Conference: Mid-scale RI-EW: Nano Systems Innovation (NanoSI)

NSF ECCS 2233559

09/01/2022-02/20/2023

Workshop: 4 November, 2022 (virtual)

2022 NanoSI workshop webpage:

https://nanosi.sites.northeastern.edu/

Workshop Co-chairs:

Matteo Rinaldi (PI), Benyamin Davaji (co-PI), Kris L. Dorsey (co-PI)

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1. High-level summary

The goal of the Nano Systems Innovation (NanoSI) workshop was to solicit feedback from researchers regarding requirements to enable a unique national infrastructure for piezoelectric and hetero-integrated nano systems. The virtual workshop, held on November 4, 2022, brought together researchers, US government, industry and foundry partners to identify the emerging needs for adaptable infrastructure that can address national research priorities in advanced hetero integration to post-CMOS and more than Moore devices. The workshop concentrated on planning for infrastructure that can close the gap between the local research and prototyping capabilities of the universities with advanced semiconductor manufacturing activities with the ultimate goal of reducing the time for innovation and transition of the new foundational nano-system technologies that are going to be the at root of our nation’s economic strength, national security and technological standing in the years to come.

The intent of the workshop was to explore the community’s preferred pathways for accessing and engagement with the future infrastructure, management plans, and ideas to strengthen the community by extending access to underrepresented groups.

NanoSI Workshop Participants:

Before the workshop, short video presentations were solicited. Presenters from 12 states representing academia (19 talks from 13 institutions), government labs (3 talks), and industry (5 talks, 2 with joint academic appointments, from 4 companies) presented a total of 27 talks. Fig. 1 demonstrates the wide national perspective we received from these videos. 59 participants registered to attend the workshop.

Fig. 1: A map of the pre-workshop video submissions.

NanoSI Workshop Outcomes:

This report, compiling the feedback we received from participants, and a planned submission to the NSF Mid-Scale program, are the outcomes of this project.

2. NanoSI Workshop Structure

A. Pre-workshop recorded talks:

The PIs solicited invited talks from 65 researchers at 45 institutions to describe their work and outline what resources would be necessary for the vision of heterogeneous systems integration. Invitees were given a powerpoint slide template with the questions:

- What would you like participants to know about your work?
- How do you envision NanoSI impacting your future work?
- Are there other impacts beyond your work that you can envision?
- What specific facilities or capabilities would you need to enable this vision?
- What questions would you like to see discussed at the in-person session?

27 pre-recorded, 8-minute presentations, were delivered by stakeholders from academia, industry and government. These talks highlighted technological areas of interest and provided multiple perspectives on the value proposition of a national infrastructure for piezoelectric and hetero-integrated nano systems.

B. During the workshop:

The workshop schedule (Fig. 2) featured an overview of the vision for a heterogeneous systems integration facility and a summary “what we heard” from the videos. These short sessions were followed by two breakout sessions to encourage participant discussion.

The stated goals of the workshop were to understand “facility financial stability, facility and tool requirements to achieve heterogenenous systems integration, researchers’ intended interaction with such a facility, and the alignment between the goals of the Mid-Scale program and a potential NanoSI facility.” The breakout sessions asked participants to comment on “impactful and distinguishing features” of the potential NanoSI facility (breakout one) and “addressing tradeoffs” (breakout two). The complete record of slides presented during the workshop is given in Appendix A.

Time	Activity
1:10-1:40 PM	Summary report and goal setting
1:40-2:20 PM	Breakout 1
2:20-2:30 PM	Break (no scheduled activity)
2:30-2:50 PM	Reports from groups and whole group discussion
2:50-3:20 PM	Breakout 2
3:20-3:30 PM	Break (no scheduled activity)
3:30-4:00 PM	Reports from groups and final discussion

Fig 2: The schedule for the workshop (all times Eastern US)

C. Post-workshop activities:

The talk videos will remain on the website until 01 July, 2023, for any participants to go back and watch. The PIs will also release this report to all attendees via email and post it on the workshop website.

The PIs submitted a letter of intent (LOI) to the NSF Mid-Scale II program and anticipate submitting a pre-proposal in June 2023.

3. Summary of meeting discussions

A. Pre-workshop NanoSI Vision

Before the workshop, the vision for the NanoSI facility was a "lab-to-fab facility for piezoelectric and heterogeneous integrated nano systems," that would:

- empower users to pilot manufacturing approaches, and close the gap between academic research facilities and industrial cutting edge manufacturing
- expand access to multi-project wafers (MPWs) and develop process design kits (PDKs)
- create talent by training students in nano- and micro-scale fabrication, and
- accelerate ventures and partnerships between industry, academia, and national labs

The PIs envisioned a "NanoSI+X" facility with a suite of materials, including piezoelectric, ferroelectric, and magnetic properties, SiC, and diamond. This facility would permit heterogeneous integration, processing, packaging, testing, and metrology to foster the next generation of microscale devices. The PIs anticipated targeting the NSF Mid-Scale II program to support the equipment, cyberinfrastructure, and start-up personnel required for this facility and vision.

B. Summary of Pre-Meeting Videos

In the pre-meeting videos, we heard participants raise topics about financial sustainability of such a feature, where it would be located (distributed or localized), how users would engage with such a facility, how to get participation from stakeholders in government research and industry as well as academia, and the importance of certain tools such as 8-inch fabrication. A full summary of our findings is available in the appendix slides on page 18. These points were presented to attendees in the workshop and they were asked to add to the list-- "what did we miss?"

C. __Breakout Sessions:__ Impactful and Distinguishing Features (breakout 1) and Addressing Tradeoffs (breakout 2)

A major point of discussion across more than one breakout room was the impact of such a facility, and its potential to help grow the US market. Several attendees highlighted that the focus only on piezoelectric material integration might limit the utility of NanoSI in these goals, but that focus on some well-scoped subset of materials would be necessary.

Advantages of the NanoSI vision included mitigating intellectual property (IP) concerns that are currently embedded in sending designs to international fabrication facilities and the benefit of domestic access to 8-inch wafer tools at small scale. Common themes were the challenges of low volumes present in academic research, scaling from a handful to 100s of devices, and the tensions in a facility built for research and prototyping in contrast to one intended for production. The need to build infrastructure that would attract small and large industrial partners was stated in all three breakout sessions.

Attendees also highlighted a few logistical challenges embedded in running such a facility: the need for a revenue model that would support long term staffing, the requirement to be "forward thinking" so that tools and facilities would not soon become obsolete, and how remote participation could be supported given local facilities with a nationwide user base. Broadly, participants encouraged each other and the PIs to consider the role and impact of NanoSI on US nanofabrication over the next 20-30 years, rather than 5-10 years.

This discussion led to a realignment of the vision for a heterogeneous "+X" facility that bridges the gap between research and prototyping facilities and commercialization fabs. Such a facility would foster translation of research out of academia, support start-up companies, and increase the technology readiness level of devices in development.

4. Updates to the NanoSI Vision and Plans for a Mid-Scale 2 Proposal

The National Infrastructure for NanoSystem Innovation and Heterogeneous Integration (INNOVATE) facility, a unique national research and development facility, will combine emerging technologies in device manufacturing and heterointegration with advanced semiconductor devices for future computational, communications and sensing hardware. The facility will accommodate diverse substrate sizes from smaller chips to 200mm wafers. This facility will help develop next-generation core technologies by providing research infrastructure for monolithic integration, wafer bonding, chip-level bonding (fanout wafers), advanced transfer and additive processes, and 2D and quantum materials manufacturing and beyond, in the US. It will also provide much needed training of a workforce for future semiconductor and quantum fabrication/manufacturing facilities. The Northeastern University's (NU's) global university system, with 13 campuses spanning the US, Canada, and the UK, and which includes EPSCoR Jurisdictions, ensures vibrant engagement across the US.

INNOVATE's vision responds to the needs identified in the NanoSI workshop and in the 2021 NSF Workshop on CMOS+X Technologies. Domestic semiconductor device manufacturing and heterointegration facilities were identified as an urgent need for bridging the current gap in exploratory and fundamental research and retaining US innovation leadership. With the rapid emergence of beyond-silicon, beyond CMOS, and quantum engineering genres, a facility that supports multiple technologies and material systems and their integration – and which is readily and affordably accessible to university researchers and trainees – is a critical need for addressing future computational, communication, sensing and workforce demands.

The heterointegration programs, supported through this proposed research infrastructure, will enable this plus, "+", that signifies new infrastructure for combining technologies, to complement and support current US commercial chip manufacturing infrastructure. *This approach is different from other facilities focused exclusively on advanced CMOS manufacturing*; INNOVATE will partner with industry to have the unique capability to bridge the integration gap between commercially available technologies (*e.g.,* CMOS, SiC, GaN and other) and research-based more-than-Moore materials and exotic substrates and devices (e.g., piezoelectric, nanowires, integrated photonics, 2D semiconductors, superconducting qubit, and others). INNOVATE will be the first research infrastructure in the US for advanced manufacturing data collection and accessibility to advanced semiconductor nanomanufacturing multidomain and multi-modal datasets, supporting research in AI-enabled and software defined hardware designs, which is critical for reducing process optimization times and equipment down time, enabling rapid and affordable turnaround of innovations and training.

5. Process, Methods, and Structure

Workshop planning meetings:

Before the workshop, the PIs and the Assistant Dean for Research and Faculty Development, College of Engineering met seven times to determine potential invitees, workshop structure and questions, and how to most effectively meet the goals of an inclusive workshop. After the PIs determined the pre-workshop videos and "flipped workshop" structure, Co-PI Dorsey met with an instructor from Northeastern's Center for Advancing Teaching and Learning through Research (CATLR) to learn best practices for structuring the workshop, including students through full professors, and getting a wide basis of interest amongst the potential NanoSI community. Co-PI Dorsey implemented these practices through the multi-breakout session + reconvening structure of the workshop.

Summarizing Pre-Meeting Videos:

The presentations were posted to the website and shared with registered workshop attendees before the workshop. The PIs watched all videos and collected points in common (or disagreement) to develop questions for discussion during the workshop. Each co-PI watched 70% of the videos that attendees submitted to ensure overlap of notes and ideas. The PIs compared common themes, questions, concerns, ideas, and suggestions for materials or tools into a shared document. This document framed the discussion points for the breakout sessions and whole-meeting discussion.

Breakout Sessions:

During the breakout sessions, attendees were asked to sort themselves into one of three breakout rooms. A moderator and scribe were present in each breakout room to keep the conversation on track and record the major points of the discussion. The first breakout session asked attendees to discuss the impact and distinguishing features of the proposed NanoSI facility over similar facilities such as the National Nanotechnology Infrastructure Network (NNIN). The second breakout session asked attendees to discuss potential tradeoffs in the discussion points they had heard throughout the afternoon.

Acknowledgements:

The PIs would like to acknowledge the support of an NSF workshop planning award “Conference: Mid-scale RI-EW: Nano Systems Innovation (NanoSI)” award ECCS 2233559.

The PIs would like to thank Northeastern University’s CATLR center for teaching and learning for guidance on best practices for the “flipped workshop” format, for workshop framing from Mariah Nobrega and Wenjun Zhang, and for the efforts of the workshop moderators and scribes: Amit Lal, Gabriel Giribaldi, Jack Guida, Nicolas Casilli, Ryan Tetro, Dana Weinstein, Sid Ghosh, Jeronimo Seogvia, Stephen Bart, Troy Olsson, and Swastik Kar.

Appendix A: Workshop slides

NANOSI
Nano System Innovation

ECCS 2233559

Mid-scale Research Infrastructure Workshop

Welcome everyone!

We will start at 1:10 pm EST

November 4th, 2022

Nano System Innovation

ECCS 2233559

Mid-scale Research Infrastructure Workshop

Co-chairs:

Matteo Rinaldi (PI), Benyamin Davaji (Co-PI), Kris L. Dorsey (Co-PI)

Organizers:

Mariah Nobrega, Wenjun Zhang

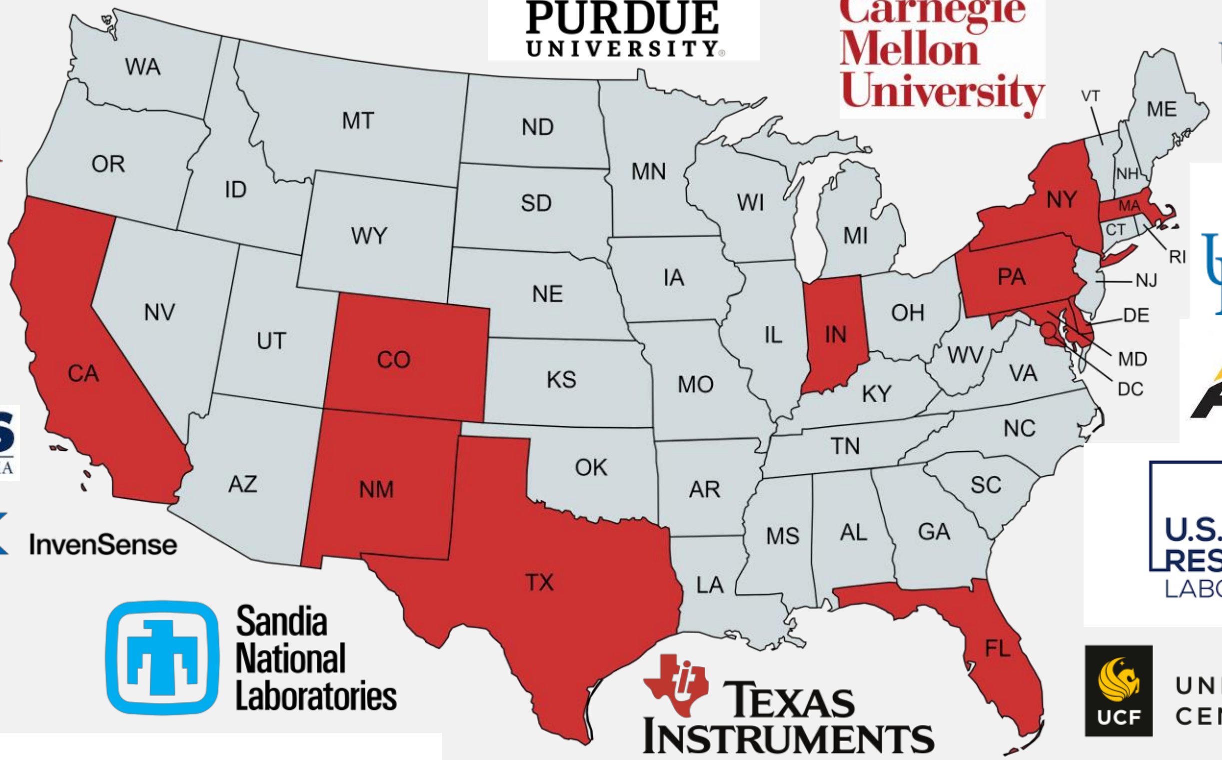
November 4th, 2022

Agenda for Today

Time	Activity
1:10-1:40 PM	Summary report and goal setting
1:40-2:20 PM	Breakout 1
2:20-2:30 PM	Break (no scheduled activity)
2:30-2:50 PM	Reports from groups and whole group discussion
2:50-3:20 PM	Breakout 2
3:20-3:30 PM	Break (no scheduled activity)
3:30-4:00 PM	Reports from groups and final discussion

Who we heard from

GEEGAH
Cornell University
Penn University of Pennsylvania
Purdue University
Carnegie Mellon University
Columbia University
Northeastern University
University of Delaware
ARL
U.S. Naval Research Laboratory
University of Central Florida
University of Florida
Stanford University
Silicon Catalyst
UC Davis University of California
TDK InvenSense
Sandia National Laboratories
Colorado School of Mines
Texas Instruments
Texas The University of Texas at Austin



By the #s

27 talks from 12 states representing:

- Academia: 19 talks from 13 institutions
- Government labs: 3
- Industry: 5 talks (2 with joint academic appointments) from 4 companies

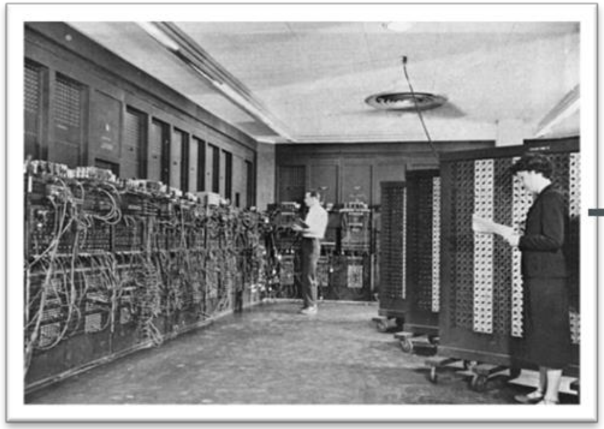
80+ registrants

End of an Era of Innovation

Past:
Predictable Scaling

Present:
End of Scaling Era

Future:
New Era of Innovation

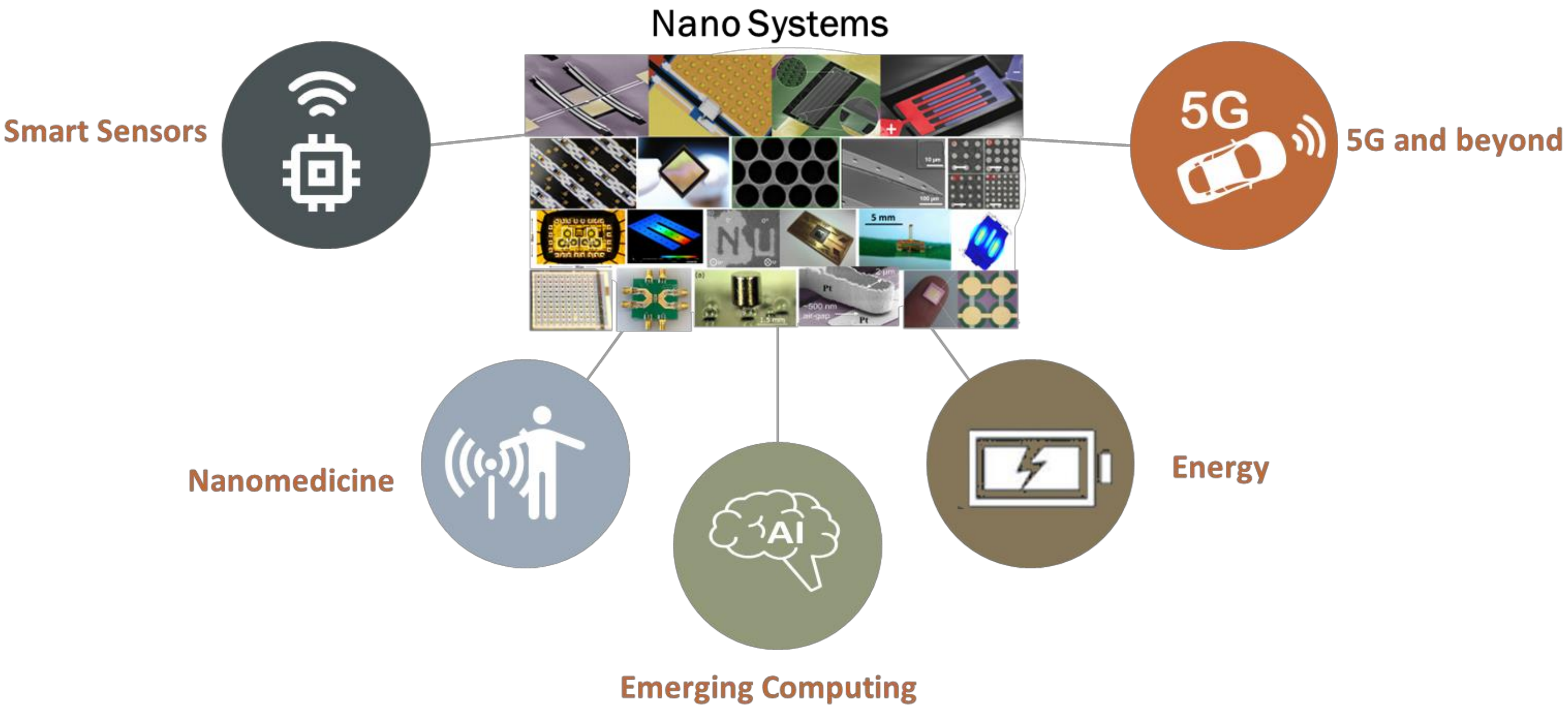


1945 Computer

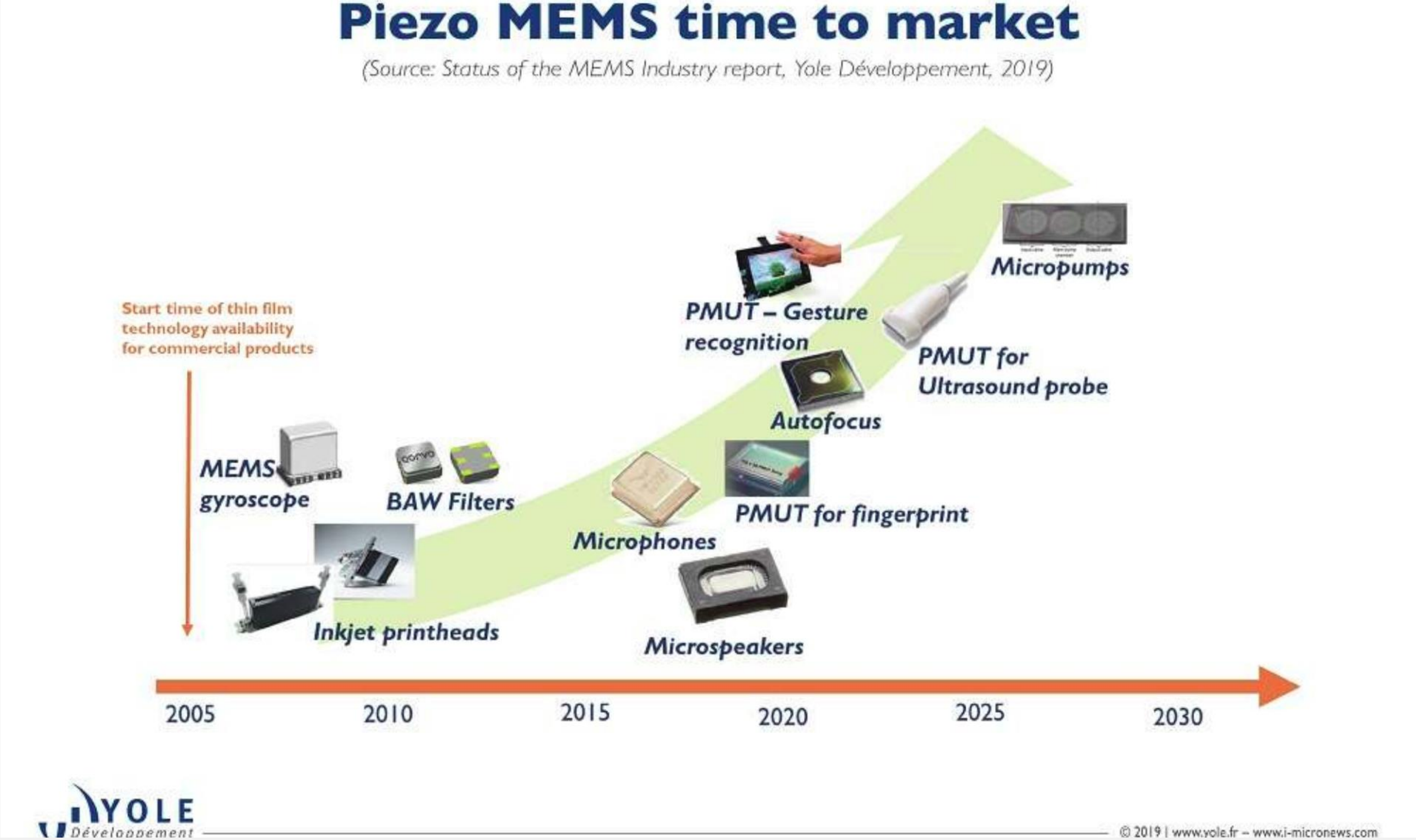
Today's CPU

Future

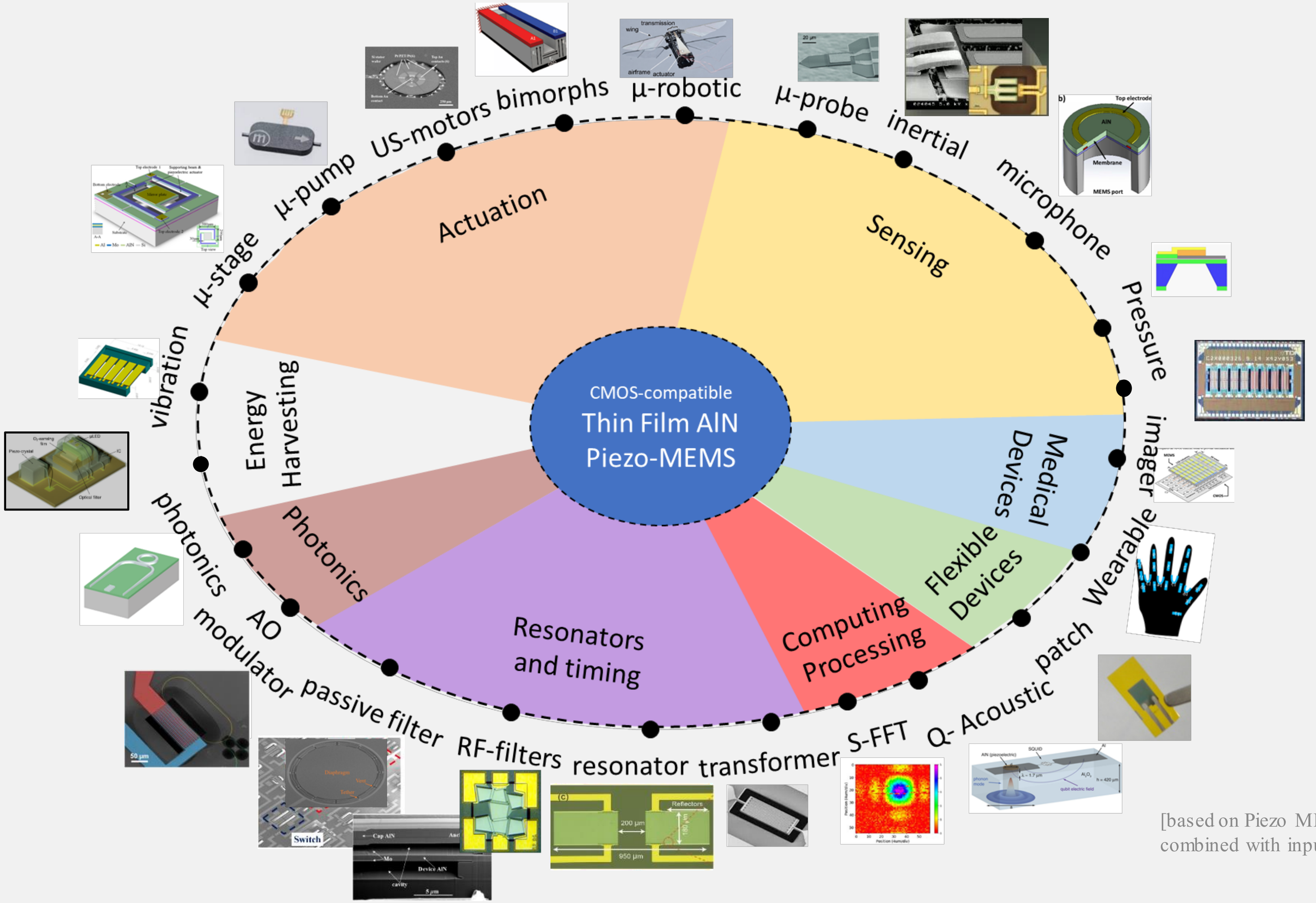
New Era of Innovation – Nano System Integration



Piezoelectric Nano Systems already have impacts on multiple areas



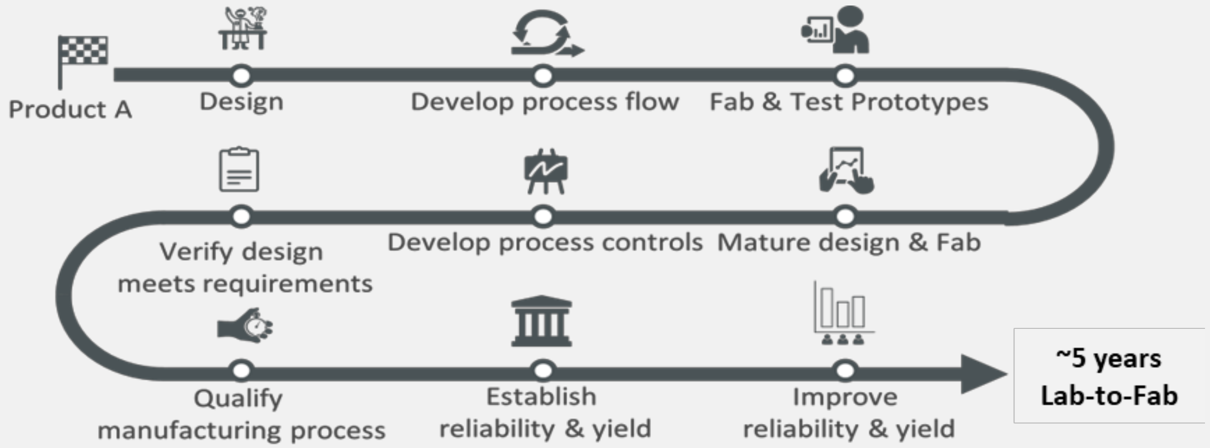
Heterogenous Nano Systems Integration opens new horizons



[based on Piezo MEMS PDK, Hilton Head 2022 combined with inputs from NanoSi participants]

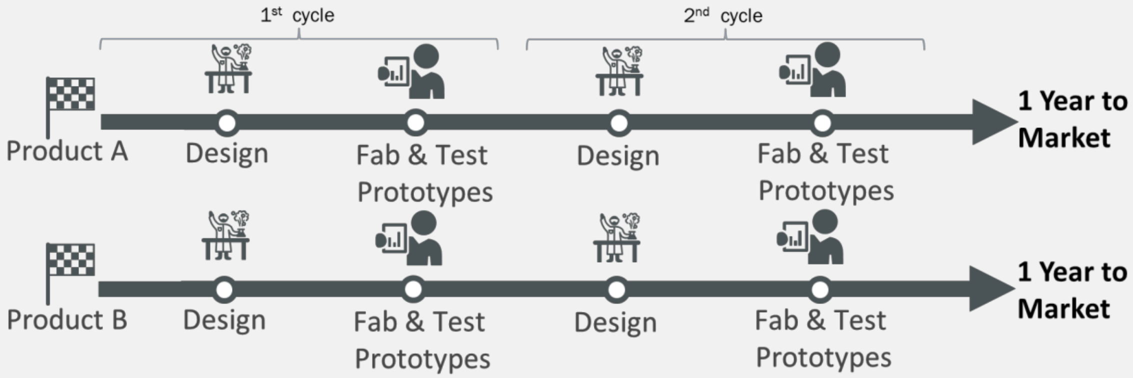
New Challenges and Paradigms

- Nano System Innovation originates in small R&D centers or universities
- Nano System Innovation and IP tied to prototype development
- Large gap between university and industry facilities
- Long development cycles due to lack of standardization and scaling rules
- Restrictions for introducing new materials and processes into high-volume fabs
- Limited access to fabs, packaging and testing
- Lack of data sets for training nanomanufacturing AI models
- Shortage of skilled technical workers (~3.4M by 2022)
- Manufacturing is now occurring in foreign countries



The Vision for NanoSI

- Lab-to-fab facility for Piezoelectric and Heterogeneous Integrated Nano Systems
- Pilot manufacturing
  - Versatile and scalable processes
  - 200 mm compatible production-ready facility
- Expand access
  - PDKs and MPWs
  - Data hub for AI-powered nanomanufacturing
  - Digital twin
- Create talent
  - Use-inspired education and R&D culture
  - Focus on value creation
- Accelerate ventures
- Enable partnerships
  - Research driven by partnerships



The Vision for NanoSI

Materials (beyond Si): Piezo/ferro electric (I.e. AlN, AlScN, LN, PZT, ZnO, HZO, Polymer); III-V (i.e. GaN); SiC; Diamond; magnetic films and substrates;

NanoSI+X:

- **Integration capabilities:** BEOL processing (monolithic heterogeneous); wafer-bonding;micro transfer, chiplets
- **NanoFab processes:** thin-film deposition/growth; lithography/nanopatterning; plasma/vapor phase etching;
- **Packaging:** stealth dicing, coring, chip and water-level packaging, package on package stacking, die stacking (wTSV)
- **Testing, metrology and data:** automated measurements capabilities (consistency, speed, large dataset creations)

NSF Mid-Scale Research Infrastructure Program

Supports the design and implementation of research infrastructure*:

- Equipment
- Cyberinfrastructure
- Large-scale datasets
- Personnel
- R1: $4M-$20M/R2: $20M-$100M

*Research Infrastructure (RI) is any combination of facilities, equipment, instrumentation, or computational hardware or software, and the necessary human capital in support of the same.

Challenges & Questions to Consider Today

Big Picture:

Is Mid-Scale the right answer for NanoSI?

Challenges & Questions to Consider Today

Facilities:

- General vs. Specific
- Agile and Modern Capabilities

Challenges & Questions to Consider Today

Interaction with NanoSI:

- Use in person
- Use remotely
- Multi-project wafers and potential processes
- Funding fab staff
- Routes for industry support and investment
- Education and training

Goal Setting

By the end of the day, we'd like to better understand:

- Facility financial stability
- What facilities are needed for heterogeneous silicon integration vision?
- How researchers would like to use/interact with facility
- Is Mid-Scale program the right answer for NanoSI?

The breakout sessions will ask the following questions:

- Breakout 1: Impactful and distinguishing features
- Breakout 2: Addressing tradeoffs

What’s unclear? What did we miss?

- Financial models for sustainability
- Localized or distributed?
- Possible examples of other facilities
- Range of costs compared to existing facility
- Timeline for building up infrastructure – affects the vision
- Other facilities we can leverage
- What is different from NNIN?
- How to go beyond existing infrastructures (reduce barriers to access)
- Identify a common scope for the facility
- Experience vs remote
- Who is the customer?
- Access to broader engineering design base
- Bigger participation from industry, gov facility
- Academic heavy – partnership university/government /industry is critical
- Centralized vs decentralized – important to be defined for government
- 8-inch capability is critical for industry
- Advanced packaging capability important for industry – advantage also for academia
- Distinctions: 8-inch, piezo, packaging, …?

What we're doing next: Breakout Session 1

What would be an *impactful*, *distinguishing* feature of NanoSI facilities, education, or other capabilities?

1:40-1:50: Move into breakout rooms and introductions

1:50-2:20: Discussion of question, what are we missing?

We will have note takers to capture discussion, but we will not record the breakout sessions

What we're doing next: Breakout Session 1

What would be an *impactful*, *distinguishing* feature of NanoSI facilities, education, or other capabilities?

How do we make this unique?

- You will be randomly assigned to a breakout room

Breakout Session 1

What would be an *impactful, distinguishing* feature of NanoSI facilities, education, or other capabilities?

1:40-1:50: Move into breakout rooms and introductions

1:50-2:20: Discussion of question, what are we missing?

2:20-2:30: Break

2:30-2:50: Full group discussion

- You will be randomly sorted into a room

Full Group Discussion 1

What would be an *impactful, distinguishing* feature of NanoSI facilities, education, or other capabilities?

- Room reports (2 min each)
- Full group discussion of any additional points

This session will be recorded for future note taking and data capture. Please let us know if you have any objections and we will not record the group summary.

What we’re doing next: Breakout Session 2

How should we address tradeoffs with what we've heard?

2:50-3:00: Move into breakout rooms and introductions

3:00-3:20: Discussion of question, what are we missing?

We will have note takers to capture discussion, but we will not record the breakout sessions

What we're doing next: Breakout Session 2

How should we think through tradeoffs with what we've heard?

Examples:

- Agile and cutting edge vs. established processes
- Material and process breadth vs. depth
- Accessible cost vs. financial sustainability
- Dependable performance vs. education

Breakout Session 2

How should we think through tradeoffs with what we've heard?

2:50-3:00: Move into breakout rooms and introductions

3:00-3:20: Discussion of question, what are we missing?

3:20-3:30: Break (no activities)

3:30-3:50: Full group discussion

- Agile and cutting edge vs. established processes
- Material and process breadth vs. depth
- Accessible cost vs. financial sustainability
- Dependable performance vs. education

Full Group Discussion 2

How should we think through tradeoffs with what we've heard?

- Room reports (2 min each)
- Full group discussion of any additional points for question 2
- Full group discussion of any other points or considerations

This session will be recorded for future note taking and data capture. Please let us know if you have any objections and we will not record the group summary.

Final Discussion

What models should we look at to make this a financially sustainable venture?

- Full group discussion for 10 minutes
- Wrap up and follow up steps

This session will be recorded for future note taking and data capture. Please let us know if you have any objections and we will not record the group summary.

Follow up: Beyond Today's Workshop

- Videos will remain on site until 4 December 2022
- PIs will release a short report to participants
- Intent to have follow-on education study with students
- Intend to propose Mid-Scale Infrastructure in January 2023

Thank you so much for attending!

Matteo Rinaldi M.Rinaldi@Northeastern.edu
Ben Davaji B.Davaji@Northeastern.edu
Kris L. Dorsey K.Dorsey@Northeastern.edu

Appendix B: Invitation email templates

Dear ___________,

We would like to invite you to attend and give a short 8-minute pre-recorded presentation at the NSF sponsored Nano Systems Innovation (NanoSI) virtual workshop that will take place **on Friday November 4th, 2022 at 1 – 4 pm EST**. The due date to upload the recorded presentation is on **Friday October 21, 2022**. Please register (free of charge) at: Registration – NanoSI (northeastern.edu). Instructions and a template for the submission are available here: Presentation Information – NanoSI (northeastern.edu)

The virtual workshop will conduct a deep dive into infrastructure requirements to enable a unique national infrastructure for piezoelectric and hetero-integrated nano systems. The virtual workshop will bring together researchers, government, industry and foundry partners to identify the emerging needs for adaptable infrastructure that can address national research priorities in advanced hetero integration to post-CMOS and more than Moore devices. More details can be found here: NanoSI – Nano Systems Innovation (northeastern.edu)

The NSF NanoSI virtual workshop will include pre-recorded 8-minute presentations given by multiple stakeholders from academia, industry and government highlighting technological areas of interest and providing multiple perspectives on the value proposition of a national infrastructure for piezoelectric and hetero-integrated nano systems. These short presentations will be made available to the workshop attendees through the password-protected event web page by Friday October 28th, 2022. Taking inputs from this asynchronous session of the workshop, the organizers will prepare a report and present it to the attendees during a three-hours synchronous virtual session that will take place on Friday November 4th, 2022 at 1 – 4 pm EST. The report presentation will be followed by breakout discussion sessions focused on providing feedback and addressing outstanding questions.

Considering your expertise, accomplishments, and overall stature in the field, we believe your inputs are essential for the identification of gaps in existing research infrastructure and the ideation of a mid-scale national research infrastructure for Nano Systems Innovation that can address national research priorities to significantly advance engineering research frontiers.

Please feel free to reach out to us in case you have any questions.

Many thanks in advance for your participation, which is highly appreciated.

Best regards,

Workshop organizers: Matteo Rinaldi, Kris Dorsey, Ben Davaji