Learnings To-date from PhD Workforce Interviews

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What are the advanced engineering workforce needs for the integrated photonics industry?

- Research questions
  - What types of workers are needed?
  - What skills do these workers need?

- Scope and focus
  - Industry
    - Photonics
  - Type of work
    - Engineering
  - Level of education and training
    - Highly-skilled workers
      - PhD and advanced masters
  - Geographic
    - Domestic workers only

Research Challenge:
How do we characterize the skills needed for PhDs and highly-skilled master's engineers?

Structure of the Interview

- Position in supply chain
  - Most firms answer: component fabricator, assembly/package/test/. & system integrator
- Types of hires
  - EE, DMSE, MechE, Physics, and occasionally from ChemE?
    - Question dropped for time and because of similarity of responses
- Number of hires
    - Question dropped because of quality of responses
- Skill importance and proficiency of new hires
  - E.g., "Create coding scripts to model photonics devices and/or parts of a photonic integrated circuit"
- Challenge in hiring US citizens

Who We've Interviewed

- 3M (Terry Smith, formerly), Promex (Dick Otte), Macom (Rich Grzybowski)
- AIM Photonics (Nick Fahrenkoff), RIT (Stefan Preble)
- Broadcom (Alexis Bjorlin, Near Margalit)
- Facebook (Katharine Schmidke)
- Genalyte (Ryan Bailey)
- GenXComm (Thien-An Nguyen)
- Infinera (Gloria Hoefler)
- Intel (Ling Liao)
- Juniper Networks (Daniel Sparacin, formerly)
- L3 Harris (Arthur Paolella)
- Lincoln Labs (Paul Juodawlkis, Cheryl Sorace-Agaskar)
- Litexel (Xiaochen Sun)
- Lockheed-Martin (Guy Chriqui)
- Luxtera/Cisco (Peter De Dobbelaere)
- Microsoft Azure (Brad Booth)
- Nokia Labs (Mark Earnshaw)
- NVIDIA (Larry Dennison, Tom Gray)
- Pendar (Christian Pfluegl)
- Phase Sensitive Innovations (Dennis Prather)
- Raytheon (Benn Gleason)
- RMD (Harish Bhandari)
- TriLumina (Jim Foresi)
- Tyndall Institute (Peter O'Brien), Univ. of Rochester (Tom Brown)
- Univ. of Rochester (Jaime Cardenas)
- MIT (Anu Agarwal, J.J. Hu, Jurgen Michel, Kazumi Wada)

Photonics PhDs: General Learnings

- Most firms say that they are able to find PhDs but…
  - Challenging to find someone with specific integration expertise
  - Challenging for
    - Specific Subsectors
      - III-V
      - RF
      - Defense
    - Startups and small firms
    - Specific locations
- Firms are hiring from many disciplines
  - EE
  - Materials Science
  - Physics
  - Optics (UofR and U of Arizona)
  - Mechanical engineering
  - A few from Chemical Engineering
- Supply seems to concentrated at a few key universities

To understand skill needs, we developed four archetypes of industrial PhD work

- Process Engineer (component fabrication):
  - An engineer trained in semiconductor materials processing, who is experienced to work in a cleanroom environment with deep UV lithography, wet and dry etching, chemical and physical vapor deposition, and thermal annealing tools, in order to fabricate integrated photonics circuits on 300mm silicon wafers.
- Process Engineer (packaging):
  - An engineer trained in semiconductor materials processing, who is experienced to work in a packaging and assembly environment with wire bonding, pick and place, wet etching, and epoxy tools, in order to manufacture a modest-to-full hermetic-sealed integrated photonics chip.
- Photonic Integrated Circuit Designer:
  - An engineer trained in photonics and semiconductor science, and a specific application area, who is experienced to work with electronic-photonics design automation (EPDA) software tools and a process design kit (PDK), in order to model integrated photonics devices, simulate and lay out integrated photonics circuits, design review check and create a tapeout file for submission to a photonics foundry for chip fabrication.
- Applications System Engineer:
  - An engineer trained in a college-level electromagnetism, and specific application area, who is experienced to create experimental models, and to create programmed software coding or operate commercial software for simulating the functions and tolerances of a technological system, in order to determine how the system performance may be enhanced by the addition of novel photonics chip components.

Photonic Integrated Circuit (PIC) Designer

- Computer modeling
  - Create coding scripts to model photonics devices and/or parts of a photonic integrated circuit
  - Advanced proficiency in commercial EPDA/EDA tools:
    - device modeling
    - PIC circuit simulation & layout
    - PIC circuit layout and DRC check (.gds tapeout)
  - Proficiency in multi-physics simulation tool
- Design
  - Use one or more commercial/open source PDKs (interpret design guide, compact models)
  - Supplement PDK w open source/custom components
  - Create parametric cells for circuit sim in a PDK
  - Design for Test (DfT): design and layout devices or sub-circuits for in-line/off-line test characterization
  - Design for (DfM): create a design-centered layout for a device. … or PIC circuit
- Fundamentals
  - Basic materials science and processing knowledge
  - Use statistical methods to evaluate process variation

- Computer modeling
  - Important for all
    - Coding is most important for firms that are:
      - not in Si, smaller firms, and those trying to be at cutting edge of performance
    - Commercial software is most important for larger firms focused on high volume production
    - Multi-physics simulations seemed universally important
  - GAP:
    - Generally students are capable with software
    - Some programs have less resources (so more coding, less commercial experience); Some research groups are very strong
- Design
  - Importance of PDKs depends on focus of firm
    - Position in supply-chain or applications translate into PDKs being less relevant (light sources, photonic sensors)
  - Grads: weaker ability to develop parametric models
  - GAP: Design for test, manufacturing, and packaging
    - Very important, but absent in new graduates
- Fundamentals
  - Most firms feel this is valuable (unlike electronics, need materials science knowledge)
    - Allows you to understand the simulations and not blindly trust tools
    - Significant variation in the amount of fundamental knowledge that new graduates have
    - Specialty firms & R&D oriented firms feel this is more important (RF, InP)
  - GAP:
    - Cross-training across thermal, mechanical, photonic, electronic
    - Communications skills among a design team
      - Ability to communicate to stakeholders in development process

Process Engineer

Very diverse interpretation of this job description across firms

- Computer Modeling
  - Create coding scripts to model materials science and/or materials processing phenomena
  - Work with EPDA or EDA software tools
- Process Design
  - Interpret Process Design Kit layout fabrication procedure
  - Design process flow for fabrication of chip die
  - Design Standard Operating Procedure (SOP) for 1+ fab tools (thin film deposition, lithography, etch, anneal)
  - Co-design safety training and execute safe practice with one or more fabrication tools
- Testing Design
  - Design optical in-line & off-line test characterization of semiconductor wafers, thin films, and/or devices; interpret test data, diagnose sources of fabrication errors
  - Design electrical in-line & off-line test characterization of semiconductor wafer, thin films, and/or devices; interpret test data, diagnose sources of fabrication errors
  - Define a reference standard and calibrate fab tool with respect to it
- Design for Manufacturing
  - Diagnose sources of fabrication errors; evaluate process variation and revise error management in fab tool
  - Use statistical methods to evaluate process variation and other aspects of statistical process control (e.g., Monte Carlo simulation method)
- Fundamentals
  - Prepare charts or diagrams describing the standard operating procedure and in-line characterization steps

- Computer modeling
  - Less important than for PIC designer
  - Packaging – Multiphysics simulation (e.g., COMSOL) is important for design (thermal management)
  - For firms
    - WITH fab
- Process design
  - Need knowledge of PDKs
    - less relevant for packaging focused process engineer and III-V firms
  - Caretakers of SOPs would only be relevant to engineers at the FAB
- Testing design
  - Very important activity for the process engineer
    - Firms without fabs also have to consider testing during the design stage
  - Generally significant gap in training because most PhD training doesn't cover this
  - Need to also test for reliability
- Design for manufacture
  - Very important for process engineer and PIC designer
  - Generally weak skill for new grads
  - Design to optimize yield and ensure reliability
  - Statistical process control was cited as a gap
- Fundamentals
  - Communication skills among the design team (and outside of the team) were cited as a gap
  - Probability and statistics was noted as a gap
  - Materials science expertise was more critical for III-V and specialty material firms
- Packaging
  - Design for packaging is a significant challenge and one where there is a notable training gap

Application Systems Engineer

- Computer modeling
  - Create coding scripts to model photonics devices and/or photonic block components in a simulated system
  - Use commercial software to model photonic block components and simulate application-specific systems
- Design
  - Define a Figure of Merit for the system and assess design trade-offs to optimize application-specific performance
  - Select system's materials, carrier freq, power source criteria, subject to manufacturing and cost constraints
- Test and troubleshoot
  - Design, build, and troubleshoot in-house prototypes of application systems; configure FPGAs for model systems
  - Design, build, and test in-field experiments to assess system controls, constraints, performance specifications
  - Identify sources & magnitude of manufacturing variation in system; determine a design-centered configuration
- Fundamentals
  - Proficiency in materials science
  - Proficiency in mechanical design
  - Proficiency in optical physcis: light confinement, guiding, interferometric concepts

- DIVERSE interpretation of this job; often for more experienced engineers
- Computer modeling
  - Important
  - Depending on specific focus may extend beyond photonic modeling to include mechanical systems issue
- Design
  - Most important task for systems engineer
  - Sometimes lacking skill for recent grads
  - Recent grads tend to focus on performance rather than
    - Cost
    - Customer needs
  - Design for in-use environment is a gap
  - Design for packaging and testing is a gap
- Test and Troubleshoot
  - Recent grads tend to be able to do this for low-volume or lab scale systems
    - May be a gap for large-volume
  - In-field testing is a gap
  - RF testing is a gap
  - Design for manufacturing is a gap
- Fundamentals
  - Knowledge of materials, mechanical, and optics is valuable
  - RF knowledge is lacking

Overall Learning:
To be successful in industry, photonics PhDs need more Cross-training

- Mentioned by nearly everyone
  - Computer modeling of devices/ circuits/systems is critical, but most PhDs are competent in modeling
    - Mastery of either custom or use of commercial packages
  - Cross-training needed in process or design
    - Designers need more knowledge about , process engineers need to understand design
  - Mindset to design for manufacturing and testing (rather than top performance)
    - Manage yield and reliability
    - Manage process variation
      - Statistical process control, Design of experiments, Data science
    - Understanding what the customer needs
  - Packaging
    - Generally, not covered in PhD programs
    - Balancing, mechanical – optical - thermal
  - Awareness of bigger picture
    - Knowing the application area
    - What are the processing, packaging, and testing options

- Other topics raised
  - Multi-physics simulation and design
    - Mechanical engineering
    - Managing thermal and mechanical stresses
    - In-use environmental constraints / impacts
  - Making cost-aware decisions
    - Make vs buy
  - Curiosity and the drive to own and therefore solve problems
  - Creativity
  - Communications
    - Particularly outside the design team (management, customers)

Courses that should be developed

- Design for manufacturing
  - Process variation and limitations, Testing
- Design for packaging
  - Multi-physics simulation
- Design for testing
  - RF, In-line, End-of-line
- Case-study based course
  - Photonic system (e.g., VCSEL in Lidar applications)
  - Successes and failures
  - Understanding the industry big-picture
- Application course to understand tradeoffs
  - RF photonics
  - Lidar
  - Chemical sensors (in development)
  - Datacom
- Fundamentals
  - … of Integrated photonics (in development)
  - … of manufacturing
    - Statistical process-control, Six-sigma methods, cost