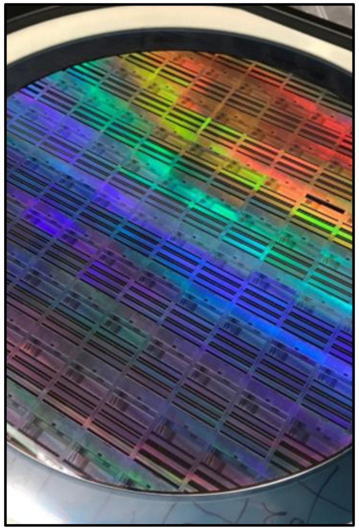
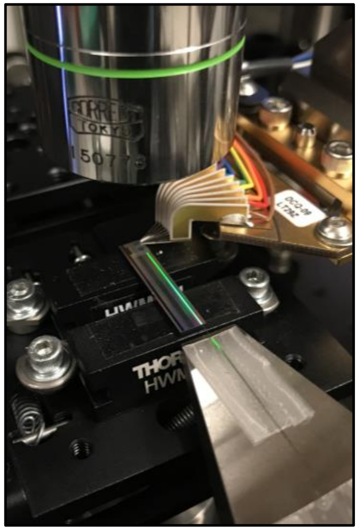
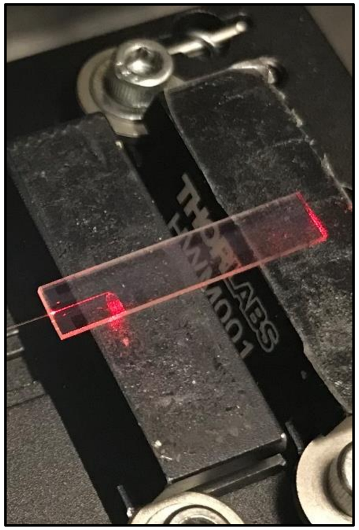
Silicon Photonics for Solid-State LiDAR and Beyond

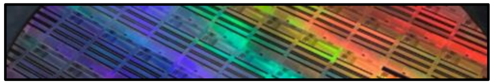
Jelena Notaros
Robert J. Shillman (1974) Career Development Assistant Professor
Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology



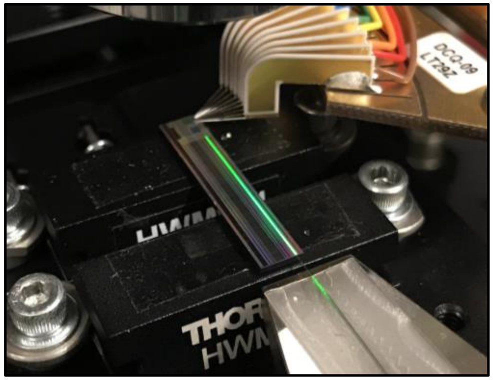




Outline

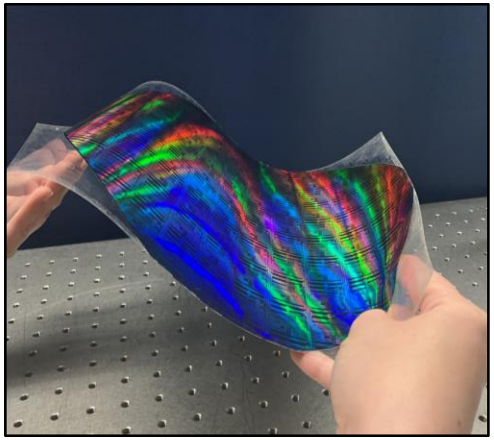


Introduction to Silicon Photonics



Silicon-Photonics-Based Solid-State LiDAR Sensors

- Motivation for LiDAR for Autonomous Systems
- Motivation for Solid-State LiDAR
- Introduction to Integrated OPAs
- Recent OPA and LiDAR Results



Other Related Research Directions

- Holographic AR Displays
- Chip-Based 3D Printers
- Optical Trapping for Biophotonics
- Flexible Wafer Bonding
- Trapped-Ion Quantum Systems

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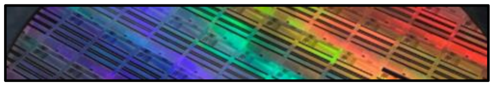

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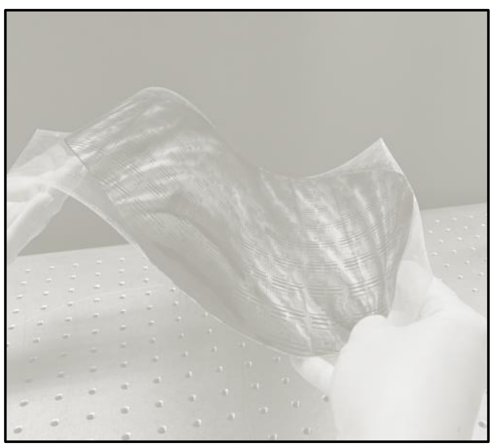

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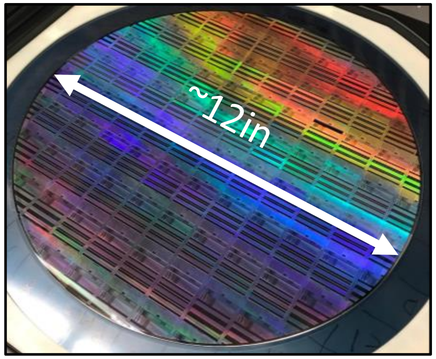
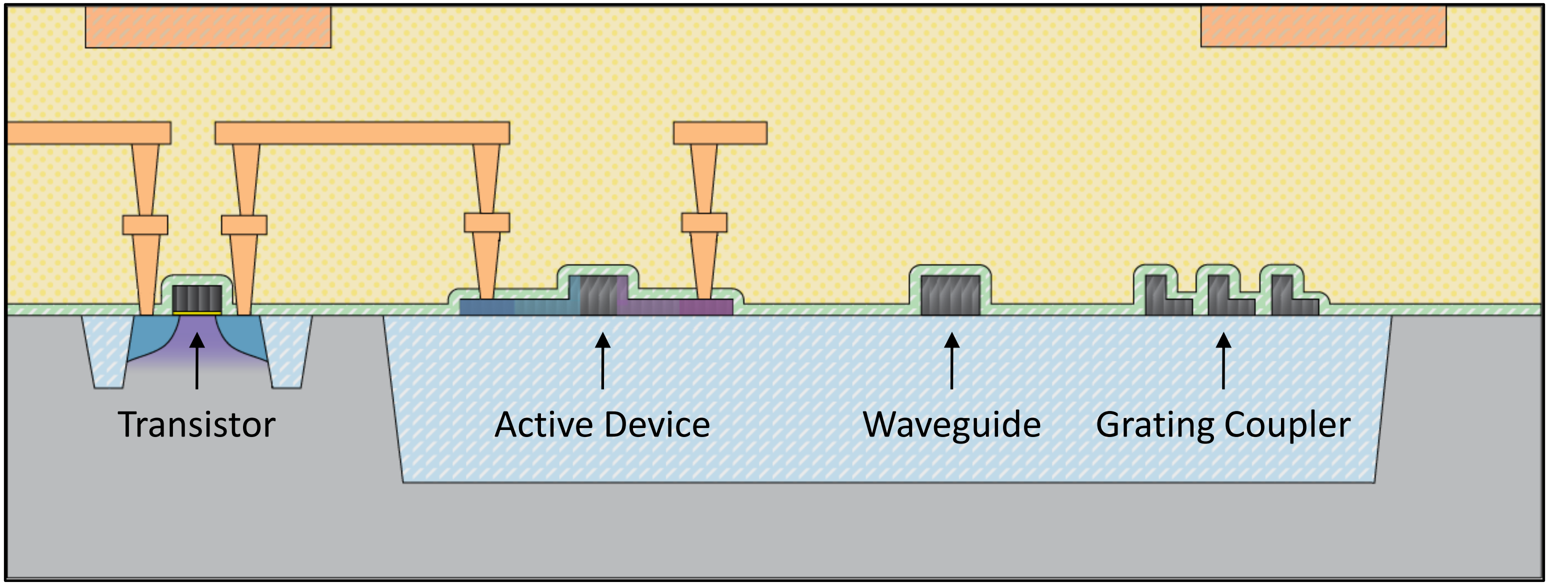


Silicon Photonics

Concept: Repurpose CMOS for chip-based optics
Result: Compact form factors, low-cost wafer-scale production, and new functionalities



[Atabaki, … Notaros et al., *Nature* 2018]

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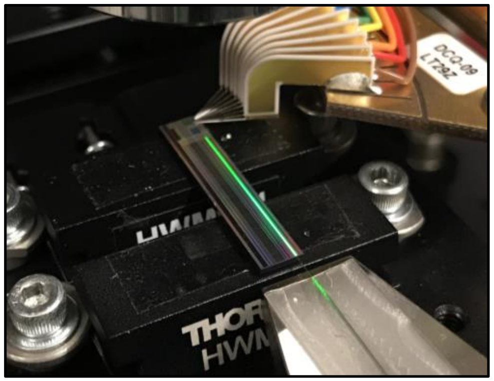

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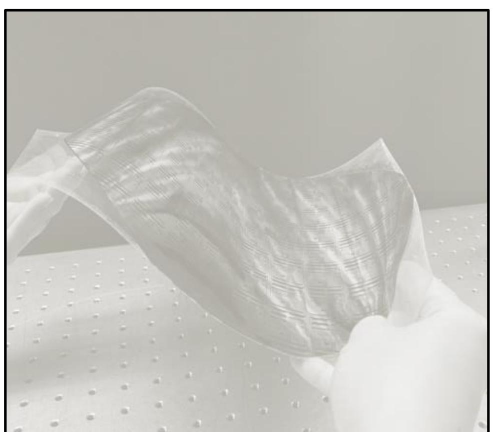

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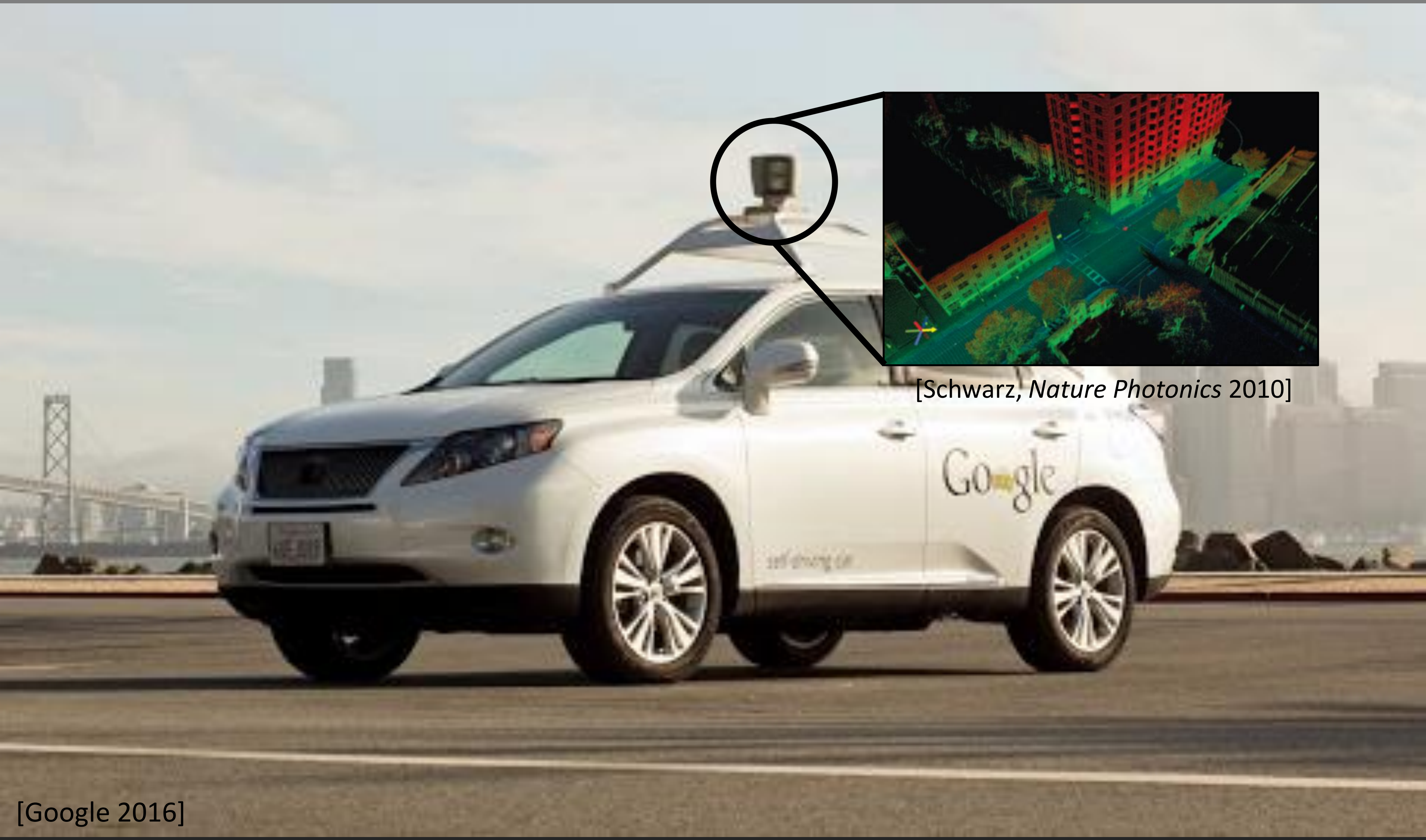
Motivation for LiDAR for Autonomous Systems

[Google 2016]

Motivation for LiDAR for Autonomous Systems



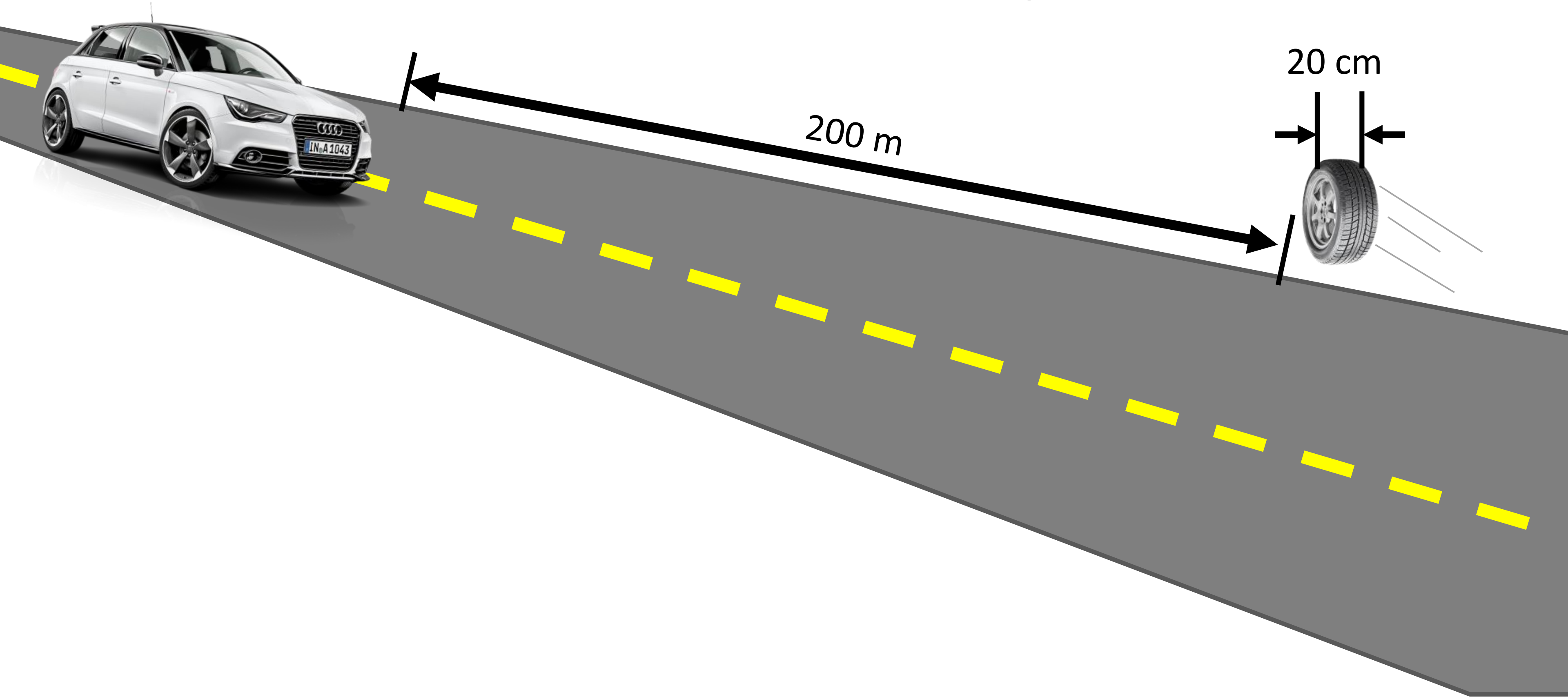
[Schwarz, *Nature Photonics* 2010]

[Google 2016]

Motivation for LiDAR for Autonomous Systems

Target Detection Goal

20-cm-tall target at a 200-m distance



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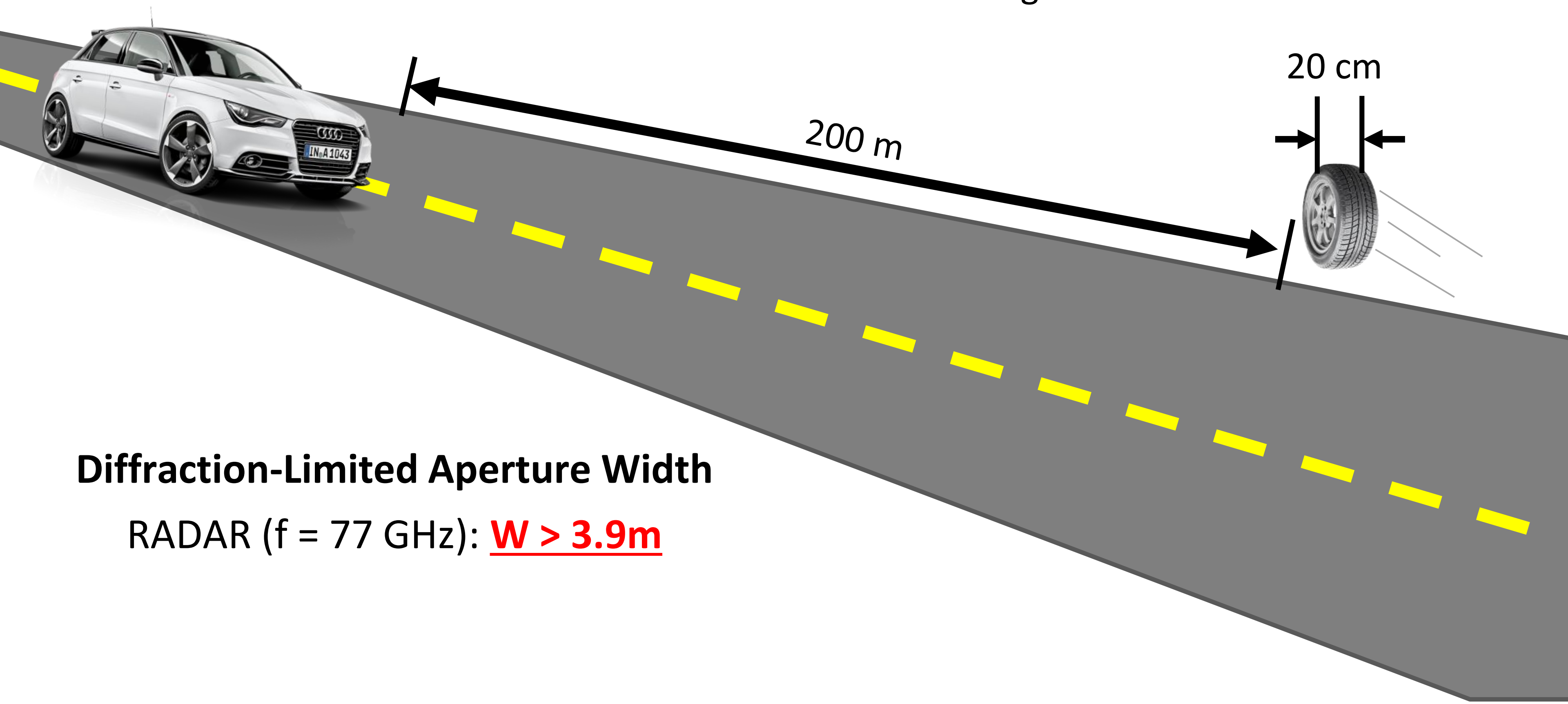

Diffraction-Limited Aperture Width

RADAR (f = 77 GHz): **W > 3.9m**

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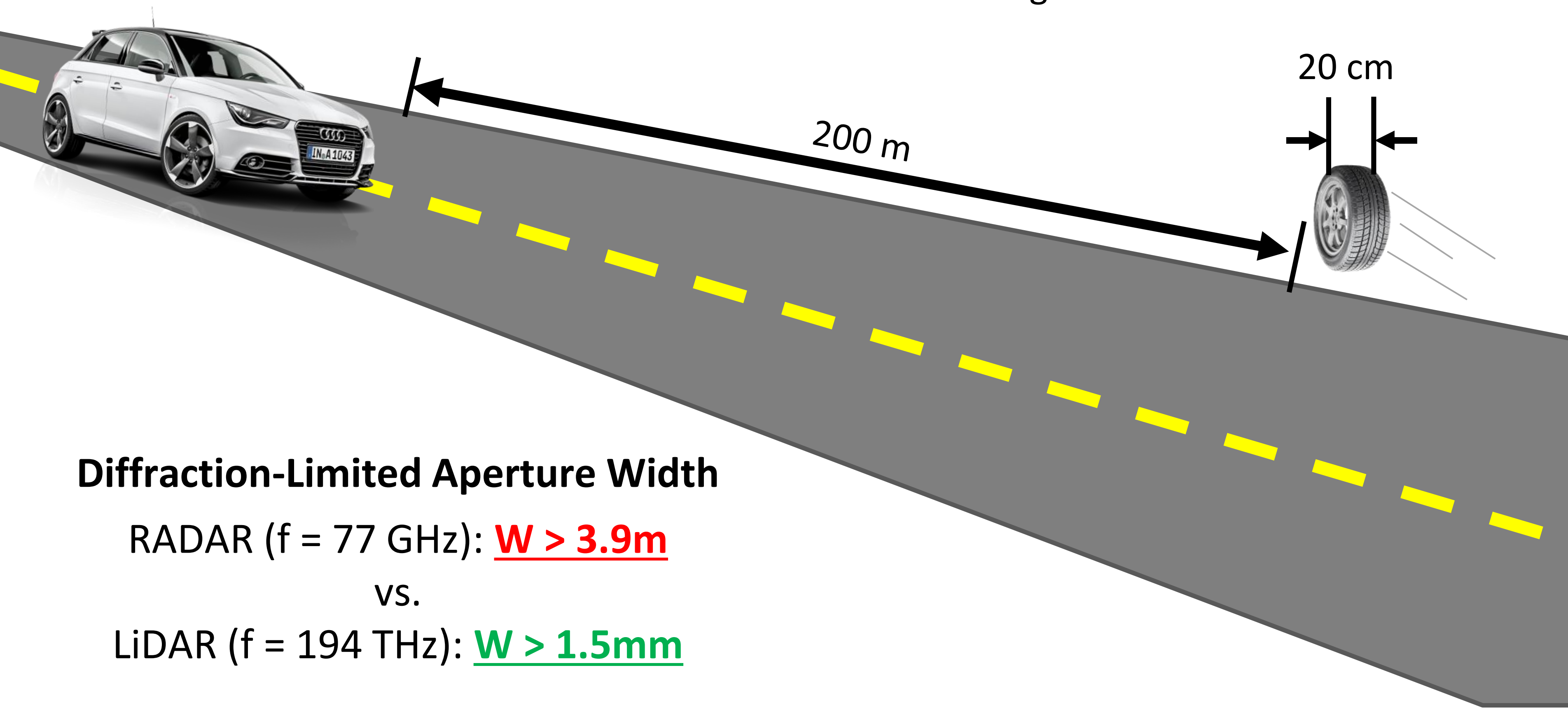

Diffraction-Limited Aperture Width

RADAR (f = 77 GHz): **W > 3.9m**

vs.

LiDAR (f = 194 THz): **W > 1.5mm**

Motivation for Solid-State LiDAR

Conventional LiDAR

[LightWare SF40/C]

Limitations

- Mechanically steering
- Heavy & bulky
- High cost
- Unsightly

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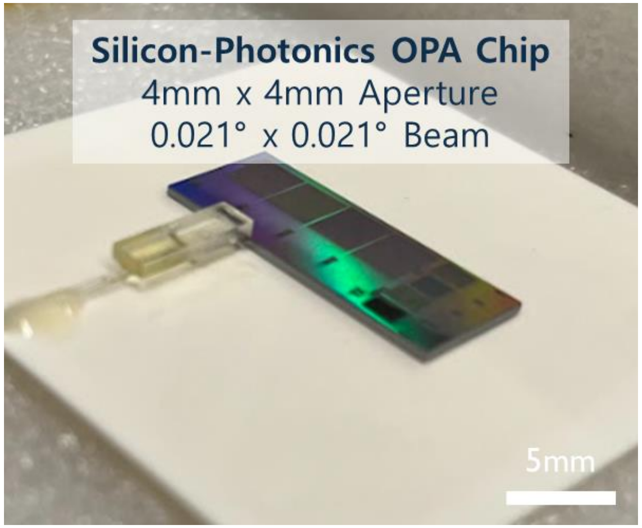
Solid-State LiDAR

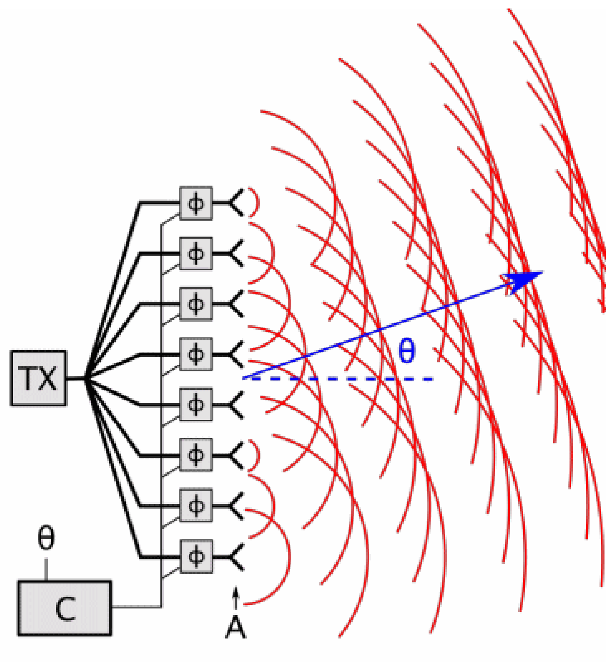


[MIT Notaros Group]

Advantages

+ Completely electronic steering
+ Compact & light weight
+ Low cost
+ Discrete

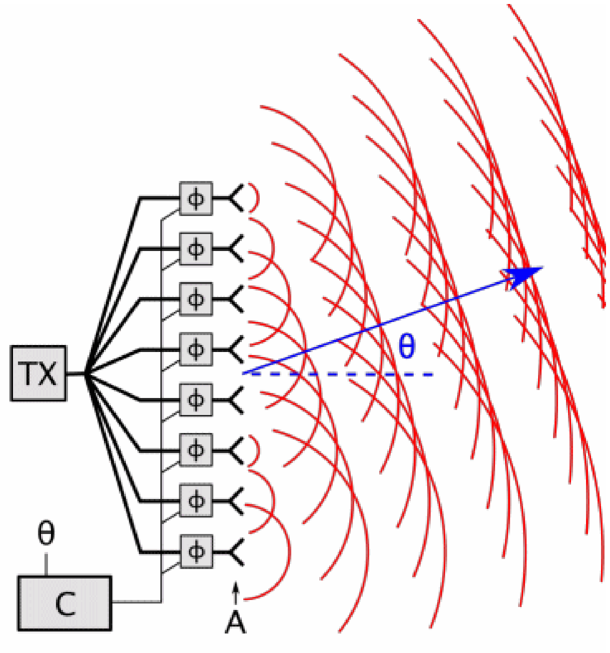
Introduction to Integrated OPAs



Integrated Optical Phased Arrays

Application: High-resolution LiDAR sensor for autonomous vehicles
Concept: On-chip antennas controlled using integrated photonic circuits
Benefits: Low-cost, compact, and high-speed beam steering

Introduction to Integrated OPAs



[Notaros et al., *JLT* 2018]

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Introduction to Integrated OPAs

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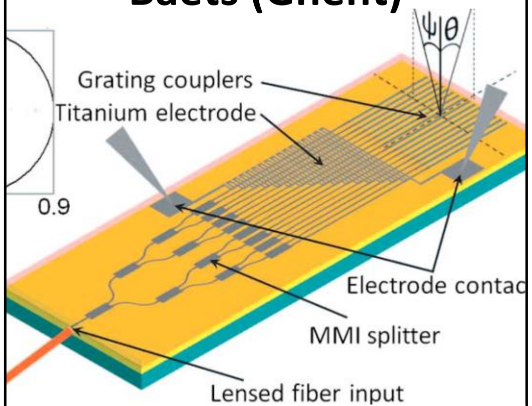
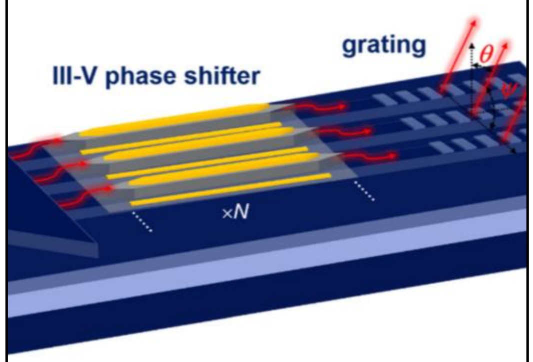


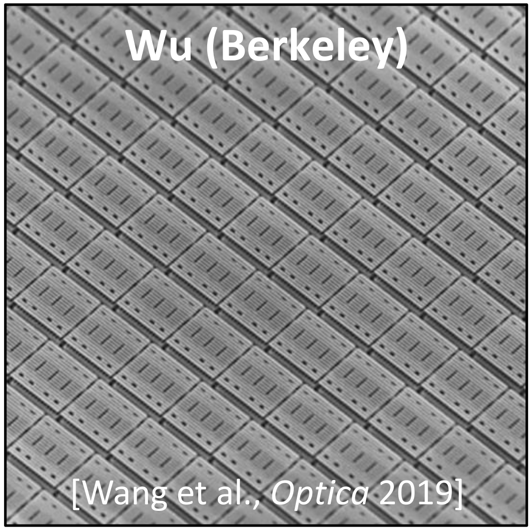
[Van Acoleyen et al., *OL* 2009]

Bowers (UCSB)



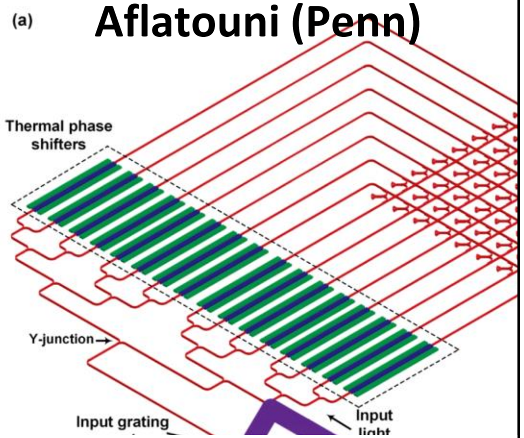
[Xie et al., *OE* 2019]

Wu (Berkeley)



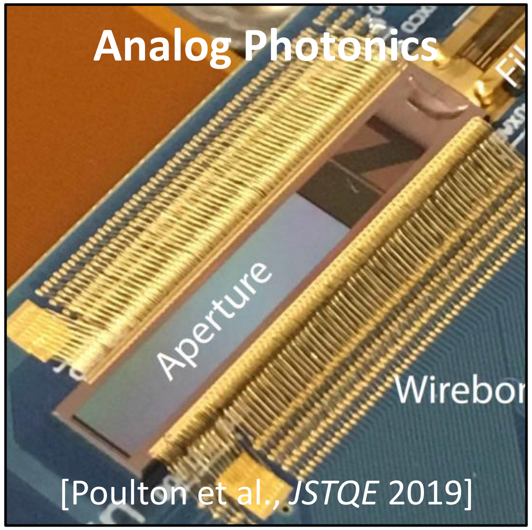
[Wang et al., *Optica* 2019]

Aflatouni (Penn)



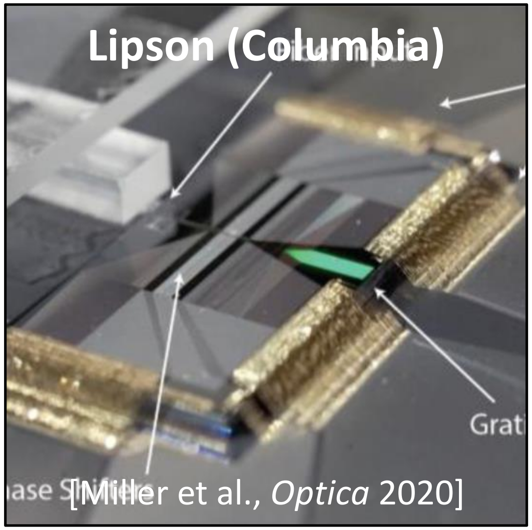
[Ashtiani et al., *OE* 2019]

Analog Photonics



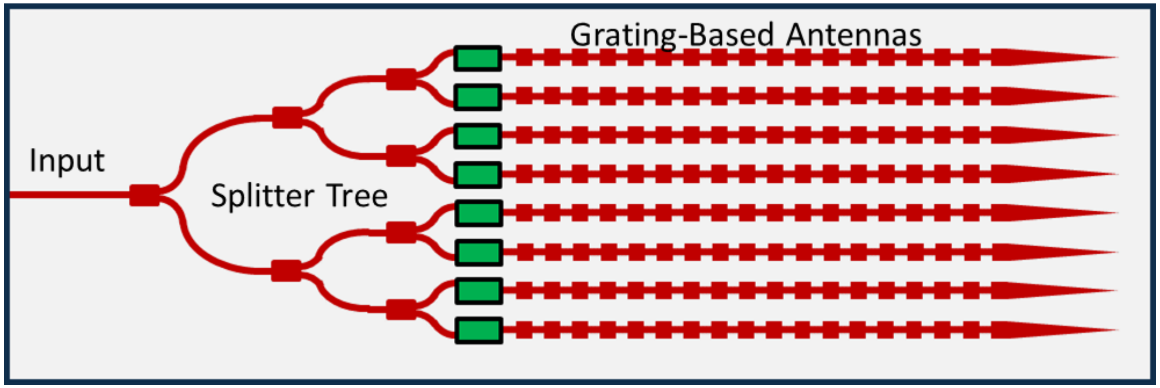
[Poulton et al., *JSTQE* 2019]

Lipson (Columbia)



[Miller et al., *Optica* 2020]

Example OPA Architecture



[DeSantis, … Notaros, *Optics Express* 2024]

Splitter-Tree-Architecture Optical Phased Array

- Splitter tree distributes power from input to grating-based antennas
- Phase shifter before each antenna for electronic phase control
- Electronic steering in array dimension & wavelength steering in antenna dimension

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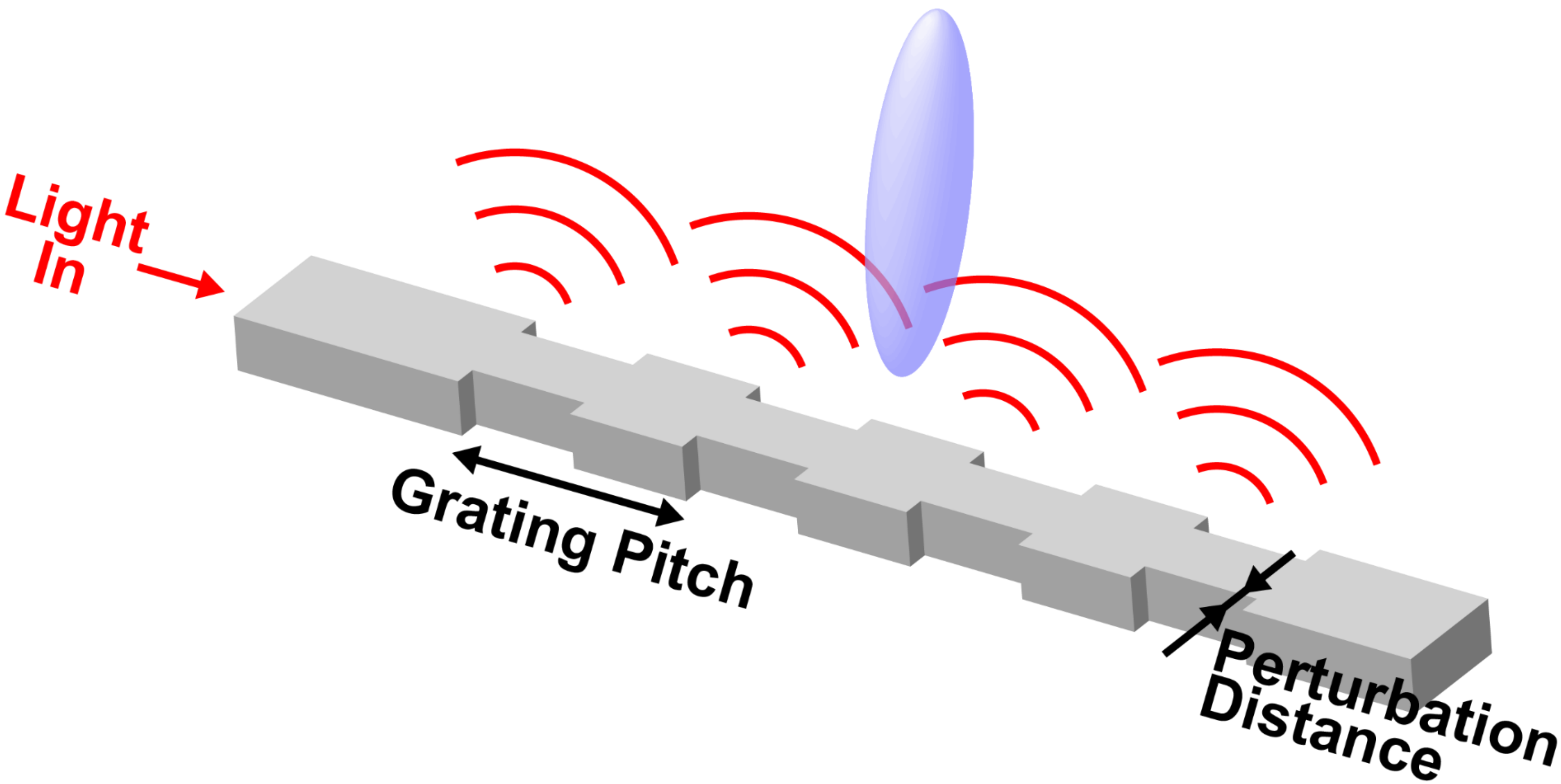

[Kim, … Notaros et al., *ISSCC* 2019]

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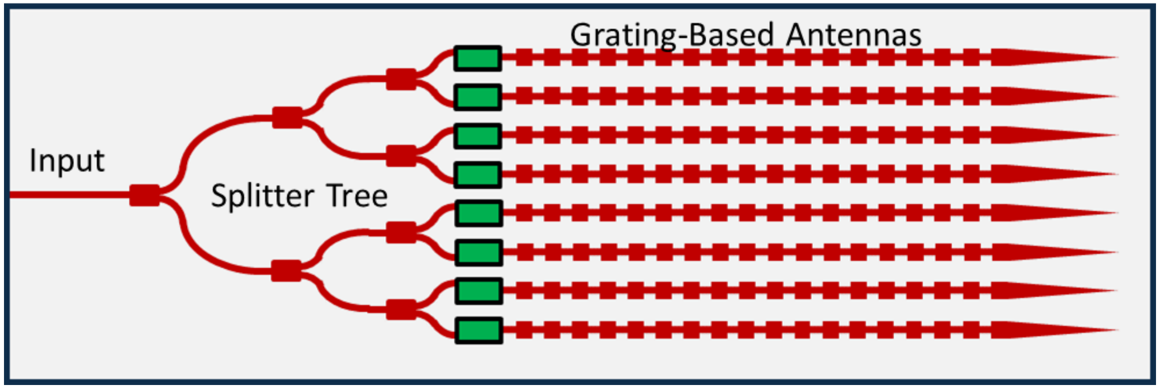

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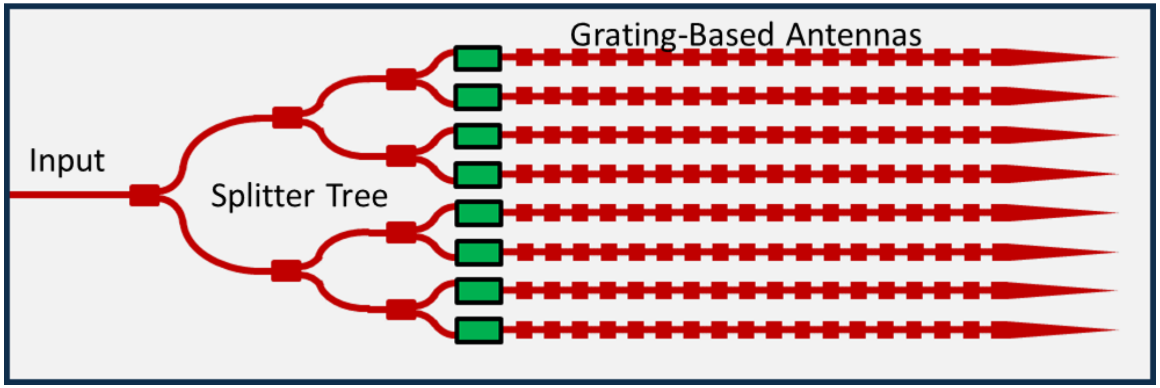

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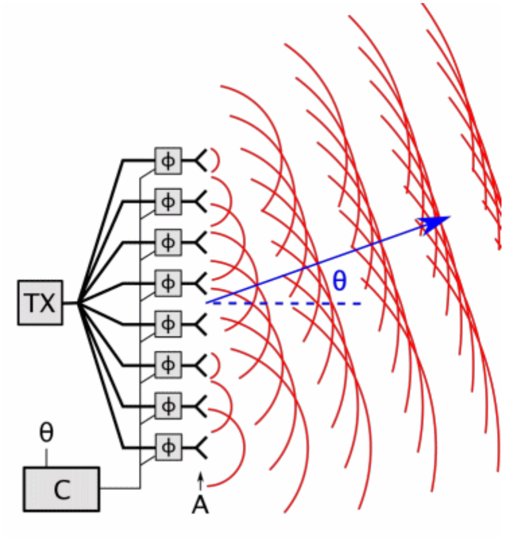

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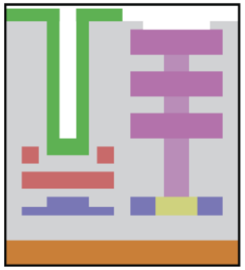
Recent OPA and LiDAR Results

300-mm SiP Platform



[Notaros et al., *IEEE JLT* 2019]

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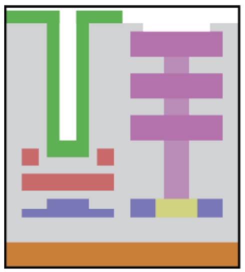

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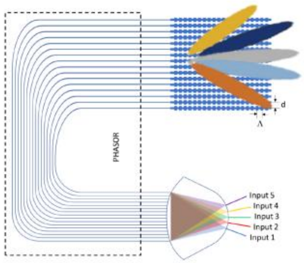
AWG-Based OPA Result



[Liu, … Notaros, Klamkin, CLEO 2024 **(Highlighted Talk Award)**]

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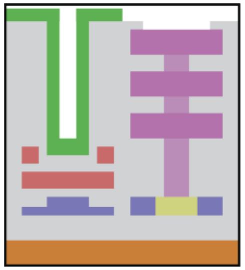

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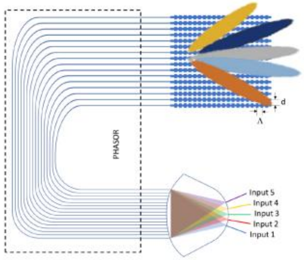

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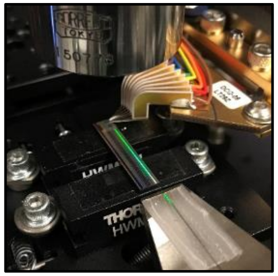
Laser-Integrated OPA Result



[<u>Notaros</u> et al., *IEEE JLT* 2019]
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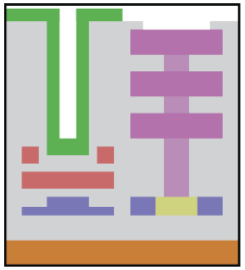

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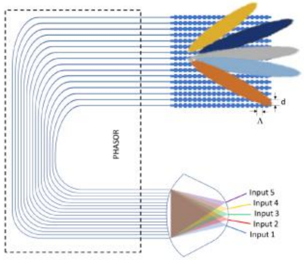

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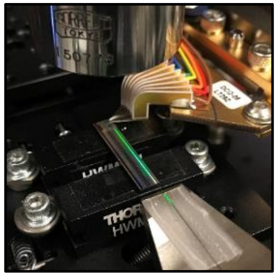

[Notaros et al., *IEEE JLT* 2019]
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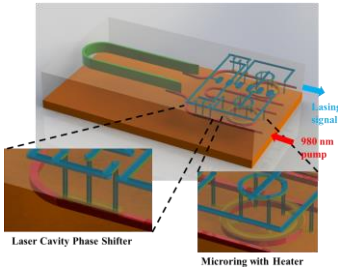
Tunable-Laser Result



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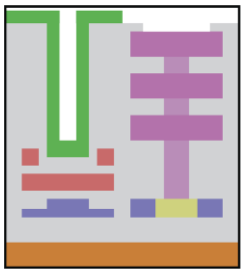

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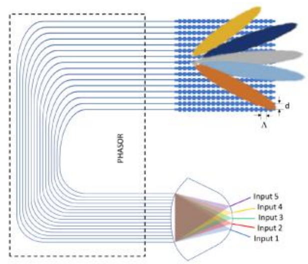

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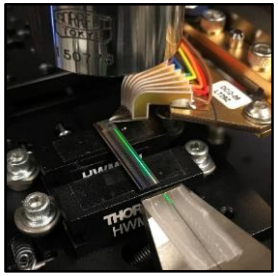

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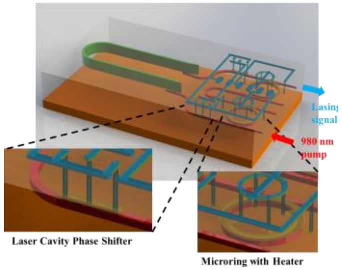

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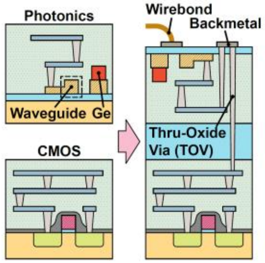
3D Elect.-Photon. Integration



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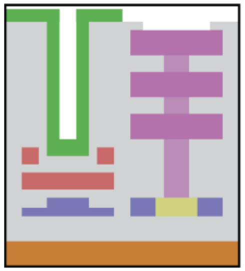

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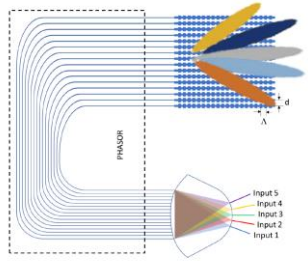

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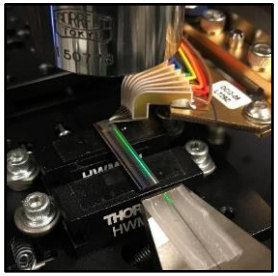

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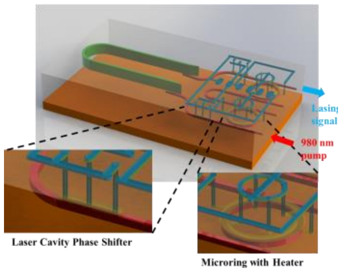

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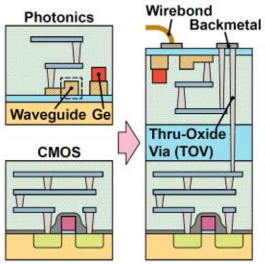

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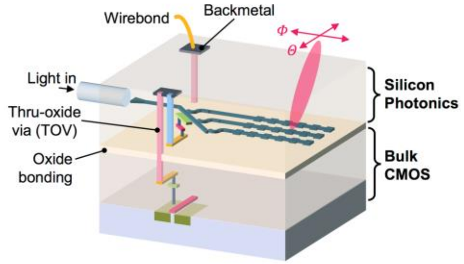
CMOS-Driven OPA Result



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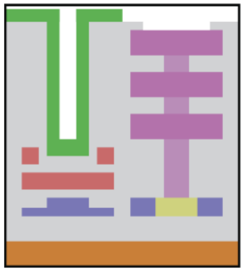

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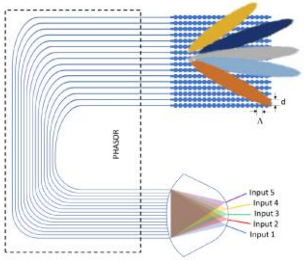

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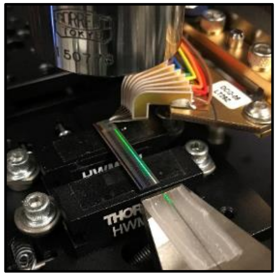

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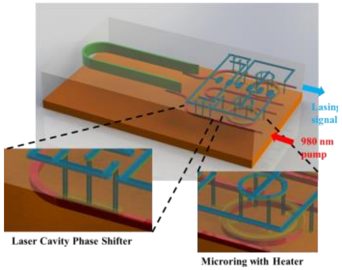

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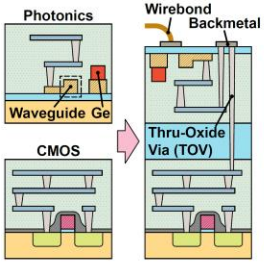
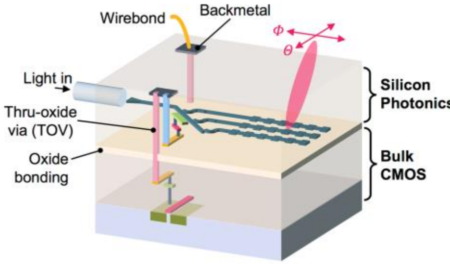


[Kim, … Notaros et al., *JSSC* 2019 (Invited)]
[Kim, … Notaros et al., *ISSCC* 2019]

CMOS-Driven OPA Result



[Kim, … Notaros et al., *JSSC* 2019 (Invited)]
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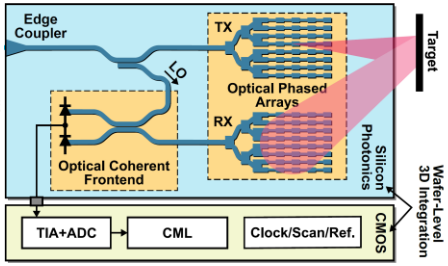
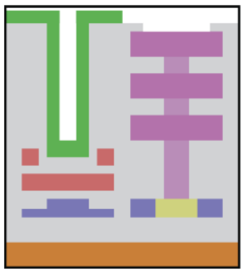
CMOS-Driven LiDAR Result



[Bhargava, … Notaros et al., *VLSI* 2019]

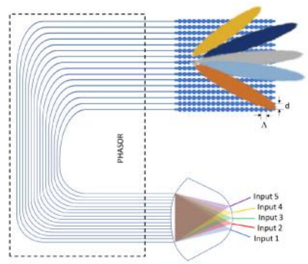
Recent OPA and LiDAR Results

300-mm SiP Platform



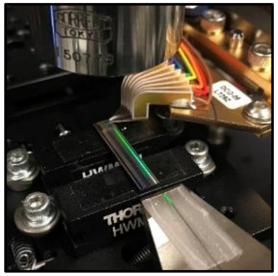
[Notaros et al., *IEEE JLT* 2019]

AWG-Based OPA Result



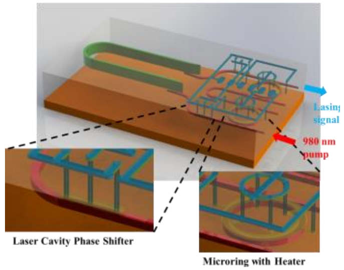
[Liu, … Notaros, Klamkin, CLEO 2024 **(Highlighted Talk Award)**]

Laser-Integrated OPA Result



[Notaros et al., *IEEE JLT* 2019]
[Notaros et al., *CLEO* 2018]

Tunable-Laser Result



[Li, … Notaros et al., *OE* 2018]
[Li, … Notaros et al., *CLEO* 2018]

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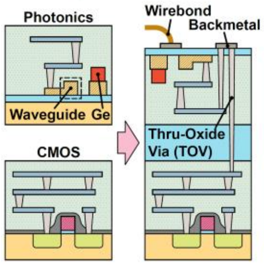

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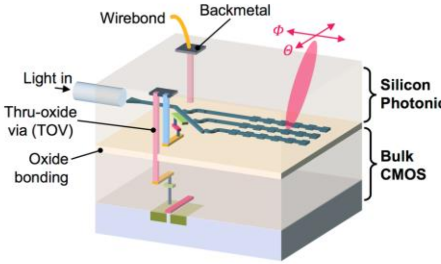

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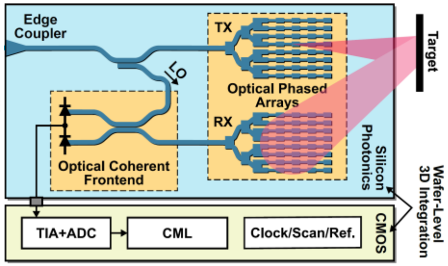
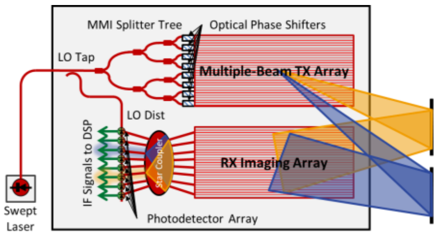


[Bhargava, … Notaros et al., *VLSI* 2019]

Multi-Beam LiDAR Result



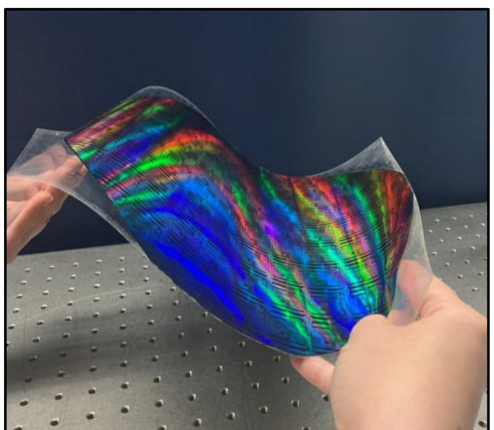
[DeSantis, … Notaros, *OE* 2024]

Outline

Introduction to Silicon Photonics

Silicon-Photonics-Based Solid-State LiDAR Sensors

- Motivation for LiDAR for Autonomous Systems
- Motivation for Solid-State LiDAR
- Introduction to Integrated OPAs
- Recent OPA and LiDAR Results



Other Related Research Directions

- Holographic AR Displays
- Chip-Based 3D Printers
- Optical Trapping for Biophotonics
- Flexible Wafer Bonding
- Trapped-Ion Quantum Systems

Our Other Related Research Directions

Holographic AR Display

[Notaros et al., *CLEO* 2019 **(Chair's Pick Award)**]
[M. Notaros, …. Notaros et al., under review]

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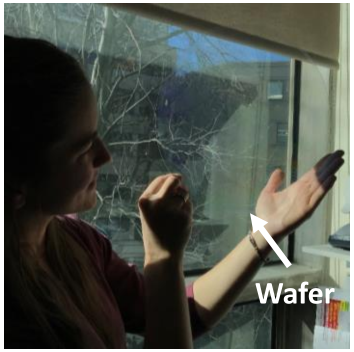
Transparent Wafer Platform



[M. Notaros, …. Notaros, *Nature Scientific Reports* 2024]
[M. Notaros, … Notaros, *FiO* 2022 **(Best Paper Finalist)**]

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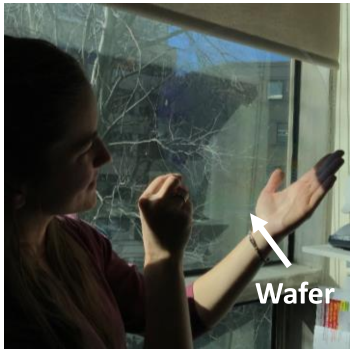

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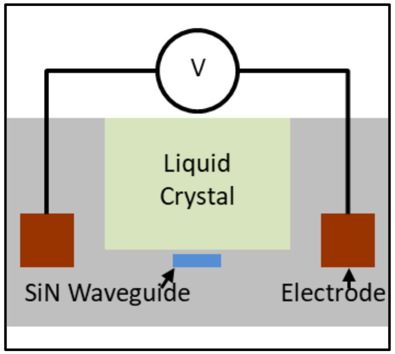
LC-Based Modulators



[M. Notaros, … Notaros, *OL* 2024]
[M. Notaros, … Notaros et al., *OE* 2022]
[A. Garcia Coleto*, M. Notaros*, … Notaros, *IPC* 2023]

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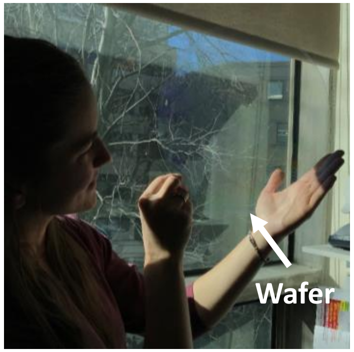

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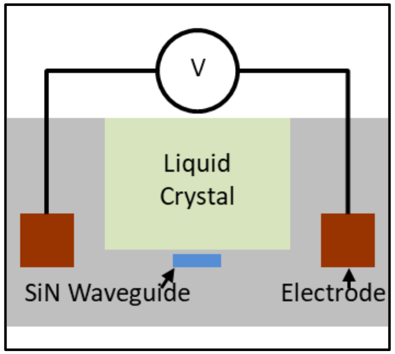

[M. Notaros, ... Notaros, *OL* 2024]
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[Corsetti, ... Notaros, *Nature LSA* 2024 **(Top Downloaded Paper**
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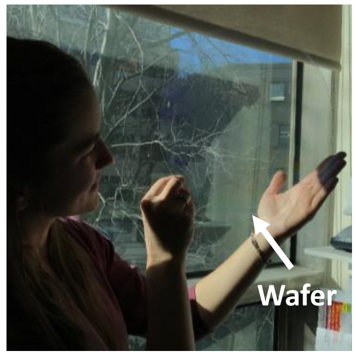

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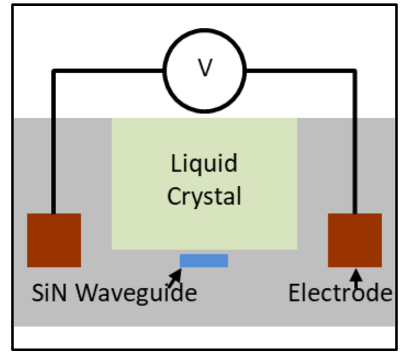

[M. Notaros, … Notaros, *OL* 2024]
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Optical Tweezing of Cancer Cells

[Sneh, … Notaros, *Nature Communications* 2024]
[Sneh, … Notaros, *CLEO* 2022]
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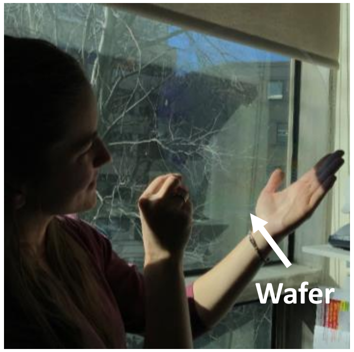

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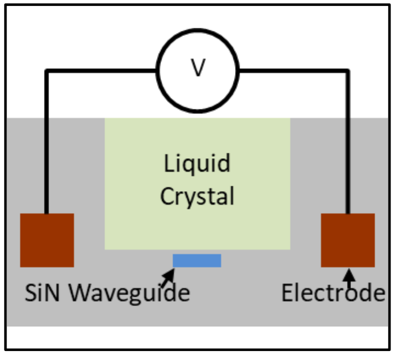

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Chip-Based 3D Printers


[MIT News 2024]

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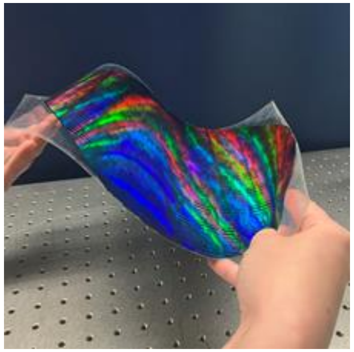
Flexible Wafers



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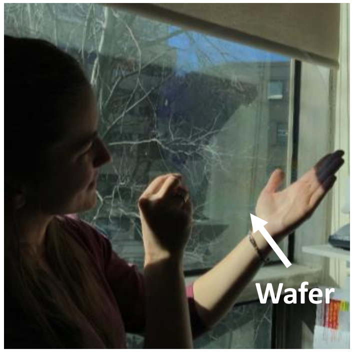

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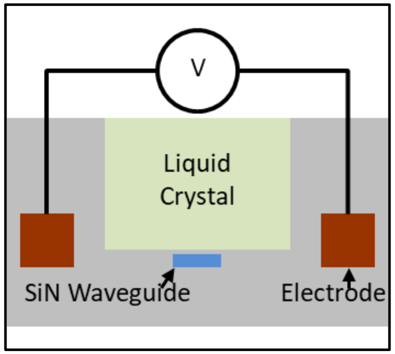

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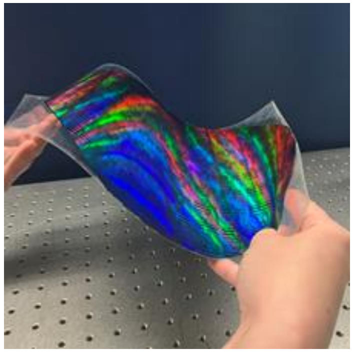

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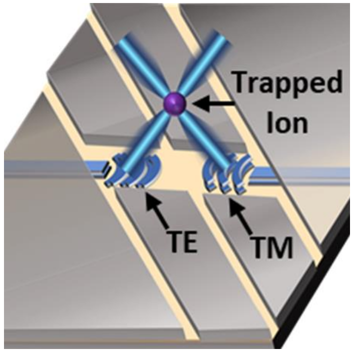
Trapped-Ion Quantum



[Hattori*, Sneh*, … Notaros, *OL* 2024]
[Corsetti, … Notaros, *FiO* 2023 **(Postdeadline Talk)**]
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[Sneh*, Hattori*, … Notaros, *FiO* 2022]

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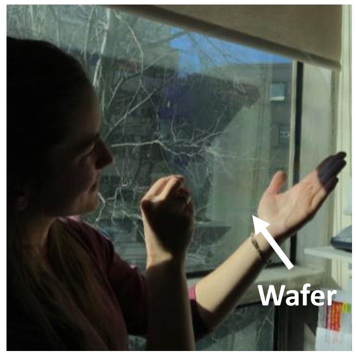

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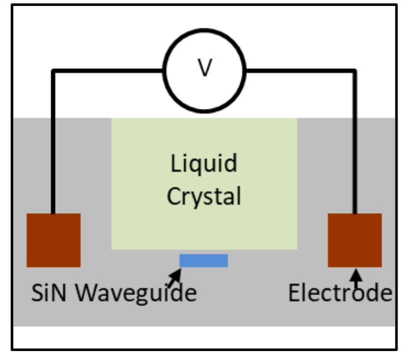

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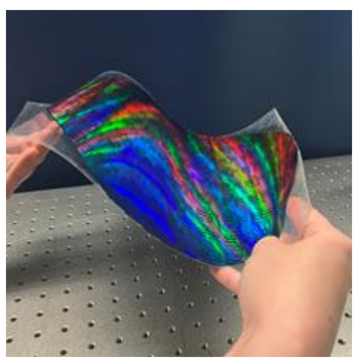

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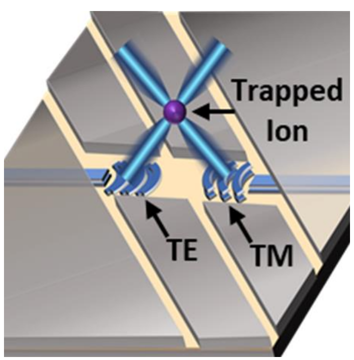

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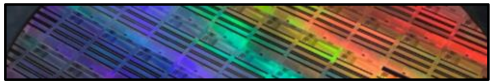
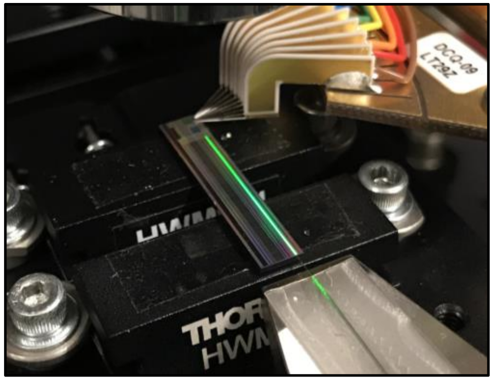
[Sneh*, Hattori*, … Notaros, *FiO* 2022]

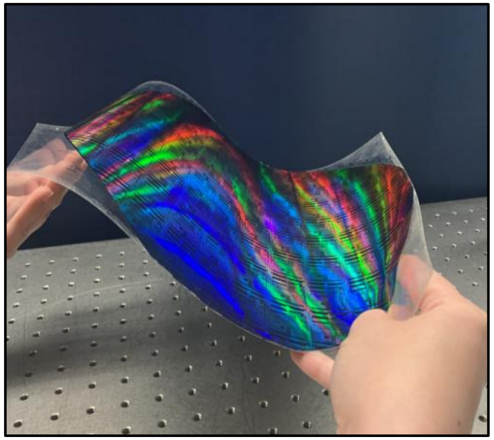
Underwater Optical Comms

[M. Notaros, … Notaros, *OL* 2023]
[D. DeSantis*, M. Notaros*, … Notaros, *IPC* 2023]

Conclusion: Summary







Introduction to Silicon Photonics

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Conclusion: Acknowledgements

MIT PERG Team

Abby Shull
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Ashton Hattori
Benjamin Mazur
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Henry Crawford-Eng
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Milica Notaros
Pearl Nelson-Greene
Sabrina Corsetti
Tal Sneh
Prof. Jelena Notaros

MIT: Manan Raval, Christopher Poulton, Matthew Byrd, Nanxi Li, Zhan Su, E. Salih Magden, Erman Timurdogan, Michael Watts, Felix Knollmann, Gavin West, Ethan Clements, Prof. Isaac Chuang, Marc de Cea, Prof. Rajeev Ram, Zhengxing Zhang, Prof. Duane Boning, Kruthika Kikkeri, Prof. Joel Voldman

Lincoln Labs: John Chiaverini, Reuel Swint, Patrick Callahan, Dave Kharas, Thomas Mahony, Colin Bruzewicz, Cheryl Sorace-Agaskar, Robert McConnell

SUNY: Tom Dyer, Christopher Baiocco, Alin Antohe, Nick Fahrenkopf, Lewis Carpenter, Kevin Fealey, Seth Kruger, Gerald Leake, Mark Wagner, Chris Striemer, Daniel Coleman, David Harame

UC Berkeley: Taehwan Kim, Pavan Bhargava, Prof. Vladimir Stojanovic

UC Santa Barbara: Yuan Liu, Chongxin Tyler Zhang, Diya Hu, Thomas Meissner, Prof. Jonathan Klamkin

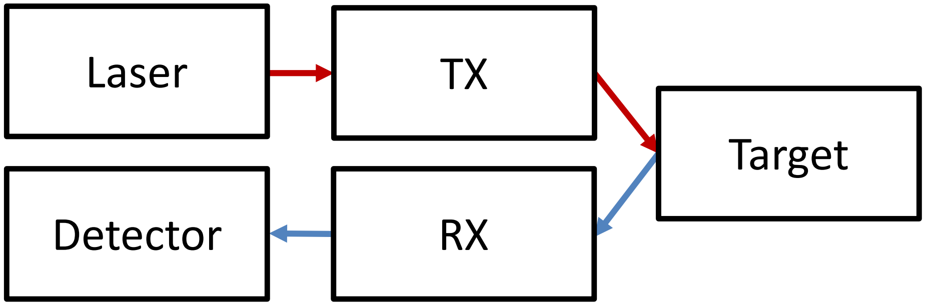
UT Austin: Alex Stafford, Prof. Zachariah Page

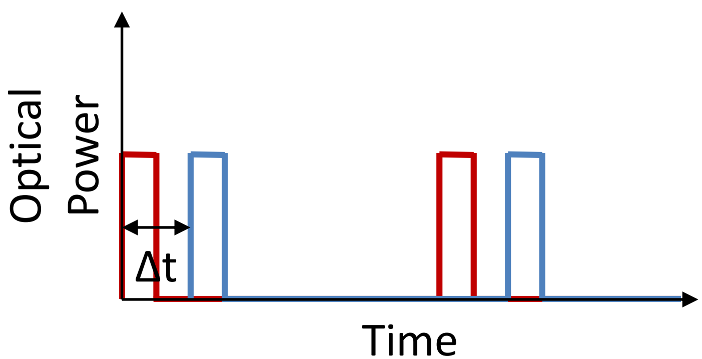
Educational Initatives: Dr. Anuradha Agarwal, Prof. Stefan Preble, Prof. Jaime Cardenas, Dr. Sajan Saini, Prof. Juejun Hu, Prof. Thomas Brown, Prof. Jifeng Liu, Prof. Samuel Serna Otalvaro, Prof. Lionel Kimerling

Funding: DARPA VIPER, DARPA E-PHI, DARPA DODOS, NSF QLCI HQAN/Q-SEnSE, MIT CQE, AIM Academy, AIM GDP4, SRC/DARPA JUMP, NSF CAREER

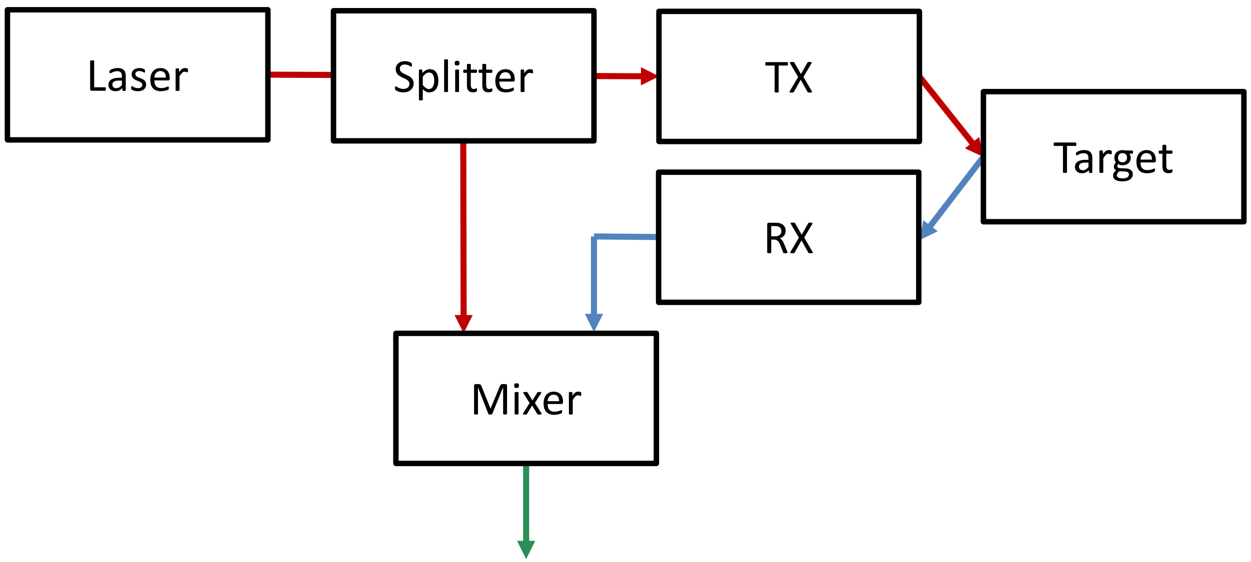
Supplementary Slides

LiDAR Sensors: TOF LiDAR Concept



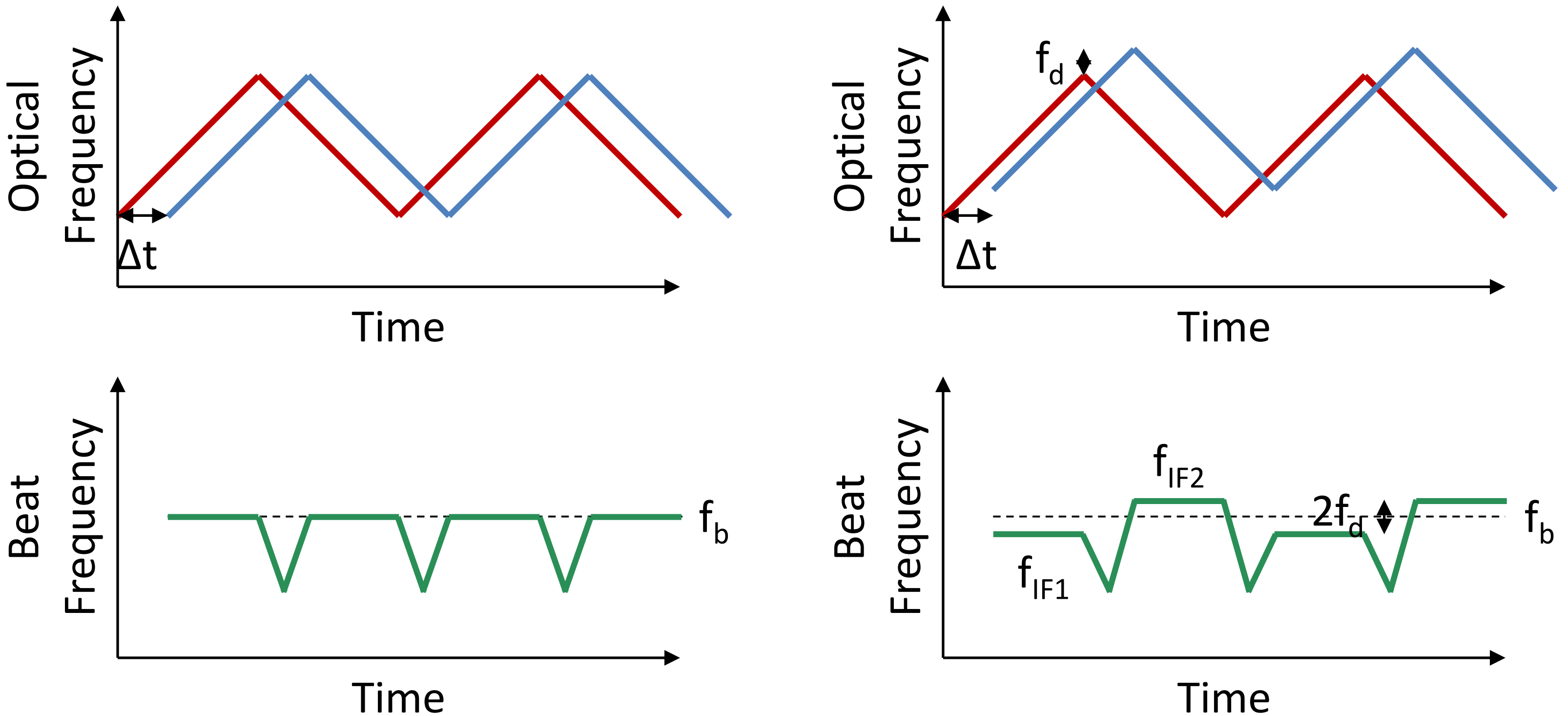


LiDAR Sensors: FWCM LiDAR Concept



LiDAR Sensors: FWCM LiDAR Concept

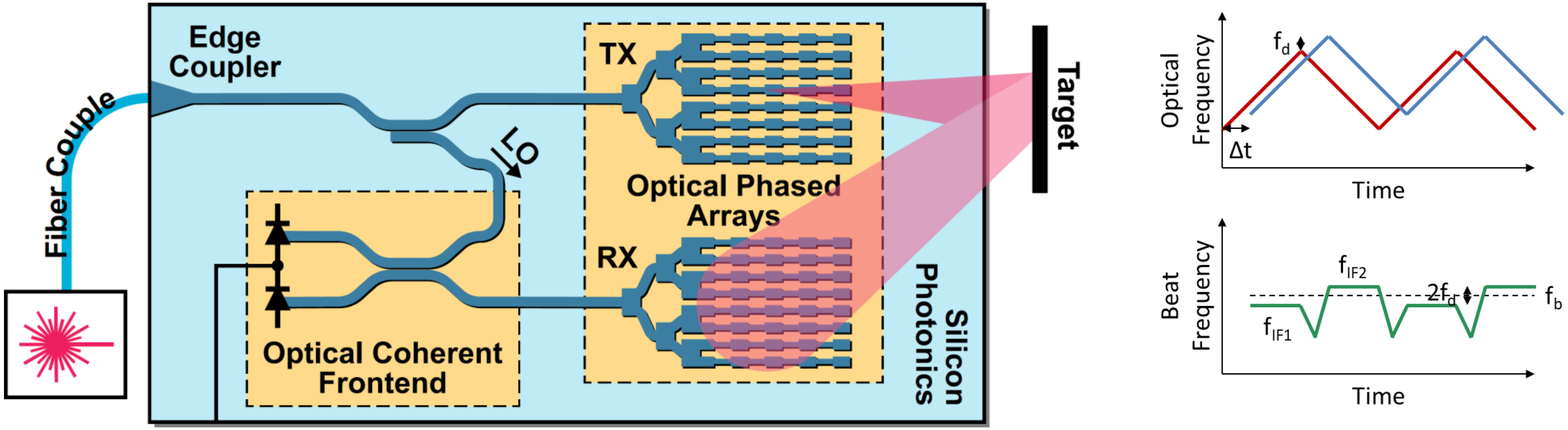
Frequency-Modulated Continuous-Wave LiDAR



Distance to Target: $r = \frac{\Delta t}{2} c = \frac{f_b}{2s} c$ where s is the laser sweep rate

Speed of Target: $v = \frac{f_d}{2 f_0} c$ where f_0 is the transmitted frequency

LiDAR Sensors: Example FWCM LiDAR System

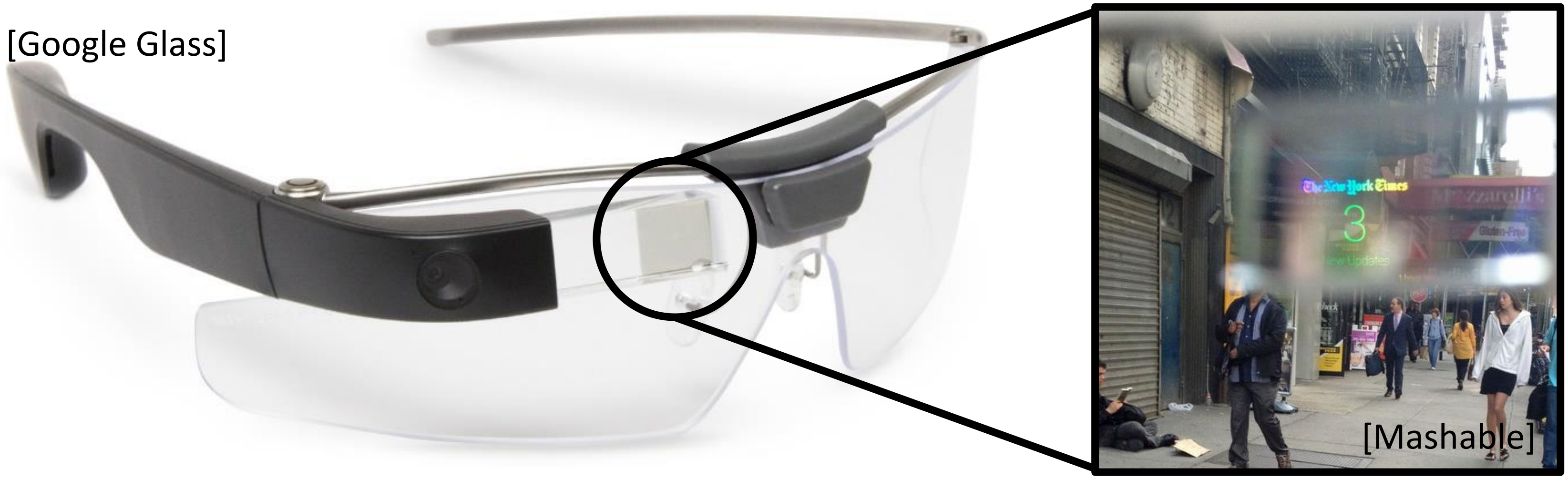


FMCW LiDAR Architecture

- Swept laser transmitted by TX OPA, reflected off target, and received by RX OPA
- Received signal beats with local oscillator via coherent detection
- Architecture allows for simultaneous distance and velocity measurement

[Bhargava, … Notaros et al., *VLSI* 2019]

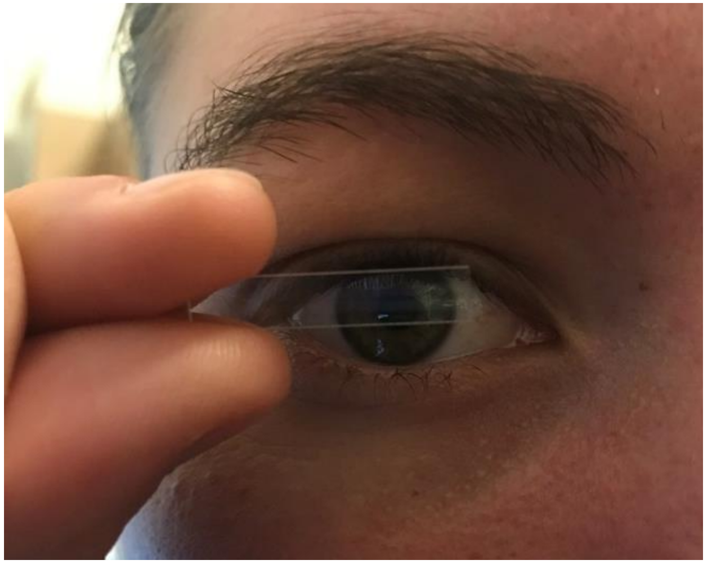
SiP for Holographic AR Displays



Current AR Display Limitations

- Large, heavy, and indiscreet
- Small field of view and low luminance
- Vergence-accommodation conflict and eye fatigue

SiP for Holographic AR Displays



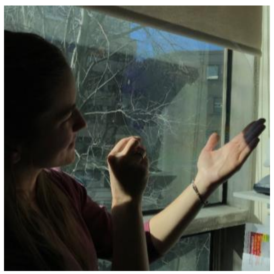
Our AR Display Advantages

Concept: Chip-based direct-view near-eye HMD
Fully-Holographic: Enables long-term use
Highly-Discreet: Flat and transparent

[Notaros, *DARPA60 Plenary* 2018 **(DARPA Riser Award)**]
[M. Notaros, … Notaros et al., under review]

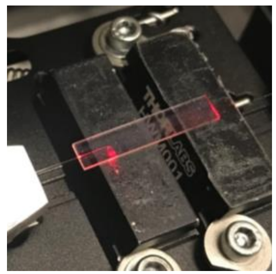
SiP for Holographic AR Displays

Transparent Wafer Bonding



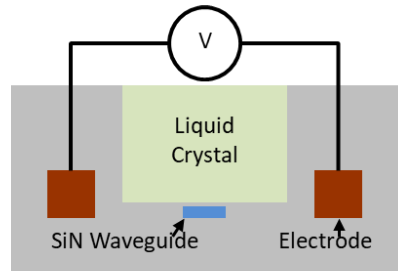
[M. Notaros… Notaros, *FiO* 2022 **(Best Paper Finalist)**]

Passive Holographic Display



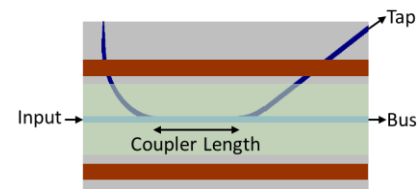
[M. Notaros, … Notaros et al., under review]

LC-Based Phase Modulator



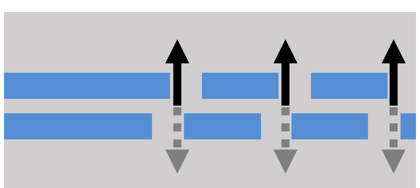
[M. Notaros, … Notaros et al., *OE* 2022]
[Garcia Coleto, … Notaros, *IPC* 2023]
[Garcia Coleto, … Notaros, under review]

LC-Based Amplitude Modulator



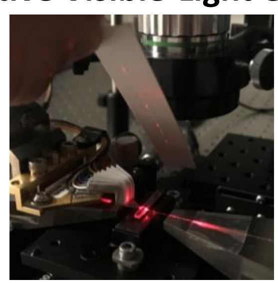
[M. Notaros, … Notaros, *OL* 2024]

Unidirectional Visible-Light Antennas



[Garcia Coleto, … Notaros, under review]

Active Visible-Light OPA



[M. Notaros, … Notaros, *OL* 2023]

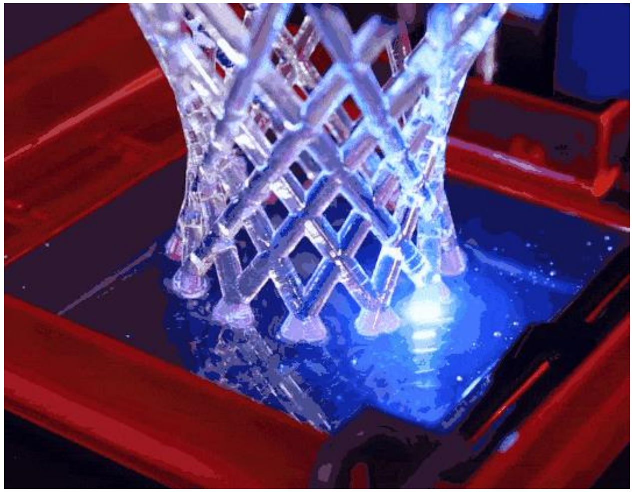
Active Holographic Display

[M. Notaros, … Notaros et al., under review]

Wafer Fabrication in Collaboration with SUNY

Chip-Based 3D Printers

Current Stereolithography 3D Printers



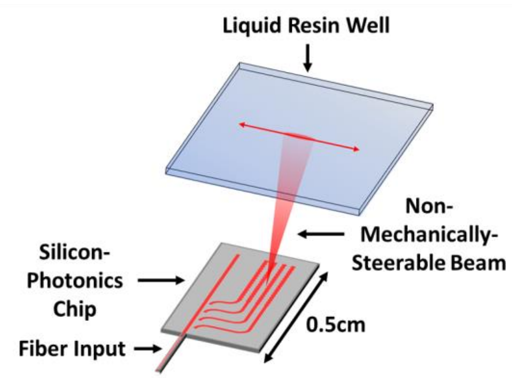
[Formlabs]

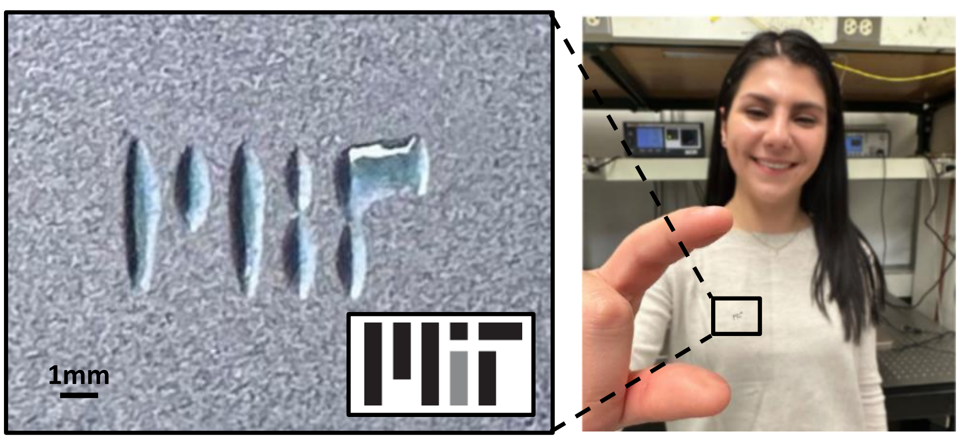
Our Chip-Based 3D Printer Concept

[Corsetti, … Notaros, *IPR* 2022 **(Best Paper Award)**]
[Corsetti, … Notaros, *Nature LSA* 2024 **(Top Downloaded Paper)**]

Chip-Based 3D Printers

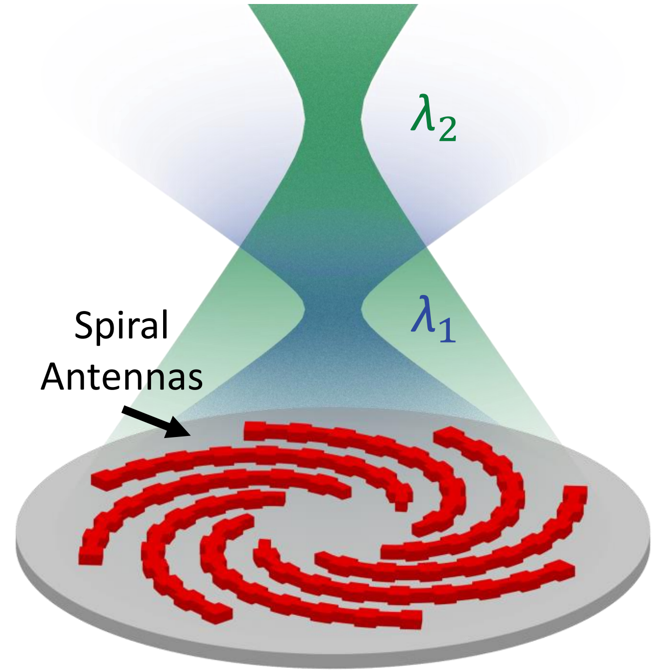
First Chip-Based 3D Printer Demo





Resins from the UT Austin Page Group
[Corsetti, … Notaros, *IPR* 2022 **(Best Paper Award)**]
[Corsetti, … Notaros, *Nature LSA* 2024 **(Top Downloaded Paper)**]

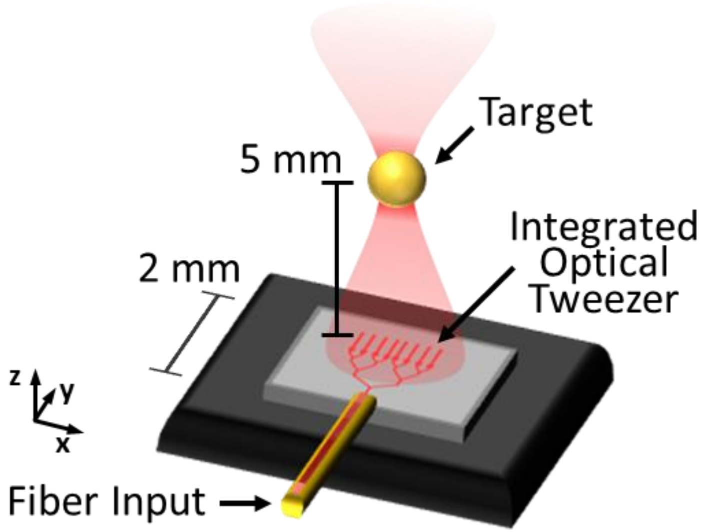
Spiral Integrated OPA



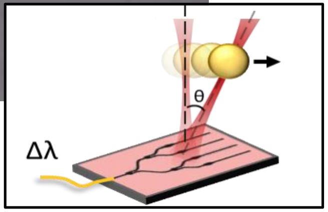
[DeSantis, … Notaros, under review]

SiP for Bio Optical Tweezers

Conceptual Diagram



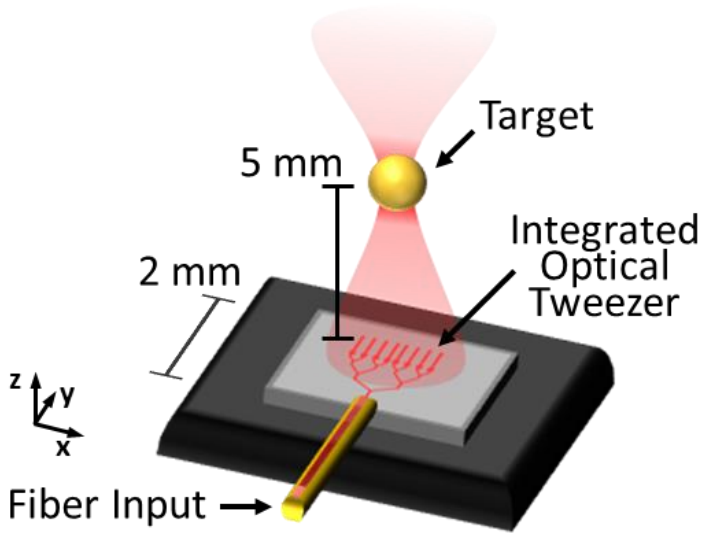
Experimental Tweezing Demo



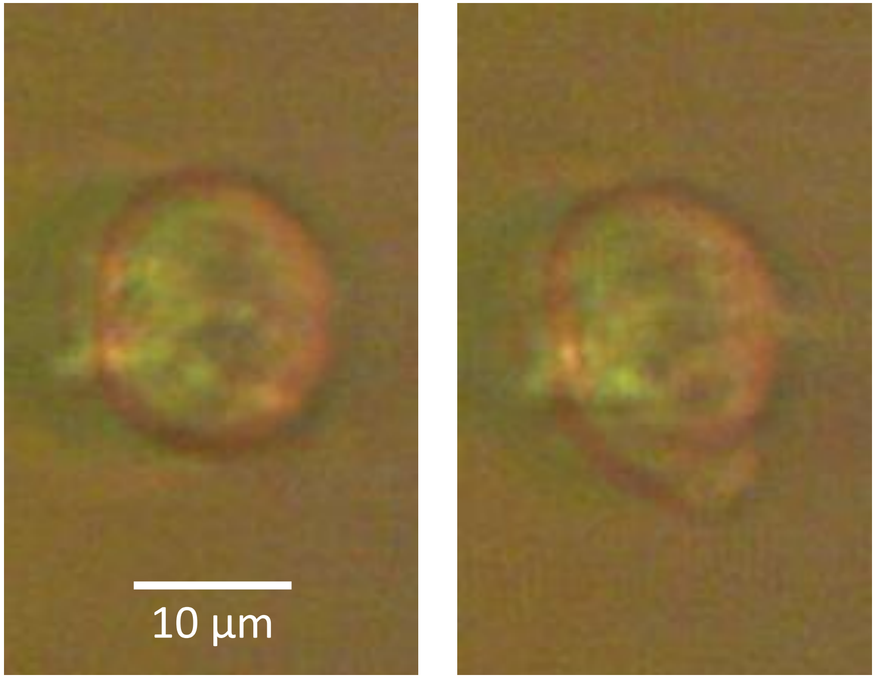
[Sneh, … Notaros, *Nature Communications* 2024]
[Sneh, … Notaros, *CLEO* 2022]
[Sneh, … Notaros, *IPC* 2023]

SiP for Bio Optical Tweezers

Conceptual Diagram



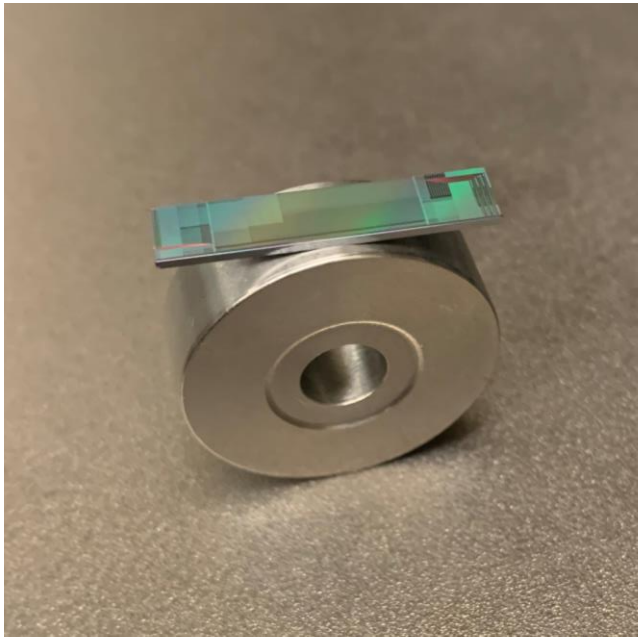
Cell Stretching Experiment



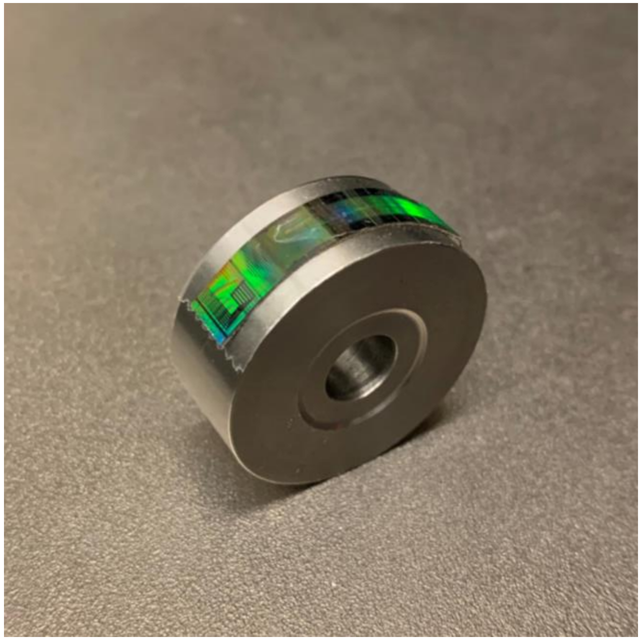
Cells from the MIT Voldman Group
[Sneh, … Notaros, *Nature Communications* 2024]
[Sneh, … Notaros, *CLEO* 2022]
[Sneh, … Notaros, *IPC* 2023]

SiP with Flexible Platforms

Rigid Photonic Chip

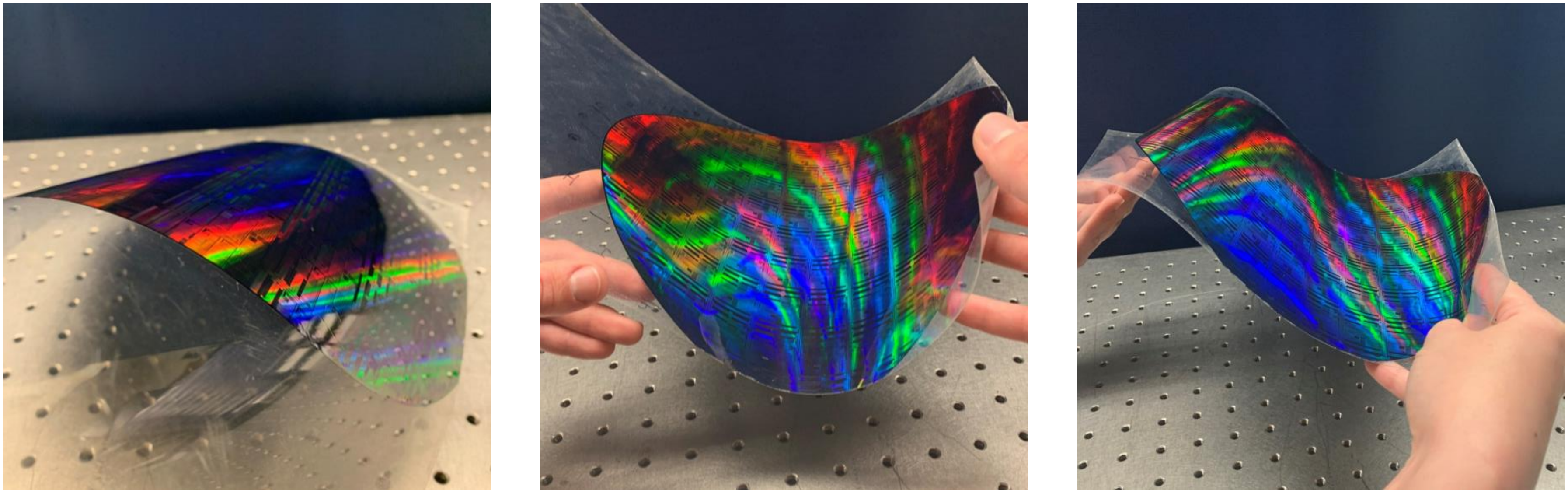


Flexible Photonic Chip



[M. Notaros, … <u>Notaros</u>, *Scientific Reports (Nature Group)* 2024]
[M. Notaros, … <u>Notaros</u>, *FiO* 2022 **(Best Paper Award Finalist)**]
Collaboration with SUNY

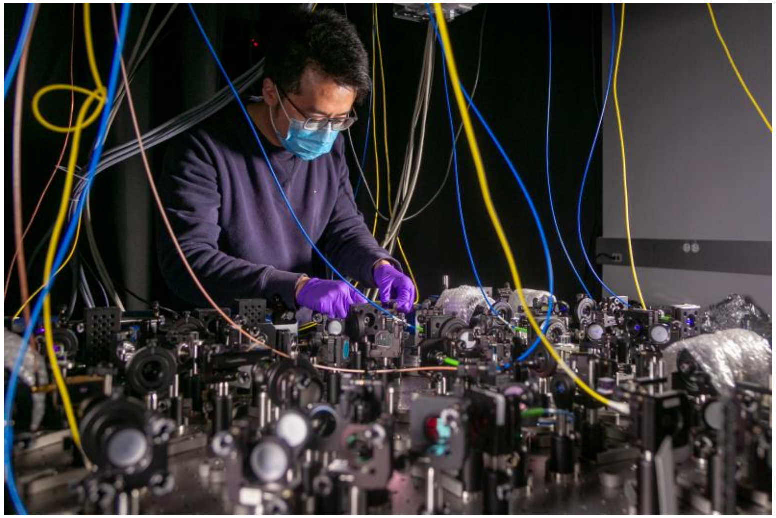
SiP with Flexible Platforms



[M. Notaros, … <u>Notaros</u>, *Scientific Reports (Nature Group)* 2024]
[M. Notaros, … <u>Notaros</u>, *FiO* 2022 **(Best Paper Award Finalist)**]
Collaboration with SUNY

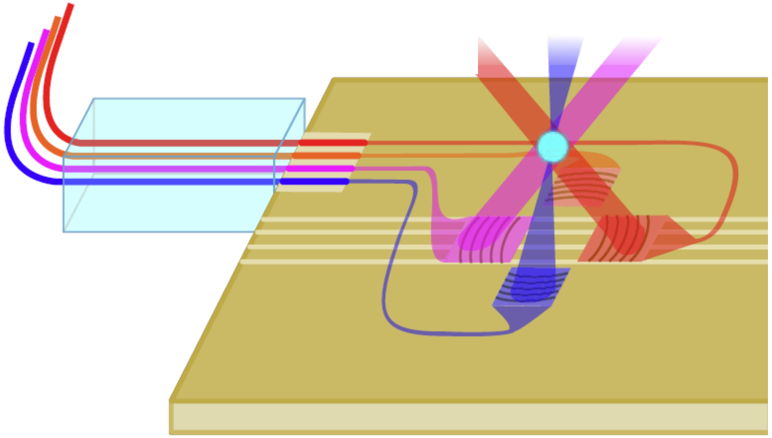
SiP for Trapped-Ion Quantum

Current Implementations



[Duke University]

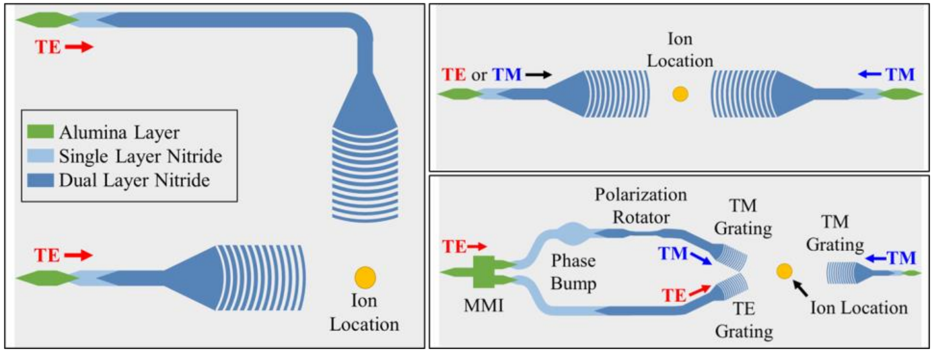
Integrated-Photonics-Based Solution



[Niffenegger et al., *Nature* 2020]

SiP for Trapped-Ion Quantum

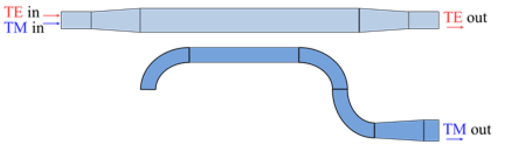
Advanced Ion Cooling Architectures



[Hattori*, Corsetti*, … Notaros, *FiO* 2022 **(Best Paper Award Finalist)**]

Visible-Light Polarization Devices

Polarization Splitter

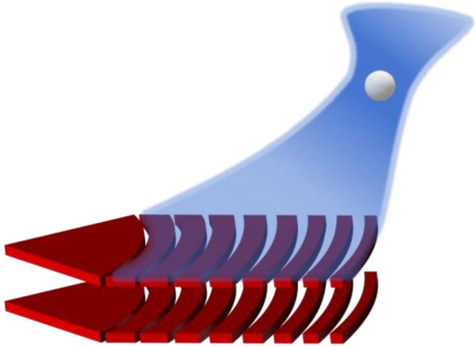


Polarization Rotator

[Hattori*, Sneh*, … Notaros, *OL* 2024]

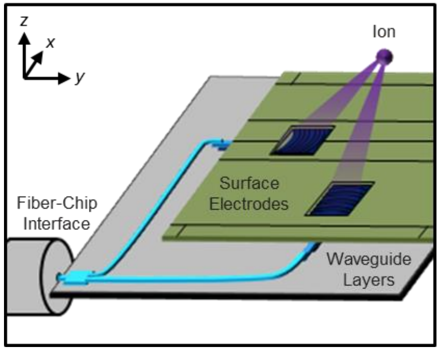
[Sneh*, Hattori*, … Notaros, *FiO* 2022]

TE and TM Gratings for Ions



[Corsetti, … Notaros, *FiO* 2023 **(Postdeadline)**]

Polarization-Gradient Ion Cooling Result



[Corsetti, … Notaros, under review]

[Clements, … Notaros, Chiaverini, in prep]

Collaboration with MIT Lincoln Laboratory and MIT Quanta Group

ANNOTATION FOR THE SESSION ON SOLID STATE LiDAR BY PROF JELENA NOTAROS

4th Oct 2024, MIT Mobility Forum
By Tanay Deshpande (as part of 11.251)

Literature

1. Yoo H.W., Druml N., Brunner D., Schwarzl C., Thurner T., Hennecke M. and Schitter G. (2018). MEMS-based LiDAR for autonomous driving. *E & I Elektrotechnik und Informationstechnik*
2. Williams G. (2017). Optimization of eye-safe avalanche photodiode LiDAR for automobile safety and autonomous navigation systems. *Optical Engineering Vol 56 No 3, DOI: 10.1117/1.OE.56.3.031224*
3. Li N., Ho C.P., Xue J., Lim L.W., Chen G., Fu Y.H., Lee L.Y.T. (2022). A progress review on solid-state LiDAR and Nanophotonics-based LiDAR sensors. *Laser & Photonics Reviews Vol 16 No 11*
4. Choe J., Cho H., Chung Y. (2023). Performance Verification of Autonomous Driving LiDAR Sensors under rainfall conditions in darkroom. *Sensors Vol 24 No 1*
5. Veronese L., Auat-Cheein F., Mutz F., Oliveira-Santos T. (2021). Evaluating the limits of a LiDAR for an autonomous driving localization. *IEEE Transactions on Intelligent Transportation Systems Vol 22 No 3*
6. Li Y. and Ibanez-Guzman J. (2020). LiDAR for Autonomous Driving. *IEEE Signal Processing Magazine: Autonomous Driving Part 1*
7. Li Y., Ma L., Zhong Z., Chapman M., Cao D., Li J. (2021). Deep Learning for LiDAR point clouds in autonomous driving: A review. *IEEE Transactions on Neural Networks and Learning Systems Vol 32 No 8*

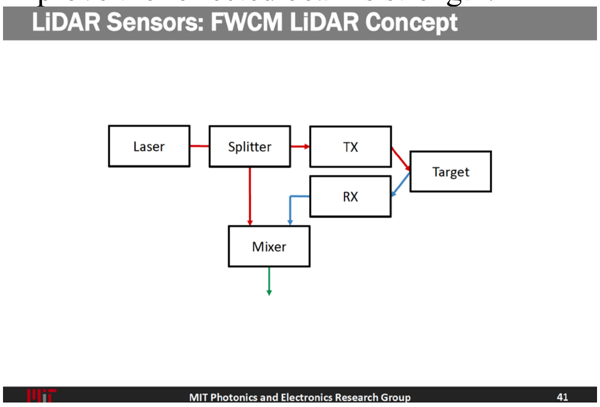
Recent news

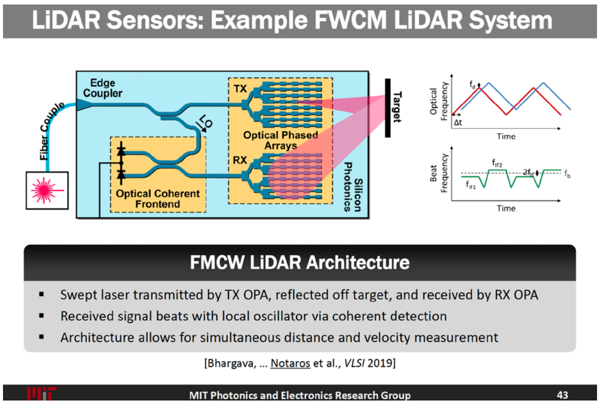
1. https://www.theverge.com/2024/5/7/24151497/tesla-lidar-luminar-elon-musk-sensor-autonomous : Tesla's reversal from Elon trashing LiDAR technology to becoming Luminar's biggest customer for LiDAR sensors with 2000 orders at ~$1000 apiece (May '24)
2. https://www.engadget.com/cameras/dji-air-3s-review-lidar-and-improved-image-quality-make-for-a-nearly-faultless-drone-130002876.html : LiDAR being used for high quality drone vision
3. https://venturebeat.com/ai/lidwave-raises-10m-to-improve-machine-vision-with-on-chip-4d-lidar/ : Early fundraising round for an on-chip/ solid-state LiDAR startup (Oct '24)
4. https://www.theverge.com/2024/5/3/24148395/luminar-lidar-layoff-outsource-autonomous-vehicle : Luminar, a top LiDAR supplier to European automotive manufacturers, lays off 20% of its workforce as it outsources certain manufacturing processes overseas (May '24)
5. https://waymo.com/blog/2024/08/meet-the-6th-generation-waymo-driver/ : Waymo announces its upgraded self-driving tech, using LiDAR vision (Aug '24)
6. https://asia.nikkei.com/Business/Automobiles/China-extends-lead-in-lidar-tech-crucial-to-self-driving-cars : China leads the way with LiDAR adoption, with the cost per LiDAR unit ~50% less than US counterparts and BYD launching its first LiDAR car (Aug '24)

Highlighted questions in the forum

Q. Could you discuss some of the recent relevant technological developments made by your group, for example in improving the capabilities of solid-state LiDAR?

A. One of the biggest challenges of conventional LiDAR is separating the reflected beam's signal from the environment's noise. For this, OPAs can split their beam and then mix it (phase-differenced) to improve the reflected beam's strength.





Q. Can you comment on the cost-effectiveness and safety features of solid-state LiDAR?
A. Research groups have managed to fabricate OPAs at 2 orders of magnitude lower costs over the last decade vs mechanical LiDAR units. Sensor fusion with built-in redundancies using multiple sensory inputs (e.g. DARPA JUMP's LiDAR and radar on the same chip) is useful and safest. LiDAR is limited in fog while radar is not. Stereo vision/ cameras meanwhile require a lot of computational processing. See details below.

Q. Can you comment on how you see the vision industry shaping out with new LiDAR tech in AVs?
A. I focus on the academic side of this field, but there are many startups raising funding and I see even Tesla's decision to never use LiDAR reversing on a large scale.

Reflection on the MMI forum session
Prof Jelena Notaros' lecture on Solid State LiDAR introduced us to the broad field of computer vision in autonomous vehicles, the dominant technologies which have been adopted so far and will be in the future, and the impact of solid-state photonics on such technologies. Historically, radar had primacy as the navigation technology for submarines, aircraft and such, but the level of detail required for on-street vision and navigation is a lot higher. Objects are smaller, the environment has many dynamic parts including relatively fast-moving vehicles and the impact of accuracy on safety is huge. As Prof Notaros pointed out in the environment of autonomous vehicles, a 77GHz radar aperture would need to be 3.9m wide to transmit and recapture reflected radar waves from a 20cm object 200m away. In contrast, we can increase the frequency to about 1550nm in the infrared spectrum (radar is about 3.9mm) and reduce the aperture size to 7.9cm which is suitable for vehicles.

Solid-state LiDAR is a step up from conventional externally mounted mechanically steering LiDAR because of its even smaller aperture requirement. This would increase the AFOV (angular field of vision) for the same focal length of the receiving lens as well. OPA (integrated optical phased array) has many CMOS transistor units of transmitters and receivers which can adjust the laser beam's angle by adjusting the phase difference between the units. The design acts as a waveguide to steer the beam by controlling the phase shifters. Prof Notaros' lab has made amazing progress on Time-Of-Flight LiDAR using the splitter & re-mixer arrays to recapture signals from the original wavefront's reflection and reduce noise.

The idea of building redundancy for enhanced driving safety was particularly appealing to me. An example from the session was DARPA's JUMP project on integrating LiDAR and radar on the same chip. Stereo vision (two cameras for 3D depth) coupled with a LiDAR system and a far-range radar system can give maximum coverage and precision of near and far objects. Although advancements in solid-state LiDAR technology have reduced its cost from $10,000 to as low as $200 per unit, the packaged cost of a multi-sensory system such as the one described above still remains a challenge. An even bigger challenge however, is to develop processing algorithms to integrate the signals from all these systems into a coherent driving strategy. In terms of hardware integration, not only is the packaging of solid-state systems difficult to prototype and manufacture, but the integration of fundamental driving technologies (steering, fuel systems, braking, drivetrains) to the inputs from the onboard processor unit is also being heavily researched. For instance, which automotive system should react to which sensory input, and how fast? I would personally love to explore optimization algorithms for mapping vision inputs to actions taken by the self-driving system.

Summary of other memos

Prof Jelena introduced us to several applications for emerging LiDAR tech. On the scale of the technology adoption S-curve, Holographic AR Display and Chip-based 3D printers have broad market appeal and manufacturing & partnership potential. Transparent Wafer Platform and LC-Based Modulators have a rapidly maturing market and these solutions could be scaled across industries. Trapped-Ion Quantum and Underwater Optical Communication, while having transformative effects over time, are open to disruption from existing larger competitors which can deploy their platform strengths. Regulatory considerations are key for Optical Tweezing of Cancer Cells while Flexible Wafers have a low capital requirement for starting up.

Multi-modal sensory systems with built-in redundancies, called ‘sensor fusion’ by Prof Jelena, are most promising for AV applications. Each sensory modality excels in different environments: cameras offer high-resolution images in clear conditions, radar penetrates through adverse weather like rain, and LiDAR provides accurate 3D mapping. Cameras/ full-vision systems are cost effective and easy to integrate (hence, Tesla’s reliance on them), but they come at the expense of safety. LiDAR has yet to prove itself in adverse visibility conditions such as rain or fog. However, OPAs/ solid-state LiDAR can at least improve upon existing tech by requiring less signal processing computation and fewer mechanical moving parts. Thus, solid-state lidar offers advantages in terms of resolution, form factor, and cost compared to mechanical systems. While CMOS based fabrication yields a much simpler and cost-effective manufacturing process, Prof Jelena emphasized the difficulties in packaging and transporting solid-state technologies where further research is necessary.

On a meta-level, transportation researchers needs a class of generalists who can and should keep abreast of such emergent tech and translate it into actionable insights for industry, lay practitioners and the general public who will interact with self-driving vehicles.

Other Points of Interest

The MIT PERG (Photonics and Electronics Research Group) partners with AIM Photonics and the 300mm wafer fabrication unit at SUNY.
https://www.aimphotonics.com/aim-photonics-announces-bestinclass-300mm-silicon-photonics-multiproject-wafer-mpw-performance