Photonics & Optoelectronics

Date: 7 MAR 2013

Gernot S. Pomrenke, PhD
Program Officer
AFOSR/RTD
Air Force Research Laboratory

Integrity ★ Service ★ Excellence

Report Documentation Page

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NAME: Gernot S. Pomrenke

BRIEF DESCRIPTION OF PORTFOLIO:

Explore optoelectronic information processing, integrated photonics, and associated optical device components & fabrication for air and space platforms to transform AF capabilities in computing, communications, storage, sensing and surveillance … with focus on nanotechnology approaches. Explore chip-scale optical networks, signal processing, nano-sensing and terahertz radiation components. Explore light-matter interactions at the subwavelength- and nano-scale between metals, semiconductors, & insulators.

LIST SUB-AREAS IN PORTFOLIO:

- **Nanophotonics & Plasmonics: Plasmonics, Photonic Crystals, Metamaterials, nano-materials & 2D materials & Nano-Probes & Novel Sensing**
- **Integrated Photonics & Silicon Photonics: Optical Components, Silicon Photonics, Hybrid Photonics**
- **Reconfigurable Photonics and Electronics**
- **Nanofabrication for Photonics: (3-D Assembly, Modeling & Simulation Tools)**
- **Quantum Computing w/ Optical Methods**
- **Terahertz Sources & Detectors**

Optoelectronics & Photonics

Nanophotonics, Plasmonics, Integrated & Silicon Photonics
Extamural & Intramural Programs

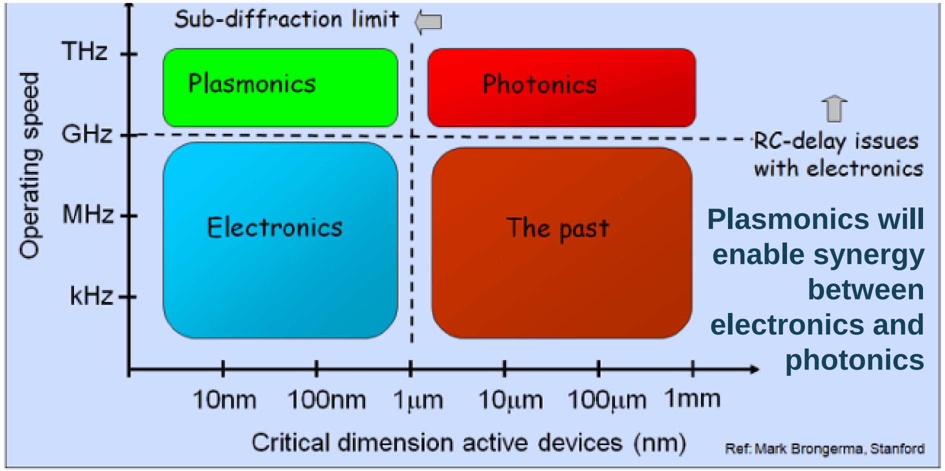
MOTIVATION

--Exploiting the nanoscale for photonics: nanostructures, plasmonics, metamaterials

--Overcoming current interconnect challenges

--Need for Design Tools for photonic IC's: scattered landscape of specialized tools

--Enable Novel Computing (Quantum Computing, All-Optical, Hybrid, HPC) & Ultra Low Power Devices



SCIENTIFIC CHALLENGES

--Explore light-matter interactions at the subwavelength- and nano-scale between metals, semiconductors, & insulators

--Radiative lifetimes and gain dynamics

--E&M fields & strong nonlinearities

--Fundamental building block of information processing in the post-CMOS era

--Precise assembly & fabrication of hierarchical 3-D photonics

PAYOFF

--Exploit CMOS: Complex circuits structures benefit from chip-scale fabrication

--Fiber-optic comm. with redundancy at silicon cost for aerospace systems

--Establish a shared, rapid, stable shuttle process

--Enable airborne C4ISR: combine SWaP benefits w/ best-in-class device performance

Optoelectronics & Photonics
Extamural & Intramural Programs
Program Components

Core – Intramural - LRIR
Core – Extramural
EOARD/AOARD/SOARD
AFIT
MURI
STTR/SBIR
DEPSCOR
HBCU/MI
DURIP
YIP
PECASE
NSA
DARPA
NNI/NNCO
BRI (2D Materials & Devices Beyond Graphene – planning phase)

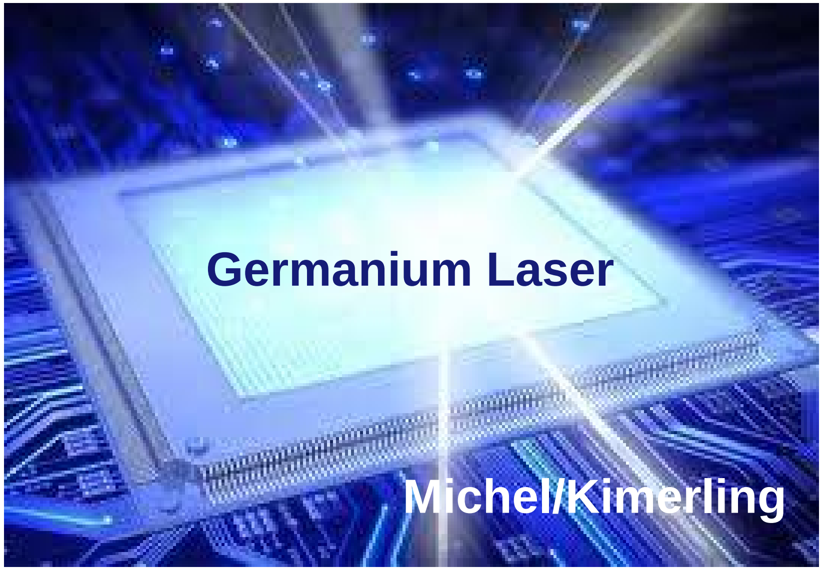
LRIR PIs

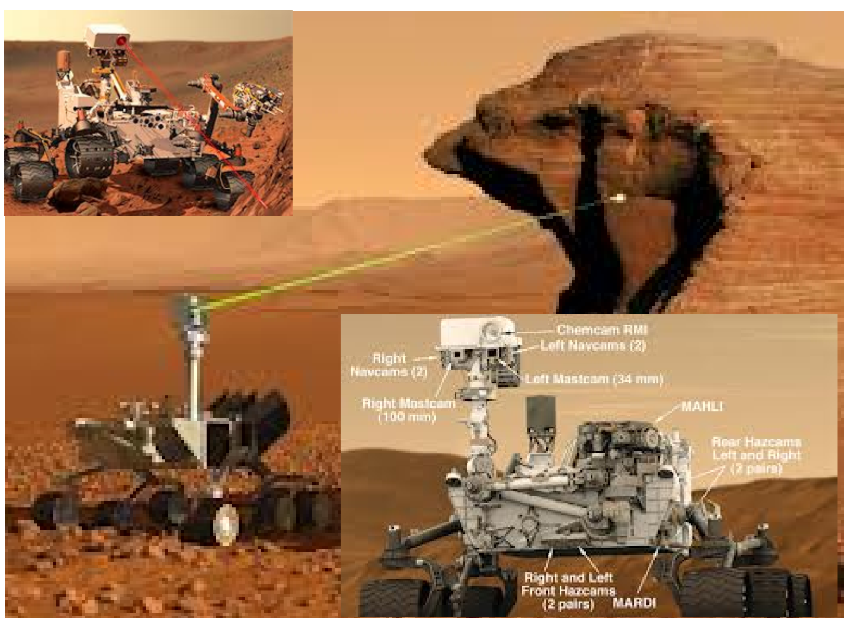
Szep – RY: PICS Quantum Information Processing
Allen – RY: Plasmonic Enhancement of NIR
Cleary – RY: IR Plasmonic Component Development
Hendrickson – RY: Metamaterial Quantum Optics
Khoury – RY: Gain-Enhanced THz Laser
Bedford – RY: Loss Engineering for III-V Lasers
Osman – RI: Electro-optics for Processor Interconnects
Huang – RV: SPP for near-field enhanced quantum detectors
Vasileyv – RY: Programmable Reconfigurable Sensors
Eyink – RX: RE-mono-pnictide Nonlinear Optical Properties
Weyburne – RY: Laser Photovoltaics for Remote Sensors

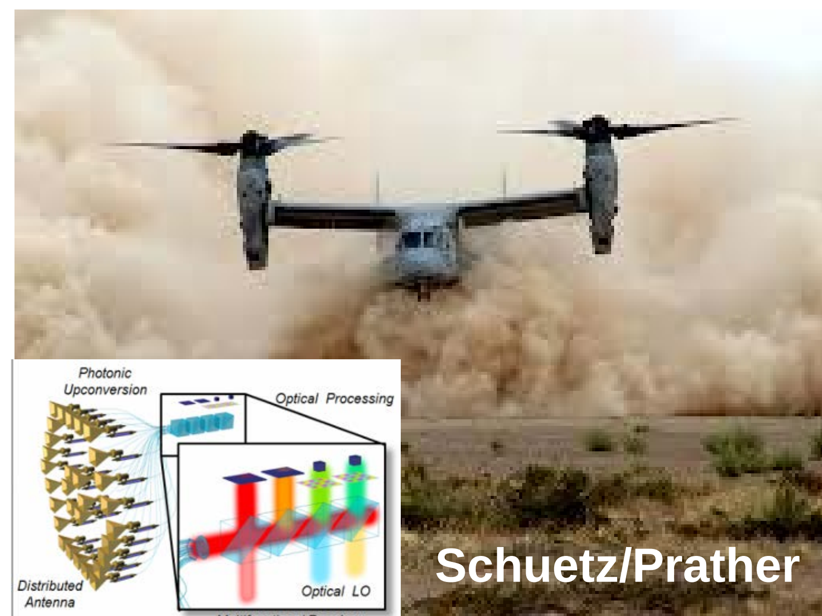
New
Heckman – RY: Sensor Printed Electronics
Claflin – RY: Synthesis of Sn Alloys for IR

The Information, Computing,& Sensing Environment

National Academies: Optics and Photonics — *ACE Report ASD(R&E)*







Outline/Agenda

- **Nanophotonics: plasmonics, nanostructures, metasurfaces etc**
- **Integrated Nanophotonics & Silicon Photonics**
- **Terahertz Sources & Detectors/Imagers**
- **Technology Transitions**

Outline/Agenda/Highlights Nanophotonics

Nanophotonics: metasurfaces, nanostructures, plasmonics etc

- **Shalaev – Broadband Light Bending with Plasmonic Nanoantennas & Generalized Snell's Law**
- **Capasso – Nanometer optical coatings based on strong interference effects in highly absorbing media**
- **Atwater – Full Color Camera via Integrated Plasmonic Filters on CMOS Image Sensor**

Vladimir M. Shalaev – Purdue Univ,
Integrated Hybrid Nanophotonics FY11 MURI

- Metamaterials can be fabricated that are capable of bending light in unusual ways
- Newly discovered generalized version of Snell's law ushers in a new era of light manipulation (2011-2012 news, Capasso):

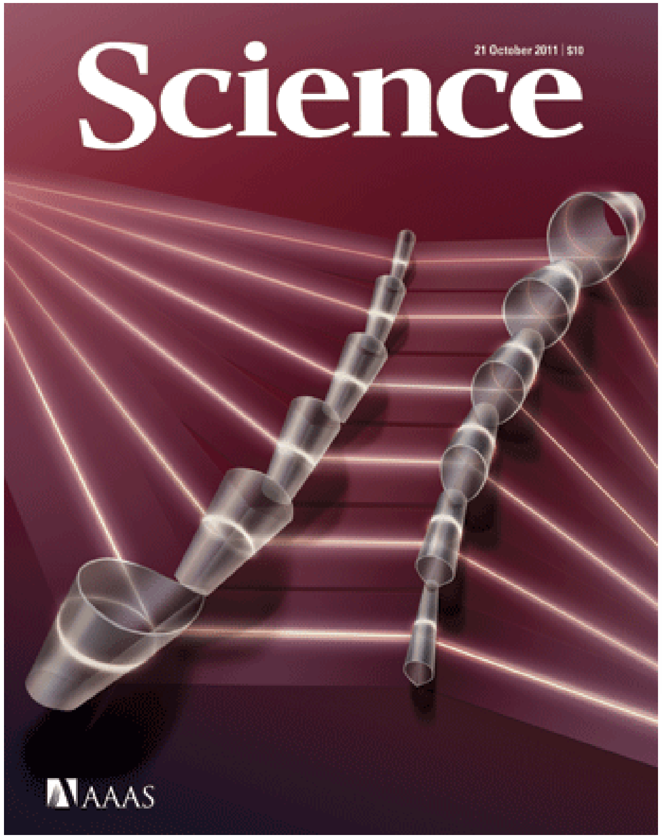
$$\sin(\theta_t)n_t - \sin(\theta_i)n_i = \lambda\nabla\Phi/2\pi \qquad (1)$$

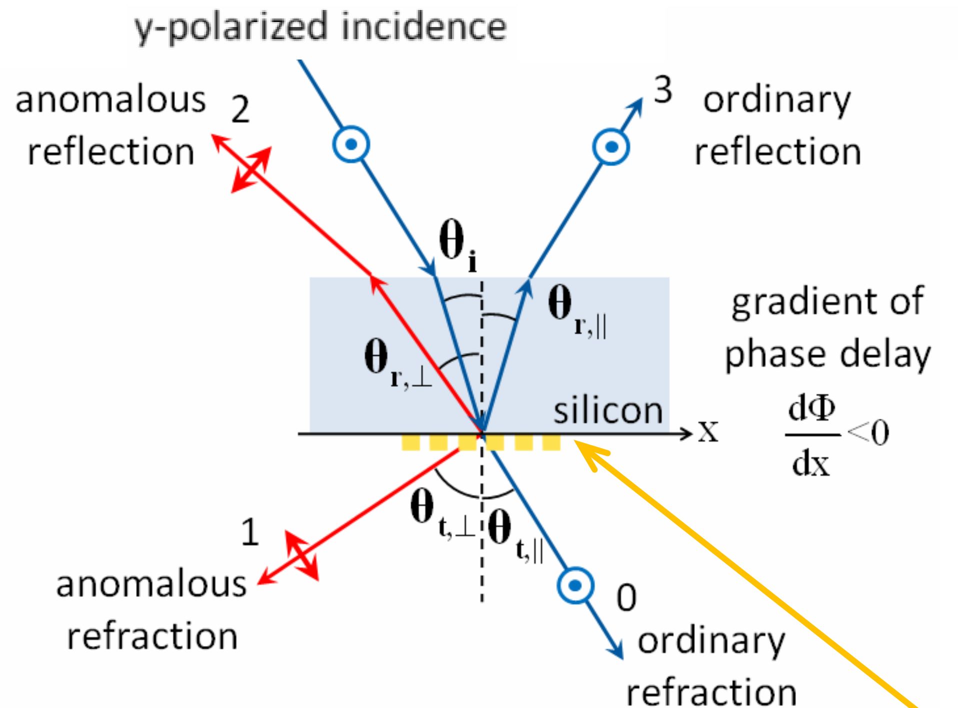
$$\sin(\theta_r) - \sin(\theta_i) = n_i^{-1}\lambda\nabla\Phi/2\pi \qquad (2)$$

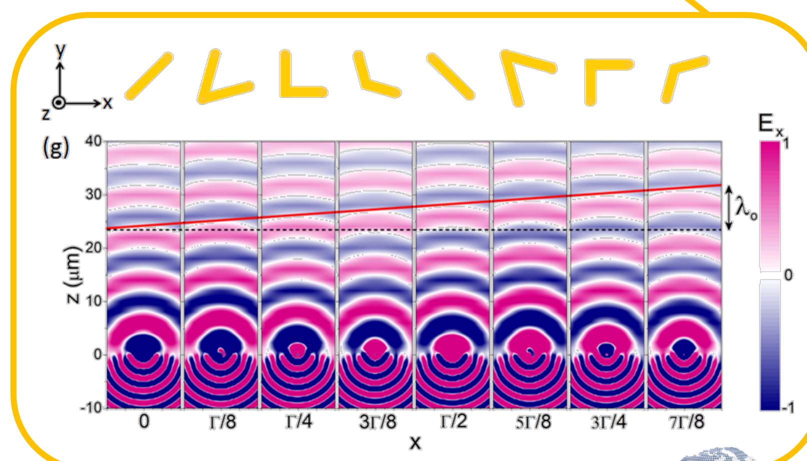
Gradient in a phase discontinuity, $\nabla\Phi$, along an interface between two media with refractive indices n(t) and n(i) can modify the direction of the refracted and the reflected waves by design and that this can occur in a very thin layer.

$\nabla\Phi$ is essentially an additional momentum contribution that is introduced by breaking the symmetry at the interface.

Generalized Snell's law







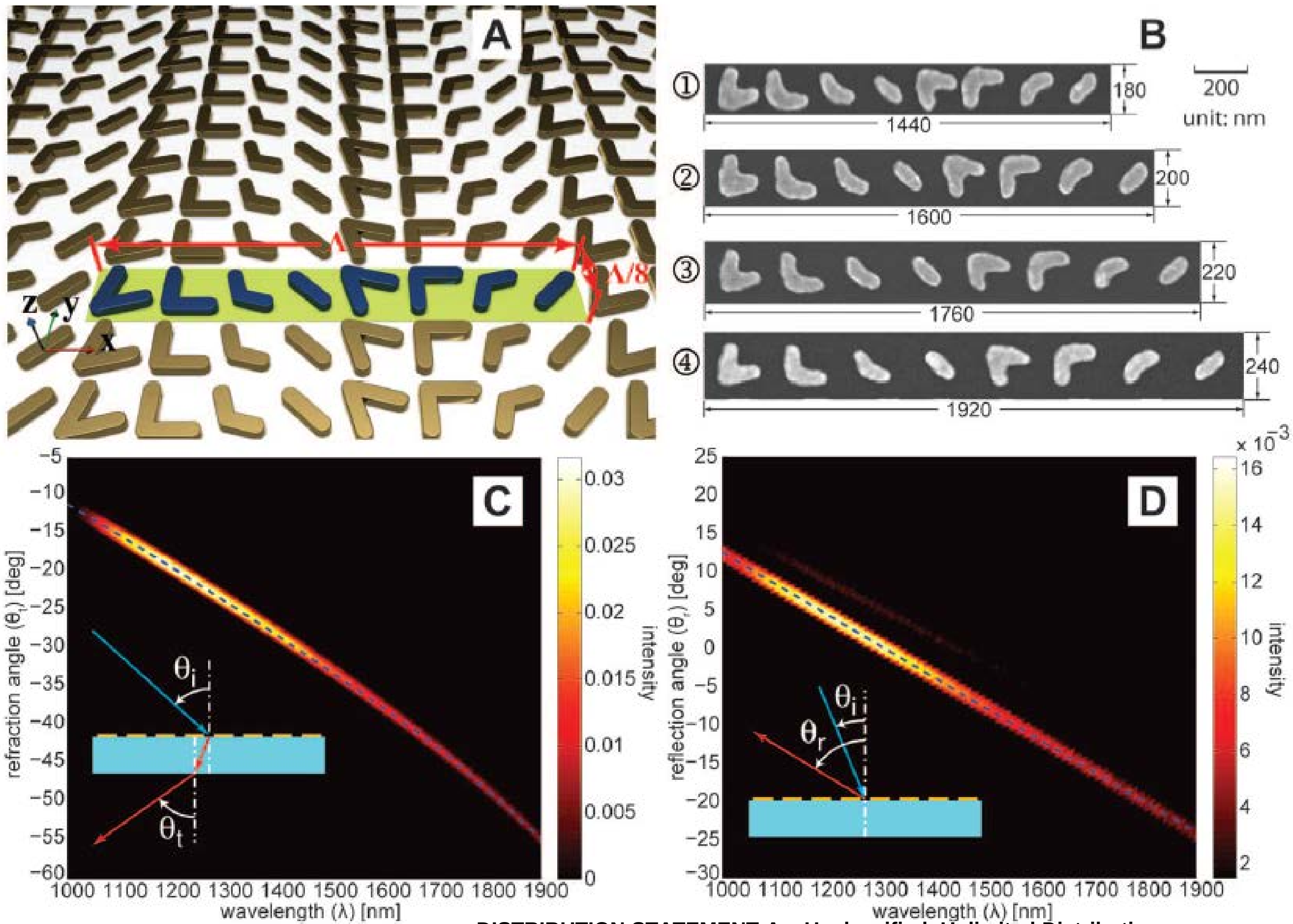
Demonstrated at 8 μm wavelength

Unit cell of a metainterface that can create circularly polarized anomalous refraction when excited by incident light polarized along the vertical direction

N. Yu, et al. Science, 2011 (Capasso Group)

By designing and engineering a phase discontinuity along an interface, one can fully control the bending of a light wave beyond conventional Snell's law

Purdue group extended work and demonstrate wavefront control in a broadband wavelength range from 1.0 to 1.9 mm, accomplished with a relatively thin 30-nm (~λ/50) plasmonic nanoantenna interface.



Applications:

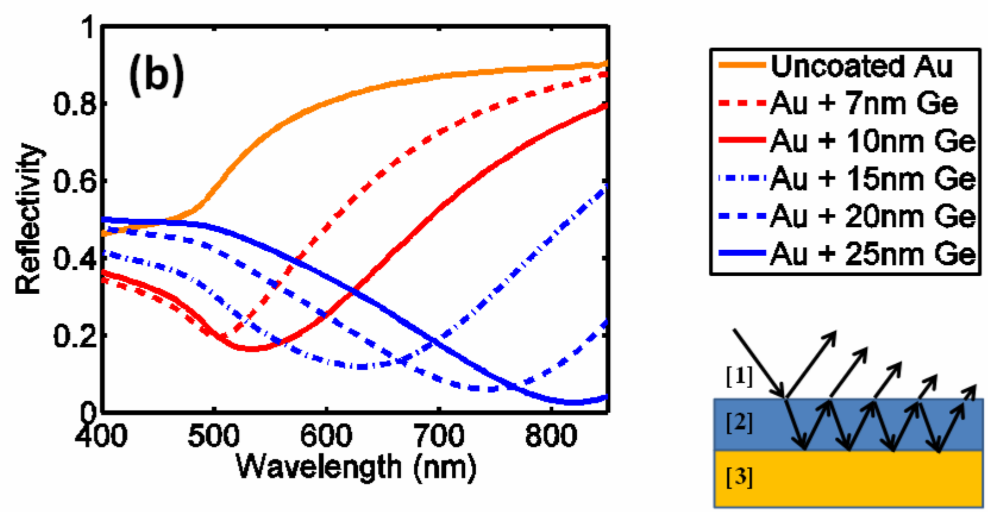
spatial phase modulation, beam shaping, beam steering, and plasmonic lenses

Optical Interference Coatings

Nanometer optical coatings based on strong interference effects in highly absorbing media
Capasso, Harvard

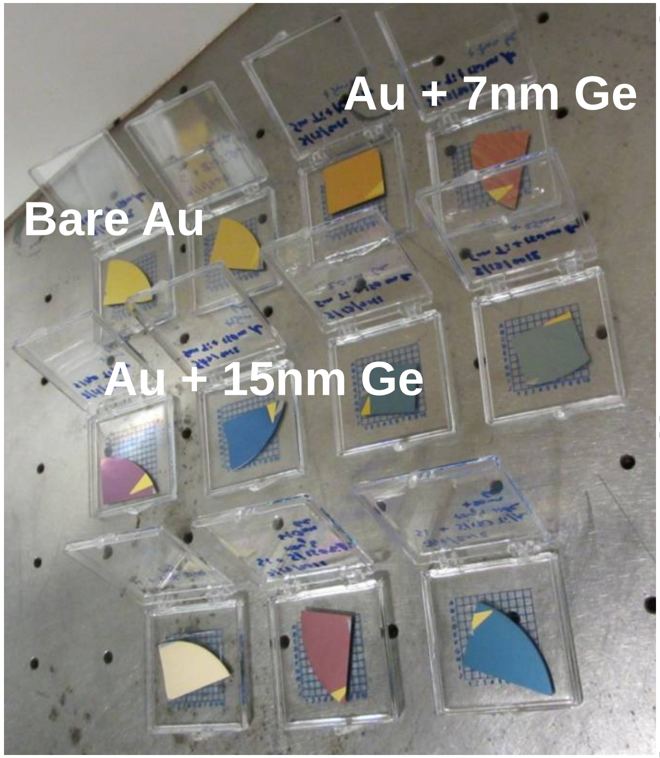
- Last half century: optical coatings and filters using thin film interference effects (color/dichroic coatings, anti-reflection, high-reflection, etc)
  - Existing thin film optical coatings use **low-loss dielectric layers** with **thicknesses on the order of a wavelength of light**
- Harvard technique uses **highly-absorbing, ultra-thin** dielectric or semiconducting layers to achieve **strong interference effects**
  - Initial demonstration: gold (Au) substrate and germanium (Ge) ultra-thin films
  - Deeply-subwavelength films exhibit strong, broadband absorption resonances
  - Enabling concept: **reflection phase shifts at an interface between two materials can be engineered by tailoring the optical losses of the materials**

Prof Capasso, Harvard, "Wavefront Engineering With Phase Discontinuities"



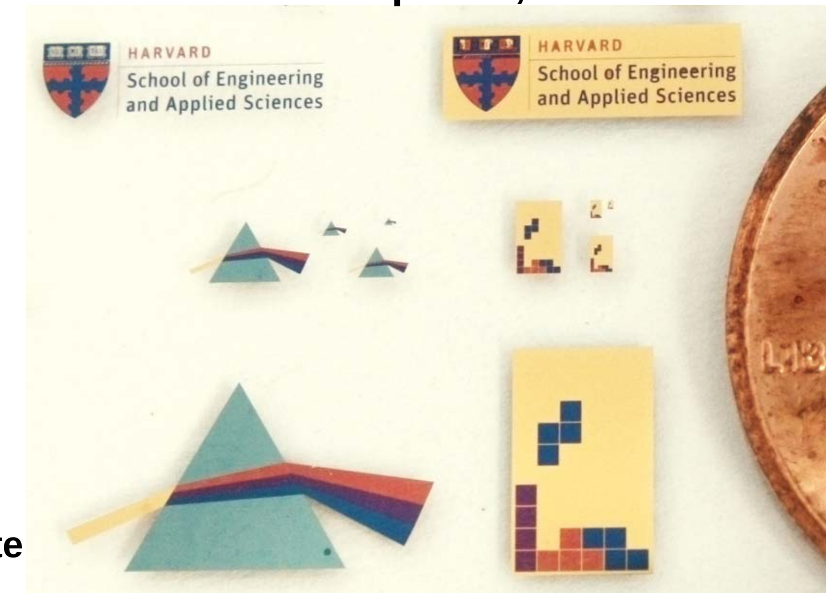
Coloring Metals with Ultra-thin Coatings

Capasso, Harvard cont.



Polished substrate

Rough substrate (still works!)



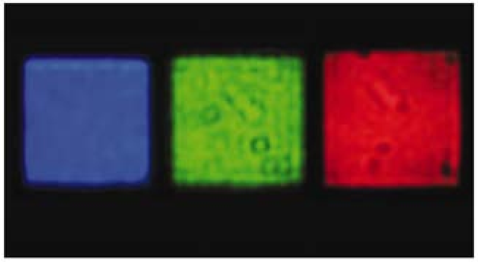
Kats et al, Nature Materials (2012) (Capasso group)

- "Colored" gold films by coating with 5-20 nm germanium films → much thinner than conventional λ/4 interference coatings
- Differences between pink/purple and purple/blue a result of just an extra 4 nm of germanium (~8 atomic layers)
- Huge light absorption within ultra-thin layers: potential for low-cost, low-footprint optical devices (detectors, modulators) as well as labeling/printing

Plasmonic Devices: Full Color Camera via Integrated Plasmonic Filters on CMOS Image Sensor

Road to Hyperspectral Imaging Arrays

Harry Atwater, Caltech



Objective: Explore the first full plasmonic color imaging camera, via plasmonic filters integrated onto a CMOS image sensor

- **Previous work has demo'd plasmonics & plasmonic hole array transmission physics, but neither filter integration with ULSI CMOS image sensor chips nor imaging**

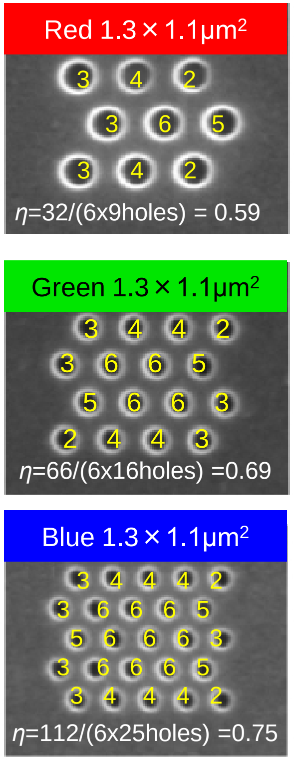
Approach: Plasmonic hole array filters fabricated by nanolithography integrated with state-of-the-art Sony CMOS image sensor:

•Large field of red, green and blue filter pixels in Bayer mosaic pattern of 1.3 x 1.1 μm^2 hole arrays in Al thin film on glass.

•Light coupled vertically from plasmonic filters into Si CMOS image sensor diodes via PMMA dielectric and SiN_x vertical light couplers -

•Designed and implemented signal processing for color fidelity from raw signal input

•Investigated filter angle dependent transmission and robustness against defects



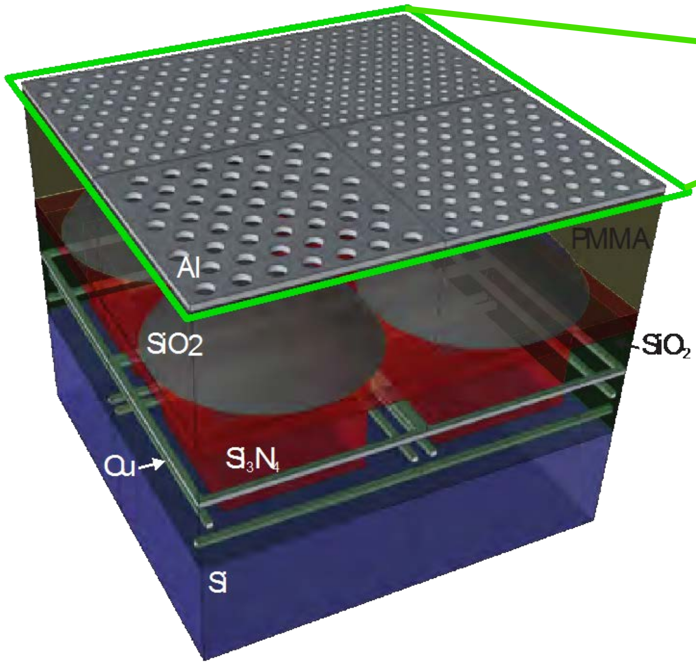
Caltech

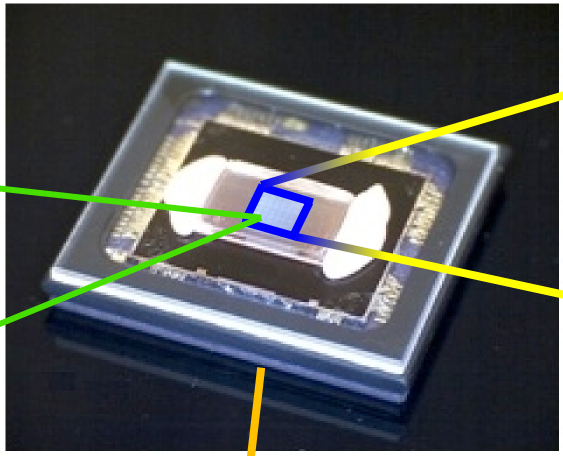
ATWATER Research Group

AFRL

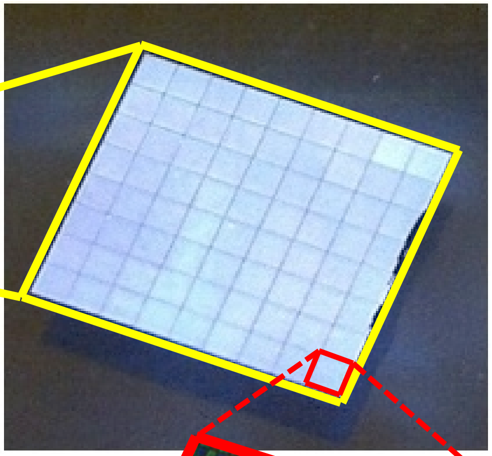
Full Color Camera via Integrated Plasmonic Filters on CMOS Image Sensor

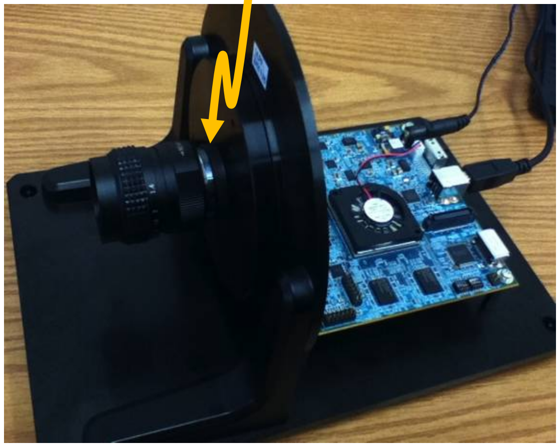
Unit Cell of Integrated CMOS IS with Plasmonic Hole Array Color Filter



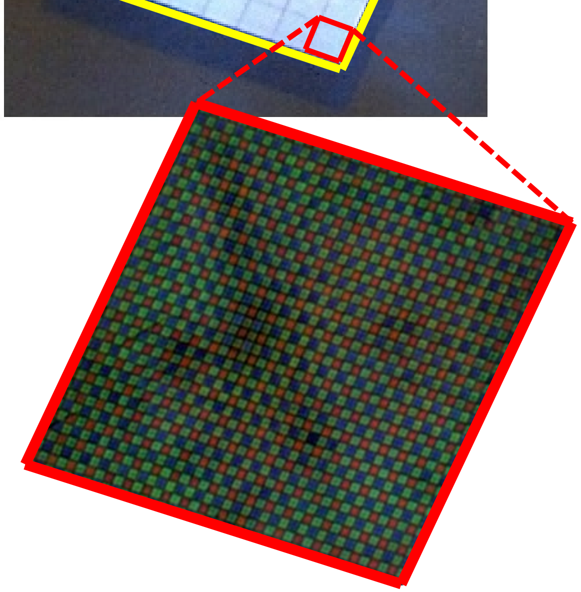


360×320 5.6×5.6μm^2 pixels (2.016×1.792 mm^2)



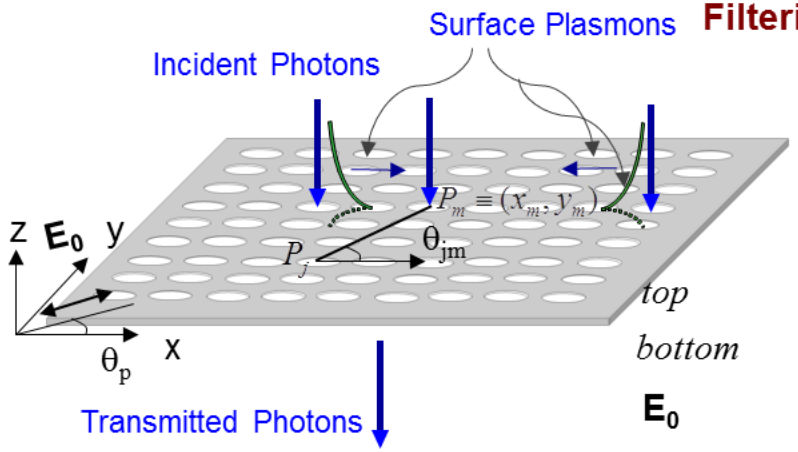


Mount on evaluation board with C-mount lens and f/number controller

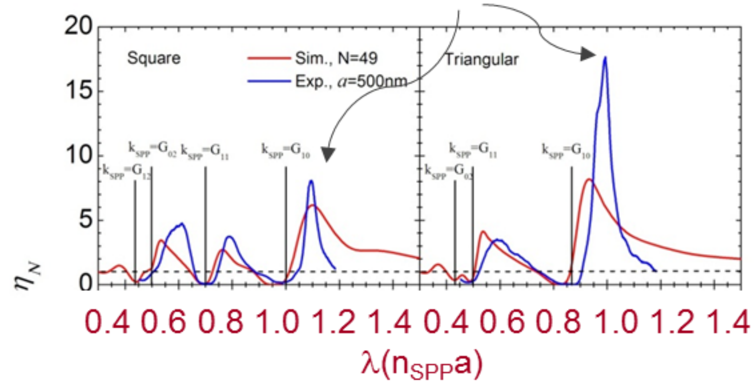


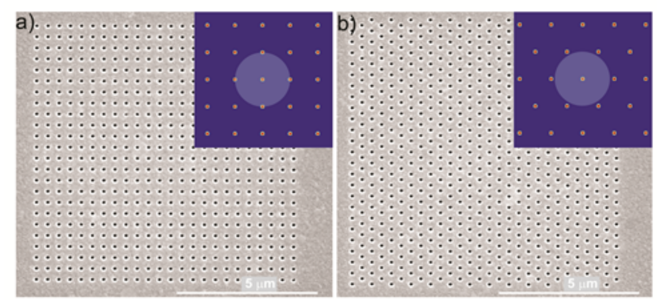
40×40 filter blocks (224×224 μm^2)

Plasmonic Hole Array Filtering Arises from Interference of Incident Photons and Surface Plasmons



Filtering - Fano Resonant Transmission:





Photon/Plasmon Hole Array Momentum Conservation:

$$\mathbf{k}_{SPP} = \mathbf{k}_{\parallel} + \mathbf{G}$$

$$a_{jm} = \overline{P_j P_m}$$

Hole-Hole Coupling:

$$x_m - x_j = a_{jm} \cos \vartheta_{jm}$$

Incident → Plasmon:

$$H_{m,top} = 1 + \sum_{j \neq m} \frac{\beta_0 \beta_0' \cos^2(\vartheta_{jm} - \vartheta_p)}{\sqrt{a_{jm}}} \exp\left[i\left(k_{SPP} a_{jm} + \frac{\pi}{2} \right) \right]$$

Plasmon → Transmitted:

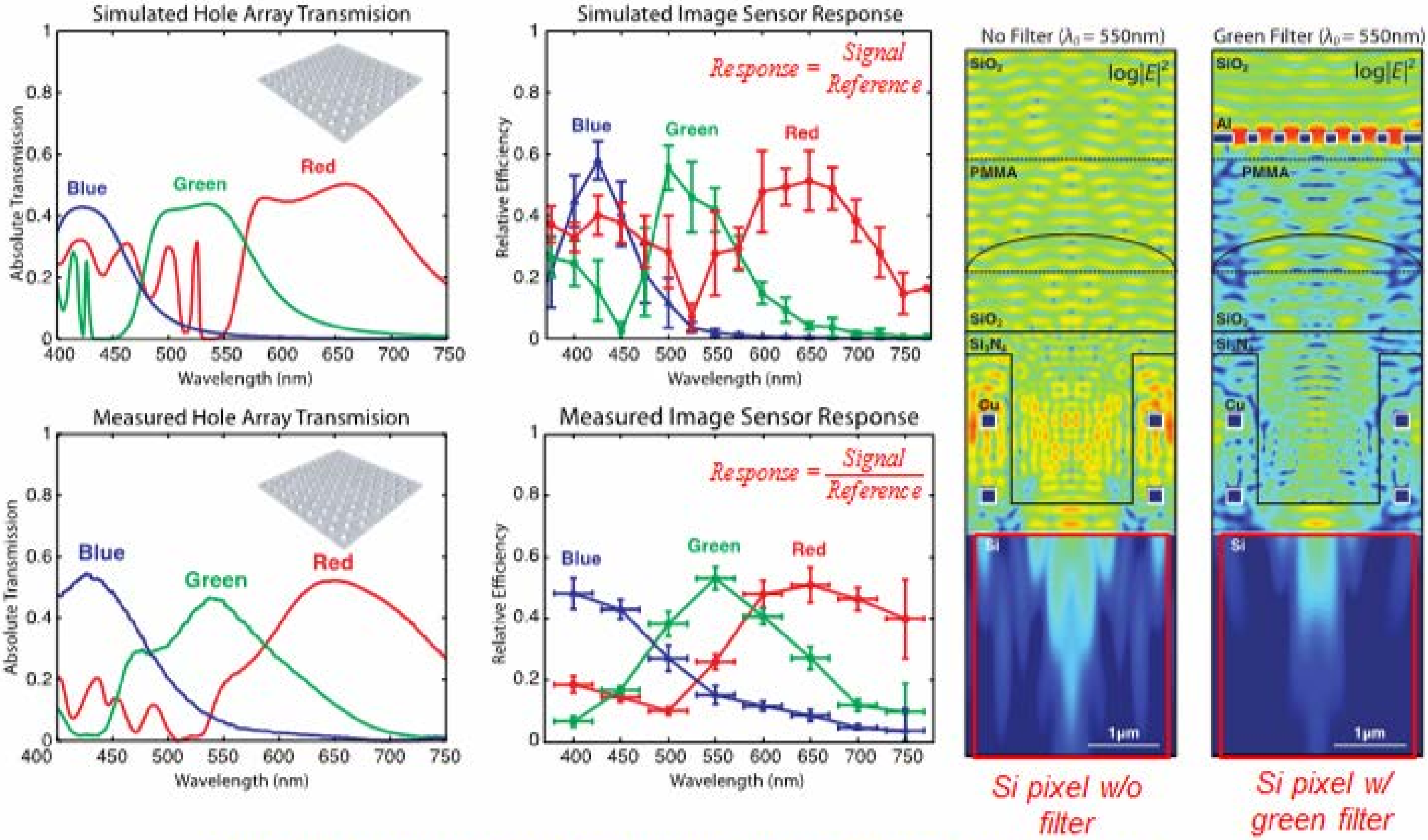
$$H_{m,bot} = H_{m,top} + \sum_{j \neq m} \frac{\beta \beta' \cos^2(\vartheta_{jm} - \vartheta_p)}{\sqrt{a_{jm}}} H_{j,top} \exp\left[i\left(k_{spp} a_{jm} + \frac{\pi}{2} \right) \right]$$

Hole Array Transmission Efficiency:

$$\eta_N = \frac{\left| \sum_{m=1}^{N} H_{m,bot} \right|^2}{N^2}$$

Pacifici et al., Optics Express **16**, 9222 (2008)

Light Coupling Efficiency from Plasmonic Filter to Si CMOS Diode



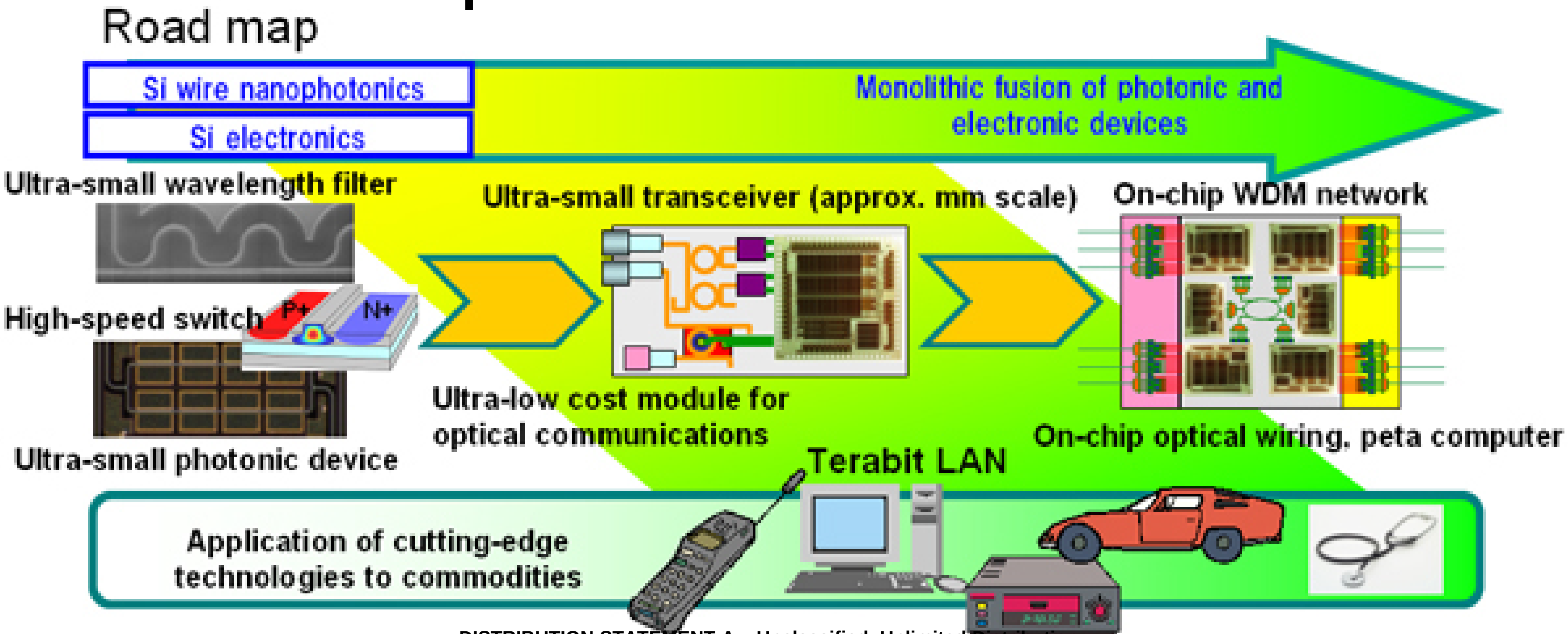
Integrated hole array filter shows high coupling efficiency to CMOS image sensor, in close agreement with simulations

Result: Demonstrated First Full Color CMOS Imaging with Plasmonic Filters:

- *High (45-60%) filter transmission efficiency – excellent agreement with theory*

Outline/Agenda/Highlights Integrated Nanophotonics & Silicon Photonics

- **Michel/Kimerling MIT - Germanium Laser**
- **Hochberg, UDel – OpSIS - Optoelectronic Systems Integration in Silicon**
- **Univ Delaware, ASU, AFIT, AFRL/RY – SiGeSn: a new material for Si photonics & IR**



Ge Light Emitters for Si Photonics

Juergen Michel & Lionel Kimerling, MIT

Objectives

- RT lasing from Germanium
- Increased Germanium n^+ doping
- Germanium passivation
- Reduction of optical losses
- CMOS compatible device design and modeling

Key Findings

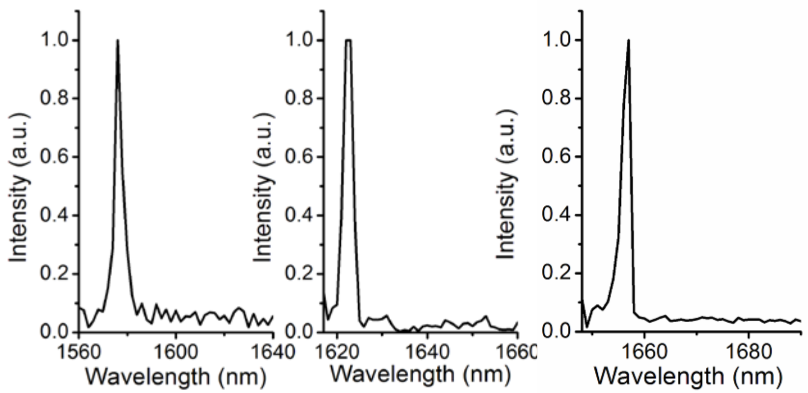
- Electrically pumped lasing observed.
- ~200nm gain spectrum from 1520nm to 1700nm
- Increased n-type doping level in Ge to >$5*10^{19}cm^{-3}$

Approach

Germanium on Si

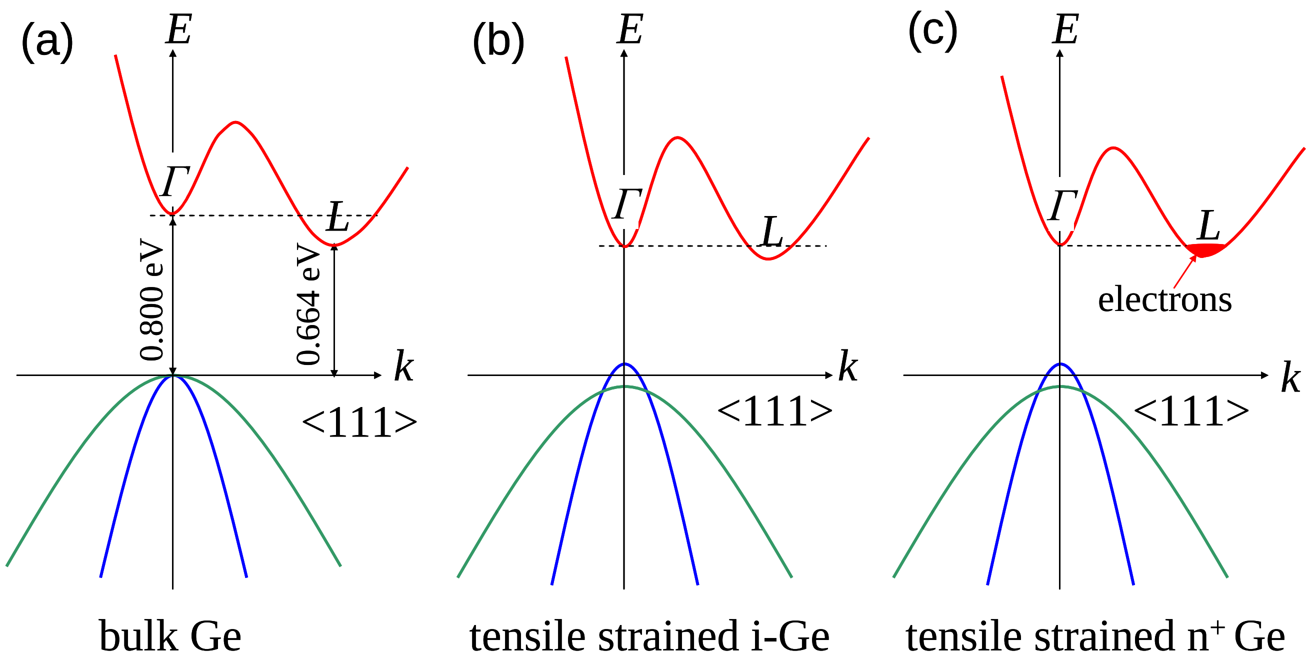
- highly doped n+ Ge
- Si/Ge/Si hetero junctions
- Ring/disc laser structures (modeling support U. Delaware)
- Carrier/Emission dynamics (collaboration with Boston U.)

Laser lines in n-type Ge at 300K



1576nm | 1622nm | 1656nm

Direct Gap Emission from Germanium
Tensile Strain and N-type doping



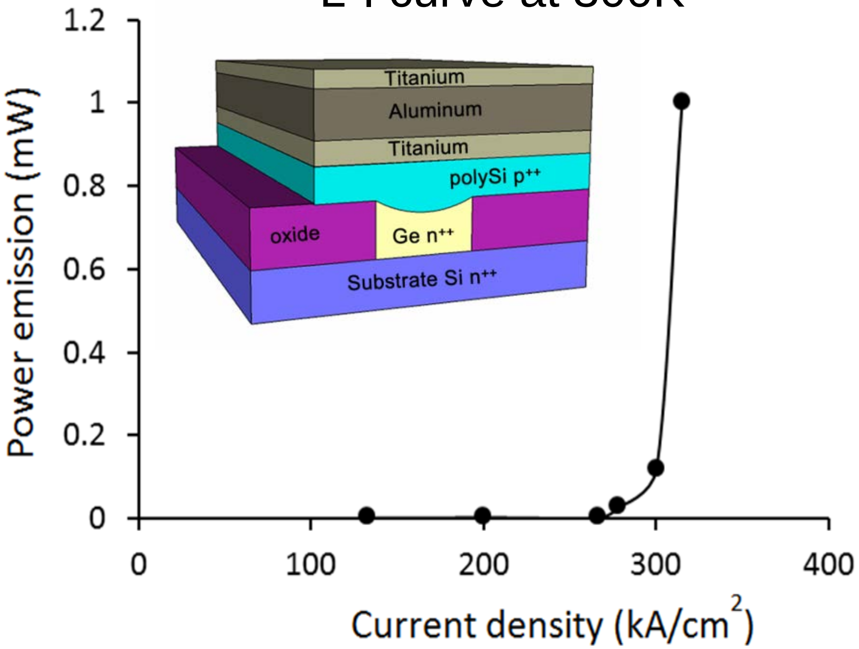
Liu et al, Opt. Express. 15, 11272 (2007)

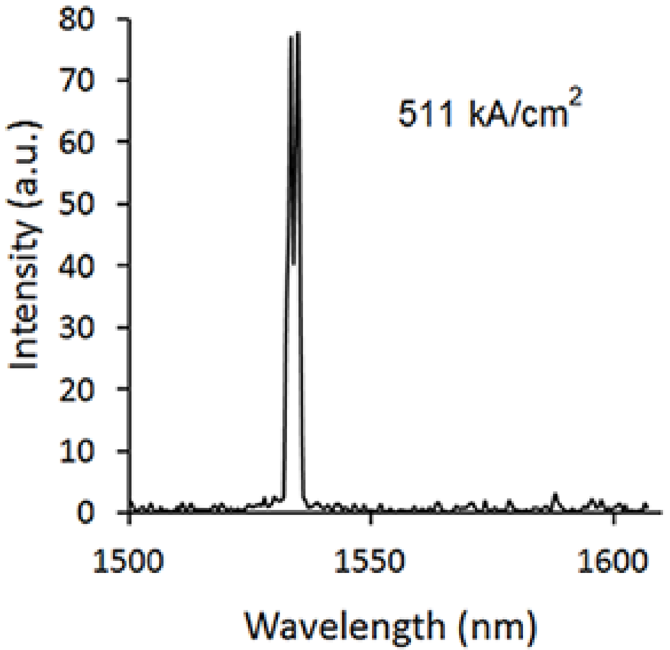
- **Ge is an indirect gap semiconductor.**
  - **It can theoretically become direct gap with 2% tensile strain, but the emission shifts from ~1550 nm to 2500 nm.**
- **For efficient emission at 1550-1620 nm: <u>0.2-0.3% tensile strain</u> plus <u>n-type doping</u> equates the energy of empty states in the Γ and L valleys.**

Lasing in Monolithic Ge-on-Si

Fabry-Perot Cavities, Electrical Pumping

L-I curve at 300K





Camacho et al., Opt. Exp. ***20,*** *11316 (2012)*

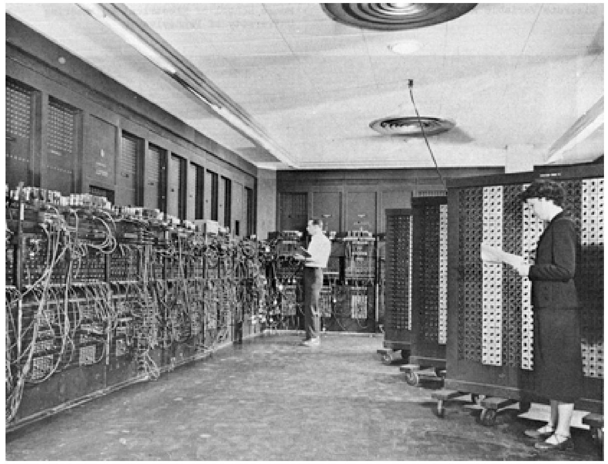
- **Laser linewidth < 1.2 nm**
- **Wide gain spectrum of about 200 nm**
- **Estimated gain of > 1000 cm^{-1}**
- **Output power up to 8 mW**

Monolithic Ge-on-Si lasers enable large scale electronic-photonic integration

Optoelectronic Systems Integration in Silicon

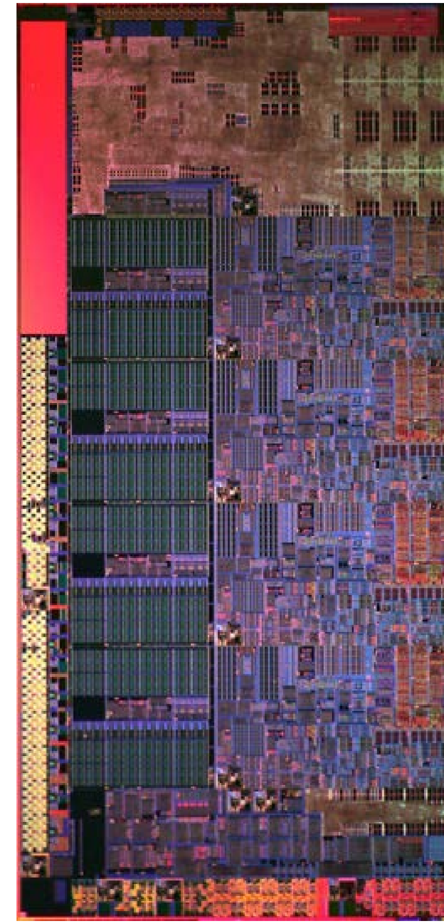
Prof Michael Hochberg, Univ of Delaware, OpSIS Foundry

An opportunity to support shared fabrication for silicon photonics

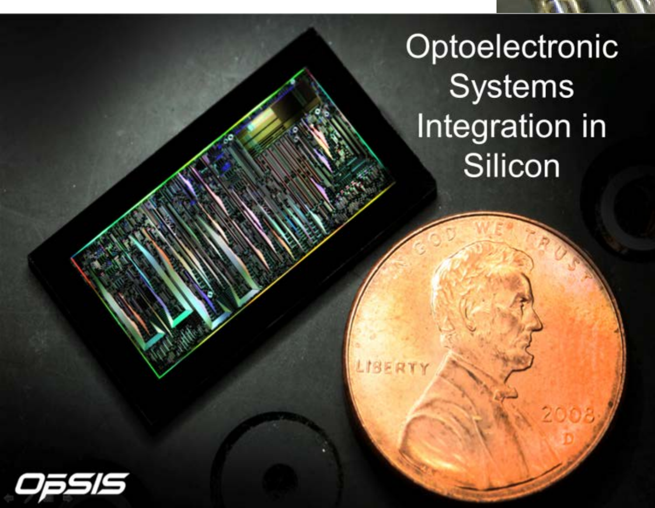


opsisfoundry.org/

60 Years



http://nanophotonics.ece.udel.edu/about the lab.html

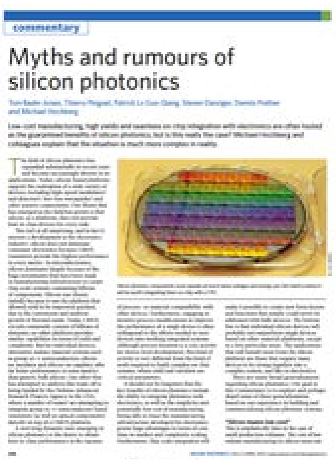


Why did silicon win?

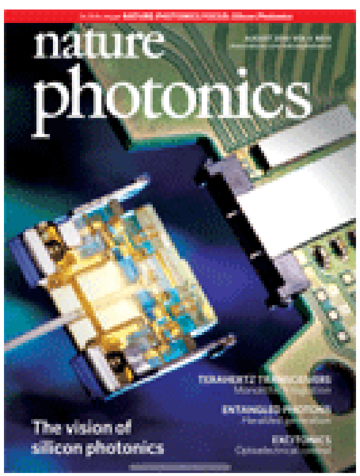
Not device performance…

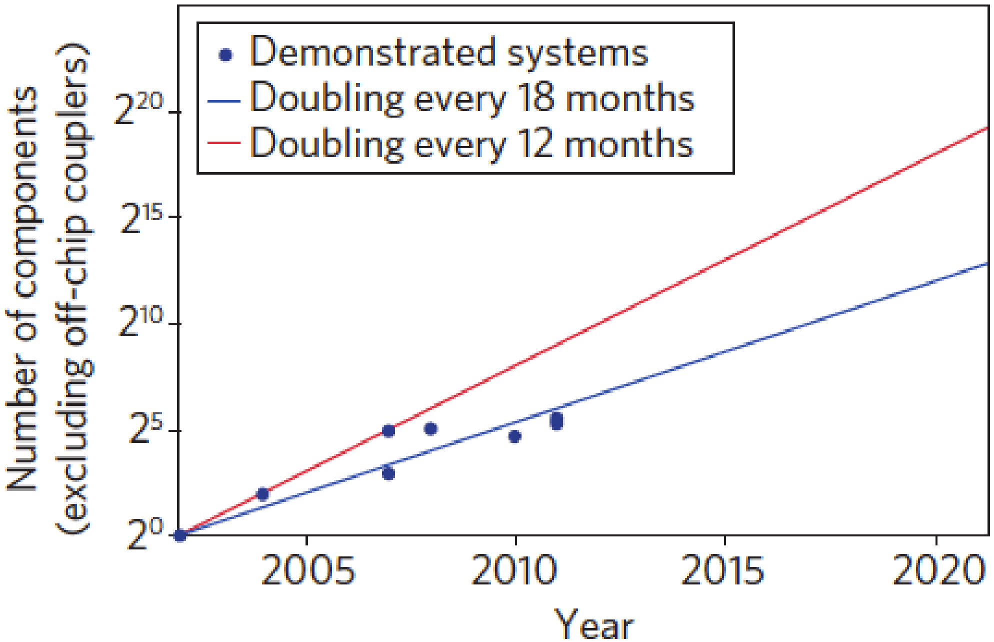
OpSIS - Scaling toward complex systems

- **We’re seeing a Moore’s Law-like growth in system complexity**
- **Doubling time is around a year**
- **Filling a reticle with photonic devices of ~500 square microns gets us to ~1.7M devices**


commentary

Myths and rumours of silicon photonics





OpSIS

An opportunity to support shared fabrication for silicon photonics

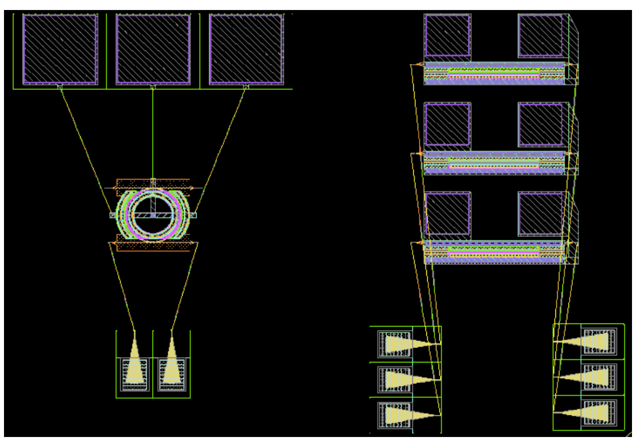
OpSIS Objective:

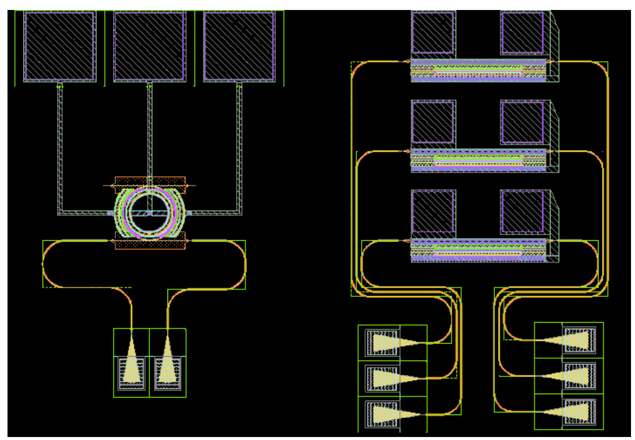
- Make integrated photonic fabrication flows easily and cheaply accessible to the research and development community through MPW shared-shuttle processes
- Drive process and tool development and standardization
- Provide educational resources and support to the community
- Develop an ecosystem of service and equipment providers to help move the silicon photonics community forward

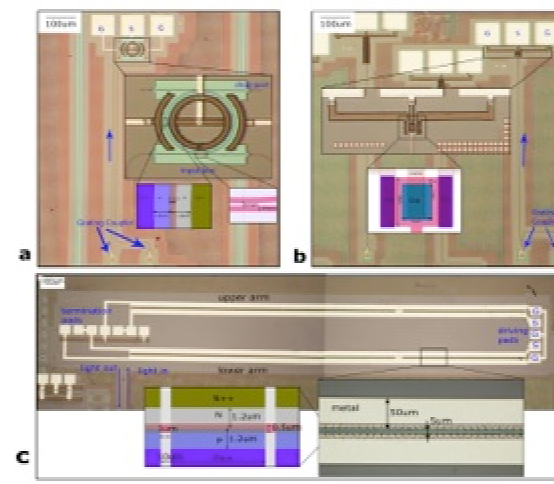
Luxtera Opens Industry Leading Silicon CMOS Photonic Process to OpSIS Community – 23 Jan 2012

OpSIS Research Activities

- **Development of design tools and design elements**
- **Demonstrations of complex systems**
- **Development of methodology and measurement tools/techniques**
- **Design automation**

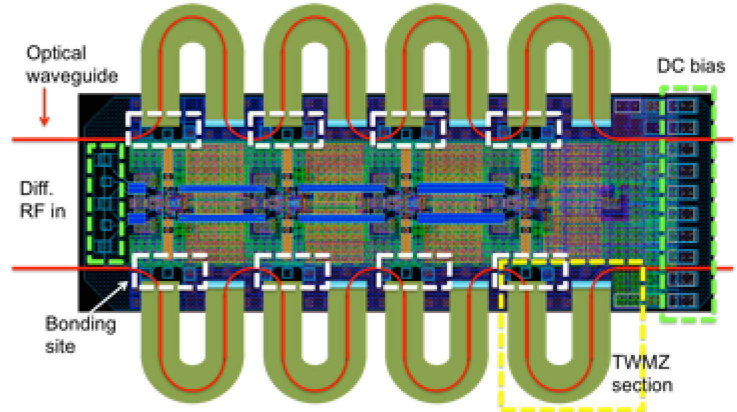


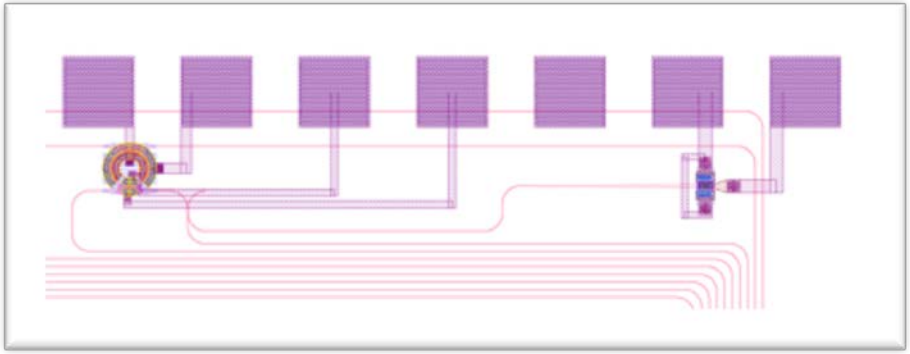


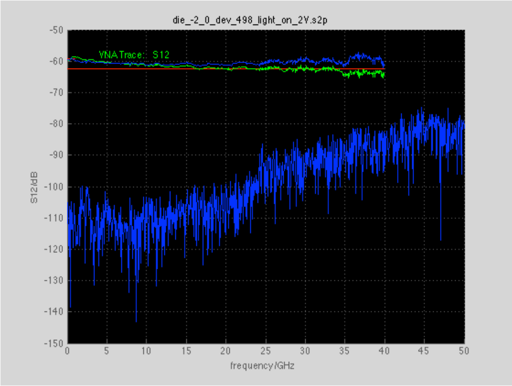


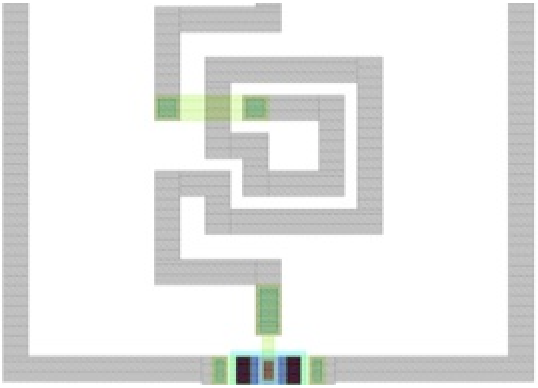
Recent results

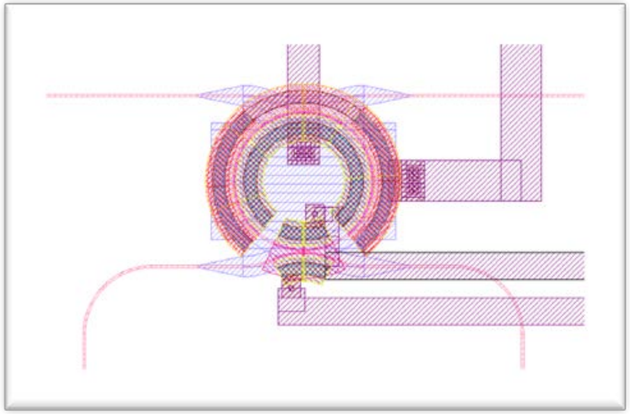
- IME001 delivered to ~30 users
- 25 Gbit/second platform – modulators, detectors, low-loss waveguides
- High-efficiency waveguide-coupled photodiodes at >40GHz
- World-record low-loss silicon modulators
- Ultra-low loss passives library – crossings, couplers, junctions, etc.
- Hybridized lasers
- Ongoing work on electronics integration







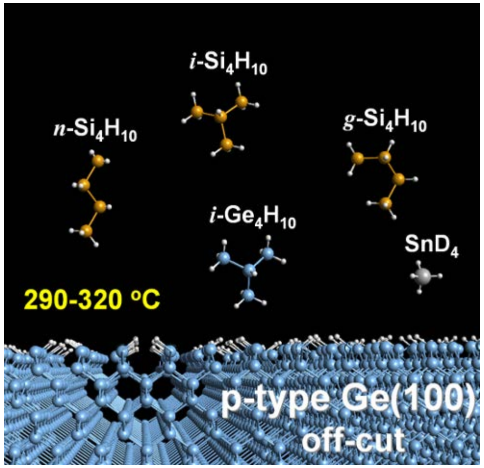


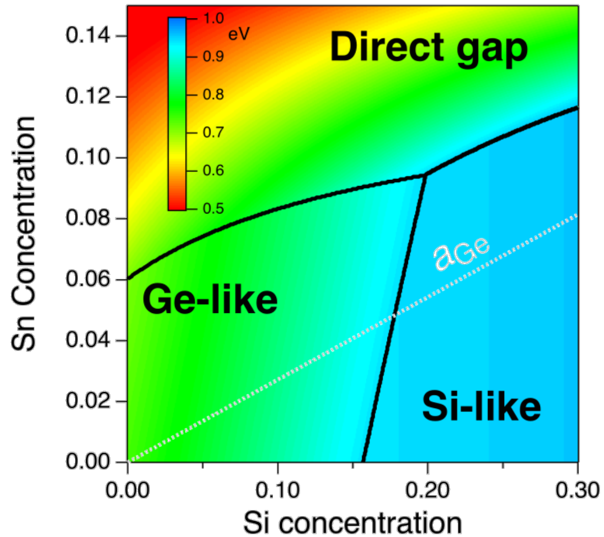


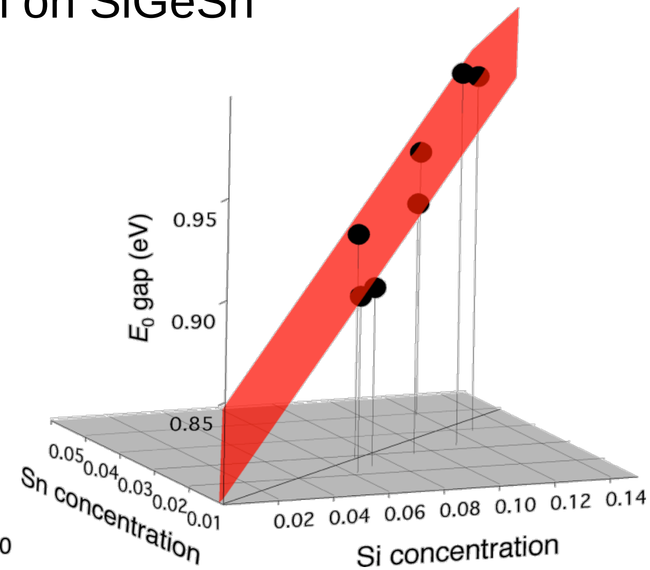
OpSIS

SiGeSn: a new material for Si photonics

Basic materials science Program on SiGeSn







The first group-IV material with a widely tunable 2D compositional space, SiGeSn makes it possible to decouple band gap and lattice constant, enabling wide-range applications from thermal imaging to photovoltaics to lasers.

Multi-PI efforts: Arizona State Univ (Kouvetakis, Menendez), Univ Delaware (Kolodzey), AFIT (Yeo), Univ of MA (Sun, Soref) & AFRL/RY (Claflin, Kiefer)

Outline/Agenda/Highlights
Terahertz Sources & Detectors

Terahertz Sources & Detectors

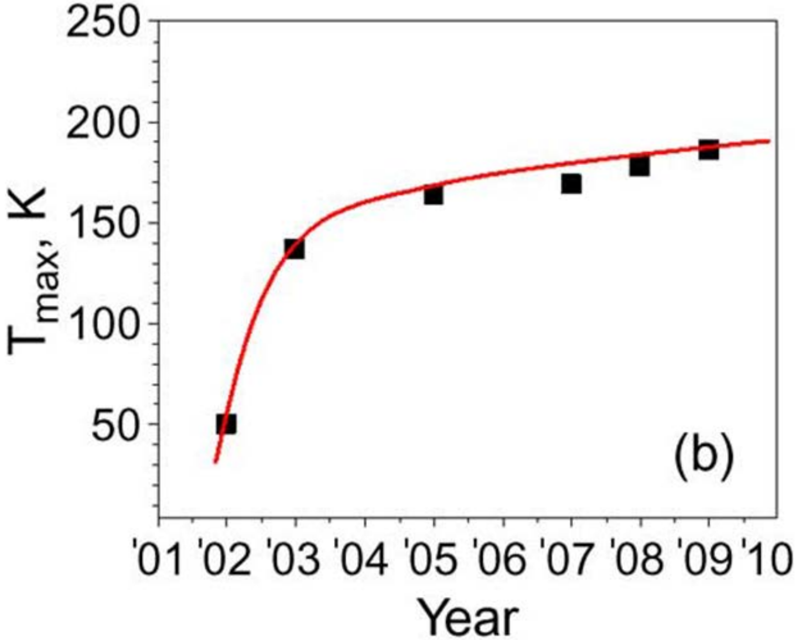
- Capasso – THz QCL
- Microtech Instruments, Inc.– THz Source (T)
- Agiltron's THz Camera Module (T)

Terahertz Quantum Cascade Nonlinear Optical Sources and Lasers

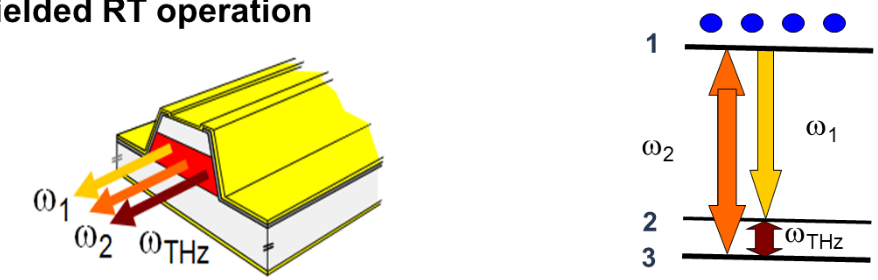
Prof.Federico Capasso - Harvard University

Temperature Performance of THz Quantum Cascade Lasers

The maximum operating temperature for THz QCLs (2-5 THz) has so far stubbornly remained below TE cooler values (< 200K)



An alternative approach pioneered by this group, based on nonlinear optics (THz difference frequency generation), has yielded RT operation



However power levels have remained so far below (10μW) those possible with THz QCLs (10-100 of mW)

A fundamental understanding of the temperature performance of THz QCLs is therefore necessary in order formulate practical strategies to overcome the current temperature barrier to THz lasing

<u>Conclusion/Follow-on:</u> Increasing the diagonality of the transition Semiconductor materials with energetic LO-phonon energies— such as GaN/AlGaN

Terahertz Parametric Oscillator

Microtech Instruments (Hurlbut), Inc & Stanford (Vodopyanov, Fejer)

- **http://www.mtinstruments.com/THz_Generators.html**

TPO system based on difference frequency generation in quasi-phase matched GaAS crystals placed inside an optical parametric oscillator (OPO) pumped by an ultrafast fiber laser

THz Generators

- THz Spectrometers
- THz Generators
- THz Detectors
- Other THz Products

Terahertz Parametric Oscillator: TPO - 1500

TPO-1500 is based on difference frequency generation in quasi-phase matched GaAs crystal placed inside an optical parametric oscilator (OPO) pumped by an ultrafast fiber laser. If generates 6-10 ps THz pulses at repetition rate of 110 MHz, delivering 0.1mW of average and more than 150 mW of peak power. Central wavelength of 1.5 THz and spectral width of 100 GHz fits perfectly into one of the atmospheric transmission windows, making this source ideal for THz imaging application.

High peak power makes TPO-1500 suitable for imaging systems employing non-linear optical effects, while sufficiently high average power makes it suitable for thermal detector array imaging as well.

2003-2012 Success Story: AFOSR (STTR), AFRL/RYH (David Bliss – OP-GaAs), DARPA (TIFT)

MICROTECH instruments, inc.

AFRL

Uncooled Photomechanical Terahertz Imagers

Agiltron, Inc. and University of Massachusetts Lowell

Air Force STTR Phase I Contract FA9550-10-C-0122

Technology: A passive, uncooled THz imager based on Agiltron's established photomechanical imager

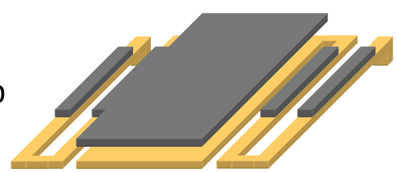
Objective

- Frequency range: **1–10 THz** (λ = 30–300 µm)
- Pixel resolution: **128×128**
- NEP: < **10^{-12} W/Hz$^{1/2}$**
- Detectivity: > **10^{10} cm Hz$^{1/2}$/W**
- Frame rate: > **30 fps**
- Operating temperature: **Rm temp (uncooled)**

Relevance: The photomechanical THz imager will reduce SWAP from rack-mounted systems consuming hundreds of watts to ultra-portable devices consuming **less than 10 W**, **eliminate the need for a THz source**, and slash the imager cost from over $200,000 to **less than $10,000**.

Technical Approach

The photomechanical THz imager contains a MEMS-based sensor chip that transduces THz radiation into a visible signal for capture by a high-performance CCD imager.



Phase II - Unfunded but Agiltron moved forward to develop the imager at own cost

Principal Investigator (PI)

Dr. Matthew Erdtmann
Agiltron, Inc.
Woburn, Massachusetts
merdtmann@agiltron.com

University Co-PI

Dr. Andrew Gatesman
Submillimeter-Wave Technology Laboratory
University of Massachusetts Lowell
Lowell, Massachusetts
andrew_gatesman@uml.edu

Outline/Agenda
Technology Transitions

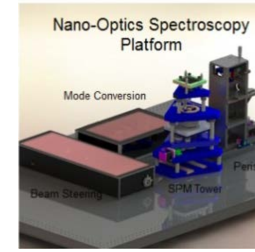
- **<u>Technology Transitions</u>**
- **RHK Technologies – Nanospectroscopy Platform**
- **FY03 Nanoprobe MURI – Boston Univ – results in IARPA – Subsurface Microscopy of Integrated Circuits**
- **FY08 Nanomembrane MURI, Univ of Tx, Austin, Prof Chen – NIH – Bio-Sensing**

- **Nanomembranes:**
  - **State of Saxony, Germany – Nanomembrane Research ($56Million)**
  - **FY08 Nanomembrane MURI (Univ WI) – "all the nanomembrane patents were recently non-exclusively licensed by Intel"**
  - **Flexible Electronics – electronic tattoos, nano-printing tech**
  - **Two Small Businesses: SysteMech, ProsperoBiosciences**

Nanospectroscopy Platform Development

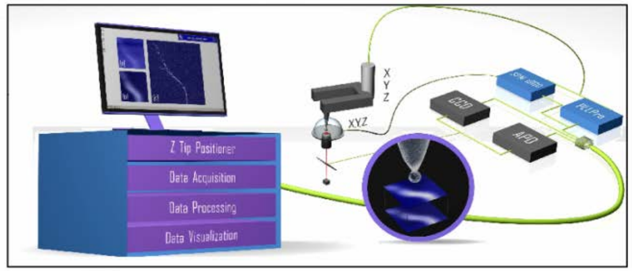
Phase II STTR topic number AF08-BT30

Ryan Murdick/John Keem PI (RHK Technology),
Prof L. Novotny, CoPI (U of Rochester)

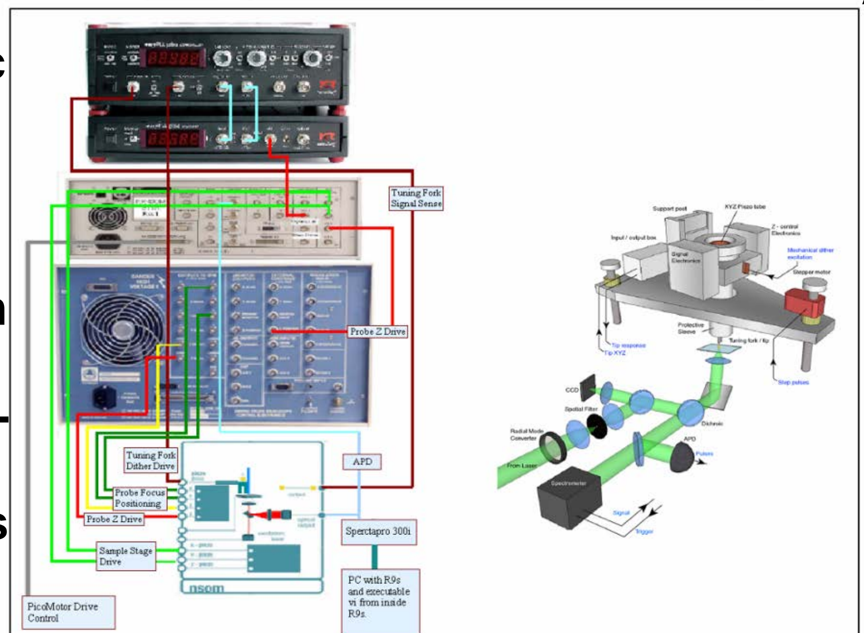


FY03 MURI Transition

Objective: Development of nanoscale spectroscopic imaging techniques providing chemically-specific information



Concept: Create an NSOM/SPM controller /data acquisition/real time analysis instrument integrated with an AFM/TERS NanoProbe.



Specification: achieve sub-100nm resolutions and acquire chemically-specific spectra in times of ~ 1-100 ms per pixel.

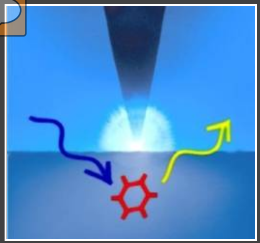
Implementation: Instrumentation & techniques for 1. Chemically-specific imaging with 2. High spatial resolution

Delivery: AFRL/RYMWA WPAFB Ken Schepler, 2013

RHK Technology
Imaging the Future of Nanoscience

Rochester Nano Optics

Ryan Murdick <ryan@rhk-tech.com>



HIGH-RESOLUTION SUBSURFACE MICROSCOPY OF INTEGRATED CIRCUITS

M. S. Unlu and B. B Goldberg (Boston University)

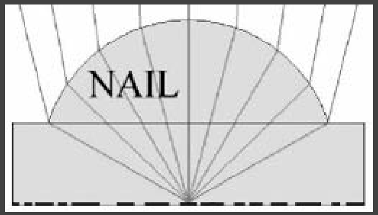
FY03 MURI Transition

Objective:

- Development of high-resolution subsurface microscopy techniques for integrated circuit (IC) imaging with angular spectrum and polarization control

Method:

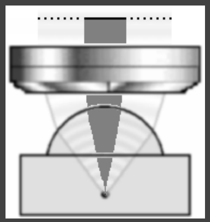
- Focal field engineering using Numerical Aperture Increasing Lens (NAIL) microscopy

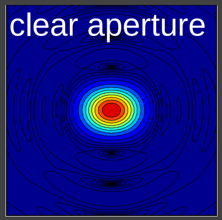


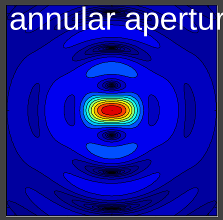
- NAIL provides NAs of up to 3.5 in silicon IC imaging which allows for vectorial focusing opportunities

Approach:

- Annular pupil plane apertures with linearly polarized light.

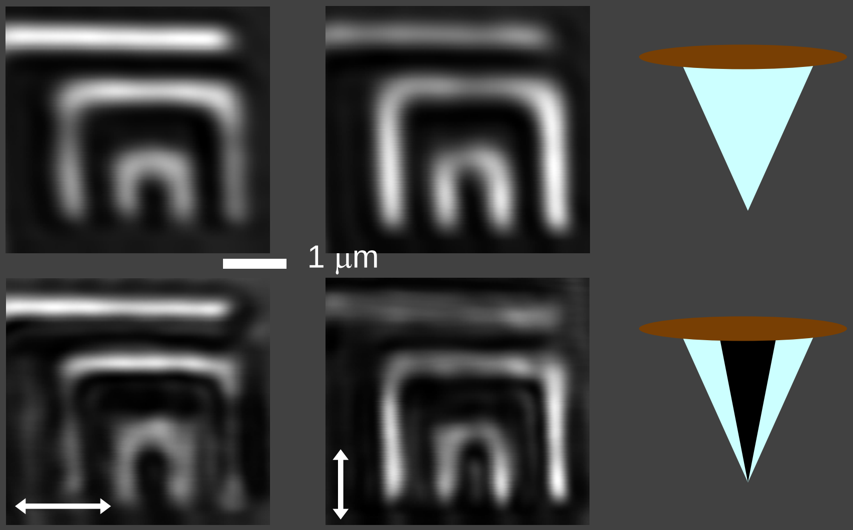






Achievements:

- Confocal imaging of passive polysilicon structures. 145nm ($\lambda_0/9$) resolution in subsurface backside microscopy of ICs (Opt. Lett. 2008).

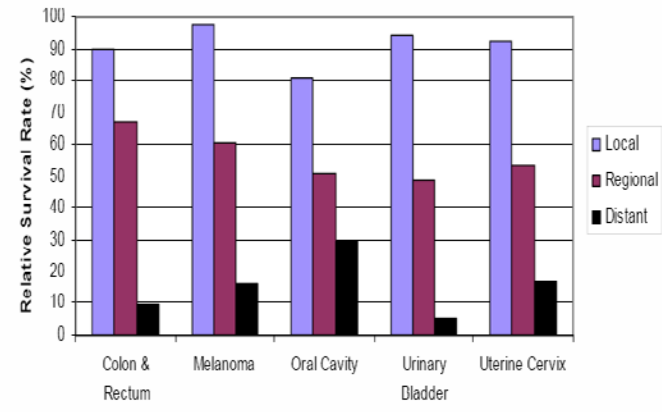


MURI to $5M IARPA program:

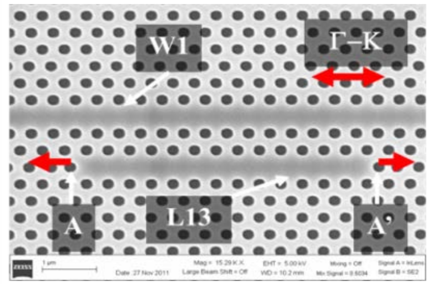
- Achievement of sub-surface nanoscale imaging with FY03 MURI was integral in winning IARPA program to advanceto 22nm and 11nm node and transition to industry

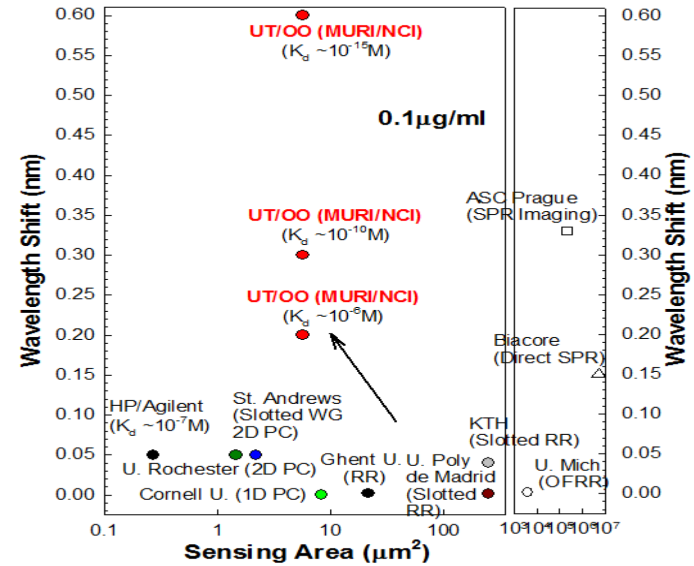
AFOSR/DoD MURI Spin-off Program funded by NCI/NIH

Silicon Nanomembrane Photonic Crystal Microcavities for High Sensitivity Bio-Sensing



Early detection and subsequent treatment is the greatest single achievement that can be made in cancer management.





Univ Tx, **Ray T. Chen** et al, Opt. Lett. 37 (8), (2012)

Important achievements through AFOSR MURI program that facilitate the support from NCI/NIH SBIR Program for early cancer detection:

1.High coupling efficiency methods to slow light silicon nanomembrane photonic crystal waveguides developed in MURI enabled enhanced coupling to L7 and L13 resonance in the NCI SBIR program

2.Slow light effect of PCW in silicon nanomembrane enhances the detection sensitivity due to longer interaction time between analytes and the sensing light

3.L13 and L7 silicon nanomembrane PC microcavities achieve high Q~26,760 in liquids due to better optical confinement and higher sensitivity bio- and chemical sensing than other PC microcavities due to larger optical mode overlap with analytes.

FY08 MURI at Univ Tx, Austin with Prof Chen (Contr. # FA9550-08-1-0394): Gernot S. Pomrenke
NCI SBIR Ph2 (Contr. #HHSN261201000085C): Deepa Narayanan

Interactions - Program Trends

AFOSR PMs

RSE: Reinhardt, Weinstock, Curcic, Nachman, Thomas, Hwang

RSL: Bonneau, DeLong

RSA: C. Lee, Harrison

RSPE: Lawal, E. Lee

AFRL – RY, RI, RX, RV, RW, 475th/RH

AFRL – HPC Resources

EOARD – Gonglewski & LtCol Pollak

AOARD – Erstfeld, LtCol Low

SOARD – Fillerup, Pokines

ONR, ARO – MURI etc eval team

- Nanophotonics — more ↗
  - ---- Plasmonics, Nonlinear, MetaPhotonics
  - ---- Chip-scale, 3D, computation
  - ---- 2D materials
- Integrated Photonics, Silicon Photonics — more ↗
- Reconfigurable El/Ph & Optical Computing — lower ↘
- Quantum Computing w/ Optical Methods (QIS) — const →
- Nanofabrication (MURI, OSD & AFOSR STTR) — const →
- Nano-Probes — lower ↘
- Terahertz Sources & Detectors — lower ↘
- THz/Microwave/Millimeter Wave photonics — *change*

Optoelectronic Information Processing

Nanophotonics, Plasmonics, Integrated & Silicon Photonics

Demo'd first plasmonic all-optical modulator, plasmon enhanced semiconductor photodetector, plasmon laser, superlens, hyperlens, plasmonic solitons, slot waveguide, "Metasurface" collimator etc

AFOSR is the scientific leader in nanophotonics, nanoelectronics, nanomaterials and nanoenergetics – one of the lead agencies to the current OSTP Signature Initiatives "Nanoelectronics for 2020 and Beyond" and coordinating member to "Sustainable Nanomanufacturing"

Close coordination within AFRL, DoD, and 26 federal agencies as NSET member to the National Nanotechnology Initiative (NNI) http://www.nano.gov/partners

FY12 Selected Awards / Prizes / Recognitions

SMART transition – Huffaker, UCLA student to Bedford AFRL/RY

Luke Lester IEEE fellow

P. Bhattacharya – Heinrich Welker Prize

" World Changing Ideas 2012" Electronic Tattoos, sciencemag , *J. Rogers UICU*

http://www.nano.gov/initiatives/government/signature

Conclusion & Future

Integrated Photonics: Engine for 21st Century Innovation – foundation for new IT disruptive technologies

Key Program ideas, thrusts, and challenges:

Plasmonics & Metamaterials/ Metasurfaces/ Meta Photonics
Bandgap engineering, Strain engineering, Index of refraction eng.
Subwavelength - Operating beyond the diffraction limit; hole transmission
Integrated photonics & establishing a shared, rapid, stable shuttle process for high-complexity silicon electronic-photonic systems (MOSIS model)

Transformational Opportunities

Reconfigurable chip-scale photonic
THz & Microwave/Millimeter Wave photonics,
Integrated photonics circuits

opsisfoundry.org/

Future: Metasurfaces/ Meta Photonics, Quantum Integrated Nanophotonics, Ultra Low Power, Graphene Optoelectronics, 3D Photonics

STTR Need: Integrated Silicon Photonics, Photonics Fabication & Packaging, SiGeSn material development

gernot.pomrenke@afosr.af.mil