Photonics in Processing

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Background

- At DARPA since 2001
- Scientific Areas of Interest
  - Quantum Coherence/Many-body Processes in Semiconductors
  - Ultrafast Dynamics
  - Semiconductor Nanostructures (Quantum Wells, Quantum dots, Superlattices, Microcavities)
  - High Field Transport And Tunneling in nanostructures
  - Electron And Phonon Relaxation Processes (non-Markovian regime)
  - Physics of Photonic and Electronic Devices
  - Excitons and their condensates

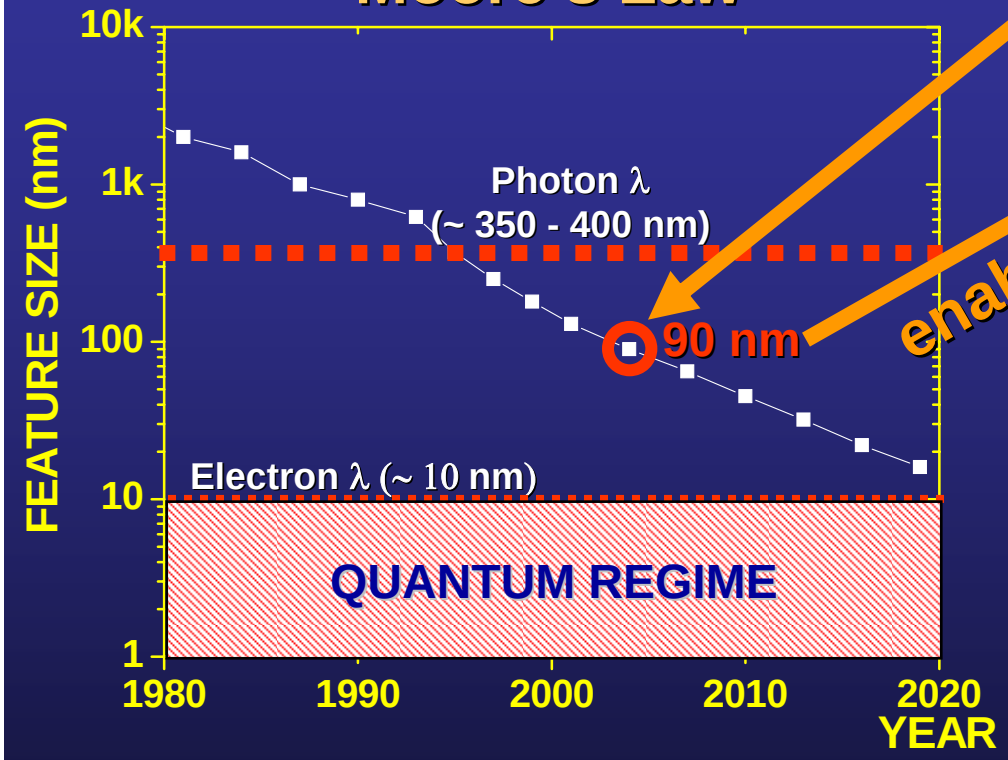
Overview of Programs Developed/Managed

PROGRAM	COMMENTS
CS-WDM Chip-Scale WDM	Photonic Integration: Multiple WDM functions on a chip
O-CDMA Optical CDMA	Optical networks with optical Code Division Multiple Access; photonic technology algorithms, systems
DOD-N Data in the Optical Domain - Networks	Optical networks with optical packet switching routers; aggressive photonic integration
EPIC Electronic and Photonic Integrated Circuits	Electronic/Photonic Integrated Circuits in silicon CMOS platform
UPR University Photonics Research Centers	Forward looking university research in photonics technologies

EPIC

Electronic/Photonic Integrated Circuits

Moore's Law



An Extraordinary OPPORTUNITY

enables

Silicon Nanophotonics

- Small index contrast makes current devices very large
- Large index contrast in Si/SiO_2 + 90 nm fab capabilities (e.g. smooth walls) → nanophotonics
- Fine Feature Size
  - Essential for very high speed

PIGGYBANK ON CMOS INFRASTRUCTURE AND PROGRESS

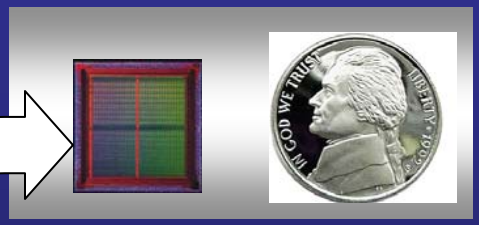
Silicon Nanophotonics + CMOS Electronics

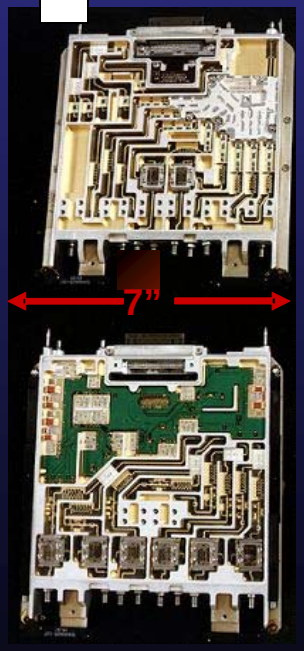
Monolithically Integrated VLSI Photonics and Electronics on a single Silicon Chip In a standard CMOS-SOI Foundry

Seamless Photonics-Electronics Interface

Signal Processing with Integrated Photonics

"Nickel" Size
Optical Signal Processing
RF Channelizer





4.5X Increase IBW
95X Reduction Size
80X Reduction in Weight
5X Reduction in *Power*
100X Reduction in Cost

An Example:

"Application Specific Electronic-Photonic Integrated Circuit" (AS-EPIC) demonstration vehicle:

Broadband RF Receiver (HF to Ku) using optical signal processing of RF signals
- ***Dramatic SWAP reduction***
- ***Increased BW***

Seamless Integration of Electronics and Photonics Will Allow Functions to be Combined

- **Wide-bandwidth photonic signal processing elements can be tightly integrated with digital control circuits**
- **Open-architecture optical component library can be completely compatible with CMOS processes and foundry fabricated**

Communications Challenge with Ultra-dense Systems

- 2D AND 3D SYSTEMS ARE BECOMING ULTRADENSE
  - MOORE'S LAW $\longrightarrow 10^{12}$ TRANSISTORS PER CM^2
    - 3D ELECTRONICS
  - 10^{12} MOLECULAR UNITS PER CM^3
- HOW DO THESE UNITS COMMUNICATE
  - WITH EACH OTHER?
  - WITH THE OUTSIDE WORLD?

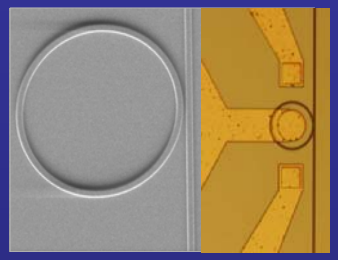
THIS IS A FORMIDABLE CHALLENGE

VISION:

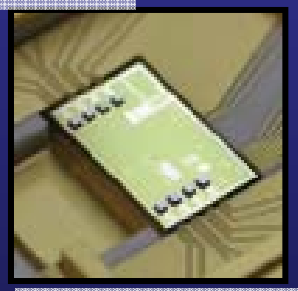
DEVELOP A PATHWAY FOR SUCH COMMUNICATIONS

WHAT IS THE ROLE OF PHOTONICS?

Intra-chip Photonic Communications



EPIC Devices



EPIC Large Scale Circuits

EPIC TECHNOLOGY PROVIDES A PATH TO ACCESSING ULTRADENSE SYSTEMS

STRATEGY

FOCUS ON INTRA-CHIP COMMUNICATIONS ON A HIGH PERFORMANCE ELECTRONIC CHIP

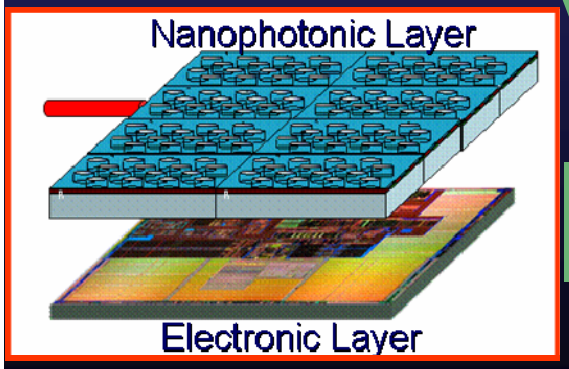
- **Electronic Processor chips are faced with severe power dissipation challenges**
- **Wire delays, DRAM latency/BW, diminishing returns from instruction level parallelism (ILP) are forcing multi-core solutions**
- ***Intra*-chip photonic communications to enable *continuation of "Moore's law for processor performance"***

Intra-chip Photonic Communications

- The technologies needed to realize this vision are very different from those for other optical communications (WAN, MAN, LAN etc.)
- EPIC technology can provide a path towards such technologies, but enormous challenges remain
- Such technology will also enable seamless ultrahigh performance interchip communications
- This will be a game-changing, disruptive technology

DoD missions must exploit
- High resolution sensors
- Integrated multi-modal data
- Short reaction times
- Many net-centric users

Embedded Supercomputers in SWaP Challenged Systems



Super Supercomputers
Exaflops, Zettaflops …

High Performance Computing
Cryptanalysis
Weather Forecsting
Simulations

Summary: Photonics in Processing

- Intrachip Photonic Communications: A game-changing, disruptive technology for processing
- Break down the four walls of processing
  - Power Wall
  - Compute Density Wall
  - Memory (Latency) Wall
  - Productivity (Programming) Wall
- Enormous challenges remain but programs such as EPIC have shown the path to meeting these challenges