Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT)

The University of Texas at Austin (lead institution)

Taking nanoscience discoveries from the lab to the marketplace through the creation of high-speed, low-cost, reliable nanomanufacturing systems

A National Science Foundation Engineering Research Center since 2012

Partner Institutions:

- ***University of California at Berkeley***
- ***University of New Mexico***

The vision of the NASCENT Engineering Research Center is to create high-throughput, reliable, and versatile nanomanufacturing systems through transformative research, educate technology leaders, and create global and industrial engagement. NASCENT will develop the machines, materials, and models required to produce nanomanufacturing systems to enable as-yet-unimagined nanoscale mobile computing and mobile energy devices. Example devices include multi-bit universal Spin Transfer Torque Random Access Memory (STT-RAM) with data densities exceeding a terabit/in^2 and high-speed FETs on flex substrates that will provide bulk Si CMOS-like transistor performance at flat panel display-like costs.

These transformational nanomanufacturing advances include:

- *Nanosculpting*: Patterning with unprecedented nanoscale shape control enabling geometries with ~1nm radii of curvatures.
- *Integration of novel nanomaterials*: Incorporation of materials such as graphene, III-V nanowires, nanoparticle inks and exfoliated silicon for ultra-low cost flex electronics.
- *High-yield wafer-scale and roll-to-roll nanomanufacturing systems*: In-line optical nanometrology coupled with real-time and off-line control systems for optimal manufacturing productivity.
- *Low fiscal and environmental cost*: High-throughput systems with low cost of ownership and low consumable material usage.

NASCENT's overarching goals are to:

- Create high yield wafer-scale and roll-to-roll (R2R) nanomanufacturing and cross-cutting in-line nanometrology systems.
- Foster a culture of innovation that seeks to deploy NASCENT technologies commercially through industrial partners and start-up companies.
- Educate highly skilled and diverse technology leaders imbued with "the Innovator's DNA."
- Integrate the transformational technologies to create a unique experimental and computational nanomanufacturing facility for prototyping new devices and demonstrating new processes.

Over the last two decades, nanoscience research has demonstrated the potential to greatly improve functionality in areas such as electronics and energy devices and systems. The promise of advanced mater-ials has been dramatically demonstrated at the laboratory scale. It is fair to say, however, that few of these discoveries have found their way into the marketplace. Deployment of these advances at societal-impact scales is not trivial: exploiting their potential requires revolutionary advances in high-volume nanomanufacturing while simultaneously addressing scalability, reliability, sustainability, and cost constraints. Furthermore, business innovation and the development of a high-tech workforce are critical to success.

Figure 1. Examples of form factor versatility for future mobile devices, which must be compact, wearable, ultra-thin, transparent, shock-resistant, and recyclable.

NASCENT seeks to overcome these limitations by developing transformative nanomanufacturing systems and processes that will enable mass production of econo-mically competitive future-generation mobile computing devices based on silicon, graphene, and organic materials.

The Center will focus on enabling mobile electronics through novel nano-manufacturing systems. These systems have enormous growth potential and their complexity provides clear metrics

needed to design nanomanufacturing systems. The systems created by NASCENT are expected to impact other areas such as healthcare, energy, and security.

Research

NASCENT will focus on five transformative high-speed nanomanufacturing processes:

- **Process 1 – Versatile Manufacturing for Mobile Device Form Factors:** Center manufacturing methods will focus on desirable mobile form factors (Figure 1), such as wrappable compliant devices fabricated via exfoliation and delamination or R2R processing (Figure 2), and non-planar processes for compact high-performance devices.
- **Process 2 – Nanosculpting:** Nanosculpting refers to patterning of complex nanoshapes. The molecular resolution potential of nanoimprint lithography will be exploited to fabricate complex 2D and 3D nanoshapes. These capabilities can directly impact mobile nano-enabled devices including shape-engineered magnetic materials for universal memory and multi-tiered nanostructures with nanoscale alignment for integrated devices on flexible substrates.
- **Process 3 – Sustainable Semiconducting Material Processing:** Exfoliated silicon (Figure 3), graphene, organic semiconductors, and III-V nanowires are chosen for their potential impact on mobile nanodevices and because most of them are based on abundantly available elements.
- **Process 4 – Ink Jet Material Deposition:** NASCENT nano-manufacturing processes will use ink jet material deposition. Ink jets are well suited for integration with R2R processes and they produce low-to-zero waste, leading to environmentally friendly, cost-effective processes.
- **Process 5 – In-line Nanometrology for Process Diagnostics and Control:** NASCENT is developing high-speed optical nanometrology for thin-film measurements, critical dimension and shape metrology, and defect characterization. These techniques

Figure 2. NASCENT roll-to-roll imprint tool in its Nanofabrication facility.

are critical for real-time diagnostics and control.

Fundamental Barriers

NASCENT will address a number of fundamental barriers that require an interdisciplinary team approach. These barriers include:

- *Materials and manufacturing scalability* – Lack of scalable and reliable manufacturing for heterogeneous materials such as graphene, organic semiconductors, and exfoliates, in conjunction with truly nanoscale sculpting of materials.
- *Manufacturing-device correlation* – Unknown correlation between device performance/cost metrics and the associated manufacturing system/ process performance and throughput.
- *Manufacturing-device integration challenge* – Inability to fabricate advanced integrated flex devices due to lack of nanoscale registration.
- *Absence of validated models for process scalability* – Lack of multiscale system-level computational models to extrapolate from prototype system performance to commercial-scale system performance.
- *Nanometrology* – Need to develop real-time optical metrology tools with sub-wavelength resolution.

Value Added

NASCENT is creating an infrastructure of nanofabrication and computational facilities for process development and nano-enabled device prototyping. This infrastructure will impact, on a worldwide scale, all aspects of healthcare, education, commerce, communications, computing, and lifestyle. These nanomanufacturing advances will help create sustainable high-paying jobs in the US and will be supported by innovative human resource development and entrepreneurship activities.

Education

NASCENT is developing a cadre of highly skilled future innovators and leaders with strong representation from underrepresented communities. The Center has launched a specialized education program for its graduate and undergraduate students and is implementing innovative programs with middle and high school partners at each partner institution to develop a pipeline of pre-college—and, in turn, university—students who are well prepared for careers in STEM fields, especially nanomanufacturing and mobile technologies.

University Education Program

The goal of NASCENT's University Education Program is to cultivate a diverse cadre of undergraduate and graduate students to grow into adaptive, agile, and creative innovators prepared to work and lead in a global nanomanufacturing environment. Students will acquire technical depth and breadth; university, industrial, and global research experiences; and "the Innovator's DNA"—namely, the skills identified by Dyer et al. of: Observing, Questioning, Experimenting, Networking, and Thinking. The University Education Program achieves these goals through:

- *Students Engaged in Research* – Effective interdisciplinary research requires each participant to master one or more specific areas and understand how it can fit and be con-

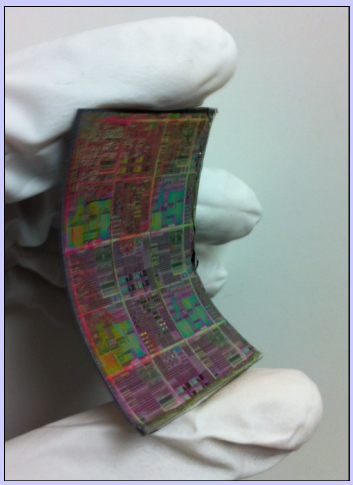

Figure 3. Image of a bent, flexible integrated circuit from silicon exfoliation with high performance CMOS devices. (From Zhai et al., Nano Letters 2012.)

nected to other areas, knowledge which is best acquired through Center research.

- *Creation of Technical and Entrepreneurial Course Work* – NASCENT is creating a Doctoral Portfolio in Nanomanufacturing with technical and entrepreneurial classes.
- *Industrial Internships* – The NASCENT Industrial Advisory Board and the Center's Student Leadership Council will work to match industrial internships with the appropriately skilled students.
- *Recruitment of Diverse Students* – Qualified students are actively recruited from underrepresented groups.

Pre-College Education Program

The goal of NASCENT's Pre-College Education Program is to create a pipeline of diverse, creative students from middle through high school with laboratory research experience who enter college and STEM degree programs.

- *Pre-College Partnerships* – The University of Texas at Austin (UT) has established partnerships with several schools with large populations of underrepresented minorities and women.
- *Pre-College and Community Outreach* – NASCENT has a variety of activities to engage the pre-college students and the community, including:
  * *NASCENT Fellows* – Students from partner high schools participate in intensive five-week summer research and academic sessions with a graduate student mentor, a defined project, and a faculty sponsor.
  * *Research Experiences for Teachers* – NASCENT has created a Research Experiences for Teachers (RET) program that allows both middle and high school teachers to work in NASCENT labs alongside graduate students. The teachers also create modules/ curriculum based on their research to take back into their classrooms.

Innovation Ecosystem

The NASCENT innovation ecosystem is an environment that accelerates the design, development, and deployment of the Center's innovative nanomanufacturing systems and develops a creative, agile workforce. The ecosystem and its flows of information, technology, start-ups, jobs, and people are illustrated in Figure 4. At the core is the NASCENT Center, which generates discoveries, technology, innovative ideas, and the graduates and faculty needed to transfer and apply these. These flow to the industrial, innovation, and translational research partners, with each of them providing its unique output and feedback to the Center.

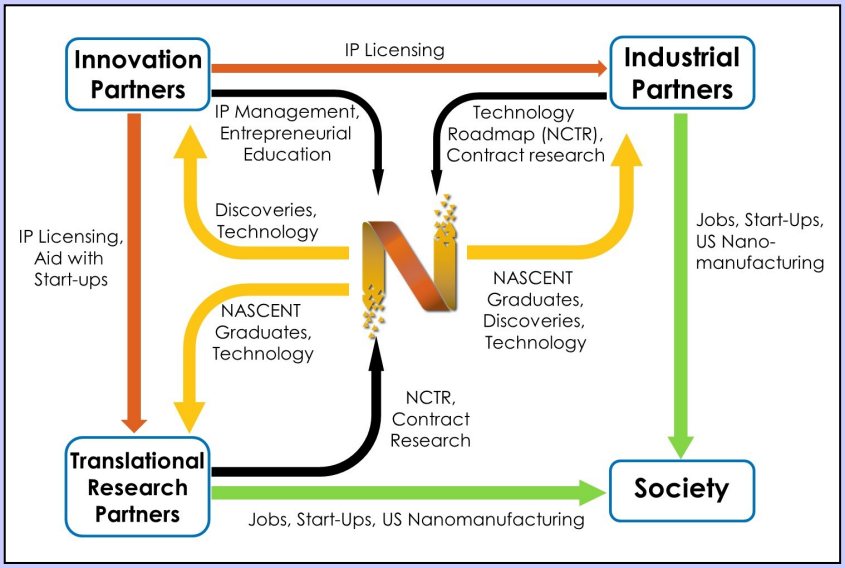

Figure 4. Flows in the NASCENT Innovation Ecosystem

NASCENT Team

The team assembled for the NASCENT Center is interdisciplinary and consists of leading specialists in nanomanufacturing and nanoelectronics and the associated materials, metrology, modeling, and computational simulation from The University of Texas at Austin (UT), the University of New Mexico (UNM), the University of California at Berkeley (UCB), Seoul National University, and the Indian Institute of Science.

Facilities

The NASCENT headquarters are in the Microelectronics and Engineering Research Building (MERB) at UT, with 2,400 sq. ft. of office space and 1,600 sq. ft. of cleanroom space and another 5,000 sq. ft. of clean-room space to be added soon. The Center leverages the facilities of the NSF National Nanotechnology Infrastructure Network (NNIN) co-located at the MERB and the high performance computing facilities at the Texas Advanced Computer Center at UT. NASCENT also benefits from the resources at the UNM Center for High Technology Materials and the UCB Flexible and Organic Electronics Laboratory.

Center Headquarters

NASCENT Nanosystems Engineering Research Center
The University of Texas at Austin
10100 Burnet Road, MER 1.206A
Austin, TX 78758

Website: www.nascent.utexas.edu

Director: S.V. Sreenivasan
(512) 471-6546 • sv.sreeni@mail.utexas.edu

Associate Director and Co-PI:
Dragan Djurdjanovic
(512) 232-0815 • dragand@me.utexas.edu

Administrative Director: Janet Monaco
(512) 232-7570
janet.monaco@austin.utexas.edu

Industrial Liaison Officer: Larry Dunn
(512) 232-8125 • larry.dunn@nascent-erc.org

University Education Director: Deji Akinwande
(512) 471-4345 • deji@ece.utexas.edu

Pre-College Education Director: Risa Hartman
(512) 232-7568 • rharman@che.utexas.edu