Reliability Physics and Engineering: Key to Transformative Research

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REPORT TO THE PRESIDENT ON CAPTURING DOMESTIC COMPETITIVE ADVANTAGE IN ADVANCED MANUFACTURING

"Advanced manufacturing is a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. It involves both new ways to manufacture existing products, and the manufacture of new products emerging from new advanced technologies."

—President's Council of Advisors on Science and Technology
Report to the President on Ensuring
American Leadership in Advanced Manufacturing,

Introduction and Motivation

- Industry profitability and success depend on yield and reliability.
- Advanced semiconductors i.e. 2D, wide bandgap systems are a key for numerous applications that extend from communications to automotive, defense and security.
- Manufacturing of components is strongly dependent on in depth reliability studies that include physics-based approaches to complement the currently used industry techniques that are not adequate for improving the current status of technology.
- Point-like nano/microscopic defects can often be the cause of a macroscopic device to collapse
- The challenge is a physics based approach to reliability through an integration of science and engineering.
- The transformative breakthroughs will be based on reliability physics, chemistry, mathematics and engineering.

Approach

- Meeting the challenge will be based on novel material and defect characterization techniques which are necessary to locate the prevalent defects as well as their concentration and dynamics over time.
- Dimensional reduction, lower and higher voltages, and higher frequencies impact impact negatively the reliability
- In-situ and ex-situ characterization, will be necessary to satisfy the program's objectives.
- Examples include reliability predictors such as spin, Transport-, Raman-, Noise-spectroscopy, Imaging for defects down to monolayer size.
- The types of defects existing in the fabricated devices need to be identified. Determining which of the defects is the cause of failure and which are effects of the failure is very important.
- Nanometer resolution characterization techniques considerably smaller than the apparent average separation between traps are required. Physics based simulation and experimental validation to further the fundamental understanding of the degradation mechanisms must also be undertaken.

Reliability Grand Challenges

Identify and Quantify the failure mechanisms arising through smaller dimensions, high electric fields, coupled effects of heat, strain, and electric polarization, gate current, and the relatively high density of extended and point defects endemic in most semiconductors.

Gain a physics based knowledge through extensive and targeted characterizations and analyses and incorporate it into the failure models which can then become the basis for the new robust manufacturing science.

Establish the basis for the new methodology for reliability prediction and manufacturing science for future technologies.

Take basic science all the way to manufacturing through education and research and enable a competitive industry to be realized.

PAST LESSONS FROM INNOVATIVE RELIABILITY ASSESSMENT TECHNIQUES

CONVENTIONAL METHOD

Fabrication → Fixture Mounting → Step-Stress Tests → Burn-in Tests → Reliability Assessment

1 week | 1 month | 6 months

7 months

7 months

NEW METHOD

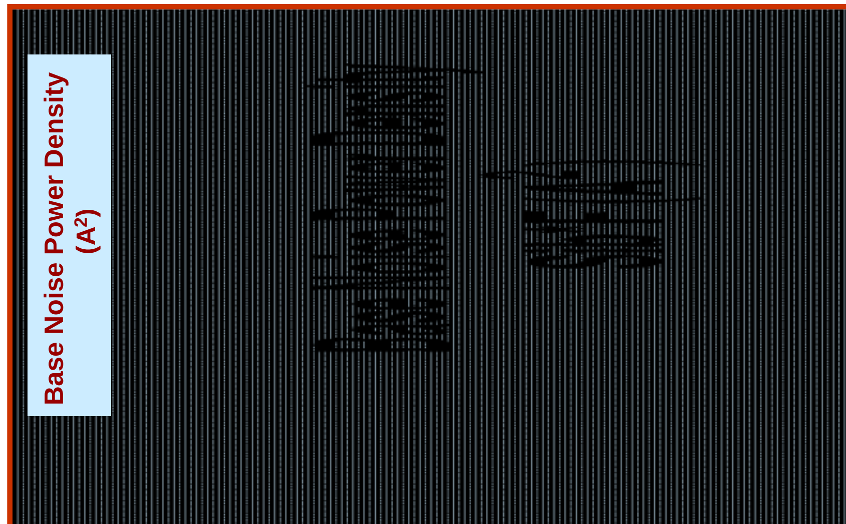
Fabrication → Noise Measurements → Reliability Assessment

7 hours

7 hours

OUTCOME

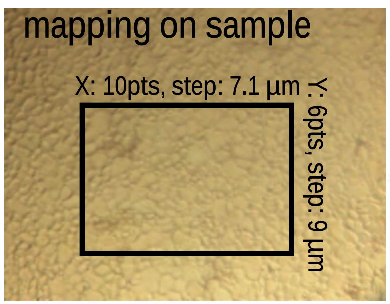
- Determined a strong correlation between device reliability and baseband noise characteristics
- Temperature dependence of peaks in base noise power density indicates reliability
- Identified trap levels responsible for degradation from temperature dependent noise measurements

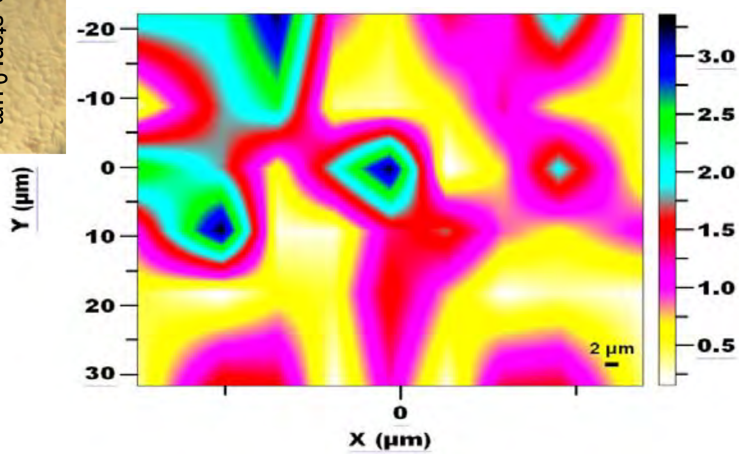


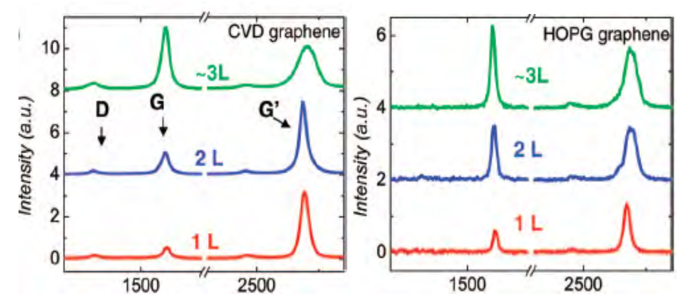
RECENT LESSONS FROM INNOVATIVE POTENTIAL RELIABILITY ASSESSMENT TECHNIQUES

Contour map of I_{2D}/I_G

- Contour map of I_{2D}/I_G: 60 points over 63.5×45 μm^2
- Thin graphene layers (mono/bi/tri-layer): $I_{2D}/I_G > 1$
- Half of the graphene layers are covered with thin graphene layers





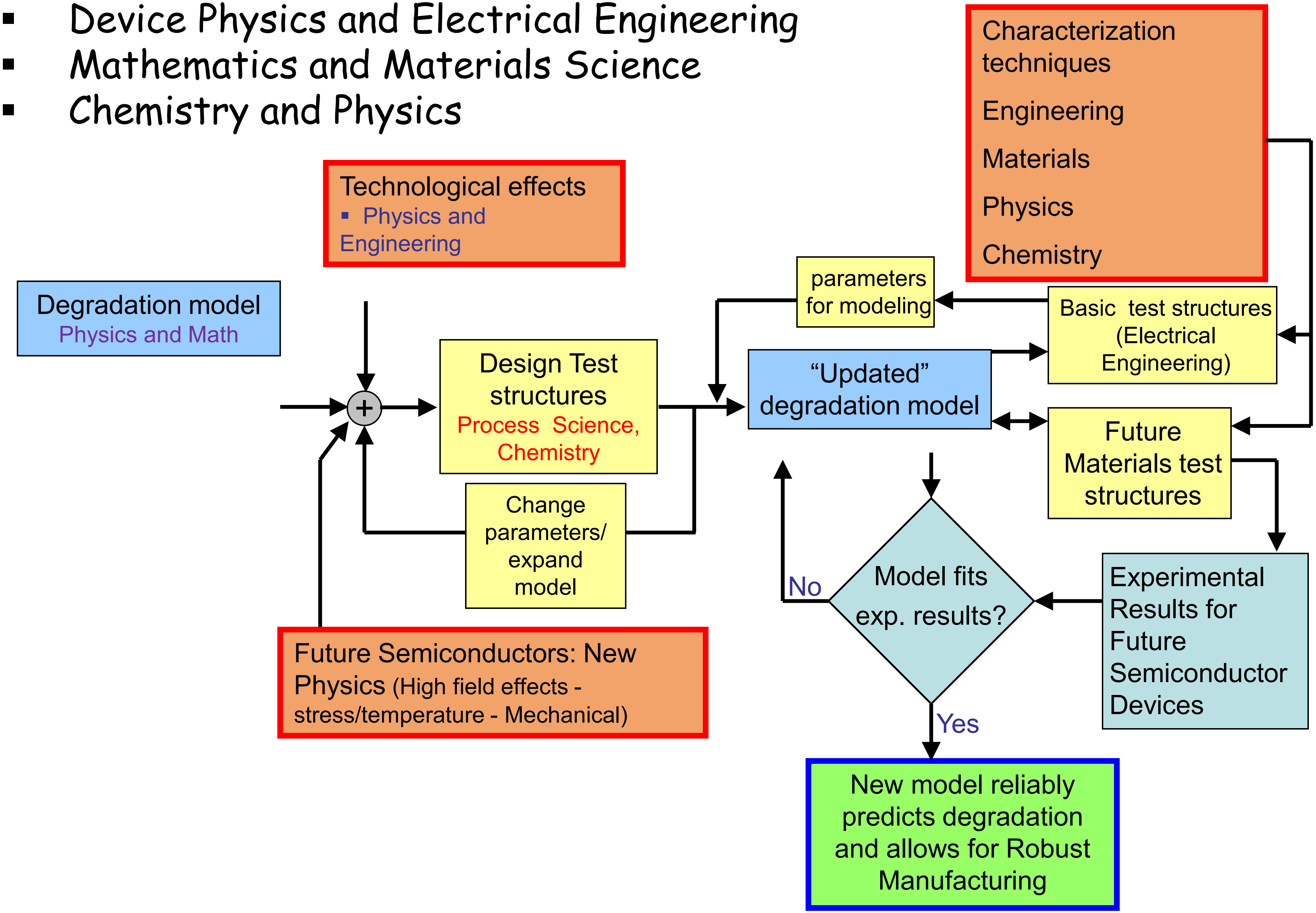


A. Reina et al., *Nano Letters* 9, 30 (2009)

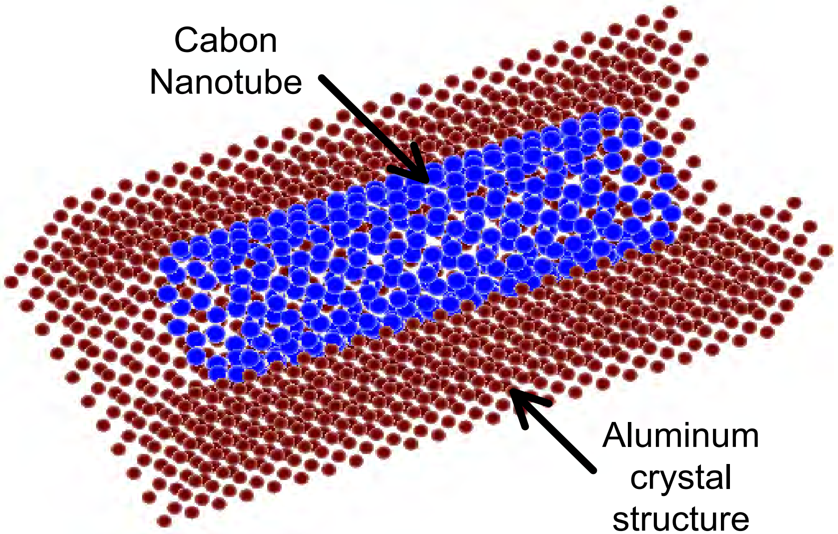
Ref: H. Kim, E. Pichonat, D. Vignaud, D. Pavlidis and H. Happy; Graphene Layers Grown by RTP-CVD on Nickel and Their Properties, WOCSDICE 2012

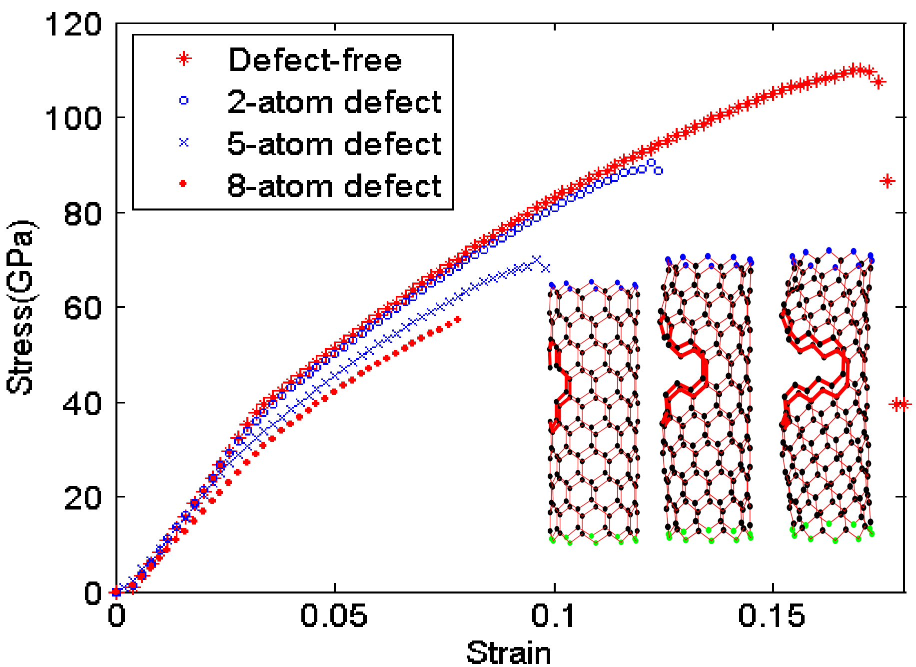
An Interdisciplinary Approach

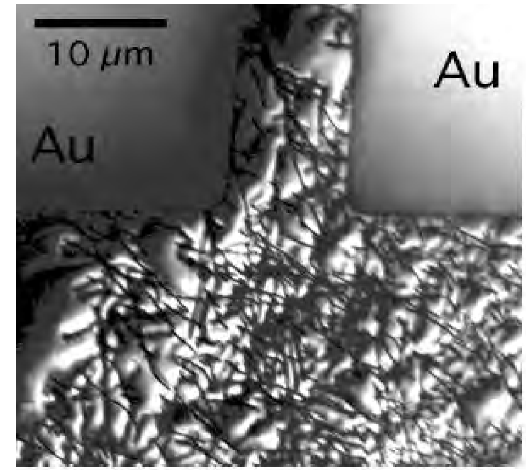
- Device Physics and Electrical Engineering
- Mathematics and Materials Science
- Chemistry and Physics



Example of Carbon Nanotube Composite Interconnects

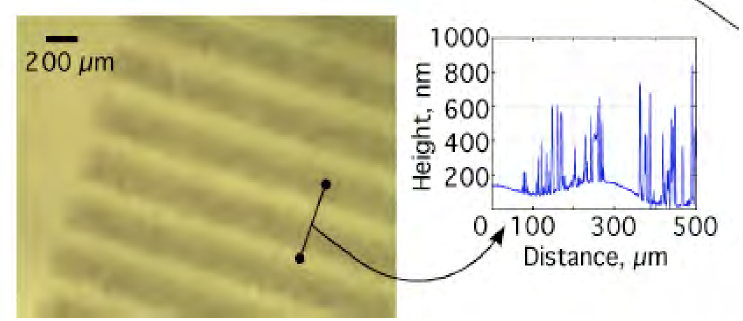






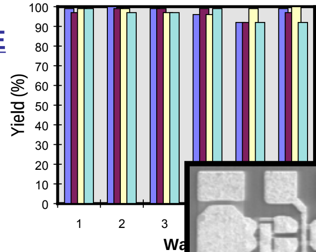
CVD grown Tubes/ PET subst

Spray coated tubes/ PC Subst.



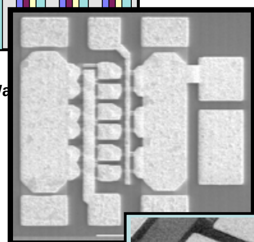
Education, Research and Innovation

REPRODUCIBLE



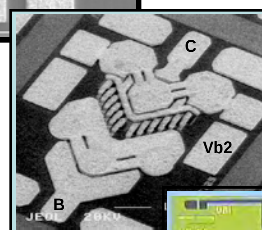
- Improve fabrication yield.

ROBUST DESIGN



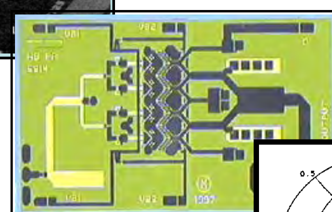
- Improved robustness

ADVANCED DESIGN

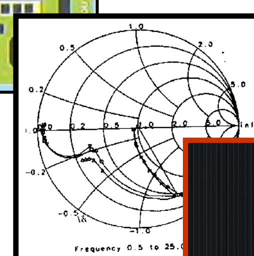


- Develop compact designs.

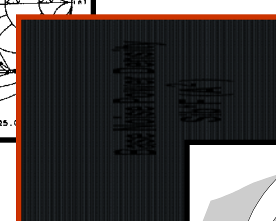
CIRCUITS AND SYSTEMS



- Improve performance with compact designs.

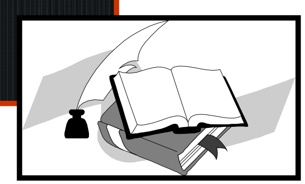


Establish Material and Device models



PHYSICAL PARAMETER - RELIABILITY CORRELATION

- Establish correlation between physical parameters and reliability.

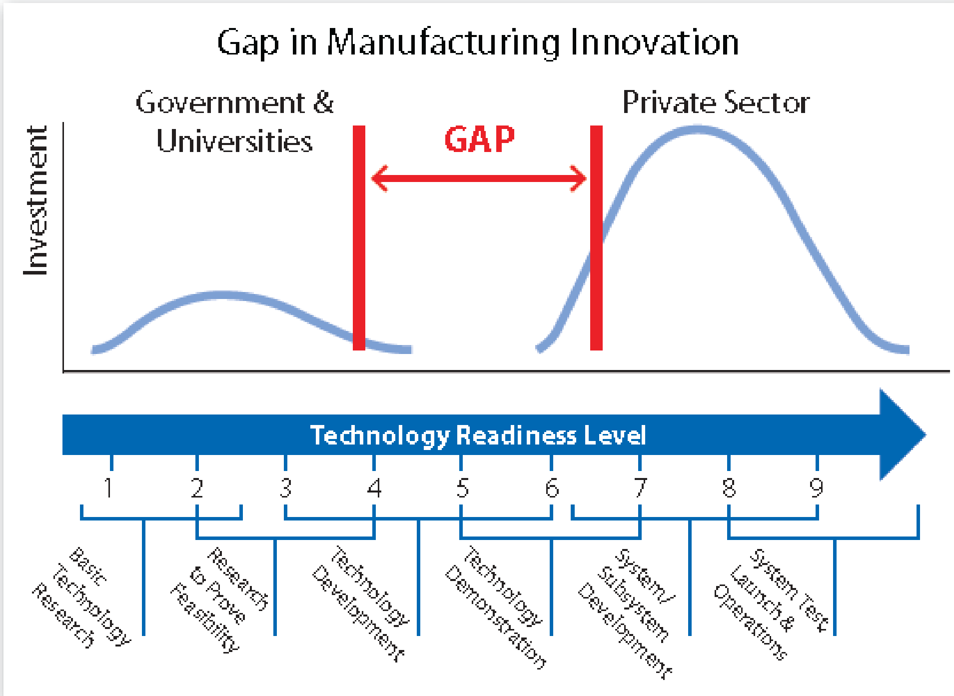


Disseminate Results through publications

Outcome and Conclusions

- Promote cross-disciplinary approaches across scientific disciplines i.e. reliability physics, materials, chemistry and more in addition to engineering.
- Initiate “transformative research” with societal impact i.e. power electronics and transport, T-Rays and medicine, communications and low-power etc. which are robust and manufacturable.
- Establish new methodologies for reliability prediction and manufacturing science for future technologies.
- Provide education and research experience for future engineers in new semiconductor technologies.

Thank you for your attention



Source: AMP Steering Committee

Table 2. Summary of Recommendations

4	*Empower Enhanced Industry/University Collaboration in Advanced Manufacturing Research* The treatment of tax-free bond-funded facilities at universities should be changed in order to enable greater and stronger interactions between universities and industry.
5	*Foster a More Robust Environment for Commercialization of Advanced Manufacturing Technologies* The AMP Steering Committee recommends actions to connect manufacturers to university innovation ecosystems and create a continuum of capital access from start up to scale up.