



2003-2009 CBAN, NRI



Nanoelectronics Research Initiative A Partnership for Exploratory Research

Mike Roco

National Science Foundation and National Nanotechnology initiative

U.S.-Korea Annual Meeting, April 29, 2009

Context: A transforming word underlying the importance of nanotechnology

- Knowledge has exponential growth, and so the potential of emerging technologies
- Education, science and technology shift in content, numbers and societal importance
- Last decade trend: transfer of wealth from "West to East"
- > <u>Demographics of discord</u>: growing, declining, diversifying at once
- > Earth resources limited: need of radically new technologies
- ➢ <u>Global governance</u>: chances for collaboration and conflict

Converging New Technologies transforming tools (overview in 2000)





M.C. Roco, 4/29/2009

Benchmark with experts in over 20 countries

"Nanostructure Science and Technology"

Book Springer, 1999

Nanotechnology

is creation of materials, devices and systems by *control and restructuring of matter* at dimensions of roughly 1 to 100 nanometers,

- ⇒ at the transition from individual to collective behavior of atoms and molecules
- \implies where new phenomena
- ⇒ enable new applications

Generations of Products and Productive Processes Timeline for beginning of industrial prototyping and nanotechnology commercialization (2000-2020)



WORLDWIDE MARKET INCORPORATING NANOTECNOLOGY (2000-2015)

(Estimation made in 2000 after international study in > 20 countries; data standing in 2008)



Reference: MC Roco and WS Bainbridge, Springer, 2001

National investment FY 2009 NNI Budget - \$1,527 million



M.C. Roco, NSF, 2009

Per Capita Total Amount for NS&E Awards (NEW and ACTIVE)

FY 2001 - 2008



AK - \$3.96; AL - \$11.28; AR - \$10.8; AZ - \$11.43; CA - \$12.24; CO - \$23.66; CT - \$10.04; DC - \$41.99; DE - \$28.37; FL - \$4.62; GA - \$7.19; HI - \$1.25; IA - \$7.82; ID - \$8.15; IL - \$18.35; IN - \$13.75; KS - \$4.91; KY - \$7.09; LA - \$6.41; MA - \$44.88; MD - \$15.67; ME - \$4.32; MI - \$8.12; MN - \$11.46; MO - \$5.97; MS - \$4.81; MT - \$10.99; NC - \$11.50; ND - \$16.06; NE - \$18.53; NH - \$7.76; NJ - \$8.95; NM - \$13.84; NV - \$4.93; NY - \$22.10; OH - \$9.65; OK - \$9.68; OR - \$8.21; PA - \$18.01; PR - \$4.56; RI - \$39.03; SC - \$8.56; SD - \$17.89; TN - \$6.93; TX - \$8.06; UT - \$9.65; VA - \$10.86; VT - \$10.74; WA - \$7.73; WI - \$18.18; WV - \$3.41; WY - \$5.54

Per Capita Total Amt. FY01-08



Industrial impact of NSECs, NCN and NNIN

Institution	Number start-ups	Industrial partnerships		Support from other organizations
		Number partners	Ind. Support (\$ million)	Total support (\$ million)
Totals NSEC	37	392	41.9	279.4
NCN	0	403	2.0	11.3
NNIN	38	358	86.0	300.0
NSECs + 2 Users Networks	75	1,153	129.9	590.8

MC. Roco, 4/2/2009

Summary of US Semiconductor Industry Initiatives



SRC Numbers

Research Programs*

- >\$1.3B invested
- 2,900 contracts
- 7,400 students
- 1700 faculty
- 242 universities

Deliverables*

42,500 technical documents324 patents granted762 patent applications573 software tools



Member Participation*

- 2,600 industry mentors
- 1,600 on advisory boards
- 2,500 events
- 1,400 technical meetings
- 64,000 event attendees
- 1,200 planning meetings

All for the benefit of SRC members





SRC-GRC Research Worldwide



Globalization of GRC Research

- 330 Research projects
- 110 universities (20 outside of the US)
- 2008 funding \$24M + ~\$46M leverage
- Research performed individually and in five centers.



Focus Center Program Structure



Nanoelectronics Research Initiative Timeline

- October 2003: NSF-SRC/SIA workshop SNB (Portland) NNI-Electronic Industry CBAN was formed with five working groups Five research vectors selected for long term R&D (15-20 years ahead, enhancing the R&D focus in both industry and government)
- 2004 Building Consensus on research needs: 4 joint topical workshops/y; ITRS-Emerging Research Device Technical Working Group, 2004-05

March 2004: SIA Board Resolution for formation of NRI

March 2005: Six companies sign NRI Participation Agreement – NERC incorporated to manage: AMD, Freescale, IBM, Intel, Micron, TI

Governing Council (GC) and Technical Programs Group (TPG) formed with one representative per participating company & government members

- NSF-NRI Solicitations released: September <u>2005</u>, 2006, 2007, 2008
- September 2007: NIST joins NRI

2003-05 SNB Joint Annual Workshops; 2006-08 NRI Joint Annual Reviews

NNI- Electronic Industry CBAN Five consultative working groups (CWG), 2003 -

- Post CMOS information processing technologies
- Novel materials and assembly methods for extending charge-based technology to its ultimate limit
- III Multi-scale, multi-phenomena modeling and simulation
- IV Novel nano-architectures

V - Nano – Environmental, Health and Safety

<u>Other functions</u>: SNB theme in NSF nano solicitations (2004-), co-review trends/proposals, address EHS, human resources, create & access to NNI supported physical infrastructure, joint NIST funding (2007-)

Nanoelectronics Research Image: Constraint of the second seco

NRI Mission: Demonstrate novel computing devices capable of replacing the CMOS FET as a logic switch in the 2020 timeframe.

To meet these goals, NRI pursues five research vectors:

•NEW DEVICE: Device with alternative state vector

•NEW WAYS TO CONNECT DEVICES: Non-charge data transfer

•NEW METHODS FOR COMPUTATION: Non-equilibrium systems

•NEW METHODS TO MANAGE HEAT: Nanoscale phonon engineering

•NEW METHODS OF FABRICATION: Directed self-assembly of devices

NNI contribution to partnership in 2008

- <u>New ideas</u>: about 4500 awards (12 funding agencies), of which 3500 by NSF, of which 500 exploratory (2nd-4th generation)
- <u>People</u>: education and training reaching 10,000 students and teachers per year by NSF alone; Broad spectrum - NIH, DOD, DOE, ...
- <u>Infrastructure</u>: laboratories, experts, centers, publications, patents 80 centers, networks, user facilities – all NNI of which 24 by NSF
- Co-review and joint workshops setting the research goals
- <u>Funding in electronics, photonics, magnetics</u>. Ex NSF
 NSF ~ \$100M relevant to NS&E in FY 2008
 - NSF ~ \$20M joint NSF-SRC review NS&E solicitation in FY 2007
 - NSF \$1M for joint NSF- SIA fellowships in FY 2008

Promote partnerships academe - SIA, through NSF centers, GOALI, PFI, industry sector partner model extended Support joint workshops: about 4 per year

Several NSF centers of relevance to NSF - SIA collaboration in nanoelectronics (2005-2008)

- Nanoscale Science and Engineering Centers NSEC ~ 10
- Networks (NNIN, NCN, NNN) 3
- Materials Research S&E Centers MRSECs ~ 7
- Nanoscale Interdisciplinary Research Teams NIRT 40
- Nanoscale Exploratory Research NER 60
- Engineering Research Centers, ERCs 2

2006-08: <u>Nanoelectonics Research Initiative</u> established 4 research centers in the New York state, California, Texas and Indiana – on topics complementing NSF funding

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- 18 NSF-NRI Graduate Student and Postdoctoral Fellow Supplements to NSF Centers in Nanoelectronics (Joint funding NSF-SIA, 2006-2008)

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NSF-NRI Graduate Student and Postdoctoral Fellow Supplements to NSF Centers in Nanoelectronics

Purpose

- Strengthen industry linkages with NSF centers and reciprocal flow of ideas
- Explore new concepts beyond the scaling limits of CMOS technology aligned with the NRI vectors, such as: Novel logical switch as a successor to CMOS; Novel architectures with post-CMOS devices.
- Industry assignees work collaboratively with students and postdoctoral fellows
- \$2M funds invested each year FY2006, FY 2007 and FY 2008
 - \$1 million NSF (ENG, MPS, CISE), \$1 million NRI
 - Average award size \$300-500K for a duration of 3 years
 - 18 supplement awards at 12 NSF centers NCN, NSECs and MRSECs
- At 2006 and 2007 NRI annual reviews, industry members expressed benefit in their collaborations with NSF-funded university researchers

NSF-NRI Supplement Awards, 2006-2008

PI	Institution	Center	Торіс
Lundstrom, Mark	Purdue U	NCN	Exploratory Theory, Modeling, and Simulation for the NRI
Hull, Robert	U Virginia/ Notre Dame U	MRSEC	Directed Assembly of Epitaxial Semiconductor Nanostructures for Novel Logic Switches
Yardley, James T.	Columbia U	NSEC	Non-equilibrium Quantum Coherent Devices in 1-D materials
Hawker, Craig	UCSB/ Stanford U/ U Mass	MRSEC	Development of Next Generation Devices using Nanolithographi Techniques
Westervelt, Robert	Harvard U	NSEC	Ultrasmall Nanowire and Oxide Switches
Johnson, Matt/ Salamo, Greg	U Oklahoma/ U Arkansas	MRSEC	Nanoferroelectric Random Access Memory

NSF-NRI Supplement Awards 2007-2009

PI	Institution	Center	Торіс
Buhrman, Robert	Cornell U	NSEC	Controlled Orbital Hybridization in the Carbon Nanotube Quantum-Modulated Transistor
Hull, Robert	U Virginia/ UCSB/ Notre Dame U	MRSEC	Coherent Spin Dynamics in Single Ion doped Semiconductors: Towards a Coherent or Quantum Spin Switch
Lundstrom, Mark	Purdue U	NCN	Exploratory Theory, Modeling, and Simulation for the NRI
Sellmyer, David	U Nebraska- Lincoln, Omaha	MRSEC	Multiferroic interfaces: new paradigms for functional switching
Tully, John	Yale U	MRSEC	Design and fabrication of magnetic- based devices with complex oxide materials
Williams, Ellen	U Maryland/ UTexas-Austin	MRSEC	Pseudospintronics

NSF-NRI Supplement Awards 2008-2010

PI	Institution	Center	Торіс
James Yardley	Columbia U	NSEC	Novel Device Architectures Based on Quantum Transport Phenomena in Graphene
Mark Lundstrom	Purdue U	NCN	Experimental Realization of Low- Power Transistors with Negative Capacitors
Kathryn Moler	Stanford U/ UTexas-Austin	NSEC	Ultra-Low Power Pseudospintronic Switching in Bilayer Graphene at Room Temperature
Robert Westervelt	Harvard U	NSEC	Tunable Ultra-fast Conductance Switching Through External Fields
Ellen Williams	U Maryland	MRSEC	Controlling the Electronic Properties of Graphene
Harry Atwater	CalTech	MRSEC	Graphene Atomic Switches for Ultracompact Logic Devices and Non- volatile Memory Elements

NRI Centers (complementing the NSF centers)

Leveraging industry, university, and both state & fed government funds, and driving university nanoelectronics infrastructure









NIST

WIN Western Institute of Nanoelectronics	INDEX Institute for Nanoelectronics Discovery & Exploration	SWAN SouthWest Academy for Nanoelectronics	MIND Midwest Institute for Nanoelectronics Discovery
UCLA, UCSB, UC-Irvine, Berkeley, Stanford, U Denver, Iowa, Portland State	SUNY-Albany, GIT, RPI, Harvard, MIT, Purdue, Yale, Columbia, Caltech, NCSU, UVA	UT-Austin , UT-Dallas, TX A&M, Rice, ASU, Notre Dame, Maryland, NCSU, Illinois-UC	Notre Dame, Purdue, Illinois-UC, Penn State, Michigan, UT-Dallas
Theme 1: Spin devices Theme 2: Spin circuits Theme 3: Benchmarks & metrics Theme 4: Spin Metrology	Task I: Novel state-variable devices Task II: Fabrication & Self-assembly Task III: Modeling & Arch Task IV: Theory & Sim Task V: Roadmap Task VI: Metrology	Task 1: Logic devices with new state- variables Task 2: Materials & structs Task 3: Nanoscale thermal management Task 4: Interconnect & Arch Task 5: Nanoscale characterization	 Theme 1: Graphene device: Thermal, Tunnel, and Spin Theme 2: Interband Tunnel Devices Theme 3: Non-equilibrium Systems Model / Meas. Theme 4: Nanoarchitecture

Western Institute of Nanoelectronics (WIN)





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South West Academy for Nanoelectronics (SWAN)





NRI Funded Universities



The Central Role of NCN in NRI



International Planning Working Group for Nanoelectronics (IPWGN, 2005-2009 -)

IPWGN is a task force WG in International Nanotechnology Conference (INC). The mission of IPWGN is to stimulate and enhance inter-regional cooperation in nanoelectronics. Three regions (the US, Europe, and Japan) join WG. Main activities:
(1) define research needs of nanoelectronics devices,
(2) understand the scope and size of regional programs,
(3) discuss potential research gaps, and

(4) identify areas where collaboration and cooperation between regions will accelerate programs.

International consensus to develop and share regional research maps was achieved following the INC1 conference (June 2005)

The Fifth International Nanotechnology Conference on Communication and Cooperation (INC5) May 18th – 21st, 2009 at CNSI-UCLA



NSF-NNI Conference on Monday, May 18th INC5 on Tuesday, May 19th – Thursday, May 21st

R&D funding opportunities, infrastructure, and research trends for Nanoelectronics, Energy & Resource management Societal Implications and Education, Nano-ESH

http://www.inc5.org