NRI TPG Meeting 9/1/10

Agenda

- GIT & UCLA Disclosure Review
- New NRI-NSF Liaison Teams
- New Potential NSF-NRI Partnership
- Metrics on NRI Students
- NRI Annual Review Plans
- Overview of NRI TPG Page
- Open Mic

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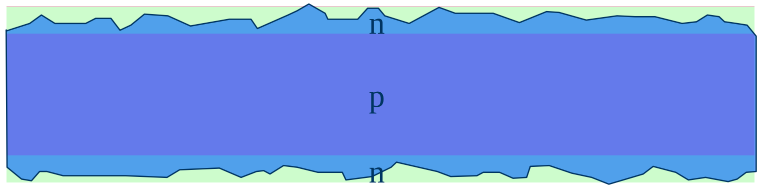
Self-aligned formation of graphene waveguided structure

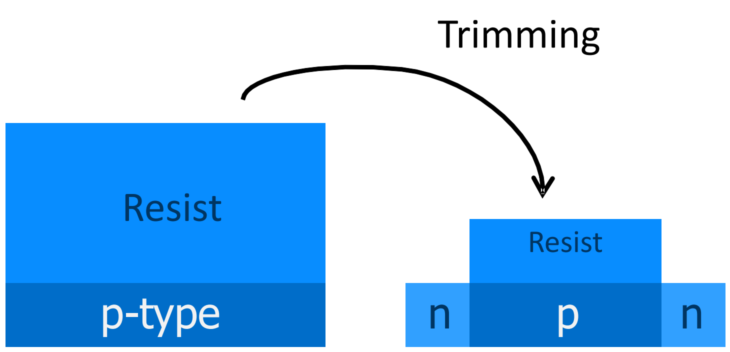
IP-1060 / GIT-5332: Y. Yang, R. Murali

carrier transport →

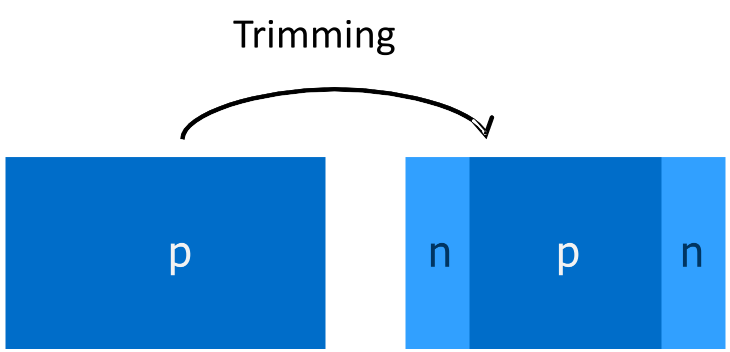


→ p-doped GNR (W<10nm) with n-doped edge regions

- Dope graphene sheet to be p-type
- Resist is used to pattern graphene nanoribbons (litho + etch); GNRs are now p-doped
- Appropriate chemical is used to trim resist by the amount needed (0.5-2nm)
- Trimming of resist atop graphene exposes the edges of the graphene ribbon while preserving the bulk
- The edges can now be doped n-type or be subjected to a variety of processes such as hydrogenation, fluorination, etc. that will convert sp^2 bonded graphene to sp^3 bonded structure (edge passivation)
- Strip resist and coat the device with a passivating layer or gate dielectric



Cross-sectional view



Top-down view

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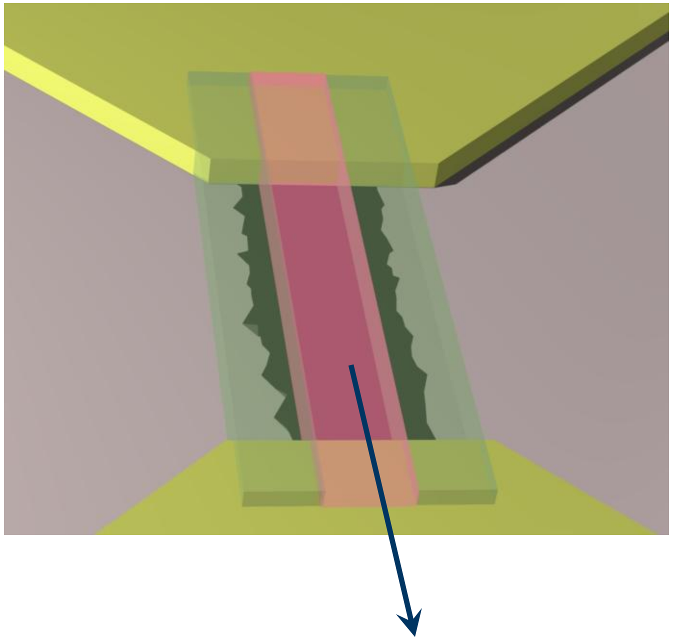

GNR with rough-edges covered by HSQ in the middle region and by weakly cross-linked HSQ at the edges

Implementation:

- HSQ is used to create graphene nanoribbons by e-beam lithography
- HF is used to trim HSQ by 1-2 nm
- The central graphene region is p-doped since cross-linked HSQ has been shown to introduce oxygen on the basal plane of graphene
- The edge regions are n-doped automatically due to the doping of graphene during resist trimming by by-products of the trimming reaction
- 1.4X to 3.5X improvement found in mobility of the n-p-n waveguided structure as compared to as-etched GNRs

Self-aligned formation of graphene waveguided structure

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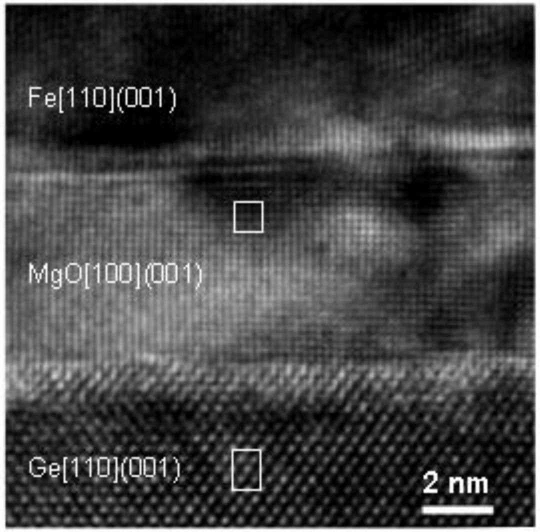
- Advantages
  - Avoids the use of multiple masking steps
  - Self-aligned method means no need for expensive alignment techniques
  - Method is applicable not only for pn waveguide structures but also for creation of passivated edges (e.g. by using hydrogenation)
- Disadvantages
  - Unclear timeline of when pn waveguides in graphene will become relevant (don't want to patent too early)
  - Tough to enforce patents of this nature (how to prove that a competitor is using resist-trimming to create wave-guided graphene ribbons?)
- Claims
  - Novel structures (graphene waveguides) can be created by using a previously known process (resist trimming)
  - pnp graphene waveguides are not novel, but the structure with hydrogenated/fluorinated edge regions is novel, as are some of the design parameters and specific e-beam/photo-resist interactions

- Background:
  - Ge surface has large density of dangling bonds which creates traps and degrades the Ge MOSFET performance.
  - MgO is known as a good tunneling oxide for spin injection due to the special symmetry induced spin filtering.
  - There is no previous demonstration of epitaxy of MgO on Ge. Spin injection in Ge has remained elusive.

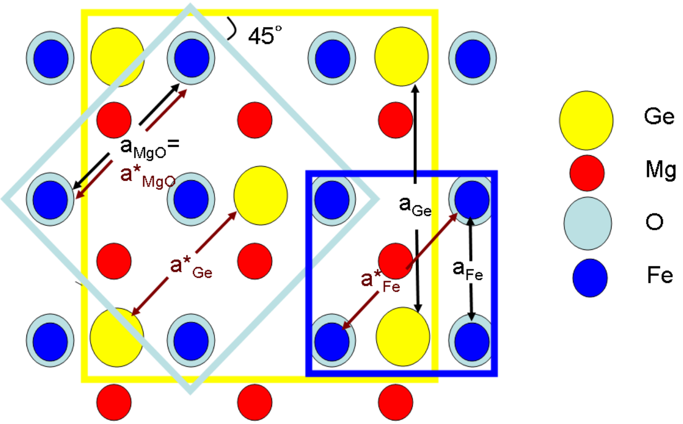
- Solution: Use Molecular beam epitaxy to grow single crystalline and atomically smooth MgO on Ge, which is intended to serve as:
  1. High-k passivation layer on Ge for MOSFET applications.
  2. Tunneling oxide in a Ferromagnetic metal/MgO/Ge junction for spin injection and spinFET application.

Implementation:

- Epitaxial growth of MgO on Ge using molecular beam epitaxy. An optimal growth condition yields single crystalline, atomically smooth MgO on Ge, with a unique 45 degree rotation of the MgO unit cell with respect to that of Ge.



TEM image of a Fe/MgO/Ge junction.



Schematics of the atom orientation to illustrate the 45 degree rotation between MgO and Ge unit cells.

Advantages:

- The MgO reduces the density of dangling bonds at Ge, depins the Fermi level [Y. Zhou et al. APL 96, 102103 (2010)] and forms a homogenous, high-k passivation layer for Ge MOSFET application.
- In combination with the use of bcc ferromagnetic metals (Fe, Co) with single crystal MgO, spin injection efficiency will be enhanced due to symmetry induced spin filtering. [We have recently achieved spin injection into Ge for the first time at room temperature. The manuscript to be submitted.]

Disadvantages:

- Requires an ultrahigh clean system to have good epitaxial growth.

Claims:

- A successful demonstration of epitaxial growth of single crystalline and atomically smooth MgO on Ge
- A successful demo of passivating the Ge surface by using as-grown MgO.
- The use of Ferromagnetic film(s)/MgO/Ge for spin injection for Ge
- Layered Ge substrate in combination of FM/MgO for efficient spin injection
- A successful demonstration of spin injection into Ge by using as grown Fe/MgO junction on Ge.

NRI-NSF Center Liaison Teams

More Inputs Needed

	GLOBALFOUNDRIES	IBM	Intel	MICRON	TI	NIST
Brown (MRSEC) ***Dir. Bill Curtin*** ***Lead PI R. Beresford (09)***	Zoran Krivokapic	C.Y Sung	Ajey Jacob	Steve Kramer	**Luigi Colombo**	Albert Davydov
Caltech (MRSEC) ***Dir. Harry Atwater*** ***Lead PI Nai-Chang Yeh (08)***	An Chen	**C.Y Sung**	Charles Kuo	Steve Kramer	Andrew Marshall	Angela Hight Walker
Columbia (NSEC) ***Dir. James Yardley*** ***Lead PI Philip Kim (08,10)***	Zoran Krivokapic	C.Y Sung	Ravi Pillarisetty	Gurtej Sandhu	**Luigi Colombo**	David Newell
Harvard (NSEC) ***Dir. Robert Westervelt*** ***Lead PI Shriram Ramanathan (08)***	Zoran Krivokapic	Ruud Tromp	**George Bourianoff**	Gurtej Sandhu	Dennis Buss	Herbert Bennett
Illinois Urbana-Champaign (NSEC) ***Dir. John Rogers*** ***Lead PI Eric Pop (10)***		C.Y Sung	Mark Doczy			
MIT (MRSEC) ***Dir. Michael Rubner*** ***Co-Leads Caroline Ross (MIT) / Stu Wolf (UVA) (09)***	An Chen	Bill Gallagher	George Bourianoff	**Steve Kramer**	Dennis Buss	Marla Dowell (Boulder)
Nebraska-Lincoln (MRSEC) ***Dir. Evgeny Tsymbal*** ***Lead PI K. Belashchenko (10)***		Bill Gallagher	Charles Kuo			
Northwestern (MRSEC) ***Dir. Monica Olvera de la Cruz*** ***Lead PI Mark Hersam (09)***	Zoran Krivokapic	**James Hannon**	Ajey Jacob	Steve Kramer	Luigi Colombo	Yaw Obeng
Penn State (MRSEC) ***Dir. Thomas Mallouk*** ***Lead PI Theresa Mayer (10)***		Aaron Franklin	**Gilbert Dewey**			
Princeton (MRSEC) ***Dir. Nai-Phuan Ong*** ***Lead PI Emanuel Tutuc (UT-Austin) (10)***		C.Y Sung	**Ravi Pillarisetty**			
Purdue (NCN) ***Dir. Mark Lundstrom*** ***Co-Lead PI Joerg Appenzeller (08)*** ***Co-lead PI Kaushik Roy, Supriyo Datta (09)***	**Zoran Krivokapic**	C.Y Sung	George Bourianoff	Chandra Mouli	Andrew Marshall	Herbert Bennett
Stanford (NSEC) ***Dir. Kathryn Moler (Stanford)*** ***Co-Leads Matthew Gilbert (UI-UC) &*** ***David Goldhaber-Gordon (Stanford) (08);*** ***Lead PI H.-S. Philip Wong (10)***	**An Chen**	C.Y Sung	Mike Garner	Steve Kramer	Luigi Colombo	Charles Cheung
U Alabama (MRSEC) ***Dir. and Lead PI Bill Butler (09)***	Zoran Krivokapic	Daniel Worledge	Ajey Jacob	Steve Kramer	**Allen Bowling**	June Lau
UC-Berkeley (NSEC) ***Dir. Alex Zettl*** ***Co-Leads Sayeef Salahuddin / J. G. Grossman (09)***	**An Chen**	C.Y Sung	Ajey Jacob	Steve Kramer	Andrew Marshall	Bob Keller (Boulder)
U Maryland (MRSEC) ***Dir. Ellen Williams*** ***Lead PI Michael Fuhrer (08)***	Ron Potok	David DiVincenzo	Roza Kotlyar	Chandra Mouli	**Luigi Colombo**	Christina Hacker, Bob Keller

New NRI-NSF NIRT Solicitation

- NRI-NSF preparing a joint solicitation to support the NNI's Signature Initiative on "Nanoelectronics for 2020 and Beyond" (http://www.nano.gov/html/research/signature_initiatives.html)
  - Three NSF Directorates: Engineering (ENG), Mathematical and Physical Sciences (MPS), and Computer & Information Science & Engineering (CISE)
  - Three primary thrusts, building off NRI's mission and recent NSF workshop on *"Interdisciplinary Challenges beyond the Scaling Limits of Moore's Law."* (http://www.nnin.org/nnin_nsf_workshop_2010.html)
    1. *Exploring New Chemistries and Materials for Nanoelectronics*
    2. *Exploring Alternative State Variables and Heterogeneous Integration for Nanoelectronic Devices and Systems*
    3. *Exploring Novel Paradigms of Computing*
- Awards will be for Nanoscale Interdisciplinary Research Teams (NIRTs)
  - NIRT is typically a small university team (3-4 PI's) working on a joint research project, where the members must come from more than one discipline
  - Total funding: $20.1M over 4 years
    - NSF funds: $18.1M
    - NRI funds: $2M grants (replaces NSEC supplements for 2011-12)
    - Award size is ~$1-2M per team over 4 years ($250-500K/yr) ➔ 10-15 awards

New NRI-NSF NIRT Solicitation

- Solicitation Schedule:
  - Program Solicitation Dissemination — September 2010
  - Proposal deadline — January 19, 2011
  - Proposal Panels — April/May 2011
  - Jackets to DGA — June 2011
  - Date of awards — August 2011
- NRI-NSF Joint Management Plan for award selection
  - NRI will help identify industry reviewers for the panels
  - NSF Program Officers and NRI Director will consult on recommendations for funding proposals
  - NSF and NRI retain final decisions on where their funds are spent
    - NRI can choose to jointly fund all or some of the proposals selected
- NRI and NSF will jointly oversee the jointly-funded NIRTs
  - Annual reports to be delivered to NSF and NRI
  - Submission of all publications to NRI website
  - Annual visit from NRI Liaison Team
  - Participation in the NRI annual review

nanoSTAR Center at UVA

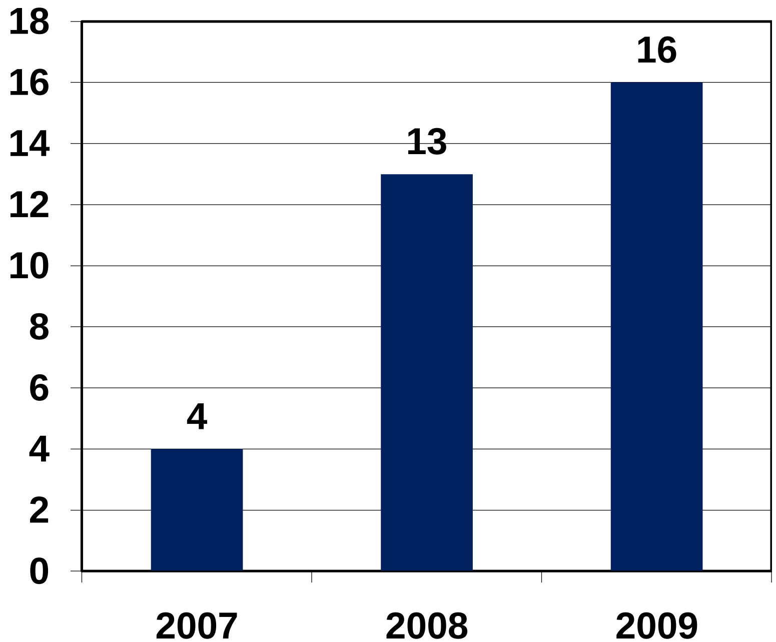
VO2 Switch Research Approved

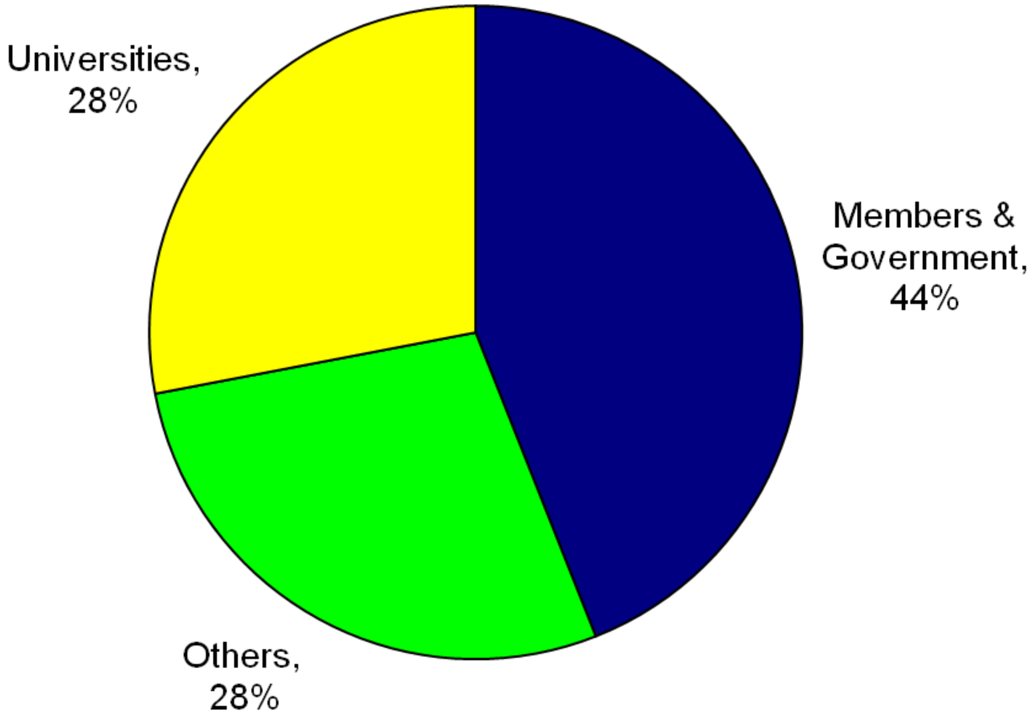
UNIVERSITY of VIRGINIA
Institute for Nanoscale and Quantum Scientific and Technological Advanced Research
nanoSTAR

- nanoSTAR is a broad Nanotechnology research program at UVA
  - NRI is an industrial sponsor of nanoSTAR ($20K/year)
- Nanoelectronics focus at nanoSTAR includes magnetic switches (RAMA), phase transition switches (VO2), thermal rachet switch, and self-assembly.
  NRI support:
  - RAMA (NRI-NSF 2009-11 grant Wolf-UVA/Ross-MIT $400K; INDEX 2010 supplement Stan-UVA $80K)
  - Thermal Rachet (INDEX 2008-10 Stan-UVA $225K)
  - Previous: Self-assembly (Hull/Wolf-UVA NRI-NSF 2006-08 $450K & 2007-09 $300K)

- VO2 Switch Research Program:
  - ~~$1.2M~~ → $1.6M over 2 years : $400K NRI / ~~$800K~~ → $1.2M state & university matching
  - Will be reviewed by UVA Liaison team – combined with nanoSTAR Annual Review

2009 Student Metrics:
Graduates/Hires 2007 - 2009



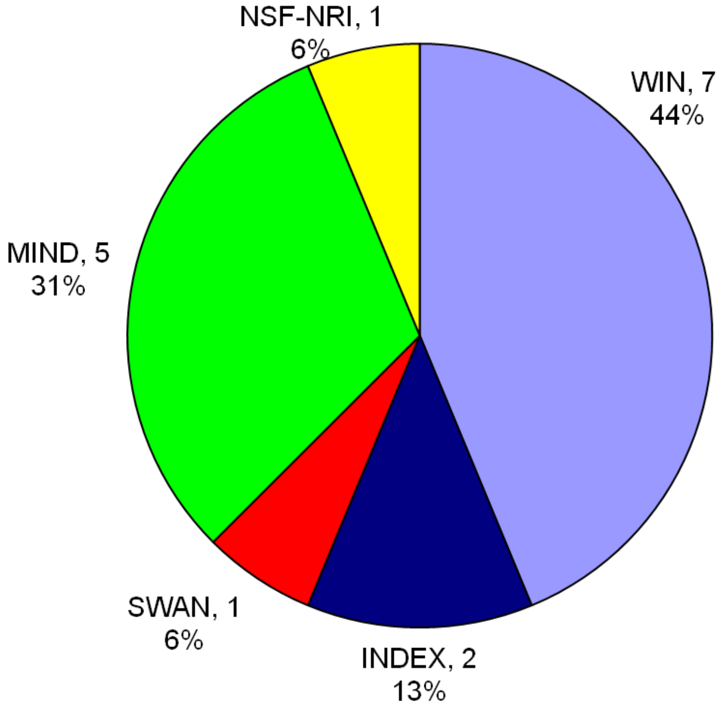


The number of NRI graduates increased slightly in the third year of the program to make a total of 33 graduates over the 3 year period.

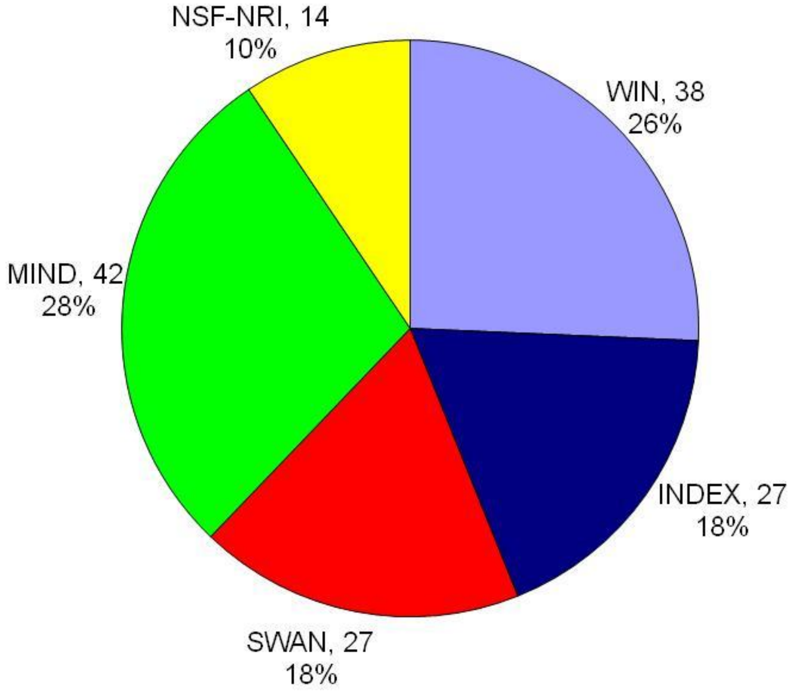
72% of NRI graduates have joined member companies, government agencies or universities over the 3 year period.

2009 Metrics: Students by Center

2009 Graduates



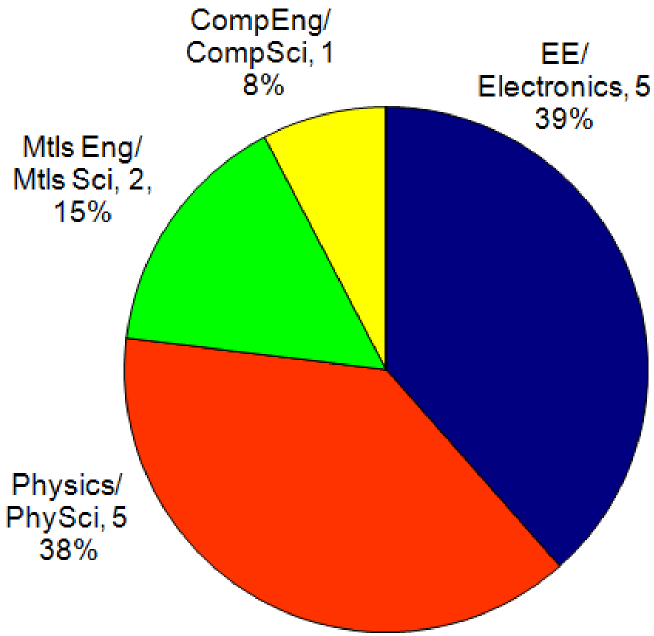
Current Students



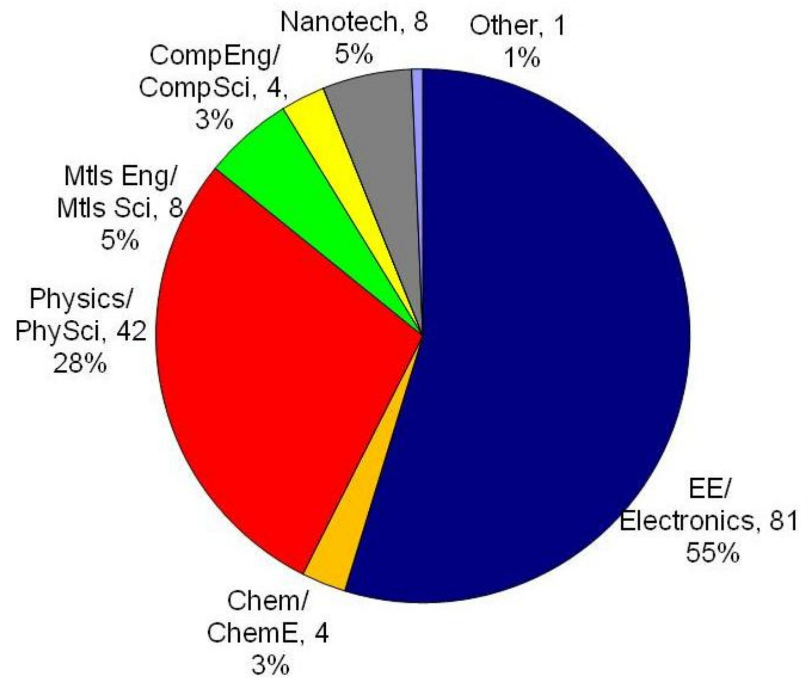
Seven of the 16 graduates were in the WIN Center, and 5 in the MIND Center. Current students are relatively evenly distributed across the Centers.

2009 Metrics: Students by Discipline

2009 Graduates



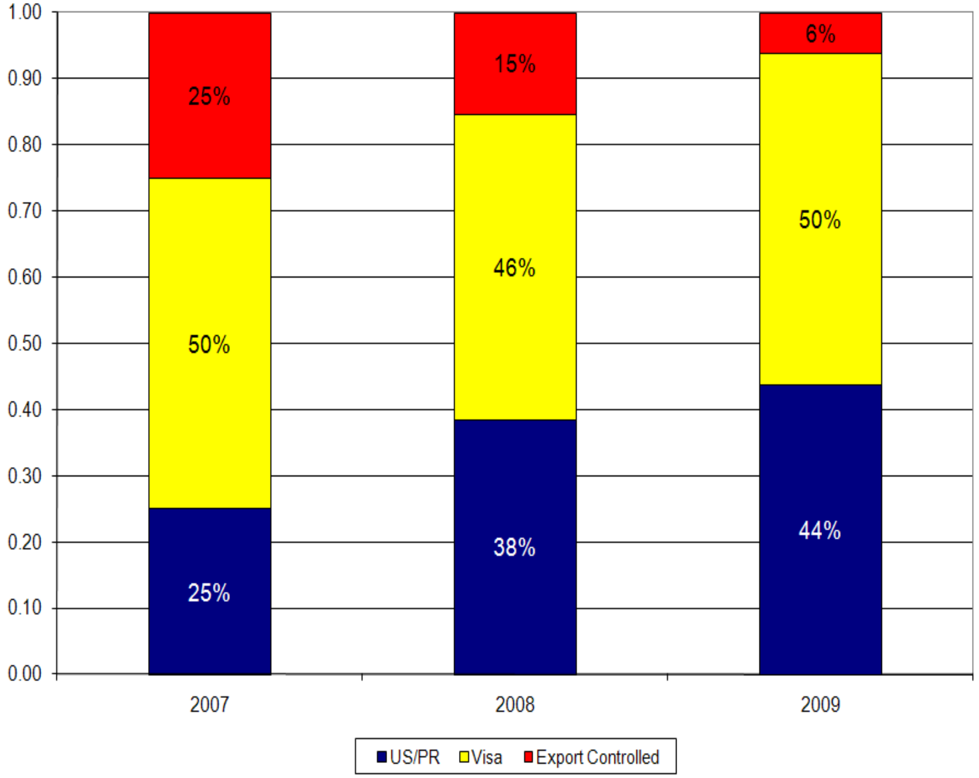
Current Students



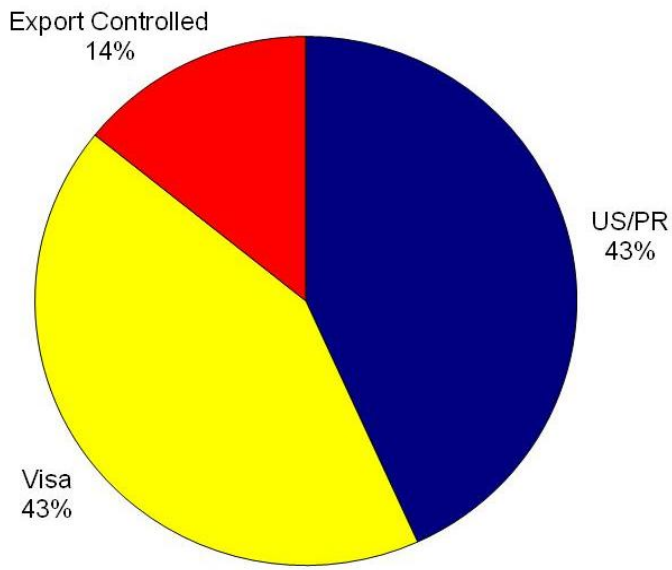
2009 graduates were primarily in EE and Physics/Physical Sciences. The current population is heavily weighted toward EEs with a higher percentage of Physics/Physical Sciences than is typical for SRC student populations.

2009 Metrics: Right-to-Work Status for 2007 -2009 Graduates

2007-2009 Graduates



Current Students 4/10



The percentage of graduates with permanent right to work (PRTW) status in the US increased by 19% between 2007 and 2009. The current population at 4/10 is virtually unchanged between 2009 and 2010.

NRI Events 2010 Summary

See calendar on www.src.org/program/nri *for all info*

- Annual Onsite Reviews – In-depth technical reviews of each center
  - MIND South Bend Aug. 9-11 (with Benchmarking Workshop)
  - SWAN Austin Sep. 15-16 (follows TECHCON Sep. 13-14)
  - INDEX Albany Sep. 21-23 (with FCRP-NRI Carbon Workshop)
  - WIN UCLA Oct. 7-8

> ➢ NRI Annual Program Review – October 26-28, 2010 in Gaithersburg, MD (NIST)
>   ➢ 10/28 AM: Discussions with the Center Directors on their Phase 1.5 proposals

- NSF Center Visits – Liaison teams visit each NSF Nanoscience Center
  - Distributed through-out the year – to be set up by each liaison team lead with NSF Center Director
- Regular telecons
  - TPG Meeting – First Wednesday of every month (4:00 ET / 1:00 PT)
  - GC Meeting – Second Wednesday of every other month (4:00 ET / 1:00 PT)
  - NRI Center Executive Committee meetings – bi-monthly, varies by center
  - e-Workshops last Tuesday of the month (4:00 ET / 1:00 PT)
    - Added a second e-Workshop in some months due to demand
- Topical Review Workshops
  - Architecture & Device Benchmarking Workshop – 8/9/10, Notre Dame (prior to MIND review)
  - FCRP-NRI Carbon Electronics Workshop – 9/21/10, Albany (prior to INDEX review)

NRI TPG Web Page

http://www.src.org/program/nri/advisory-board/tpg/

- One-stop shopping for all your NRI TPG needs!
- Accessible at link above, or go to the NRI homepage and click on the "Technical Program Group" link on the RHS under "Advisory Boards"
- Tabs contain the most frequently needed documents in each category
  - E.g. Semi-annual reports, onsite review presentations, feedback, etc.
  - Full description in the accompanying PDF file
  - Let Allison know if you want something else added