National Advanced Packaging Manufacturing Program
NIST RFI Workshop/Roundtable, associated with 5th Heterogeneous Integration Symposium

Comments accompany this video: https://ieeetv.ieee.org/hi/nist-rfi-roundtable-advanced-packaging-manufacturing

General Comments:

Isam Salama – Not quite clear on incentives. Need explicit funding for high density substrates in high volume manufacturing. There needs to be sufficient or more resources for facilities.

Bob Connor – Would new manufacturing be part of NSTC?

Tim Lee – What is NIST's definition of advanced packaging? Recommend using HIR's definition.

Lei Shan – Is this incentive more for big companies?

Jon Rosencrans – Develop a standard to help abdicate usable standards in 2.5 and 3D

From Sam Karikalan to Everyone: 05:27 PM - We may need a proper definition of "National Leadership in Semiconductor Packaging" itself :)

From Tim Lee to Everyone: 05:27 PM - what are the success criteria for the program?

Lei Shan – will all or part of the facilities be outside the US?

From Bob Conner to Everyone: 06:34 PM

I noticed some healthy overlap in questions in each of the four sections. Will reviewers read the entire RFI response or will different reviewers look at only particular sessions?

From EJan Vardaman to Everyone: 06:38 PM - IT might be too expensive to locate everything in the US (especially legacy packaging) so we may need to find a way to improve the global ecosystem, but at the same time increase the advanced packaging capability in the U.S.

From Scott Sikorski to Everyone: 06:39 PM - With respect to facilities outside of US, there is one very strong facility in Bromont Canada, just across the boarder from VT (and it is already a Trusted facility). Such facilities could be considered as part of the extended NAPMP infrastructure.

Chris Bailey – build up capabilities in US, but interesting to se how we can collaborate globally and have funding provided by the respective countries. Bring experts from across the world to share capabilities and solve grand challenges.

Scott Sikorski – many of the materials and equipment are outside the US

1. **Please describe the application areas that are essential to long-term national leadership in semiconductor packaging, and, where possible, identify groupings where work must be closely coordinated in a program distributed in multiple hubs.**

   Francoise – The list is a combination of end use and device types. I view it as 2 parts. Device types and applications maybe part A and part B.

   From Groot to Everyone: 04:51 PM - Onshoring of advanced packaging (e.g., OSAT-type work, Cu pillar bumping, integrated photonics, defense and aerospace, etc.) packaging is less defined by the application such as those listed and more by the type of circuits (digital, analog/rf, mixed signal, memory), the environment they need to operate in and the underlying chip technology incorporated in the package.

From Andy Mackie - Indium Corporation to Everyone: 04:51 PM - Substrates for high power density power devices

From Scott Sikorski to Everyone: 04:51 PM -The list provide in Q1 is a mix of end use applications and device types. The question itself focuses on "applications". How should the responder think about end use applications vs device types in answering this question?

From Andy Mackie - Indium Corporation to Everyone: 04:51 PM -Interconnect materials

From Raj Jammy to Everyone: 04:51 PM - Could you please help us understand the vision behind packaging activities in NSTC and NAPMP, given that they are heavily interconnected today.

From Art Wall to Everyone: 04:51 PM - As a MII consortium, NextFlex sees all of these application areas and relevant

From Scott Sikorski to Everyone: 04:51 PM -The list provide in Q1 is a mix of end use applications and device types. The question itself focuses on "applications". How should the responder think about end use applications vs device types in answering this question?

From Raj Jammy to Everyone: 04:51 PM - Could you please help us understand the vision behind packaging activities in NSTC and NAPMP, given that they are heavily interconnected today.

From Sam Karikalan to Everyone: 04:52 PM - Rather than the environments, we should focus on specific technologies such as 3D Integration, Wafer Level Packaging, Flexible / Bio-Packaging, Advanced Materials, etc.

From Ed Hendricks NextFlex to Everyone: 04:53 PM - I would include Asset & Structural Health Monitoring and RF, Communications, and High-power Applications Where you are integrating things more intensely. Adv packing placys an improtant tole in making these things more effective (wearables)

From John Shalf to Everyone: 04:49 PM - Something that came up in today's HIR was that another potential goal (or need) in advanced packaging is to bring down the barriers to entry for small/startup companies.

From Andy Mackie - Indium Corporation to Everyone: 04:54 PM - Chiplet "actual packaging" post singulation and pre assembly into the SiP/HI assembly. How are chiplets best stored and transported?

From Jim Rosencrans to Everyone: 04:54 PM - That "lowering of barriers" are involved in financial incentives part of the budget. Others are developing standards (like OCP is with BoW. NOt everyone will engineer their own solution.

From Benson Chan to Everyone: 04:54 PM - interconnect technologies, such as solders, hybrid bonding, nano materials will be key to producing reliable assemblies as the interconnect pitch gets finer, this goes along with advances in underfills, adhesives etc

From Bob Conner to Everyone: 04:55 PM - Heterogeneous integration of compound semiconductors (GaN, SiC, InP, etc.) and silicon offer disruptive potential for many of these applications. This integration could be done in a silicon or compound semiconductor fab or a wafer- or panel-level advanced packaging facility.

From Carl Zweben to Everyone: 04:57 PM - High-power lasers

From Bill Bottoms to Everyone: 04:57 PM - There should be a library of chiplets that can be accessed by everyone

From Andy Mackie - Indium Corporation to Everyone: 05:00 PM - Dummy chiplets for HI process and materials thermomechanical testing

From Chee Ping to Everyone: 05:00 PM - advanced packaging technology generally can be used across multiple application areas. for example, 3D stacking can be used in almost of these. if we have to pick a few high market growth segment or high problem value (in technical challenge) or high criticality, these areas will likely be of interest: ○ Automotive ○ Defense and aerospace ○ High performance computing, quantum computing, data centers ○ Integrated photonics ○ Integrated power electronics ○ Medical, health & wearables ○ Mobile telecommunications

From John Shalf to Everyone: 05:03 PM - @JimRosencrans - Its good to have incentives to lower barriers to entry, but it would be even better if standards like OCP BoW and @BillBottoms suggestion of an open chiplet library could lower capital cost barriers at a more fundamental level (so that we don't have to subsidize small player).

Bill Chen – each area has different charateristics and use different set of process tools.

From Andy Mackie - Indium Corporation to Everyone: 05:04 PM - Thermomechanical FEA digital twins keyed to specific mission profiles "Open Ansys"

Bill Bottoms – what are the environmental issues they are facing? Specify mechanical, thermanl, external and environmental

Robert – end use application and the R&D needed to assist in the designing. How do we cluster the application areas with the research areas to meet the environmental needs?

From Chris Bailey to Everyone: 05:06 PM - Design supported by modelling (e.g. thermo-mechanical) requires accurate materials data to input into the models. This is a an area for metrology and how data can be made available to community.

From Dave Henshall/ SRC to Everyone: 05:07 PM - along Bill's line of questioning, would there be elements of design/simulation, test, software, materials, metrology, etc. or would that be out of scope?

From Andy Mackie - Indium Corporation to Everyone: 05:08 PM - To Bill's point, "Mission profiles"/use cases for automotive are already being addressed by AEC and others. Maybe we need these for servers / quantum computers etc.

From Tim Lee to Everyone: 05:08 PM - how would the NIST Packaging program be related or different from the OSD SHIP Program?

2. **Please describe the R&D Core-competencies that are essential to national leadership in semiconductor packaging, and, where possible, identify groupings where work must be closely coordinated in a program distributed in multiple hubs.**

Chris Bailey – funding data sets across thermal mechanical, and optical electrical that are available to everyone. It is a competitive advantage to have this data.

Bob Connor – applications such as analog is a big market being served by WLP. Asian manufacturers are ahead of the US. How concerned is the US government in catching up on panel level packaging? Or are they just focused on WLP? There is a lack of design simulation tools.

Jan Vardaman – Panel level problem is a econoic issue. Do you have enough parts to fill up a panel? Investing in panel may not make sense for every application you are considering.

James Lu – Lacking University facilities and infrastructure. Need to provide funding for EDA tools that can shortcut some of the development process. Support Universities in developin EDA tools.

Ming (Synopsis) – EDAs role is to help develop chips faster. Let us know how we can help.

From Chris Bailey to Everyone: 05:14 PM - Q2: Metrology/M&S/Co-Design as underpinning technologies for predicting electrical/thermal/mechanical behaviour and reliability of advanced packaging and HI systems.

From Bob Conner to Everyone: 05:14 PM - How about panel-level packaging? i.e., use Gen 2 or Gen 3 glass or ceramic substrates. The US is behind in panel-level packaging which offers lower cost potential than wafer-level packaging for some applications such as analog.

From Art Wall to Everyone: 05:15 PM - #2 Materials, HI, High-density Substrates, PCBs, Test solutions, Other = Additive processing

From Carl Zweben to Everyone: 05:16 PM - Q2: I suggest specifically citing advanced thermal management materials. There is a significant lack of awareness of these in the industry. For example, diamond particle-reinforced copper has higher thermal conductivity than copper, along with low CTE and lower density than copper. It is being used in phased array antennas.

From Art Wall to Everyone: 05:17 PM - Excellent Point!!! How to make the data available and available to the people that you want to share it with.... Excellent point

From Andy Mackie - Indium Corporation to Everyone: 05:17 PM - Emphasis on FEA for interfaces and changes within materials such as ageing or intermetallics.

From Benson Chan to Everyone: 05:17 PM - materials characterization (full mechanical / thermal) are key to ensuring any model will properly predict the behavior of the assembly. Then use DIC to validate the model.

From Andy Mackie - Indium Corporation to Everyone: 05:17 PM - failure at interfaces is most complex to model

From EJan Vardaman to Everyone: 05:19 PM - If we care enabling commercial activities, shouldn't out metrology activities include inline metrology developments to improve yield? If NIST had a database with independent verification of material properties, it would be helpful.

From Dave Henshall/ SRC to Everyone: 05:20 PM - We'd be glad to consider holding the data (Dave at SRC)

From Benson Chan to Everyone: 05:23 PM - The materials data needs to be measured at the full temperature from mK to 600K if we are to support all markets / applications.

From James Lu to Everyone: 05:24 PM - Q2: Provide funding to develop software for processing and material design (and prediction).

From John Shalf to Everyone: 05:27 PM - Q2: Perhaps missing from this list is EDA tools (I think someone mentioned that). And particularly tools that can handle 3DI. Also, it would be useful if there was an open source version of these EDA tools to democratize access (like OpenROAD) to complement the more professional grade and higher performance commercial tools. This availability of open source EDA to complement commercial tools is also likely essential to workforce development.

From Andy Mackie - Indium Corporation to Everyone: 05:29 PM - Q2: XPS for surface analysis

From Benson Chan to Everyone: 05:29 PM - We have a HAXPES for surface analysis

From Scott Sikorski to Everyone: 05:30 PM - John Shaif makes a very good point. Especially EDA to enable complex packaging structures like 2.5D/3D where chip-package must be co-designed

From Benson Chan to Everyone: 05:32 PM - Reliability and failure analysis, acceleration models, power cycling

3. **A proposed National Advanced Packaging Manufacturing Program could be oriented to address multiple needs, including but not limited to prototyping, the provision of pilot lines, work force development, and supply chain development. Please describe the most critical needs on which the program should focus.**

From Bill Bottoms to Everyone: 05:33 PM - work force development is the most critical

Benson – Need to start packaging education earlier. Joint programs exist but mostly geared toward the graduate level.

David – Need more funding for education; increase capabilities.

From James Lu to Everyone: 05:34 PM - I think that the workforce is probably the most critical need.

From Chris Bailey to Everyone: 05:34 PM - Workforce development (supported by new university programs - multi-disciplinary)

From EJan Vardaman to Everyone: 05:35 PM - All are important, but I like the idea of the photonics lab/training facility at Tyndall in Cork, Ireland, They do prototype assembly and also have a 2 week training class. Are we trying to do something on where we are today or where we need to be? If we are looking at the future, Photonics is an up and coming area.

From Bob Conner to Everyone: 05:36 PM - Pilot lines because reliability and yield are key gating items for product commercialization and workforce development requires hands-on experience in a pilot line.

From EJan Vardaman to Everyone: 05:37 PM - We are lacking 300mm bumping capability and advanced substrate capability in North America. That needs to be included.

From Scott Bukofsky to Everyone: 05:38 PM - Using artificial intelligence to take away a lot of the "busywork" of design is also another way to help out workforce issues, and to keep desigers focused on being creative

From Alan.Huffman to Everyone: 05:39 PM - Work force and pilot line developments can be thought of as complimentary. Development of pilot lines that will eventually grow into larger capacity organizations that provide opportunities for a well-trained workforce. Both of these will take time to develop and if done in parallel, can be very effective to establishing strong manufacturing capability and talent.

From John Shalf to Everyone: 05:41 PM - @MingZhang : Yes, that's definitely the point that I'm trying to make about Open vs. Commercial EDA are not in conflict.

4. **What attributes are the most important for a National Advanced Packaging Manufacturing Program to deliver? Examples include but are not limited to:**

Bill Bottoms – workforce development is the most important. The right starting point is undergraduate, classes can be available earlier but they will not be interested if they do not understand. There are not many packaging courses at Universities. Need to inject programs into more Univs.

John Shalf – Commercial EDA Open Source to complement and support workforce development and interest to make a more accessible, more agile research environment.

Open Road should be expanded into HI and 2.5 & 3D – wouldn't be a competition but a resource for companies.

James Lu – Use the ERC model.

From Isam Salama to Everyone: 06:01 PM - no question there is critical work force shortage in packaging. our effort to quantify this gap, both in type, quantity and time horizon, will be of great utility to communicate to academics and get them enlisted to help

Francoise – the young people going into STEM now know what chip shortage and semiconductors. SEMI created a a set of videos and documentary for tv. College students who are traveling around the country to learn about the industry. Roadtrip Nation. Bring to the elementary schools. US gov't can help with these programs. 3D Incites – majority of readers are less than 50. They use the platforms the younger audiences use.

James Lu – ERC has an outreach to high schools.

From John Shalf to Everyone: 06:03 PM - @question #4 it says “Leading Edge Tools”. As per our discussion earlier with Ming Zhang from Synopsys, the leading edge EDA tools offer more accurate physical models of real leading-edge process technologies. But most of our undergraduates can learn many of the important skills for packaging and ASIC design using OpenSource tools that are not as intensive about the details of the process technology. So you should have Open Source EDA tools *and* “Leading Edge” tools. If you go straight to the leading edge tools, you’ll likely scare new students away.

Jan Vardarman – Photonics and co package Optics is up and coming. We should focus on something that is in the future.

From Françoise von Trapp to Everyone: 06:08 PM - https://3dincitespodcast.buzzsprout.com/1731672/10045401-a-conversation-about-semi-foundation-and-roadtrip-nation

https://media.3dincites.com/view/702652325/22-23/

From Art Wall to Everyone: 06:11 PM - AGREE!!! Need to have a path in the program opportunities for fostering new and emerging approaches including new materials, processing, etc.

From Scott Sikorski to Everyone: 06:13 PM - Jan is making a great point of forward focused technologies, not only opto-electronics/photonics but also other necessary packaging technologies to enable mega-trend applications like AI/HPC & 6G

From James Lu to Everyone: 06:13 PM - Q4: (James Lu from RPI): Agree with Jan. Focus on advanced research, while developing workforce development curriculum and outreaching high school students.

5. **What factors are critical to enable a National Advanced Packaging Manufacturing Program to provide a successful packaging R&D hub(s)?**

Bill Bottoms – workforce development and money. Have University facilities to have protype building.

Bill Chen – what are the new advanced packaging that can be developed out of this program.

From Tim Scott to Everyone: 06:13 PM - Industry participation and support

From Chris Bailey to Everyone: 06:13 PM - University faculty with packaging expertise. Collaboration between universities/industry to ensure outreach.

From Benson Chan to Everyone: 06:14 PM - workforce is key, there are less and less engineers coming into the packaging industry today.

From EJan Vardaman to Everyone: 06:14 PM - Can we leverage on some of the institutions and organizations that we have to meet the future needs?

From Dave Henshall/ SRC to Everyone: 06:16 PM - Must be well aligned with industry's needs, otherwise industry won't participate. Also, must grow the academic research resources, give academics the resources to grow and the freedom to be creative.

From Alan.Huffman to Everyone: 06:16 PM - Having facilities with enough AP capabilities and infrastructure to carry out R&D objectives efficiently, without having to find multiple third parties to support processes on an inconsistent basis.

Janos - Need to make sure we are resourcing it appropriately.

From Art Wall to Everyone: 06:16 PM - #5 Agree w Dave - One way to get good integration of academic and company participation is a consortium as the hub

From EJan Vardaman to Everyone: 06:17 PM - It would also be good to be able to support small business and the innovation that comes from these companies.

From Tim Scott to Everyone: 06:17 PM - Also need to have some focus on advanced packaging of WBG semiconductors. Not just digital/photonics.

From James Lu to Everyone: 06:18 PM - Agree with Dave Henshall -- we need so called Industry Day (for university research program) to get industry involved.

6. **Identify processes, equipment, measurement capabilities, environmental conditions, and training facilities that are most crucial for facilities provided by a National Advanced Packaging Manufacturing Program. How might organizations access such facilities?**

Bill Bottoms – how do we take the knowledge of the things we need and provide the seed funds. Identify the funding sources so that it can eventually pay for itself.

James Lu – need critical equipment within Universities. Hub – Univ and Industry together.

From Carl Zweben to Everyone: 05:18 PM - Q6: There is a need for reliable measurement of thermal conductivity of high-conductivity materials.

From Bob Conner to Everyone: 06:21 PM - Compound semiconductor and silicon heterogeneous integration

From James Lu to Everyone: 06:21 PM - Few hubs, which may serve as share facilities and/or pilot lines for prototyping.

From EJan Vardaman to Everyone: 06:21 PM - We need to keep this focused on the advanced packaging needs of the future not just today, so this requires us to identify the specific area of advanced packaging.

From Alan.Huffman to Everyone: 06:23 PM - agree with James...having hub facilities that have complimentary capabilities and are able to efficiently work together would work well.

From Scott Sikorski to Everyone: 06:23 PM - Question related to Dave's excellent point that there needs to good alignment to Industry needs: In the end, there needs to be an industry catcher / implementer of the leadership technologies to be developed in the NSTC, but Yole Development estimates that 75% of the world's advanced silicon is packaged by just 9 entities: TSMC, Intel, Samsung and 6 OSATS (ASE Group, AMKOR, JCET Group, PTI NEPES) - only AMKOR and Intel are US entities and both have extremely well staffed/funded R&D units (AMKOR's is not in US). Who beyond these companies are envisioned to implement the technologies to be developed by the NSTC? A new entity? A smaller player who will massively scale?

Complimentary hubs that have specific capabilities and designs.

Chris Bailey – Fraunhofer, Catapult in the UK bridge the Univ with Industry. Equivalent to Fraunhofer and IZM.

7. **How closely aligned should the capabilities enabled by a National Advanced Packaging Manufacturing Program be with those provided by the NSTC?**

Bill Bottoms – they should be aligned but it may for the NSTC to align with the National Advanced Packaging Manufacturing Program.

Bill Chen – important the NAPMP is not inferior to the semiconductor industry. It needs to be indepenent.

From James Lu to Everyone: 06:29 PM - I believe the NSTC and Adv Packaging program should be complementary.

From Tim Scott to Everyone: 06:32 PM - They should be equals with NSTC. It's not about all about chip development like it has been for the past 40 years.

From Scott Sikorski to Everyone: 06:32 PM - Strongly agree with Bill Chen's point here. For packaging technologies that are wafer-based (fan-out, 2.5D, 3D), the NAPMP should be closely associated with the NSTC, collocated and perhaps even a single entity The inter-relationships in design and processing demand this close relationship. Also there are process/CAPEX efficiencies to be gained. The success of TSMC InFO and CoWoS speak to the success of the model for this wafer-based packaging platforms which will be increasingly important going forward

From Bob Conner to Everyone: 06:32 PM - Two complementary steps are required: 1) wafer fab of semiconductor die that are optimized for subsequent heterogeneous integration (this could be part of the NSTC) and 2) the heterogeneous integration itself (which could be part of the Advanced Packaging Program).

9. **Describe anticipated needs in education and workforce development, including retraining and upskilling, in the semiconductor packaging area. How adequate is it currently, and what are future expectations of need? How should the workforce training pipeline be developed?**

From Tim Scott to Everyone: 05:45 PM - I think it needs to be maybe a 2-year highly specialized program at a community college instead of a BS or MS program at a university

From Isam Salama to Everyone: 05:46 PM - we need to attack the work force development issue at all levels, community college and associate level, undergrad level and graduate level. with ta balanced proportion

From John Shalf to Everyone: 05:47 PM - You do need to come up with a better name than “packaging” because it does (in the English language) sound just like the wrapper around a present. There must be something more complex sounding like HIR or some other word that implies something more complicated and deeper.

From Abhijit Dasgupta to Everyone: 05:48 PM - We do have a packaging course at the undergraduate level at UMD, but its a stand-alone course and needs to expand into a more integrated comprehensive program

From Art Wall to Everyone: 05:48 PM - #9 - Another source to attract and inspire young people to get interested and in the funnel are the programs within the MFG USA MII institutes.

From Sam Karikalan to Everyone: 05:49 PM - Work force development should not be limited to only Universities. Short term trade school certificate and community college level education opportunities should be created.

From Françoise von Trapp to Everyone: 05:50 PM - We need to start much earlier than university level to help young people understand the opportunities in advanced packaging. As early as elementary school. See this article in our Yearbook. https://media.3dincites.com/view/702652325/

From James Lu to Everyone: 05:51 PM - Develop adv packaging curriculum with funding for facilities from technician level to PhD level.

From Tim Scott to Everyone: 05:54 PM - Packaging is ALWAYS thought of as an after thought. Somehow it needs to be promoted as equally as important as chip design, photonics, etc.

From Bob Conner to Everyone: 05:55 PM - The “breakdown” is companies have moved packaging jobs off-shore as fast as possible. There needs to be attractive jobs and careers in the US to attract people to enter the workforce and pursue workforce traning.

From Alan.Huffman to Everyone: 05:56 PM - There are programs being implemented by companies to directly address work force development for the industry: https://www.skywatertechnology.com/press-releases/skywater-launches-apprenticeship-program-to-support-employee-career-growth-and-domestic-semiconductor-workforce-development/

From Art Wall to Everyone: 05:57 PM - https://www.nextflex.us/learning-portfolio/

From EJan Vardaman to Everyone: 06:01 PM

Tyndall National Institute has an optoelectronics packaging and assembly program that includes silicon photonics. www.tyndall.ie and PIXAAP Photonics Packaging Photonics Line (see YouTube videos) https://pixapp.eu

From Chris Bailey to Everyone: 06:02 PM

Tools/Characterisation/Collaboration/International Participation/Workforce Development

From Art Wall to Everyone: 06:03 PM - #9 - A big part of the challenge is filling the pipeline early... get even high school interested in advanced manufacturing so they are open to packaging when they attend comm college or university.... grad student is ok but feel it is too late