Needs of the Integrated Photonics Industry in Central Massachusetts

An Interactive Qualifying Project
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by
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Abstract

The purpose of this project was to provide information on the status of the integrated photonics industry in Massachusetts in light of the creation of WPI's Integrated Photonics Laboratory for Education and Application Prototypes (LEAP@WPI/QCC) facility. This LEAP was created to service the emergent integrated photonics industry in the Massachusetts area. Following interactions with stakeholders in the industry at the LEAP's inaugural Integrated Photonics Symposium at WPI, we surveyed a broad array of companies with an interest in different aspects of the industry such as fabrication, packaging, and workplace education to determine the various needs associated with the different sectors of the industry. We combined this information with an analysis of current technologies based on current and relevant academic literature to provide a snapshot of the current strengths and needs of the industry for its development in the near future. Based on this information, a set of supporting information and recommendations for the operation of the LEAP@WPI/QCC facility are presented.

Acknowledgements

Our team would like to thank Professor Jacob Longacre of Quinsigamond Community College (QCC) along with the other QCC faculty involved for providing us a tour of the physics- and optics-related facilities and equipment on the QCC campus and providing us information about the integrated photonics industry.

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Executive Summary

Emerging at the cross section of photonics research and integrated circuit technology is a new industry dedicated to the development of photonic integrated circuit (PIC) technology. Such technology uses light for the transfer of information where electricity would traditionally be used via intricate, microscopic optical circuitry [1]. This has the potential to improve performance, lower latency, and decrease costs in certain areas such as signal transmission and sensing. This field was one of fourteen areas identified in 2014 by the Manufacturing USA initiative for funding by public-private partnership. The American Institute for Manufacturing Integrated Photonics (AIM Photonics), a foundry dedicated to integrated photonics manufacturing located in Rochester, New York, was selected as a member institute of the Manufacturing USA initiative [1]. AIM Photonics Academy (AIM Academy), established in 2016, is the education, workforce development, and roadmap arm of AIM photonics located Cambridge, Massachusetts [2]. In support of AIM Photonics and AIM Academy, three Labs for Education and Application Prototypes (LEAPs) have been established in Massachusetts along the I-90 corridor using funding from the Commonwealth of Massachusetts' M2I2 program [3]. These LEAPs include specialized equipment for integrated-photonics-related prototyping along with education and workforce-training resources [3]. One such LEAP has been established at WPI's Gateway Park II in partnership with Quinsigamond Community College. In this Interactive Qualifying Project, we provide information on the status of the integrated photonics industry in Massachusetts in light of the creation of WPI and QCC's Integrated Photonics Laboratory for Education and Application Prototypes (LEAP@WPI/QCC) facility. The project was initiated prior to the completion of LEAP's construction, and sought to provide recommendations for the LEAP's focuses moving forward.

In order to provide this information and make recommendations, several analyses relating to the industry were conducted. First, our group attended the LEAP@WPI/QCC's inaugural symposium held at WPI on September

18th, 2018. This symposium gathered representatives from area companies and academic institutions to view information about the LEAP and the greater industry, as well as to gather in break-out groups to discuss the issues most pertinent to their interests. After hearing from the speakers at the symposium, our IQP group divided amongst the breakout groups to take notes on the ensuing discussions. Next, using research on the current state of the integrated photonics industry in the region and analysis of notes taken at the symposium, a survey was created to query companies in the Massachusetts area about several aspects of their involvement in the emergent industry. We collected these survey responses with the intention of suggesting optimizations to the resources used and provided by the LEAP@WPI/QCC facility. Finally, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis was conducted regarding the worldwide integrated photonics industry. In this analysis, existing literature relating to the field was reviewed and and sources of funding were identified. The goal was to clearly outline possible areas for growth as well as potential issues within the industry. A summary of the procedures and findings used in each of these analyses is presented below.

Integrated Photonics Symposium Breakout Session Analysis

Following analysis of the notes taken at the inaugural symposium at WPI, we gauged the main interests and concerns of attendees. Additionally, we used this information to inform the questions asked on the survey discussed below. On the topic of photonics education in the current workforce, we found representatives leaned towards the idea of broadening the education relating to the photonics industry. While many companies are aware of the industry, it is an issue that companies and their employees are often not familiar with the subject. Regarding the future of photonics, one representative stated that participation in the industry "requires looking ahead, but legacy equipment will always exist. Additive manufacturing could transform the path ahead tremendously." Another concern was that not enough of the education is focusing on current, practical applications. We found uncertainty stemmed from the idea that students preparing for the workforce are learning material that has the potential to be outdated in the near future. One representative explained, "students are already working with optics, but this is like training for a job that doesn't exist yet." Regarding student training, there is also uncertainty involving the technology they are using because in some cases, the technology is touchless; in some cases, students may need to worry more about programming than circuitry. Meanwhile, some representatives felt that a particular area of the field such as circuit testing was a more certain area for employment prospects. A final question posed was "who is being educated?" Are the students who would benefit from education via the LEAP future engineers, physicists, factory workers, or something else entirely? This question can be partially answered by taking a look at what companies are interested in the field and the types of people they employ. On the whole, the largest interest among representatives was in education. This is likely due to the academic nature of the symposium. However, their concerns are broadly applicable to the field since the direction of the industry informs the requirements of engineering educators.

Involvement and Interests Survey of Area Photonics-Related Companies

Following research on the industry and analysis of the sentiments conveyed by industry stakeholders at the symposium described above, we created a survey which was sent to sixty-nine area companies we identified as being in some way related to the photonics ecosystem. From the results of this survey, we inferred that the companies most interested in the LEAP@WPI/QCC are companies that are involved with manufacturing, while engagement elsewhere in the supply-chain is more ambiguous. Of the companies that selected manufacturing, the majority also indicated they would be most interested in development collaboration and equipment access and use. This is important because this means that companies will come to the LEAP facility, working together to design and innovate new technology, perhaps with a focus on product development. Regarding business/academic relationships, companies appeared to be interested in working with academic institutions. We found respondents were split between desires for sharing resources and desires for technology co-development. Respondents tended to have interacted with academic institutions before, through co-ops, internships, and various other programs. However, the information shows that a minority directly develop technology with these academic institutions. The split in interest can shed light on a market for co-development between businesses and academic institutions. A notable aspect of the data is that none of the companies chose training as an option. This is interesting because it is expected that companies want their workers to be sufficient in the crafts. This lack of interest can be credited to the possibility that the companies that filled out our survey have training resources at their own locations. When in collaboration with other companies at the LEAP facility, we suspect that certain companies and workers will attempt to seek training from the facility. Future work could attempt to gauge the interests of workers themselves rather than focusing only on company leadership personnel.

SWOT Analysis of the Integrated Photonics Industry

Finally, we conducted a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis on the integrated photonics industry globally to help frame the placement the LEAP@WPI/QCC in the industry as a whole. Through this analysis, we found significant future potential for the industry. We predict that the likelihood of need for training and prototyping from a facility like the LEAP at WPI will increase as the industry moves forward. However, issues such as the production of on-chip lasers and efficient waveguides are likely to delay the widespread adoption of PIC technology in the near future. This does not prevent the facility from being useful for prototyping of flip-chip and edge-coupled technologies, nor does it prevent the

LEAP@WPI/QCC from assisting in the development of improved laser and waveguide technologies.

Recommendations

In conclusion, we identified concerns from industry stakeholders regarding what skills and technologies should be taught to prepare future workers in the industry. While uncertainty about the future of the industry makes planning somewhat difficult, it also provides an opportunity for the LEAP@WPI/QCC to emerge at the forefront of integrated-photonics-related education. In order to plan for and accomidate the rapidly changing nature of the industry, we recommend that the LEAP@WPI/QCC focus on open communication with industry leaders as they make progress on PIC technology so that the facility is prepared to adapt as the technology evolves. This can be done through co-development and project partnerships as well as industry events, for which we have identified significant interest among industry stakeholders. Finally, we recommend that the LEAP@WPI/QCC focuses on the market for collaboration with academic institutions through the creation of academic projects such as Major Qualifying Projects in partnership with photonics-related businesses. These types of projects will open the door to academic-industry collaboration while allowing the LEAP to keep up-to-date with changes in the industry as they occur.

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1 Introduction

Emerging at the cross section of photonics research and integrated circuit technology is a new industry dedicated to the development of photonic integrated circuit (PIC) technology. Such technology uses light for the transfer of information where electricity would traditionally be used via intricate, microscopic optical circuitry [1]. This has the potential to improve performance, lower latency, and decrease costs in certain areas such as signal transmission and sensing. This field was one of fourteen areas identified in 2014 by the Manufacturing USA initiative for funding by public-private partnership. The American Institute for Manufacturing Integrated Photonics (AIM Photonics), a foundry dedicated to integrated photonics manufacturing located in Rochester, New York, was selected as a member institute of the Manufacturing USA initiative [1]. AIM Photonics Academy (AIM Academy), established in 2016, is the education, workforce development, and roadmap arm of AIM photonics located Cambridge, Massachusetts [2]. In support of AIM Photonics and AIM Academy, three Labs for Education and Application Prototypes (LEAPs) have been established in Massachusetts along the I-90 corridor using funding from the Commonwealth of Massachusetts' M2I2 program [3]. These LEAPs include specialized equipment for integrated-photonics-related prototyping along with education and workforce-training resources [3]. One such LEAP has been established at WPI's Gateway Park II in partnership with Quinsigamond Community College.

The Laboratory for Education and Application Prototypes at Worcester Polytechnic Institute and Quinsigamond Community College (LEAP@WPI/QCC) facility is a prototyping laboratory and educational center for partners working in the emergent integrated photonics industry in Massachusetts to conduct research, use equipment, and participate in training and education. This IQP was initiated prior to the completion of LEAP's construction. The purpose of the project was to gather information from companies and partners interested in the LEAP@WPI/QCC facility in order to help inform the types of services on which the LEAP should focus to accommodate the wants and needs of facility partners. Additionally, this project sought to gather information on the status of emergent technologies and initiatives within the existing integrated photonics industry globally in order to paint a clear picture of where the LEAP@WPI/QCC fits in the industry as a whole.

The first step taken by our group was to attend the LEAP@WPI/QCC's inaugural symposium held at WPI on September 18th, 2018. This symposium gathered representatives from area companies and academic institutions to view information about the LEAP and the greater industry, as well as to gather in break-out groups to discuss the issues most pertinent to their interests. After hearing from the speakers at the symposium (see Appendix C for agenda), our IQP group divided amongst the breakout groups to take notes on the ensuing discussions. The analysis of these notes can be found in Section 2. This analysis was used to inform our next step, a survey sent to sixty-nine area companies which we identified as being potentially related to the integrated photonics industry.

Following research on the current state of the integrated photonics industry in the region and attendance of the symposium outlined above, a survey was created to query companies in the Massachusetts area about several aspects of their involvement in the emergent industry. We collected these survey responses with the intention of suggesting optimizations to the resources used and provided by the LEAP@WPI/QCC facility. For example, many of the resources provided by the facility can be divided into (1) materials and equipment relating to integrated photonics fabrication, and (2) education and training resources. The results of this survey could be used to help determine the portion of resources that should be allocated between these categories of services. An in-depth analysis of the results of this survey can be found in Section 3, and the complete survey can be found in Appendix B.

Finally, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis was conducted regarding the worldwide integrated photonics industry. In this analysis, existing literature relating to the field was reviewed and and sources of funding were identified. The goal was to clearly outline possible areas for growth as well as potential issues within the industry. The conclusions drawn from this research are presented in Section 4.

2 Integrated Photonics Symposium Breakout Session Analysis

In September of 2018, our school hosted the LEAP@WPI/QCC's inaugural Integrated Photonics Symposium to which representatives from photonics-related companies in the Massachusetts area attended. A full list of invited attendees can be found in Appendix E. This symposium was used as a means to gauge interest in the LEAP@WPI/QCC facility and provide a way for photonics companies to collaborate. At the end of the symposium, the guests were broken off into discussion groups. Members of our IQP sat in with the groups to take notes. Our findings based on these notes are discussed below.

On the topic of photonics education in the current workforce, representatives leaned towards the idea of broadening the education of photonics within the industry. While many companies are aware of the industry, it is an issue that companies and their employees are often not familiar with the subject. Regarding the future of photonics, one representative stated, "Requires looking ahead, but legacy equipment will always exist. Additive manufacturing could transform the path ahead tremendously." This statement helped form our questions for how companies would make use of the LEAP@WPI/QCC facility. In using the LEAP facility, we expect that companies with substantial knowledge of photonics will use their resources to better familiarize their peers through employee training and collaborative work with other institutions. Another concern is that not enough of the education is focusing on current, practical applications. The argument for this is that the conceptual aspects of photonics are widely known, meaning that it is potentially more beneficial for students to focus on applying practical technology.

Concerns of uncertainty can be partially addressed by finding what is in demand. We found uncertainty stemmed from the idea that students preparing for the workforce are learning material that has the potential to be outdated in the near future. One representative explains, "Students are already working with optics, but this is like training for a job that doesn't exist yet." Regarding student training, there is also uncertainty involving the technology they are using because in some cases, the technology is touchless; in some cases, students may need to worry more about programming than circuitry.

Some representatives felt that a particular area of the field such as circuit testing was a more certain area for employment prospects. Ideas such as these can be informed by the results of survey questions relating to where a company fits in the supply chain. A high concentration of responses in a particular area may indicate large employment potential for certain areas over others.

Another question asked by a representative was "who is being educated?" Are the students who would benefit from education via the LEAP future engineers, physicists, factory workers, or something else entirely? This question can be partially answered by taking a look at what companies are interested in the field and the types of people they employ. For instance, if most respondents are involved in theory, perhaps physicists would be the most in demand.

On the whole, the largest interest among representatives was in education. This is likely due to the academic nature of the symposium. However, their concerns are broadly applicable to the field since the direction of the industry informs the requirements of engineering educators. As a result, the questions and opinions of representatives at the symposium informed our choices about the questions to ask on the survey of companies.

3 Involvement and Interests Survey of Area Photonics-Related Companies

3.1 Methodology

A survey was constructed to determine the type of companies who may be interested in the LEAP@WPI/QCC facility and the services they will require. The questions posed on the survey were informed by analysis of the notes taken at the Symposium. The survey was made using Qualtrics and was sent to sixty-nine area companies which we identified as being potentially related to the integrated photonics industry. Opened on April 16th, 2019, and closed one month later, ten companies (15%) responded to the survey, and their responses are analyzed below. A full list of the companies contacted for the survey can be found in Appendix A. Companies received the survey via email. Additionally, those addressed were provided with our contact information in case of any questions or concerns. The complete survey can be found in Appendix B.

Users of the LEAP@WPI/QCC will require different tools and services depending upon several factors. The area of involvement in the supply chain determines the general type of tools that will be required by a company. Further, the changing landscape of technological field, as identified through research using existing academic papers (see Section 4), will require an evolving toolset. At the same time, this will provide further opportunities for company involvement. As a result, the survey explores both areas represented in the supply chain and strategies used by businesses to adapt to change.

To create the questions, feedback was examined from the Integrated Photonics Symposium's break-out groups, as well as notes from attending follow-up meetings with faculty at Quinsigamond Community College. These notes provided insight into what sort of concerns and interests are currently prevalent within the field of integrated photonics.

Question one asks the respondent to state their company and their role in the company. While the results are ultimately anonymized, this question was meant to give us an idea of the type of experience common among respondents. Questions two through six relate to their company's involvement with the photonics industry and related fields. In these questions, we ask where their company stands in the ecosystem, where it is in the supply chain, and how their company works with other companies or institutes. Through these questions, we gain information relating to how respondents can utilize the LEAP@WPI/QCC facility's tools and services.

Questions seven and eight relate to how the respondent's company adapts to a rapidly changing market. Since many of these companies are not yet directly involved with the integrated photonics industry, strategies to adapt will be needed during the adoption of future integrated photonic technology. Additionally, due to the emergent nature of the market, even those companies which are already involved in the field are expected to see rapid change in technologies.

The last question asks the respondent if there is anything that we did not ask previously that should be asked in the future. With any questions that are provided, we gain insight on what types of questions are the most relevant in the industry today. A full transcript of the survey is provided in Appendix B.

3.2 Analysis

3.2.1 Placement in the Photonics Ecosystem

During our survey, we asked respondents what their position or role was in the photonics ecosystem. Their options were between manufacturing, utilization, and packaging. Of the responses, none of the companies were a part of the packaging aspect of the ecosystem. 30% of the group said that they're apart of manufacturing and utilization. The remaining 70% opted for other. In the group that provided other, there were two companies that distributed photonics products, while the others did not specify their role.

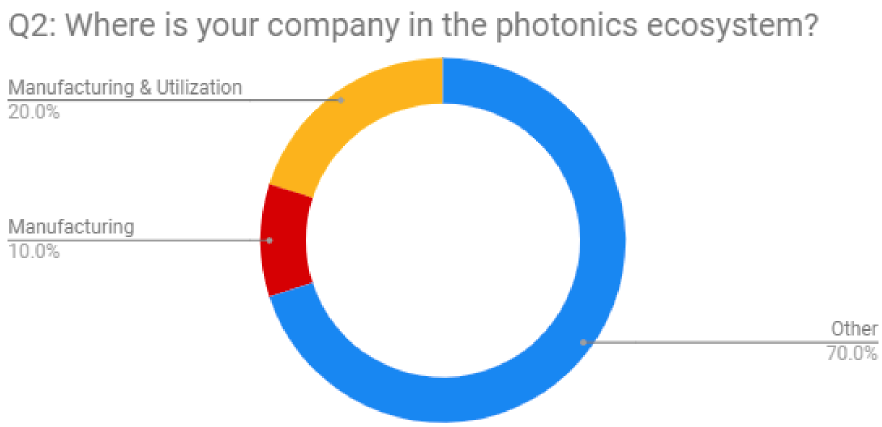

Figure 1: Placement of Respondents within the Photonics Ecosystem

3.2.2 Placement in the Supply Chain

As shown in Figure 2, two-thirds of respondents are directly involved in the production of photonic equipment. The striking part of this data stems from the lack of respondents who are involved in the category we labeled “information” which was intended to encompasses the educational side of the industry. Those who felt compelled to complete the survey tended to be directly involved with production. This is in contrast to the portion who self-identified as being directly involved in manufacturing as shown in Figure 1. These companies can be accounted for by those who identified as ”other” in 1. These companies would likely also be involved in other aspects of the industry such as workforce training and education. Although companies were allowed to select multiple responses, we suspect respondents typically only selected the single field most pertinent to their operations. This fact paired with any confusion around the differences between categories could account for the discrepancy. Also of note is the lack of any respondents involved with planning, inventory, location, transportation, or return of goods. These categories, along with information, likely operate in a high number of fields and thus may be less likely to identify as “photonic-related” companies. While these companies may produce photonics equipment, it is a sec-

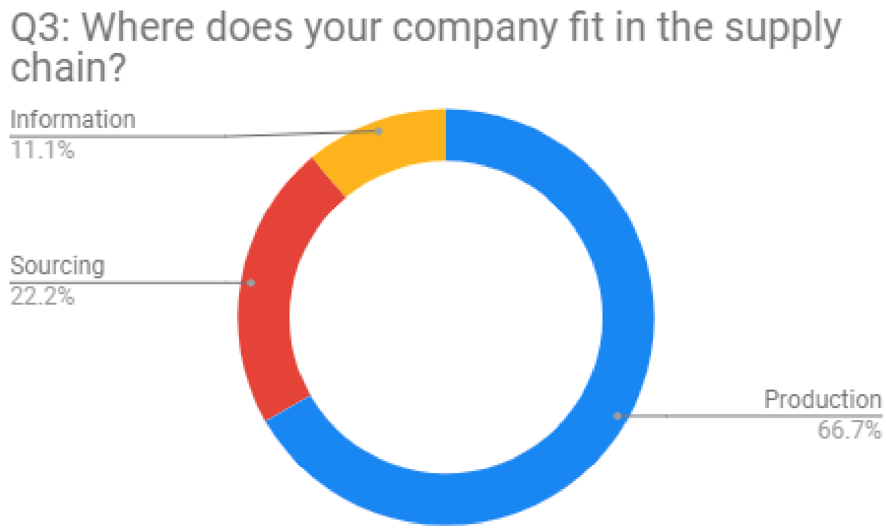

Figure 2: Placement of Respondents within the Supply Chain

tion of their manufactured equipment, making them a broad manufacturing company.

3.2.3 Level of Involvement

Most respondents (70%) considered themselves to be "very involved" or "extremely involved" with photonics as shown in Figure 3. This makes sense due to the fact that companies we sought out were in some way associated with the industry. This information fits well with the distribution of supply chain placement categories found in Question 3–those involved with production likely consider themselves to be most involved with the overall industry.

3.2.4 Relationship with Academic Institutions

As shown in Figure 4, sixty percent of respondents stated that they primarily worked with academic and regional institutions through the sharing of resources. This could include the sharing of equipment, facilities, and teaching resources. Within the LEAP@WPI/QCC facility, this type of company may be most interested in renting hours on equipment or classrooms.

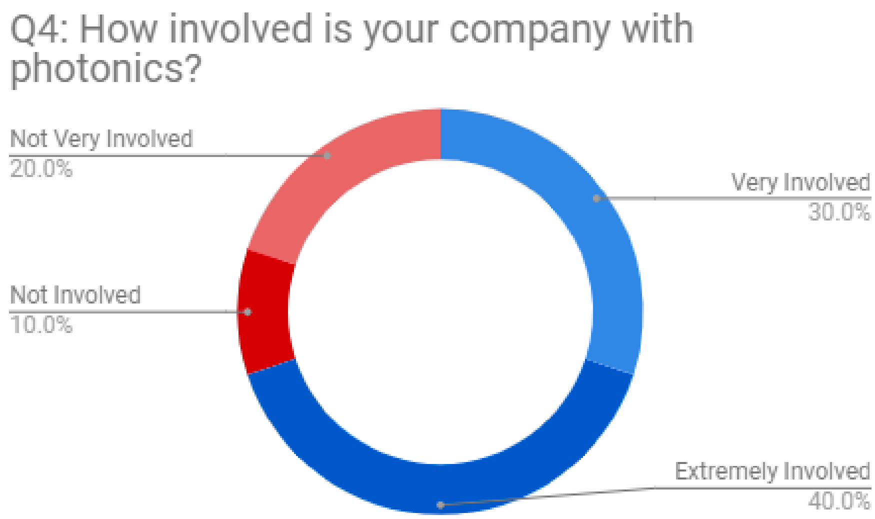

Figure 3: Level of Involvement of Respondents with the Industry as a Whole

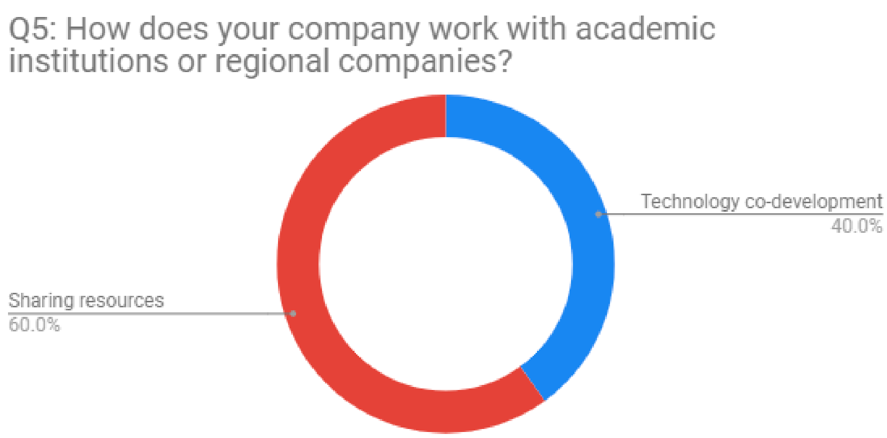

Figure 4: Relationship of Respondents with Academic Institutions

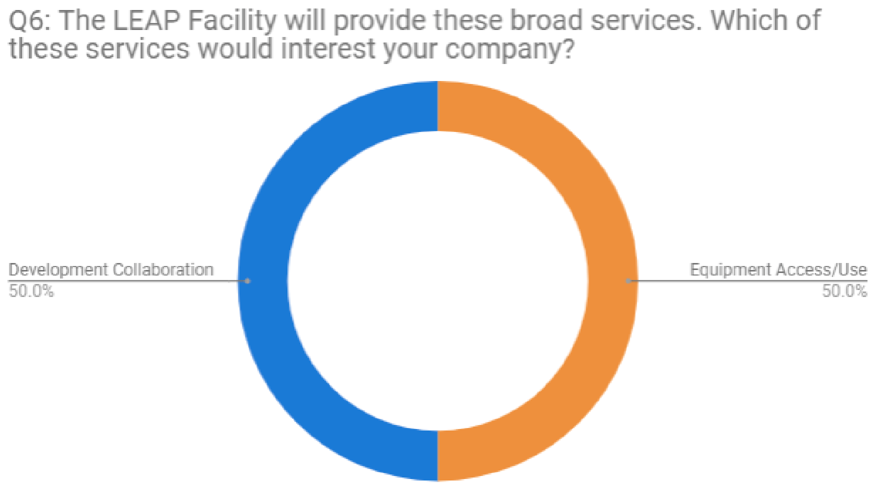

Figure 5: LEAP Facility Services Desired by Respondents

Meanwhile, a substantial minority (forty percent) of respondents said that they interacted with academic institutions through technology co-devlopment. For the LEAP@WPI/QCC to accommodate these companies, more direct involvement by WPI and QCC students and faculty is required. Beyond simply renting resources, we expect these companies to desire close collaboration on the research being conducted, with intellectual property ownership perhaps being split between institutions for true co-development.

3.2.5 Desired Services

The question posed in Figure 5 is very similar to that of Figure 4. However, rather than relying on the typical relationship of a company to other institutions in general, this question asks specifically what type of services might be used at LEAP@WPI/QCC. When provided with the LEAP Facility, the data from Figure 5 indicates that companies will use our facilities equally for development collaboration and equipment access. This inference can be drawn up because of the 50/50 split between the group. The proportion of companies seeking development collaboration at the facility per this question is slightly higher than the proportion indicated by the previ-

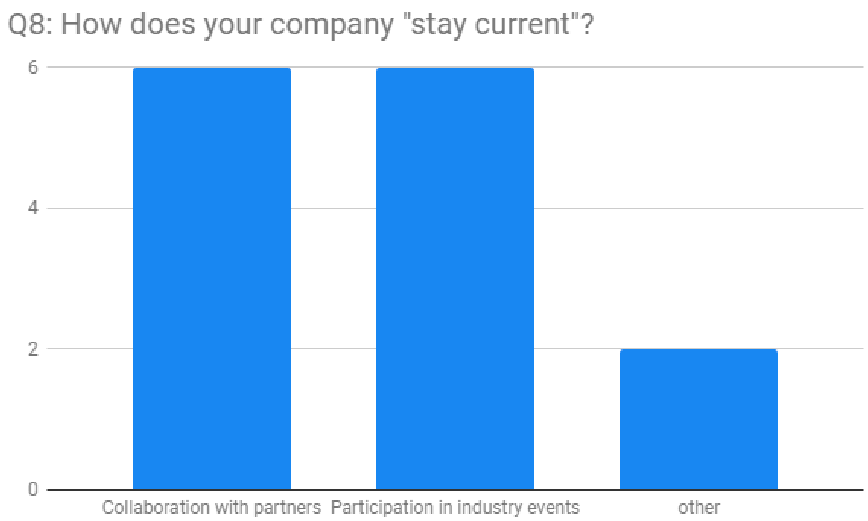

Figure 6: Adaptation Strategies Used by Respondents

ous question. This could be due to the phrasing of the questions, or could imply that at least one company plans to use the LEAP facility differently than its typical interactions with other institutions. Future work could attempt to further clarify this distinction. It should also to be noted that none of the groups chose training as an option. This may be due to the training resources that companies have at their own facilities. This is in contrast to the interests expressed in Section 2, where education was a priority.

3.2.6 Adaptation Strategy

An equal number of "collaboration with partners" and "participation in industry events" responses were provided for the question of how companies are able to stay current. Usage of the LEAP would qualify as "collaboration with partners," while participation in the Integrated Photonics Symposium would qualify as "participation in industry events". Thus, these responses indicate that companies may be used to and interested in the types of collaboration offered by WPI and QCC.

4 SWOT Analysis of the Integrated Photonics Industry

In addition to assessing the needs of companies involved in the photonics industry, we studied the current state of the industry globally via analysis of recent academic papers and other publications. We categorized current efforts and discoveries in the industry into four categories: strengths, weaknesses, opportunities and threats (SWOT).

4.1 Strengths

Among the strengths of the industry we identified was significant academic interest in emerging integrated photonic technology. For instance, the International Conference on Group IV Photonics convenes yearly to "deliver insight on current and future innovations on Group IV element-based photonic materials and devices, including silicon photonics..." [4]. The group has met sixteen years running. There is also tremendous government interest in the field. The European Union funded the Silicon Heterostructure Intersubband Emitter (SHINE) program in 2004 [5]. Meanwhile, the US Air Force Office of Scientific Research has funded a three-year project for room-temperature electrically-pumped 1.55 micrometer silicon lasers–a potentially important aspect of future integrated-photonic chips. Significantly, DARPA made investment in the industry via its Electronic and Photonic Integrated Circuits (EPIC) program [5]. The program's stated goal is the monolithic integration of photonic and electronic circuits in silicon, making it one of the most directly significant programs to the industry [6]. Lastly, significant headway has already been made in industry. 100Gb/s transceiver technology has been realized and shipped by multiple companies for the data center industry and has shown commercial success [7]. The AIM Photonics consortium to which the LEAP@WPI/QCC is connected to and the Commonwealth of Massachusetts' M212 program which provides funding are further examples of government interest and long-term funded initiatives in the field.

4.2 Weaknesses

Despite significant investment in the industry by academic, government, and corporate institutions, the integrated-photonic industry harbors significant weaknesses at this point in time. The most obvious weakness is the heightened complexity of fundamental integrated-photonic circuitry compared to CMOS technology [8]. Significant work remains to be done for the development of improved manufacturing processes of this circuitry. Furthermore, modern waveguide technology can in some cases leave much to be desired [4]. Another issue stems from the duality between development of telecom-focused photonic integrated circuit (PIC) technology and technology targeted at sensing and spectroscopy [8]. Although both benefit significantly from this technology, devices in the different categories tend to require different wavelength bands. While applications of PIC technology are being realized in fields such as communications, a long term strategy for investment and development in other fields requires further development.

4.3 Opportunities

We identified potential opportunities for the improvement of waveguide technology via accumulated self-focusing of ultraviolet light in silica glass as described in [9]. The lab explored the creation of permanent waveguide microchannels in silica glass using multiple accumulated pulses of light. Such technology could have a significant effect on the feasibility of difficult waveguide manufacturing. Current electron-beam lithography methods also see the potential for refinement [10]. The LEAP@WPI/QCC could partner with industrial organizations for collaborative research in these fields as well as solicit recommendations for toolsets related to these technologies as they are refined.

4.4 Threats

The integrated photonics industry sees a threat from the fact that 2.5D and 3D integration continues to be preferred over direct integration with CMOS circuits since photonic processes are difficult in modern electronic node sizes [7]. Furthermore, production of on-chip power-efficient lasers is currently expensive. Generally, lasers are flip-chip attached or edge-coupled. This could lead to a preference for these integration methods for the foreseeable future, although it could be remedied by improved silicon-on-insulator technologies [7]. The competition between these routes has the potential to cause setbacks as one route begins to overtake the other if significant investment is made in only one technology. As a result, the LEAP could focus on synergistic support of both technologies in order to stay relevant moving forward.

5 Conclusions and Recommendations

The purpose of this project was to gauge the interest of the companies in the Massachusetts area to gain an understanding of how potential partners will utilize the LEAP@WPI/QCC facility. Using the data from the survey, it can be inferred that the companies most interested in the LEAP@WPI/QCC are companies that are involved with manufacturing, while engagement elsewhere in the supply-chain is more ambiguous. Of the companies that selected manufacturing, the majority also selected the options for development collaboration and equipment access/use. This is important because this means that companies will come to the LEAP facility, working together to design and innovate new technology, perhaps with a focus on product development.

Regarding business/academic relationships, companies appeared to be interested in working with academic institutions. Shown earlier in Figure 4 and Figure 5, companies were split between sharing resources and tech co-development. Companies have interacted with academic institutions before, through co-ops, internships, and various other programs. However, the information shows that the minority directly develops technology with these academic institutions. The split in interest can shed light on a market for co-development between businesses and academic institutions. We recommend that the LEAP@WPI/QCC focuses on this market through the creation of academic projects such as Major Qualifying Projects in partnership with photonics-related businesses.

A notable aspect of the data is that none of the companies chose training as an option. This is interesting because it is expected that companies want their workers to be sufficient in the crafts. This lack of interest can be credited to the possibility that the companies that filled out our survey have training resources at their own locations. When in collaboration with other companies at the LEAP facility, we suspect that certain companies and workers will attempt to seek training from the facility.

The SWOT analysis we performed for the industry indicates significant future potential. We predict that the likelihood of need for training and prototyping from a facility like the LEAP at WPI will increase as the industry moves forward. However, issues such as the production of on-chip lasers and efficient waveguides are likely to delay the widespread adoption of integrated photonics technology for the near future. This does not prevent the facility from being useful for prototyping of flip-chip and edge-coupled technologies, nor does it prevent the LEAP@WPI/QCC from assisting in the development of improved laser and waveguide technologies. As a result, we recommend that the LEAP@WPI/QCC focus on open communication with industry leaders as they make progress on PIC technology so that the facility is prepared to adapt as the technology evolves. This can be done through co-development and project partnerships as well as industry events, for which we have identified significant interest among industry stakeholders.

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Appendix A List of Sixty-Nine Companies Contacted for Survey

A&M Tool & Die Co. Inc.
A.M.F. Optical Solutions LLC
Acton Research Corporation
Advance Reproductions Corp.
Aerovox Inc.
Amptek Inc.
Analogic DCP
Antron Engineering and Machine
Applied Analytics Inc.
Artel Video Systems Inc.
Associated Environmental Systems
AST Products Inc.
Barr Associates Inc.
Bascom-Turner Instruments Inc.
Bauer Associates Inc.
Berkshire Corp.
Bern Optics Inc.
Bomco Inc.
Boston Electronics Corp.
Boston University
Bruce Diamond Corp.
CableLAN Products Inc.
Segue Manufacturing Services
Cambridge Isotope Laboratories Inc.
Cambridge Technology Inc.
Capacitec
CardioFocus
CeramOptec Inc.
Chomerics

Cognex Corp.
Control Engineering Inc.
Control Resources Inc.
CoreTek Inc.
Corning Applied Technologies
CTC Inc
Design Technology Corp.
Diamond USA Inc.
Dielectric Sciences Inc.
Dolan-Jenner Industries Inc.
DYNAMICS RESEARCH CORP.
E. McGrath Inc.
ETEC Inc.
Fiber Optic Center Inc.
Fiberoptic Components Inc.
Fibersense Technology Corp.
Fibertech
Gigaband Corp
Hardric Laboratories Inc.
Holographix Inc.
INCOM Inc.
Innovations in Optics Inc.
InPhotonics Inc.
International Light Inc.
Kinetic Systems Inc.
Kolmar Technologies Inc.
Louis Rudzinsky Associates
McPherson Inc.
Corning NetOptix Inc.
NEF Inc.
Fiber Optic Center
Nye Lubricants

OPCO Laboratory Inc.
Optikos Corporation
Optimark
Dynasil Optometrics
Pegasus Glassworks Inc.
Cognoptix
Fiber Optic Association
New England Optical Systems

Appendix B Transcript of Survey Provided to Companies

IQP Survey (Integrated Photonics)

Start of Block: Default Question Block

Q1 Please share your employer and your job title.

- ○ Company (1) ____
- ○ Position (2) ____

Q2
Where is your company in the Photonics ecosystem?

- ☐ Manufacturing integrated photonics products (1)
- ☐ Utilizing manufactured photonics products (2)
- ☐ Packaging products (3)
- ☐ Other (4) ____

Q3 Where does your company fit in the supply chain?

- ○ Planning (1)
- ○ Information (2)
- ○ Sourcing (3)
- ○ Inventory (4)
- ○ Production (5)
- ○ Location (6)
- ○ Transportation (7)
- ○ Return of Goods (8)

Q4 How involved is your company with photonics?

- ○ Extremely Involved (1)
- ○ Very Involved (2)
- ○ Moderately Involved (3)
- ○ Not Very Involved (4)
- ○ Not Involved (5)

Q5 How does your company work with academic institutions or regional companies?

- ○ Sharing resources (e.g. funding, supplies, information) (1)
- ○ Technology co-development (2)
- ○ Co-development of industry courses and training (3)

Q6 The LEAP will provide these broad services, which might your company be interested in (select all that apply)

- ☐ Training (1)
- ☐ Equipment Access/Use (2)
- ☐ Development Collaboration (3)

Q7 How does your company adapt to market change/ new technologies?

____
____
____
____
____

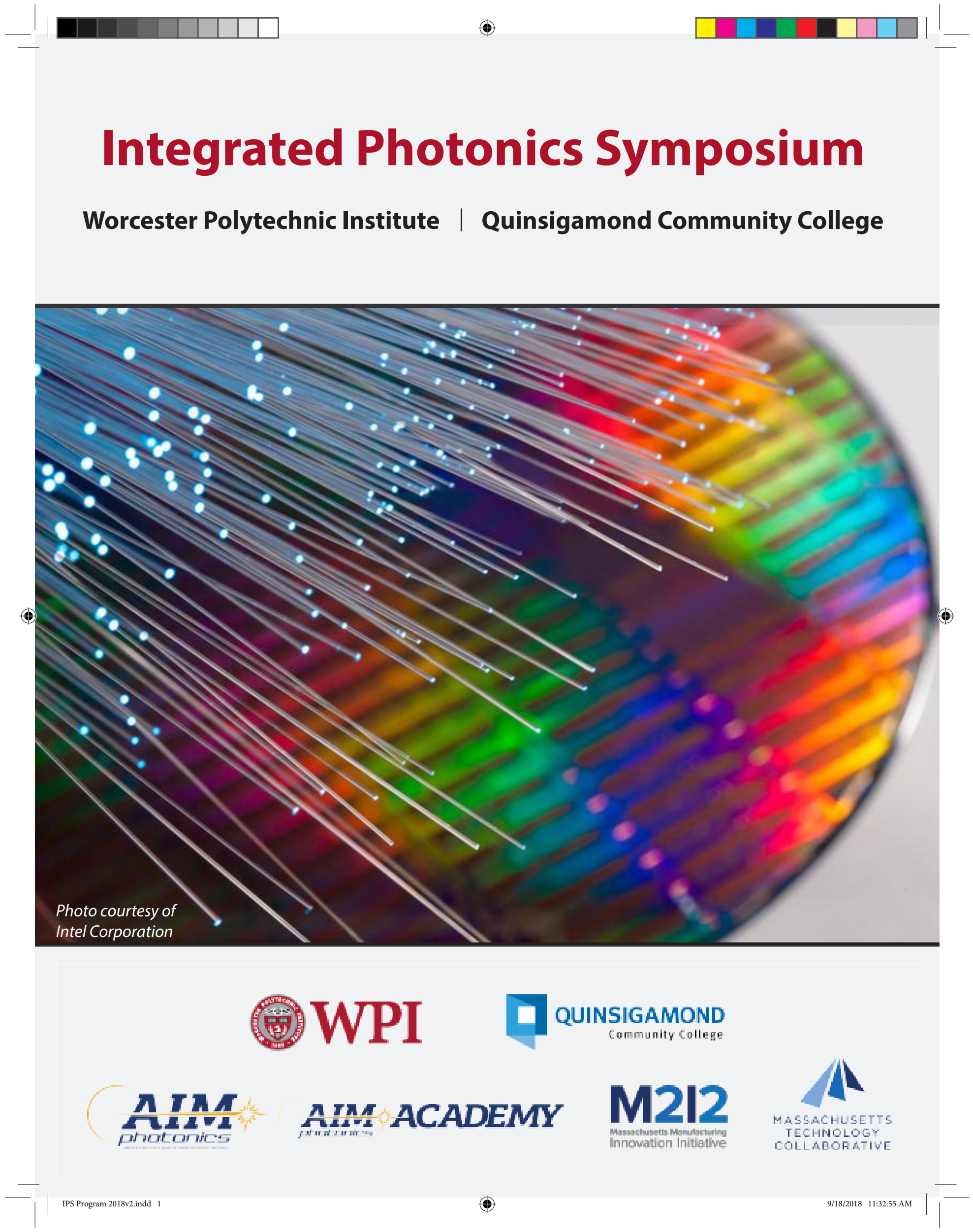
Q8 How does your company "stay current"?

- ☐ Collaboration with partners (1)
- ☐ Participation in industry events (e.g. Symposium) (2)
- ☐ other (3) ____

Q8 What has not been asked here that should be asked in the future?

____
____
____

Appendix C Integrated Photonics Symposium Program, September 2018



AGENDA

9:00 am: Welcome Remarks
Winston Soboyejo, *Provost, Worcester Polytechnic Institute* and Luis Pedraja, *President, Quinsigamond Community College*

9:15 am: Academic and Corporate Engagement
Rachel I. LeBlanc, *Assistant Vice President, Academic and Corporate Engagement, Worcester Polytechnic Institute*

9:30 am: Introduction - The WPI/QCC Vision
Bogdan Vernescu, *Vice Provost for Research, Worcester Polytechnic Institute* and Kathy Rentsch, *Assistant Vice President for Workforce Readiness and Innovation, Quinsigamond Community College*

9:50 am: AIM Photonics Overview
Michael Liehr, *CEO, AIM Photonics*

10:20 am: Break

10:35 am: Future of Integrated Photonics
Michael Watts, *President and CEO, Analog Photonics* and Sajan Saini, *Education Director, AIM Photonics Academy*

11:30 am: Government Panel
Moderator: Ira Moskowitz, Director, *Advanced Manufacturing Programs, Massachusetts Technology Collaborative* Brian Kimball, *Soldier Protection and Survivability Directorate, U.S. Army Natick Soldier; Reserach Development and Engineering Center*; Cheryl Sorace-Agaskar, *Technical Staff, MIT Lincoln Laboratory*; and Nicholas Usechak, *Director of the Ultrafast Photonic Devices and Research Laboratory, Air Force Research Laboratory*

12:30 pm: Lunch/Student Panel
Moderator: Anu Agarwal, *Principal Research Scientist, AIM Photonics Academy*
Gerald Gagnon, *Springfield Technical Community College*; Alex Medeiros, *Electronic Photonic Test Engineer, MIT Lincoln Laboratory, Bridgewater State University*; Erin Morissette, *Worcester Polytechnic Institute*; and Shwan Reese, *Quinsigamond Community College*

1:40 pm: Industry Panel
Moderator: Preetinder Virk, *Senior Vice President and General Manager, Networks, MACOM*
Matthew Adams, *Senior Product Line Manager, Viavi Solutions*; Richard Grzybowski, *Director of Research and Development, MACOM Lightwave*; Carlos Macias, *Senior Director Packaging Solutions, Networks, MACOM*; and Yi Qian, *Vice President, Product Management/Marketing, MSRI*

2:40 pm: LEAP Facility Overview
Doug Petkie, *Department Head and Professor of Physics, Worcester Polytechnic Institute*
Jacob Longacre, *Associate Professor of Engineering Technology, Quinsigamond Community College*

2:50 pm: Breakout Sessions
Education and Workforce Development
Testing, Assembling, Packaging
Technology/Application Development

3:30 pm: The Path Forward

4:00 pm: Reception

Speaker Bios

EXHIBITORS

M2I2
Quinsigamond Community College
MRSI Systems
Worcester Polytechnic Institute

Appendix D Integrated Photonics Symposium Notes

- Education of the current workforce
  - QCC is a good model
  - Even those with mathematical background are not always able to use photonics equipment and software without some "handholding" – this is a different beast
  - Speaking the language is important—short courses in photonics can sometimes be enough to work with photonics with background in traditional circuit
  - How does a c. college go about training a workforce when we aren't sure what jobs technicians will be doing in this field in the future
    - Students are already working with optics, but this is like training for a job that doesn't exist yet
    - Even with training, in some cases the technology is touchless—people may not need to know about constructing circuits as much as using programs
  - It is important to identify the highest priorities in education
    - Which systems guys are the best to "ramp up" to photonics?
  - In many cases courses could be integrated with traditional electronics—often the same software is used
  - There's a big difference between cutting edge theoretical physics and engineering these devices—there is an impending transition from the former to the latter
  - Education is pivotal in moving the industry to open-mindedness towards photonics
    - Training on existing RF/other technologies helps (even if they aren't always the end goal)
    - This education is geared towards short, interactive courses
    - Requires looking ahead, but legacy equipment will always exist o Additive manufacturing could transform the path ahead tremendously
    - Perhaps silicon won't be central—also an important consideration which has been overlooked so far
  - Perhaps a course bringing both groups (integrated photonics, traditional) together rather than focusing on one
  - Most of the education needs to be focused on practical current applications—much of the conceptual aspect is widely known
  - There is potential for cross-industry work with AIM academy
  - After finding what jobs are most in need (designers?) what comes next—there are not that many jobs available
    - More people doesn't always help, and a limited number of companies currently do this work
    - Automation is often harder (DP: Use Python!)
    - This is far from unskilled labor—it's evolving, often no one has done something before

- Instead of saying “you’re a designer,” focus can be given on general knowledge. Instead “you’re a translator” into the new era

- Much of the technology could be rapidly displaced
    - Focus on general concepts is helpful in general for emerging technology
    - Encourages thinking outside of the box—not holding onto the change, but being the change ○ A universal understanding/language is needed to allow collaboration and understanding of what can and can’t be done

LEAP Engagement

-1-

OFS →

- Support project based / MQP's
- tours, exposure to optical fiber / test processes
- prototyping?
  - OTDR's / optical time domain – exposure to equip.
  - working side by side w-engineers
  - training in LEAP – fiber characterization

Natick NSR DEC →

- need steady influx of new people w. capabilities
- need to make components (energy conversion device, sensors, etc)
- look for 'field test'
  - ↳ batches of "40" { Sensor / ambient light; Subcontract this out
- Contracted NSR → WPI – AIM Photonics to build – "how do we build this"

have system level requirements

Also → looking for students to work @ Natick (classified content – not at all)

Concern → re funding mechanisms – What needs to get done? How?

2 - Need to know capabilities - Similar to rel. w. Lincoln Lab

LincolnLab → have people who can generate good ideas.
- need more entry-level test/support -
- Contract w. LEAP for testing services

WPI → possible solutions / MQP -
established project ctr over time

Contracting concerns → AirForce / AIM - (M. Liehr)

MWCC → workforce dev - no credit programs -
Could engage employers in LEAP - Could use QR-TEC materials in work dev - K-12 outreach to engage pipeline

- Joint research / project work (bet cc's & WPI)

QCC → coop. requirement -
Opportunity for students to engage in LEAP - Shared research / testing / etc.

3 WPI - also interested in research / project-based work

Can we emulate MIT-Lincoln Lab work experience in LEAP?

- Inspirational projects → to appeal to non-STEM / young students
(Consumer-level / Interactive engagements w. science

- Multiple work experiences int. w. education

→ Attracting more people into field -
Career Pathways
Apprentice-type Models

→ Competing needs in technolgies

→ Publicizing opportunities -

→ Need to understand industry needs / requirements (PhD - BS - technician) in int. photonics

Kratap's Notes.

+ Joseph Menda
MAcom
(reliability engineer)

WPI/QCC LEAP Break-Out Session

~~Area~~

① Education & Workforce Dev.

Abraham Michelen – most important Pipeline from CC → 4 yr. → Industry

James Fasina – Who are we trying to educate? (CC → Industry) And for what? Physicists? Engineers? Technicians? and what skill set is needed?

Nick Moore STCC → really good technicians focused on company needs. lot of cooperation w/companies.

↳ workshops targeted to skills

↳ SPC, RF, automation, mechatronics. Plasma

Yi Qian – marketing photonics career to students & parents of K-12

↳ enrichment courses, eng. tech / module/kits

↳ or even just exposure

② Testing and characterization

very different expertise { ◦ Chip-level testing — much preffered, but not easy
◦ wafer-level testing → test structures to test grating spacing, refractive index

very different expertise { ◦ final device-testing → needs lots of volume to establish correlation

facets polished, coupling → lot of work

fiber transmission tests

Shortcut to reliability testing? Accelerating w/ temperature, Humidity, light intensity — still 1000 hours huge issue

Important to identify → ◦ representative PIC structures, models ← activation energy fitting

◦ ~~contact~~ temperature, reliability more critical for mounted, & packaged, coupled chips. Chips themselves can be quite repeatable

◦ Material system – Si, InP ... different degradation mechanisms

TEC cooling

◦ lack of standards for reliability

Frank:

- woman from MIT, I believe it was Julie Diop, was a driving force in the group, she was looking for input for something she was starting
- Springfield technical community college Nicholas Massa
    - needs Advertising / awareness for their photonics projects
    - Expansion of technical training is necessary, demand for graduates is incredibly high
    - Some concern over current boom resulting in industry poaching students with only certificates which may be less marketable long term than associate's degrees
- Joe Carr (industry)
    - Lots of employers looking for trained technicians
    - Can provide equipment training
- Cheryl Snitzler Stonehill College

School Program / Curriculum Note for Non-four-year Schools

Advanced Manufacturing (AM).
Technician training

B.S.U. / S.C.C.
industry.

how to keep students in program
before getting employed mid-way.

Lab. class
In-lab procedure. ME3901?

Less relevant ↑
↓ more relevance for WPI.

Wave physics, basic lab.

<12 people lab. for photonics
class size.

experience from Springfield Technique C.C.

New class in ME department?

maybe to teach optic equipment more in the new building.

Advertising.

Appendix E List of Registered Attendees to the Inaugural Symposium

Registered Attendees (does not mean they showed up). We did have ~100+ attendees.

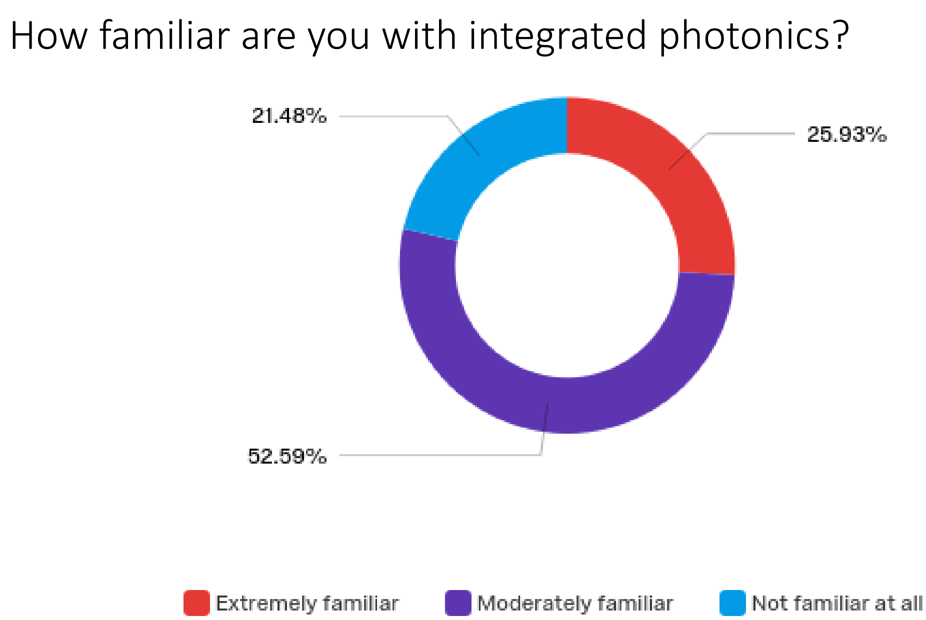
Company/Organization	Title
M2D2	Director
MassHire Central Region Workforce Board	Executive Director
Waters Corporation	Director
Fraunhofer USA Center for Manufacturing Innovation	Business Development
WPI	Dr.
The MassTech Collaborative	Senior Manager, Advanced Technology Programs
Massachusetts Technology Collaborative	Director, Advanced Manufacturing Programs
MACOM Technology Solutions	Reliability Engineer
MassMEP	Workforce Development Manager
Bridgewater State University	Prof. Physics
WPI	Assistant Vice President, Government and Community RElations
WPI	Operations Manager
Quinsigamond Community College	COO/CFO Vice President of Administrative Services
SUNY Polytechnic Institute/AIM Photonics	VPR, SUNY Poly/ CEO, AIM
MassDevelopment	VP Business and Economic Development
Analog Photonics	CEO
Massachusetts Eye and Ear Infirmary/Harvard Medical School	Investigator/Assistant Professor
Quinsigamond Community College	Professor, Chair of Engineering & Biomedical Engineering
AIM Photonics	Chief Marketing Offices
Berkshire Bank	VP
ASML	Engineering Manager
MACOM	Senior Reliability Physicist
MIT Lincoln Laboratory	Electronic Photonic Test Engineer
New Dalton Group	Principal
AIM Academy MIT	Program Manager
MRSI Systems	VP Product Management
Air Force Research Laboratory	Government CTO, AIM Photonics
Junto Studios Works & Co	Founder/Systems Engineer
Mercury Wire Products	Business Development
Mercury Wire Products	Technical Support / R&D
Industrial Marketing	Founder
Barbara Donohue Communications	principal
Quinsigamond CC	Asst. Vice-President, Academic Affairs
Worcester Polytechnic Institute (WPI)	Director of Manufacturing Innovation
Central MA Workforce Investment Board	Resource Development Coordinator
Quinsigamond Community College	Workforce Development Specialist
Energetiq Technology, Inc	Technical Sales Engineer
MIT	Principal Research Scientist
NEATEC / SUNY Poly	Managing Director
Worcester Polytechnic Institute	Department Head and Professor of Physics
WPI	Student
WPI	Admin
Worcester Polytechnic Institute	Assistant Professor
VPIphotonics	Managing Director
MACOM	VP of Global Foundry Operations

BAE Systems	Senior Principal Engineer
Quinsigamond Community College	Dean for the School of Business, Engineering and Technology
St Mary Health Care	Director of Clinical information Systems
WPI	Dean
AIM Academy	Assistant Director
US Naval Research Laboratory	AIM Photonics Gov't Chief Scientist
QCC	Dean of Workforce Development and Continuing Education
Macom Technologies	Director of Operations
Macom Technology Solutions	Engineering Manager
Twin Rivers Technologies	Regulatory Affairs Manager
OFS	Sr. Manager, QA/Lean
Town of Southbridge	Dir. Ec. Dev. & Planning
MRSI Systems	Marketing
Chamber of Central Mass South	Executive Director
Worcester Polytechnic Institute	Integrated Photonics IQP Student
Mass AFL-CIO	Assistant to President WFD
Mount Wachusett COmmunity College	Dean, Workforce Development
Massachusetts House of Representatives	State Representative
MACOM	Director of Research and Development
QCC	Associate Professor, Photonics
WPI	WPI Integrated Photonics IQP Student
Viavi Solutions	Sr. Product Manager
US Army Natick Soldier Research Development and Engineering Center	Research Physicist
WPI	Assistant Professor
WPI	Assistant Vice President
Quinsigamond Community College	Professor / Coordinator of Electronics Engineering Technology
University of Hartford	Roosa PRofessor of Manufacturing Engineering
Quinsigamond Community Collete	Assistant Vice President of Extended Campuses Operations
Worcester Polytechnic Institute	Associate Director of Public Relations
d's L	Director
WPI	Associate Professor, Biomedical Engineering
WPI	Professor
Quinsigamond Community College	Program Administrator, STEM Initiatives
Self	Failure Analysis Engineer
WPI	Associate Teaching Professor
Smith & Wesson	Assembly Manager
WPI	Assistant Professor
CMTC	FHE Practice Lead at NextFlex
Dassault Systemes SIMULIA CST	Technical Sales Director
Catalyst Connection	Senior Technical Consultant
Catalyst Connection	Consultant
WPI Foisie Business School	Associate Teaching Professor
WPI	Dean of Graduate Studies
MassMEP	President
Massmep	Director Workforce Development Strategies
MassMEP	Project Manager
Keysight	Field Engineer

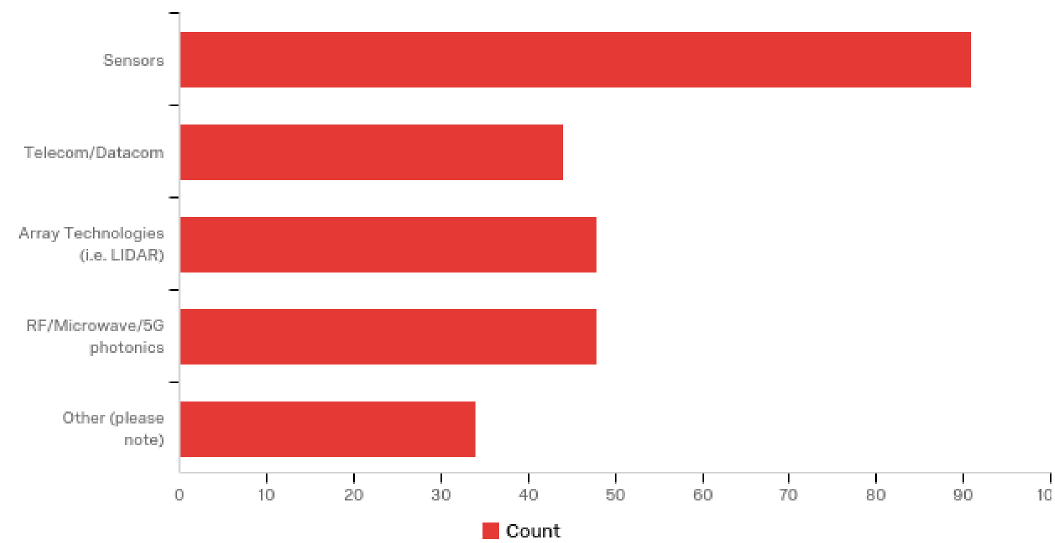
WPI-ME/CHSLT	Associate Professor
NRL/ AIM Photonics	AIM Gov't Chief Scientist
AIM Photonics Government Program Management Team	Project Management Consultant
Empire State Development, NYSTAR Div	Business Development - Photonics
EarlyBird Power LLC	Business Development Director
Mount Wachusett Community College	Dean, Workforce Development
Springfield Technical Community College	Dept Chair/Professor - Optics & Photonics Technology Department
MassTech Collaborative	Director, Advanced Manufacturing Programs
Schott	Manufacturing Engineer
FormFactor Inc	Market Development DIrector
Leviathan Vacuum Process Technology Inc.	President
Semilab USA LLC	Sales Manager
MassHire Central Region Workforce Board	Resource Development Coordinator
Denton Vacuum, LLC	Sales Manager
Northeast Advanced Manufacturing Consortium	Director
BAE Systems, Inc.	Principal Scientist
Stonehill College	Associate Professor of Chemistry
Prof.	Head of ME Department
Worcester Polytechnic Institute	Student
Gentex Optics /Essilor	Engineering Manager
Gentex Optics	Controls and Instrumentation Engineer
ECRM	VP Strategic planning
CMTC	Robotics Practice Lead
QCC Institutional Communications	Tech Specialist/Photographer: FT Professional Staff
Macom Technology Solutions	SVP
WPI	Student
Worcester Polytechnic Institute	Student
AIM Photonics Academy/MIT	Education Director
Stonehill College	Assistant Professor
ARMI	Outreach Coordinator
mass mep	Field Operations Director
Quinsigamond Community College	Student
UMass Lowell	Professor
Quinsigamond Community College	Admissions Counselor
MassMEP	ManufacturingUSA Project Directot
Worcester Polytechnic Institute	Post-doctoral fellow
photonic tools	R&D/App
WPI	Student
WPI	Mr
Advanced Regenerative Manufacturing Institute (ARMI) / MassMEP	Director of Outreach
MIT	Assistant Director, Washington Office
WPI	Mr
WPI	Mr.
WPI	PhD Candidate
Worcester Polytechnic Institute	Graduate Student
Keyence Corporation of America	Senior Sales Engineer
Worcester Polytechnic Institute	Student

Worcester Polytechnic Institute	Graduate Student
Quinsigamond CommunityCollege	Vice President of Academic Affairs
WPI	Graduate Research Assistant
Mentor Graphics Corporation	Tanner Sales Rep
Mentor Graphics	Applications Engineer
Viking Industrial Products	Product Manager
Worcester Polytechnic Institute	Ph.D

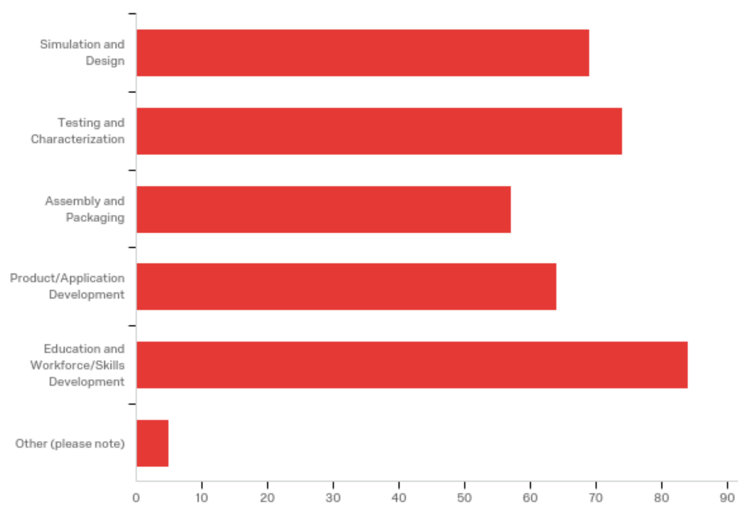
Appendix F Results of Survey Given to Attendees of the Integrated Photonics Symposium



Please indicate your organizations areas of interest from the following broad Key Technology Manufacturing Areas (check all that apply):



Product development broadly includes the following areas. Please check all areas that your organization would be interested in:



Appendix G SWOT Analysis Notes

STRENGTHS of the integrated photonics Industry

- Academic interest
  - International Conference on Group IV Photonics created 2006, first convening in Hong Kong [1]
  - Continues to meet today, 16 years running, to "deliver insight on current and future innovations in Group IV element-based photonic materials and devices, including silicon photonics, as well as other integration and fabrication technologies." [2]
- Government interest
  - European Union funded the Silicon Heterostructure Intersubband Emitter (SHINE) program in 2004 for SiGe/Si quantum-cascade structures for the 8-120 micrometer range [1]
  - Air Force Office of Scientific Research funded a three-year project for room-temperature electrically-pumped 1.55 micrometer silicon-based lasers
  - DARPA microelectronics technology office made an investment in 1.55-micrometer silicon photonics via EPIC (Electronic and Photonic Integrated Circuits) program [1]
    - The program goal is monolithic integration of photonic and electronic circuits in silicon [3]
- Existing successes in the data center and high-performance computing (HPC) field
  - 100Gb/s transceiver technology has been realized and shipped by multiple companies using silicon photonics technology for the data center/HPC industry [7]

WEAKNESSES of the integrated photonics Industry

- Heightened complexity of fundamental circuitry as compared to CMOS technology [4]
- The necessity for further development of waveguide technology which prevents loss and can be produced easily [2][4]
- The duality of development of telecom-focused PIC technology vs. sensing & spectroscopy [4]
  - The two typically require different wavelength bands, thus interoperation necessitates the development of optical delay lines or resonators on-PIC [4]
- Pure silicon is fundamentally difficult to use for optical sources, optical modulators, and photodetectors, though research is consistently finding solutions to these problems [7]

OPPORTUNITIES in the integrated photonics industry

- Application of novel waveguide manufacturing technology which could make use of e.g. Rostislav Khrapkoa "Accumulated self-focusing of ultraviolet light in silica glass" [5]

    - Waveguides formed from focused light in silica over multiple accumulated pulses
    - Paper explores lasting effects of waveguide formation, i.e. for the creation of waveguide microchannels in small circuits--the guides are permanently inscribed in the glass and can be viewed via microscopy
- Refinement of existing methodology for the creation of waveguides in Silicon-On-Insulator (SOI) tech via electron-beam lithography as in [6].

THREATS to the integrated photonics industry

- Heterogenous 2.5D and 3D integration continues to be preferred over direct CMOS integration since photonic processes are difficult in modern electronic node sizes [7]
- On-chip power efficient lasers remain expensive in manufacturing and packaging [7]
    - Most lasers are flip-chip die attached or edge-coupled--this constitutes a difficulty in the path to truly integrated photonic circuits and could lead to heterogeneous (flip-chip) or hybrid (butt/edge-coupled) circuits continuing to be preferred for the foreseeable future
    - However, many of the remaining challenges can be solved using SOI technology

Citations

1. https://ieeexplore.ieee.org/abstract/document/4032698
2. https://ieee-gfp.org/welcome-message/
3. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1516382
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