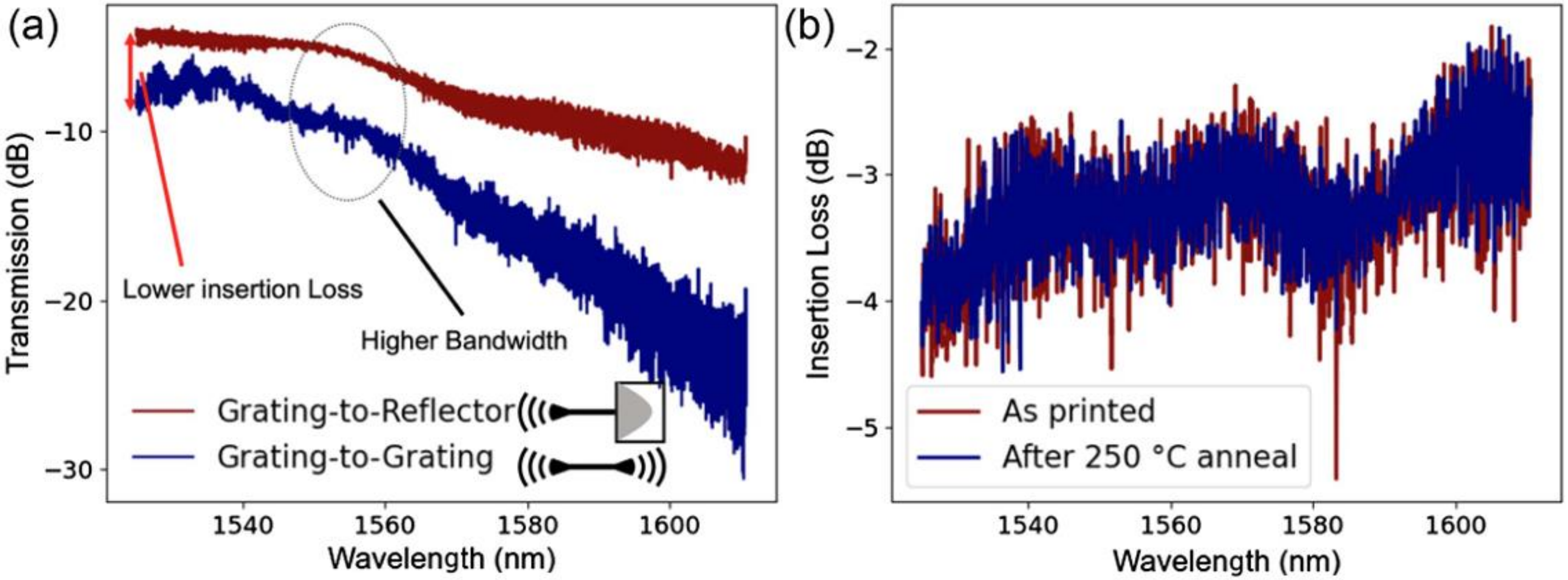
Performance tests

- The TPP reflector on silicon was compared with an optimized grating coupler
- Also with an annealing test at 250 °C



Ranno, L., Sia, J. X. B., Popescu, C., Weninger, D., Serna, S., Yu, S., ... & Hu, J. (2024). Highly efficient fiber to Si waveguide free-form coupler for foundry-scale silicon photonics. *Photonics Research*, *12*(5), 1055-1066. Editor's pick

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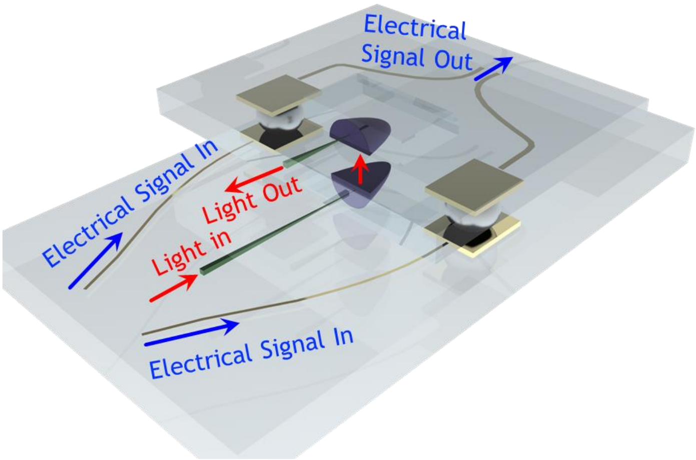
Vertical Optical Interconnect Comparison

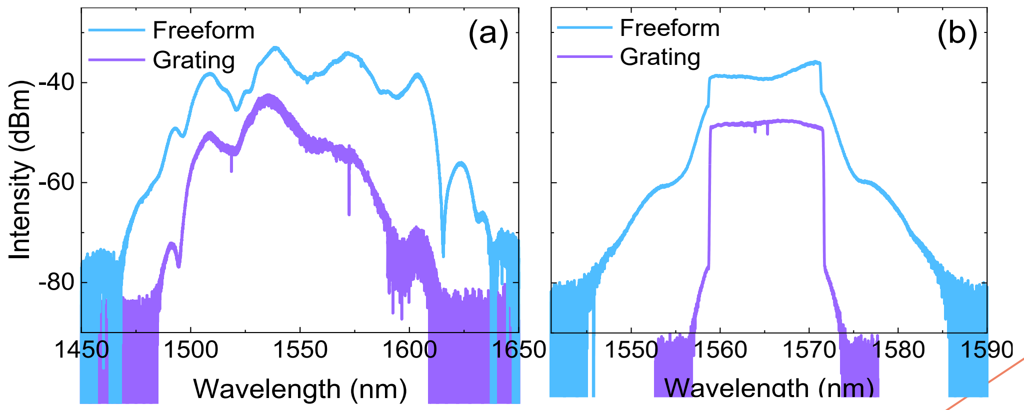
Coupler Type	Coupling Loss (dB)	1dB Bandwidth (nm)	1dB Alignment Tolerance (µm)	Size (µm)	
Grating	6.0 (TE)	< 10	1.25 (lateral)	//	**CEA-LETI:** IEEE ECTC, pp. 557–562. (2017)
Evanescent	2 (TE)	> 300	2 (lateral)	> 1000 long 6 wide	**IBM**: IEEE J. Sel. Top. Quantum Electron. 24(4), 1–11 (2018).
Photonic Wire Bond	0.4-1.3 (TE)	> 50 nm	//	//	**KIT:** Optica 5(7), 876–883 (2018).
Free-form	0.22 (TE)* 0.25 (TM)*	> 350	1.3 (lateral) 35 (vertical)	10 long 30 wide	**MIT-PMAT:** J. Lightwave Technol. 38, 3358-3365 (2020)
Evanescent	< 1 (TE/TM)	~ 60	4 (lateral) 3 (vertical)	1500 long 12 wide	**Corning:** vol. 39, no. 4, pp. 912-919, 15 Feb.15, (2021)
Evanescent	0.2*	180	> 5(lateral) 0.5 (vertical) 1.5 deg (twist)	200 long 15.3 wide	**MIT-QPL:** arXiv:2110.12851 (2021).
Evanescent	0.18 (TE)*	> 300	~3 (lateral/vertical) > 250 (longitudinal) 2.5 (twist) 0.5 (tilt)	500 long 1 wide	**MIT-EMAT:** Optics Express, Vol. 31, No. 2, pp 2819, (2023)

Evanescent VOI offers scaling of alignment and pitch for > 1 Pbps

Conclusion

- We experimentally demonstrated a coupling loss of 0.5 dB and 0.8 dB for SiN and Si, representing the lowest loss figure reported for surface-normal couplers at 1550 nm wavelength.
- Low loss, broad-band operation, high bandwidth density, as well as wafer-scale testing and solder reflow compatibility qualify our approach as a promising optical interfacing solution.
- No sign of optical damage for optical pulses up to 8 kW peak power.
- Nonlinear frequency generation and quantum photonics applications.





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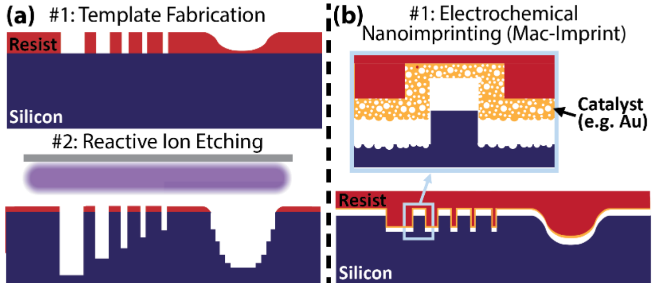
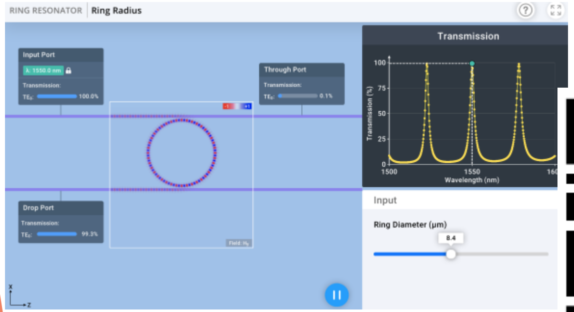
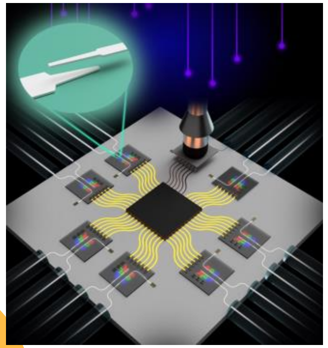


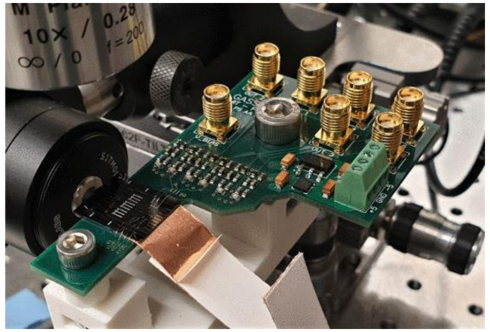
(a) DRIE limitations, (b) advantages of Mac-Imprint

MIT Virtual Manufacturing Lab





Optics Express, Vol. 31, No. 2, 2023
Advanced Eng. Materials, Vol. 27 (4), 2025



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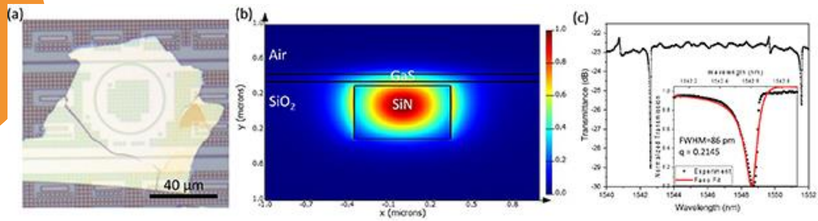
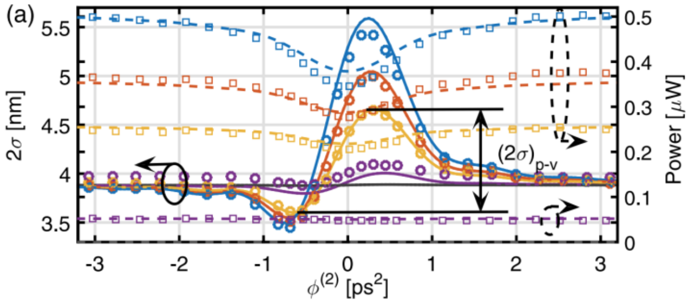
- Strategies for EO packaging
- MidIR Photo-detector
- Hybrid NL optimization
- Ultrafast/ temporal wg response
- Sustainability and road mapping
- Education
- 3D integration



Journal of Optics, vol. 23, no 2, 2021



Optics letters, vol. 42, no 16, 2017

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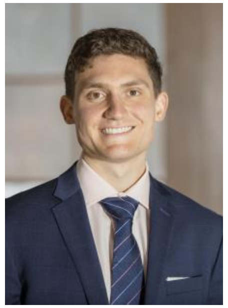


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