PSMC
Photonic Systems Manufacturing Consortium

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The Photonic System Manufacturing Consortium (PSMC)

Semi-Annual/Technical Progress Report

October 2015

1. Executive Summary

In July 2015 Vice President Biden announced that AIM Photonics was awarded the IP-IMI (Integrated Photonics Institute for Manufacturing Innovation). PSMC had committed in both our Sustainability Plan and our April 2015 Semi-Annual/Technical Progress Report that we would support the IP-IMI. The PSMC Principal Investigators had communicated with the three contenders for the IP-IMI DoD Award. The PSMC Principal Investigators committed to play a major role in the Administration's Institutes for Manufacturing Innovation and subsequent entities under AMP (Advanced Manufacturing Partnership). 2.0 PSMC will cooperate and support all AMP entities in the development of a strong US integrated photonics manufacturing base. Professor Lionel Kimerling, PSMC Co-Principal Investigator has been appointed Executive of the AIM Photonics Academy, and Dr. Robert Pfahl PSMC Co-Principal Investigator has been appointed Leader of the AMP Photonics Integrated Photonics Technology Roadmap.

In the Phase 2 of PSMC activities we will offer our experience in establishing an organization dedicated to manufacturing innovation; we will provide data and analyses based on our industry-wide strategic Technical Working Groups. The PSMC Technology Roadmap and supply chain coordination are critical elements for the AIM Photonics missions of manufacturing technology implementation and job creation. Definition of technology roadblocks and potential solutions will help structure AIM Photonics requirements; and technology timelines and cost analyses will help forecast the pace and content of the Education and Work Force Development in support of job creation. The PSMC technology targets, production and market data, and gap analyses will give continuous guidance to the IP-IMI strategic objectives.

With the announcement of AIM Photonics we have modified our program to include a series of six seminars on the results of our roadmapping activities to date:

- 10/20 Monolithic Integration Technology Working Group (TWG), Lionel Kimerling
- 10/27 Data Center Product Emulator Group (PEG), Robert Pfahl, Internet of Things (IoT) PEG, Richard Grzybowski, and Cost Modeling PEG, Randolph Kirchain and Elsa Olivetti
- 11/3 Packaging of Electronic-Photonic Systems TWG, Wilbur (Bill) Bottoms
- 11/10 Interconnection (Circuit boards, Backplanes and Connectors), TWG John MacWIlliams
- 11/17 Assembly and Test TWG, Richard Otte

These seminars are part of our efforts to transfer results to AIM Photonics and building the integrated Photonics community discussed later in this report. The first two seminars were both attended by over 100 individuals from industry, academia, and government.

On December 7 2015 PSMC will present the 2015 Photonics Roadmap at a joint meeting of PSMC, MIT Microphotonics Center, and AIM Photonics Academy at MIT.

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2. Introduction

In this, our third semi-annual report we continue to follow the format established in previous reports. Chapter 3 defines our overall objectives established in the proposal and Chapter 4 documents our performance against these original objectives. Minor modifications have been made as a result of the establishment of the IP-IMI. Chapter 6 describes the technical "heart" of our activities in terms of the results of each of the Technology Working Groups (TWGs) which produce the individual roadmaps and the Product Emulator Group (PEG) reports which describe the cost and performance needs of the identified market segments.

3. Overall Project Objectives (Established in Proposal)

Outcomes: Advances to Be Achieved

The PSMC project addresses i) the unprecedented growth of data centers, ii) the increasing volume of internet traffic, and iii) the introduction of short reach optical interconnection in distributed architectures for communication, computing and sensing. The continued scaling of this massive growth and accompanying architecture changes require the creation of a platform for the high-volume, low-cost manufacturing of integrated photonics. The nation that establishes the system design-for-function capability to address these needs, and the high volume, low cost infrastructure to manufacture high performance, energy efficient hardware will dominate the industry. This section describes our initial

objective. Note that in several areas we have refined our objectives as we have executed the program. These changes are identified in Sections 2-4.

The PSMC strategy is centered on building a common manufacturing ecosystem that supports the necessary Technology Supply Chain. The key outcomes of the Phase 1 planning stage are i) building mutual trust and cooperation among the supply chain stakeholders to establish a common vision for high volume photonic system manufacturing system and for the technology gaps that need to be closed and ii) developing a cohesive roadmap for integrated photonic system design.

Building an Integrated Photonics Community

The Photonic System Manufacturing Consortium (PSMC) has facilitated a strong working relationship among the stakeholders to address both the research needs and the required manufacturing infrastructure for integrated photonics. This structure can serve the nation well in the Phase 2 execution phase of cooperative research and development to address the critical challenges for integrated photonics that are identified in the Roadmap.

The Manufacturing Roadmap for Photonic Systems: Phase 1 Planning and Phase 2 Execution

In Phase 1 the PSMC is developing a strategic Roadmap and Technical Plan that i) identifies critical technical requirements for next-generation system integration and packaging, ii) details potential solutions to meet those requirements economically, and iii) identifies the technology supply chain limitations for commercial deployment of the required component performance in the 2014-2035 time frame.

The expected work products of the associated Technology Working Groups (TWGs) will include i) a framework for electronic-photonic convergence, ii) a common design vernacular, and iii) the characteristics of a common design platform that will reduce time to solution.

The Roadmap should motivate, inform and enable the creation of integrated tools that are interoperable among Architecture, Hardware, and Software designers.

The Roadmap is responsible for I) promoting Design for Manufacturing (DfM) philosophy and ii) raising the issue of packaging science and engineering to significance for academic research and for allocation of industry and government resources. Three dedicated Workshops will develop and cement the goals for Phase 2.

Impacting the Nation by Establishing Integrated Photonics Manufacturing

Achievement of the PSMC objectives will promote significant capability and job growth in the design, development, and photonic system manufacturing that are required to meet the insatiable global market for increased communication bandwidth, massive data center processing and ubiquitous connectivity of distributed systems. Additionally, it is essential to the security of the nation that the technology foundation for communication/computation/sensing resides in the United States.

During Phase 1 PSMC will identify areas for public and private resource allocation in:

- Technology R&D
- Materials R&D
- Development of processes and equipment for a common manufacturing platform.

A Self-Sustaining Industry Consortium

The PSMC Roadmap projects that a 1000 X increase in photonic system performance must be achieved at constant cost during the next decade. The advance of functional performance will require coordination of architecture, hardware, software and new application developments. Today's leading commercial firms may not be capable of surviving the reduction in margins as production volume is ramped higher. The PSMC is positioning its constituency to be the complete Technology Supply Chain from materials-and-tools to end-users. The key to sustaining the Consortium Value Proposition is commercial application of the benefits of i) identifying roadblocks, ii) developing new technology and iii) practicing that new technology to build a common manufacturing learning curve. The PSMC strategic plan provides for ongoing Consortium-based development for the next 30 years.

The PSMC sustainability model for research, development, and manufacturing (R, D, &M) presumes development of a strong U.S.-centric supply chain that will draw industrial funding to the domestic research community to enable manufacturing growth. The PSMC Roadmap will continue, with the support of iNEMI, MIT Microphotonics Center and the associated consortia, the specification of components, materials and technology needs at the system level; the packaging roadmap will continue to be a joint ITRS-iNEMI activity; and the integrated photonics roadmap likely will become part of the ITRS semiconductor roadmap. A relevant precedent for this transfer is radio frequency (RF) functionality that transitioned from components to semiconductor devices. When it was no longer a niche market, iNEMI transferred this roadmapping to ITRS. The two-part process in place between these two organizations, in recognition of "More than Moore" is to i) link roadmapping closely and ii) transfer the process when system functions enter high volume production.

The overarching goal of Phase 1, the planning phase, is to create the processes and infrastructure necessary to conduct focused research and development during Phase 2. During Phase 1 we will integrate the roadmapping efforts of iNEMI and of the MIT Microphotonics Center to address the systems needs and the manufacturing needs of integrated photonics. From extensive previous experience we believe that 18 months will be required to complete the Roadmap and establish agreement on a technical plan of action for Phase 2, the execution phase.

We have organized the goals of the Phase 1 planning into three "stages" as follows:

- Stage 1: Initial Roadmap Development (9 Months)
- Stage 2: "Emulator" Development to Quantify Needs (3 Months)
- Stage 3: Creation of the R&D "Technical Plan" for Phase 2 and refresh of roadmap (10 Months)

Activities during Stage 1: Initial Roadmap Development

- iNEMI roadmaps Manufacturing Needs for Integrated Photonics Packaging.
    - Existing Packaging TWG, Optoelectronics, and Connector TWGs will continue to hold regular meetings for the 2015 iNEMI Roadmap.
- MIT Microphotonics CTR roadmaps Open Architecture System Needs.
    - Open Architecture Systems TWG will hold regular meetings.
- Additional one day Workshops of all Roadmap TWGS and industrial stakeholders were held at MIT in conjunction with the Fall 2014 and the Spring 2015 Microphotonics Center meeting. This meeting began broader discussions on architectures and component needs that will require further definition.
- Based on the first Workshop, PSMC started dynamic modeling development for supply chain transition to integrated photonics.

- The one day workshop at MIT in conjunction with the Fall Microphotonics Center meeting focused on the architecture and component needs to quantify the cost-performance relationship of the system building blocks.
- Dynamic modeling development for cost and environmental considerations will commence.

Activities during Stage 2: "Emulator" Development to Quantify Needs

In this part of the planning phase PSMC will develop a product emulator that features the technology, cost, and performance attributes of a product that represents future industry needs. These attributes are quantified over a ten year horizon, providing specific targets for future research projects. Activities will include:

- Discussions to agree on an "Emulator" that would meet the needs of users
- Meeting with stakeholders to present emulator requirements
- The results of this phase might require an additional workshop.

Activities during Stage 3: Creation of an R&D "Technical Plan" for Phase 2

During this stage, a technical plan will be developed that proposes the initial research and development projects to commence technology initiatives that will meet the "emulator" technical requirements.

4. Overall Project Baselines

Bi-weekly conference calls of the Steering Committee are held on a set schedule that reviews status to plan and assigns actions to address issues identified. All critical participants/organizations are expected to attend.

The PSMC milestones have been developed and are managed on a regular basis. The following schedule is based on our actual start date of June 1, 2014. As described in the goals and objectives, PSMC has divided the work of the planning phase into three stages:

1. Roadmapping
2. Emulator Development
3. Technical Planning

The following Figure 1. Milestones for the PSMC Program map the activities chronologically.

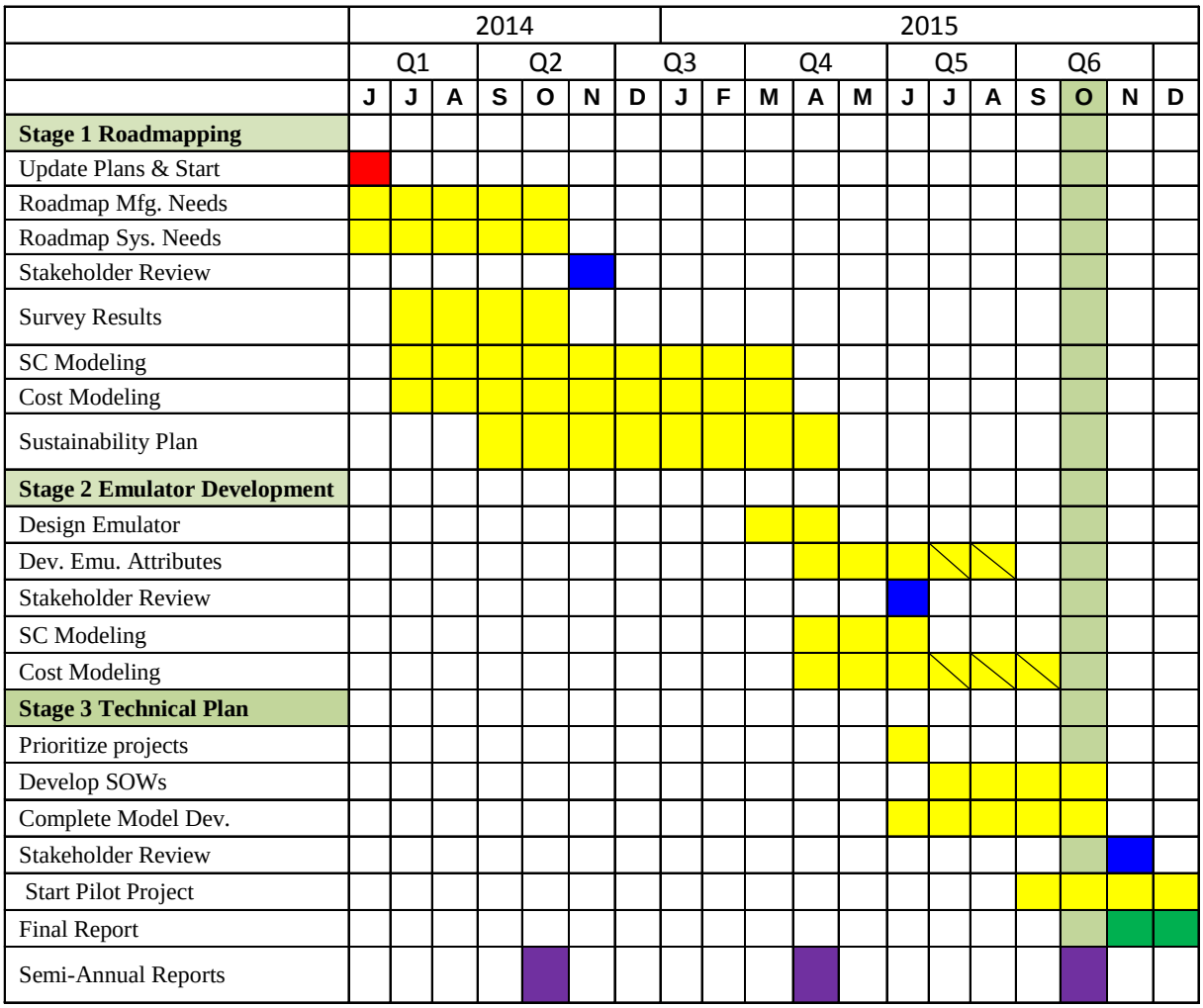

Figure 1. Milestones for the PSMC Program

Color Key

Red	Start-Up Phase
Yellow	Development Activities
Blue	Workshops
Dark Green	Final Report
Purple	Semi-Annual Reports
Light Green	Our Current Position
	Extended Activities

5. **Project Milestones**

June-October 2014: Start Up Milestones

During its first five months PSMC achieved all six of its scheduled milestones listed in Figure 1. During the first three months we established the Leadership Committee's responsibilities and the necessary infrastructure: accounting system, website, and contact data base. In August we held the first meeting of our eight-member Leadership Committee:

Robert C. Pfahl, Jr, iNEMI, Principal Investigator, PSMC

Lionel C. Kimerling, MIT, Principal Investigator, PSMC

Jim McElroy, iNEMI, Executive Director, PSMC

Bill Bottoms, Third Millennium Test Solutions, Packaging TWG Chair

Richard Otte, Promex Industries, Integration TWG Chair

John L. MacWilliams, Bishop Associates, Connectors & Substrates TWG Chair

Richard Grzybowski, MACOM, Integrated Photonic Systems Product Emulator Groups (PEGs) Chair

Randolph E. Kirchain, MIT, Emulator Modelling Co-Chair

Elsa A. Olivetti, MIT, Emulator Modelling Co-Chair

The Leadership Committee held seven meetings on a biweekly basis. The Committee's accomplishments are as follows:

- Defined Titles, Scope, Charters and Content for Website.
- Developed and distributed a survey to identify technology concerns and needs.
- Provided guidance for the process to create a quantified product emulator and acquired data from industry for emulator development.
- Identified firms and individuals to recruit.
- Planned our first workshop for November 6-7 to be held in Cambridge, MA, hosted by MIT.
- Recruited plenary, technical, manufacturing, and user speakers to present their viewpoints at the conference as background for roadmap development.
- Developed a PowerPoint template for PSMC to use at the first workshop and all subsequent presentations.
- Prepared a survey tool to use following the first workshop to gather feedback for evaluation
- Established a regular process to review progress against schedule and take necessary steps to address roadblocks.

November 2014-April 2015: Six Month Milestones

PSMC achieved the first nine milestones listed in Figure 1. We are on schedule for all milestones scheduled for Stage 2 "Emulator Development." In fact we held our Spring Stakeholder Review and Roadmapping Meeting two months ahead of schedule. The eight-member Leadership Committee continues to meet on a biweekly basis.

During these six months the Leadership Committee:

- Prepared, reviewed and submitted PSMC's 20 Year Sustainability Plan for the Integrated Photonics Integrated Manufacturing Institute (IP-IMI).

- Provided guidance for the process to create a quantified product emulator and acquired data from industry for emulator cost modelling.
- Recruited key firms and individuals to participate in the roadmapping process.
- Held two major stakeholder reviews and workshops in Cambridge, MA, hosted by MIT. The two-day meetings attracted 100 and 96 participants respectively.
- Recruited plenary, technical, manufacturing, and user speakers to present their viewpoints at the Spring Workshop as background for roadmap development.

The two Principal Investigators committed during the previous semi-annual report to establish an Executive Advisory Board (EAB). The purpose of establishing this board as discussed in the following two sections was to:

- Coalesce the integrated photonics community
- Gain executive support for establishing a jointly funded public-private partnership

The EAB has been established and its initial members are:

- Sanjay Patel, VP, IP Transport, Alcatel-Lucent
- Kal Shastri, Distinguished Engineer, Cisco
- Richard Otte, President, Promex Industries
- Terry Bowen, Fellow Corporate Technology, TE Connectivity
- Richard Grzybowski, Director of R&D, MACOM
- Bob Sankman , Intel Fellow, Intel
- Thomas Hausken, Senior Advisor, OIDA
- Katharine Schmidtke, Strategic Sourcing Manager, Facebook

An initial WebEx meeting and a face-to- face meeting at the Optical Fiber Conference (OFC) were held during this period. In addition, most of the members participated in the PSMC Workshops.

April 2015- October 2015 Six Month Milestones

During the first three months significant work was done by the TWGs and Leadership Committee on strengthening the TWGs and developing the roadmaps. Some TWGs held large meetings at major technical conferences while others drafted a “strawman” roadmap and then circulated it to leading technology experts and users to get their input.

With the awarding of IP-IMI to AIM Photonics the Principal Investigators and Leadership Committee team reviewed our activities to determine how we could best support AIM Photonics. We decided to make three changes to our project scope:

1. We added the six seminars identified above to transfer information to AIM Photonics and to further aid in building the Integrated Photonics Community.
2. We decided to collocate the Fall 2015 meetings of PSMC and the MIT Microphotonics Council with the first meeting of the AIMP Photonics Academy.
3. Since AIM Photonics had scheduled an early standup of their first Projects in the same time frame as we had recommended, we decided to defer the completion of **Stage 3: Developing the PSMC Technical Plan** until the first quarter of 2016 when we can join with AIM Photonics to integrate the Roadmap direction into the next project decision process.

The following figure reflects the changes that we have made to the schedule for developing the PSMC Technical Plan in conjunction with AIM Photonics.

	2015												2016			
PSMC Quarter	Q3		Q4			Q5			Q6			Q7			Q8	
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Stage 3 Technical Plan																
Cost Model Dev.																
Stakeholder Review																
AIM Pilot Projects										AIM Pilot Projects						
Prioritize Tech Gaps																
Develop SOWs																
Issue Technical Plan																
Semi-Annual Reports																

Figure 2. Revised Milestones for Stage 3 of the PSMC Program

Building the Integrated Photonics Community

We believe that coalescing the integrated photonics community to develop a shared vision of the future is of equal importance to the technology plan that we ultimately deliver. We plan to report on our progress on this objective in all semi-annual reports. To assist us in bringing together the diverse integrated photonics community, we scheduled a plenary session at our first workshop; Frank Gayle, Deputy Director of the Advanced Manufacturing National Program Office spoke on "National Initiatives in Advanced Manufacturing." We requested his presentation to insure that our participants understood our objective. Tom Hausken, Senior Advisor of the Optical Society of America spoke on "The State of the Industry." We requested his presentation as an important step in coalescing Integrated Photonic Systems stakeholders to focus on the technology needs for high volume, low-cost systems for commercial IT applications. Katharine Schmidtke, Facebook, spoke in the plenary session on "Expectations for the Microphotonics Supply Chain".

In the plenary session of our Spring workshop Mr. James Kisner, Senior Vice President, Jefferies LLC spoke on "Silicon Photonics: The Final Countdown." His presentation emphasized that consolidation and vertical integration of firms was necessary and already had begun in silicon photonics and provided several examples. He and Dr. Kal Shastri of Cisco stated that the silicon photonics hardware would be commoditized. All of these issues are necessary steps to build the integrated silicon photonics community from today's competitive market of small vendors.

Sustainability Plan

In January 2015 PSMC submitted its "Sustainability Plan for the Integrated Photonics Integrated Manufacturing Institute (IP-IMI) as required by our NIST AMTech award. This sixteen page document is attached as Appendix A to this document. This report defined our vision of the:

- Efficient 'stand up' and operation of the Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) funded by a five-year grant from the U.S. Government (DoD-AFRL) and matching contributions from industry, states, universities and research institutes.

- Support of Advanced Manufacturing Partnership (AMP) 2.0 goals by establishment of a new public-private manufacturing research and development infrastructure to support the innovation pipeline, that complements Manufacturing Innovation Institutes at earlier and later technology maturation stages, through the creation of manufacturing centers of excellence (MCEs) and manufacturing technology testbeds (MTTs) to provide a framework that supports manufacturing innovation at different stages of maturity and allows small and medium-sized enterprises to benefit from these investments.

The PSMC Principal Investigators communicated with the three contenders for the IP-IMI DoD Award. The PSMC Principal Investigators committed to play a major role in the Administration's Institutes for Manufacturing Innovation and subsequent entities under AMP 2.0. PSMC will cooperate and support all AMP entities in the development of a strong US integrated photonics manufacturing base. In Phase 2 we will offer our experience in establishing an organization dedicated to manufacturing innovation; we will provide data and analyses based on our industry-wide strategic Technical Working Groups; and we will actively compete to partner or lead AMP 2.0 MCEs and MTTs. The PSMC Technology Roadmap and supply chain coordination are critical elements for the IP-IMI core missions of manufacturing technology implementation and job creation. Definition of technology roadblocks and potential solutions will help structure the IP-IMI project requirements; and technology timelines and cost analyses will help forecast the pace and content of the Education and Work Force Development in support of job creation. The PSMC technology targets, production and market data, and gap analyses will give continuous guidance to the IP-IMI strategic objectives. For further details see Appendix A.

6. Technical Progress

Introduction

The Technical Progress section of this report presents PSMC's technical progress in terms of accomplishments of the major functional groups of PSMC:

- PSMC Technology Working Groups
- PSMC Product Emulator Groups and Cost Modelling
- Workshops and Stakeholder Reviews

PSMC Technology Working Groups (TWGs)

During Phase 1 we have integrated the roadmapping efforts of iNEMI and the MIT Photonics Center to address both the systems needs and the manufacturing needs of integrated photonics The five Photonic

Systems Manufacturing Consortium (PSMC) Technology Working Groups (TWGs) have been established and are developing the roadmap. They are similar to existing iNEMI and Microphotonics Center TWGs, but they differ in scope. PSMC has been added to all TWG titles to make this distinction in scope. The PSMC TWGs include many members from existing iNEMI-MIT groups, but their charters are more detailed and cover a longer period of time.

Since August the TWG leaders have been recruiting additional members and working with their TWGs. The titles of several of the TWGs have changed from the previous report to reflect more accurately their focus and the needs identified by the participants in the TWGs. The four PSMC Technology Working Groups (TWGs) and their leaders are:

- PSMC Monolithic Integration TWG: Lionel Kimerling, MIT
  - Chips: silicon photonics, InP
  - Tradeoffs for cost, bandwidth density, power efficiency, and functional latency
- PSMC Packaging TWG: Bill Bottoms, Third Millennium Test Solutions:
  - Cost, materials, heat, footprint, port count, bandwidth, integration, functionality
- PSMC Connector & Substrate TWG: John MacWilliams, Bishop Associates
  - Connectors includes: all separable interfaces within the system scope
- PSMC Assembly and Test TWG: Dick Otte, Promex Industries
  - Design for Manufacturing
  - Assembly and Test
  - Supply Chain Trade Offs

PSMC Monolithic Integration TWG

This PSMC TWG addresses chip-level integration on the Si and InP platforms, design for manufacturing, and tradeoffs for cost, bandwidth density, power efficiency, and functional latency. The long term view will include identifying functional optical components such as optical switching. The chair of this TWG is Lionel Kimerling: lckim@MIT.EDU

Professor Kimerling described the status of the TWG on October 20 at the first PSMC Seminar. His presentation summarized the TWGs activities to date and is available on the PSMC Website.

PSMC Packaging of Electronic Photonic Systems TWG

This PSMC TWG focuses on the Packaging Technology and cost objectives needed to meet market requirements for low cost high volume photonic components and sub-systems for integration into the global network. Cost and performance objectives for system level, board level, package level and where it is practical chip level integration of photonics are the initial step. Members will develop the needs for cost, materials, thermal, footprint, port count, and bandwidth. The chair of this PSMC TWG is: Bill Bottoms: bill_bottoms@3mts.com

During the last six months this large TWG has met at both ECTC and during Semi They have focused on developing agreed upon quantified key parameters. Bill Bottoms will be presenting highlights of their results at the November 3 PSMC Seminar.

PSMC Circuit boards, Backplanes and Connectors TWG

This PSMC TWG covers the intra-system connector and circuit board technology that will be needed for integrated photonic systems. Connectors include all separable interfaces within the system scope. Substrates include all circuit board and backplane components. The chair of this PSMC TWG is John MacWilliams: jmacwilliams@bishopinc.com

The draft roadmap for this TWG has been circulated with technical leaders in the industry during the past six months to get their input. The document is in the final stages of editing with focus on agreeing on the final quantification of key parameters. John MacWIlliams will be presenting highlights of their results at the November 10th PSMC Seminar.

PSMC Assembly and Test TWG

This PSMC TWG addresses the development of manufacturing processes, materials and equipment to produce integrated photonic systems with ever decreasing cost and increasing volume. The PSMC TWG covers the needs for cost, integration, assembly, test, functionality, and tools. The chair of this PSMC TWG is Dick Otte: otte@promex-ind.com

The draft roadmap for this TWG has been circulated with technical leaders in the industry during the past four months to get their input. The document is in the final stages of editing with focus on agreeing on the final quantification of key parameters. Dick Otte will be presenting highlights of their results at the November 17 PSMC Seminar.

PSMC Product Emulator Groups (PEGs) and Cost Modelling

Introduction

Two Product Emulators have been defined utilizing input from the MIT Microphotonics Open Architecture System Optimization (OASO), the Leadership Committee, and the EAB. The emulators define the application needs and system performance targets, based upon an understanding of the consequences of parallelism, virtualization, and software defined networks. Each PEG report will be divided into near term (10 years) and long term (30 years) sections. The near term will look more like a traditional iNEMI Product Emulator Group (PEG) structure with well-defined attributes evolving over specific time intervals (application needs). The long term will be more speculative with less specificity on attributes (system targets).

PSMC Data Center PEG

Data centers are a critical node of network architecture that is driving higher bandwidth from the core network to ever shorter distances. As single channel data rates exceed 10Gb/s, copper transmission lines introduce excessive loss, necessitating a transition to photonic interconnects. The pervasive use of photonic interconnects at short distances means that photonic transport becomes a higher fraction of system data movement, requiring system design, architecture, software and hardware to be reconsidered. The Grand Challenges for information hardware are i) photonic integration for bandwidth density and ii) high volume manufacturing to meet the system demand. The chair of this activity is Bob Pfahl bob.pfahl@inemi.org

Requirements for these applications focus on:

- High bandwidth (single mode/Wave Division Multiplex)
- Low latency
- Low power consumption
- Continuous duty at full speed
- Thermal stability for photonic components
- Heterogeneous integration
- Variable frequency for power reduction
- Redundancy or other means to insure no failures
- Optical to Electronic and Electronic to Optical (O to E and E to O) located in PWB mounted SiP (System in Package)
- Low cost with path to continuous cost improvement

The draft documentation for this product emulator was completed in August and has been circulated with technical leaders in the industry to get their input. The document is in the final stages of editing with focus on agreeing on the final quantification of key parameters. Bob Pfahl described the status of the TWG on October 27 at the second PSMC Seminar. His presentation summarized the TWGs activities to date and is available on the PSMC Website.

PSMC Internet of Things (IoT) PEG

Chip-scale integrated photonic sensing systems are emerging as diagnostic sensors for medical, environmental and security applications, structural health monitoring, military sensing, and wireless sensor networks – the entire Internet of Things (IoT) space. The field is advancing rapidly, with fabrication technologies that leverage standard microfabrication infrastructure and enable the co-integration of sensors, photonics, electronics, and microfluidic sample preparation systems. The chair of this activity is Rich Grzybowski: grzybowski@macom.com. Requirements for these applications focus on:

- Very Low cost with path for continuous cost reduction
- Store and forward capability for sensor data
- Very Low power consumption
- Intermittent duty, standby/sleep mode
- Standard photonic parts for all applications
- Security
- Heterogeneous integration with standard and customized parts integrated into a single SiP

The draft documentation for this product emulator was completed in August and has been circulated with technical leaders in the industry to get their input. The document is in the final stages of editing with focus on agreeing on the final quantification of key parameters. Richard Grzybowski described the status of the TWG on October 27 at the second PSMC Seminar. His presentation summarized the TWGs activities to date and is available on the PSMC Website.

PSMC Emulator Cost Model Development

PSMC is developing technology-based models for the cost, energy, and environmental implications of various component and architecture alternatives for the two emulators under consideration. These process-based cost models (PBCM) will enable the modeling team to characterize how technologies will perform as photonics are integrated further into electronic systems. These tools will also serve to answer economic and energy use questions surrounding system architecture, enabling reliability and redundancy. Randolph Kirchain and Elsa Olivetti have started developing the PSMC cost emulator. They have had several discussions between themselves and with other members of the Leadership Committee on process, content and data acquisition. They have received manufacturing data from one PSMC participating firm which they are using to develop a process-based cost model to guide engineering decisions to select options in design and manufacturing. The models will be constructed using actual cost data from participating companies.

Preliminary results from the cost model were presented on October 27 at the second PSMC Seminar by Randy Kirchain. His presentation summarized the TWGs activities to date and is available on the PSMC Website. The team requested additional manufacturing cost data from other firms. The data will be accurate for application and anonymized to protect sensitive source value points.

Semi-annual Workshops

PSMC has held two stakeholder reviews and roadmap workshops. The following summarizes the results of the two workshops:

Fall 2014 Stakeholders Review and Roadmap Workshop

Appendix A provides the agenda and speakers for the Fall 2014 Workshop that was held on November 6-7. One Hundred people participated in the program. Following are three areas of key learning points from the meeting:

- Packaging TWG
  - Major Challenges
    - Power
    - Latency
    - Thermal management
    - Bandwidth density
    - Cost
  - We must move things closer together
- Hybrid Integration TWG (Renamed the Assembly and Test TWG)
    - Implement Panel Processing
    - Implement a Flexible Architecture to serve changing, evolving needs
    - Accurate Assembly Equipment
    - US Integrated Photonic Systems Foundry
    - Optical Test Functions
    - Suggested list of classic functions needed in an integrated photonic system

- Monolithic Integration TWG
    - Light Source
    - Process Tools (193nm litho, 65nm CMOS)
    - Universal E-P CAD for photonic integration
    - E-P process integration
    - Power distribution
    - Athermal devices
    - Wafer-level inspection and test
    - Scalable (single mode, E-P) packaging solution

Spring 2015 Stakeholders Review and Roadmap Workshop

Appendix C provides the agenda and speakers for the Spring 2015 Workshop that was held on April 23-24. Ninety-six people participated in the program. This stakeholder meeting demonstrated that consensus was developing on a number of key requirements for establishing a low-cost high-volume silicon photonics manufacturing supply-chain. In particular the Assembly and Test TWG reached consensus on a number of issues.

Following is a summary of Key learning points from the meeting:

- Importance of high volume, low cost
    - Need for consolidation in supply chain
    - Reducing Cycle Time is central to cost reduction
        - Improved materials (epoxies) are needed
    - Equipment for low volume processing from electronic packaging industry is available
        - Unique equipment will be needed for high volume
- Use Two emulators: Data Center & IoT
- Single Mode fiber is the focus & is not a packaging Challenge
    - Use Self Alignment similar to Silicon Optical Bench-No active alignment
- InP mounted on silicon photonics substrate will be the initial approach to Monolithic Integration
- Importance of Technology Training
    - DfX (Manufacturing & Testing) training for designers
    - Training for manufacturing engineers on impact of going from multimode to single mode on accuracy requirements
- Leading OEMs are now working with test and equipment vendors. This activity may stimulate the development of necessary infrastructure and tools.

In addition the stakeholders identified a number of issues and questions where more information is needed to reach a consensus opinion. Those issues were then assigned to members of the Leadership Committee for resolution:

- Monolithic Integration
    - Will a foundry model (Global Foundries, TMSC, Infinera) or OEM (Intel, STMicro. Freescale) Prevail?
    - How will design IP be addressed? Synopsys?

    - What will be the technology for InP Mounting?
        - Bonding
        - Monolithic Deposition oxide to oxide
        - Solder Bumps
- What is the definition of a Standard Platform?
- Two emulators: Data Center & IoT
    - What is the market size for each and how will they grow (Sources of Info: Yole, IHS, Prismark, Light Counting,
    - What application will need a million devices?
- How do we continue the supply-chain dialogue established in the Assembly & Test TWG at Workshop?

Fall 2015 Stakeholders Review and Roadmap Workshop

The Fall 2015 PSMC Roadmap Workshop will be held on December 7-8 at the MIT Media Lab, E14, 6th Floor, 75 Amherst St. Cambridge MA. In conjunction with the AIM Photonics All-Institute Meeting, and the MIT Microphotonics Center Fall Meeting. At this meeting the PSMC Roadmap will be released. The title of the two day meeting is "Implementing Photonic Integration. Details of the meeting are in Appendix D.

Supporting AIM Photonics

PSMC had committed in both our Sustainability Plan and our April 2015 Semi-Annual/Technical Progress Report that we would support the IP-IMI. The PSMC Principal Investigators had communicated with the three contenders for the IP-IMI DoD Award. The PSMC Principal Investigators committed to play a major role in the IP-IMI. AIM Photonics has accepted this commitment and Professor Lionel Kimerling, PSMC Principal Investigator has been appointed Executive of the AIM Photonics Academy, and Dr. Robert Pfahl PSMC Principle Investigator has been appointed Leader of the AIM Photonics "Integrated Photonics Technology Roadmap."

In the Phase 2 of PSMC activities we will offer our experience in establishing an organization dedicated to manufacturing innovation; we will provide data and analyses based on our industry-wide strategic Technical Working Groups. The PSMC Technology Roadmap and supply chain coordination are critical elements for the AIM Photonics missions of manufacturing technology implementation and job creation. Definition of technology roadblocks and potential solutions will help structure AIM Photonics requirements; and technology timelines and cost analyses will help forecast the pace and content of the Education and Work Force Development in support of job creation. The PSMC technology targets, production and market data, and gap analyses will give continuous guidance to the IP-IMI strategic objectives.

PSMC Seminars

With the announcement of AIM Photonics we have modified our program to support early technology project definition with a series of six seminars on the results of our roadmapping activities to date:

- 10/20 Monolithic Integration Technology Working Group (TWG), Lionel Kimerling
- 10/27 Data Center Product Emulator Group (PEG), Robert Pfahl, Internet of Things (IoT) PEG, Richard Grzybowski, and Cost Modeling PEG, Randolph Kirchain and Elsa Olivetti

- 11/3 Packaging of Electronic-Photonic Systems TWG, Wilbur (Bill) Bottoms
- 11/10 Interconnection (Circuit boards, Backplanes and Connectors), TWG John MacWIlliams
- 11/17 Assembly and Test TWG, Richard Otte

These seminars are part of our efforts to transfer results to AIM Photonics and Building the Integrated Photonics community discussed next in this report. The first two seminars were both attended by over 100 individuals. Presentations will be posted on the PSMC Website.

Building the Integrated Photonics Community

We believe that coalescing the integrated photonics community to develop a shared vision of the future is of equal importance to the technology plan that PSMC ultimately delivers. The Principal Investigators believe that the success of PSMC and AIM Photonics depends on the degree to which the microphotonics stakeholders can develop a shared vision and work together to develop the tools, materials, and processes in a public-private partnership which results in manufacturing silicon photonics in high-volume and at low-cost. Achieving this shared vision is a much greater challenge than producing a roadmap and a technical plan for implementation.

We were greatly encouraged at our Spring Workshop to see that a core group of stakeholders now:

- Recognize the need for consolidation in the industry
- Agree on certain technology choices
- Agree on the need for Technical Training in the new technology particularly for the designers.

In particular this workshop highlighted three keys issues related to reducing cost and implementing the IP IMI:

- While many current optical communication products are built today utilizing multi-mode technology that requires assembly tolerances of +/- 5 microns, the future for optical communications is single mode due to the greater bandwidth, reach and data density single mode offers. Hence, assembly technology development must focus on cost effective methods suitable for single mode photonic devices.
- The assembly technologies used in electronics are the starting point for photonic assembly. These technologies are solder and epoxy based methods that typically utilize bond lines that are 25 to 75 microns thick on substrate pads that have X and Y tolerances of +/- 25 microns. The resulting uncertainty in X, Y and Z locations are far greater than the < 1 micron tolerance required for single mode optical assembly. Hence high accuracy, thinner bond line processes, including attachment materials, placement tools and control of part dimensions, all need to be developed for low cost photonics.
- In recent years, approximately 250 million transceivers are sold each year. That number contrasts with the approximately 250 billion integrated circuits sold each year. That 1000:1 ratio highlights the size of the infrastructure and industrial activity supporting the two industries. Photonics can adopt a lot from the integrated circuit industry, but eventually an infrastructure specifically adopted for photonics needs to be developed.

7. Summary of Project Changes

In September 2014 the Leadership Committee identified that PSMC needed to hold a brainstorming session with leading industry thinkers to get their views on long term needs to implement Photonic Integrated Systems and develop the required technical solutions. The two-hour meeting of six leaders was held in Santa Clara, CA, and was led by Dick Otte and Bill Bottoms of the Steering Committee. This meeting that had not been anticipated has been valuable in establishing a strawman vision that led to the definition of the two product emulators. During the current period we modified the definition of the Assembly and Test TWG to attract key stakeholders to participate in defining key manufacturing roadblocks.

In August 2015 the leadership team reviewed our activities to determine how we could best support AIM Photonics. We decided to make three changes to our project scope:

1. We added the six seminars identified above to transfer information to AIM Photonics and to further aid in building the Integrated Photonics Community.
2. We decided to collocate the fall 2015 meetings of PSMC and the MIT Microphotonics Council with the first meeting of the AIMP Photonics Institute.
3. The PSMC Roadmap release on December 7 will identify the 'low hanging fruit' for technology development projects. AIM Photonics Institute instituted an independent process for a 'pilot' project call; AIM and PSMC will integrate the Roadmap direction into the next project decision process.

8. Problems and Opportunities

Integrated photonics manufacturing is at a critical launch point for high volume applications and production. The firms in this industry are extremely busy in building customer bases and in evaluating technological directions. The PSMC will have to present necessary value in every activity to attract a constituency of technology leaders and to meet its Phase 1 goals of i) building mutual trust and cooperation among the supply chain stakeholders to establish a common vision for high volume photonic system manufacturing system and for the technology gaps that need to be closed, and ii) development of a cohesive roadmap for integrated photonic system design. As previously stated in Section 3 of this report, we have used our first workshop to help coalesce the integrated photonics community. We selected our plenary speakers with that opportunity in mind: Frank Gayle, Deputy Director of the Advanced Manufacturing National Program Office spoke on "National Initiatives in Advanced Manufacturing," to insure that our participants understood our objective. Tom Hausken, Senior Advisor of the Optical Society of America spoke on "The State of the Industry," as an important step in coalescing Integrated Photonic Systems stakeholders to focus on the technology needs for high volume, low-cost systems for commercial IT applications.

We used our second workshop to further contribute to ownership of the project by stakeholder. Key note presentations by James Kisner of Jefferies and Kal Shastri of Cisco predicted that silicon photonics hardware would be commoditized. Acceptance of this prediction is a necessary step to build the integrated silicon photonics community from today's competitive market of small vendors.

While we have drafts of PEG and TWG chapters, we are behind schedule on two documents. It is our plan to have those in place prior to the December 2015 meeting.

9. Organizational Issues

Because the entire Leadership Committee and many of the TWG members have worked together over many years, we have not encountered any organizational issues. We have integrated a number of new participants and firms into our Roadmapping and Technology Planning through the Fall and Spring Stakeholder Meetings. We are encouraged that additional firms and AIM Photonics now recognize the need for a roadmap which drives technology consolidation to achieve high-volume, low cost integrated photonics manufacturing in the United States.

PSMC has reached agreement with AIM Photonics Institute to integrate its Roadmap into AIM Photonics Academy, the unified knowledge, technology, and workforce interface for AIM Photonics. PSMC recommends continuation of an expanded PSMC Roadmap under NIST AMTech to serve its electronics and photonics industry constituents. The expanded activity would add TWGs in new essential areas such as Photonic Design Automation and it would commission application and technology research teams to construct models to inform industry decision makers.

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PSMC Sustainability Plan

For the Integrated Photonics Integrated Manufacturing Institute

January, 2015

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PSMC Sustainability Plan

Driving a Photonics Manufacturing Ecosystem

Introduction

PSMC Sustainability Mission Statement: The PSMC will become a vital, industry-sustained infrastructure element within the next five years. The PSMC value proposition is based on three pillars: Roadmap, "Big M" Technology Evaluation, and Supply Chain Integration. The pace of value creation is dependent on the emergence of cost effective, platform-based, high volume photonics manufacturing. Significant adoption of integrated photonics manufacturing is required during the next five years for PSMC to meet it sustainability goals.

Figure 1. Sustainability Mission of PSMC

The Photonics Systems Manufacturing Consortium proposal envisions three phases of development. "Big M" manufacturing practice for Integrated Photonic Systems is defined as coordination and global optimization of every node in the technology and material supply chains: spanning from material synthesis, design-for-X and chip fabrication to assembly, delivery and end-of-life recycling.

Phase 1: June 2014-December 2015

Three value points are being established during this period: i) creation of the PSMC Roadmap and associated Technical Working Groups; ii) development of a complete photonics manufacturing supply chain; and iii) support of an Integrated Photonics Institute for Manufacturing Innovation (IP-IMI).

This period of activity is being funded by the NIST AMTech Program, volunteers from research institutes, and the Big M manufacturing supply chain.

Phase 1 goals:

- Establish a consortium of academics, technologists, and companies that will create an Integrated Photonic Technology Roadmap.
- Bring together the fragmented, customization-focused photonics industry to engage collaboratively in developing a common roadmap.
- Support development of high-volume mass-manufacturing, assembly, and packaging technologies and processes that are reliable and cost-effective.

Phase 2: July 2015-July 2020

Two value points are targeted for this period: i) efficient 'stand up' and operation of the Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) and ii) support of Advanced Manufacturing Partnership (AMP) 2.0 goals by creation of "Big M" technology research, development and evaluation centers.

- Establishment of an IP-IMI with PSMC providing the Technology Roadmap support. Funded by a five-year grant from the U.S. Government (DoD-AFRL) and matching contributions from industry, states, universities and research institutes.
- Establish a new public-private manufacturing research and development infrastructure to support the innovation pipeline, which complements Manufacturing Innovation Institutes at earlier and later technology maturation stages, through the creation of manufacturing centers of excellence (MCEs) and manufacturing technology testbeds (MTTs) to provide a framework that supports manufacturing innovation at different stages of maturity and allows small and medium-sized enterprises to benefit from these investments.

Phase 3: July 2020-2035

During this period PSMC will coordinate the establishment of an industry led, self-sustaining Research, Development, and Manufacturing (R&D&M) infrastructure and ecosystem from the IP-IMI, IP-MCE and IP-MTT foundation. Establishment of a cooperating and coordinated end-to-end supply chain will be the gating and sustaining activity for this enterprise.

This document describes our plan for the success of Phases 2 and 3 for the IP-IMI and succeeding entities as specified by our NIST AMTech Grant. As noted throughout our proposal the critical step is to utilize the roadmapping and technical planning process of Phase 1 to bring all stakeholders in both the commercial and military markets together to focus on the key roadblocks or "red brick walls" that cannot be solved without government support to reduce the risk to individual supply chain firms. Achieving this 'unity of purpose' within the industry is a daunting task. Milestone charts for all three Phases are provided in an appendix to this report.

Phase 1: PSMC Roadmap, Technical Working Groups, Executive Advisory Board, and Technical Planning for IP-IMI: June 2014-Jan. 2015

PSMC held its initial Roadmap Workshop on November 6-7 in Cambridge MA. Approximately 100 representatives from the research community, government, not for profits, the entire manufacturing supply chain, and technology users ("customers") attended the meeting. Six months into the program we have identified a key list of attributes and activities to be addressed in Phase 2. Three data sources have been developed:

- Industry brainstorming sessions in Silicon Valley,
- Breakout groups and workshops in Cambridge,
- Leaders of the Technology Working Groups.

They have identified the following attributes for integrated photonics manufacturing success:

- A strong leader and a team with unity of purpose
- Institutional, state and federal collaboration in creating an 'industrial commons'
- A feasible plan for sustainable independence
- Industry supply chain cooperation and adoption of common manufacturing platforms
- Common platforms with common interfaces for design and process development
- Cooperative R&D&M foundries with assignees from industrial supply chain
- Smart partitioning of electronic and photonic functionality with self-test capability
- A packaging process revolution that reduces assembly steps and layout complexity
- Accurate cost models for evaluation of alternate technologies

The recent Consumer Electronics Show in Las Vegas has demonstrated a multitude of new product concepts that depend on a strong and viable Internet to support the next generation of products. The successful execution of the PSMC roadmap and technical plan is becoming critical to new jobs and growth in the United States economy. During PSMC's Phase 1, we are establishing a non-fiduciary Executive Advisory Board. The key reasons for establishing this group are to develop trust, cooperation, and shared objectives within a leadership team that is representative of the manufacturing supply chain. The objective is to provide the executive-level industry support that will be essential for a successful

stand-up of an IP-IMI. PSMC has identified the incumbent proprietary culture as a source of the hesitancy of the optoelectronics industry to cooperate and accelerate the broad introduction of "integrated photonics." During Phase 1 a major effort is being made to build trust and cooperation between the stakeholders. The 'seat classifications' for executive members of this board (listed below) reflect the diversity of the integrated photonics manufacturing industry and the organizations participating in the PSMC activities:

1. Produce end-manufactured electronic products ("OEM Representatives"),
2. Produce components, materials, subassemblies or equipment used in manufacturing photonic- and electronic products ("Supplier Representatives"),
3. Provide Electronics Manufacturing Services ("EMS Representatives"),
4. Provide integrated packaging ("Packaging Representatives"),
5. Manufacture semiconductor and/or photonic devices ("Foundry Representatives"),
6. Conduct advanced research (University and Research Institutes),
7. Engage relevant stakeholders (not for profit organizations and Government Representatives)
8. Engage technology users (Customers).

The board will include representatives of major firms, and small and medium size enterprises. At this time the following individuals have agreed to participate in this executive board.

Figure 1. Initial PSMC Executive Advisory Board

Organization	Individual	Position	Representing
Alcatel-Lucent	Sanjay Patel	VP, IP Transport	Telecom OEMs
Cisco	Kal Shasti	Distinguished Engineer	IT OEMs
Promax Industries	Richard Otte	President	Small Assembly Manufacturers
MACOM	Richard Grzybowski	Director of R&D	Medium Size Integrated Photonics OEMs
Intel	Bob Sankman	Intel Fellow	Semiconductor Mfg.
NIST			Research Institute
OIDA	Thomas Hausken	Senior Advisor	Stakeholders
Facebook	Katharine Schmidtke	Strategic Sourcing Manager	Commercial Customers
Lockheed-Martin	Dan Blass	Senior Scientist, MST	Military Customers

Milestones

The milestones for Phase 1 of the PSMC activities are discussed at the beginning of this section and in the Appendix of Milestones. They are the roadmapping phase, the development of a product emulator to develop a cost model for success, and the establishment of a technical plan to attract industrial participants to fund an IP-IMI.

Phase 2: IP-IMI with PSMC Support and AMP 2.0: July 2015-July 2020

Introduction

The PSMC is committed to play a major role in the continuing role out of the Administration's Institutes for Manufacturing Innovation and subsequent entities under AMP 2.0. PSMC will cooperate and support all AMP entities in the development of a strong US integrated photonics manufacturing base. In Phase 2 we will offer our experience in establishing an organization dedicated to manufacturing innovation; we will provide data and analyses based on our industry-wide strategic Technical Working Groups; and we will actively compete to partner or lead AMP 2.0 MCEs and MTTs. The PSMC Technology Roadmap and supply chain coordination are critical elements to the IP-IMI core missions of manufacturing technology implementation and job creation. Definition of technology roadblocks and potential solutions will help structure the IP-IMI project requirements; and technology timelines and cost analyses will help forecast the pace and content of the Education and Work Force Development in support of job creation. The PSMC technology targets, production and market data, and gap analyses will give continuous guidance to the IP-IMI strategic objectives.

Leadership of IP-IMI

To address the technology needs and collaborative leadership requirements already identified by PSMC, it is critical for Phase 2 that a standalone IP-IMI organization be established with a strong CEO and a strong Board of Directors with executives/senior technologists that are representative of the user community for the IMI. Both Sematech and iNEMI have shown that this practice was critical to their development as organizations that meet the needs of the manufacturing supply chain.

Board of Directors. We recommend that the IP-IMI Board of Directors be industry (Commercial and Military) led with designated seats for various portions of the supply chain; and with provision for Ex Officio members, similar to the structure being used for the PSMC Executive Advisory Board (EAB). The IP-IMI BoD would have ultimate fiduciary and oversight responsibility for the business, operations, and general affairs of the new organization. At least two members of the board should represent small and medium size enterprises.

The representative structure of the iNEMI Board of Directors as defined in its by-laws could serve as a model for the IP-IMI BoD:

> *"(a) Elected Directors*
>
> *The number of Directors shall be established by The Board of Directors, provided that there shall be not fewer than eight (8) Directors or more than twelve (12) Directors. Directors shall reflect the diversity of the electronics manufacturing industry and shall include representatives of iNEMI Participating Organizations: (i) who produce end-manufactured electronic products ("OEM Representatives"); (ii) who produce components, materials, subassemblies or equipment used in manufacturing electronic products ("Supplier Representatives"); (iii) who are Electronics*

Manufacturing Services providers ("EMS Representatives") and (iv) other iNEMI Participating Organization Members.

(b) Ex-Official Directors

The Chief Executive Officer and the Chairs of the iNEMI Technical Committee shall serve as non-voting ex-officio members of the Board of Directors. The Board of Directors may appoint government representatives and representatives of research institute members, who work with the electronics industry, and such additional individuals, as it deems appropriate, as ex-official non-voting members of the Board of Directors."

CEO. The first and most critical activity of the Board will be to appoint the first CEO. This appointee must be an energetic leader with a commitment to implementing "Big M" manufacturing technology that can produce both secure military components and low-cost, high-volume commercial components. An example of such a leader would be Hector Ruiz, the retired CEO of Global Foundries, who has demonstrated leadership and has respect within the industry.

Infrastructure and Membership of the IP-IMI, IP-MCE and IP-MTT

In terms of establishing the critical infrastructure such as IP policy, rules of engagement, and bylaws, the best practices of iNEMI, Sematech, and existing IMIs will be used.

The organizational structures should consist of one HQ and two hub sites: one to focus on chip technology and one to focus on packaging and assembly technology. This dual hub organization is capable of agile and coordinated innovation across the two critical elements of R&D infrastructure. The PSMC has already targeted establishment of a consortium for enabling packaging and assembly technology that is even more critical to low-cost, high volume success than device technology. Key gaps that must be overcome in packaging technology are the development of i) precision assembly equipment and ii) a new generation of test technology for all steps of the manufacturing process.

Membership. We propose to develop a tiered membership, described in the next section, which will emerge as the sustaining support for an independent Integrated Photonics Manufacturing Association. Each member must commit to their participation in terms of both funds and in-kind support. The iNEMI experience has shown that separate commitments on a technical level and a resource level are advisable. Some levels of the tiered membership must commit to send personnel to work at the hub sites.

Activities Taken to Secure Funding

A key responsibility of the CEO and Board of Directors will be to secure matching funding for Phase 2 and total funding for Phase 3. The AMP entities will provide an initial funding foundation. In addition, the IP-IMI, IP-MCE and IP-MTT must secure funding support from a complete "supply-chain" of partners to insure that the technology developed meets the commercial and military requirements for performance, cost, and market entry. Key players in the supply chain must be attracted to use the hub facilities, staff, and educational programs to meet their R&D needs through both pre-competitive R&D

and unique partner programs. The PSMC Phase 1 Roadmap and Technical Planning will stimulate and establish consensus within the supply chain of needs that provide high-payback from funding and in-kind support. This information will be shared with the leadership of the hubs to assist them in developing committed sources of industrial support and funding.

Funding Model. During Phase 2 the MIT Microphotonics Center and iNEMI will conduct their biannual roadmap workshops on integrated photonics based on funding from the IP-IMI. We have responded with estimates for such funding to requests from all of the major participants in the IP-IMI FOA process.

We will participate in building a successful funding model for the IP-IMI that should transfer forward to MCE and MTT entities where we anticipate a leadership role. Significant initial participation and funding from the user community is necessary if any of the entities are to become self-supporting in just five years. Sematech took considerably longer to become self-supporting.

A possible scenario for different classes (tiers) of annual membership for a sustaining entity follows with examples of interested firms.

- Specify system requirements for their applications: $2 M (Verizon, Facebook, Microsoft, Akamai) (MIT, BU, Carnegie Mellon, Arizona)
- System providers: membership: cash or in-kind equivalent $1M: establish common platform for next 5-25yrs (Intel, Cisco, IBM, A-L Bell Labs, Luxtera, Infinera, Lockheed-Martin, Raytheon, MACOM, Juniper, ADI…) (MIT, BU, Carnegie Mellon, Arizona)
- Tool and packaging/test technology providers: membership: development platforms: develop solutions to identified Roadblocks (Palomar, IMT, Chiral, Teradyne, Amkor, Brooks Automation…) (MIT, BU, UMass Lowell, UMass Amherst, GaTech, SUNY Binghamton…)
- Chip manufacturers: membership: $500K or equivalent: specialized tools/designs/personnel to develop next platform modules for chips, packages and connectors. (Luxtera, Finisar, Oclaro, Avago, ADI, JDSU, MACOM, Intel, Cisco, IBM, Infinera…) (MIT, Colorado, UC Berkeley, Stanford, BU,…)
- Fabs: membership: contribute PDK, equivalent value or $500K: fabricate designs for members(IBM-Burlington VT, Intel NM, Freescale CA, Global Foundries NY, National/TI ME, Fairchild Semiconductor ME) (CNSE, MIT.nano, Sandia, MIT-LL) 4 runs/yr. @ $500K/run and 3mo/run + 1mo for packaging
- Materials and specialty products: membership: $500K or equivalent: support entire supply chain projects (3M, Corning, Soitec …) (MIT, BU, UMass Lowell, UMass Amherst, New Mexico)
- Cost modeling: membership: $500K or equivalent: evaluate tradeoffs among alternate technologies and sensitivity to volume and yield (all companies, RHK, industry, analysts) (MIT)

PSMC Phase 2 Strategy

Two value points are targeted for this period: i) efficient ‘stand up’ and operation of the Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) and ii) support of Advanced Manufacturing

Partnership (AMP) 2.0 goals by creation of "Big M" technology research, development and evaluation centers:

- Establishment of an IP-IMI with PSMC providing the Technology Roadmap support. Funded by a five-year grant from the U.S. Government (DoD-AFRL) and matching contributions from industry, states, universities and research institutes.
- Establishment of a new public-private manufacturing research and development infrastructure to support the innovation pipeline, which complements Manufacturing Innovation Institutes at earlier and later technology maturation stages, through the creation of manufacturing centers of excellence (MCEs) and manufacturing technology testbeds (MTTs) to provide a framework that supports manufacturing innovation at different stages of maturity and allows small and medium-sized enterprises to benefit from these investments.

The PSMC in Phase 2 will continue to function as a roadmap and organizer of R&D project consortia in support of the successful funded "winner" of the IP-IMI. These are two functions in which iNEMI and the MIT Microphotonics Center have demonstrated successful outcomes. The MIT Microphotonics Center has published 15 years of editions of the Communication Technology Roadmap, focusing on manufacturing platforms for photonic integration. The results of INEMI's roadmapping process are well documented[1]. Several of the other NIST AMTech programs have requested support from iNEMI in developing their roadmapping processes. iNEMI has also developed and utilized a successful process for identifying key development needs for electronics manufacturing and establishing supply-chain based industrial Technology Implementation Groups to develop statements of work and conduct precompetitive consortium-based R&D. Using this process during the past twenty years iNEMI has established more than 100 projects with participation from more than 150 firms, universities, research institutes, and NIST. Technology areas that have been addressed include electronic packaging, optoelectronics, high density interconnect, Pb-free soldering, Bromine-free printed circuit board, direct flip-chip attach, electronic testing including boundary scan, development of equipment for board assembly, and next generation power supplies. Many of these projects have included development of reliability data and recommendations for industry standards. iNEMI staff has facilitated not only the development of the teams and their statements of work, but also the project management function.

PSMC's Organization and Funding During Phase 2

Funding. PSMC has notified all organizations competing for the IP-IMI of our willingness to perform the roadmap, project development and execution functions during our Phase 2. The scope of these activities is defined in the following paragraph. We have provided each competitor a preliminary budget of the expenses to perform these functions.

[1] The Flexible Electronics Opportunity, National Academies Press

Organization. PSMC has established its Executive Advisory Board (EAB). This executive group is responsible for leading and guiding PSMC through Phases 1-3. The Board consists of recognized leaders from industry, research institutes, and key stakeholder organizations. The EAB is responsible for developing and reviewing technical goals, plans and commitments to the evolving AMP manufacturing ecosystem. In that role, the EAB plays a de-facto advisory role to all engaged AMP partner entities.

PSMC Responsibilities during Phase 2

Roadmap. The PSMC for Roadmap objectives for Phase 2 are:

- Create an industry needs-focused Integrated Photonics Roadmap for the next decade by drawing upon the expertise of a broad cross-section of individuals from industry, academia, and government. The results of this work will be available to the electronics industry worldwide. This roadmap will be refreshed on a regular basis as technology evolves and the market responds.
- Identify the major areas on which the iNEMI-MIT PSMC will focus based on definition of system requirements, TWG participation, and economic impact.
- Conduct a gap analysis of these major areas that identifies the challenges and opportunities facing the industry.
- Create rolling 5-10-15-25 year plans for the major areas that identify the projects and activities deemed necessary to close the identified gaps. These plans will become the basis for the formation of the Integrated Photonics Manufacturing projects.

This roadmap process is a bottoms-up "Delphi process" relying on numerous technology experts to give their consensus vision of the technologies that are required to meet their view of future products. The roadmap process does not explicitly identify disruptive technologies, but by identifying needs, particularly those for which there are no known solutions that meet the performance and cost requirements, the members of the PSMC TWGs will implicitly identify areas for innovation and the utilization of disruptive technologies. The full electronics manufacturing supply chain and its R&D institutions will be stakeholders in the process. Existing vital links to twelve roadmap organizations will be maintained: ITRS, OIDA, TPCA, IPC, EIPC, INSIC, IEEE-CPMT, SMTA, ECA, IMAPS, MEMS Industry Group, and PSMA.

Project Development and Execution. The experiences of Sematech and iNEMI have shown the need to develop a strategic plan with key milestones that address the "red brick walls" that cannot be crossed without industry collaboration. To achieve the ultimate goal of low-cost, high-volume manufacturing the Project Development and Execution activity must be a collaborative function that develops consensus within the stakeholder community of the preferred technology direction. PSMC participants have many years of experience in developing collaboration and industrial support. PSMC also has experience in project management and cost modeling of product emulators to insure that the enabling technology being developed is consistent with the volume and cost goals. For a number of years, iNEMI and MIT-MphC have been managing industry collaborations and have developed solid methodologies to plan and execute R&D programs. The elements of that process include:

- Attracting industrial partners across the supply chain,

- Developing a Statement of Work (SOW) for each effort that details the resources needed by task/activity,
- Holding Bi-Weekly conference calls on a set schedule that review status to plan and assign actions to address issues identified. All critical participants are expected to attend.

Key Organizational and Technical Milestones

The Appendix of Key Milestones is a preliminary list some of the events which must occur during Phase 2 to insure:

- Meeting the identified needs for R&D knowledge in both semiconductor chip fabrication, packaging and system assembly technology;
- Quickly producing technology demonstrators;
- Strongly coupled Research, Manufacturing and Development;
- Evaluating the reliability of the new materials and processes;
- Achieving low volume production;
- Achieving high-volume, low-cost objectives;
- Establishing a record of success and sufficient support from industry to become self-funded in five years.

Phase 3: Integrated Photonics Manufacturing Ecosystem; beyond AMP 2.0; and Sustainable Self-Sufficiency: July 2020-2035

Overview

During this period PSMC will coordinate the establishment of an industry led, self-sustaining R, D&M manufacturing infrastructure and ecosystem from the IP-IMI, IP-MCE and IP-MTT foundation. Establishment of a cooperating and coordinated end-to-end supply chain will be the gating and sustaining activity for this enterprise. Adoption of common manufacturing platforms for cost effective, high volume manufacturing is dependent on projection of i) a >15 year life of the platform and ii) a scalability of performance/cost under a common learning curve. As PSMC stated in its proposal, given the strong and growing markets for Integrated Photonics, we must implement strategies that ensure the sustainability of the research and development programs beyond Phases 1 & 2.

Success in Phase 2 will be measured by the extent of implementation of the R, D&M project results. Significant adoption of the project results in the manufacturing supply chain Roadmap and products should create a strong US-centric supply chain that will lead to a stream of industrial funding that will sustain manufacturing growth and the AMP hub ecosystem that support them. These funds are typically in the form of grants or fees for development services from the industry, government, and academic institutions. The AMP hubs will continue to provide support for training and education of needed skills that will be sustained by direct company funding of classroom, internship and apprentice activities.

The sustainability model for roadmap and technical planning for Phase 3 is that PSMC will continue to research and release the Roadmap for component, materials and system technology needs; the packaging roadmap will continue to be a joint PSMC-ITRS-iNEMI activity; and the integrated photonics

technology roadmap will merge with the ITRS semiconductor roadmap. The Project Development and Execution function of PSMC would transfer to the IP-IMI, IP-MCEs and IP-MTTs at the end of Phase 2.

Key Milestones.

The Appendix provides an initial list of key milestones for Phase 3. It is essential that commercial Integrated Photonics Systems be based on a high volume, low cost manufacturing platform by 2021 to attract funding to support the performance/cost scaling learning curve. One of the first areas of focus for the self-supporting organization will be developing the enabling technology for photonic switching. Phase 1 and phase 2 milestones are also included for completeness.

Appendix: Key Milestones for each Phase

Table 1. Key Milestones for PSMC Phase 1

	2014							2015											
	Q1			Q2			Q3			Q4			Q5			Q6			
	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Stage 1 Roadmapping																			
Update Plans & Start																			
Roadmap Mfg. Needs																			
Roadmap Sys. Needs																			
Stakeholder Review																			
Survey Results																			
SC Modeling																			
Cost Modeling																			
Sustainability Plan																			
Stage 2 Emulator Dev.																			
Design Emulator																			
Dev. Emulator Attributes																			
Stakeholder Review																			
SC Modeling																			
Cost Modeling																			
Stage 3 Technical Plan																			
Prioritize projects																			
Develop SOWs																			
Complete Model Dev.																			
Stakeholder Review																			
Start Pilot Project																			
Final Report																			
Quarterly Reports																			

Table 2. Key Milestones for IP-IMI: Phase 2

	2015		2016				2017				2018				2019				2020	
Phase 2 Key Milestones by Quarter	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**
Establish BoD, Leadership Team																				
Establish IP, Initial Membership, Operating Procedures, etc.																				
Establish Technical Committee																				
Initial Development Projects		Packaging																		
Initial Research Projects		Silicon PDK																		
Begin Educational, Training Programs																				
2nd Phase R&D Projects																				
First Working Technology Demonstrators																				
Qualification of New Materials																				
Initial Prototype Mfg. Equipment																				
Application of Technology To Prototype Products																				
Reliability Qualification of New Technology																				
First Component Manufacturing for Military Product																				
R&D on Photonics Switching Manufacturing																				
First Photonic Systems Manufacturing																				
Medium Volume Production																				
Begin Phase 3 Funding Model																				
Achieve Five Year Cost Objectives																				

Table 3. Key Milestones for IP-IMI: Phase 3

	2020		2021				2022				2023				2024				2025	
Phase 3 Key Milestones by Quarter	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**
Funding by Industry, & Research Org for Development and Prototype Fabs and Packaging Facilities																				
Members Achieve High Volume Commercial System Production																				
Members begin Photonic Switching Manufacturing																				
Members Achieve Low Cost Objective																				

MIT MICROPHOTONICS CENTER FALL MEETING

Le Méridien Cambridge-MIT, 20 Sidney St., Cambridge
November 6-7, 2014

THE TECHNOLOGY SUPPLY CHAIN

Co-Organized By:
The MIT Microphotonics Center and iNEMI
The NIST-AMTech Photonic Systems Manufacturing Consortium

Information systems are being deployed with greater fractions of photonic links as systems scale to higher bandwidth. Cost effective, high capacity manufacturing of photonic systems is dependent on i) the coordination of a technology supply chain under an inclusive Roadmap, and ii) the coordination of a vendor supply chain under efficient business practices. This meeting will examine enabling technologies for pervasive commercialization of optical interconnects and signal processors.

DAY 1: THURSDAY, NOVEMBER 6

8:15 **Registration and Light Breakfast**

SESSION I: PLENARY SESSION

THE IMPORTANCE OF INTEGRATED PHOTONICS MANUFACTURING

Session Chair: Dr. Richard Grzybowski, Director of Research and Development, MACOM Integrated Photonic Solutions

8:50 **Fall Meeting Context and Expectations**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

9:00 **Keynote: The State of the Industry**
Dr. Tom Hausken, Senior Industry Advisor, OIDA/OSA

9:25 **Keynote: Expectations for the Microphotonics Supply Chain**
Dr. Katharine Schmidtke, Strategic Sourcing Manager, Optical Technology, Facebook

9:50 **Break**

10:00 **Production in the Innovation Economy**
Dr. Elisabeth Reynolds, Executive Director, Industrial Performance Center, MIT

10:25 **National Initiatives in Advanced Manufacturing**
Dr. Frank Gayle, Deputy Director of the Advanced Manufacturing National Program Office (AMNPO)

10:50 **Break**

SESSION II: ROADMAPS, ROADBLOCKS AND PLATFORM SOLUTIONS

THE INDUSTRY TRANSITION TO HIGH VOLUME PHOTONIC SYSTEM MANUFACTURING

Session Chair: Dr. Frederick Sears, Research Director, Science & Technology, Corning, Inc.

11:00 **The Roadmap for Electronic-Photonic System Packaging**
Dr. Bill Bottoms, Chairman, 3MTS

11:20 **Assembly of Photonic Systems: Value Points and Roadblocks**
Dr. Richard Otte, President and CEO, Promex Industries, Inc.

11:40 **The Transition to High Volume Manufacturing of Photonic Systems**
Dr. Randolph Kirchain, Principal Research Scientist, Materials Systems Laboratory, MIT

12:00 **Attendee Lunch**
Microphotonics Center Industry Consortium Board Meeting

MIT MICROPHOTONICS CENTER FALL MEETING

Le Méridien Cambridge-MIT, 20 Sidney St., Cambridge

November 6-7, 2014

SESSION III: INTEGRATED PHOTONICS MANUFACTURING

THE FOUNDRY ROLE IN RESEARCH, DEVELOPMENT AND MANUFACTURING

Session Chair: Dr. Mark Webster, Engineering Manager, Cisco Systems

2:00 ***Keynote:*** **Supply Chain Perspectives from Silicon Photonics Manufacturing: From Optical Chipsets to Modules**
Dr. Subal Sahni, Principal Engineer, Luxtera

2:25 **Integrated Photonics Fab at CNSE – SUNY Poly**
Dr. Michael Liehr, Executive Vice President for Innovation and Technology, CNSE

2:45 **European Photonic Foundry Services**
Dr. Pieter Dumon, Research Engineer, IMEC; CTO, Luceda Photonics

3:05 **The TIA-SCR R&D Foundry for Silicon Photonics**
Dr. Youichi Sakakibara, Senior Researcher, AIST, Japan

3:20 Break

SESSION IV: INTERFACES, PACKAGING, ASSEMBLY AND TEST

COST, TOOLS, TROUGHPUT, YIELD AND RELIABILITY

Session Chair: Dr. Vivek Raghunathan, Sr. Process Engineer, Intel

3:30 **Tool Automation for Hybrid Photonic Integration**
Dr. Daniel D. Evans, Jr., CTO/Applications Manager, Palomar Technologies

3:50 **Enabling Technologies: Hermetic Micro-Packaging of Edge Emitting DMLs**
Dr. Chris Gudeman, CTO, Innovative Micro Technology (IMT)

4:10 **Leveraging the Silicon Platform for Packaging and Reliability**
Dr. Dong Pan, CEO, SiFotonics Technologies

4:30 **Connector Industry and TE Connectivity**
Dr. John MacWilliams, Principal Consultant and Analyst, Bishop and Associates (for Terry Bowen, TE Connectivity)

4:50 Break

SESSION V: INTRODUCTION TO THE PSMC WORKSHOP

Session Chair: Dr. Bill Bottoms, Chairman, 3MTS

5:00 **Introduction to PSMC: Goals and Progress**
Dr. Robert Pfahl, Senior Consultant, iNEMI

5:10 **TWG Briefing Presentations (suggested length: 10min)**
- Hybrid Integration TWG: *Dick Otte, Promex Industries*
- Packaging of Electronic Photonic Systems TWG: *Bill Bottoms, 3MTS*
- Circuit boards, Backplanes and Connectors TWG: *John MacWilliams, Bishop*
- Monolithic Integration TWG: *Lionel Kimerling, MIT*

6:00 Networking Reception

MIT MICROPHOTONICS CENTER FALL MEETING

Le Méridien Cambridge-MIT, 20 Sidney St., Cambridge
November 6-7, 2014

DAY 2: FRIDAY, NOVEMBER 7

8:15 **Light Breakfast**

8:50 **Key Points from Day 1**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

SESSION VI: OPEN ARCHITECTURE SYSTEM DYNAMICS

APPLICATION REQUIREMENTS, SYSTEM PERFORMANCE TARGETS AND MANUFACTURING
Session Chair: Dr. Tremont Miao, Engineer, ADI

9:00 **Keynote: The Data Center: Evolving Architecture and Hardware**
Dr. Madeleine Glick, Senior Research Scientist, University of Arizona

9:25 **TWG Report: Connector & Printed Circuit Input to Roadmap**
Dr. John MacWilliams, Principal Consultant and Analyst, Bishop and Associates

SESSION VII: BUILDING PLATFORMS FOR MONOLITHIC INTEGRATION

CHIP-LEVEL INTEGRATION, DESIGN FOR MANUFACTURING
Session Chair: Dr. Anuradha Agarwal, Principal Research Scientist, MIT

9:40 **Keynote: High Spectral Efficiency with Microphotonic Integration**
Dr. Long Chen, Photonic Integration Lead, Acacia Communications

10:00 **Integrated Photonic Technologies for On-Chip, Fiber-Optic and Space Communications**
Prof. Jonathan Klamkin, Assistant Professor, Boston University

10:20 **Case Study in Cooperative Development: CMP Process for Germanium**
Dr. Jurgen Michel, Senior Research Scientist, MIT and Zhan Chen, Global Business Director, Cabot Microelectronics Corporation

10:40 **Monolithic Microphotonics for Ubiquitous Sensing**
Prof. Juejun Hu, Assistant Professor, University of Delaware and MIT

SESSION VIII: PSMC WORKSHOP

PSMC Leadership Team: Dr. Bill Bottoms, Dr. Richard Grzybowski, Prof. Lionel C. Kimerling, Dr. Randolph Kirchain, Dr. John MacWilliams, Dr. Jim McElroy, Dr. Elsa Olivetti, Dr. Richard Otte, and Dr. Bob Pfahl

11:00 **Working Group Discussion Breakouts (opportunity to give TWG prep materials)**
-Survey Data Analysis and Validation: Lisa is completing compilation; to all today
-Brainstorming Data: in Dick's Thursday talk (perhaps a summary slide for Bill)
-OASO TWG Report (Kim: one summary slide for Bill)

12-1 **Working Lunch**

2:00 **Workshop reports**
-Problem Definition: Pareto Chart for "Limitations in the Supply Chain"
-Now, Next, Future: Roadmap Refinements
-TWG and IMI Action Items

3:00 **Conference summary**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

3:15 **Adjourn**

Appendix C: Agenda for Spring 2015 Workshop

Le Méridien Cambridge-MIT, 20 Sidney St., Cambridge

April 23-24, 2015

PLATFORMS FOR GROWTH

Co-Organized By:

The MIT Microphotonics Center · iNEMI · NIST-AMTech · PSMC

Photonic components are being deployed to meet the energy, bandwidth density and latency requirements for Information System scaling.

- *The number of photonic components deployed in IT systems is increasing.*
- *The contribution of photonics to system cost is becoming significant.*
- ***If a common manufacturing platform is shared across the industry, one can expect that cost reduction will scale with manufacturing volume.***

High volume production will establish a global learning curve for photonic system manufacturing that will deliver 1000x cost reduction and functionality increase during the next decade. The key technology value points during this transition are design, processing, assembly, packaging, test and Big M manufacturing. ***Firms that cling to high margin, low volume paradigms will lose market share to firms that embrace the new platforms that deliver simplicity, cost reduction and fast time-to-market.*** *The Spring Meeting will assess this platform development with contributions from the key suppliers of materials, tools, assembly-package-test and foundry services. Each session will feature a NOW-NEXT-LIMITS Technology Roadmap to be updated during the meeting.*

DAY 1: THURSDAY, APRIL 23

8:15 **Registration and Light Breakfast**

8:55 **Spring Meeting Context and Expectations**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

SESSION I: MANUFACTURING PLATFORMS AND LEARNING CURVES

PHOTONIC COMPONENTS MUST BE IN HVM AT LOW COST WITH THE HIGHEST POSSIBLE LEVELS OF INTEGRATION.

Session Chair: Ms. Alexis Bjorlin, GM, Silicon Photonics Solutions Group, Intel Corporation

9:00 **Introduction: The Photonic System Manufacturing Roadmap**
Dr. Richard Grzybowski, Director, Research & Development, MACOM Integrated Photonic Solutions

9:05 **Commercial Silicon Photonics: Volume and Cost Targets**
Dr. Kal Shastri, Distinguished Engineer, Cisco

9:30 **Optical Transceiver Trends for Data Center Applications – How Much Photonic Integration Do We Need?**
Dr. Robert Blum, Director of Strategic Marketing, Oclaro Inc.

9:55 **Silicon Photonics: The Final Countdown**
Mr. James Kisner, Senior Vice President, Jefferies LLC

10:20 **Break**

SESSION II: ROADMAP EMULATORS AND COST ANALYSES

CONCEPTUAL SYSTEM PHYSICAL ARCHITECTURES SERVE AS TARGETS FOR COMPONENT ROADMAPS, AND COST MODELS SUPPORT TRADEOFF DECISIONS.

Session Chair: Dr. Atul Srivastava, CTO, NEL-America

10:35 **TWG Report: The Two PSMC Roadmap Emulators**
Dr. Robert Pfahl, Senior Consultant, iNEMI, Principal Investigator of PSMC Program

10:40 **Heterogeneous Integration for Data Center Applications**
Prof. John E. Bowers, Professor, UCSB

11:00 **Emulator #2 – IoT, Sensors**
Prof. Juejun Hu, Assistant Professor, MIT

11:20 **The PSMC Microphotonics Cost Model: A Status Update**
Ms. Wei Yu, Graduate Student, MIT

Le Méridien Cambridge-MIT, 20 Sidney St., Cambridge

April 23-24, 2015

Session III: Open Architecture System Optimization

Open systems enable a more competitive, flexible, multi-vendor approaches to high volume manufacturing with benefits to all players. The industry models for cooperation may need modification.

Session Chair: Dr. Rob Stone, Technical Director, Broadcom

11:40 **TWG Report: Open Architecture System Optimization**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

11:45 **Digital Optical Phase Locked Loop for Low Power Consumption and High-Speed Coherent Detection**
Dr. Tetsuya Kawanishi, Professor, NICT/Waseda University

12:10 Attendee Lunch
Microphotonics Center Industry Consortium Board Meeting

Session IV: Packaging of Electronic Photonic Systems

Packaging of SiPh chips is a major challenge: Thermal, electrical, and optical output from a small micro-module with Stacked Die, Electro-Optical Substrate, Interposer or Socketed to PWB

Session Chair: Dr. Alan Evans, Program Director, Optical Connectivity Solutions, Corning Incorporated

1:35 **TWG Report: Photonic System Packaging**
Dr. Bill Bottoms, Chairman, 3MTS

1:40 **Packaging for Integrated Photonics and Electronics Converged Systems at PETRA**
Dr. Takahiro Nakamura, Chief Technology Director, PETRA

2:00 **Photonic Packaging and Assembly for Cost-Efficiency and Scalability**
Dr. Tymon Barwicz, Research Scientist, IBM

Session V: Manufacturing Tools: Assembly and Test

New tools will be necessary to provide HVM capability for component parts, subsystems and final assembly of SiPh systems. This will be a moving target as component technologies change.

Session Chair: Mr. Daniel Evans, CTO, Palomar Technologies

2:20 **TWG Report: Assembly and Test**
Mr. Richard Otte, President and CEO, Promex Industries, Inc.

2:25 **Production Test Method for Optical Interconnect Device**
Mr. Hidenobu Matsumura, R&D Manager, Advantest Corp.

2:45 **Precision Automation**
Mr. Michael Chalsen, President, MRSI Systems and Mr. Cyriac Devasia, Vice President of Engineering, MRSI Systems

3:05 Technical Working Group Breakouts

5:30-7:30p Networking Reception

DAY 2: FRIDAY, APRIL 24

8:30 **Light Breakfast**

9:00 **Key Points from Day 1**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

SESSION VI: CIRCUIT BOARDS, BACKPLANES AND CONNECTORS

CONNECTORS WILL MOVE FROM MM TO SM, AND BACKPLANE ARCHITECTURE WILL CHANGE TO A CABLED STRUCTURE. THE REQUIRED OPCB, WITH SMT CONNECTORS IS A MAJOR CHALLENGE.
Session Chair: Dr. Patrick Thomas, Lab Manager, E&E Group, 3M

9:10 **TWG Report: Markets and Technology Roadmap**
Mr. John MacWilliams, Principal Consultant, US Competitors LLC

9:25 **Connector and Optical Cable Technology and Manufacturing**
Mr. Terry Bowen, Fellow Scientist, TE Connectivity

9:45 **Silicone Polymer Waveguides for Optical Interconnects**
Dr. Mustafa Mohamed, Program Manager, Dow Corning Corp.

10:05 **Multifiber Ferrule and Connector Technology**
Mr. Darrell Childers, Vice President of Development, US Conec

10:25 **Break**

SESSION VII: MONOLITHIC INTEGRATION

ULSI INTEGRATION OF SIPH ICS WILL BE NECESSARY TO ACHIEVE COST TARGETS. INTEGRATION MUST BE COST-EFFECTIVE, BALANCING ULSI AGAINST MULTI-VENDOR DEVICE AVAILABILITY AND SIP ASSEMBLY.
Session Chair: Mr. Bill O'Mara, Advanced Technology Development, Analog Devices

10:40 **TWG Report: Monolithic Photonic Integration**
Dr. Jurgen Michel, Senior Research Scientist, MIT Microphotonics Center

10:45 **Silicon Photonics for Coherent Communications: Design for Manufacturing**
Dr. Christopher Doerr, Director of Photonic Integration, Acacia Communications

11:05 **Silicon Photonics for Future Systems: A University Project**
Prof. Graham T. Reed, Professor, University of Southampton

11:25 **Panel Discussion - Silicon Photonics: An Industry Roadmap**
Panel Chair: Prof. Kazumi Wada, Professor, University of Tokyo

11:45 **Attendee Lunch**

12:45 **Technical Working Group Breakouts and Reports**

2:45 **Conference Summary**
Prof. Lionel C. Kimerling, Director, MIT Microphotonics Center

3:00 **Adjourn**

AIM PHOTONICS INSTITUTE MEETING
PSMC ROADMAP RELEASE
MIT MICROPHOTONICS CENTER FALL MEETING

December 7-8, 2015

BY INVITATION ONLY

IMPLEMENTING PHOTONIC INTEGRATION

SUNDAY, DECEMBER 6

12:30p **Registration**

1:00-5p **Short Courses** *(Chipman Room 6-104)*

Integrated Silicon Photonics, Jurgen Michel, MIT

Photonic Design Automation, Robert Scarmozzino, Synopsys

MONDAY, DECEMBER 7

8:15a **Registration and Light Breakfast**

9a-12p **Technical Session1: Photonic System Manufacturing Roadmap**

Final Report and Document Release: 6 Technical Working Groups

12-1:30p **Attendee Lunch** *(Winter Garden)*

Microphotonics Center Industry Consortium Board Meeting *(Silverman Skyline)*

1:30-3p **Technical Session 2: Integrated Photonic Design Automation**

Session Chairs: G Lamont, Cadence; P Dumon, Luceda; M Watts, MIT

3-5p **Roadmap Workshop** *(Winter Garden)*

Joint meetings of the AIM and PSMC TWGs

5:30p **Networking Reception and Poster Session** *(Winter Garden)*

TUESDAY, DECEMBER 8

8:15a **Registration and Light Breakfast**

9-11a **Technical Session 3** *(MPR Room)*

Industry Reports

Needs and Barriers: Leading Users, OEMs and Component Suppliers

11a-12p **Technical Session 4** *(MPR Room)*

AIM Photonics: Vision for Manufacturing Excellence

Application Drivers and Manufacturing Technology

12-1:30p **Attendee Lunch** *(Winter Garden)*

1:30-4p **AIM Photonics Institute Executive Meeting** *(Silverman Skyline)*

1:30-5p **Professional Development Sessions and Breakouts** *(Chipman Room 6-104)*

Workforce Needs and Solutions: Industry, Faculty and Students