Institute of Microelectronics
A*STAR IME

R&D Catapult Platforms for Photonics and Flat Optics

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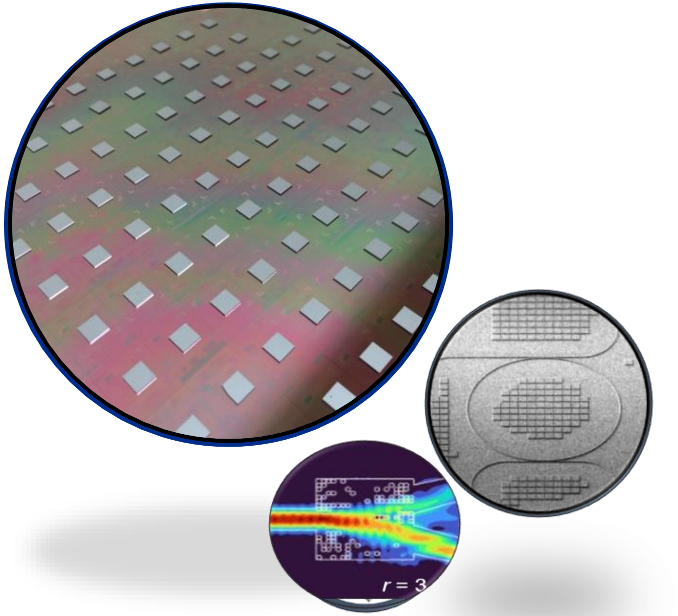
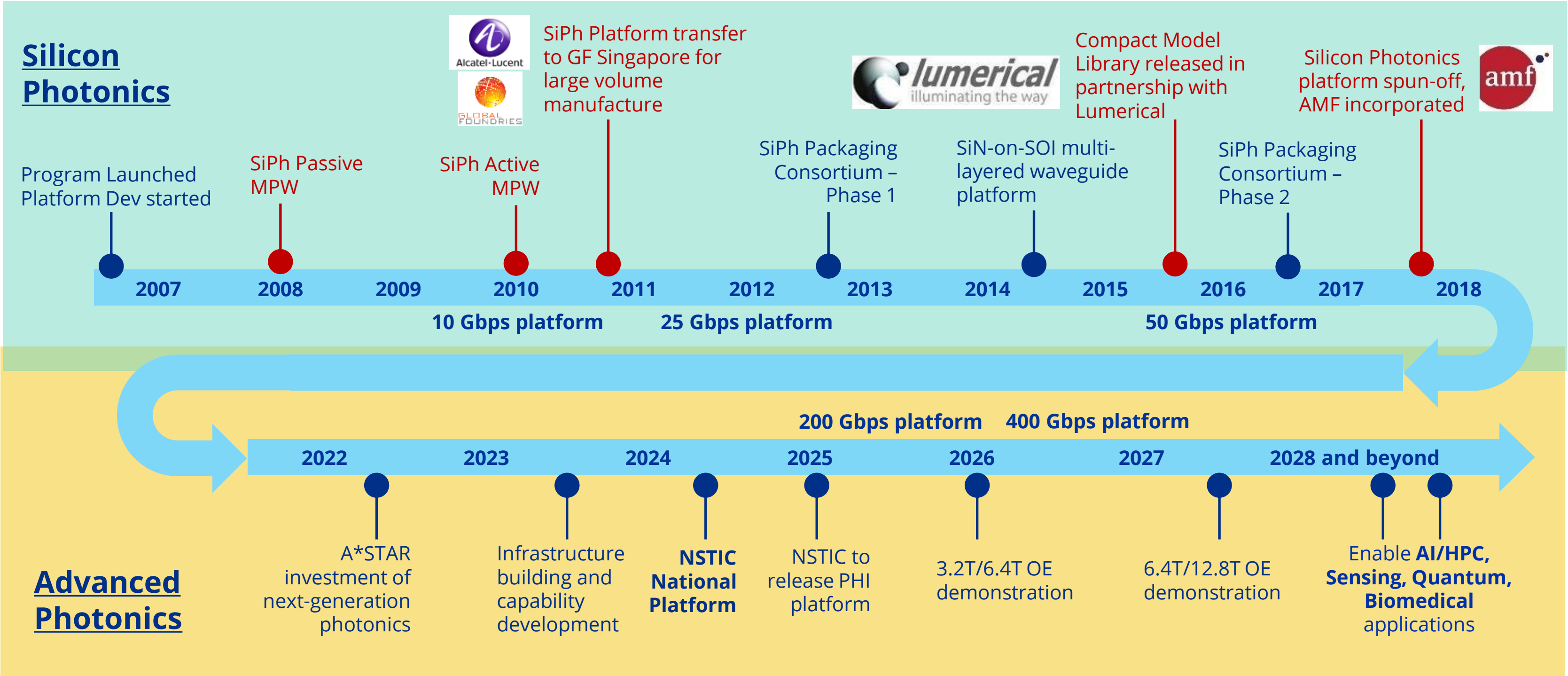
NSTIC
NATIONAL SEMICONDUCTOR TRANSLATION AND INNOVATION CENTRE



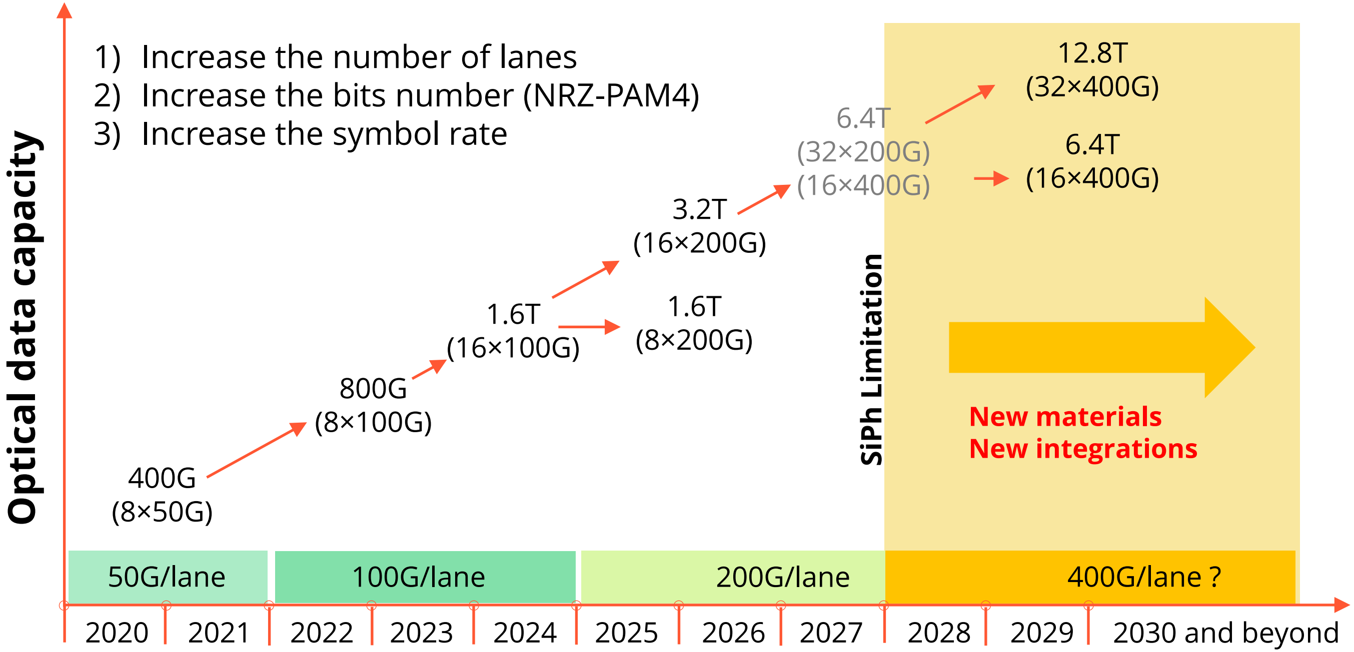
Advanced Photonics

A*STAR Silicon Photonics — Past, Present, and Path Forward



Continuous efforts pushing photonics technology enabling industry partners and eco-system!

Optical Transceiver Development Roadmap*



* Based on various source of information

Data rate in Silicon Photonics-based transceiver is fundamentally limited by:

a) Modulator: intrinsic tradeoff among modulation speed, modulation efficiency, and optical loss due to the free-carrier dispersion effect.

b) Photodetector: Intrinsically high dark current and low bandwidth due to the Ge quality.

Photonics Heterogeneous Integration (PHI)

– Disruptive technology to lead next-generation silicon photonics market

New material is the MUST for 400G/lane technology

Silicon CMOS manufacturability is the key for low-cost product

→ Photonics Heterogenous Integration

Key Issue to address:

The bottleneck of currently silicon photonics technology due to material limitation

Key Research Areas:

a) To **develop PHI technology** through D2W bonding technical with scalability and manufacturability
b) To **explore and develop various new materials** (barium titanate, BTO) based high-performance devices
c) Co-packaged optics (CPO) through 3D EIC and PHI integration

Target:

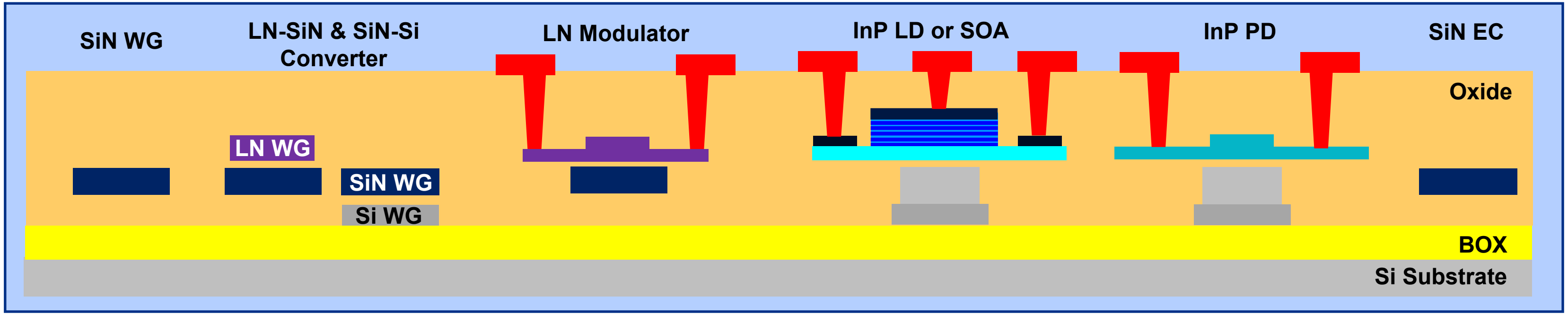
a) To develop 400G/lane PIC technology and lead the market
b) To develop CPO technology targeting AI/ML application

Photonic Heterogeneous Integration Platform

– Enhancing all functionalities on SiPh platform

Next-Generation Photonic Heterogeneous Integration via die-to-wafer bonding

1) Silicon serves as the substrate for manufacturability with low-loss Si / SiN / AlN waveguide for light routing.
2) Best-in-class optical functional materials for active devices
   a) III/V gain material for LD or SOA, while III/V PIN diode for high-speed photodetector
   b) Various Pockels effect materials (ScAlN, LN, BTO, etc) for extremely high-speed modulators
   c) Other materials for different applications (OM materials for isolator or circulator)

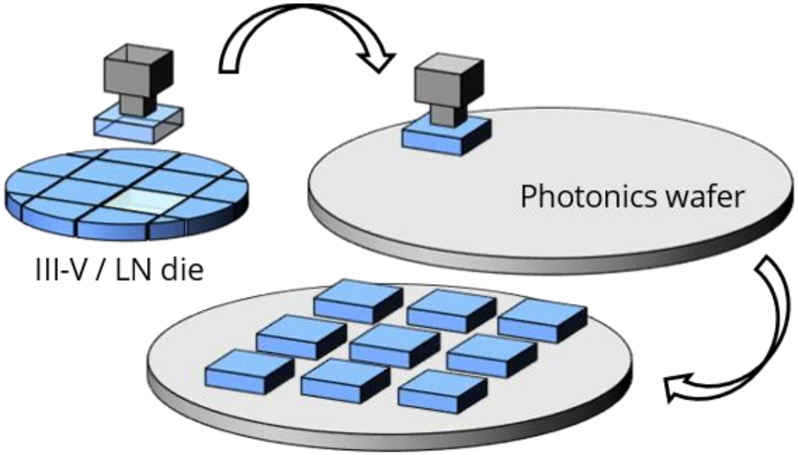


Die-to-Wafer Bonding Process

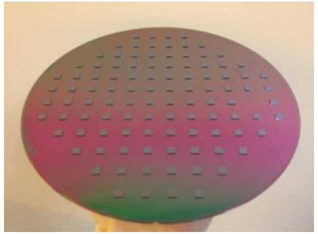
Developed using high-throughput pick-and-place bonding

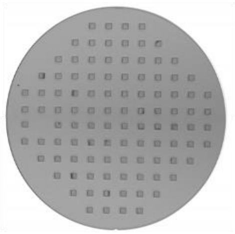
1) **Flexibility**: bond dies of different materials onto the same wafer
2) **Scalability**: scalable for both 8-inch and 12-inch wafers
3) **Manufacturability**: post-bond wafer-level (InP & LN) fabrication via CMOS process
4) **Cost-effectiveness**: Use III-V & LN only where needed; minimize material wastage

Pick-and-place bonding

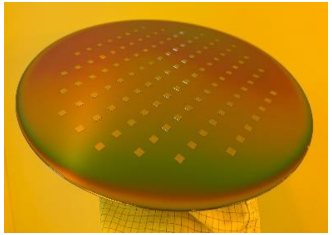


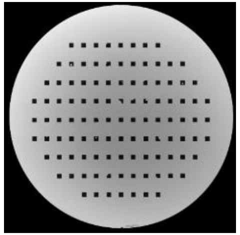
InP on Si





Lithium Tantalate on Si





Advanced Opto-Electrical Testing Capability

– Fully equipped for over 200G/lane data communication testing

FormFactor Summit200 Wafer Level Tester

- Semi-auto 8” wafer-level test
- Motorized piezo-based optical probes for automatic fiber alignment
- RF probes (up to 110 GHz) and DC probes for OE device
- Temperature from -40 to 125 °C

Keysight Lightwave Component Analyzer

- 110 GHz transmitter module at 1310 and 1550 nm for photodetector test
- 110 GHz receiver module 1260 – 1620 nm for modulator test

Keysight Arbitrary Waveform Generator

- Analog bandwidth of 65 GHz
- 2 channels at 128 GSa/s (upgrade option to 256 GSa/s)
- Used for serial data generation for NRZ/PAM-4/PAM-8

Keysight Real-time Oscilloscope

- 70 GHz frontend analog bandwidth (software upgradable to 110 GHz)
- 256 GSa/s sampling rate
- Calibrated receiver up to 65 GHz for transmitter module testing

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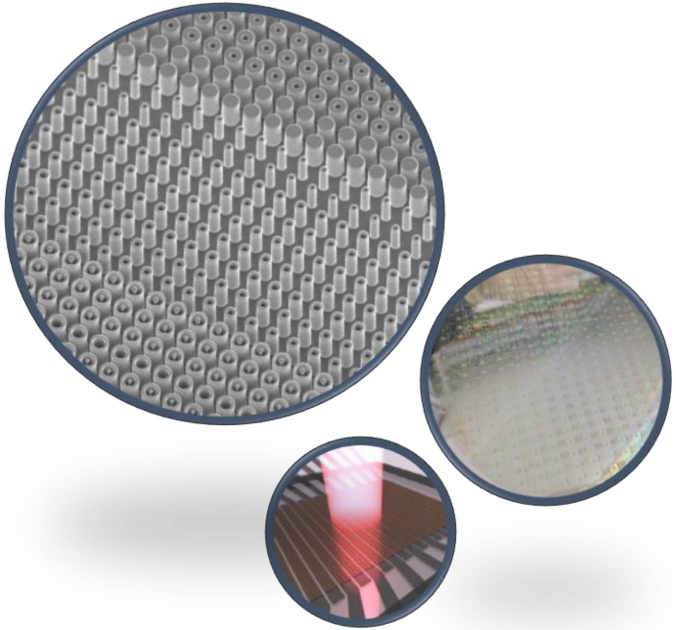
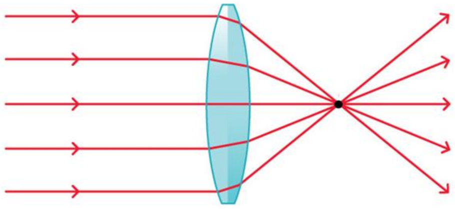
Flat Optics



Flat Optics: A shift in the optics paradigm

From traditional optical elements…

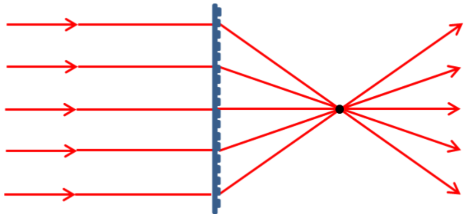
size >> wavelength



They rely on small, cumulative changes induced by propagation.

…to flat optical elements

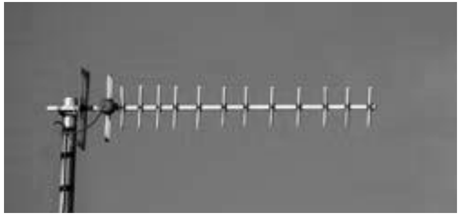
size < wavelength



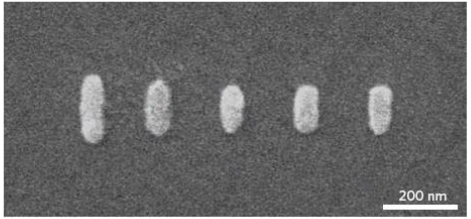
They rely on large, abrupt changes induced by **nanoantennas**.

The nanoantenna concept. Light control at the nanoscale for **extreme miniaturization:**

From GHz…



…to light



Nanoantennas allow efficient manipulation of light on sub-wavelength (nanometre) scales!

CREATING GROWTH, ENHANCING LIVES

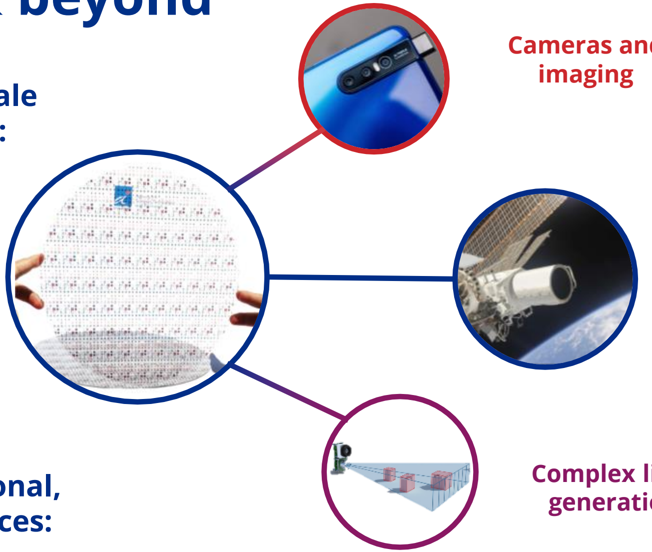
Flat Optics: Wafer-scale optics & beyond

CREATING GROWTH, ENHANCING LIVES

From polishing and assembly…

…to wafer-scale fabrication:

12” flat optics wafer produced by IME

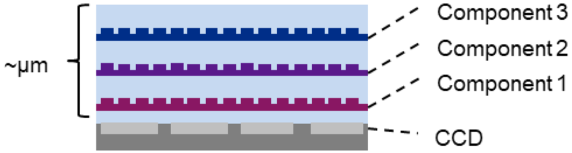


Cameras and imaging

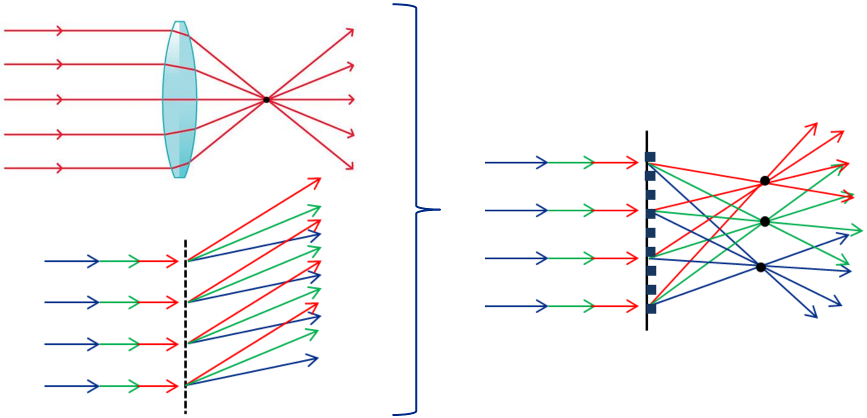
Technical tools

Complex light generation

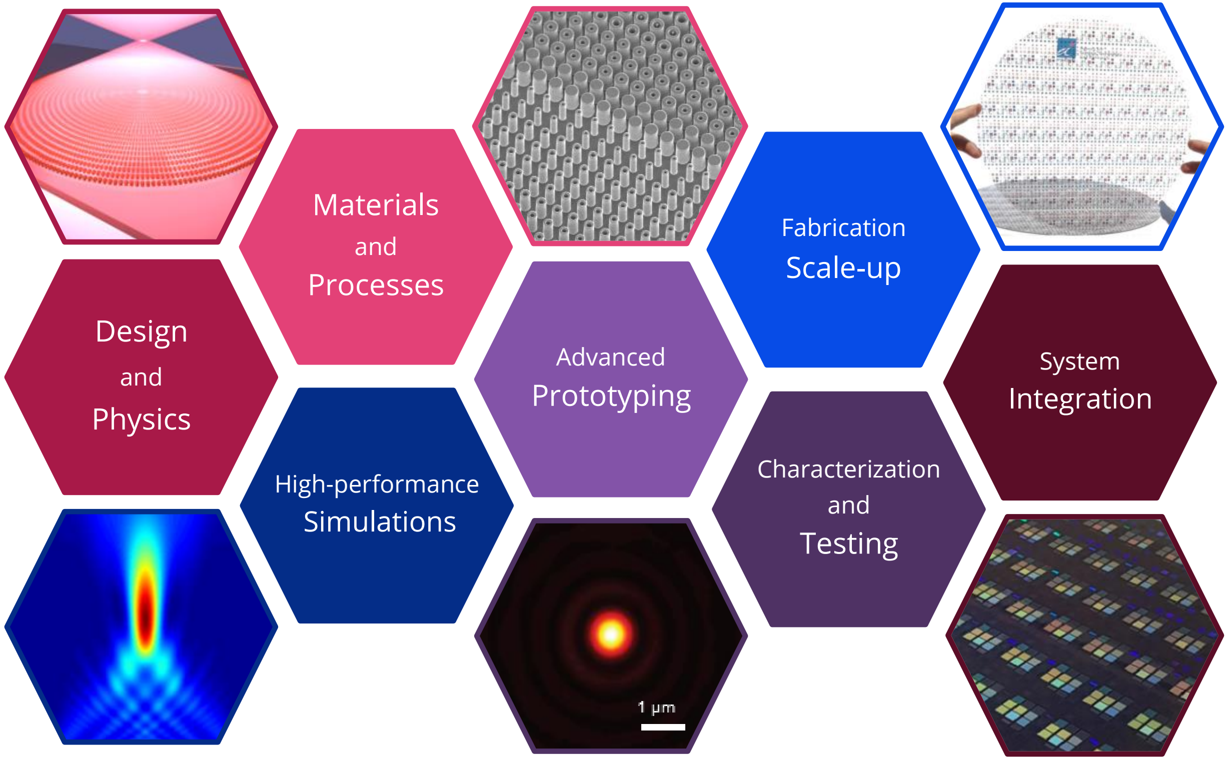
…to monolithic integration:



…to multi-functional, single-layer devices:



Our Capabilities in Flat Optics



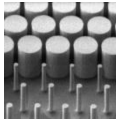
>50 patent applications/know-hows filed

>100 papers published (incl. high-impact journals: Science, Nature Photon, Nature Nanotech, etc.)

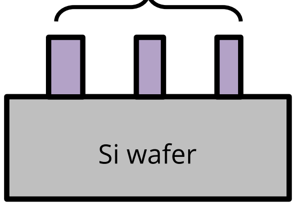
CREATING GROWTH, ENHANCING LIVES

Our Platform Technologies in Flat Optics

8"/12" Silicon wafer patterning

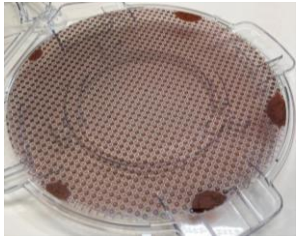
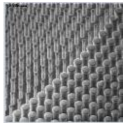
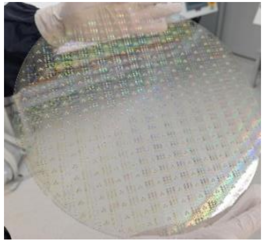
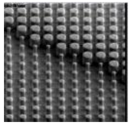



a-Si Metalens

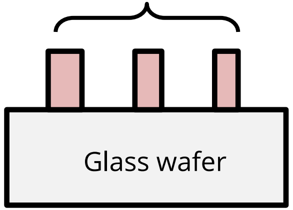


Far/Mid-infrared spectrum
(3-10μm)

12" Glass wafer patterning

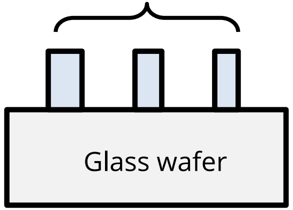






a-Si Metalens



Near Infrared spectrum
(940nm-2500nm)

SiN/TiO_2 Metalens

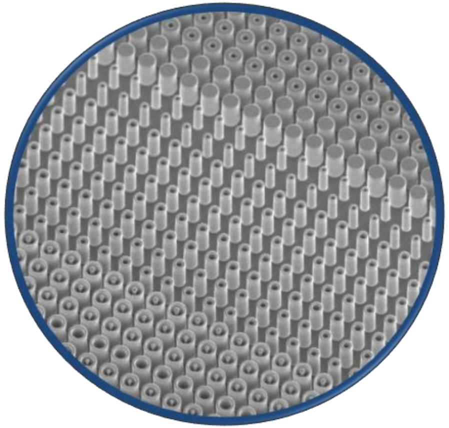


Visible spectrum
(400nm-700nm)

In development: Multilayer processing – multiple layers of metalenses

Technology showcase

Beyond what traditional optical components can do

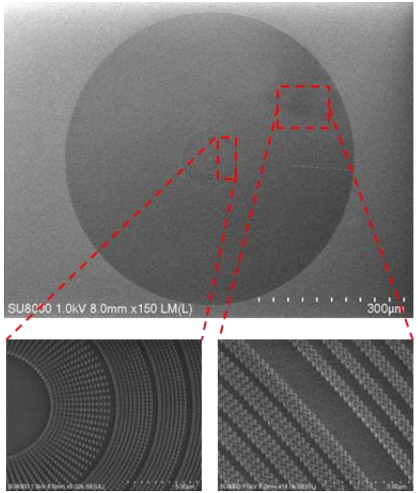


Technology showcase I: Metalens with NA>0.99

Numerical aperture (NA): Defines the resolution of a lens, how tightly can focus light and the maximum collection angle from a point source at its focus:

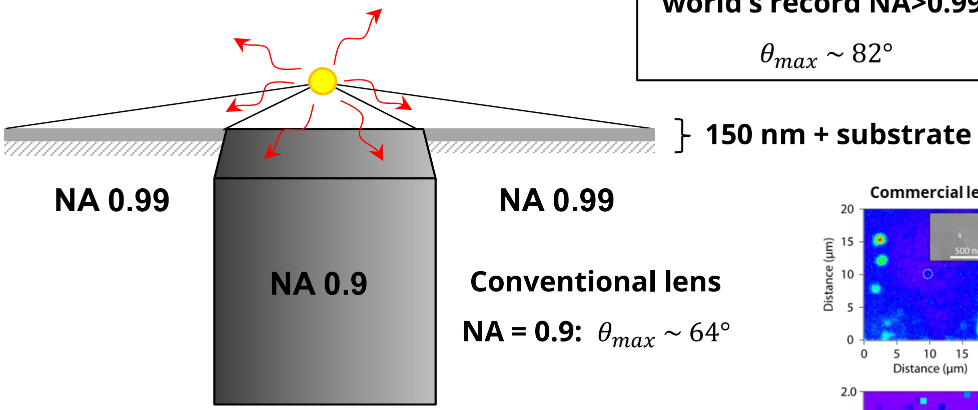
$$NA = \sin(\theta_{max})$$

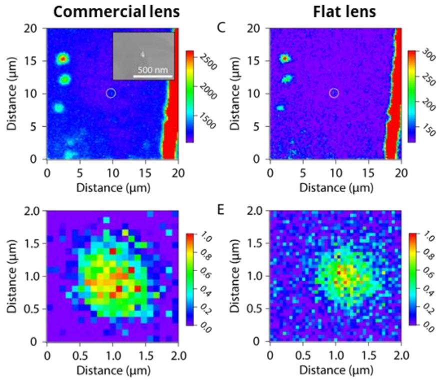
$$\Delta x \sim \lambda / 2NA$$



Flat lenses with world's record NA>0.99:

$\theta_{max} \sim 82°$



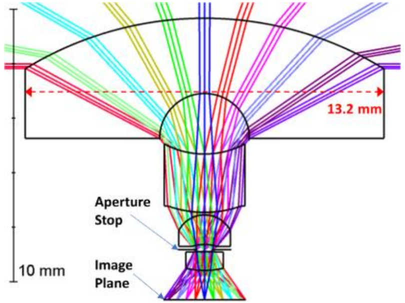


Nano Letters 18, 2124 (2018), US 11204452 B2

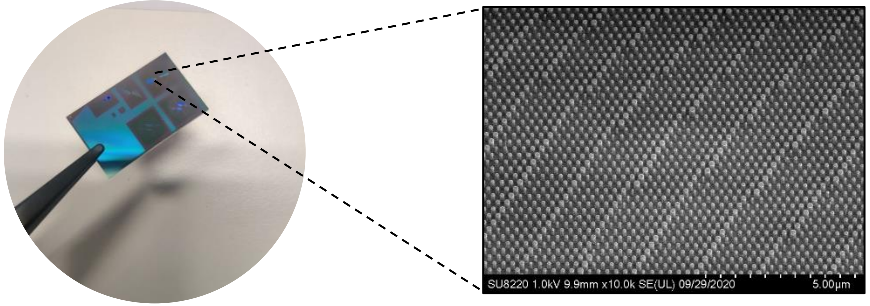
Technology showcase II: Full-FOV metalens

Nikon FC-E8
(© J. Aasland)

Captured with Meikes fisheye lens
(https://www.diyphotography.net)



Repr. from J. of Photonics for Energy, 8(3), 035501 (2018)



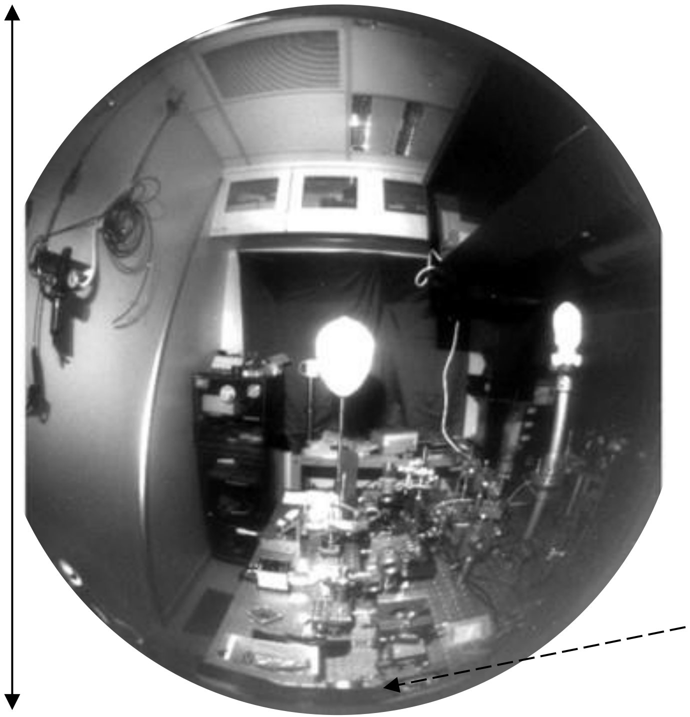
Wide-FOV metalens

ACS Photonics 8, 1457 (2021)

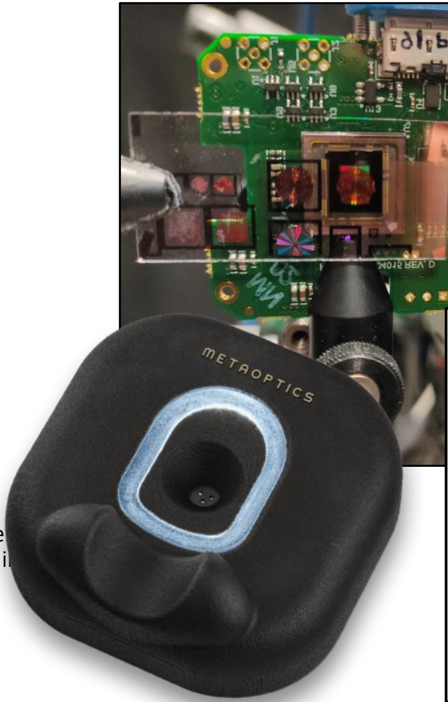
Technology showcase II: Full-FOV metalens

Full FOV

~180 degrees



Wide-FOV camera prototype
(5mm lens + 5mm x 4mm sensor)



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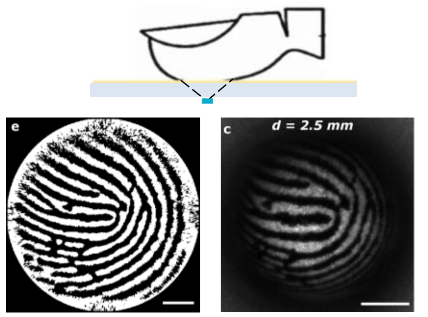
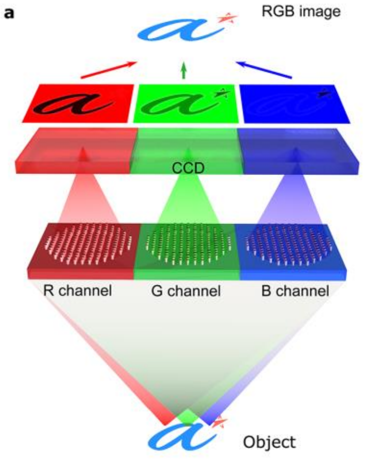
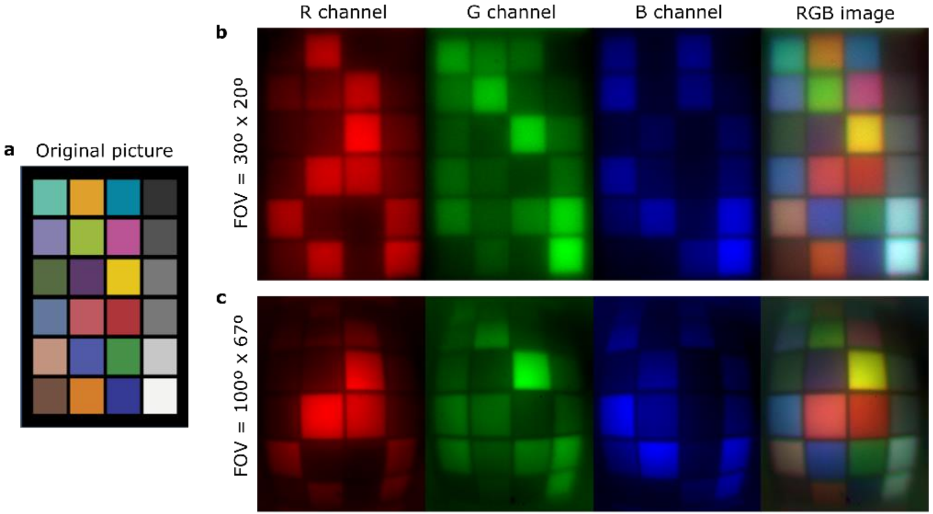
Fingerprint module (<0.5mm lens)

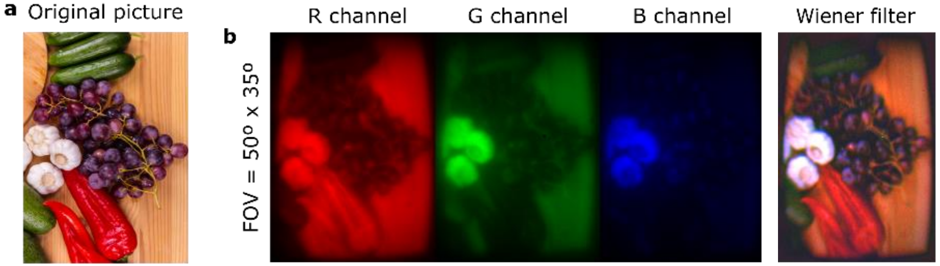


ACS Photonics 8, 1457 (2021)

Technology showcase III: RGB metalens camera module







Laser & Photon Rev 18, 2300553 (2024)

PCT/SG2022/050485

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