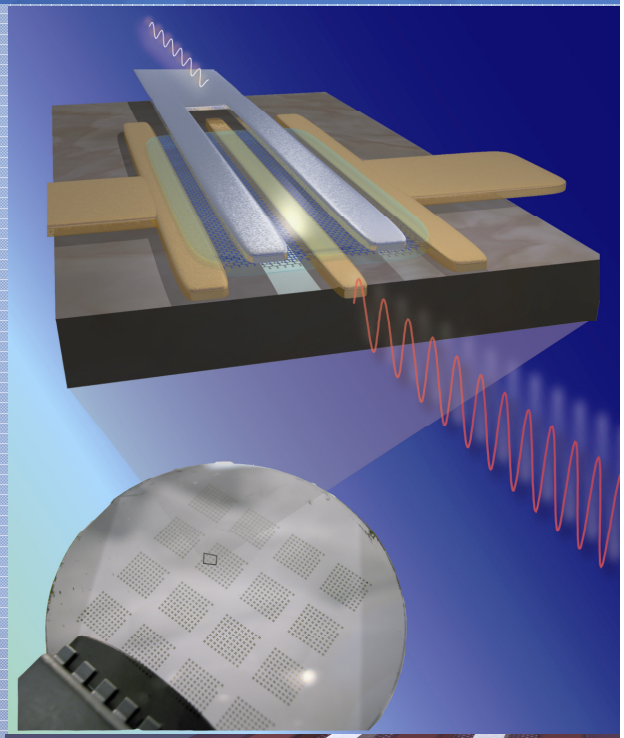
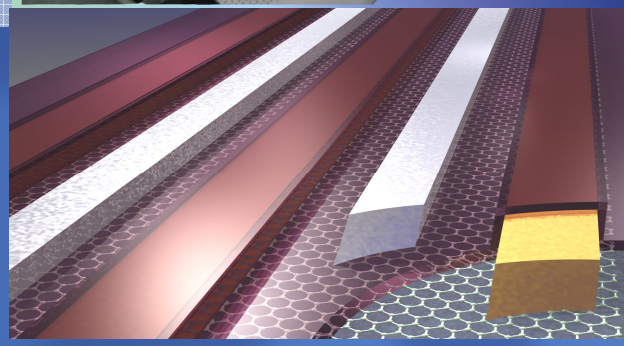
IBM Research | Science & Technology

IBM Nanoelectronics / Nano-system Strategy and Wafer Scale Graphene Nanoelectronics

C.Y Sung
Nanoelectronics Program Manager
IBM T.J. Watson Research Center
Science and Technology Strategy Department





Integrated Nanosystems Challenges-Opportunities

Workshop Objectives:

Realize heterogeneous smart nanosystems: provide active and intelligent complex functionalities (sense, communicate, remember and actuate) based on nanoscale phenomena, (eg. biologically inspired and hierarchical designs)

IBM Experiences:

Micro/Macroscale systems engineering:

-Design nanosystem structure for manufacturability
-Plan and supply of elements
-Model and integrate process
-Nanoscale process control and optimization

Common Goals:

Process engineering to scale-up and build for nano-manufacturing, nano-factory and nano-assembly to integrate nanoscale devices and systems

Outline

- IBM Nanoelectronics Strategy
  - Pushing to Si CMOS Limits
  - Subnanosystem Solutions
  - Post CMOS Carbon Electronics Opportunities
- Applications
- Conclusions

Outline

- **IBM Nanoelectronics Strategy**
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Technical Transition Plan

Fundamental Research

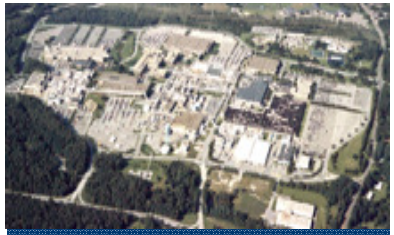
Screen new materials & processes

IBM Almaden & Yorktown

Advanced Semiconductor R&D

Innovation in integrated device & process technology

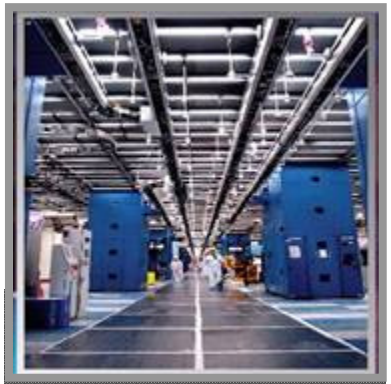
Albany Nanotech Center



Technology Development

Multi-company co-located joint development

IBM East Fishkill

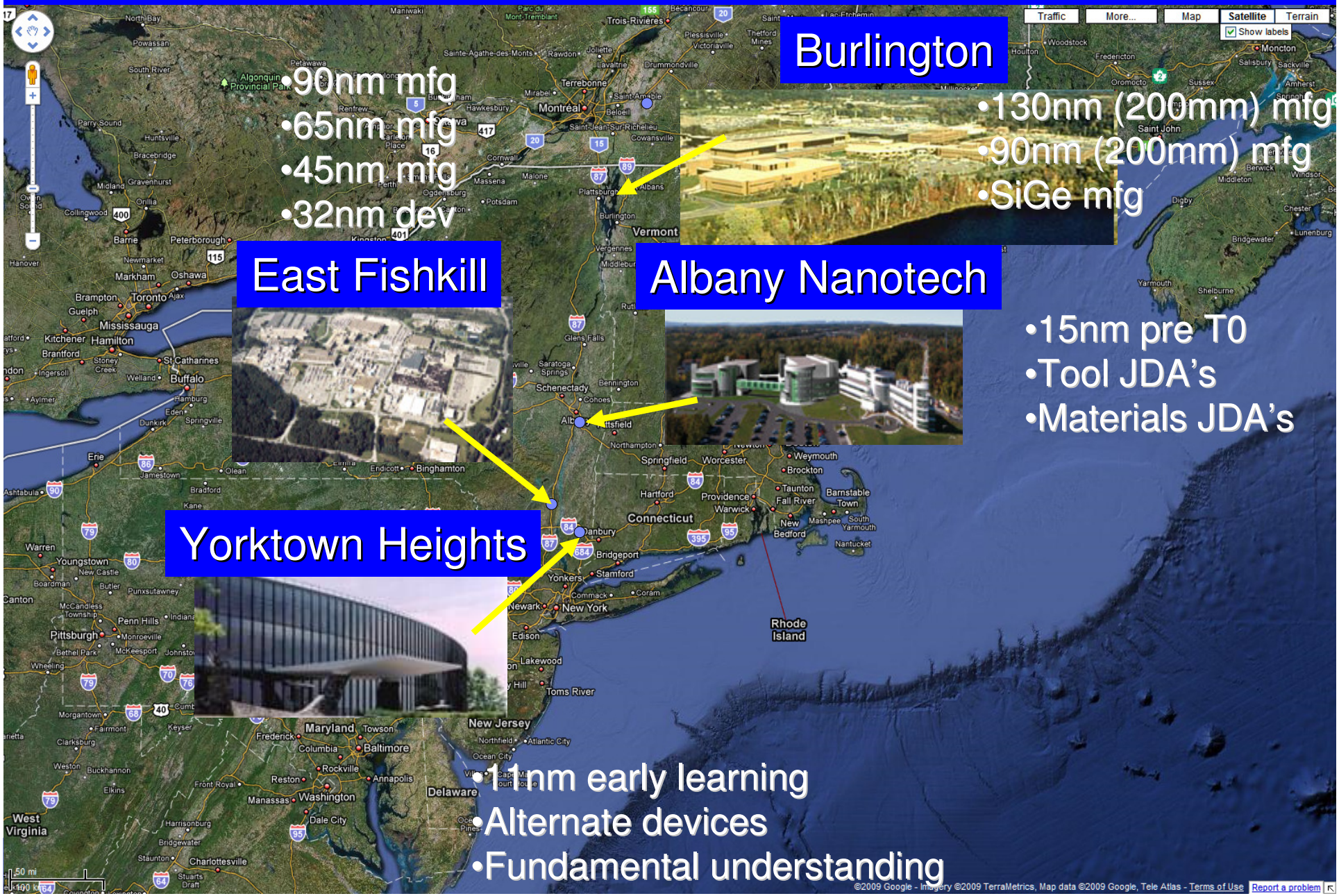


Manufacturing

Process synchronized fabricators (GDSII compatible)

USA

IBM Semiconductor Research, Development and Manufacturing Sites



IBM –SUNY Albany Nanotech Center

State-of-the-Art Infrastructure

NanoFab 300S
$50M, 150K ft²
32K Cleanroom
Completed: 03/04

NanoFab 300N
$175M, 228K ft²
35K Cleanroom
Completed: 12/05

NanoFab 300E
$100M, 250K ft²
15K Cleanroom
Completed: 05/09

NanoFab 200
$16.5M, 70K ft²
4K Cleanroom
Completed: 06/97

IBM Albany Nanotech has 80,000 ft² 300mm Wafer Cleanrooms with $4.5B Cutting-edge Facilities

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- IBM Nanoelectronics Strategy
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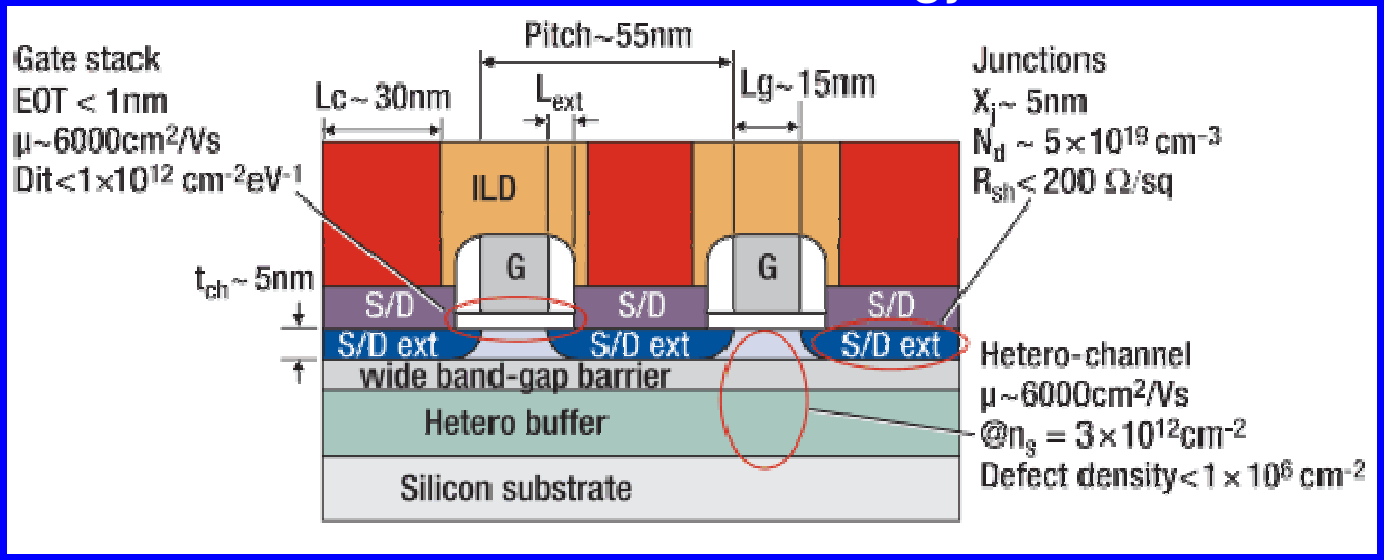
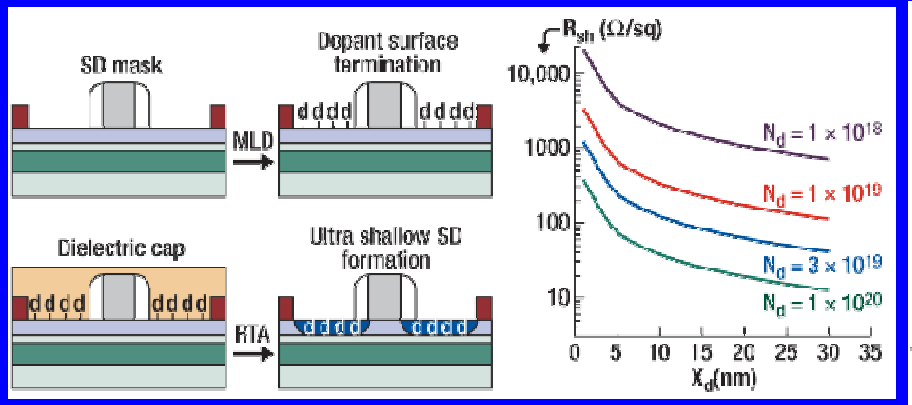
High Mobility III-V Channel Materials

(from Sematech)

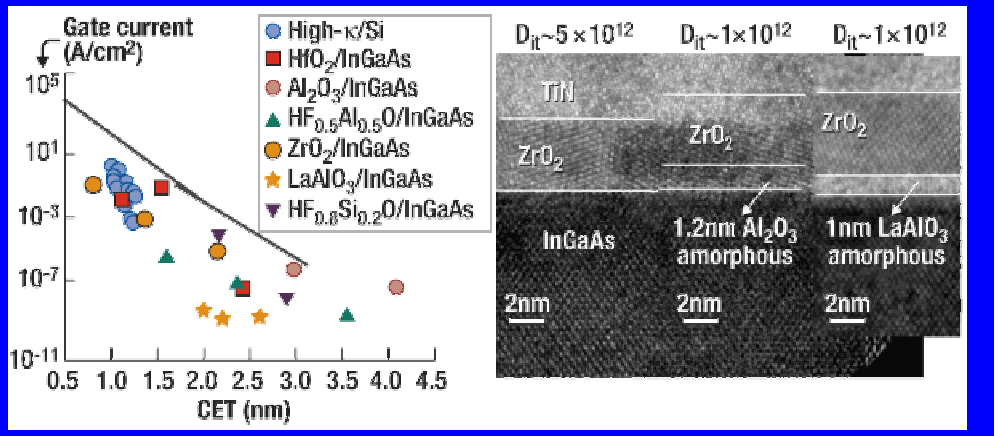
nFET 15nm technology



Mono-layer doping

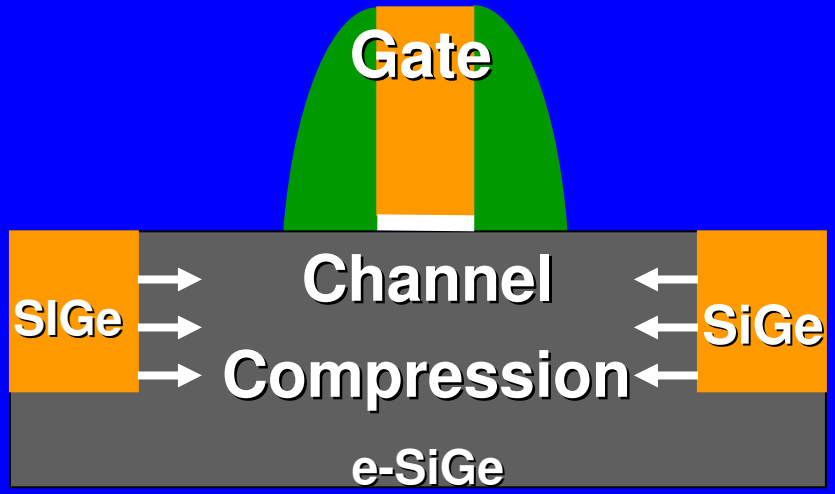


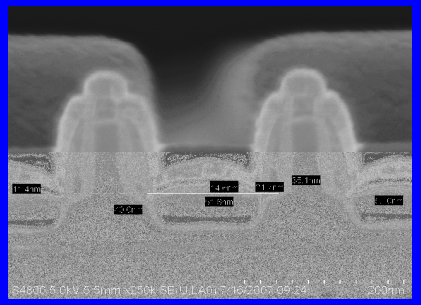
High-k gate on In0.53Ga0.47As

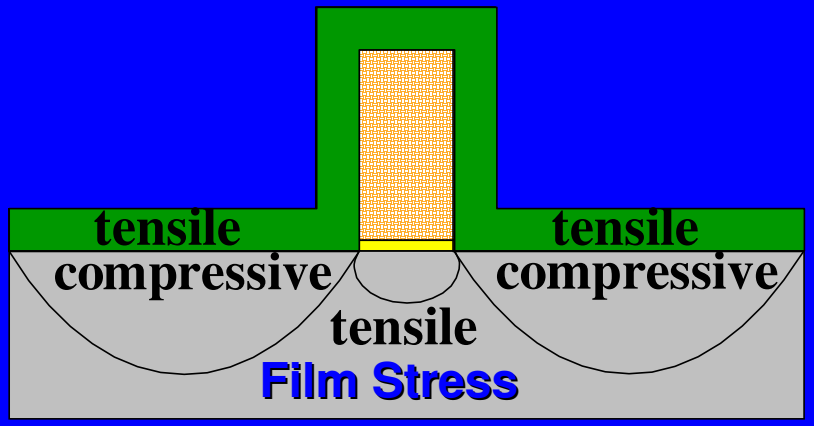


Mobility Enhancement Techniques

Strain & Substrate Engineering to give mechanical Stress enabled performance improvements







Device Count

Node	Device Pitch (nm)	Transistors / cm2	Transistors in 450 mm2	Year
45	170-180	**0.4 B**	**1.8 B**	2008
32	130	**0.8 B**	**3.6 B**	2010
22	100	~1.6 B	7.2 B	2012
15	80 - 56	~3.2 B	14.4 B	2014
11	50 - 40	~6.4 B	25.8 B	2016
8	35 - 28			
5	25 - 20			

- **Add 3D integration**

100 Billion Transistor/Chip

Do we need it? How to use them?

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  - **Post CMOS Carbon Electronics Opportunities**
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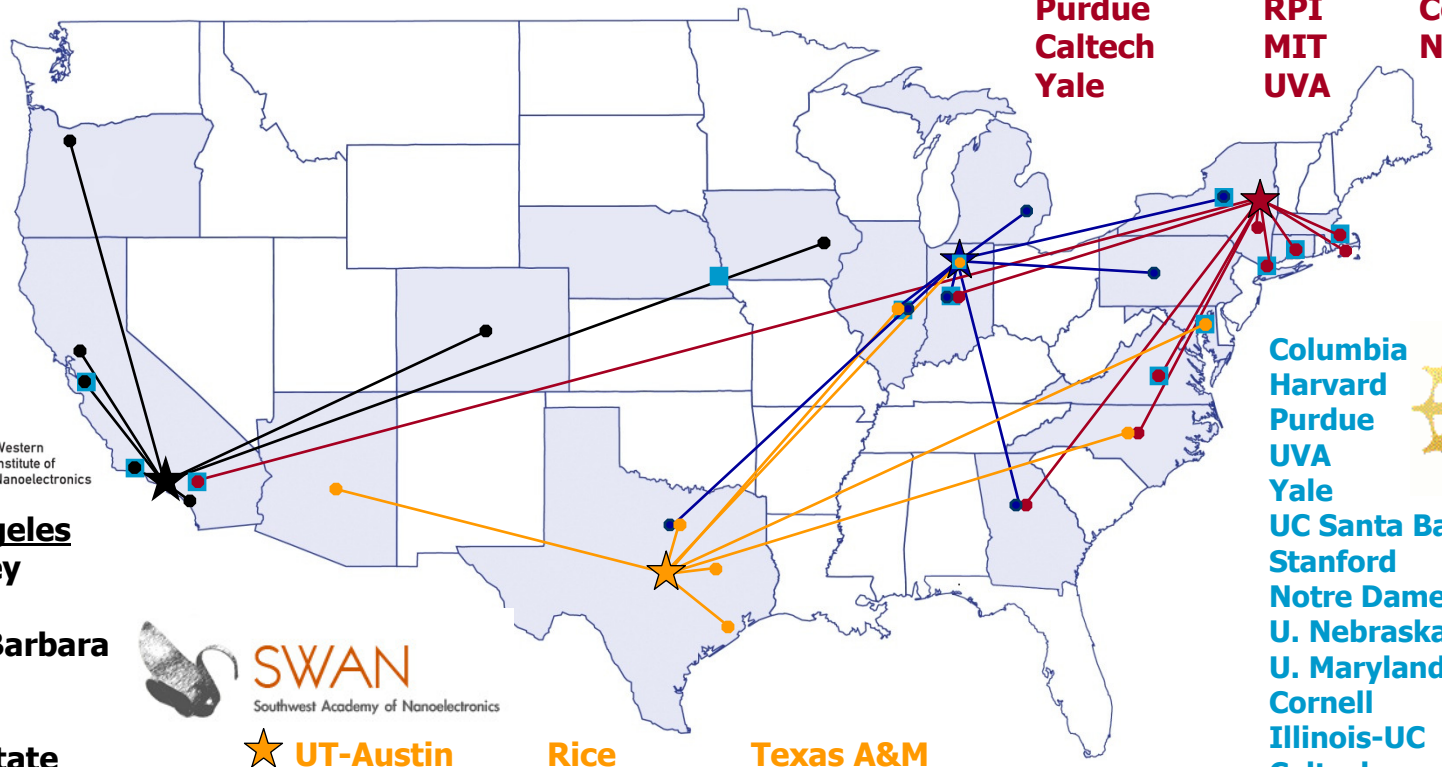
4 NRI Centers and Funded Universities



Nanoelectronics • Architectures
MIND
MIDWEST INSTITUTE FOR NANOELECTRONICS DISCOVERY

★ **Notre Dame**
Illinois-UC
Michigan
Cornell
Purdue
Penn State
UT-Dallas
GIT

INDEX
INSTITUTE FOR NANOELECTRONICS DISCOVERY AND EXPLORATION

★ **SUNY-Albany**
Purdue
Caltech
Yale
GIT
RPI
MIT
UVA
Harvard
Columbia
NCSU

WIN
Western Institute of Nanoelectronics

★ **UC Los Angeles**
UC Berkeley
UC Irvine
UC Santa Barbara
Stanford
U Denver
Portland State
U Iowa

SWAN
Southwest Academy of Nanoelectronics

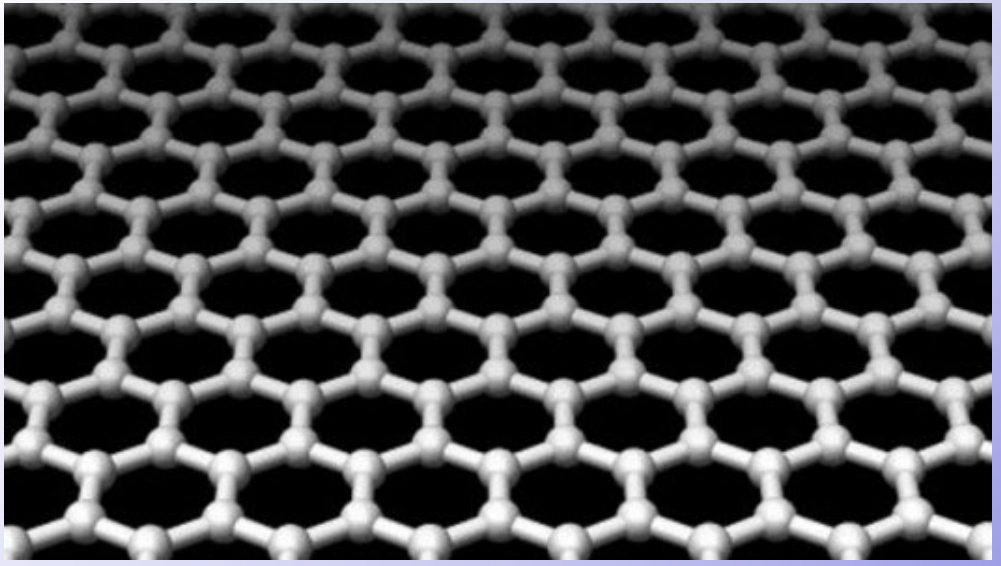
★ **UT-Austin**
UT-Dallas
U. Maryland
Rice
ASU
NCSU
Texas A&M
Notre Dame
Illinois UC

NSF

Columbia
Harvard
Purdue
UVA
Yale
UC Santa Barbara
Stanford
Notre Dame
U. Nebraska/Lincoln
U. Maryland
Cornell
Illinois-UC
Caltech

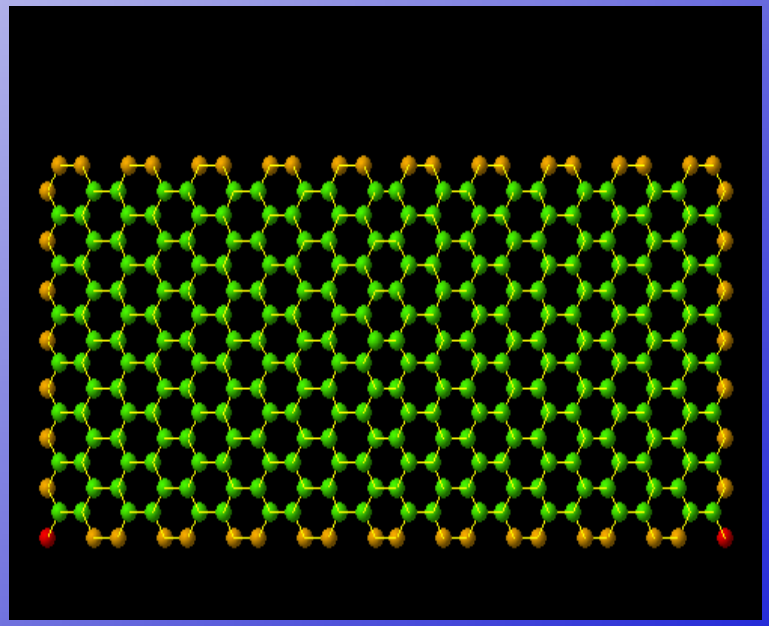
Over 30 Universities in 18 States

Graphene and Carbon Nanotube

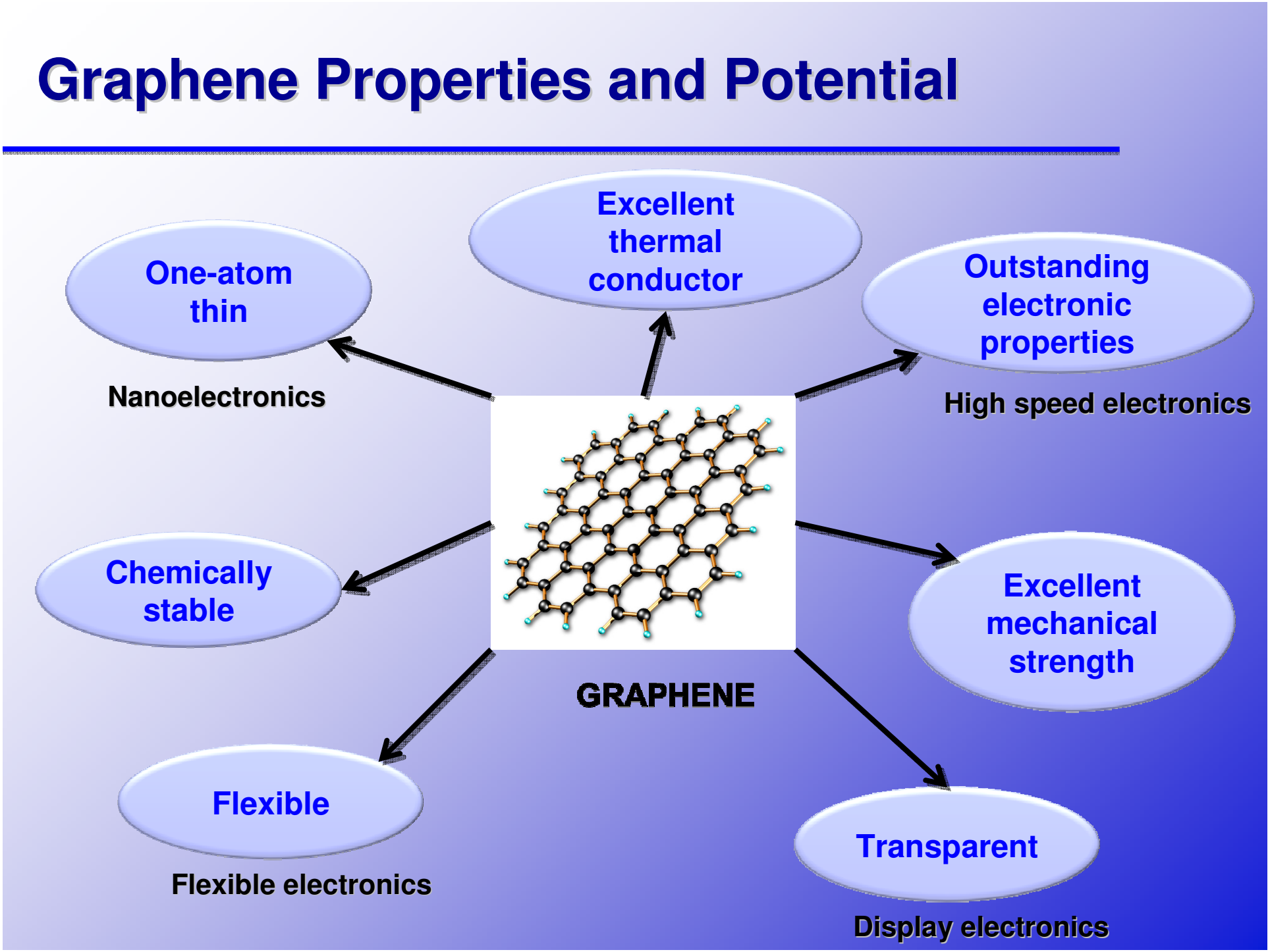


Graphene

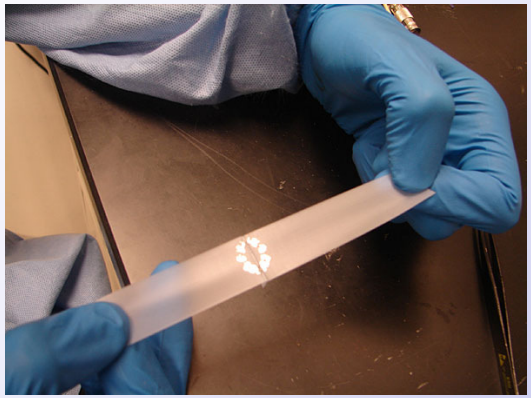
Nanotube

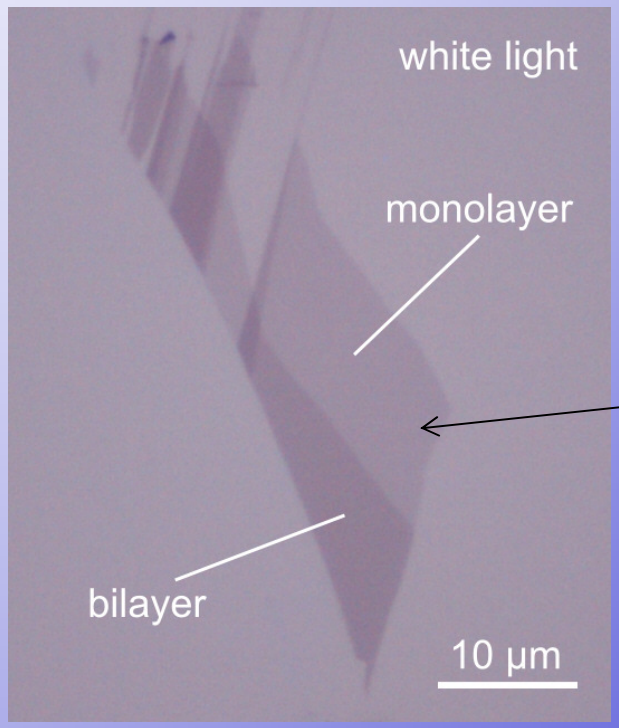


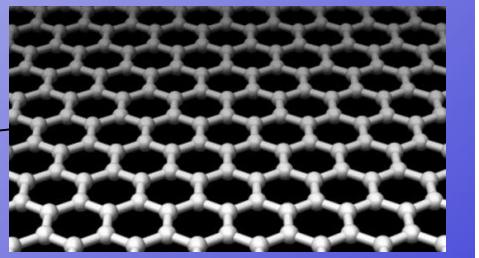
Graphene Properties and Potential



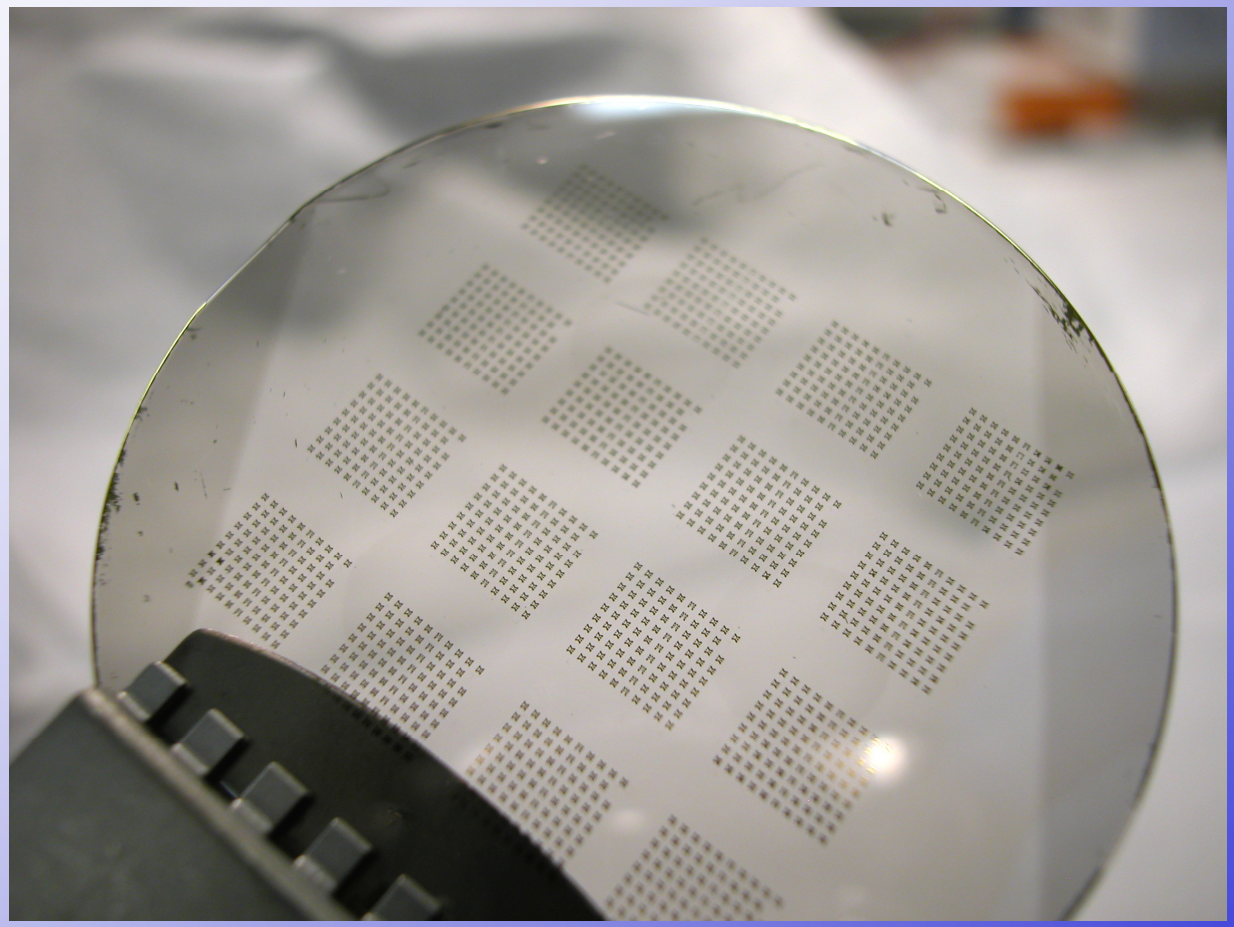
Peeling Graphene Layer from Graphite



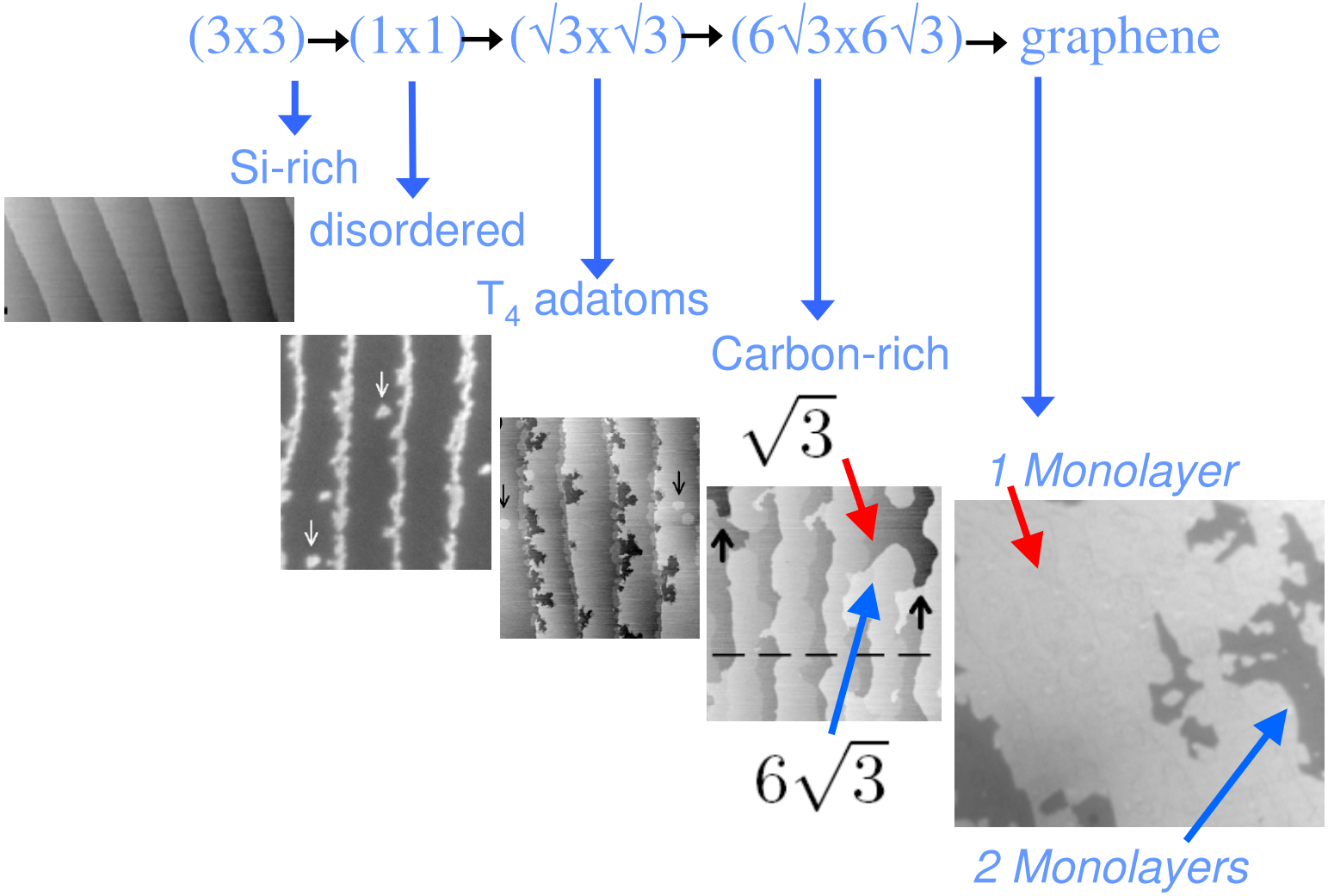




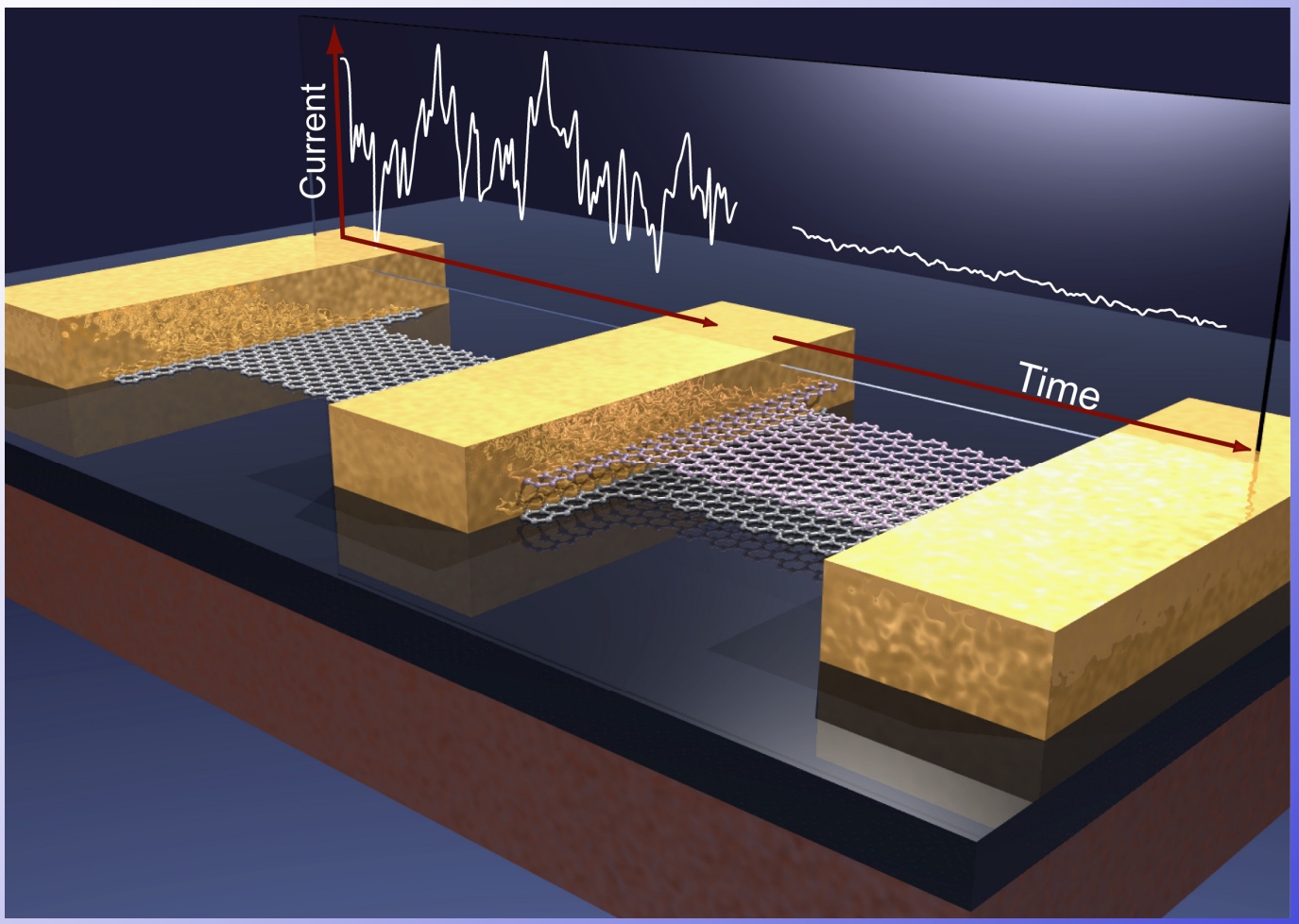
Epitaxial Graphene on a SiC Wafer



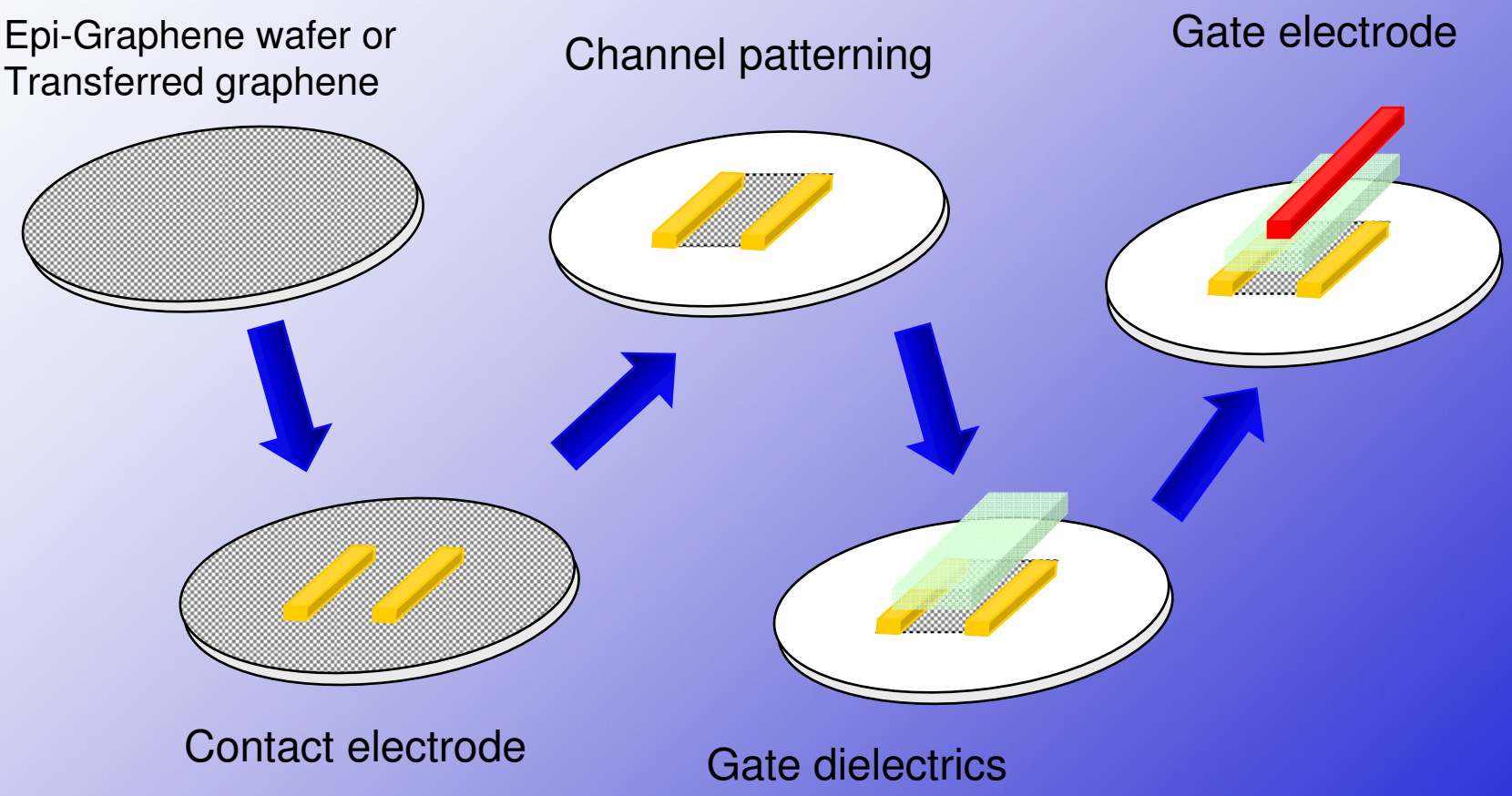
In-Situ Monitor Graphene Formation



Graphene Electronics



Fabrication of Graphene Transistor



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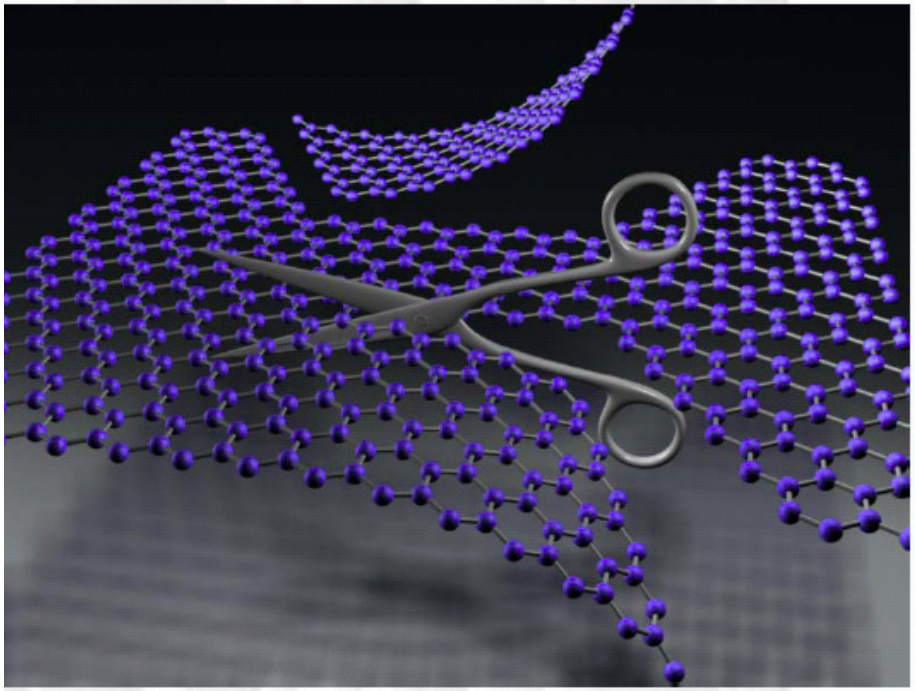
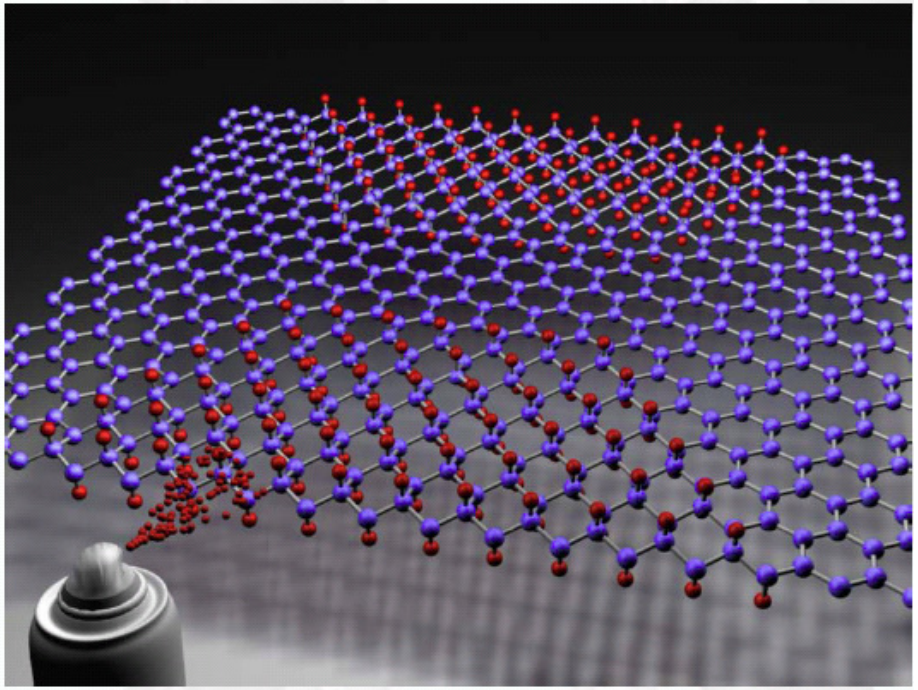
Atomic Layer Cutting or Painting

Nanoribbon, Quantum Dots, Quantum Point Contacts



RIE Etching



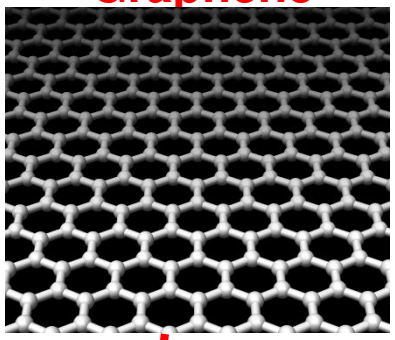
Hydrogenation

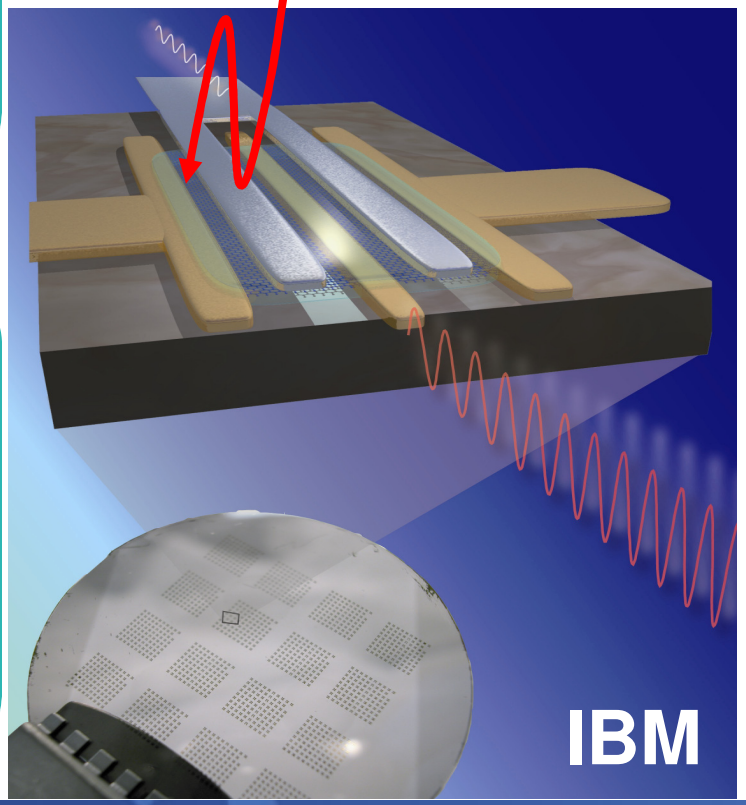
>100 GHz Graphene Devices Enable

Automobile Electronics

Adaptive cruise control radar for automobiles

Graphene

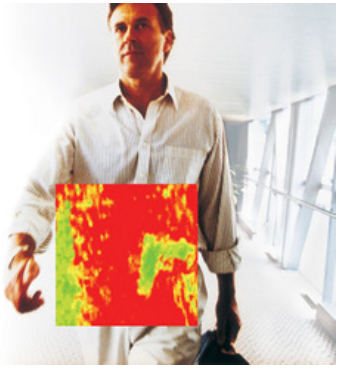




Communication

Lower power, higher resolution radar and communication systems

Security

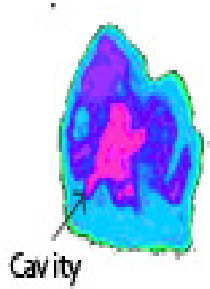


Improved weapon detection

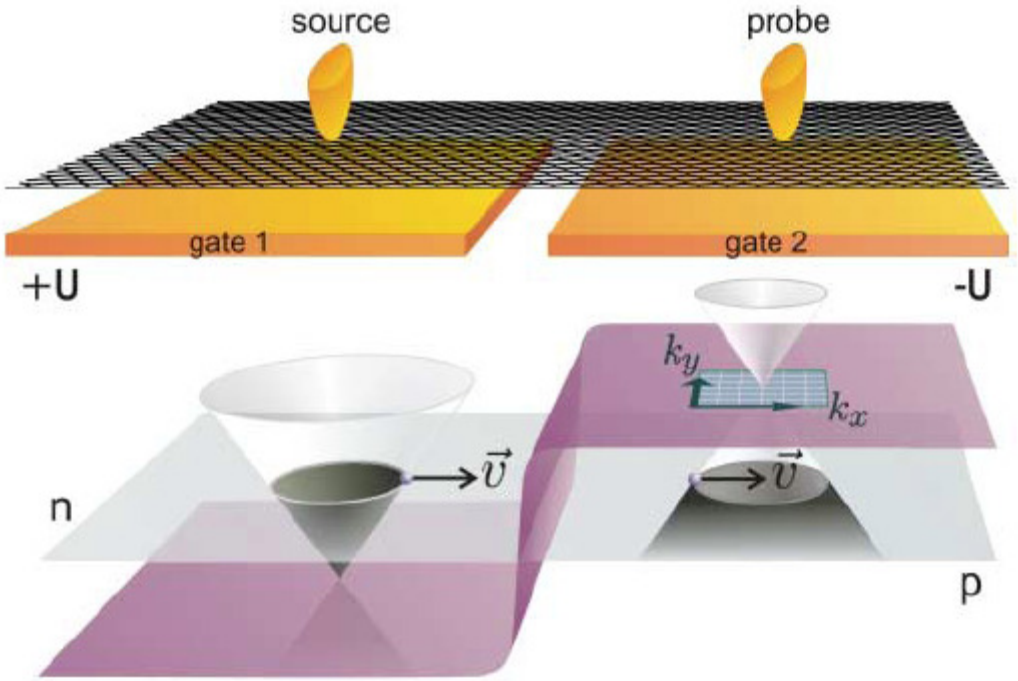
Imaging for Health Care

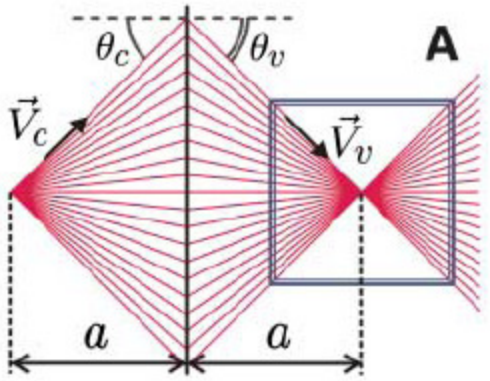
Visual Image

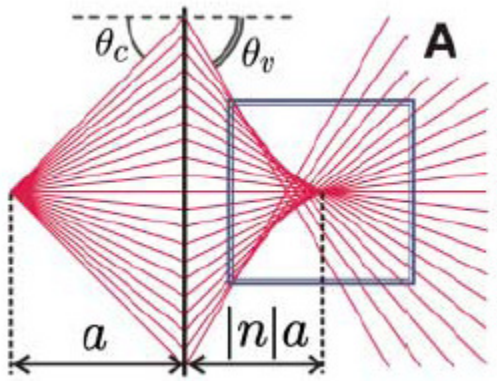
Terahertz Image



Veselago Lens Switches





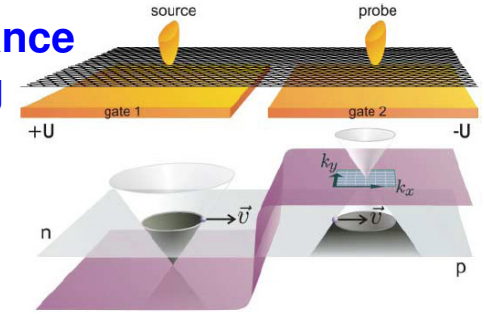


- **On/Off via electron focusing**
- **Speed**

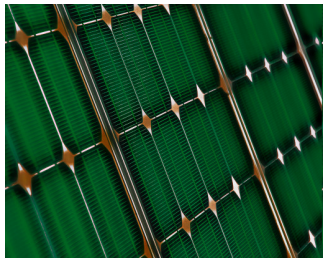
Cheianov, Fal'ko & Altshuler, *Science* (2007)

Graphene Roadmap

High Performance Computing

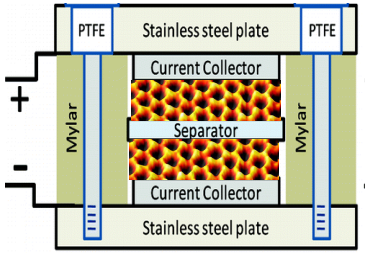


Low-cost RF Circuits
Mid-performance (GHz)



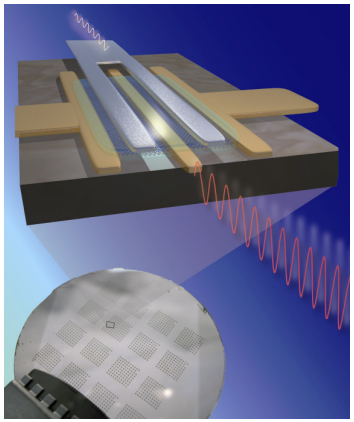
Photovoltaics

Processing Challenges

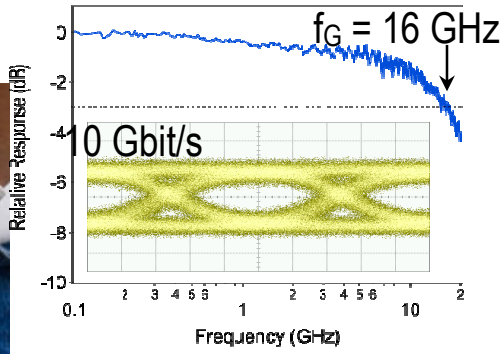


Supercapacitors

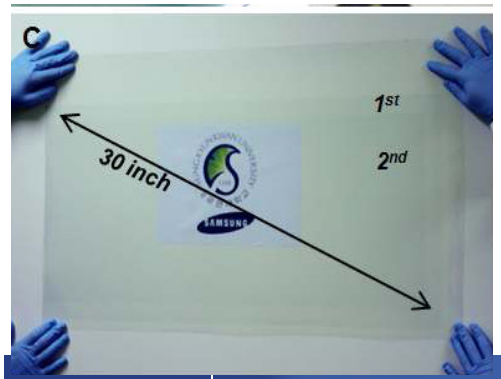
Optoelectronics Devices



Smart Sensors



Transparent electrodes



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Graphene Research Model

Government Participation

DARPA

Internal Partners

IBM Almaden Center

Watson Research

Academic Partners

Columbia University

University of Texas (Austin)

- Conduct Research in bold exploratory science and technologies
- Collaborate with universities and government
- Maximize technology impacts

Leverage with SRC- NRI Research Centers

Western Institute of Nanoelectronics

INDEX INSTITUTE FOR NANOELECTRONICS DISCOVERY AND EXPLORATION

SWAN Southwest Academy of Nanoelectronics

MSD

FENA

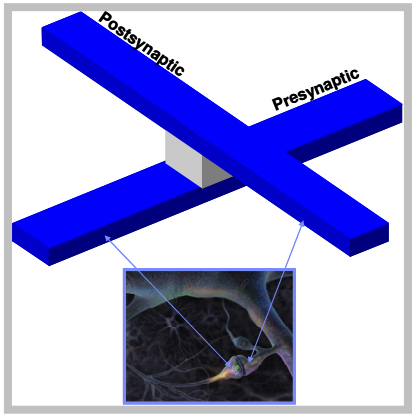
MIND

Frontiers in Energy Per Operation & Functional Diversification

Energy per Operation

Exascale Systems

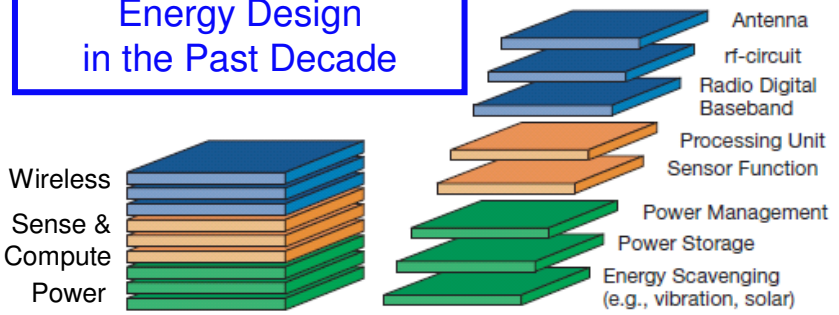
DARPA Synapse Project

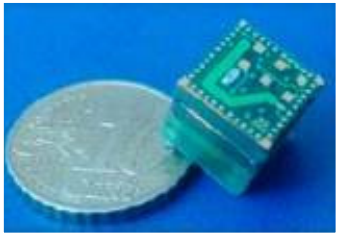


IBM's Strengths

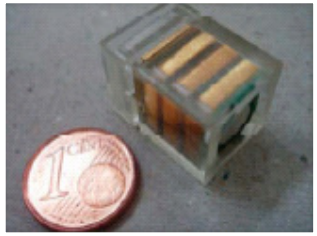
Functional Diversification

The Driver for Ultra-Low Energy Design in the Past Decade

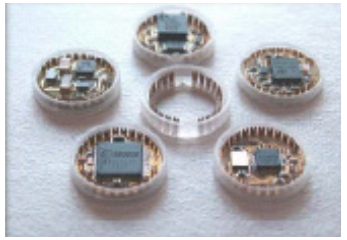




IMEC e-Cube



UCB PicoCube



Philips Sand Module

Intel Mote

IBM New Opportunities

Frontiers of IT Nanosystem

Frontiers of IT: Vision

A new class of learning systems, architected with people as an integral and central element of the process, **to seamlessly enhance human cognition for better outcomes and a better life**.

Go beyond increased storage, better search, and more complex analytics to systems that **enable humanity to reach its greatest potential for human creativity, innovation and ingenuity**.

Learning Systems Will Impact Key Sectors of the Economy

Financial

Fraud Prevention

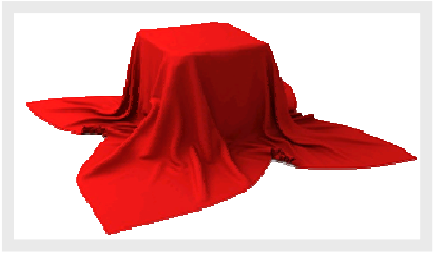
Retail

Revenue Maximization

Medical

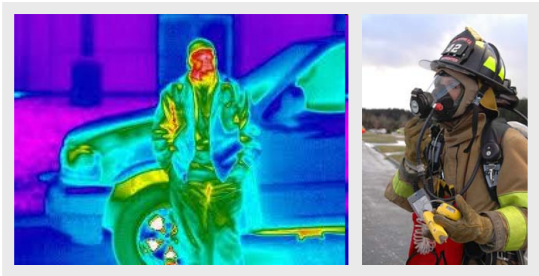
Enhanced Wellness

General Business



Product Design, Launch and
Time to Revenue & Profit Optimization

Security



Better Security in a More Complex World

Learning Systems Roadmap to Meet the Challenge

Autonomously & accurately identify essential features across multiple domains. Learning systems must understand context to disambiguate.

Keyword Search

Delivers lists based on keywords & human filters

Static Learning Systems

Expert teams identify features across industries, create first commercial learning systems

Dynamic Learning Systems

Dynamic Data Corpus
Expand Hypothesis Generation to different domains (leverage crowd-sourcing)
Add Scorers for Different Input Modalities: images, video, voice, environmental, biological; leverage new devices & hardware acceleration
Deeper Reasoning: Allow higher-levels of semantic abstraction. Leverage new hardware.
Domain Adaptation Tools

Autonomous Learning Systems

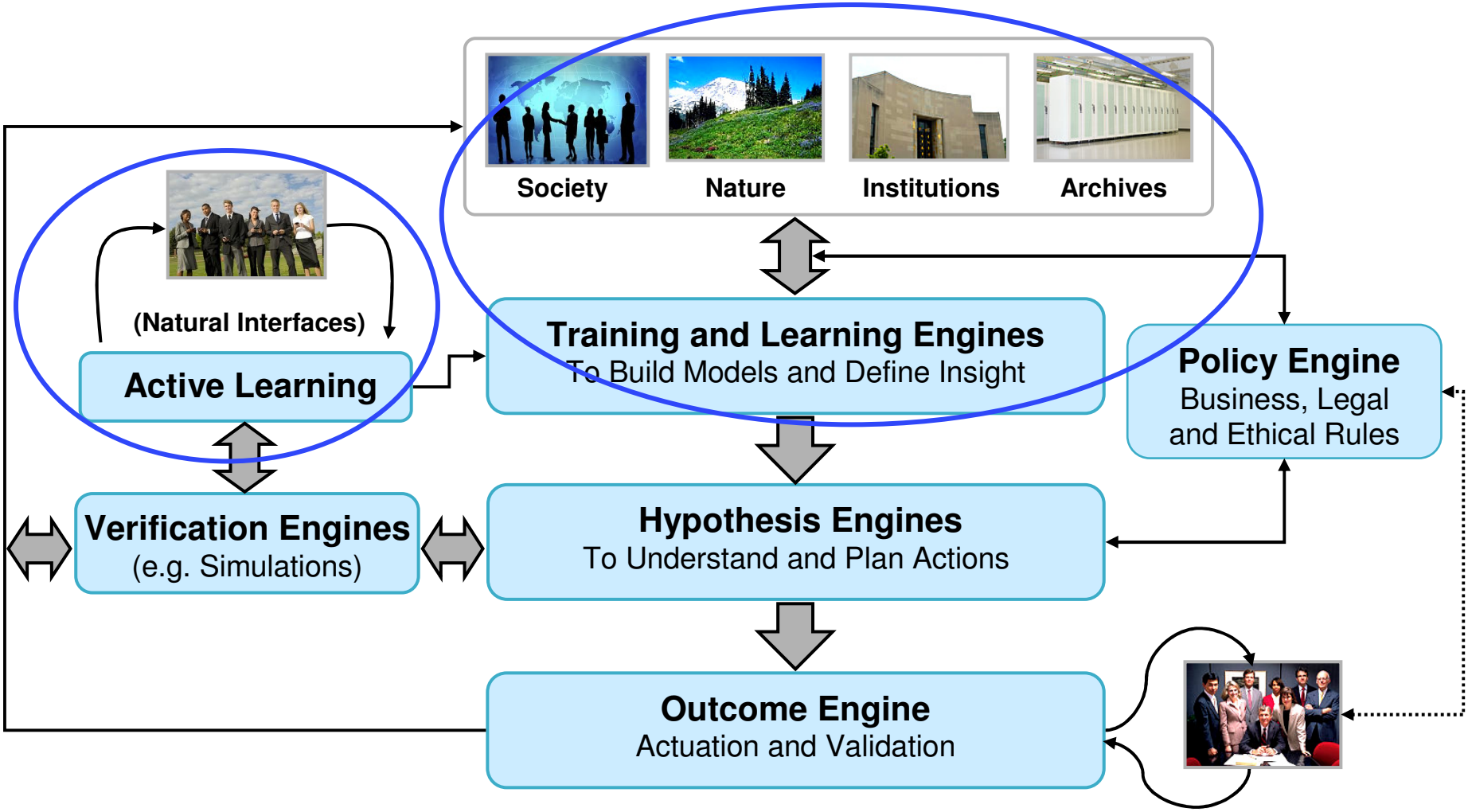
Achieve understanding of natural language, images and other sensory information. Hypothesis and question generation across arbitrary domains; meta-heuristic to automate algorithm choices

Biological Inspiration: Cognitive Process Understanding

1985 2010 2015 2020 2025

Greater Autonomy

Future Systems – The Learning Paradigm



Future IT System in New World

Bio Inspired Nanosystem

Deep Blue in Chess Game (1997)

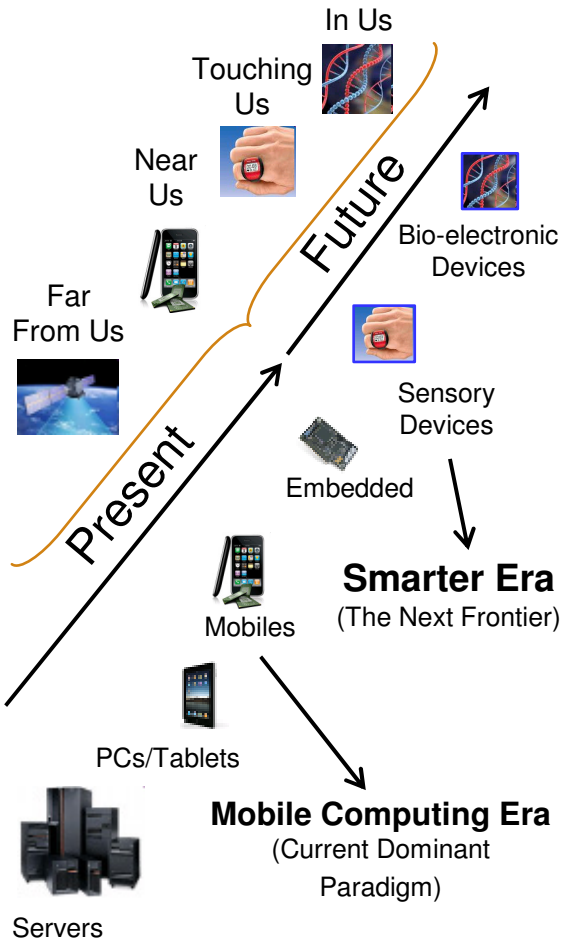
IBM supercomputer famously beat the grandmaster Garry Kasparov at chess game

IBM Supercomputer (Watson) won Jeopardy! (2/16/2011)

Medicine, Investment (msec trading), war games, data analysis, assist judgment

Pulling it All Together: The Technology Frontiers

Computing Everywhere and in Everything



Natural Interfaces and Connectivity


Nature


Work and Leisure


Biology

Sensory Computing
(voice, movement, natural sensing, etc)

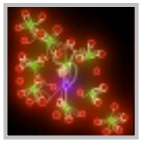
Touch Computing

Keyboard Entry

New Computing Paradigms

Bio-Inspired Computation

Quantum Computing



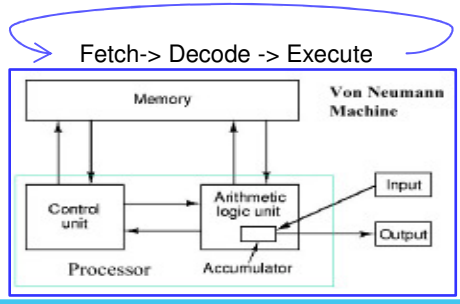
Neuromorphic and Cognitive Computing

Computing without Programming

Non Von Neumann Architectures

\+

Von Neumann Architectures



Inspiration from Biology

Nowhere Near Done with Technology!

Energy per Operation Frontier

The Human Brain

Pavg = 20W

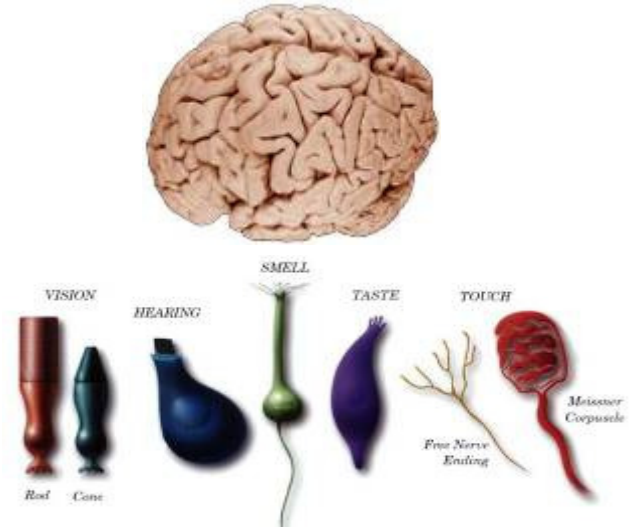
(20% of body dissipation, 2% of weight)

Power Density: ~15mW/cm3

Avg Neuron Density: 70 million/cm3

10^{16} Computations/second

1-2 fJ per computation <1 aJ per operation



Thank you !