



Integrity ★ Service ★ Excellence

Photonics & Optoelectronics

Date: 7 MAR 2013

**Gernot S. Pomrenke, PhD
Program Officer
AFOSR/RTD**

Air Force Research Laboratory

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 07 MAR 2013		2. REPORT TYPE		3. DATES COVERED 00-00-2013 to 00-00-2013	
4. TITLE AND SUBTITLE Photonics and Optoelectronics				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research ,AFOSR/RTD,875 N. Randolph,Arlington,VA,22203				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Presented at the AFOSR Spring Review 2013, 4-8 March, Arlington, VA.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 37	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



2013 AFOSR SPRING REVIEW



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**



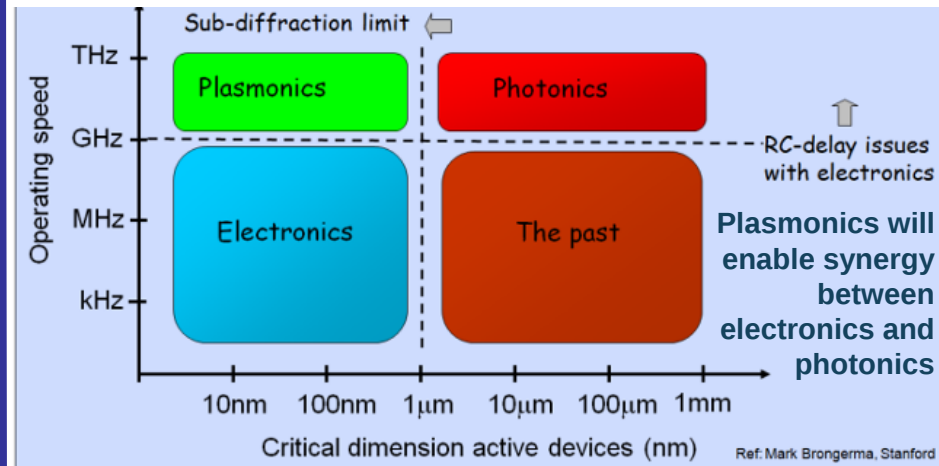
Optoelectronics & Photonics

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**

Vasilev – RY: Programmable Reconfigurable Sensors

**Eyink – RX: RE-mono-pnictide Nonlinear Optical
Properties**

**Weyburne – RY: Laser Photovoltaics for Remote
Sensors**

New

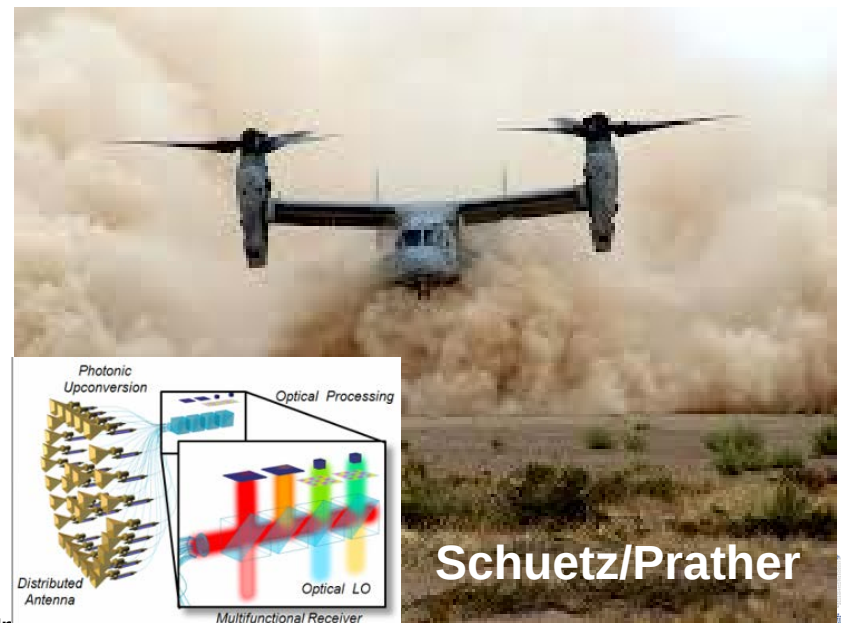
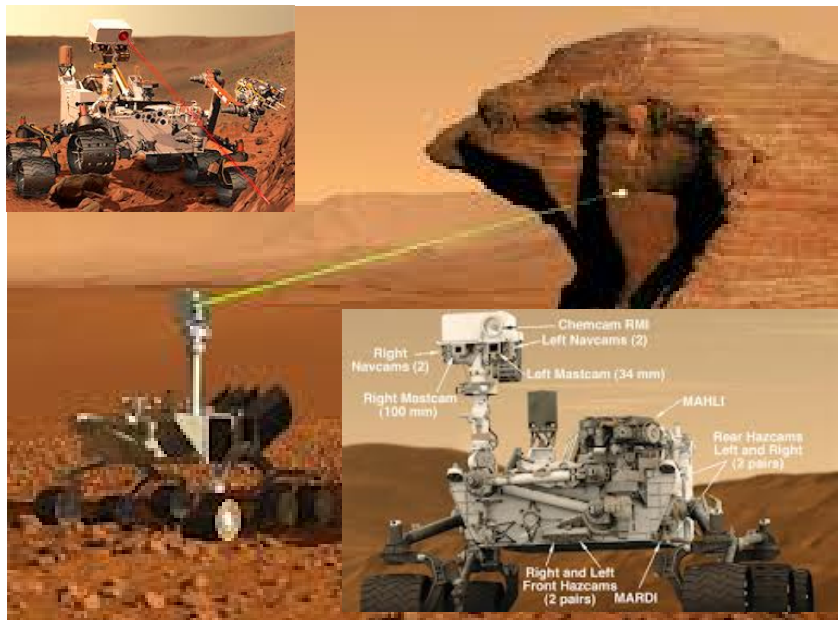
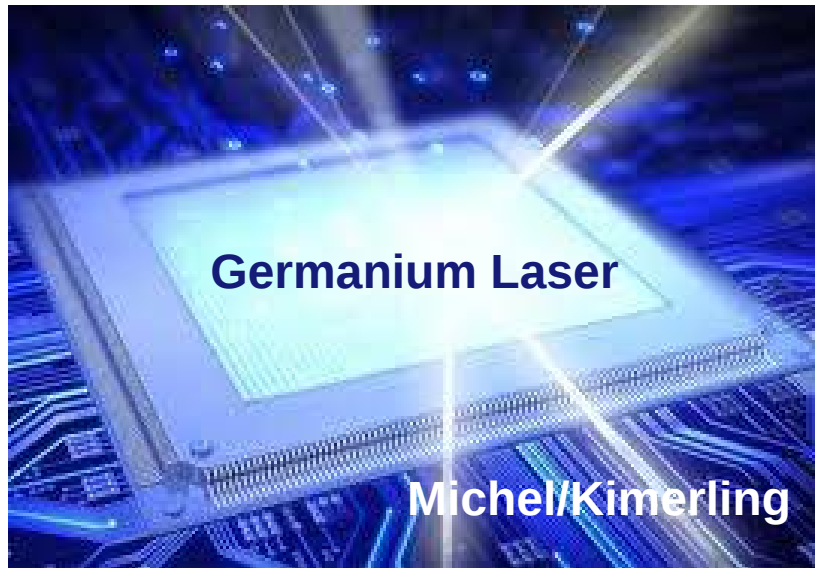
Heckman – RY: Sensor Printed Electronics

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):**

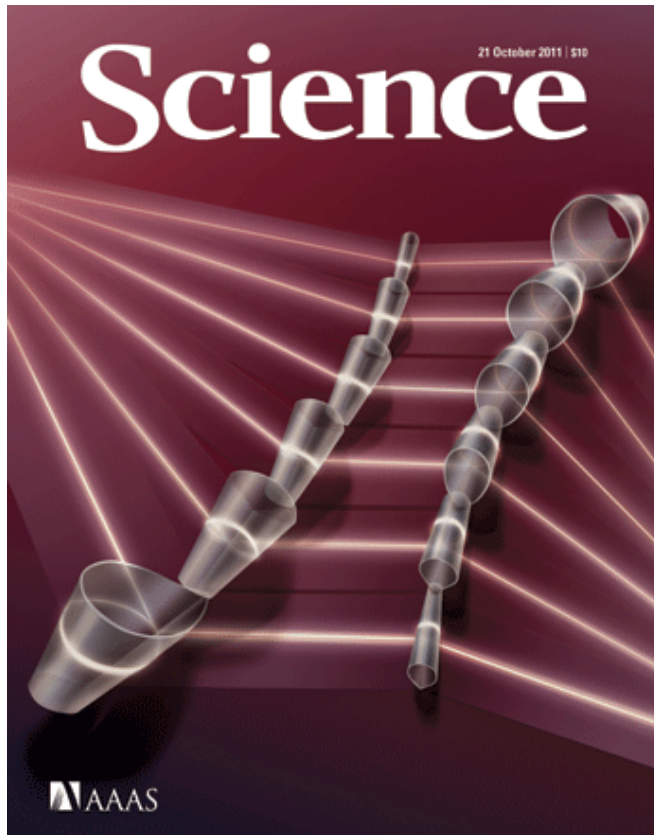
$$\sin(\theta_t)n_t - \sin(\theta_i)n_i = \lambda \nabla \Phi / 2\pi \quad (1)$$

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

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.

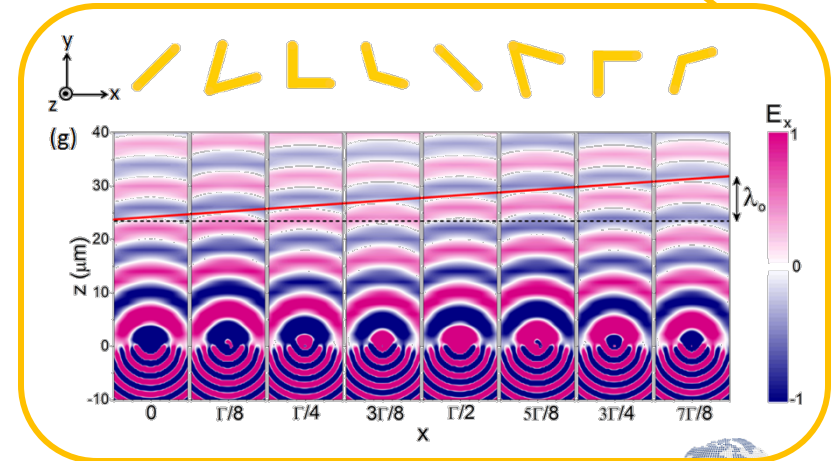
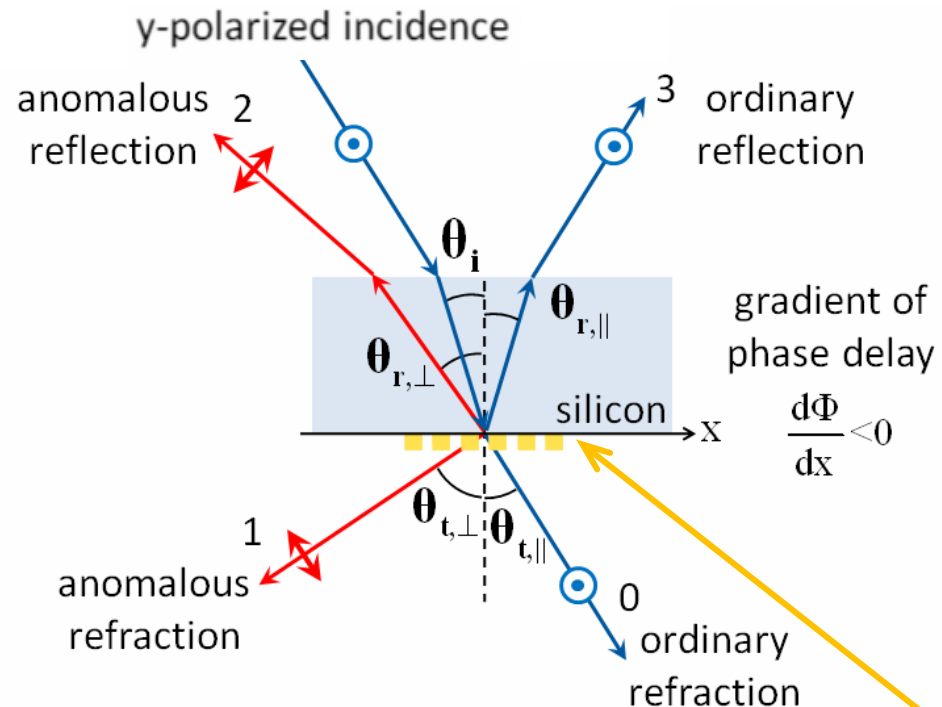
$\nabla \Phi$ is essentially an additional momentum contribution that is introduced by breaking the symmetry at the interface.

Generalized Snell's law



Demonstrated at $8\ \mu\text{m}$ wavelength

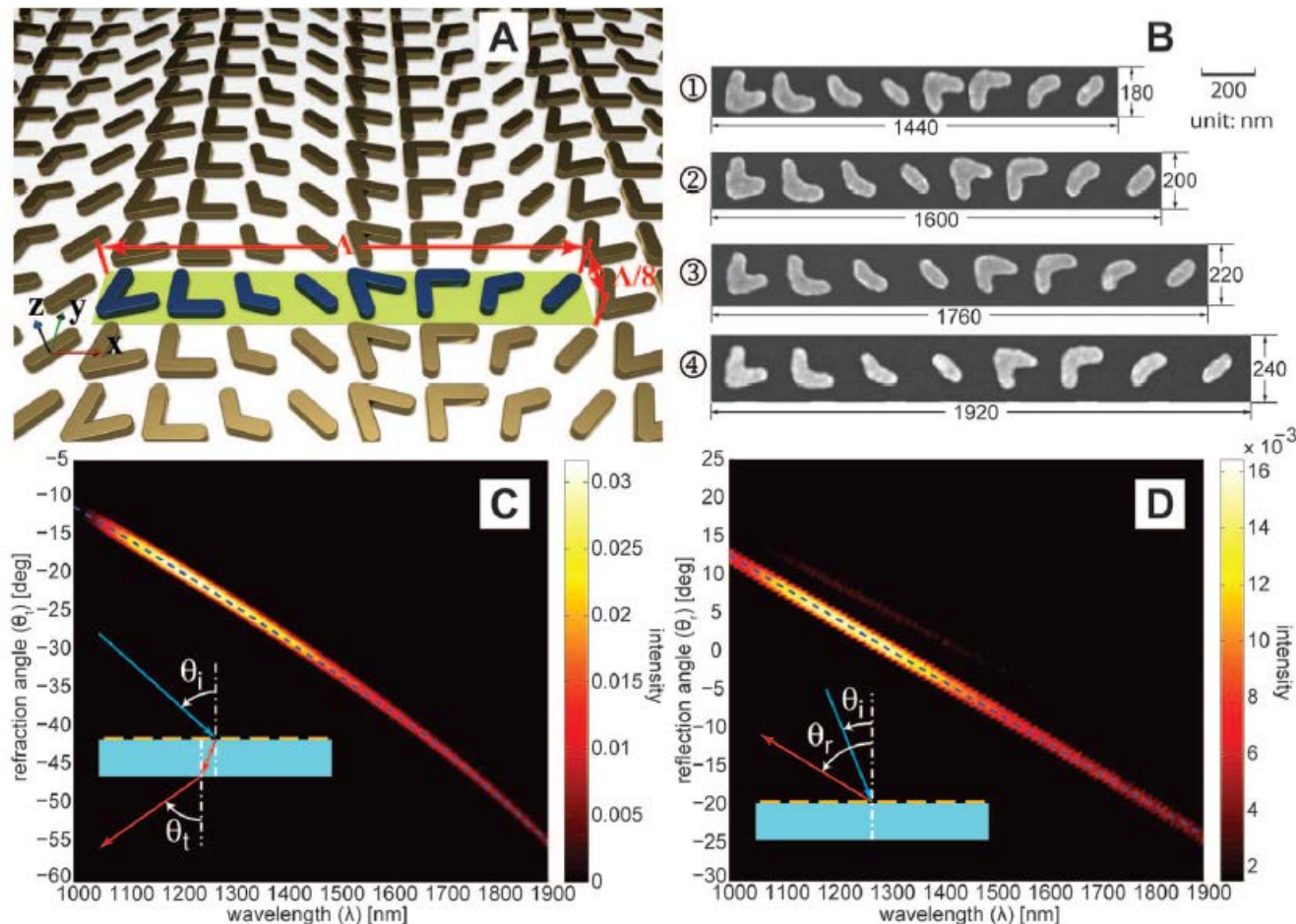
Unit cell of a metainteface that can create circularly polarized anomalous refraction when excited by incident light polarized along the vertical direction



Broadband Light Bending with Plasmonic Nanoantennas, Purdue (cont)

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 μm , accomplished with a relatively thin 30-nm ($\sim \lambda/50$) plasmonic nanoantenna interface.



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



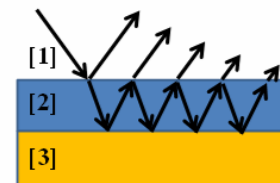
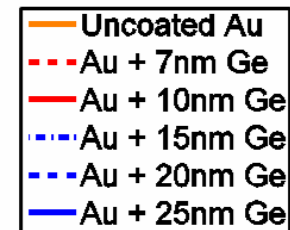
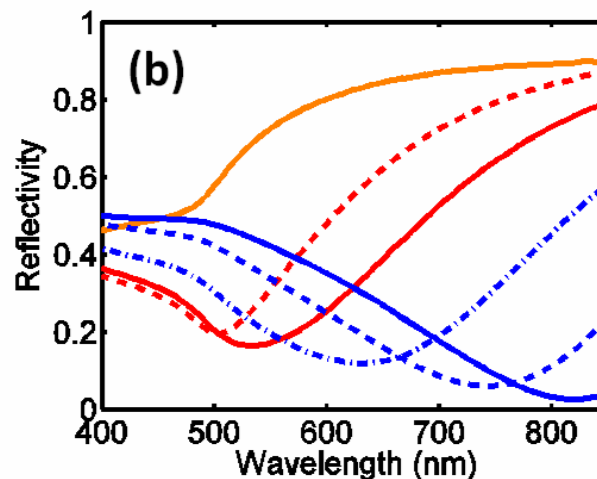
Optical Interference Coatings

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



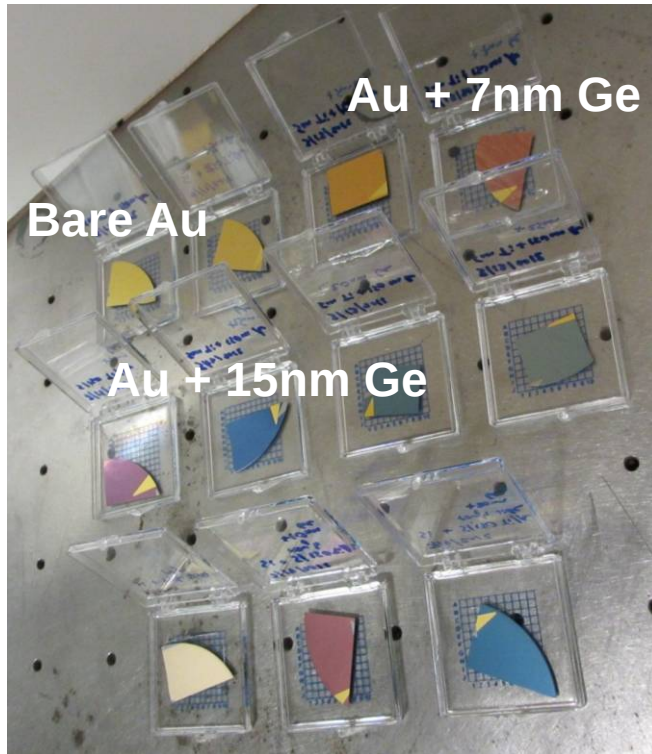
- ▶ Last half century: optical coatings and filters using thin film interference effects (color/dichroic coatings, anti-reflection, high-reflection, etc)
 - ▶ Existing thin film optical coatings use low-loss dielectric layers with thicknesses on the order of a wavelength of light
- ▶ Harvard technique 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”



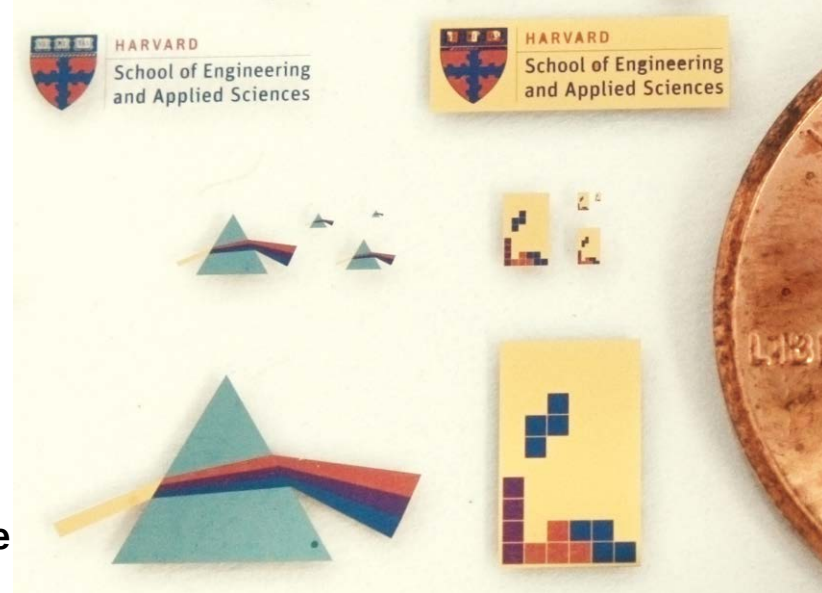
Coloring Metals with Ultra-thin Coatings

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 $\lambda/4$ 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

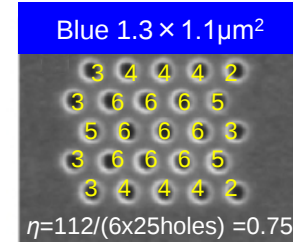
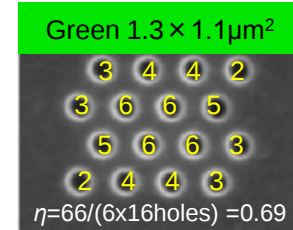
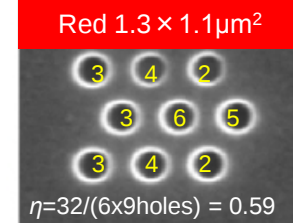
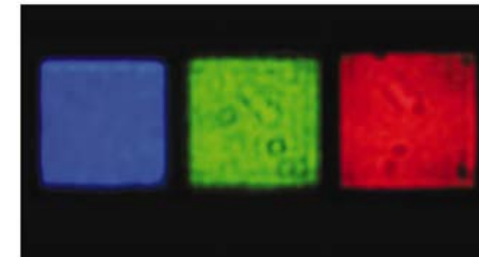
Harry Atwater, Caltech

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 $1.3 \times 1.1 \mu\text{m}^2$ 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



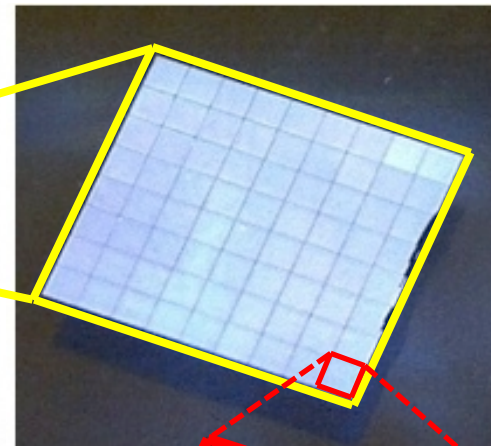
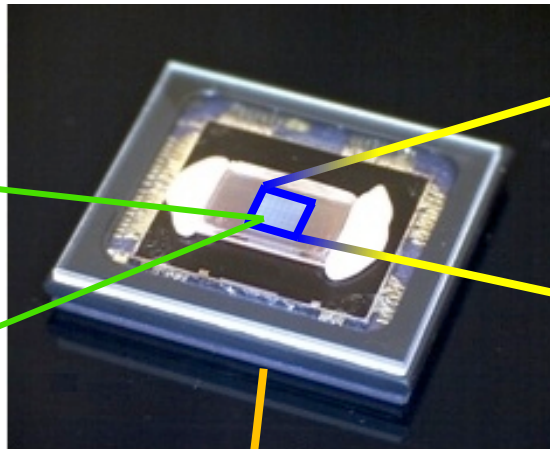
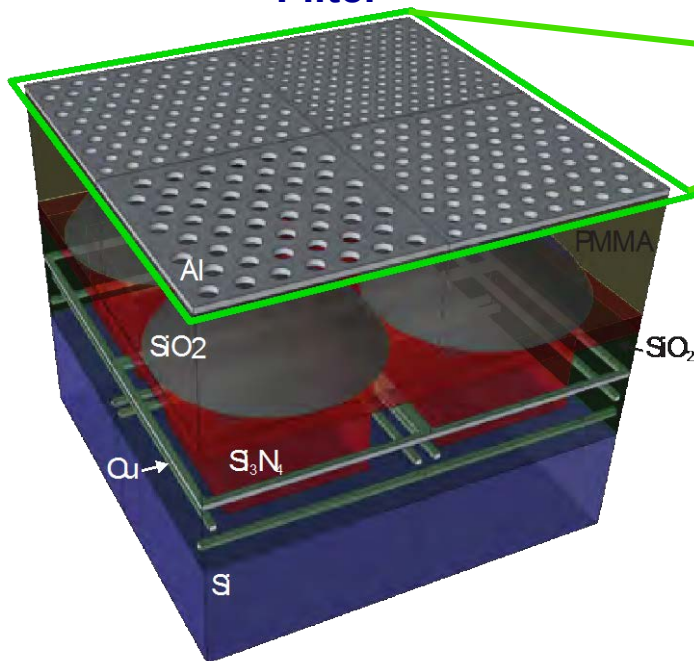
Caltech



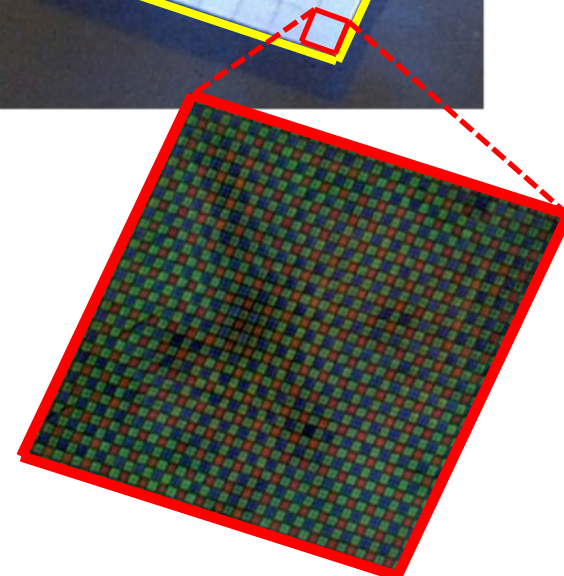
Full Color Camera via Integrated Plasmonic Filters on CMOS Image Sensor

360×320 5.6×5.6μm² pixels
(2.016×1.792 mm²)

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



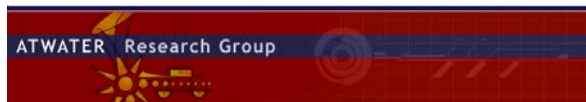
Mount on evaluation board with
C-mount lens and f/number
controller



40×40 filter blocks
(224×224 μm²)

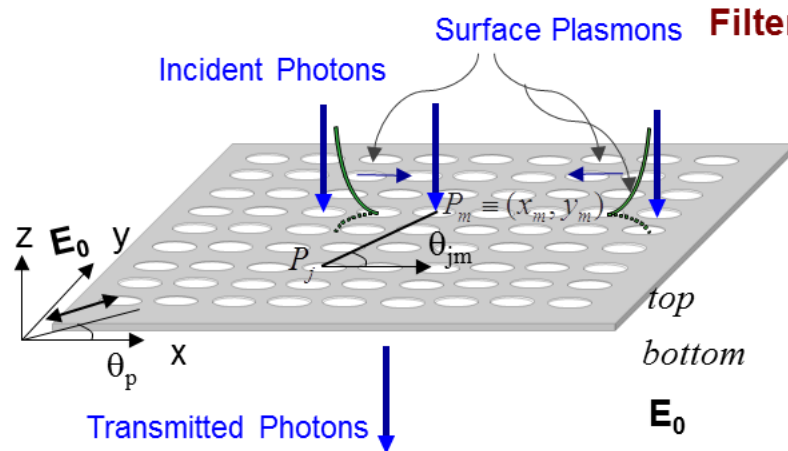


Caltech

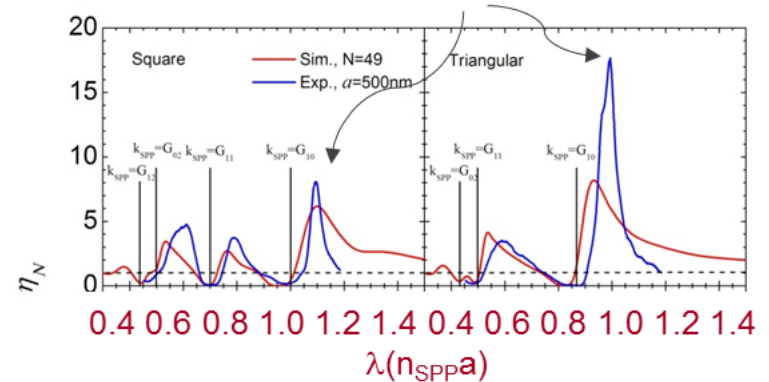




Plasmonic Hole Array Filtering Arises from Interference of Incident Photons and Surface Plasmons



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 $\rightarrow$ 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 $\rightarrow$ 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)



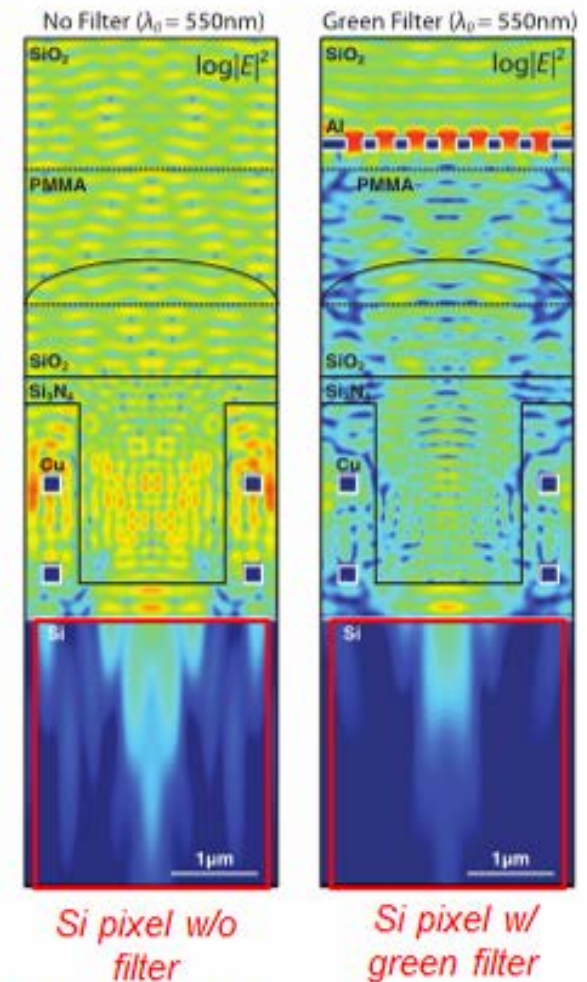
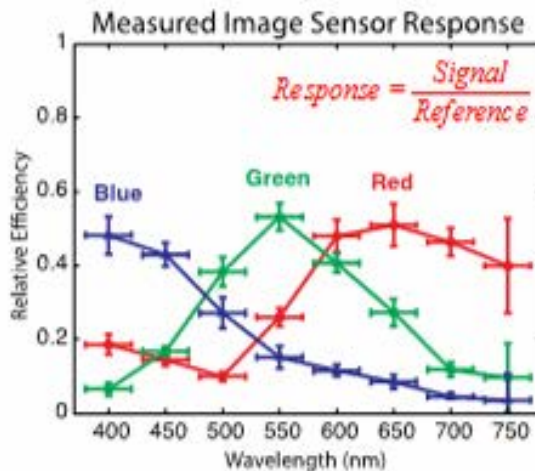
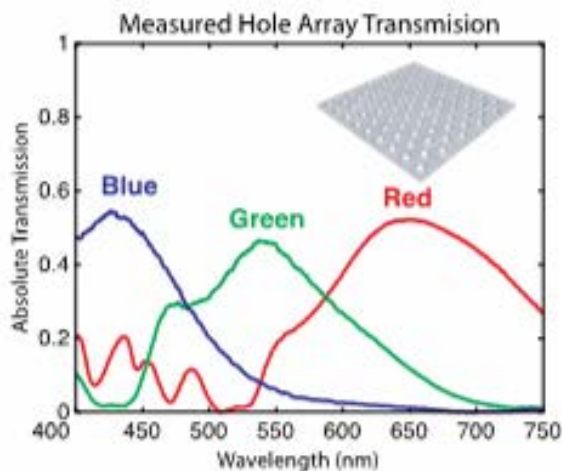
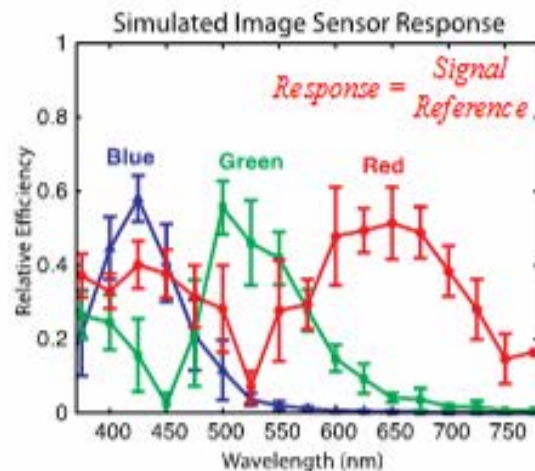
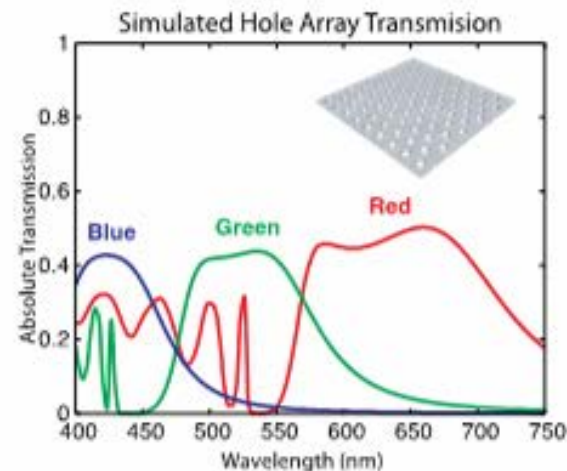
Caltech



DISTRIBUTION STATEMENT A - Unclassified, Unlimited Distribution



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



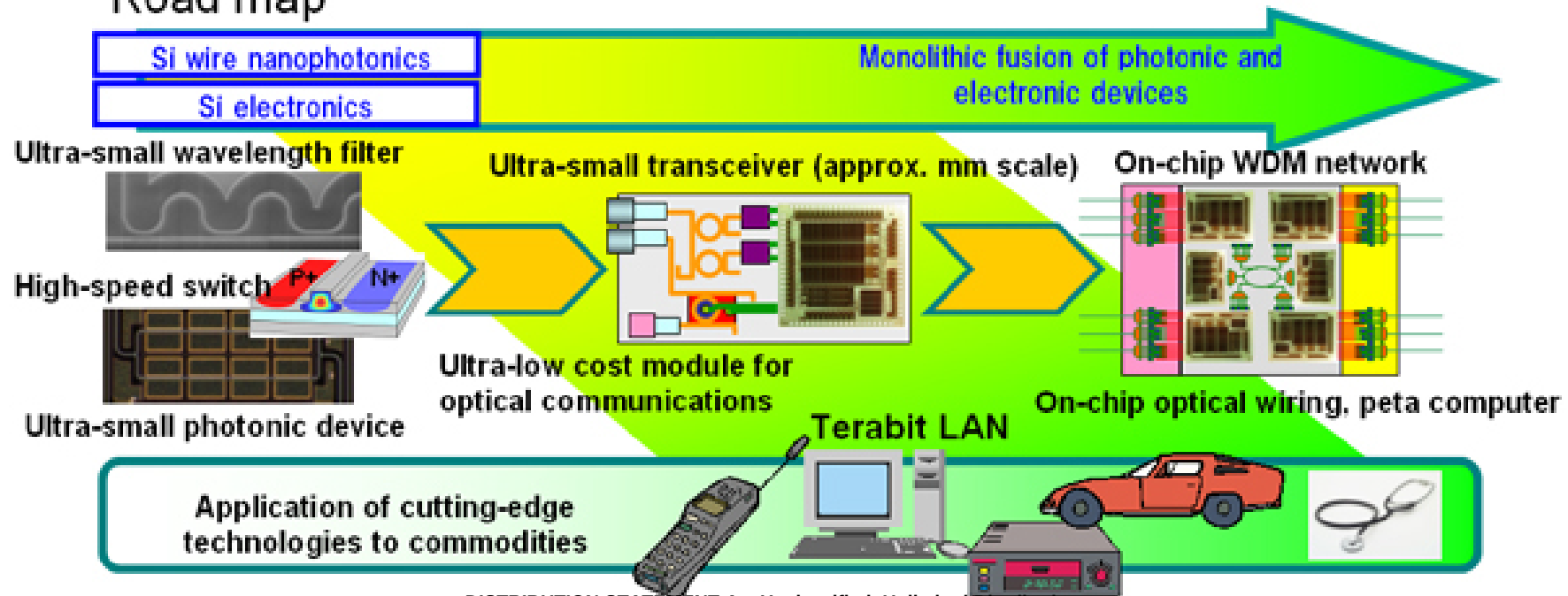
Outline/Agenda/Highlights

Integrated Nanophotonics & Silicon Photonics



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

Road map





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

Approach

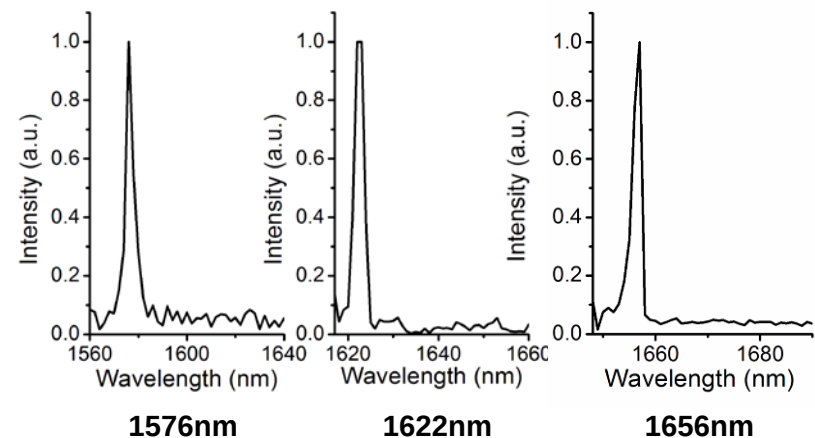
Germanium on Si

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

Key Findings

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

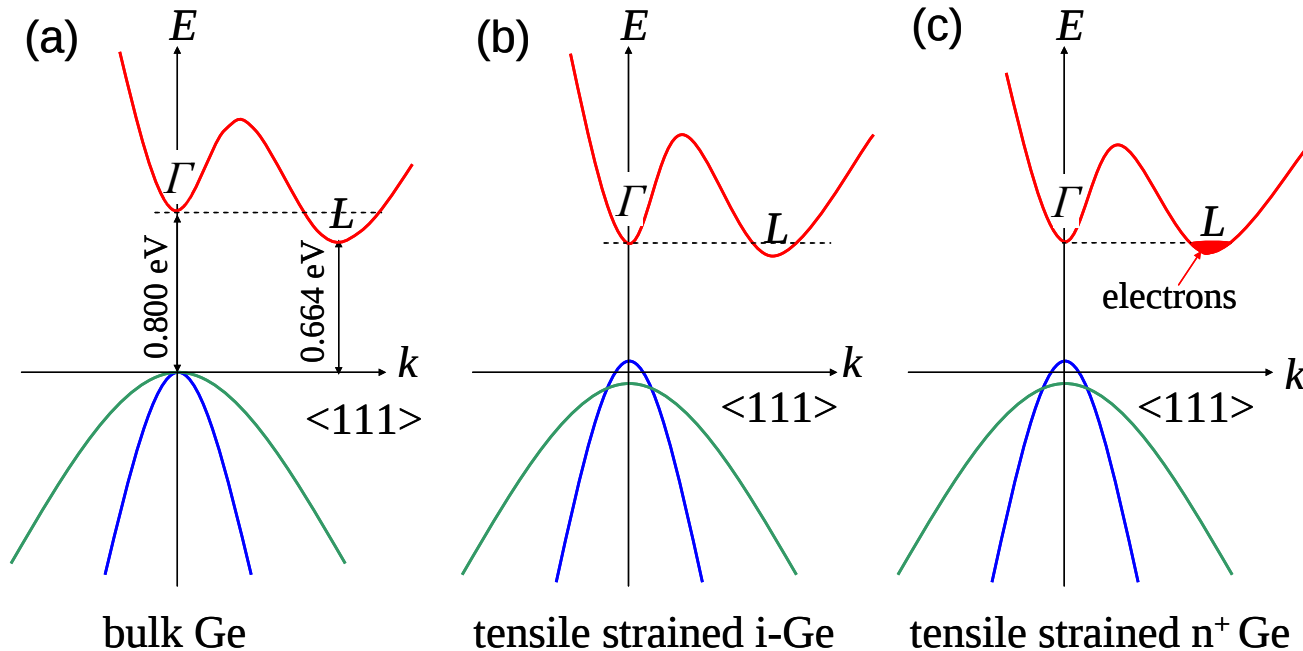
Laser lines in n-type Ge at 300K





Direct Gap Emission from Germanium

Tensile Strain and N-type doping



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

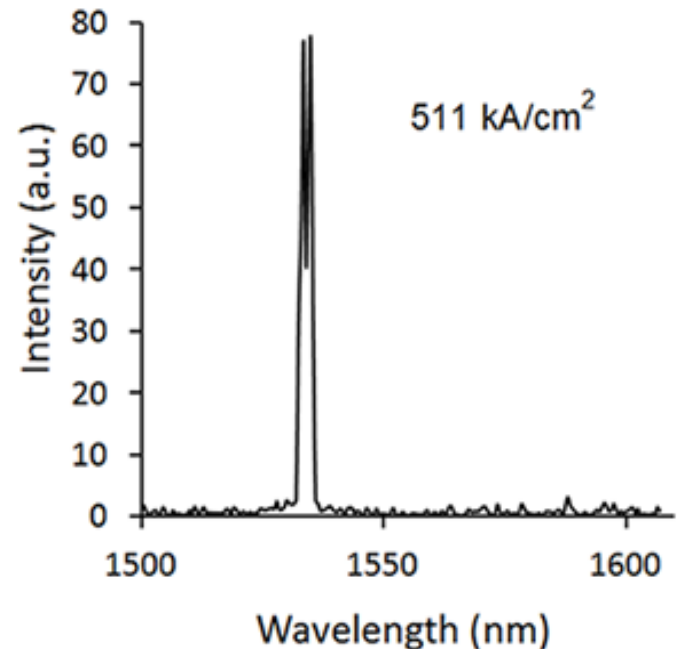
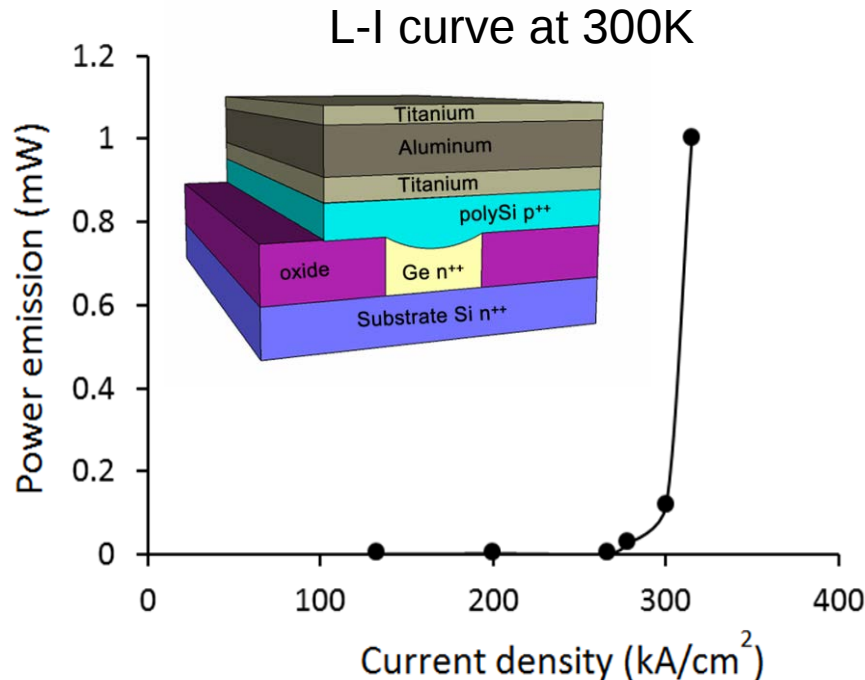
- Ge is an indirect gap semiconductor.
 - It can theoretically become direct gap with 2% tensile strain, but the emission shifts from ~1550 nm to 2500 nm.
- **For efficient emission at 1550-1620 nm: 0.2-0.3% tensile strain plus n-type doping** equates the energy of empty states in the Γ and L valleys.



Lasing in Monolithic Ge-on-Si



Fabry-Perot Cavities, Electrical Pumping



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

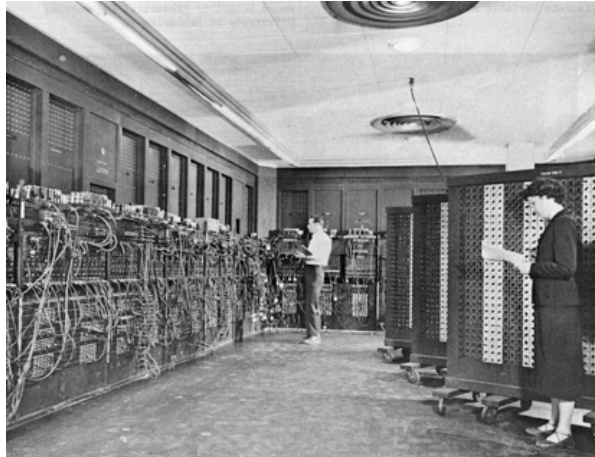


Optoelectronic Systems Integration in Silicon

Prof Michael Hochberg, Univ of Delaware, OpSIS Foundry



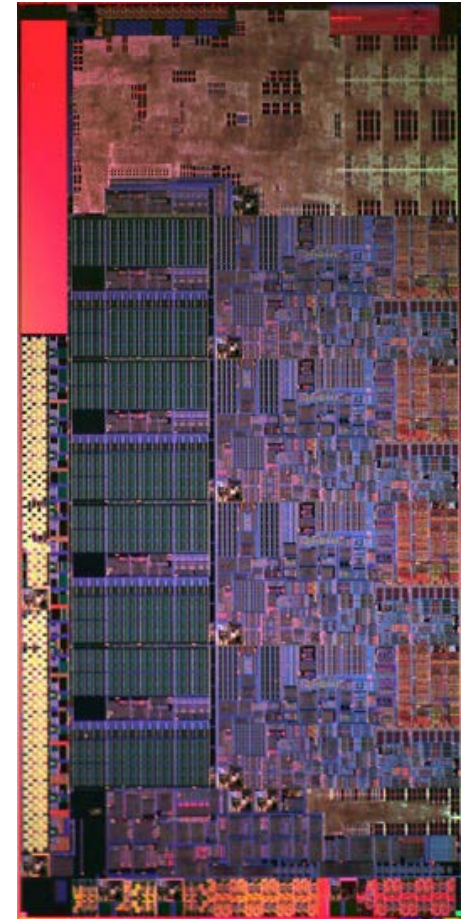
An opportunity
to support
shared
fabrication for
silicon
photonics



opsisfoundry.org/



60
Years



Optoelectronic
Systems
Integration in
Silicon



Why did silicon win?
Not device performance...

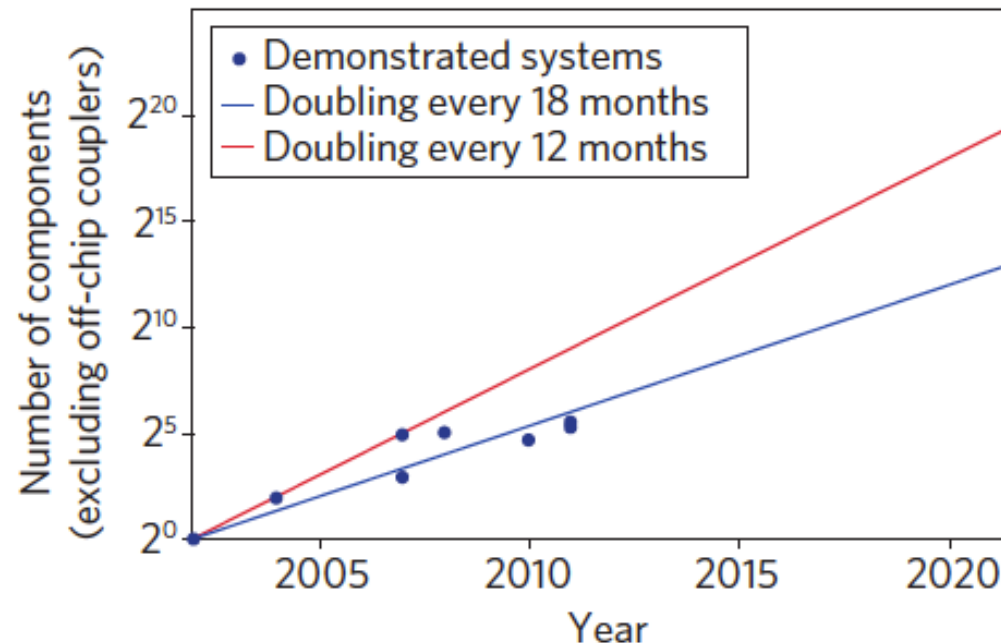
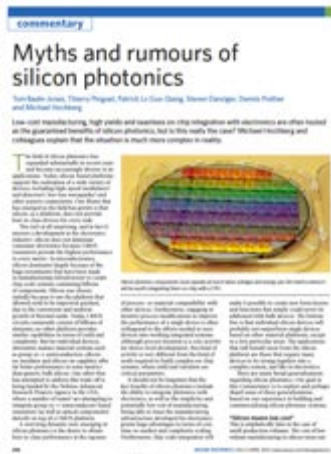
http://nanophotonics.ece.udel.edu/about_the_lab.html



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





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

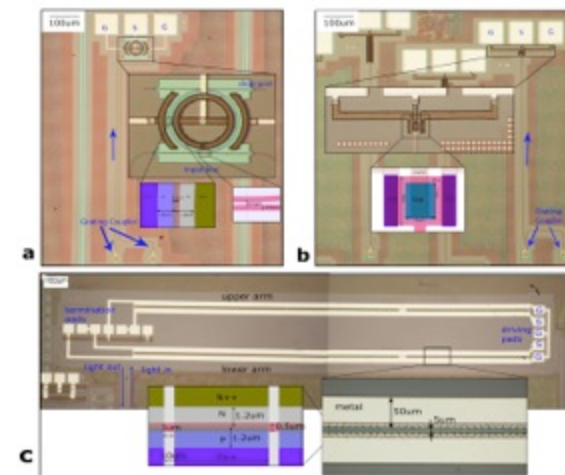
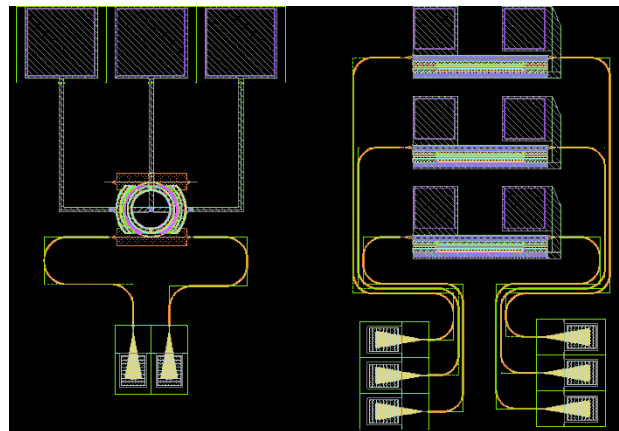
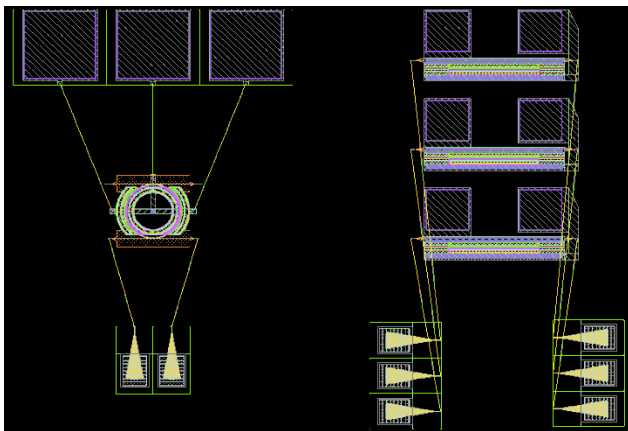
Luxtera Opens Industry Leading Silicon CMOS Photonic Process to OpSIS Community – 23 Jan 2012



OpSIS Research Activities

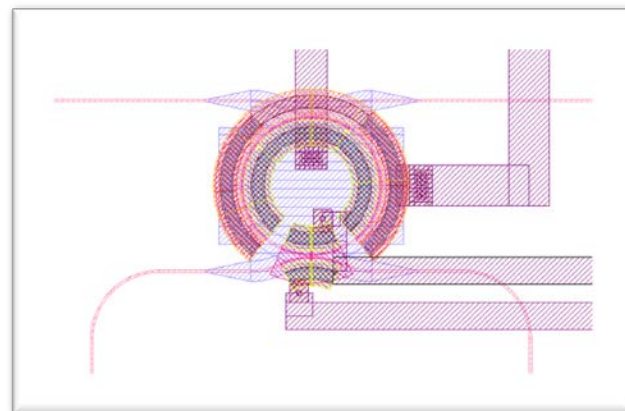
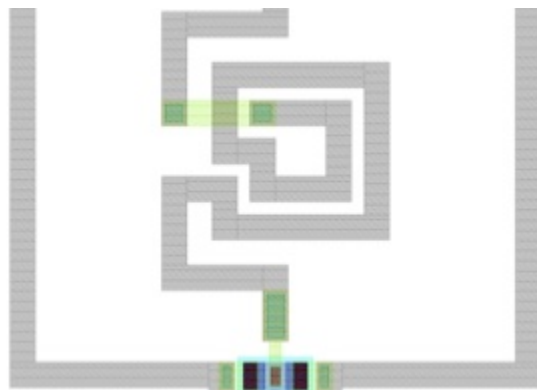
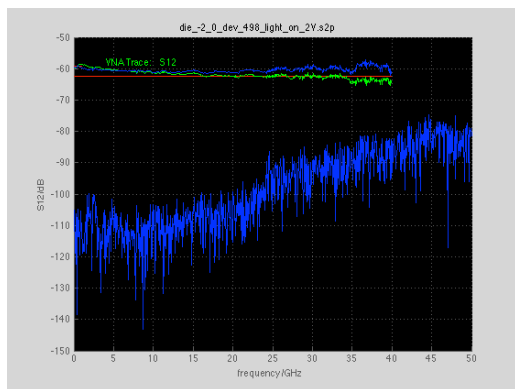
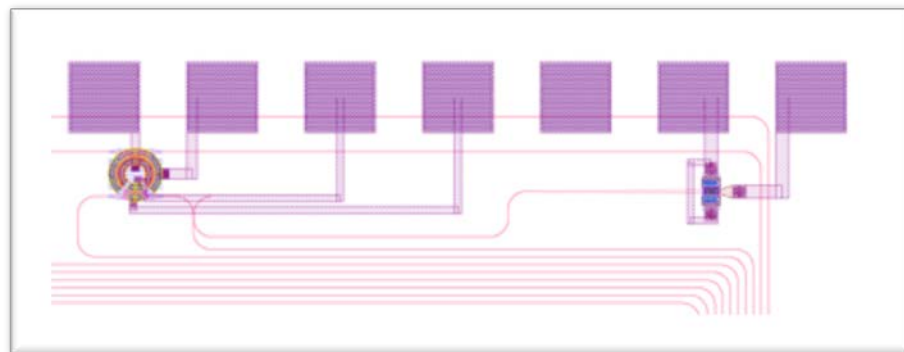
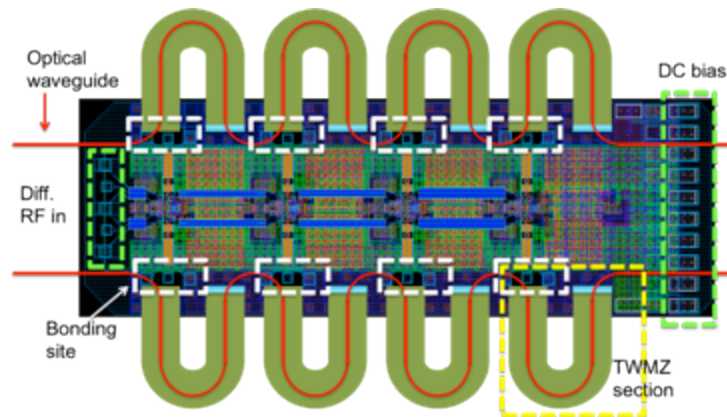


- Development of design tools and design elements
- Demonstrations of complex systems
- Development of methodology and measurement tools/techniques
- Design automation



Recent results

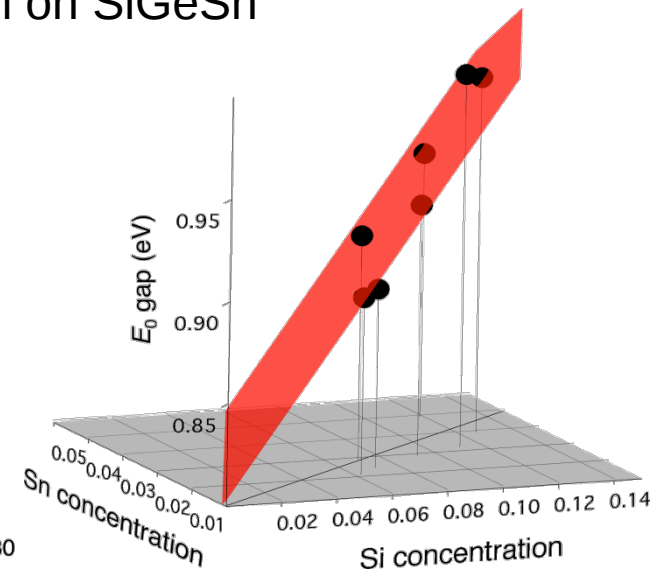
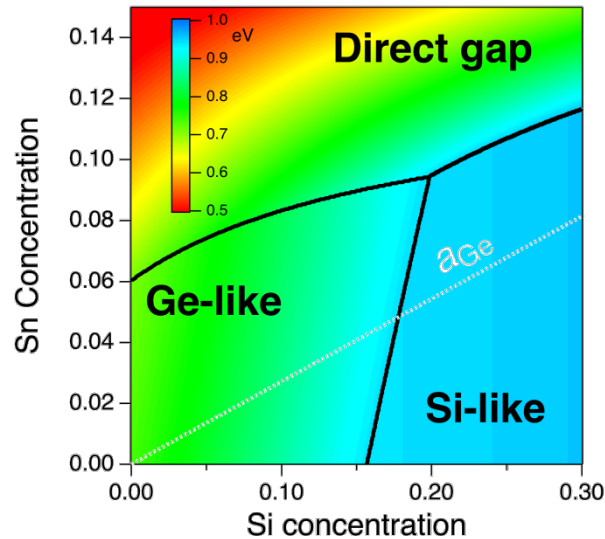
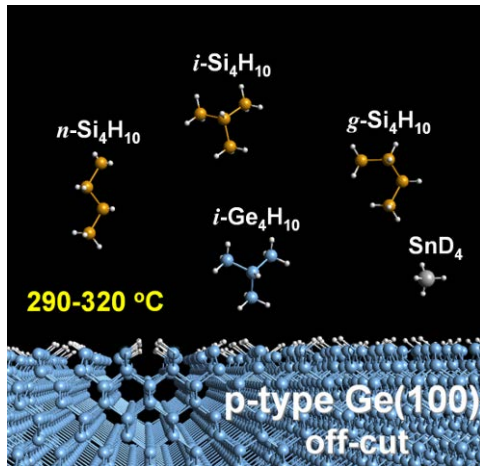
- IME001 delivered to ~30 users
- 25 Gbit/second platform – modulators, detectors, low-loss waveguides
- High-efficiency waveguide-coupled photodiodes at >40GHz
- World-record low-loss silicon modulators
- Ultra-low loss passives library – crossings, couplers, junctions, etc.
- Hybridized lasers
- Ongoing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

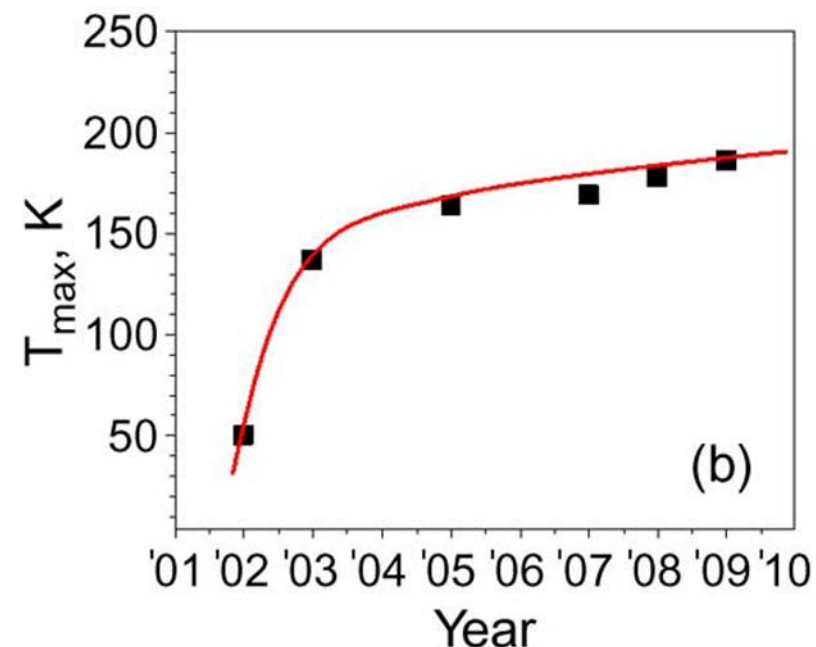


Terahertz Quantum Cascade Nonlinear Optical Sources and Lasers

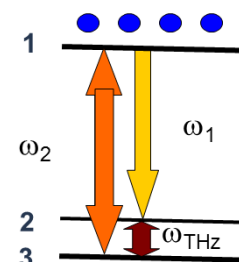
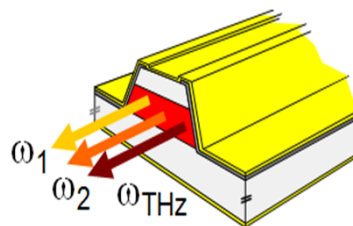
Prof. Federico Capasso - Harvard University

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 ($< 200\text{K}$)



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 ($10\mu\text{W}$) 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

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



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

Terahertz Parametric Oscillator: TPO - 1500



TPO-1500 is based on difference frequency generation in quasi-phase matched GaAs crystal placed inside an optical parametric oscillator (OPO) pumped by an ultrafast fiber laser. It 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.

THz Spectrometers

THz Generators

THz Detectors

Other THz Products



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





Uncooled Photomechanical Terahertz Imagers

Agiltron, Inc. and University of Massachusetts Lowell

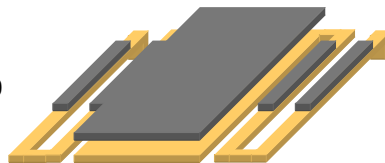
Air Force STTR Phase I Contract FA9550-10-C-0122



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

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

Objective

- Frequency range: **1–10 THz** ($\lambda = 30\text{--}300\ \mu\text{m}$)
- Pixel resolution: **128×128**
- NEP: **< $10^{-12}\ \text{W/Hz}^{1/2}$**
- Detectivity: **> $10^{10}\ \text{cm Hz}^{1/2}/\text{W}$**
- 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**.

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



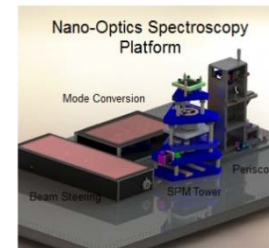
- Technology Transitions
- RHK Technologies – Nanospectroscopy Platform
- FY03 Nanoprobe MURI – Boston Univ – results in IARPA – Subsurface Microscopy of Integrated Circuits
- FY08 Nanomembrane MURI, Univ of Tx, Austin, Prof Chen – NIH – Bio-Sensing
- **Nanomembranes:**
 - State of Saxony, Germany – 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),

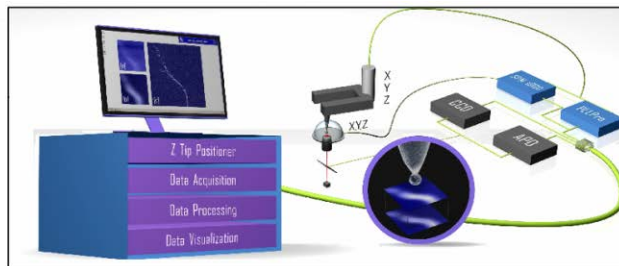
Prof L. Novotny, CoPI (U of Rochester)



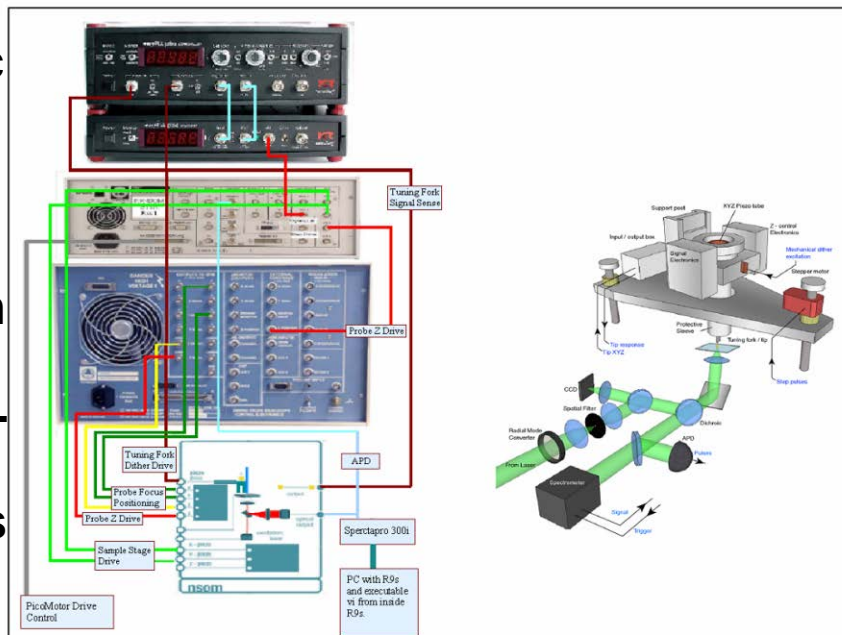
FY03 MURI Transition

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

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



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



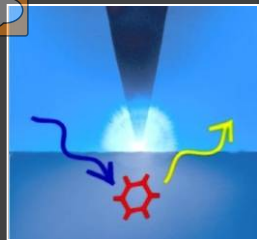
Implementation:
Instrumentation &
techniques for 1.
Chemically-specific
imaging with
2. High spatial
resolution

Delivery:
AFRL/RYMWA
WPAFB Ken
Schepler, 2013

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:

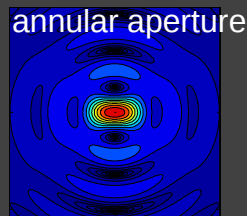
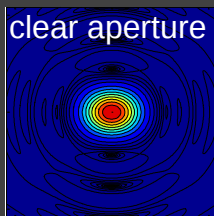
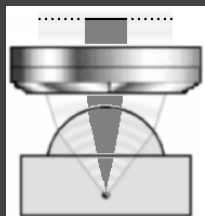
- Focal field engineering using Numerical Aperture Increasing Lens (NAIL) microscopy



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

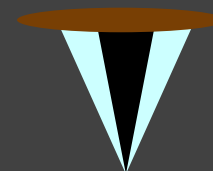
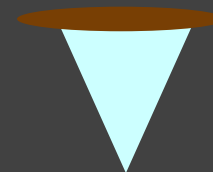
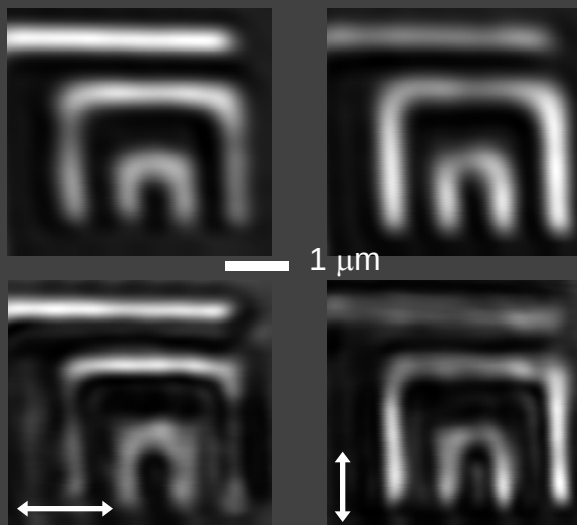
Approach:

- 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 advance to 22nm and 11nm node and transition to industry



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 EI/Ph & Optical Computing

lower



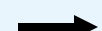
- Quantum Computing w/ Optical Methods (QIS)

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>

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

FY12 Selected Awards / Prizes / Recognitions

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

Luke Lester IEEE fellow



P. Bhattacharya –
Heinrich Welker Prize



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





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-photonics 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 Fabrication &
Packaging, SiGeSn material development