Microsystems Technology Office
Brief to MAYO Foundation

Mr. Zachary J. Lemnios, Director
Dr. John C. Zolper, Deputy Director

13 January 2004

DARPA Mission

To develop, imaginative, innovative and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

-- DoD Directive 5105.15

February 7, 1958

Outline

- DARPA Overview
- MTO Thrusts
- Impact that MAYO has had on current MTO Programs

DARPA Organization

Director, Tony Tether
Deputy Director, Bob Leheny

Information Exploitation
Ted Bially
Stephen Welby/Robert Tenney

- **Sensors**
- **Exploitation Systems**
- **Command & Control**

Tactical Technology
Art Morrish
Gary Graham

- **Air/Space/Land Platforms**
- **Unmanned Systems**
- **Space Operations**
- **Laser Systems**
- **Future Combat Systems**
- **Planning / Logistics**

Special Projects
Amy Alving
Joe Guerci

- **Chem/Bio Def Systems**
- **Counter Underground Facilities**
- **Space Sensors/Structures**
- **Navigation/Sensors/ Signal Processing**

Advanced Technology
Dave Honey
Larry Stotts

- **Assured C3ISR**
- **Maritime**
- **Early Entry/Special Forces**

Common Systems & Technologies
Mike Francis
CDR Ralph Alderson
Marc Pitary/Lt Col Paul Waugh

- **UCAV(AF)**
- **UCAV(N)**
- **Autonomous Operations**

Defense Sciences
Steven Wax
Brett Giroir

- **Bio Warfare Defense Technologies**
- **Biology**
- **Materials & Devices**
- **Mathematics**

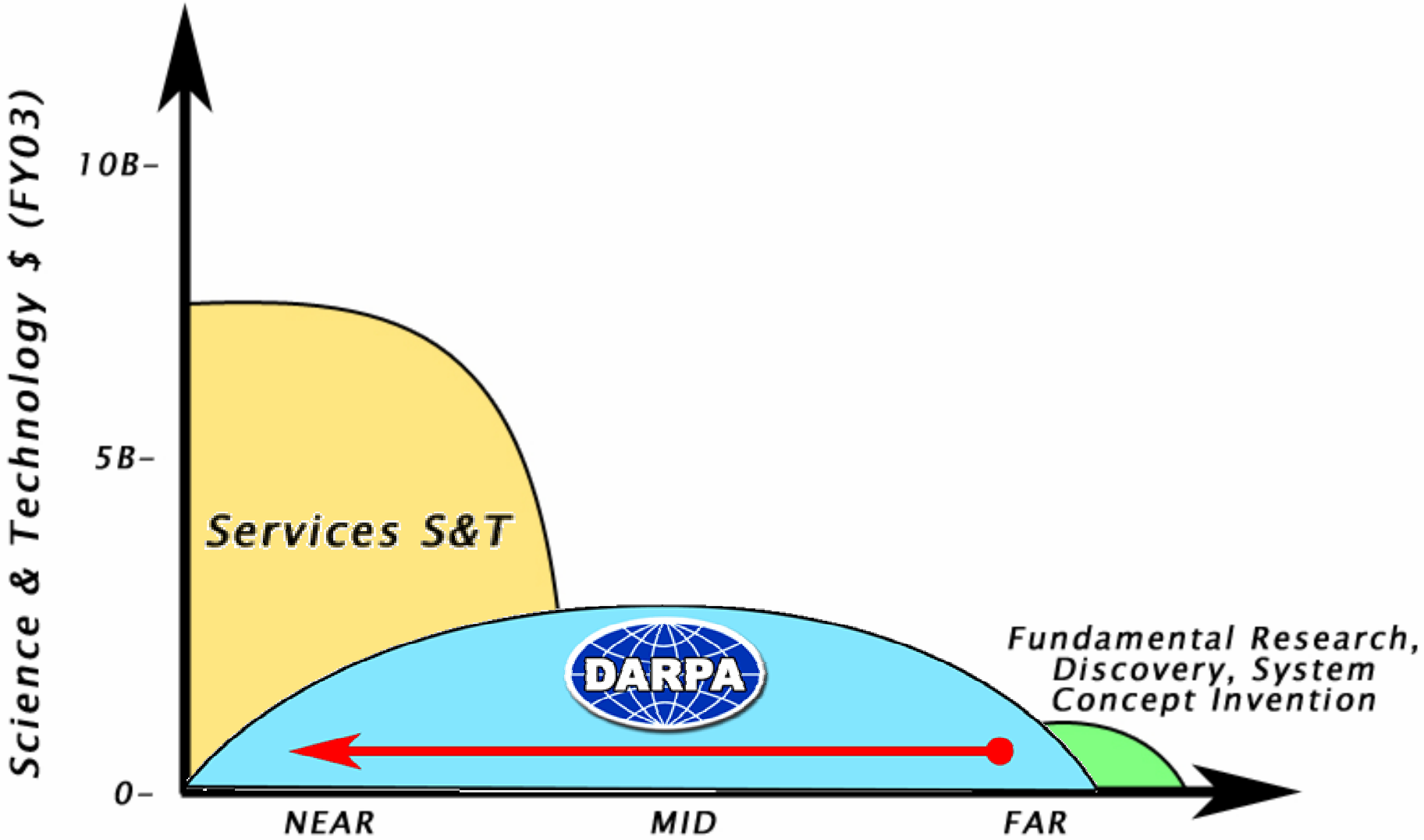
Information Processing Technology
Ron Brachman
Barbara Yoon

- **Cognitive Systems**
- **Computational - Perception**
- **Representation & Reasoning**
- **Learning**
- **Natural Communication**

MicrosystemsTechnology
Zach Lemnios
John Zolper

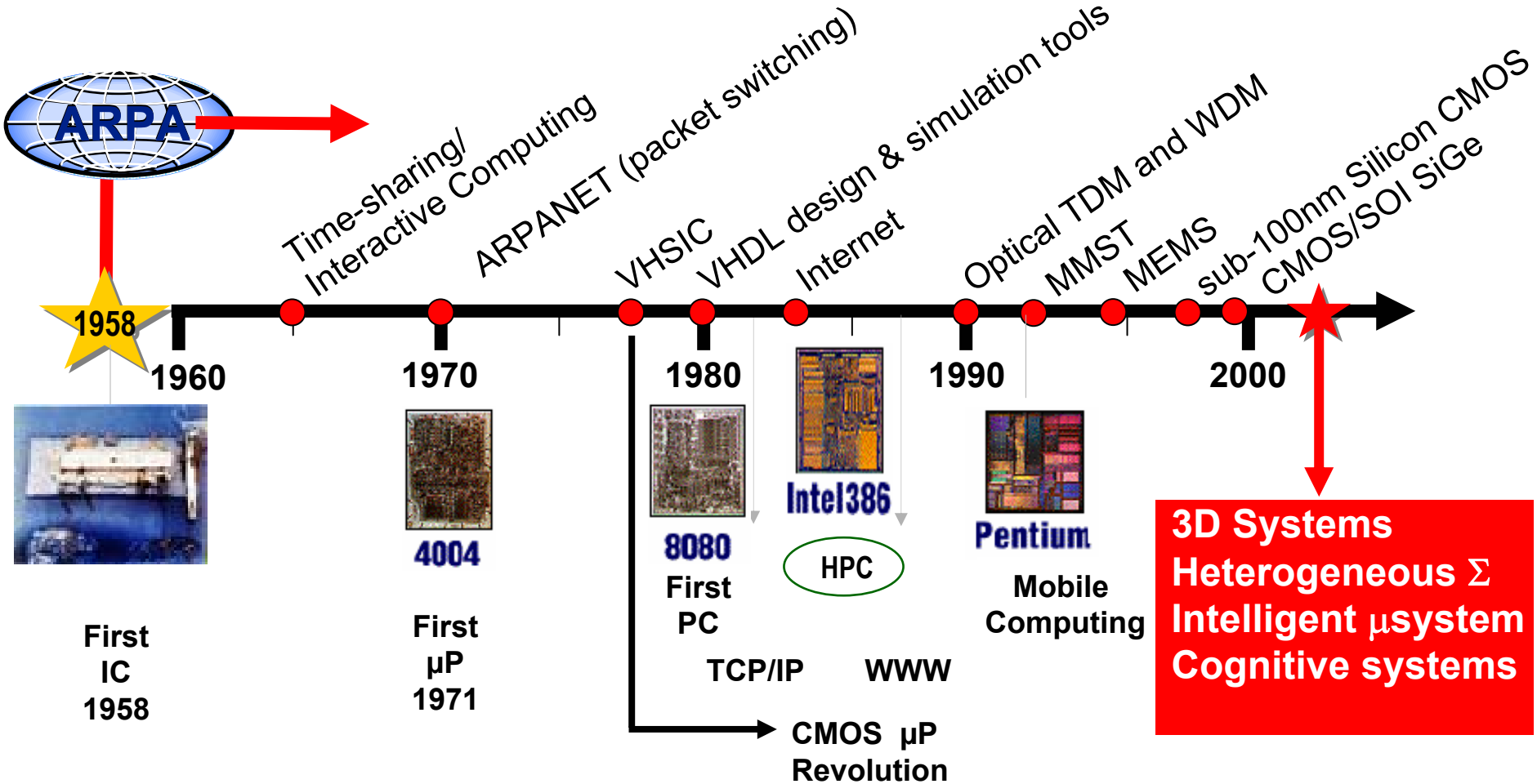
- **Electronics**
- **Optoelectronics**
- **MEMS**
- **Combined Microsystems**

DARPA Role in Science and Technology



DARPA and the Computing Revolution

DARPA largely drove the information technology revolution of the second half of the 20th century



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DARPA/MTO Mission

Develop, demonstrate and transition the key solid state technologies that enable dominant system concepts and capabilities for the Department of Defense

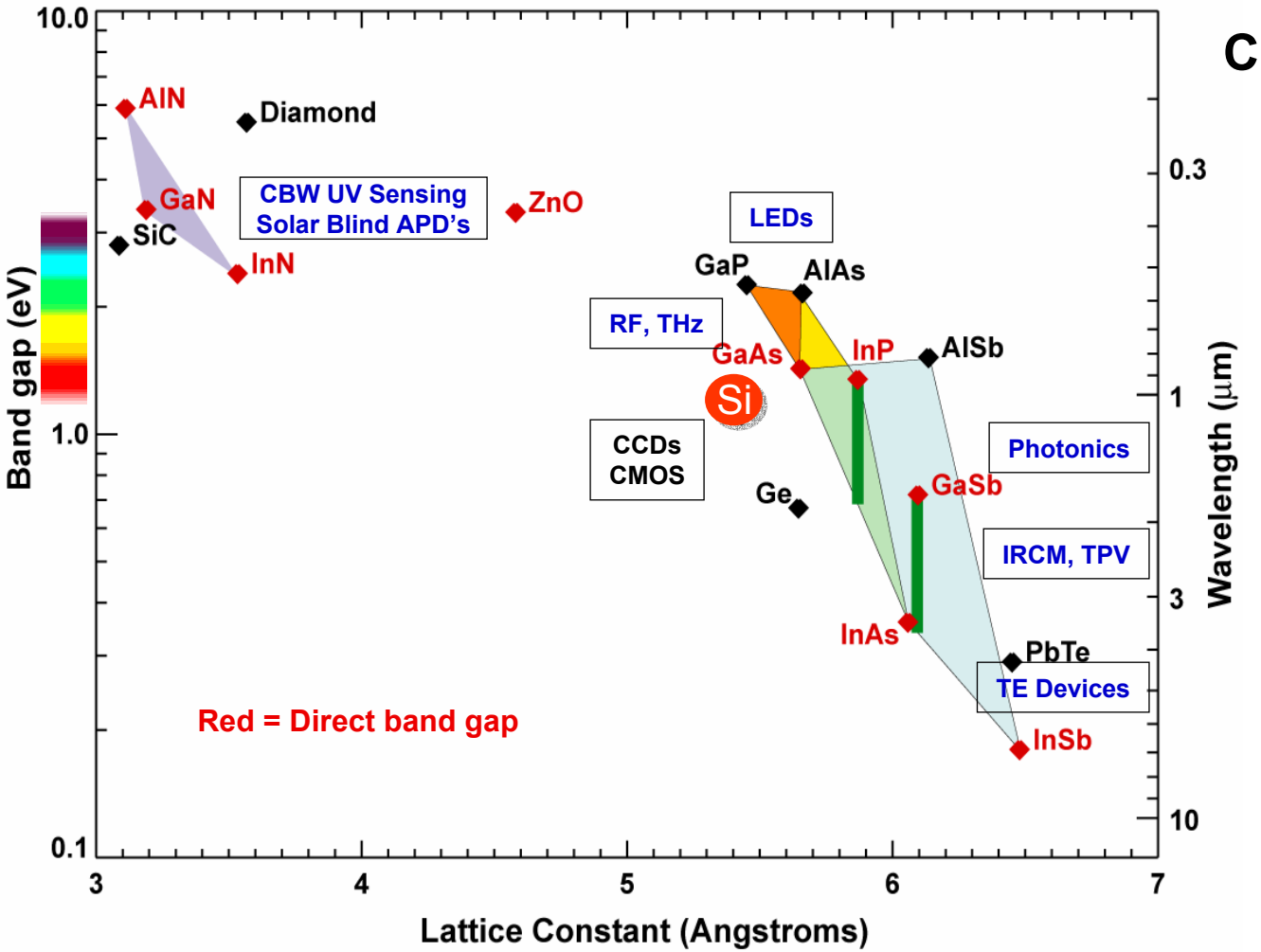
- **Pushing the limits of scaling and integration**
- **Microsystems for spectral exploitation and sensor dominance**
- **Systems that intelligently interact with the environment**
- **Tools that enable scaleable and affordable access to leading edge components**

DoD Access to Winning Microsystem Technology

DARPA/MTO Technical Staff

Zachary J. Lemnios	RF systems, deeply scaled CMOS, tech insertion
John Zolper	Semiconductor Materials, Devices, & Circuits
Andy Hutchinson	Short Pulse Lasers, Photonics / Sensors
Edgar Martinez	Electronics- Materials, Devices & Circuits
James Murphy	Electronic & Photonic devices, Circuits & ICs
David Patterson	Lithography, Semiconductors, Materials
John Carrano	Photonic devices & materials
Clark Nguyen	MEMS
Dan Radack	Electronics / Heterogeneous Integration
Dennis Healy	Mathematics/Advanced Processing Algorithms
Mark Rosker	THz technology and high speed electronics
Stephen Pappert	Photonic/Electronics RF links and comms
Kwan Kwok	Molecular & Nano tech, Sub-atomic physics
Ravi Athale	Optical computing & interconnects, Imaging
Robert Tulis	Digital & intelligent imaging devices
Elana Ethridge	Distributed robotics & Electro-textiles
Robert Reuss	Silicon microelectronics & flexible / macroelectronics
Jagdeep Shah	Photonic / Electronic device physics
Martin Stickley	Lasers, Sensors & Materials
John Evans	MEMS

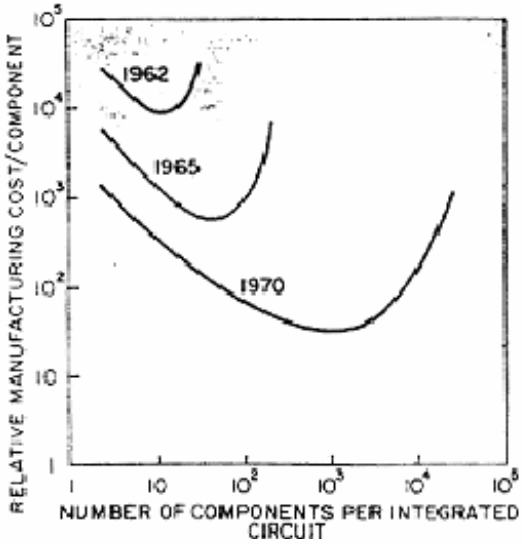
DoD's Need for Advanced Materials

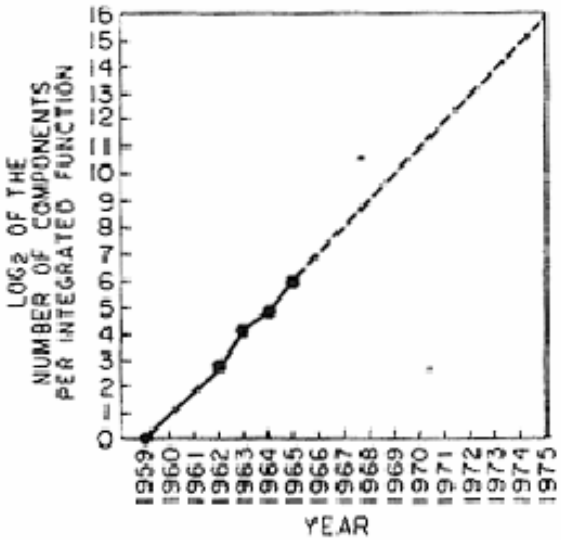


Critical Applications

- IR detectors
- Thermophotovoltaic devices
- Solar blind UV detectors
- Lasers / LEDs
- Thermoelectric devices
- Optical waveguides and photonics
- THz Sources

1965 Publication of "Moore's Law"





The experts look ahead

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

But the biggest potential lies in the production of large systems. In telephone communications, integrated circuits in digital filters will separate channels on multiplex equipment. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in completely different ways. For example, memories built of integrated electronics may be distributed throughout the machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turn-around.

Present and future

By integrated electronics, I mean all the various technologies which are referred to as microelectronics today as well as any additional ones that result in electronics functions supplied to the user as irreducible units. These technologies were first investigated in the late 1950's. The object was to miniaturize electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including microassembly techniques for individual components, thin-film structures and semiconductor integrated circuits.

Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future to be a combination of the various approaches.

The advocates of semiconductor integrated circuitry are already using the improved characteristics of thin-film resistors by applying such films directly to an active semiconductor substrate. Those advocating a technology based upon films are developing sophisticated techniques for the attachment of active semiconductor devices to the passive film arrays.

Both approaches have worked well and are being used in equipment today.

The author

Dr. Gordon E. Moore is one of the new breed of electronic engineers, schooled in the physical sciences rather than in electronics. He earned a B.S. degree in chemistry from the University of California and a Ph.D. degree in physical chemistry from the California Institute of Technology. He was one of the founders of Fairchild Semiconductor and has been director of the research and development laboratories since 1959.

Electronics, Volume 38, Number 8, April 19, 1965

Moore's Law Scaling

Transistors Per Die

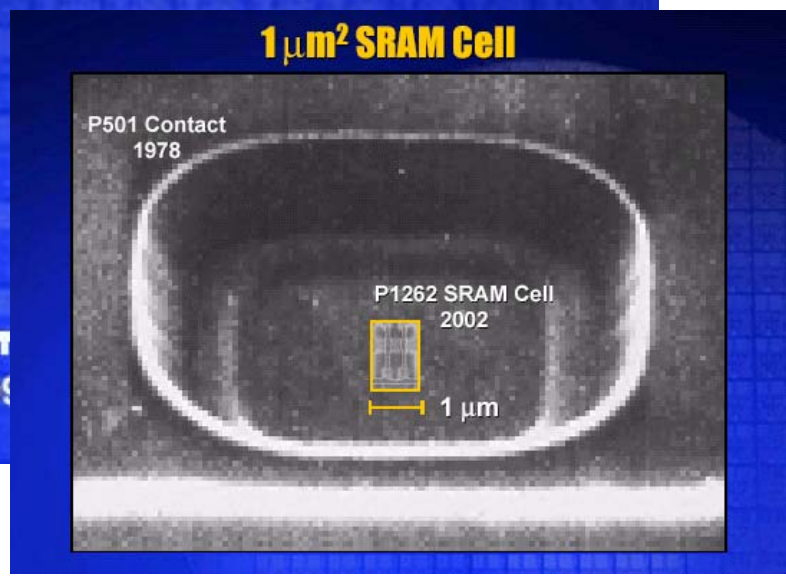
10^{10}, 10^{9}, 10^{8}, 10^{7}, 10^{6}, 10^{5}, 10^{4}, 10^{3}, 10^{2}, 10^{1}, 10^{0}

1965 Actual Data
MOS Arrays
MOS Logic 1975 Actual Data
1975 Projection
Memory
Microprocessor

1960, 1965, 1970, 1975, 1980, 1985, 199

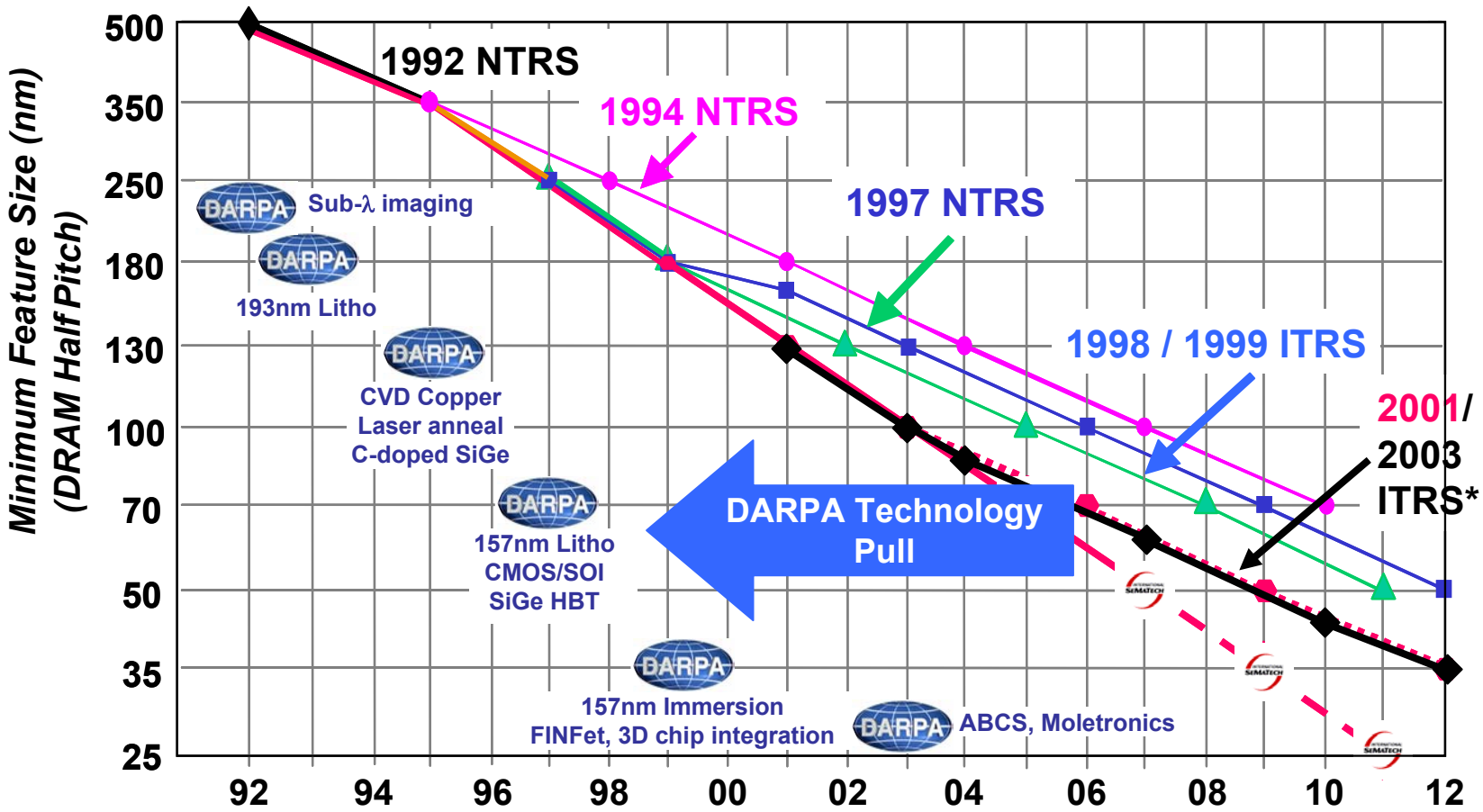
1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M, 64M, 128M, 256M, 512M, 1G, 2G, 4G

4004, 8080, 8086, 80286, i386™, i486™, Pentium®, Pentium® II, Pentium® III, Pentium® 4, Itanium™

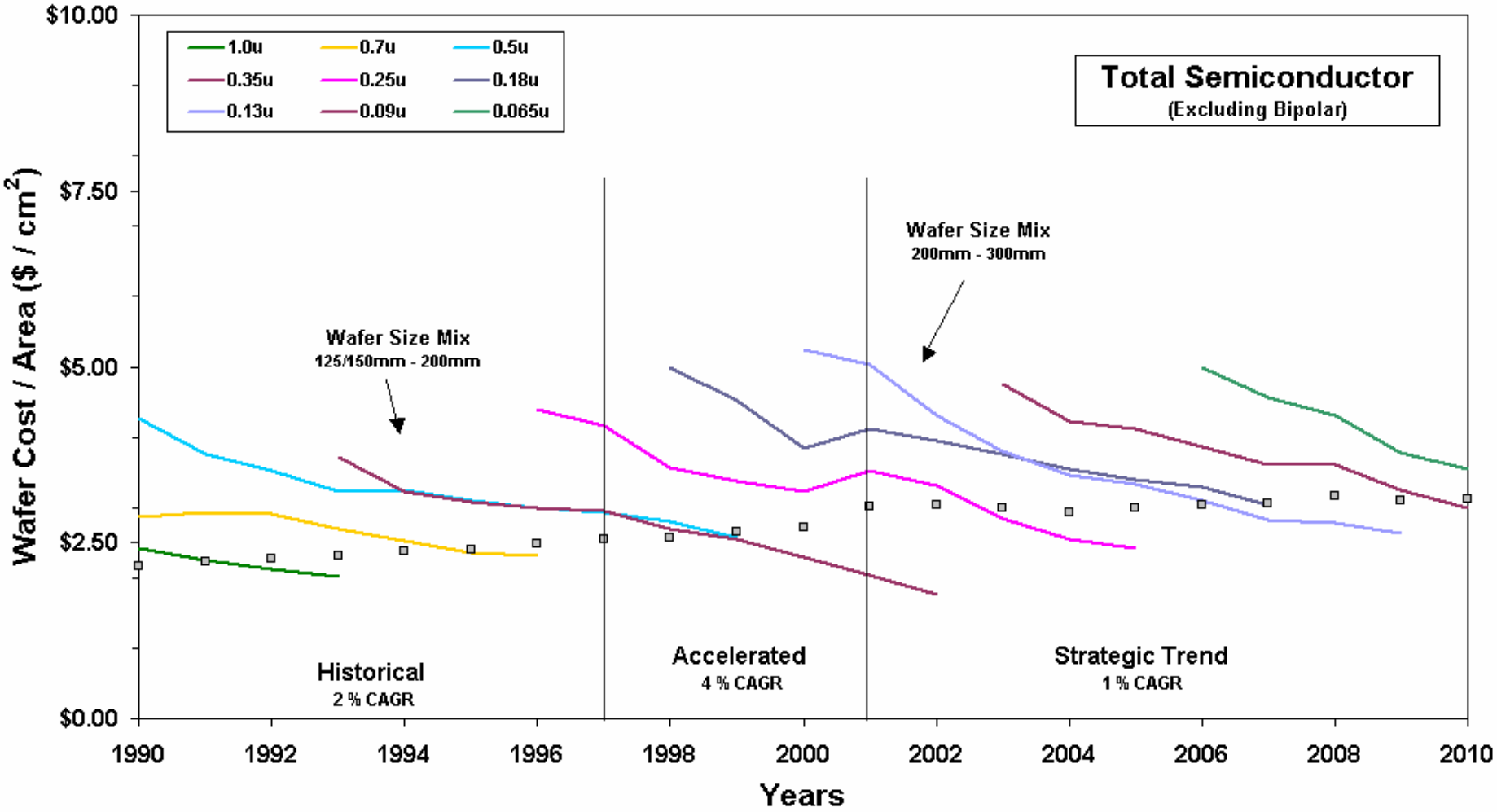


From Peter Asbeck

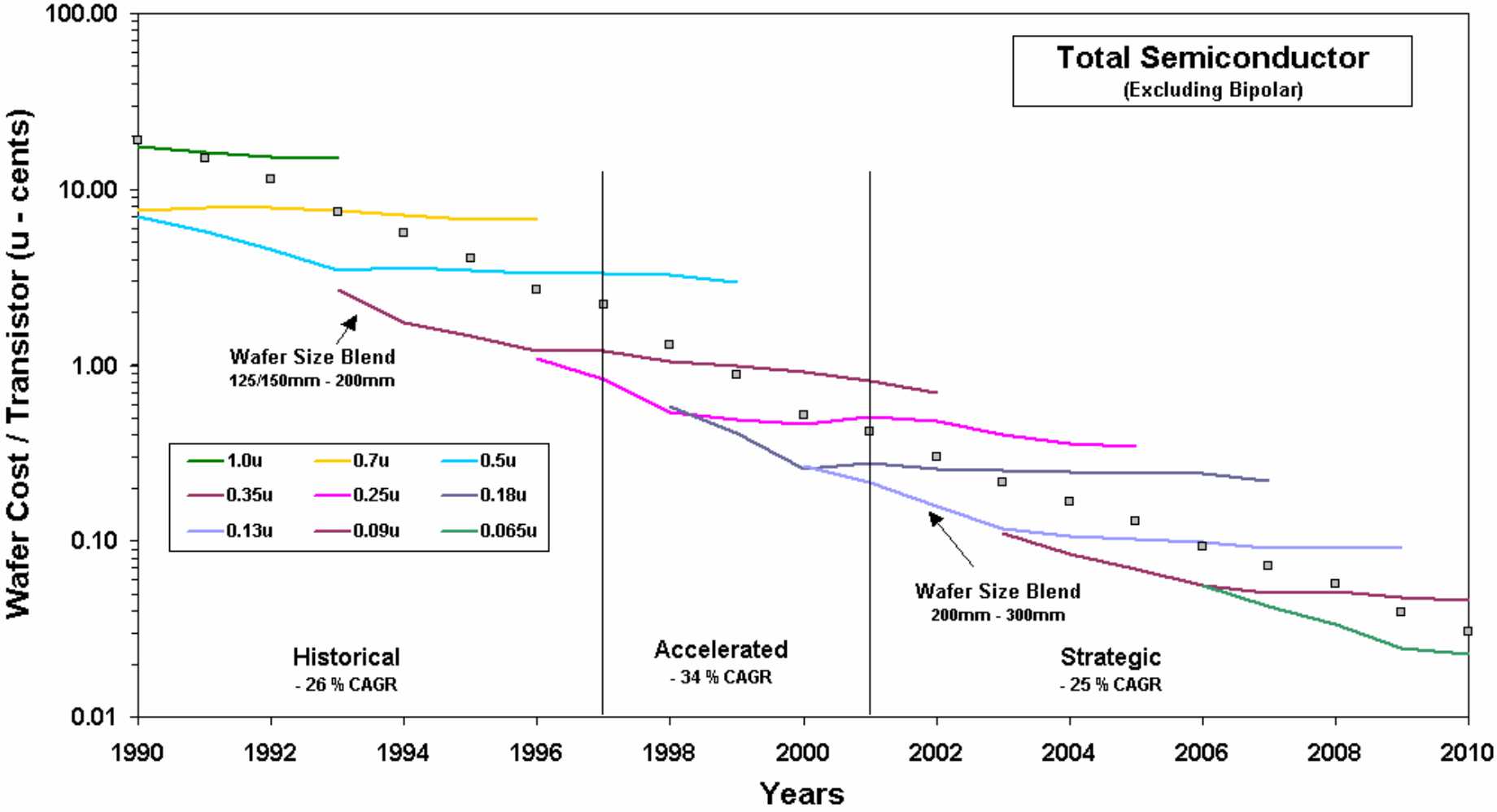
Technology Roadmap



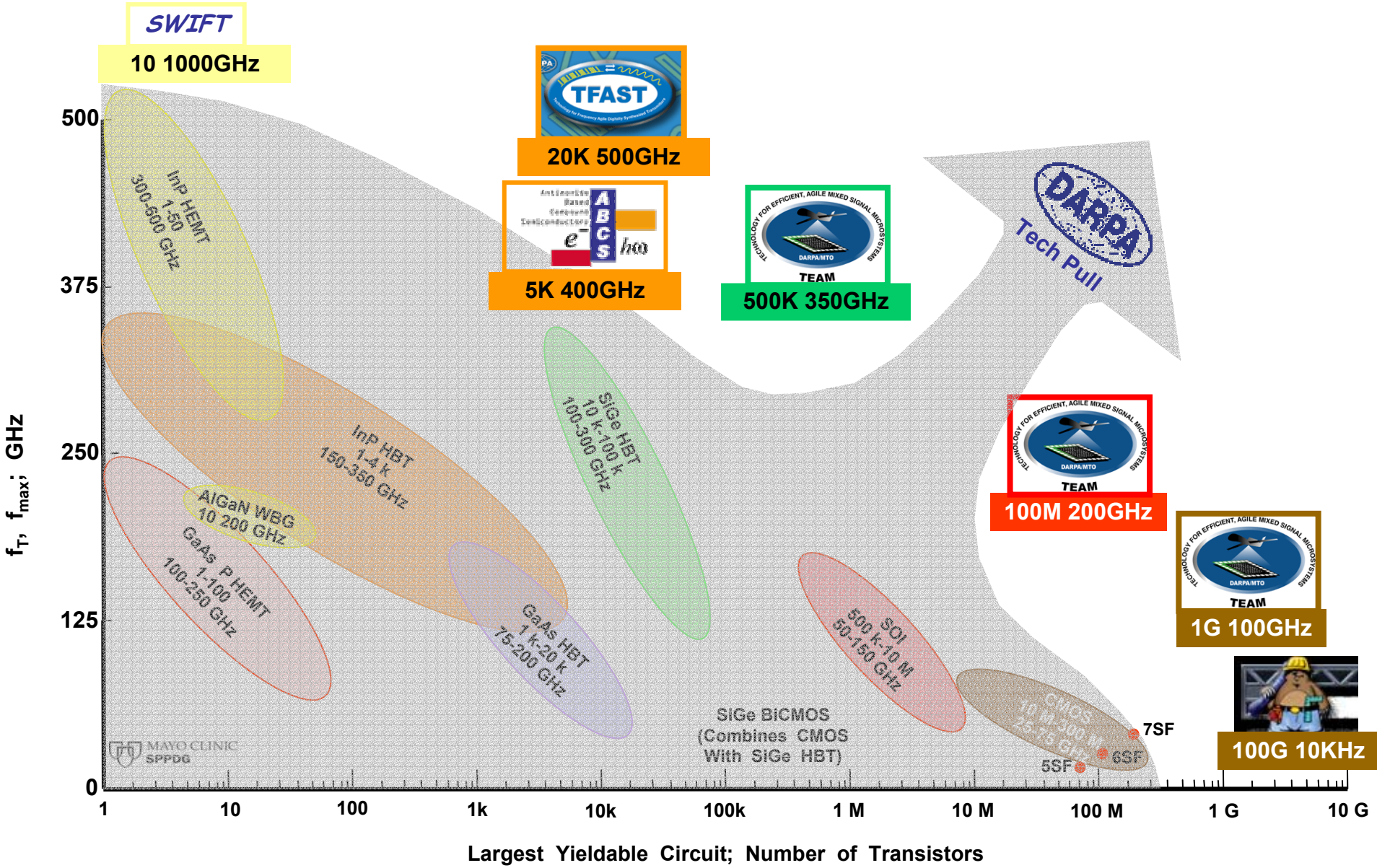
Constant Wafer Cost / Area



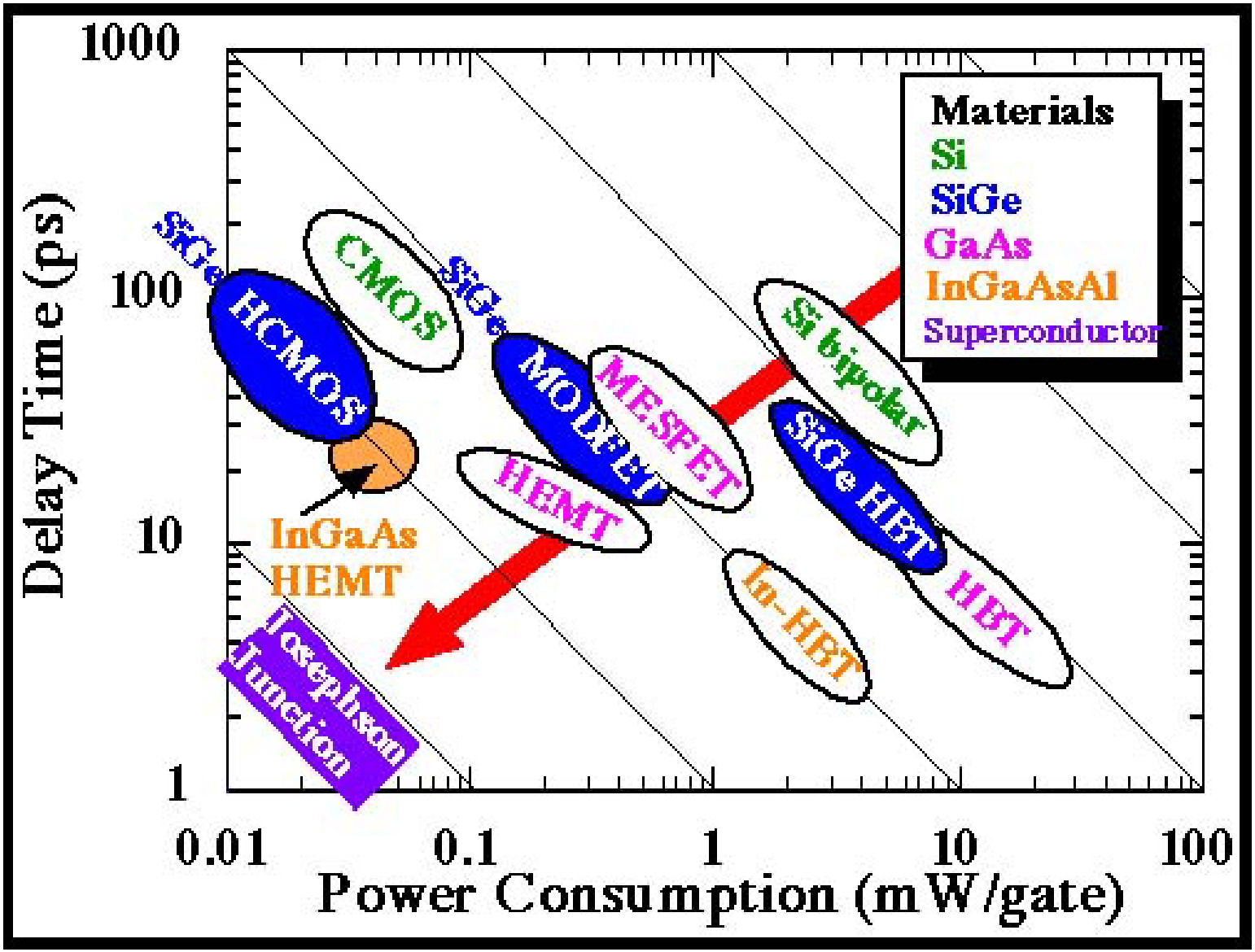
Commercial CMOS Productivity Engine



Integrated Ft Device Scaling



Power Gate Delay Chart



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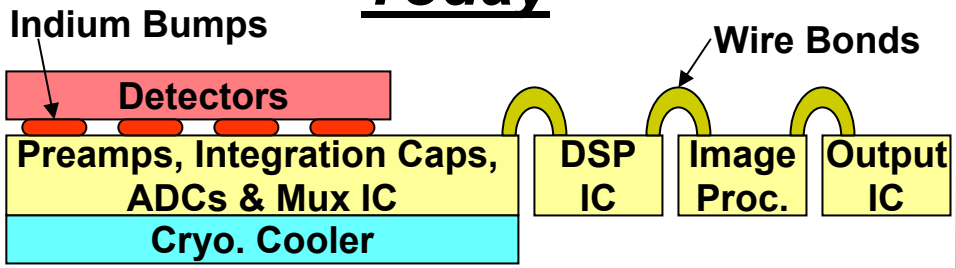
Vertically Interconnected Sensor Arrays (VISA)

Today



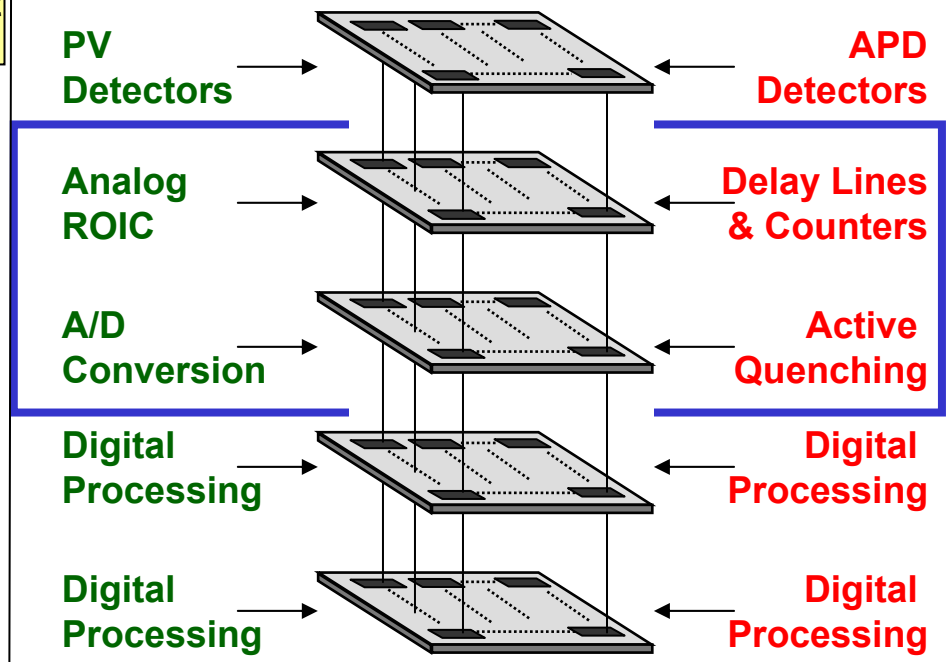
For Passive IRFPAs

- Low Frame Rates (Serial read out (<0.3kHz))
- Narrow Dynamic Range (capacitor/pixel limited (12-bits max.))
- ROIC-limited array format

For Ladar FPAs

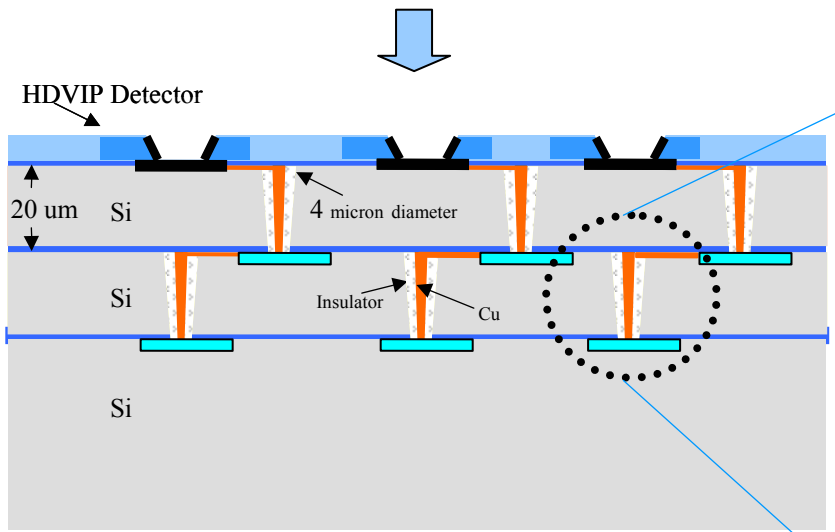
- Large Pixel Sizes (100μ x 100μ)
- Low Sampling Rates (1.0GHz)

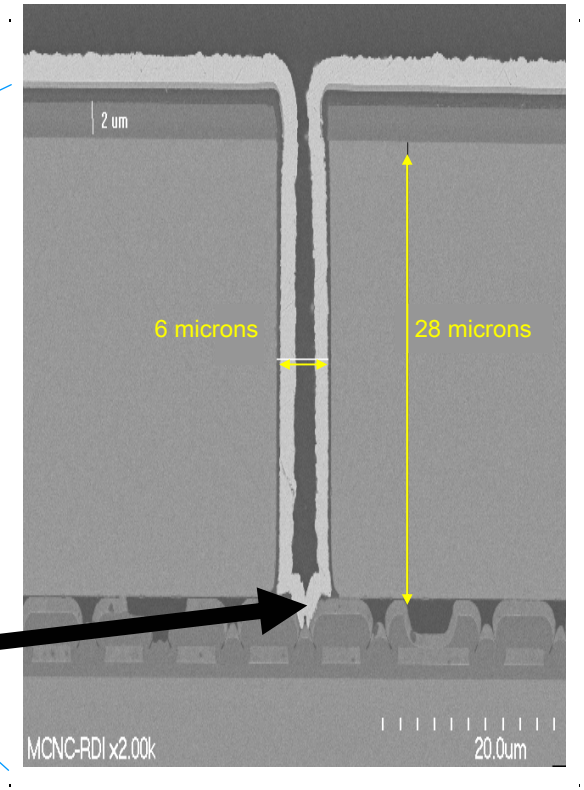
VISA



- High Pixel Access Rates (up to 100MHz)
- Wide Dynamic Range (>20-bits)
- Reduced Ladar Pixel Sizes (30μ x 30μ)
- High Ladar Sampling Rates (10GHz)

VISA Process Feasibility Demonstrated

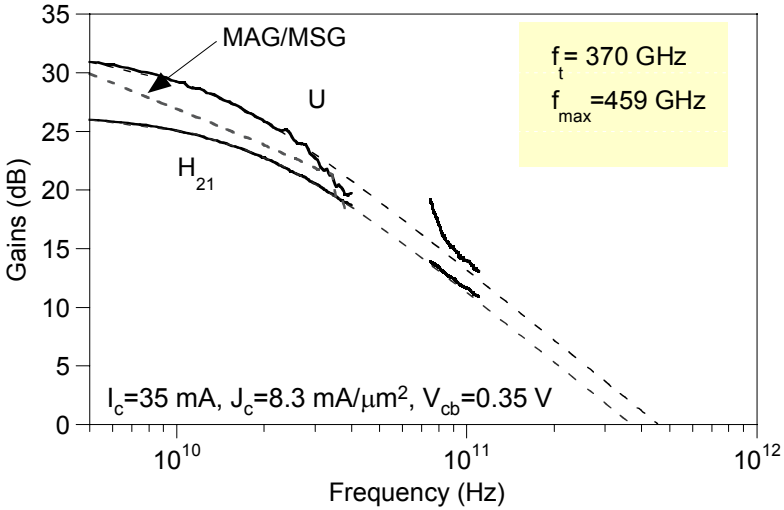


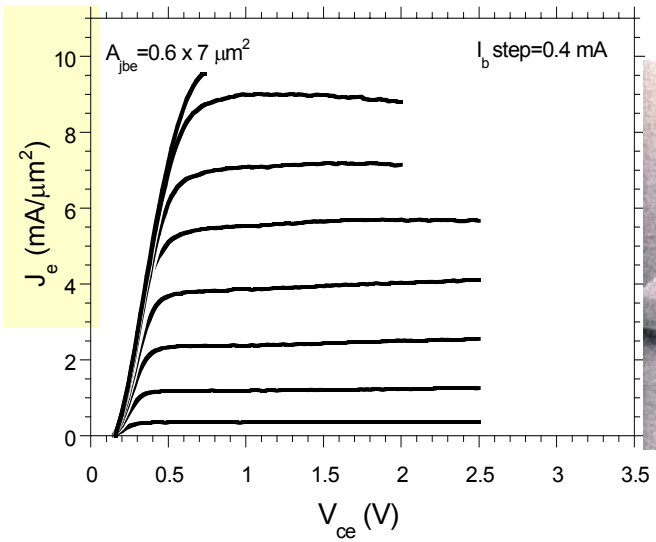


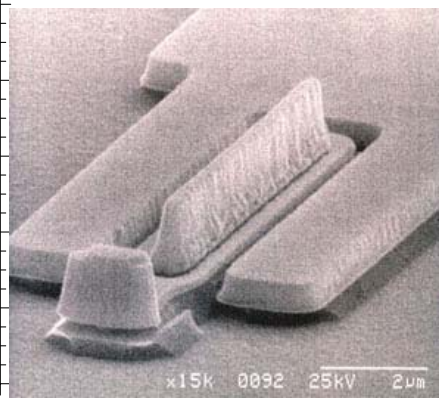
Note contact between vertical Interconnect and bottom metal pad !

Feasibility of VISA interconnect process has been demonstrated. Refinements to improve operability and yield now in progress.

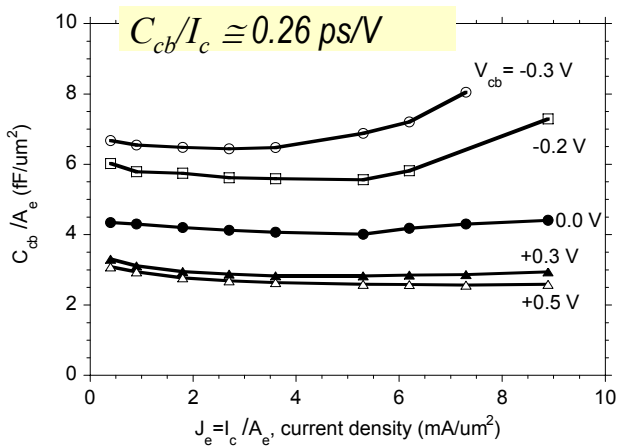
InP DHBTs: 150 nm collector, 30 nm base





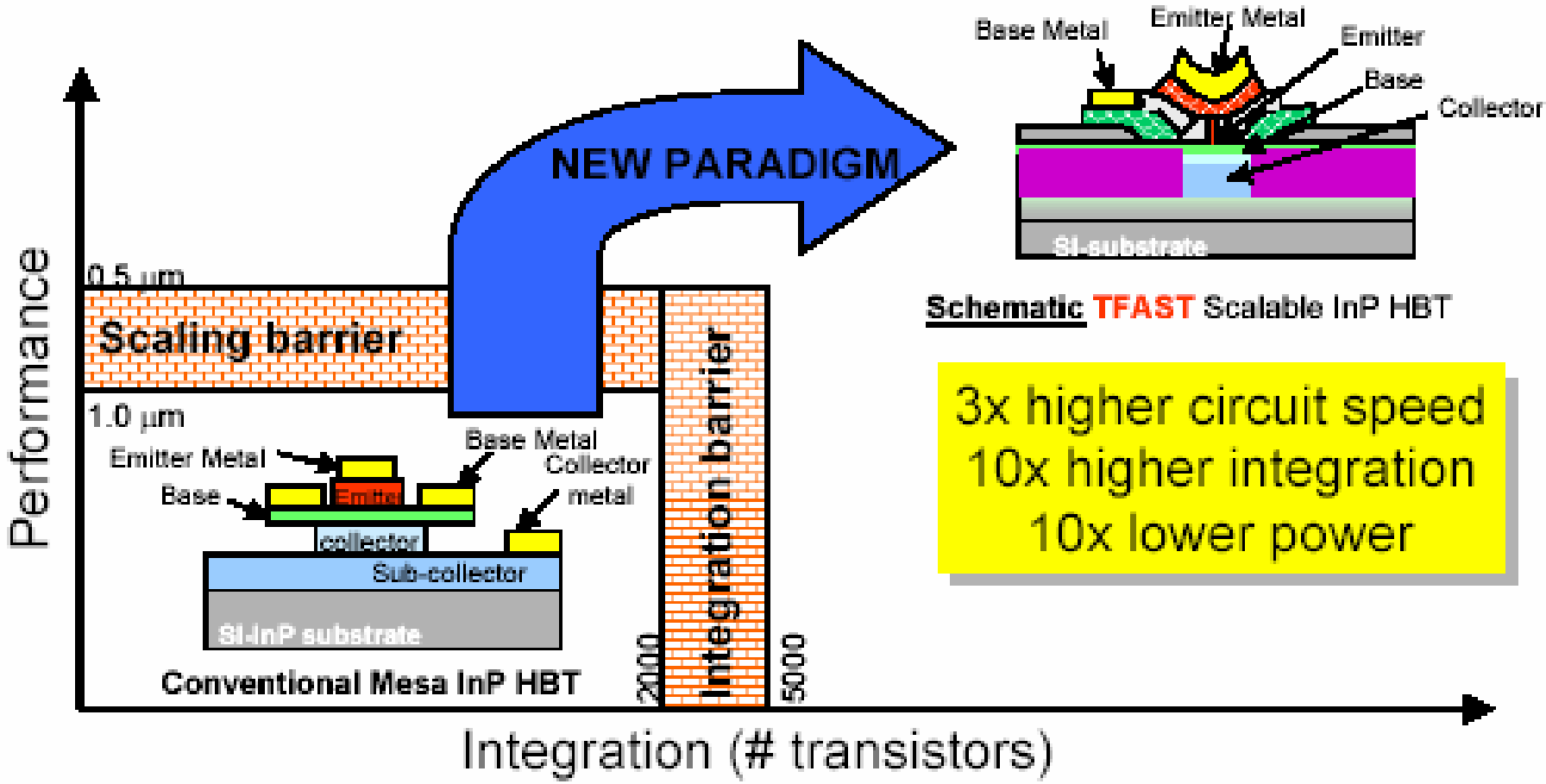


3 nm InGaAs base: $8*10^{19}/cm^3 \rightarrow 5*10^{19}/cm^3$ base: 603 Ω/square
15 nm InP collector base contacts: 20 Ω-μm²
0.6x 7 μm emitter junction (0.7 x 8 um contact) emitter contacts: 15 Ω-μm²
0.5 μm base contacts



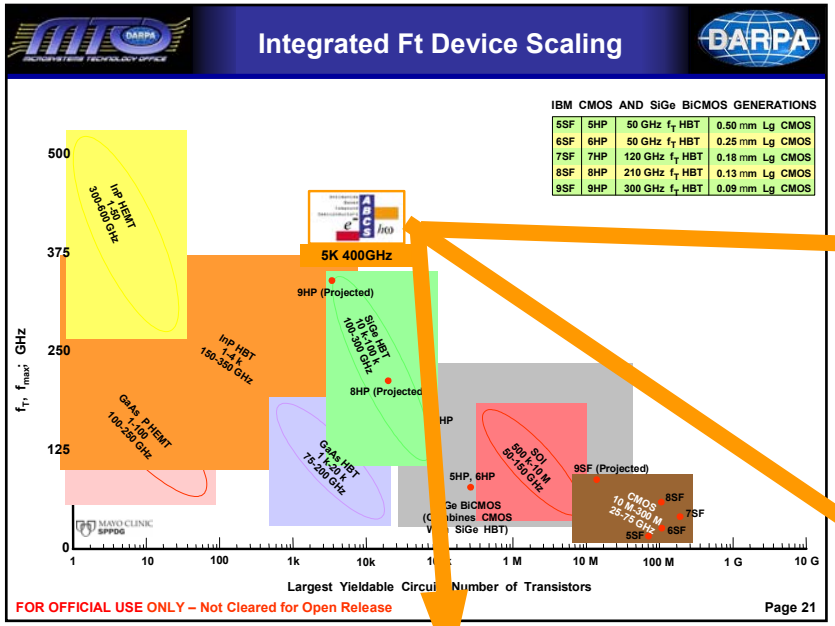
Thickness (Å)	Material	Doping cm^{-3}	Description
400	$In_{0.53}Ga_{0.47}As$	3E19 : Si	Emitter Cap
800	InP	3E19 : Si	Emitter
100	InP	8E17 : Si	Emitter
300	InP	3E17 : Si	Emitter
300	InGaAs	8E19-5E19:C	Base
200	$In_{0.53}Ga_{0.47}As$	3E16:Si	Setback
240	InGaAlAs	3E16 : Si	Base-Collector Grade
30	InP	3.0E18 : Si	Delta doping
1000	InP	3E16 : Si	Collector
250	InP	1.5E19:Si	Sub Collector
125	$In_{0.53}Ga_{0.47}As$	2E19 : Si	Sub Collector
3000	InP	2E19 : Si	Sub Collector
Substrate	SI : InP		

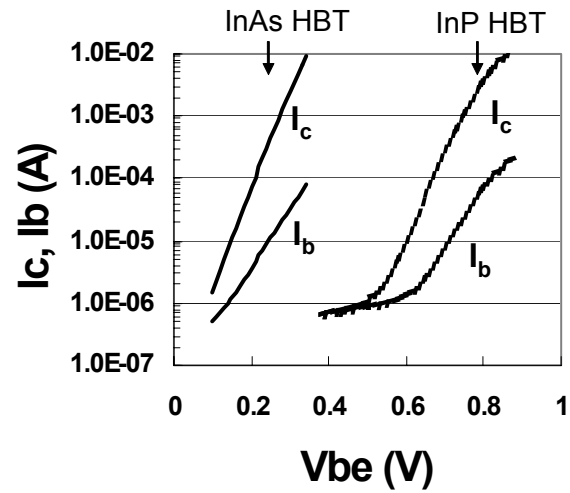
InP HBT Technology Being Redefined by TFAST



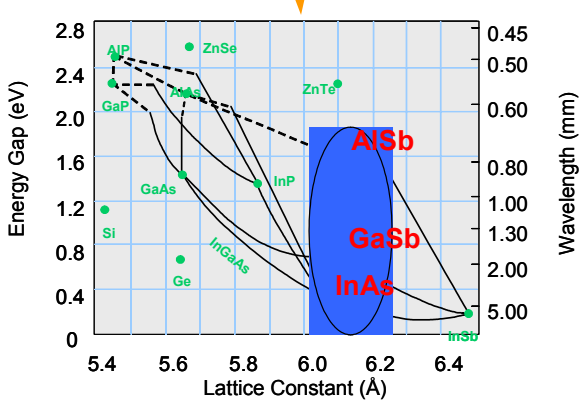
Antimonide-based Compound Semiconductor (ABCS)

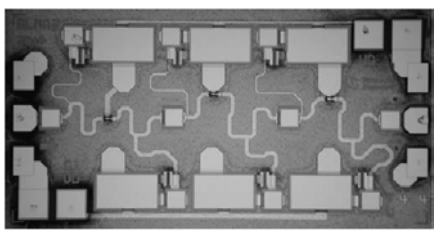
Exploiting Antimonide Materials for High Speed at Low Power





ABCS InAs-HBT Operates at Low Voltage

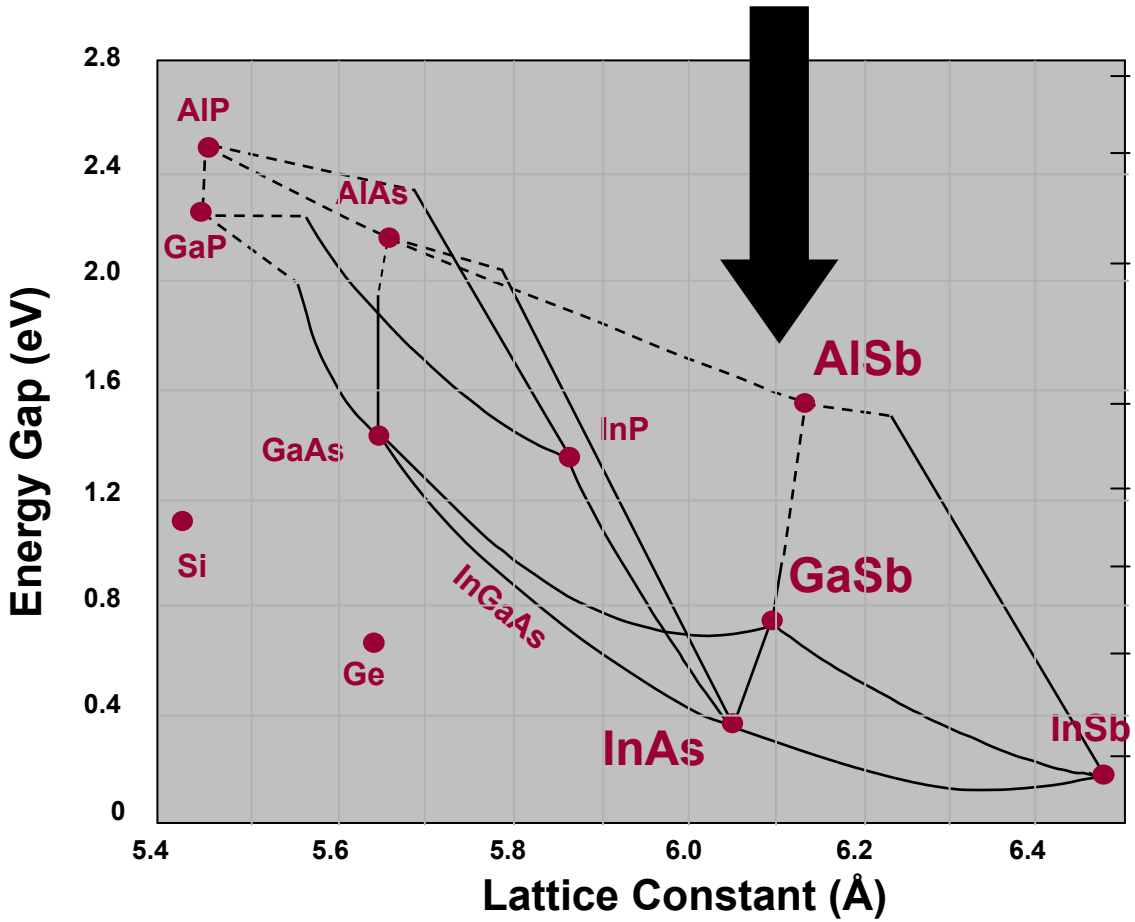




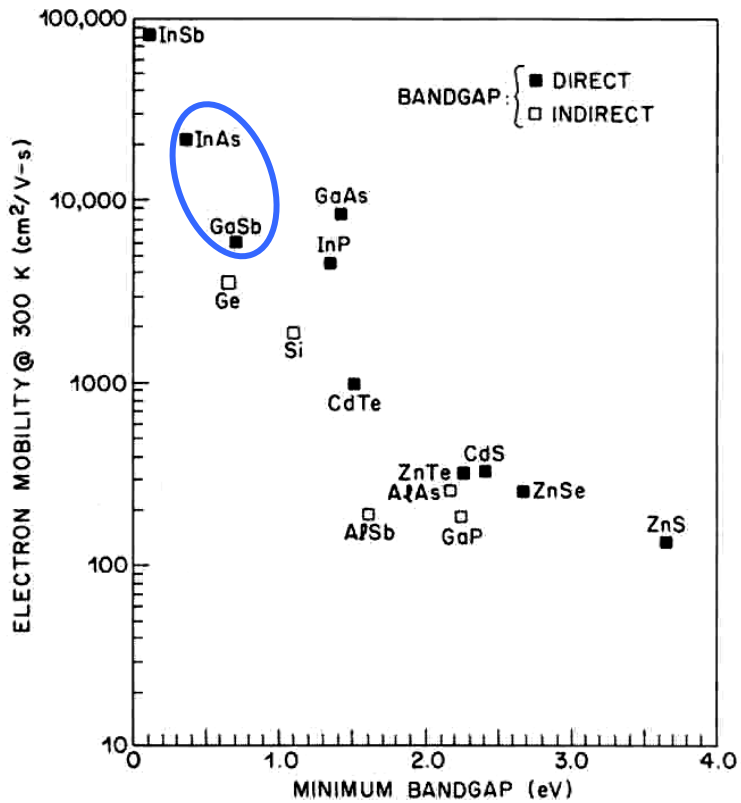
34-36 ABCS Low Noise Amplifier
NF = 2.1 F, P_{dis} = 4.5 mW
>10 X lower power than InP PHEMT

ABCS Material System

6.1 Å III-V Materials

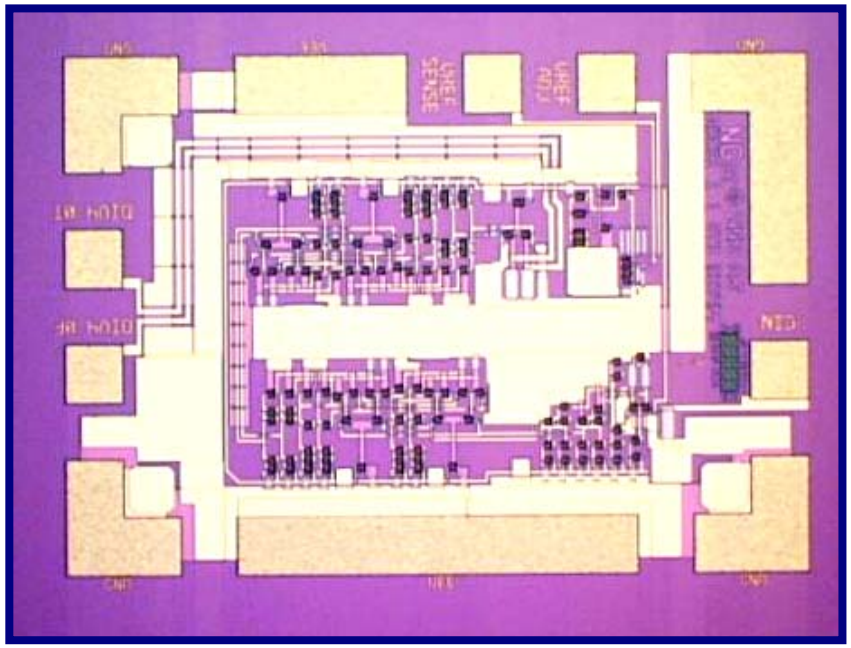


Electron Mobility



The main focus of the ABCS program is to demonstrate integrated circuits with ultrafast speed and low consumed power

ABCS LNA Circuit Development



F_{clock} = 21.2 GHz

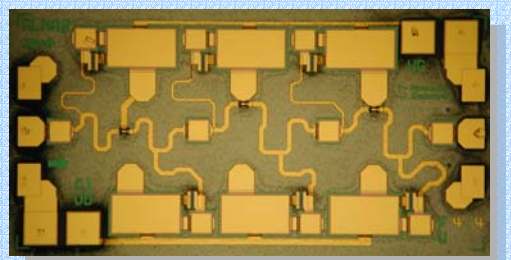
F_{output} = 5.3 GHz

High InAs / AlSb MMIC Integration

Demonstrated a divide by 4 circuit with ~ 100 HBTs operating at fclock = 21.2 GHz

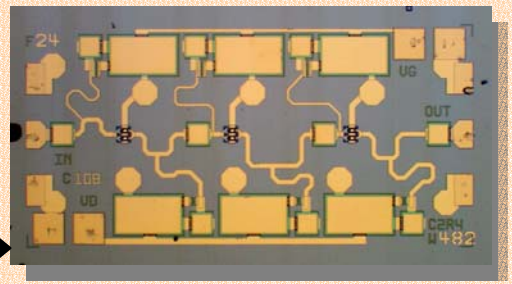
ABCS

Ka-Band LNA
0.35V, 12mA Fets
Gain = 28dB
NF < 2.2 dB
Power = 4.2mW



GaAs

Ka-Band LNA
4V, 40mA Fets
Gain = 20 - 27dB
Power = 160 mW

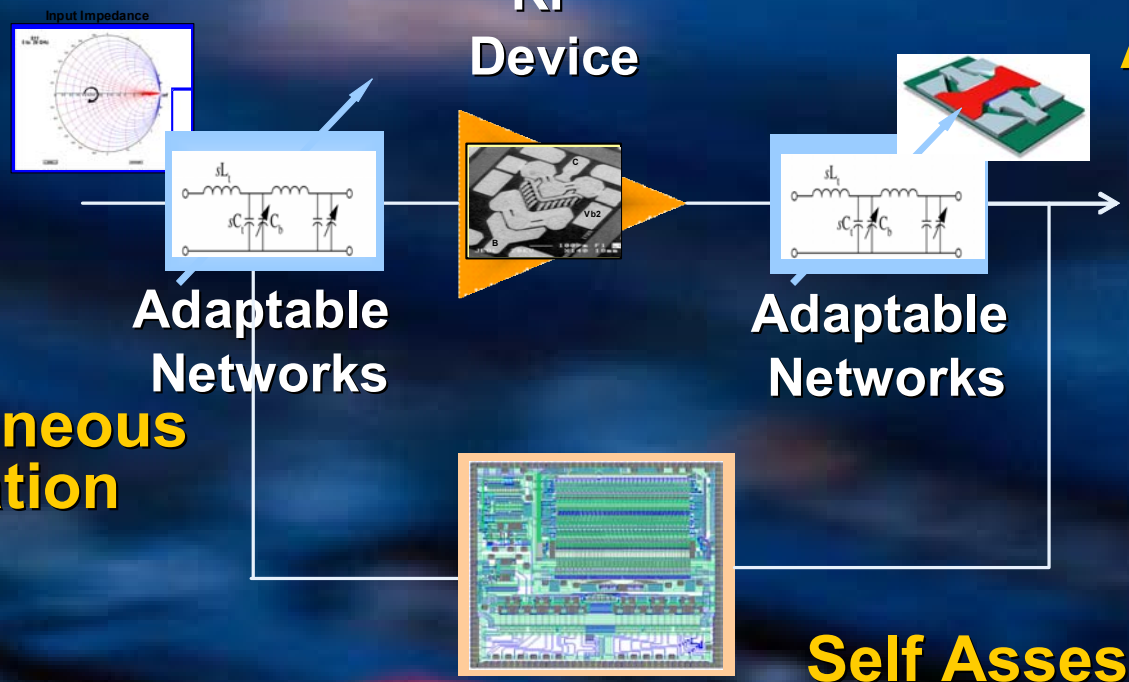


Part currently used in PAC-3

World's First InAs / AlSb MMICs

3-Stage Ka-Band LNA Using only 4.2 mW DC Power
~40 X Less Power than GaAs with Equivalent Performance

Intelligent RF Front Ends



Real Time Adaptation

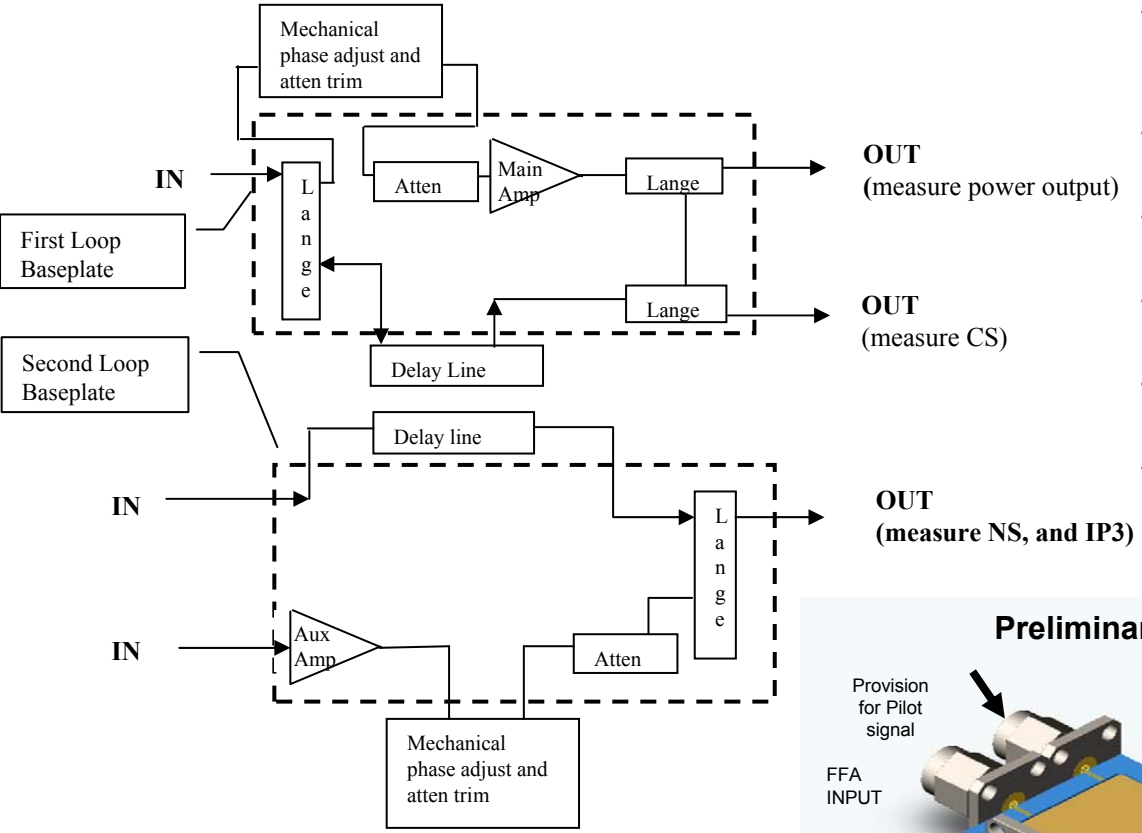
Heterogeneous Integration

Self Assessment and Intelligent Control

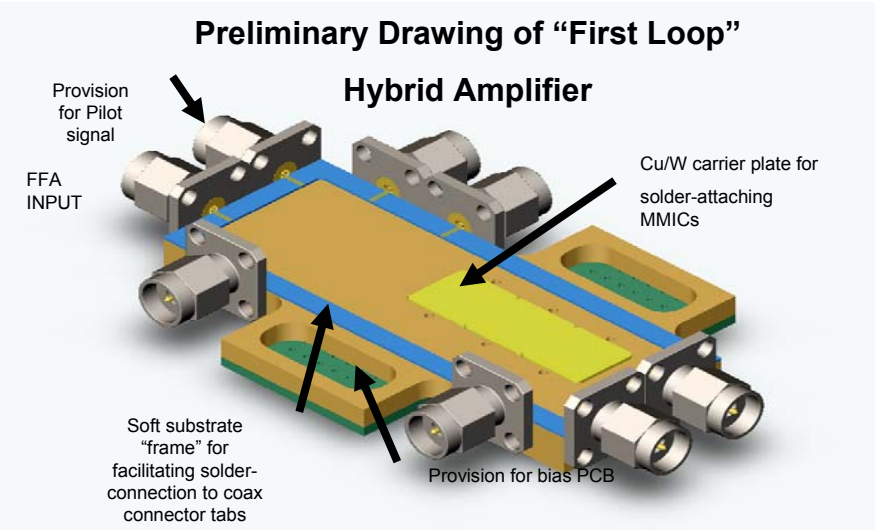
Enabling Adaptive Multifunctional RF Sensors for Rapid Changing Environments

X-band Feedforward Amplifier (FFA) Development

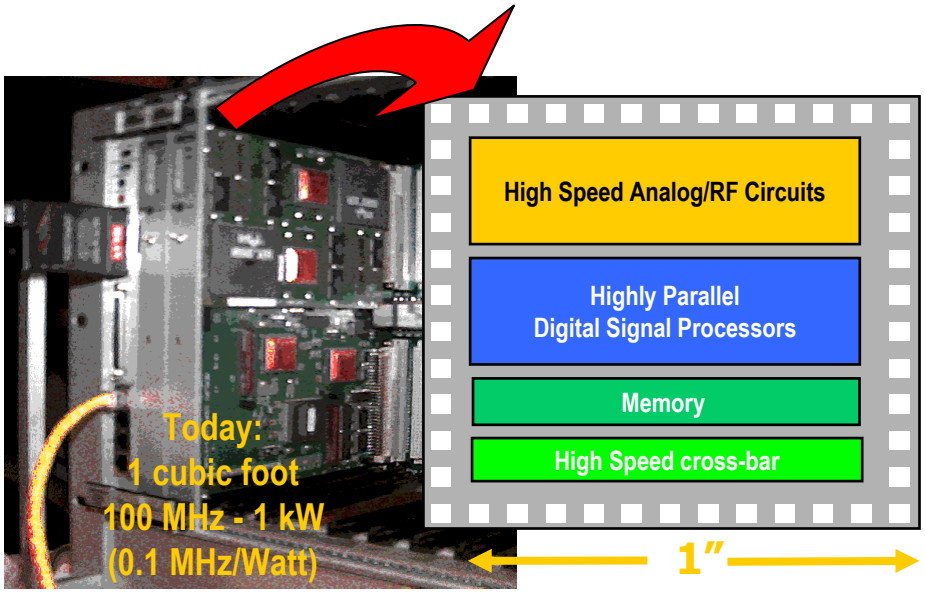
Component Layout for Hybrid FFA

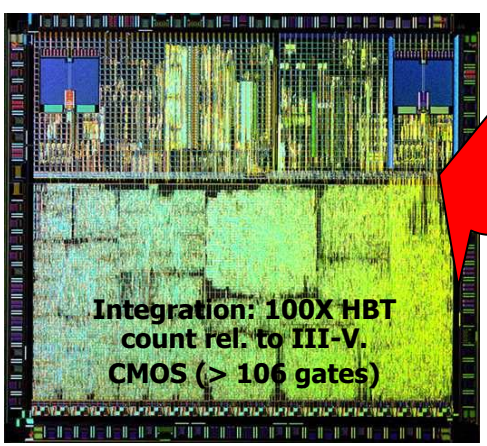


- Initial FFA design being implemented
  - Chip set procured (in-house) including a 2.8 W GaAs PHEMT MMIC amplifier from TriQuint for main amplifier
  - Cu/W carrier plates (for TCE match to GaAs) procured (in-house)
  - Custom collets (for solder die-attach) procured (in-house)
  - Beginning to set up solder die-attach experiments with mechanical samples
  - Coupler designs in progress; sample couplers on alumina in-house
  - Base-plate mechanical drawings in progress (first loop and 2nd loop hybrid circuit)



Technology for Efficient, Agile Mixed Signal Microsystems (TEAM)





TEAM :
1 square inch
Mixed Signal
System-on-Chip

10's GHz, 10's W

Goal:

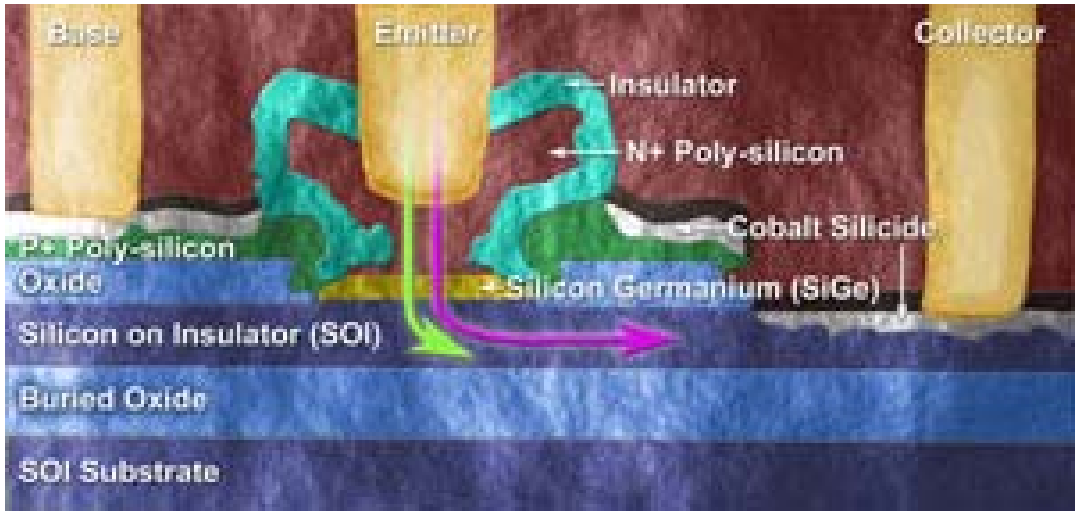
Demonstrate silicon (SiGe) devices with f_t > 200GHz in low power circuits operating at up to 60GHz that deliver III-V device performance @ integration levels of 10K analog/RF devices & with submicron CMOS capable of > 10M transistors/chip to provide advanced, single chip RF systems

Challenges:

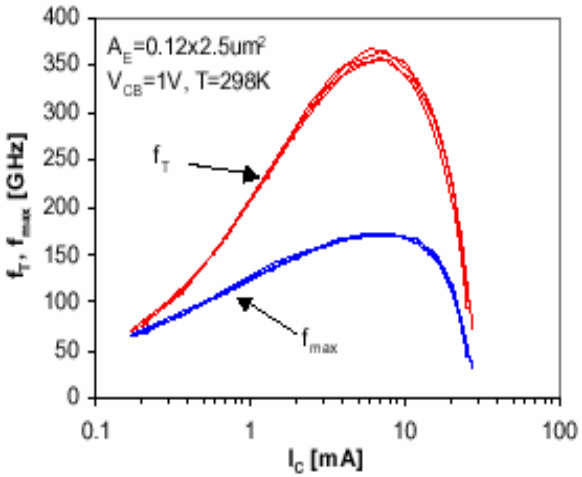
- **High f_T, high gain silicon devices with low output conductance, low noise figure (<2dB @ 20GHz), high linearity and low power dissipation**
- **Techniques to achieve isolation between RF and digital blocks (~ 100dB) and on-chip Qs of >20**
- **Device integration levels for complex, single chip RF systems**

Integrated chip-scale radar & radio transceivers with high performance, real time signal processing

Extending Si-based Transistors to >200 GHz Operation



Cross-section of SiGe SHBT



350 GHz IBM 0.12 μm SiGe SHBT

Scalable and affordable access to leading edge components
SENSE
PROCESS
ACTUATE
POWER
Microsystems for spectral exploitation and sensor dominance
DARPA
MICROSYSTEMS TECHNOLOGY OFFICE
DoD Access to Winning Microsystem Technology
Systems and Sub-systems
Devices and Modules
Processing
Electronics
Photonics
MEMs
Pushing the limits of scaling and integration
Systems that interact with the environment