Nano-Optoelectronic Integrated System Engineering

Arka Majumdar

Assistant Professor, Electrical Engineering and Physics

University of Washington, Seattle

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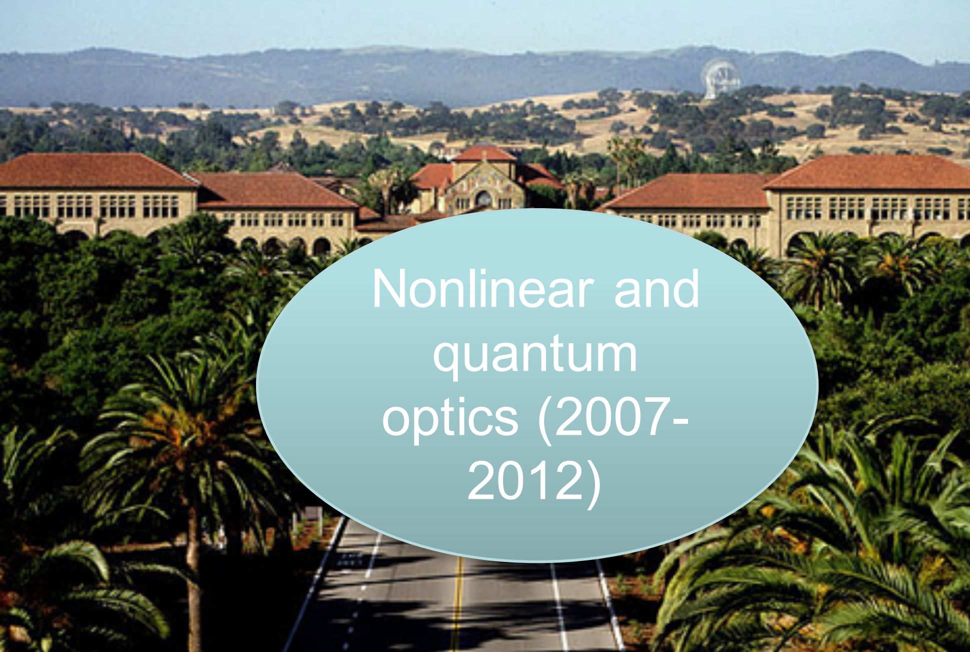
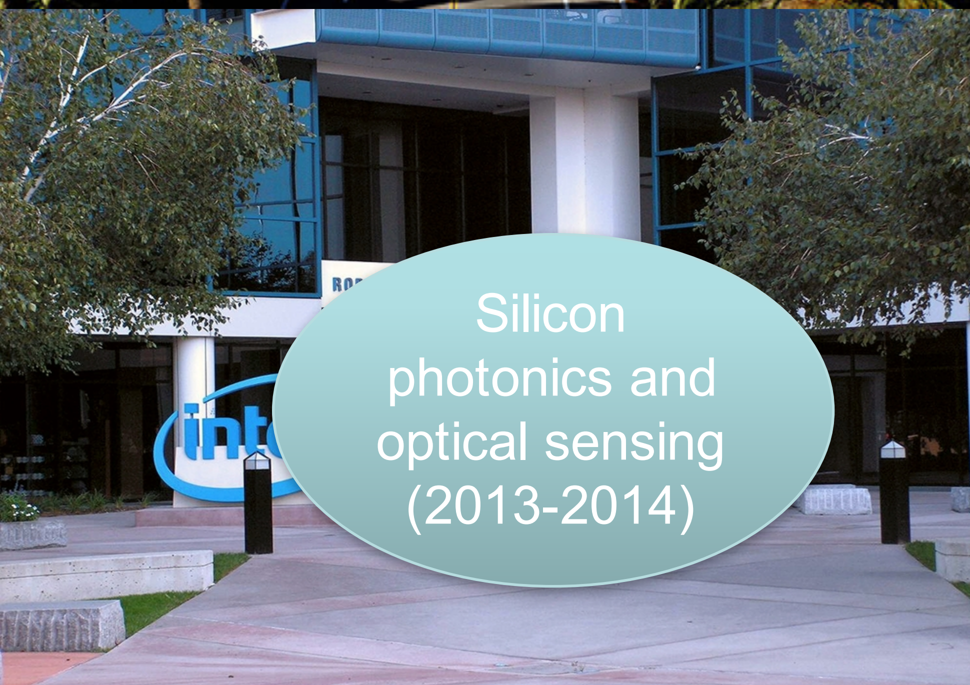
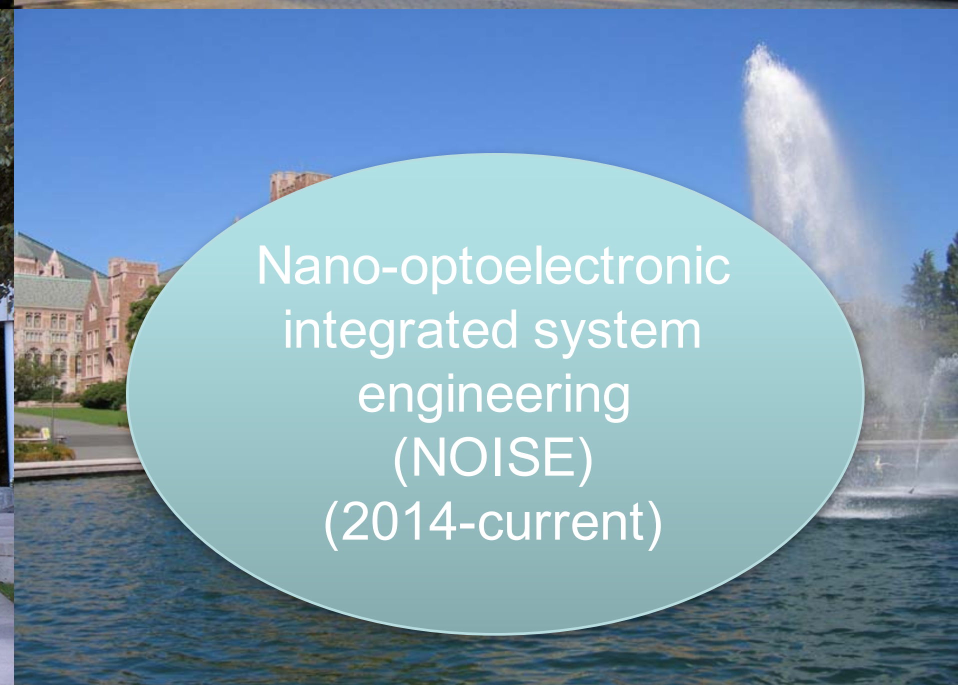


Nonlinear and quantum optics (2007-2012)

New materials: Monolayer material (2012-2013)



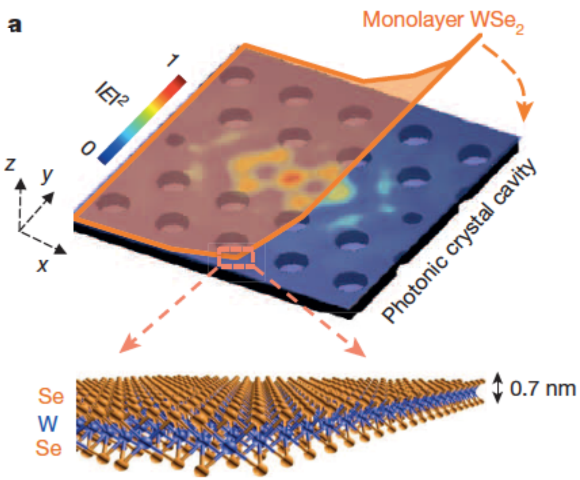
Silicon photonics and optical sensing (2013-2014)



Nano-optoelectronic integrated system engineering (NOISE) (2014-current)

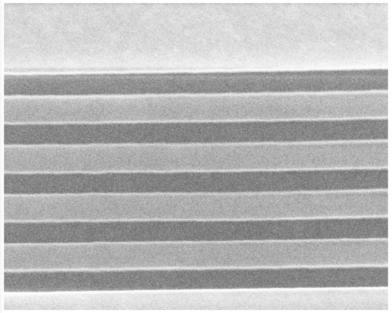
NOISE: Nano-Optoelectronic Integrated System Engineering Lab

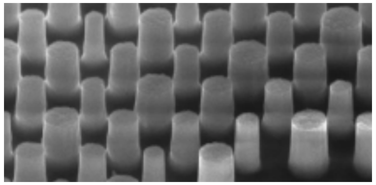
HySiP: Hybrid Silicon Photonics



Integrate new materials with new nanophotonic devices to enable energy-efficient, high speed optoelectronic systems.

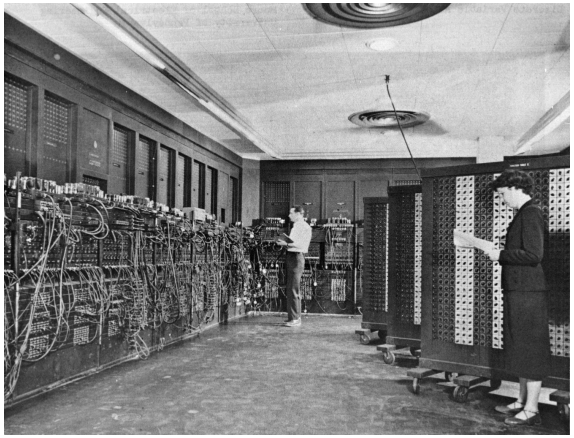
iCOS: Intelligent compact optical sensors





Design new compact optical devices, which uses computation (either in hardware or software) to enable intelligent sensing.

Evolution of computing



Eniac

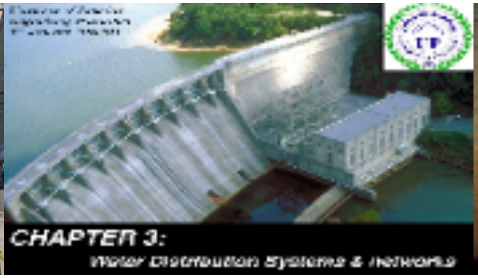
1980 computer

Moore's law (for CMOS transistors) will end!!
Replace CMOS?

Paper Mill

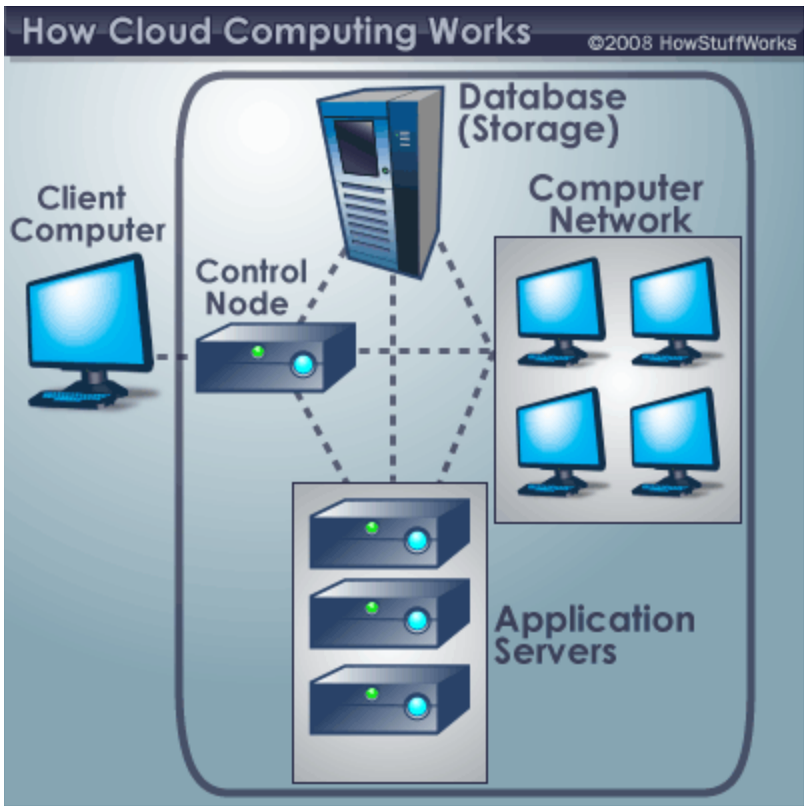
Water Distribution

Electric Grid



Increased connectivity

- Future : cloud computing; parallel computing; ubiquitous computing: more communications
- Massive data centers



More communication channels required.

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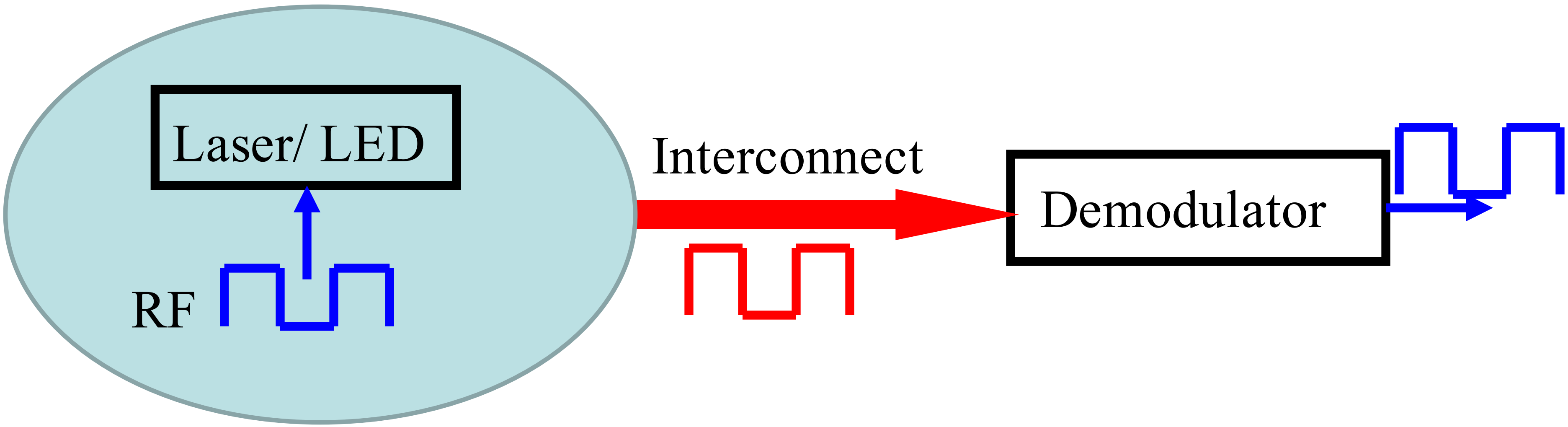
Low power optoelectronics

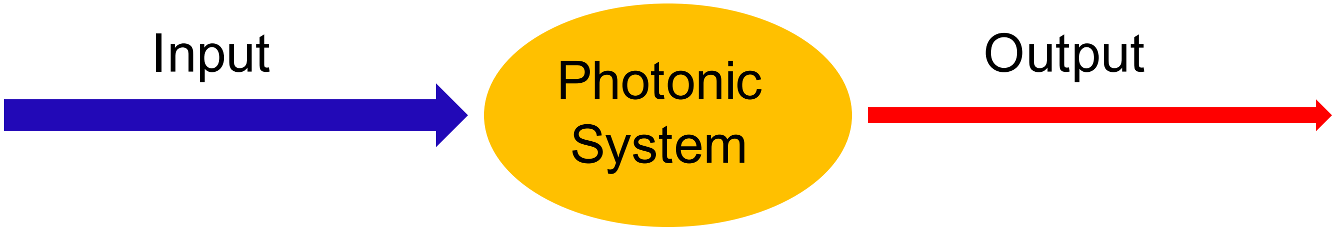
- Switching energy in electronics: 100's of fJ
- Metallic interconnects are lossy at high frequency
- Huge energy consumption: environmental sustainability issue



- Use optical signal along with electronic signal
- Efficient (low energy, fast) modulator and (sensitive, fast) detector
- To bring optics to chip scale: energy required attojoule (~10 photons)

David Miller, Proc. IEEE Special Issue on Silicon Photonics, 2009.

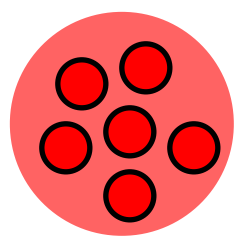
Modulate optical beam & optical computing



Fundamental questions:

- *How do we change amplitude, phase and frequency of light with lower energy, higher speed and smaller size?*
- *How do we increase the photon-photon interaction?*
- *Resonator enhanced nonlinearity and tunability will be key to build these devices.*

photon



Matter

photon

photon

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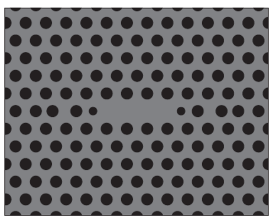
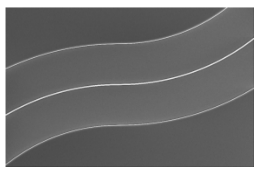
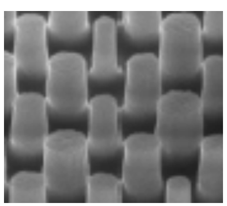
Light-Matter Interaction at Nano-scale

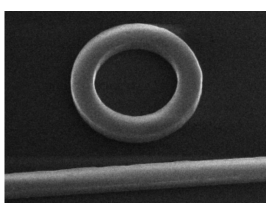
Light

Nanophotonic structures
Strong localization, long storage, light manipulation


Photonic crystal cavity


Waveguide

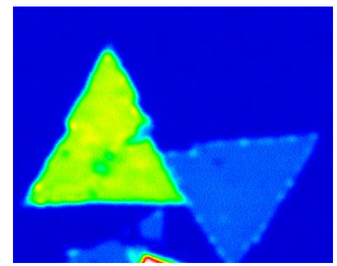

Dielectric metasurface

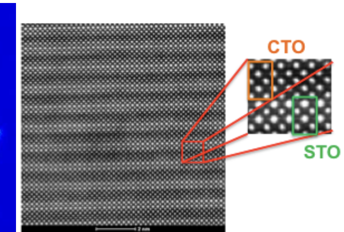

Ring

Low power optoelectronics
- Computing
- Communication
- Sensing

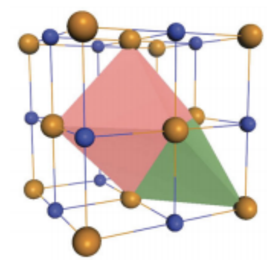
Matter

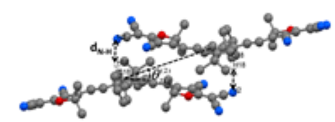
Bulk+ Quantum emitters + 2D materials


Graphene, WSe_2, $MoSe_2$

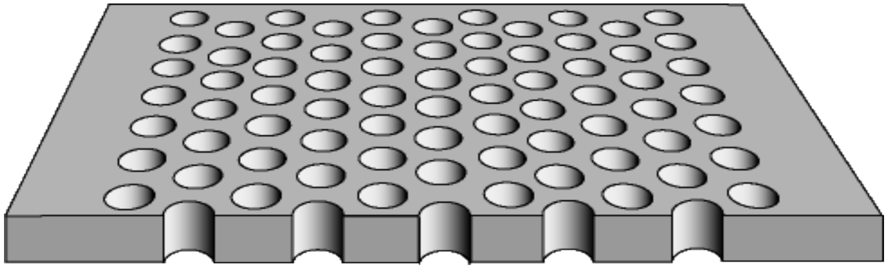


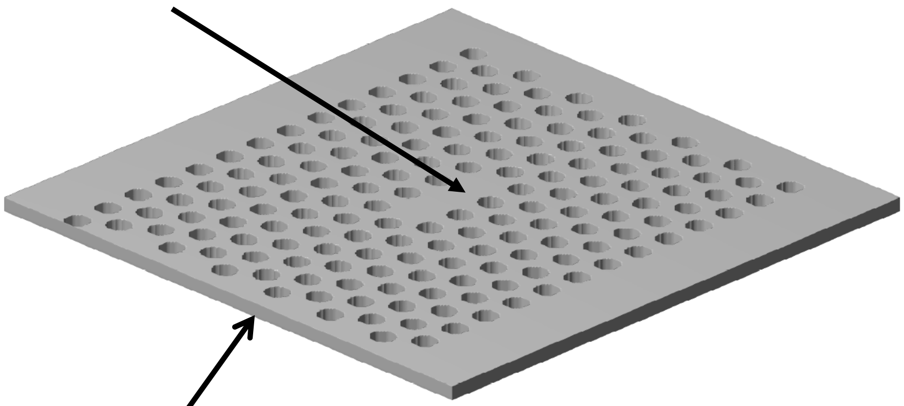
Complex Oxides

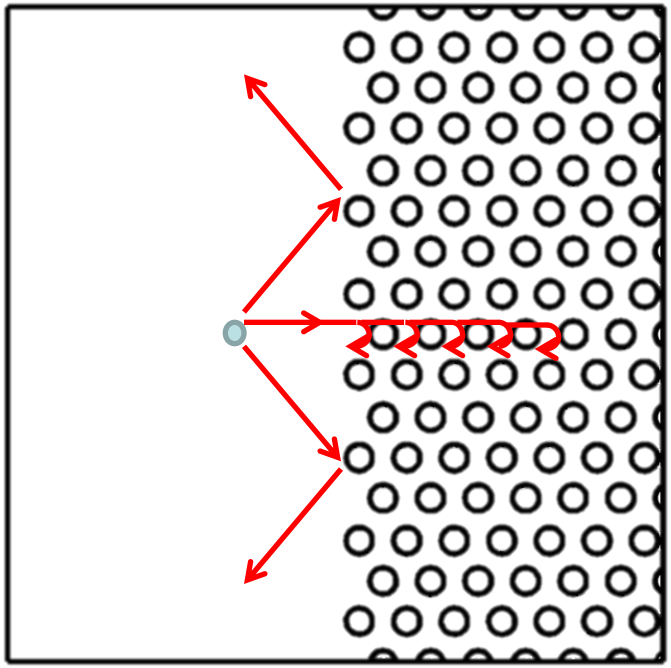

GST


Chromophores

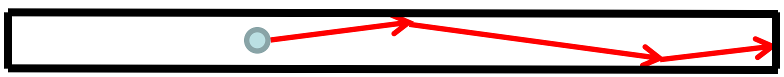
Light: Planar photonic crystals





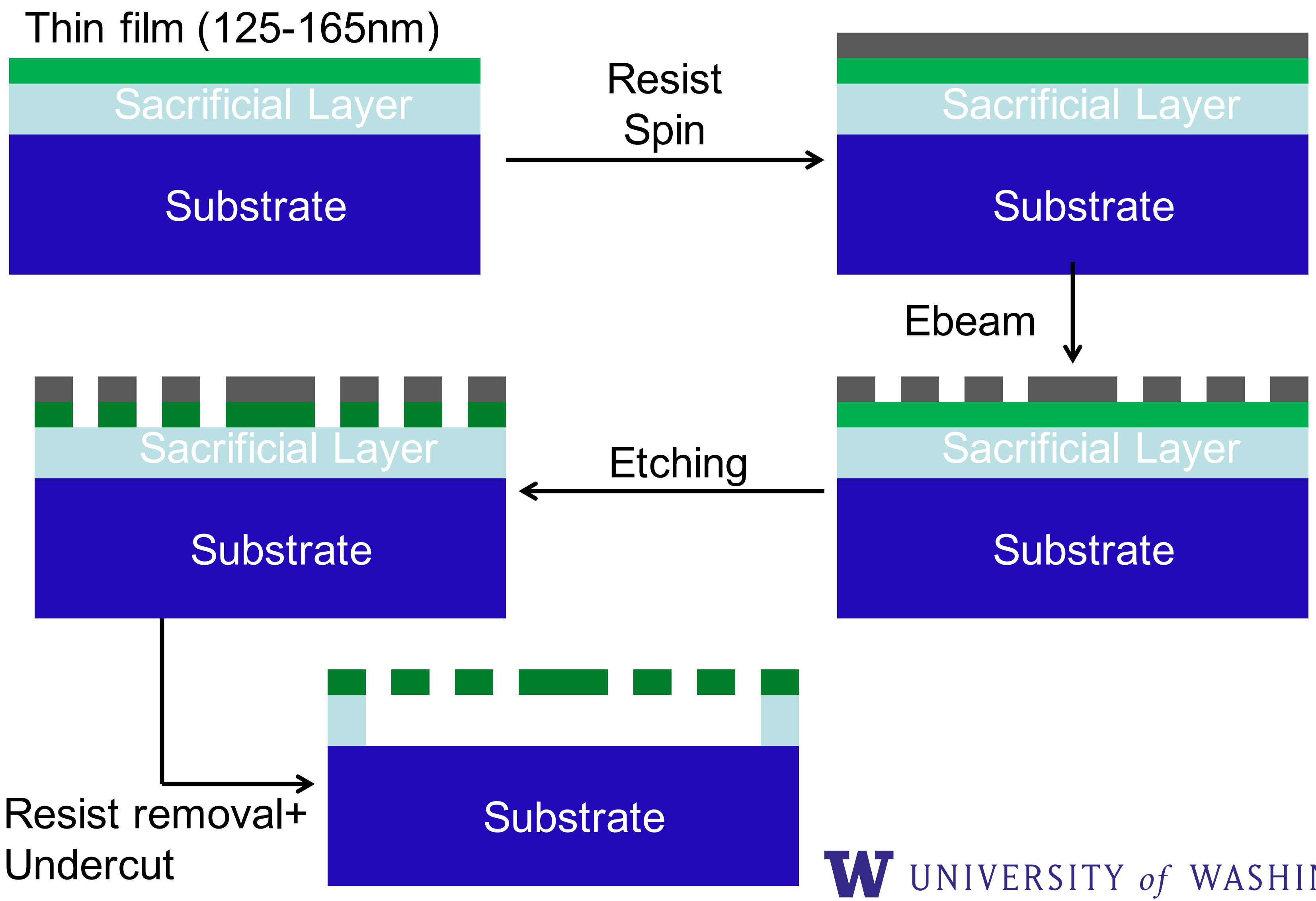


Distributed Bragg Reflection

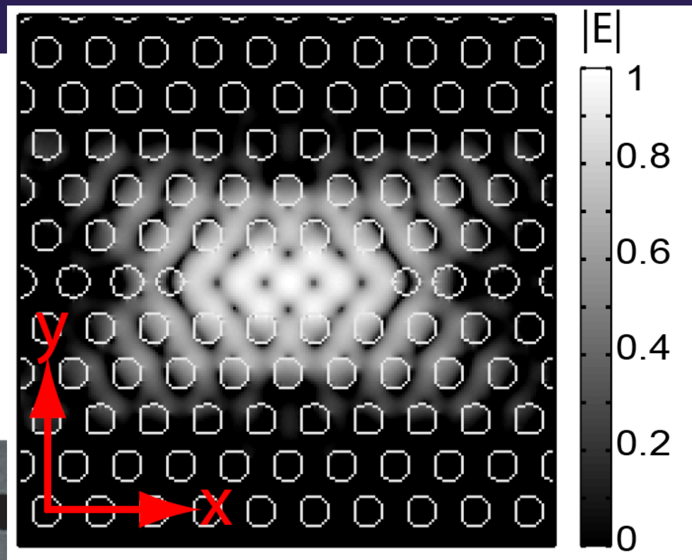


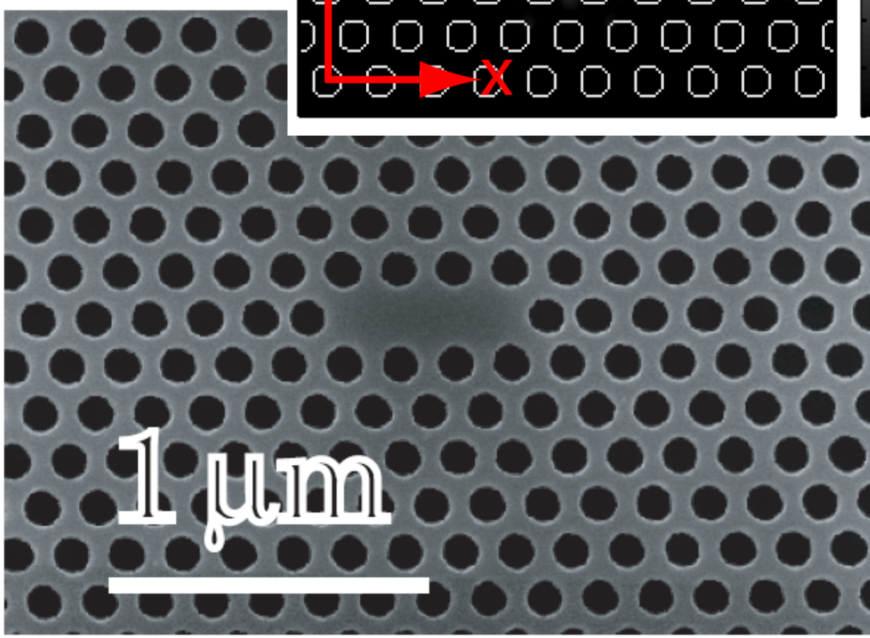
Total Internal Reflection

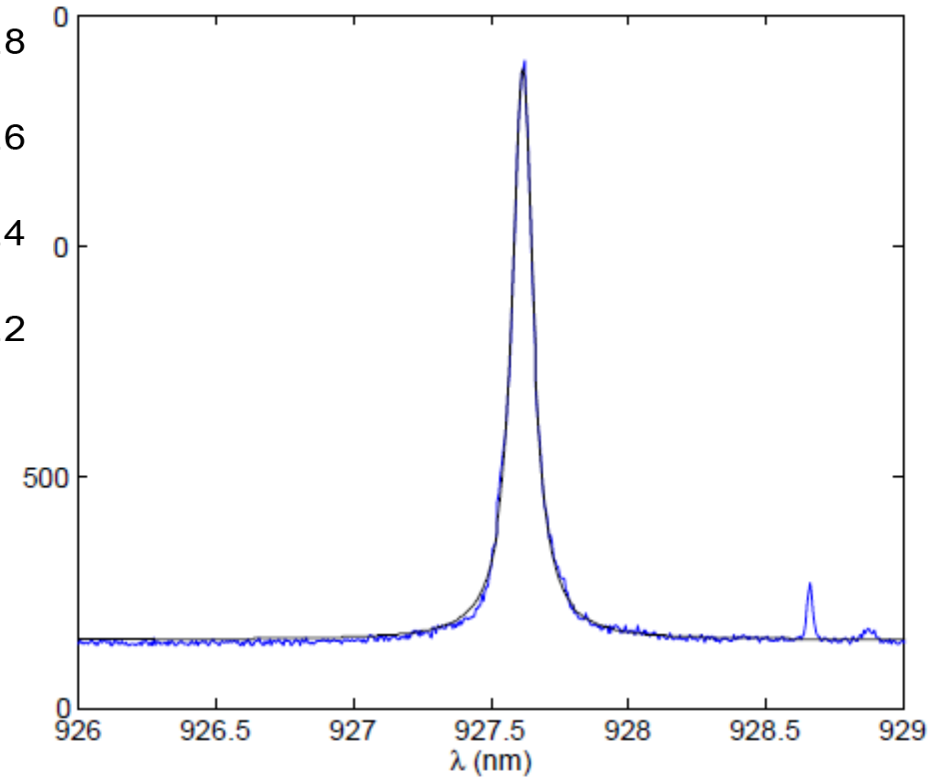
Cavity fabrication



Low mode volume (V) and high quality factor (Q) cavity







Quality Factor: 10000

Maximize Q/V

Confinement volume: 0.7 $(\lambda/n)^3$

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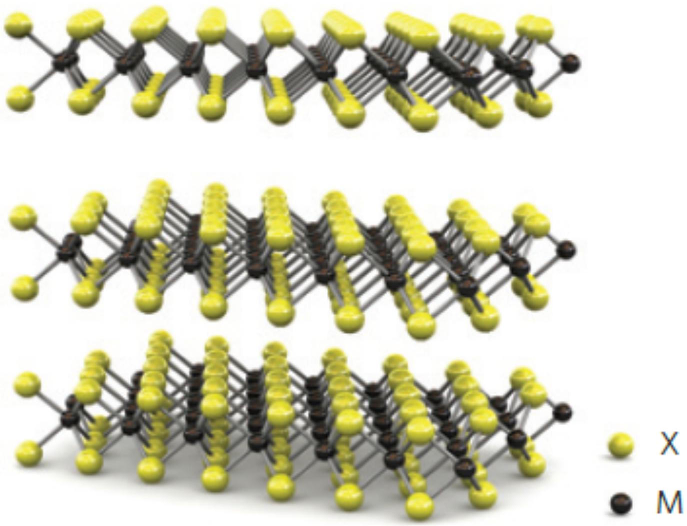
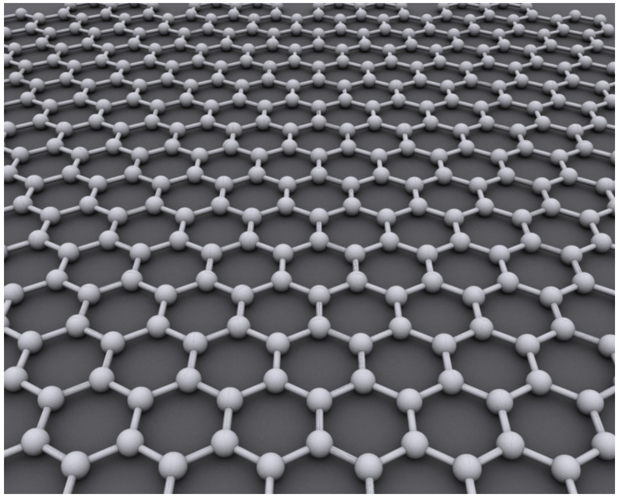
2D material?

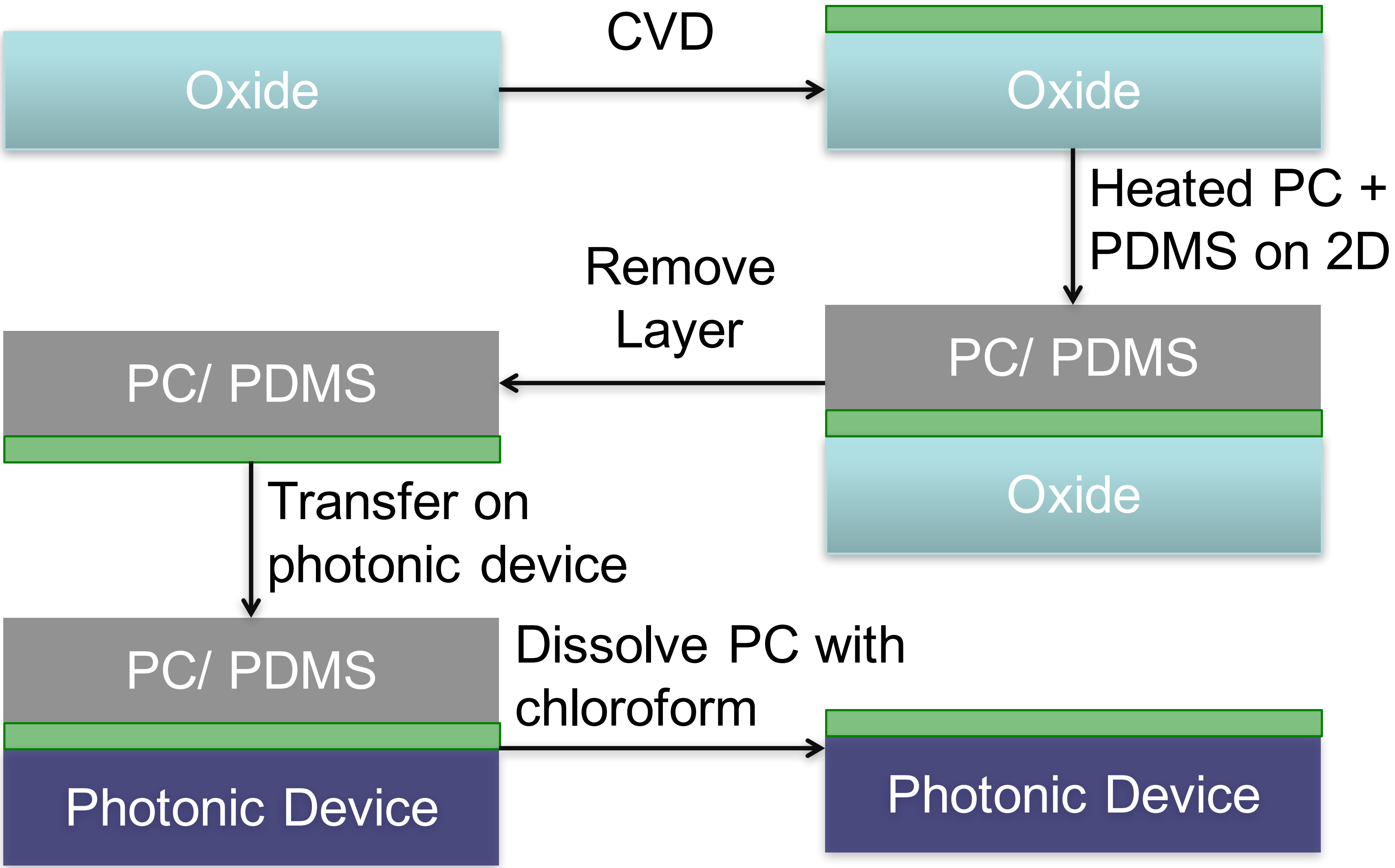


Nature nanotechnology, 7, 699, 2012

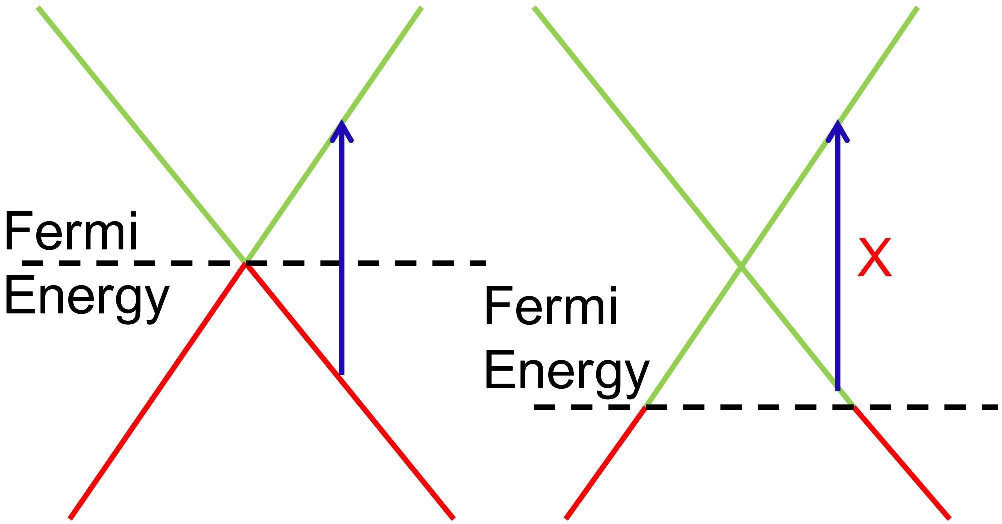


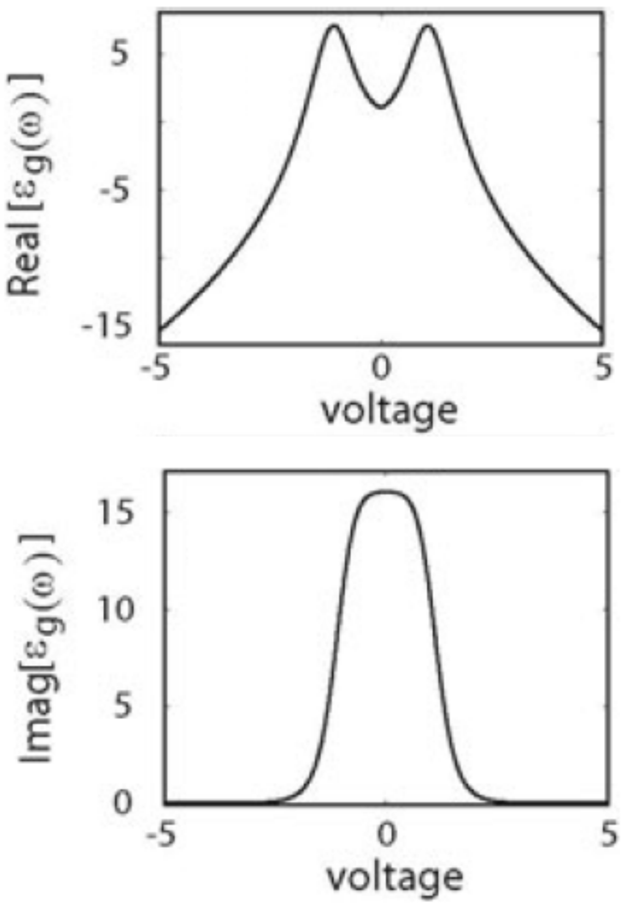
- Low control energy
- Enable quantum well like functionality.
- No lattice matching.
- Can be transferred on any material system.
- The thinness of the material is ideal for evanescent coupling.
- Unique and advantageous properties
  - Graphene - extremely high carrier mobility
  - Transition metal dichalcogenides - strong emission

2D material transfer



Electro-optics with graphene





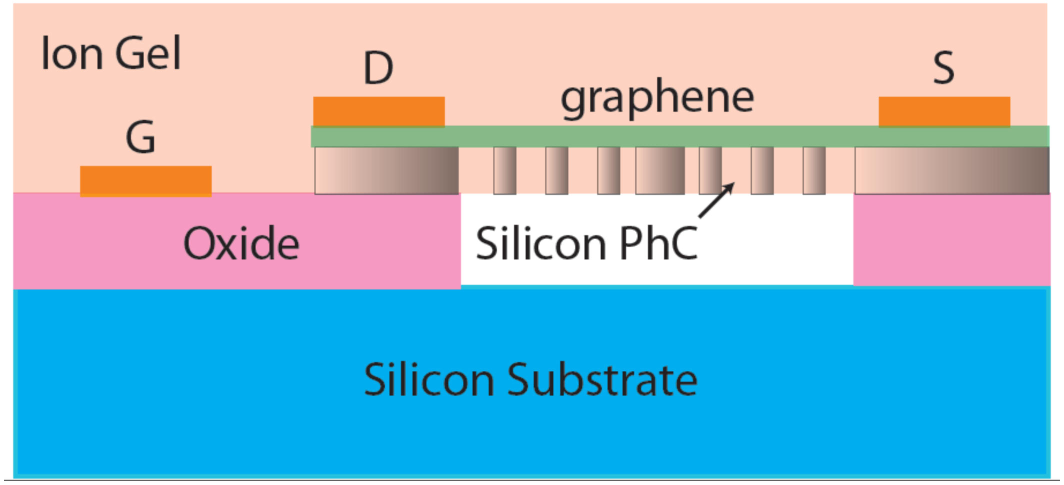
Properties of graphene:

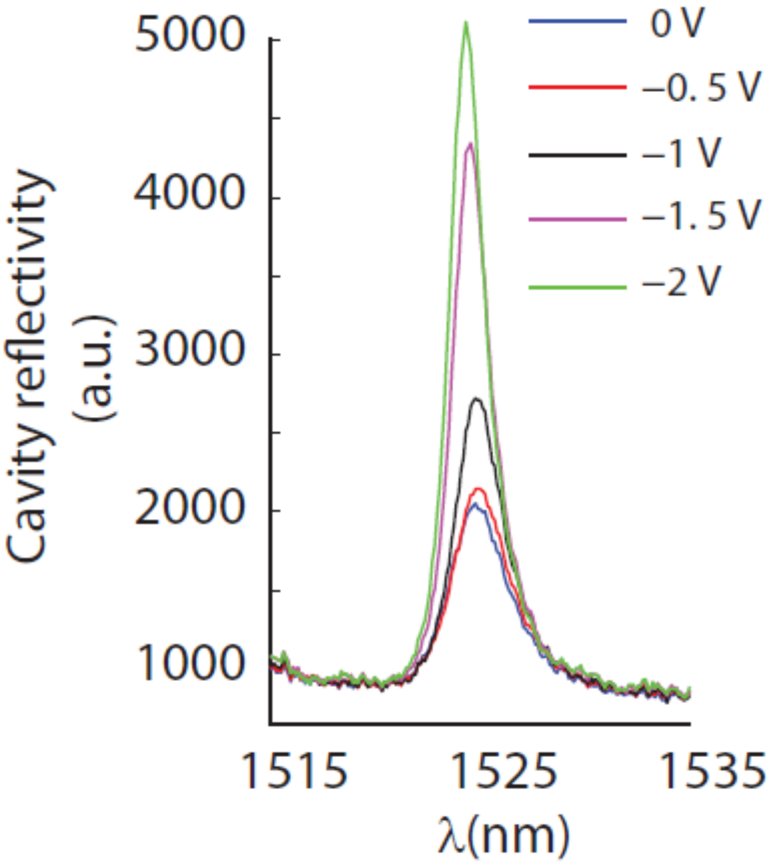
- High carrier mobility.
- Large broadband absorption.
- Ease of electrical control.

Large fractional change in refractive index

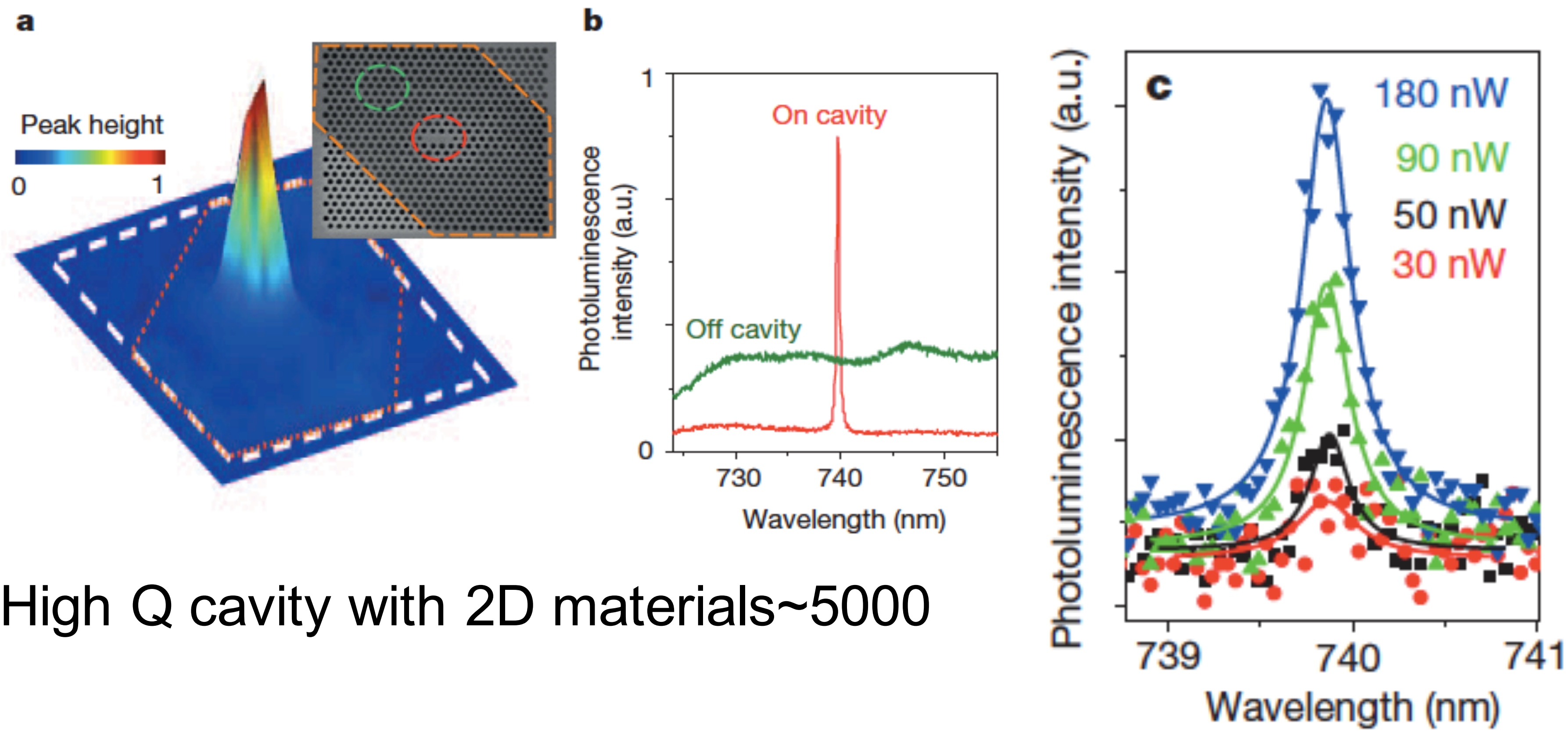
- Electro-optic modulation
- Optical beam steering
- Reflective display
- Solid-state spatial light modulator

Electrical Control of graphene-SOI cavity



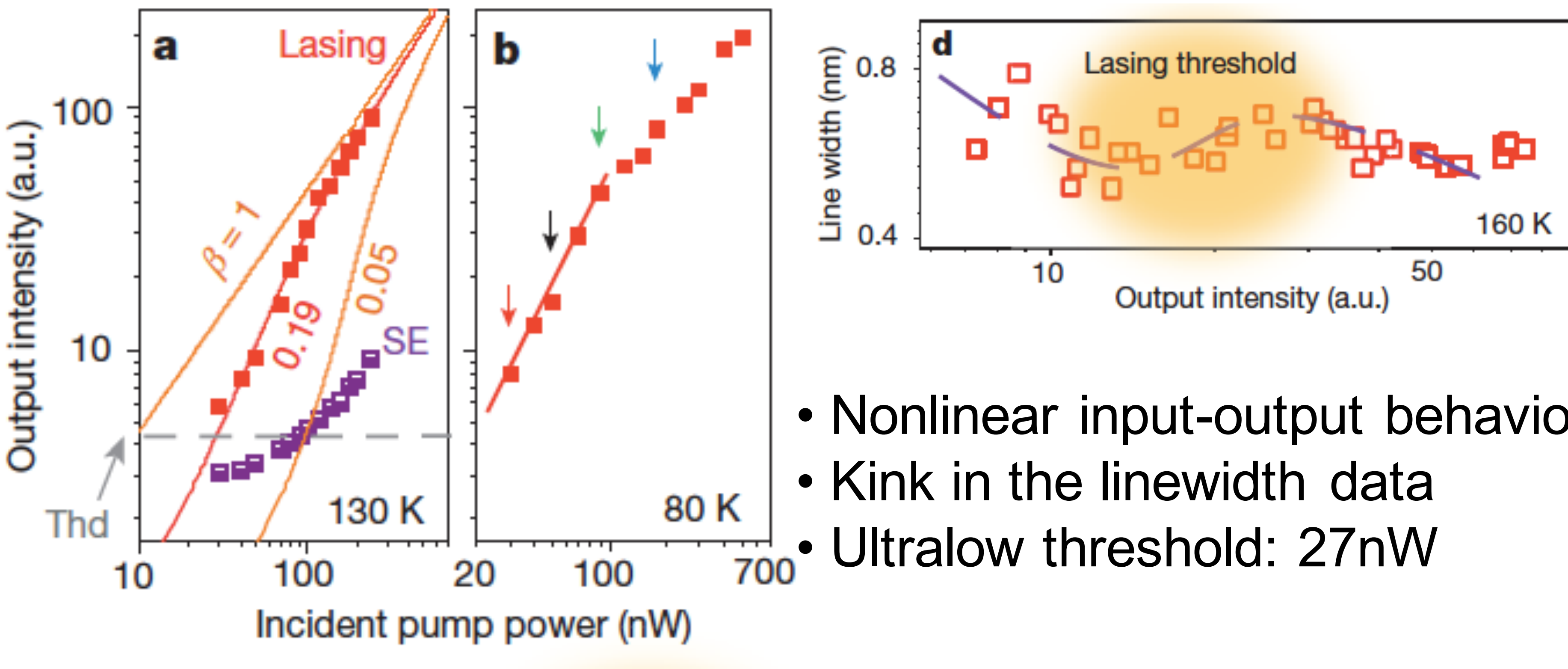


Transition metal dichalcogenides on GaP cavity



High Q cavity with 2D materials~5000

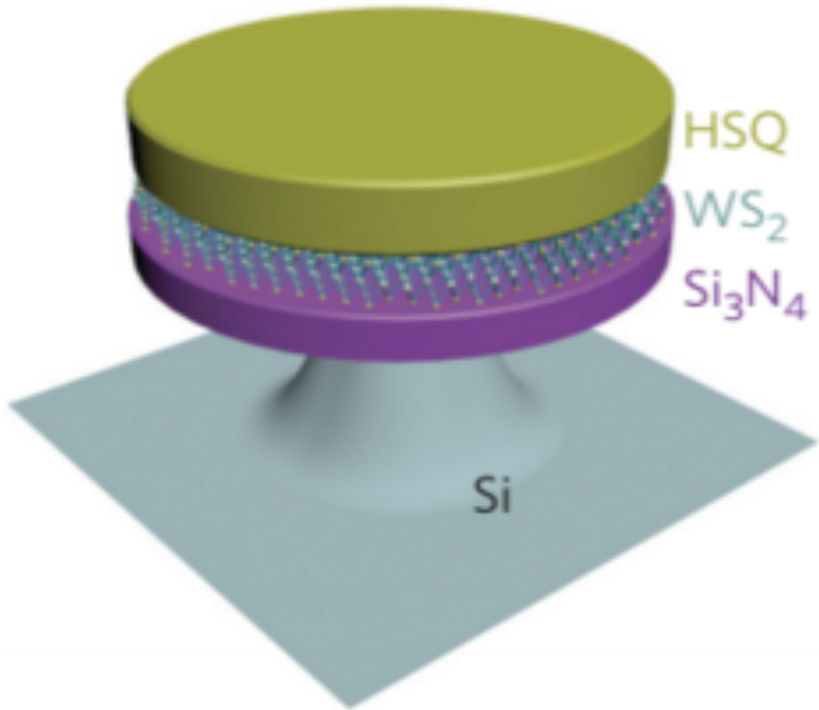
Optically pumped laser



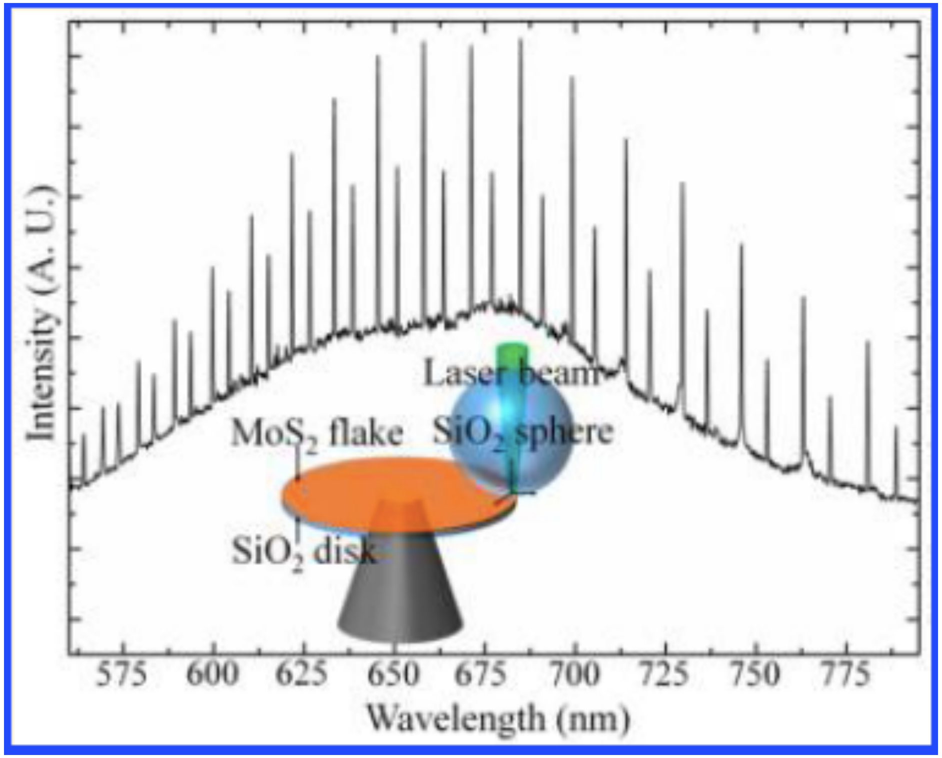
- Nonlinear input-output behavior
- Kink in the linewidth data
- Ultralow threshold: 27nW

Sanfeng Wu et. al., Nature, 2015

Other reported optically pumped lasers

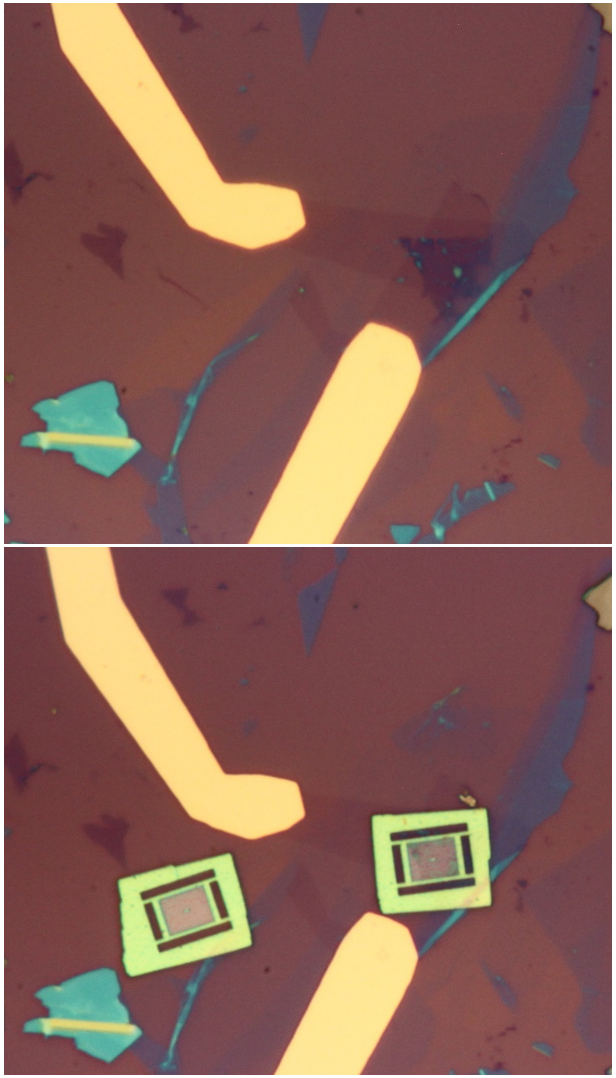


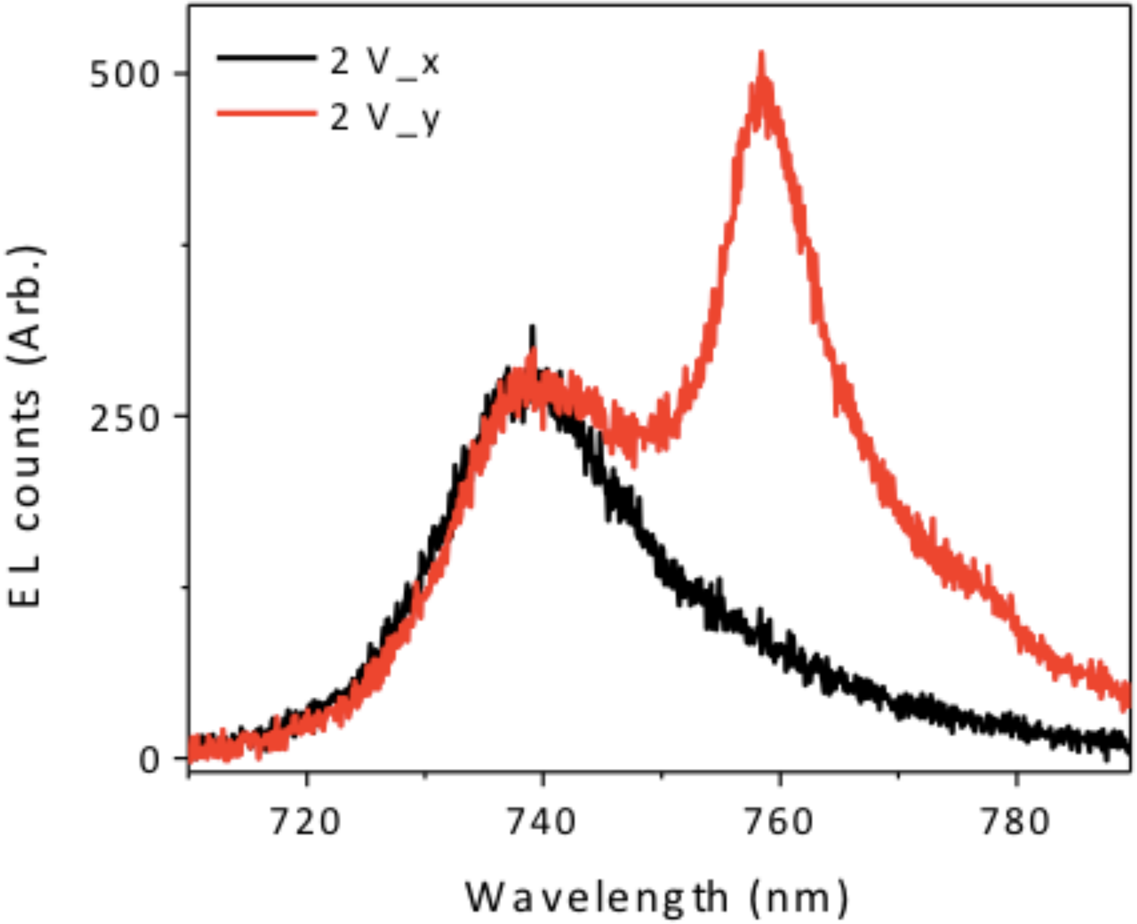
Xiang Zhang, Nature Photonics, 2015



Omid Salehzadeh, Nano Letters, 2015

Electrically pumped device

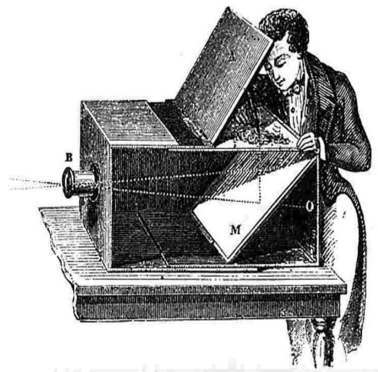




Modulation at 1MHz is also observed

Majumdar & Xu, in preparation

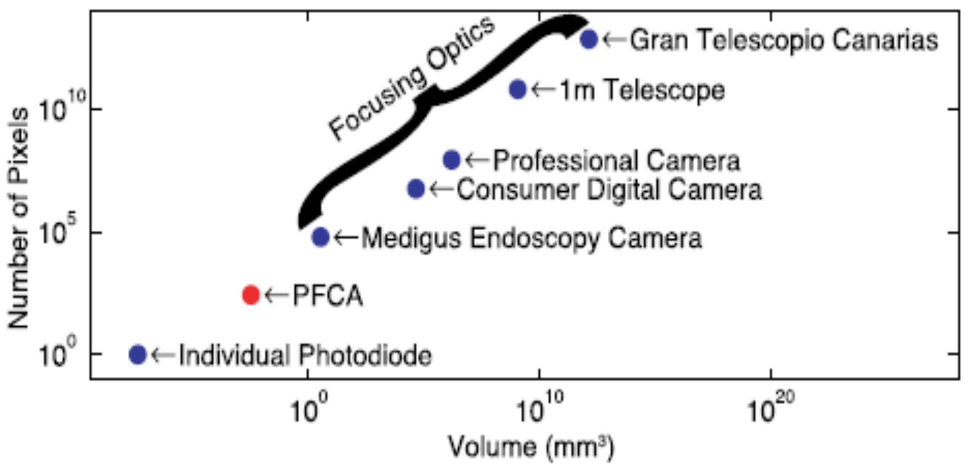
Compact Optical Sensor

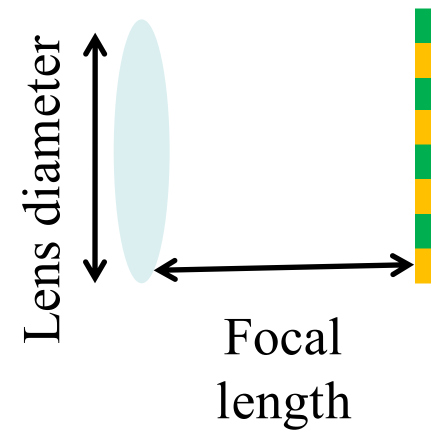

Old camera


Mobile camera

?

IoT

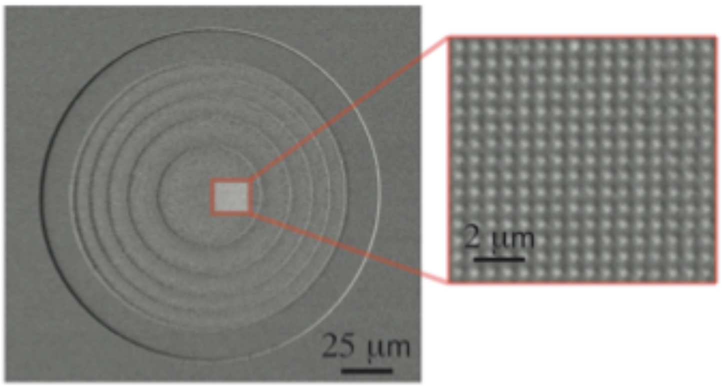




- Volume of a camera is fundamentally limited by a lens
- A compact short focal length is difficult to make

iCOS: Two innovations

Flat efficient optical elements and systems

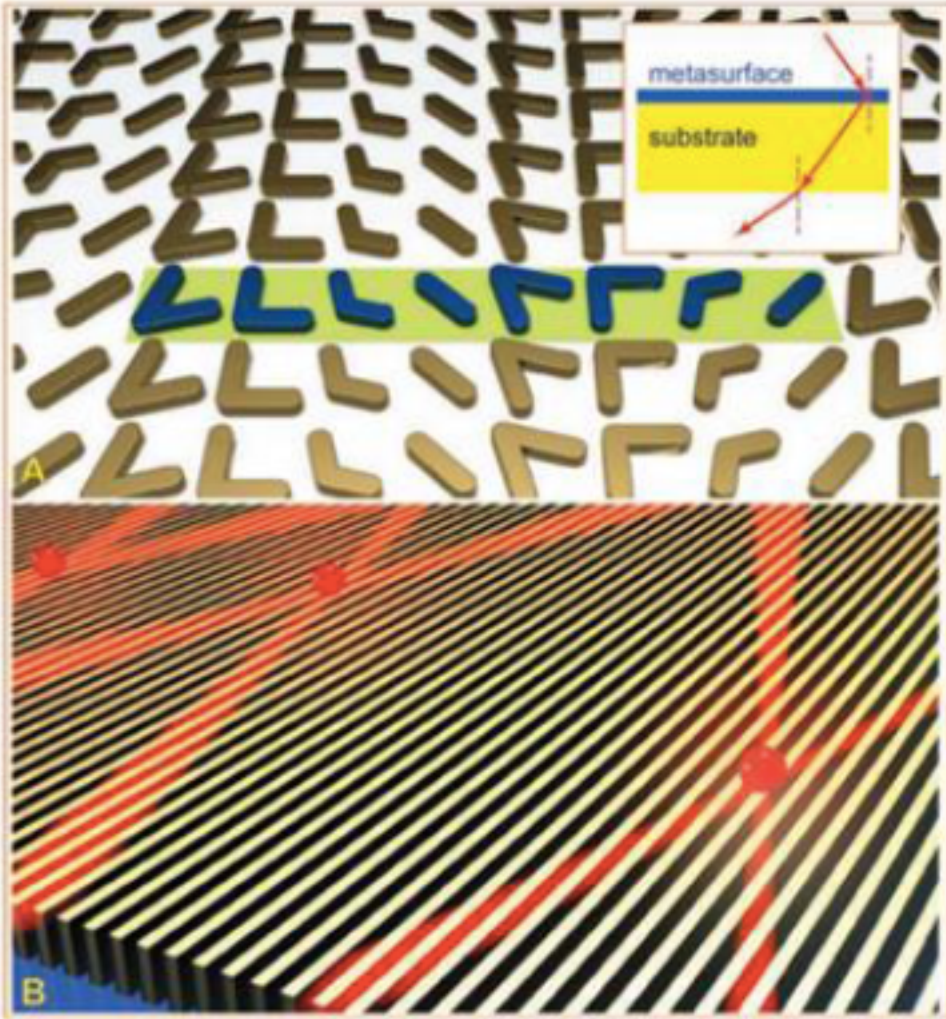


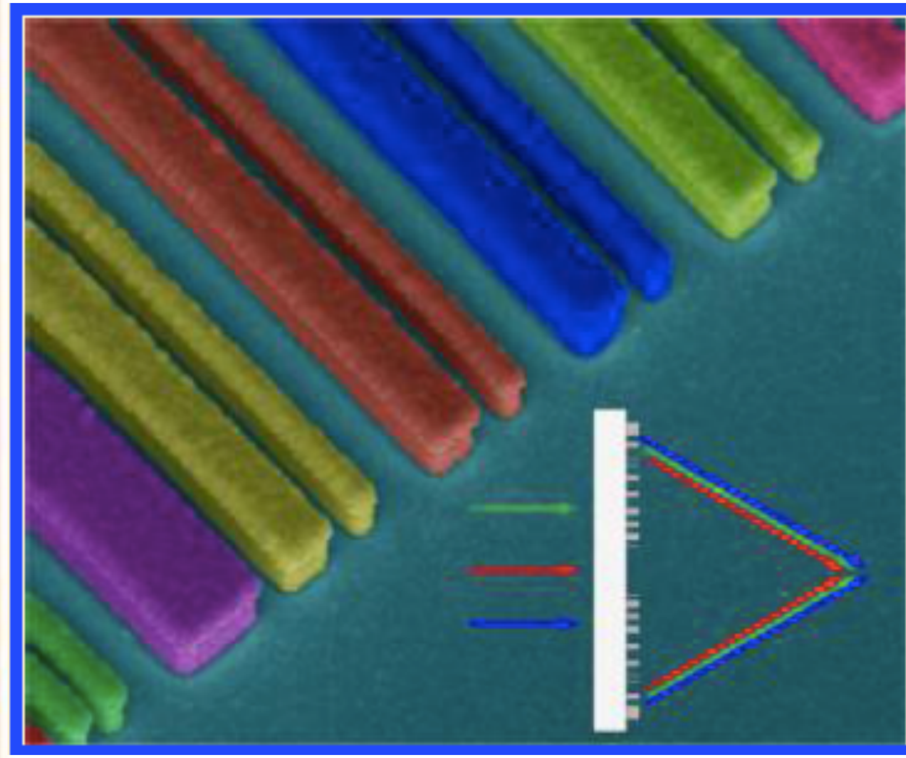
Build optical elements and systems based on new physical principles.

Feature specific imaging

Perform arbitrary optical transformations to capture only relevant information.

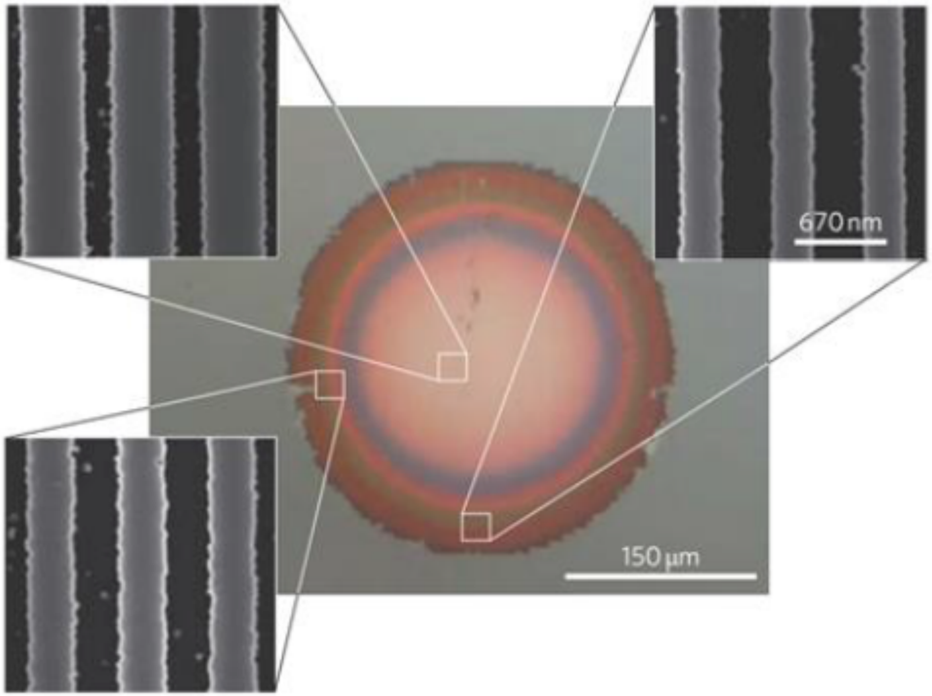
Flat lens + semiconductor technology?

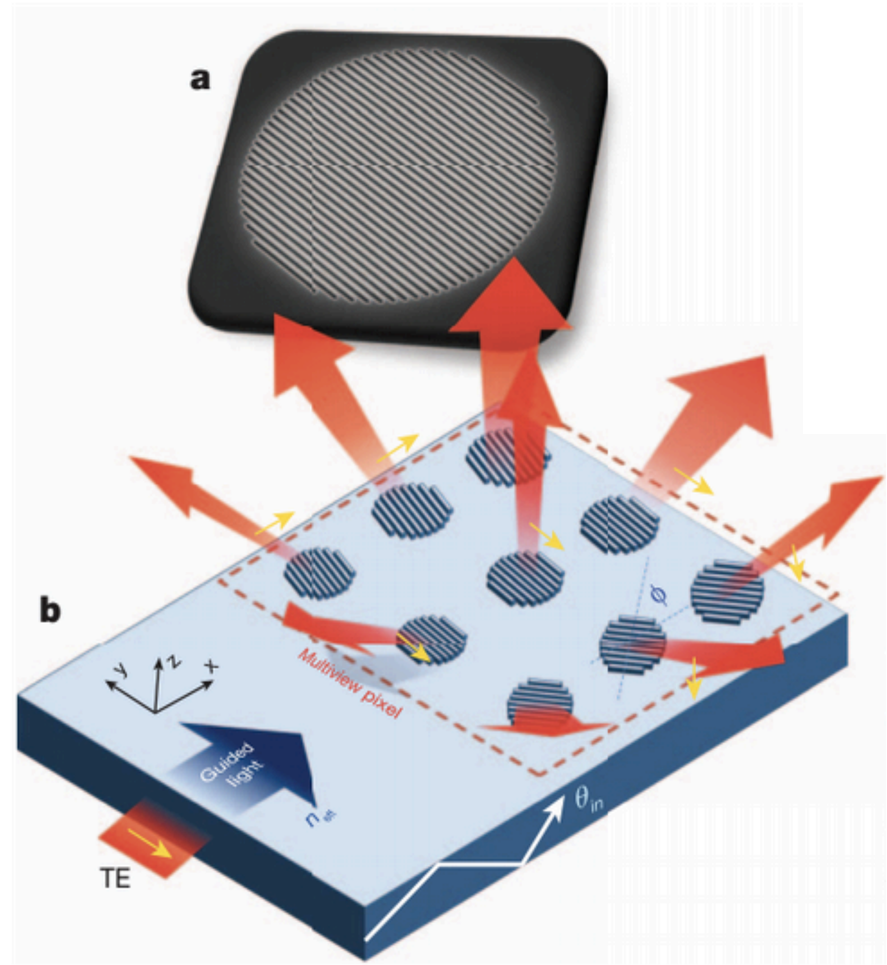




Federico Capasso, Harvard University

Dielectric Metasurface

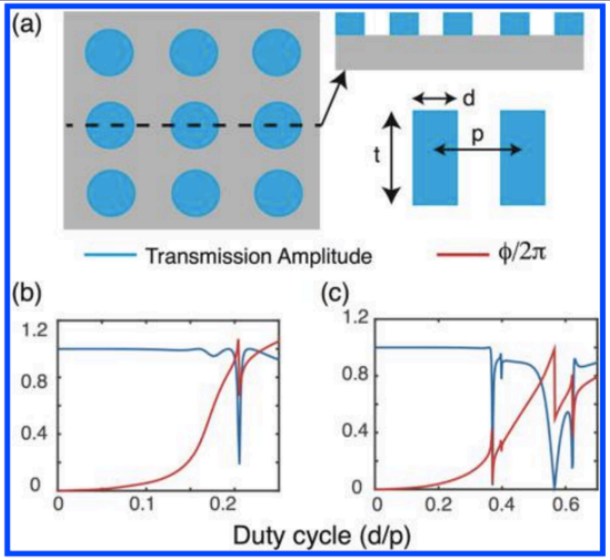


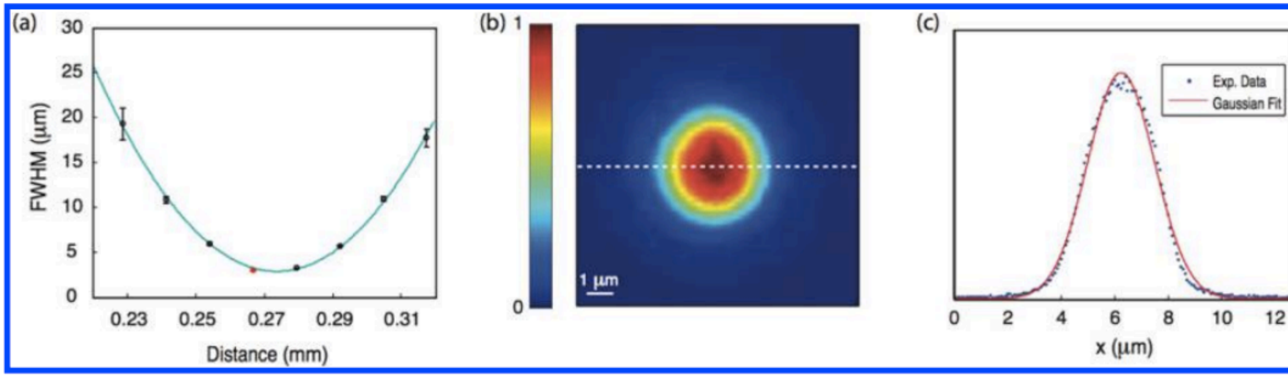


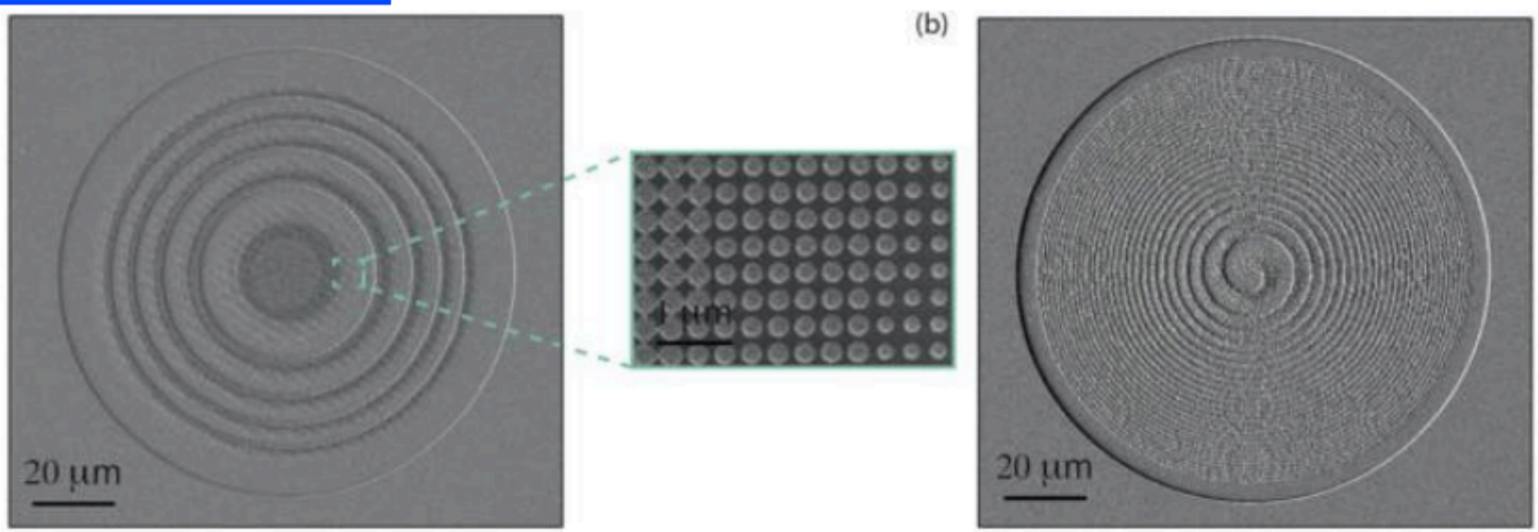
- Metasurface based lens
- Current being explored for mobile holography.

David Fattal, HP Labs & Leia Inc.
Mark Brongersma, Stanford
Andrei Faraon, Caltech

Low-contrast metasurface: Silicon Nitride







Alan Zhan et. al., ACS Photonics, 2016

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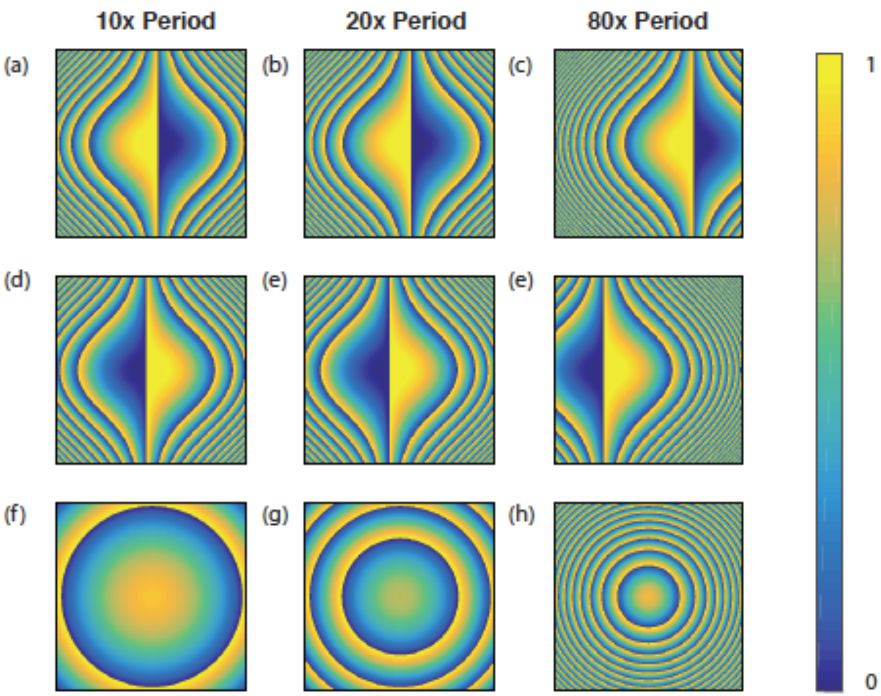
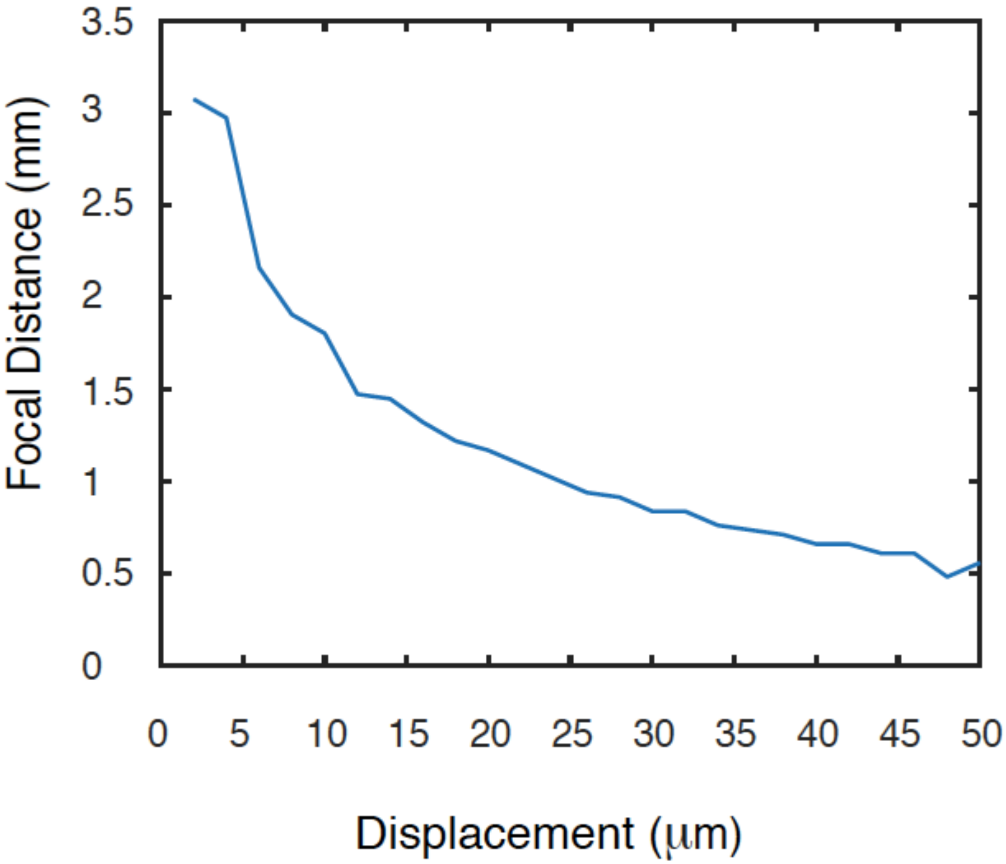
Metasurface freeform optics: cubic and Alvarez lens





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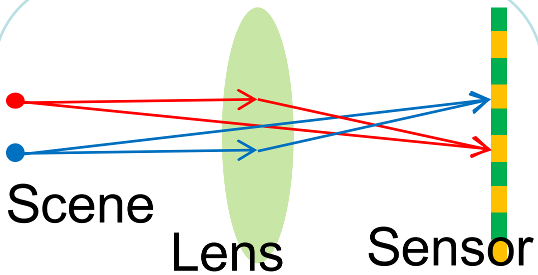
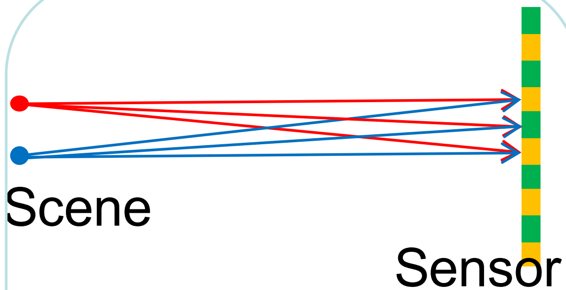
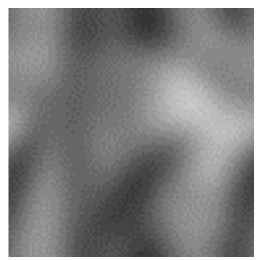
Computation + device innovation



Exact scene captured by lens

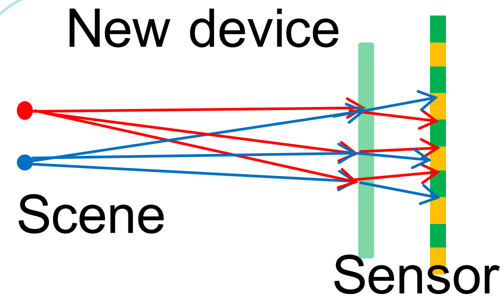
Lens-based imaging

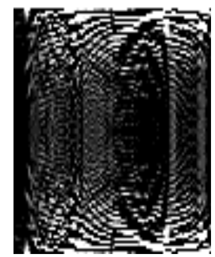




Without lens we get blurry image

Without any lens



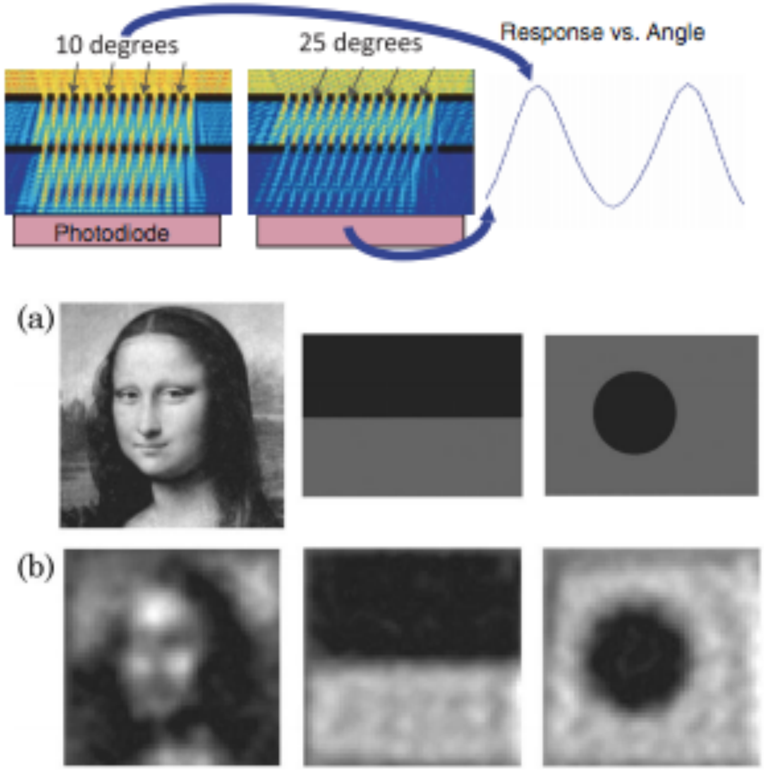


Transformation on the scene: illegible to eye

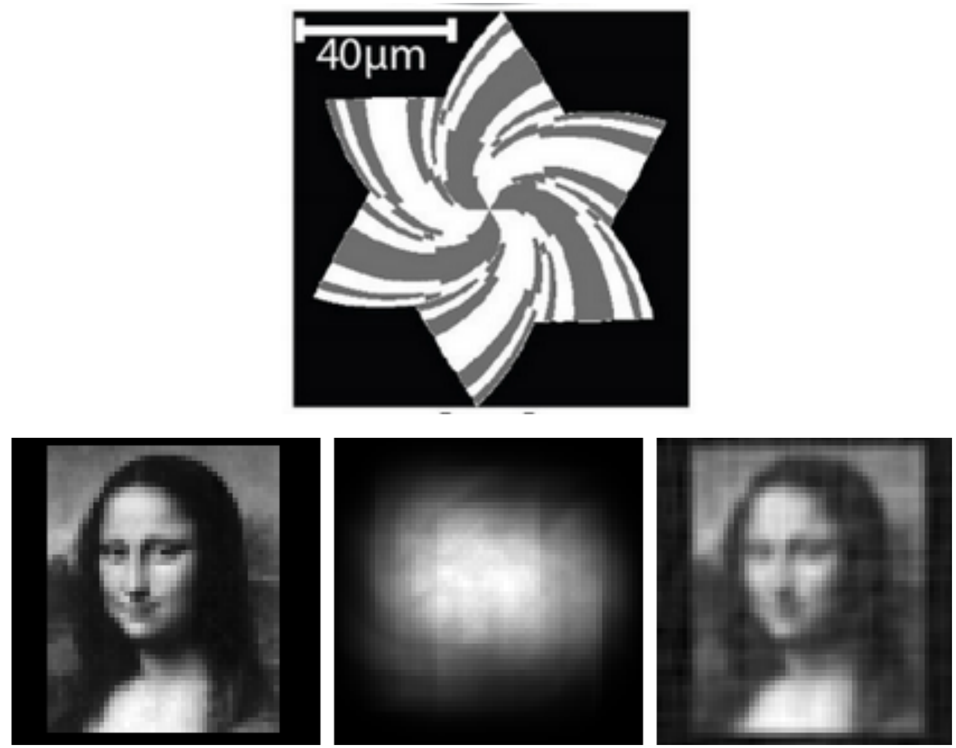
Metasurface based imaging

Computation

Computational lensless imaging



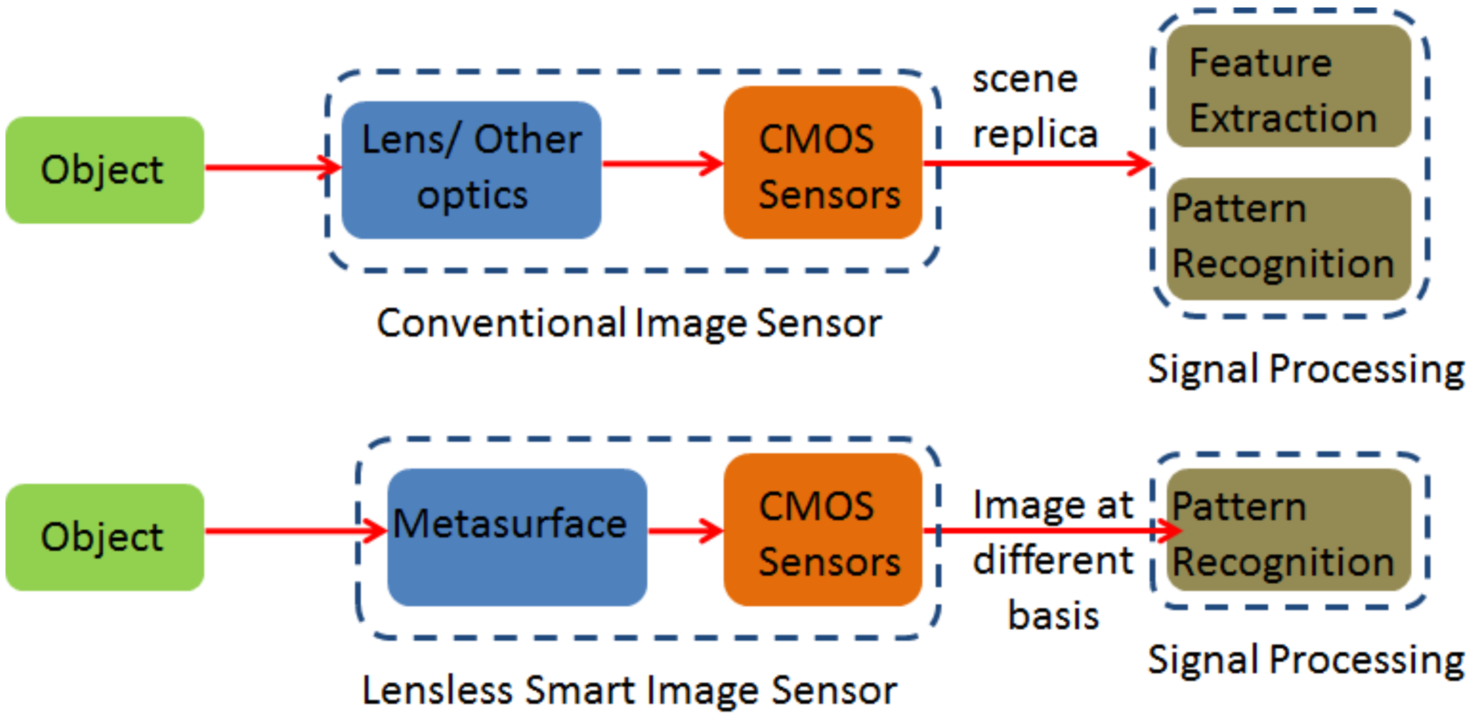
Alyosha Molner, Cornell



Rambus Labs

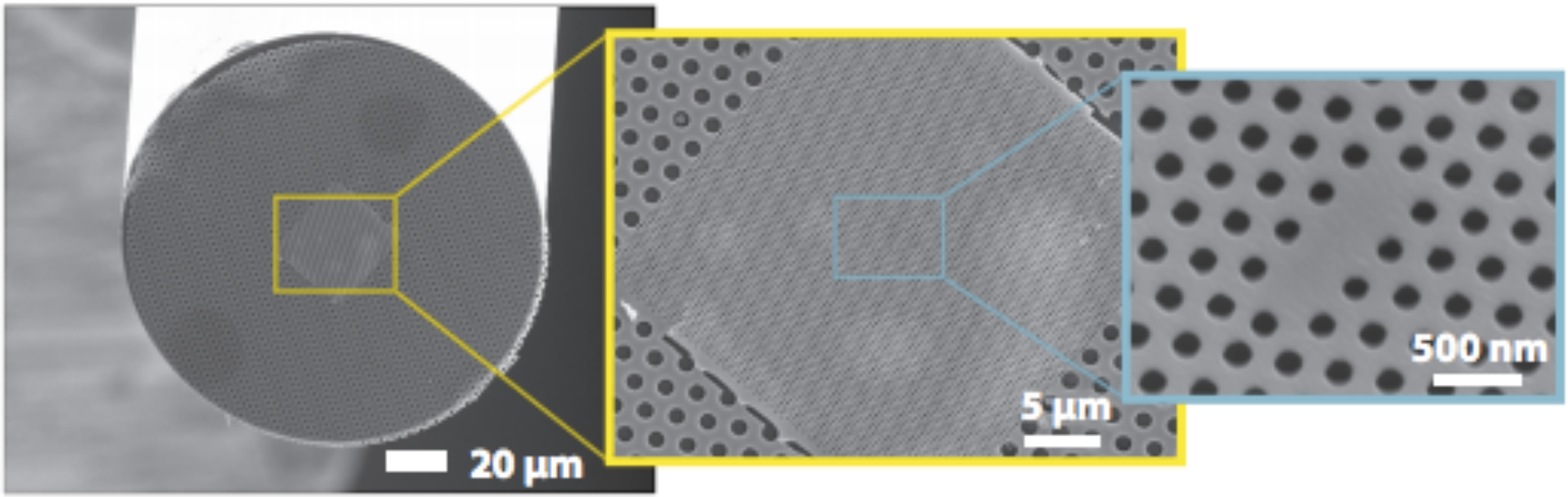
- Diffraction destroys color information
- Reconstruction complexity is large

Optical co-processor for sensing



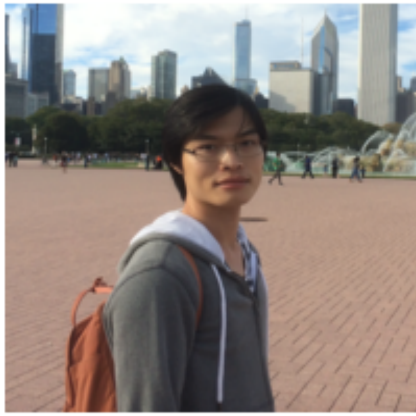
Use optical processing to capture only useful data.

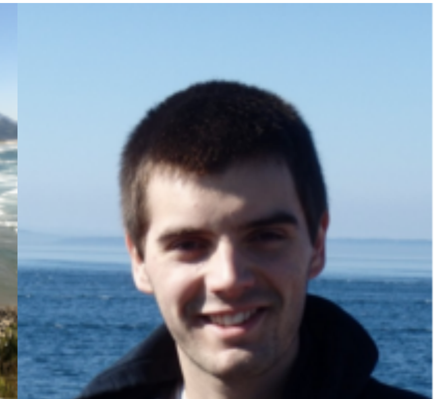
Implantable bio-sensor

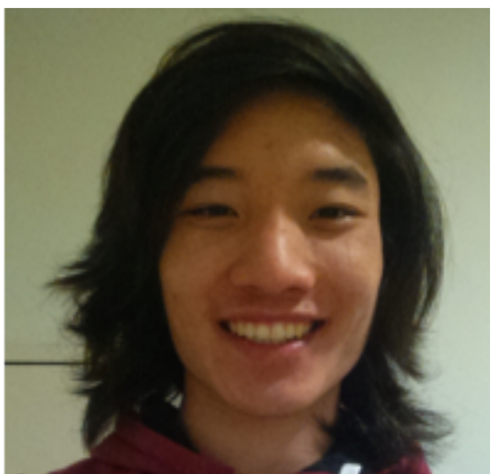
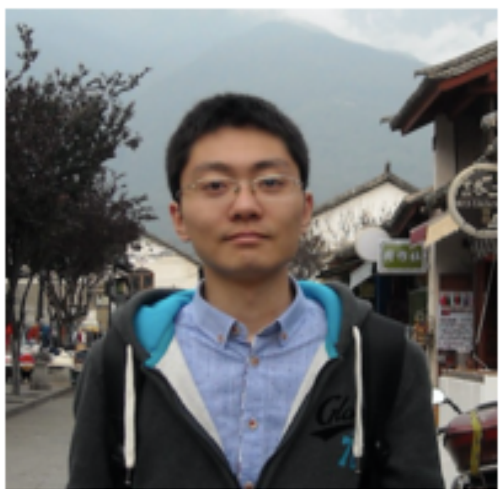


- Integrate metasurface optics with fibers.
- Build an optical system, like microscope on top of the fiber

Our Team (http://www.ee.washington.edu/research/amlab/)




Went to Apple inc.

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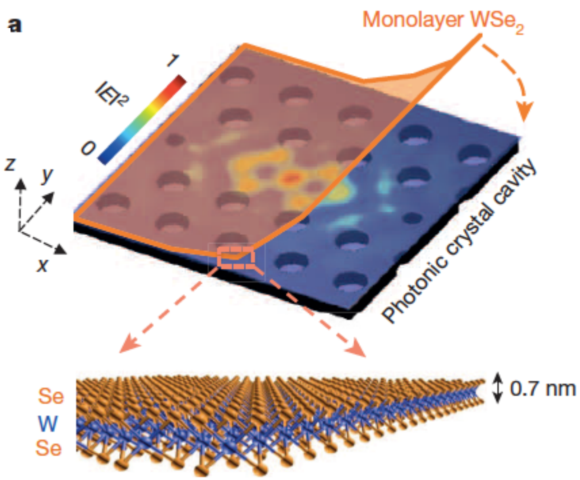
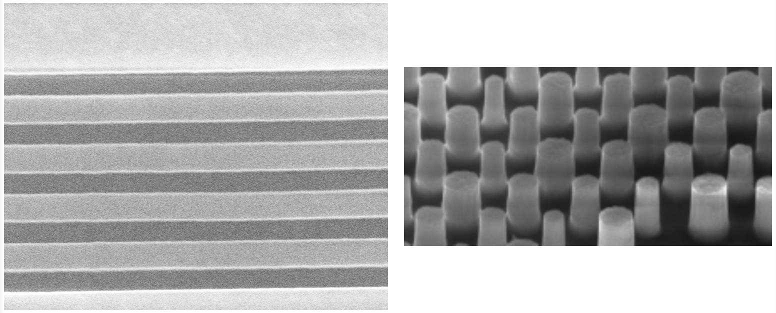
NOISE: Nano-Optoelectronic Integrated System Engineering Lab

HySiP: Hybrid Silicon Photonics



Integrate new materials with new nanophotonic devices to enable energy-efficient, high speed optoelectronic systems.

iCOS: Intelligent compact optical sensors



Design new compact optical devices, which uses computation (either in hardware or software) to enable intelligent sensing.