How Rockley Photonics works with academia, and why it works for us

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A Brief 30 Year History of Silicon Photonics Industry

- 1989 – 2000: First commercial Si Photonics platform developed
  - Bookham platform started based purely on producing optimum photonic structures in Si, not considering previous semiconductor processes (inspired from Soref work, conducted with Graham Reed at Surrey University)
  - Large scale, two fabs built with automated backend assembly lines qualified to demanding Telcordia standards, but curtailed after the dotcom crash

- 2000 - 2010: Commercial development of Si photonics for high data rates
  - Early 2000s: New Si photonics startups form in California
  - 2005: First commercial 10Gb/s Mach-Zehnder (MZ) modulators demonstrated in small 220 nm waveguide size
  - Kotura continues technology commercialization based on Bookham platform with integration of high speeds actives based on SiGe electro-absorption modulator, integrated WDM
  - Other commercial Si Ph platforms are based on MZs in small waveguides, use of CMOS processes and foundries, monolithic integration with CMOS, but encounter manufacturing challenges, move to separate processes, and hybrid integration

A Brief 30 Year History of Silicon Photonics Industry

- 2010-2016: Si Photonics companies achieve volume production for 100 Gb/s datacenters
  - MZ-based small-waveguide platforms achieves successful volume production of 4x25 Gb/s (100 Gb/s) PSM transceivers for datacenters, but with some compromises (e.g. no WDM)
  - Successful production of 4x25 Gb/s transceivers based on large waveguide platform, sees application in High Performance Computing (HPC)

- 2013-now: Rockley Photonics develops silicon photonics platform with wide scope and flexibility to accommodate differing applications and having no compromises, drawing on 30 years of experience and research and development

Attributes of a Leadership Photonics Platform

Important Platform Criterion:

1. Active devices with high bandwidth that can scale for future communication needs
   - And compatible with the lowest cost and lowest power leading edge CMOS
2. Low loss passives, low loss fiber attach to deliver systems with demanding loss budgets
3. High manufacturing tolerances to ensure sufficient wavelength registration
   - Using readily-available semiconductor manufacturing capabilities
   - High devices yields under typical variations of line width, etch and film thickness
4. Passive-aligned packaging using conventional automated semiconductor tools with sufficient alignment tolerances for high-throughput assembly
5. Operate within a broad temperature and environmental range.
6. Accommodate many material systems and waveguides of any size
7. Handling of high optical power allowing for high levels of multiplexing

Rockley Photonics

We make products with broadly functional silicon photonics and dense integration with CMOS

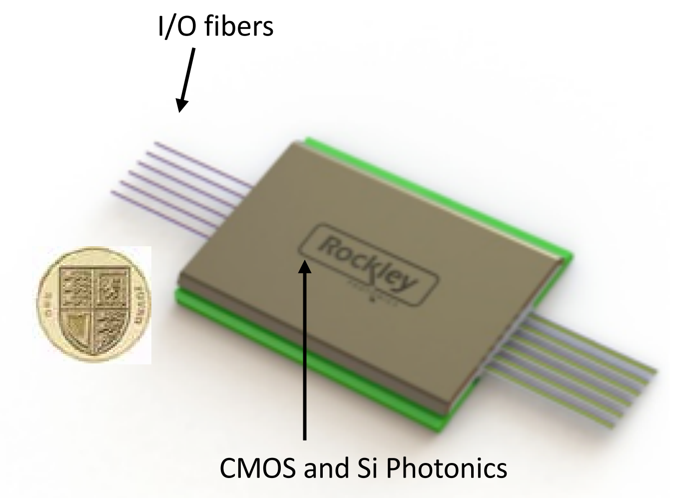
Our chip-sets are massively scalable and manufacturable
Optical Packet Switching solution "opto-ASIC" called *Topanga*™

- → reduces power & cost by removing high speed electrical connections
- → Densely integrated WDM and optical IO, uniquely designed for hyper-scale DCs
- → simplified, higher performance network solution delivered using single switch module
- → Breadth of photonics platform allows scaling to meet future demands without major re-design

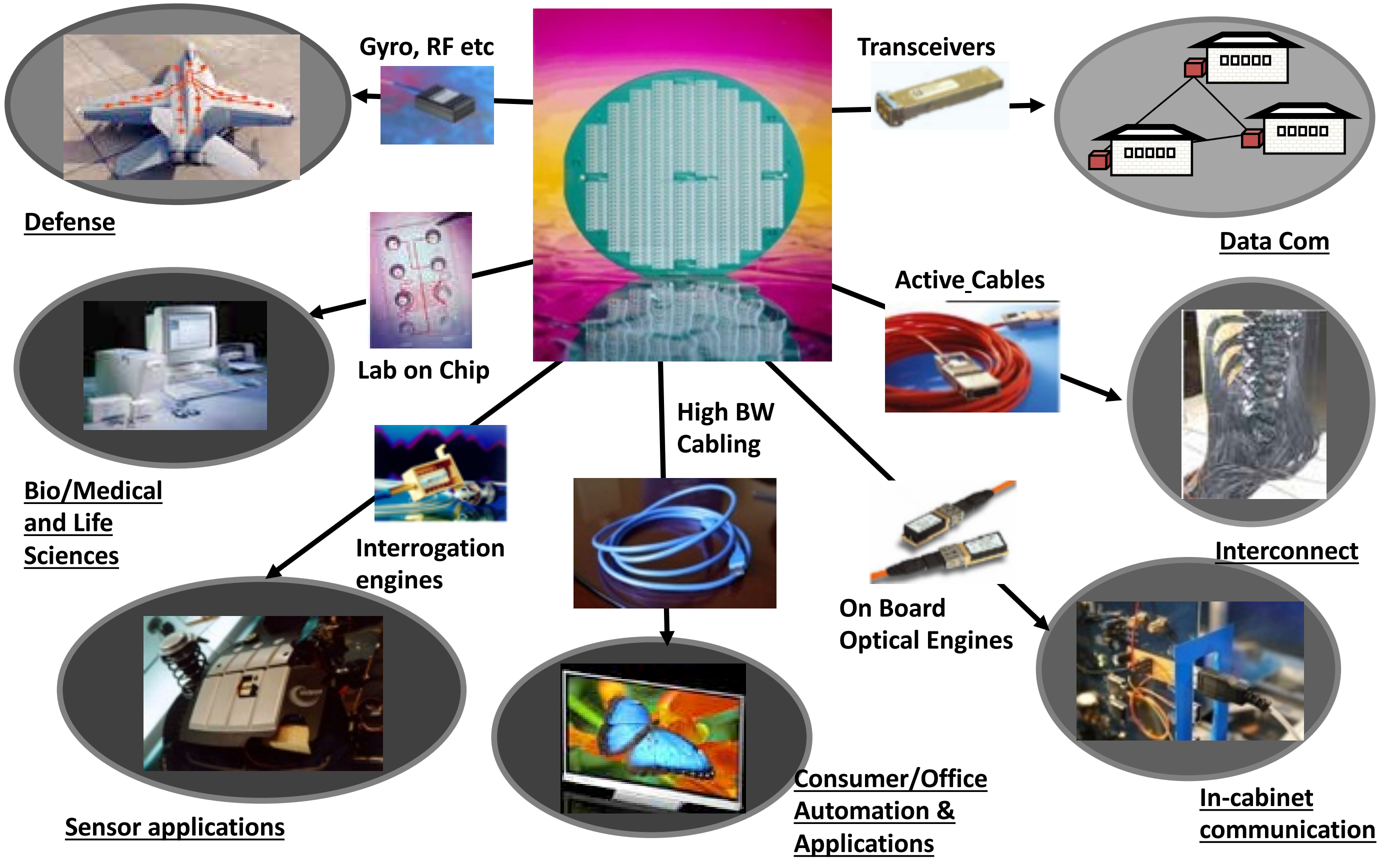
Delivering what the customers want:

High Data Density
Lower cost
Lower power
Smaller footprint

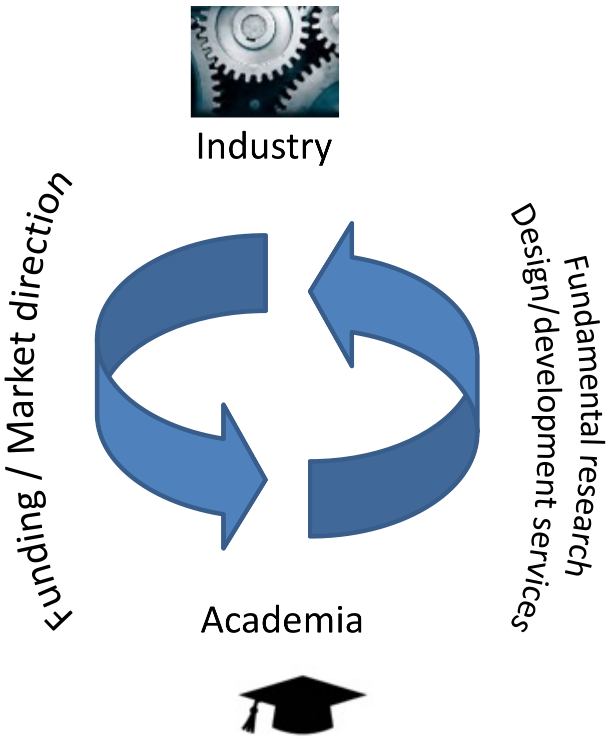
Topanga ™
CMOS Packet Switch and embedded photonics I/O in a single ASIC-like package



Broad Range of Markets for Si Photonics Platform



Industry and Academia – Symbiotic Relationship



Industry provides

A) Funding
- ideally leveraging matching from government funding for 50% or more coverage of costs

B) Market and application guidance
- Companies have direct dialog with customers and can provide guidance for industry-relevant research

C) Industry-relevant research and publications

D) Commercial exploitation of research
- additional IP license income

E) IP development
- joint patents, joint process know-how to license to others

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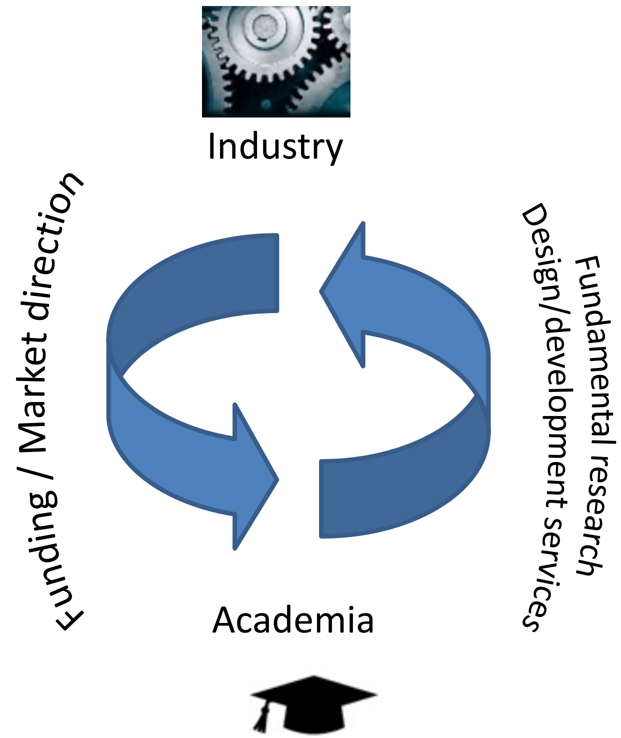


Academia provides

A) Economical fundamental research
– leveraging government funding

B) Process development services

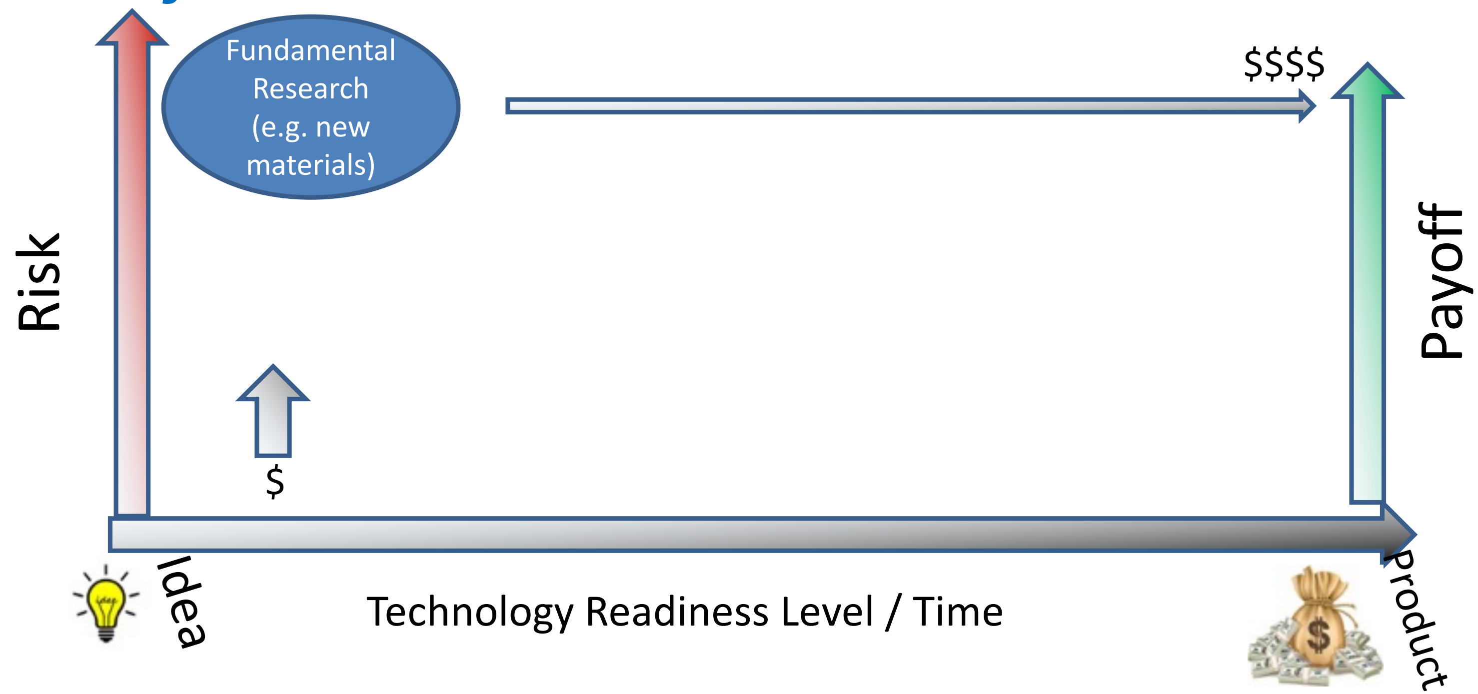
C) Additional focused expertise/capabilities
– Expand company's resources beyond what they have in-house
– Minimal additional cost

D) Background IP and knowhow to exploit

E) Access to academic networks and research community developments

F) Training for employees or employees for supplies/partners

Rockley and Academia – Cost/Reward Benefits for Industry



- Highest value with largest payoff → work on high risk/high reward fundamental research without the company having to invest in internal resources / capital equipment

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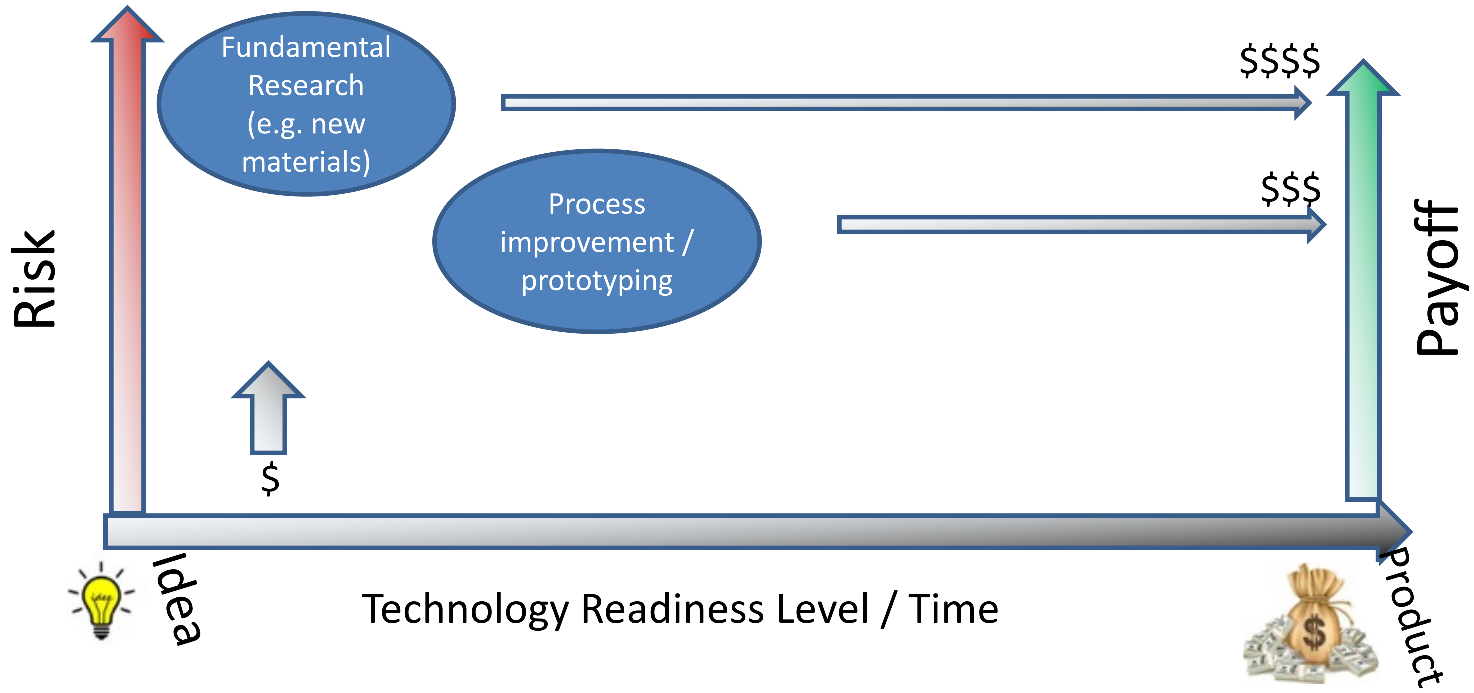

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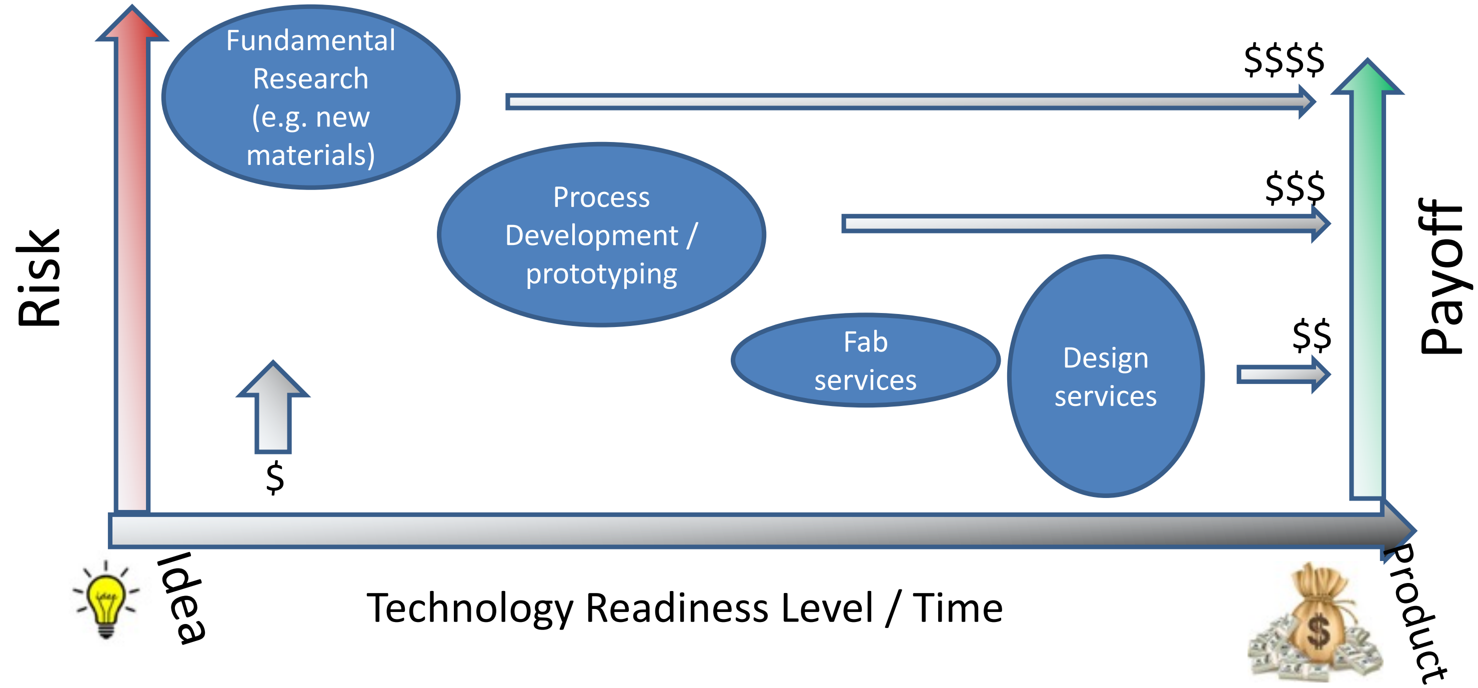

- Highest value with largest payoff → work on high risk/high reward fundamental research without the company having to invest in internal resources / capital equipment
- Also high value → improvement or device prototyping with new combinations of existing materials/processes
- Low risk and quick payoff → Design and test services using specialty expertise of research group or lab

Rockley/Academia Interaction

Rockley has engaged academia and research institutes for a variety of research and development tasks having varying technology readiness levels:

1. Design and test services for feasibility studies of new concepts
   - leveraging existing design and test experts and labs with specific expertise and capabilities not in the company
2. Fab services for pathfinding and prototyping
   - Innovating new combinations of existing materials and processes, applying them to new applications, or challenging the boundaries
   - Including licensing and prototyping of designs/process/materials developed previously in the University, and customizing it for company applications
3. Fundamental research / materials development
   - Feasibility demonstrations and integration development for new materials/new processes
   - High risk, high reward development

Case Study – Southampton University

- Task: Prototype new Rockley high-speed modulator design, plus fundamental materials research for next-gen improvement
  - Uses mostly known material and processes plus potential for improved performance
  - needed to make prototype and demonstrate process for transfer to production
- Why Southampton University?
  - Already had ongoing research and expertise with same materials and similar processes
  - Had existing background IP on new material method with potential for very high payoff
  - Experience working with industry (helps for contracts and IP)
  - Rockley needed additional resources and expertise to augment and de-risk existing development efforts
- Method: SOW with Multiple phases, milestones for each acting as go-no-go points for major risk points

Phase 1: Modeling of device structure to verify device feasibility

Phase 2: Process short loops of material growth to confirm process working for good-quality active material

Phase 3: Partial device fabrication run (passive only) to confirm passive performance and material capabilities

Phase 4: 2nd round device modeling – update model based on first run, correlate model with measurements

Phase 5: 2nd round process short loops to solve problems identified in 1st run (e.g. annealing trials)

Phase 6: Full device run

Case Study – Southampton University Cont.

- Resources: 1 dedicated RA, 2 PhD students
- IP:
  - Rockley device design IP
  - University owns IP on method for next-gen material improvement
  - Additional IP (patents) generated during the project
- Results and postmortem:
  - *Successfully demonstrated world-leading device performance after first full device run*
  - However a couple of process challenges were encountered which need to be solved before it can become a product (risks of making new device structure)
  - Publications: 1 conference presentation, 2 conference posters, 1 journal paper in submission
- Next-gen material improvement fundamental research project still ongoing, challenges encountered for making practical in device for Rockley, but results still TBD
  - High risk, long development time, still potential for high reward, but company product needs shifting

Case Study – Caltech

- Task: Electronics circuit designs for both short- and long-term company applications
  - Project 1: design chip for use in initial product prototype
  - Project 2: design chip for improved performance for next-gen products
- Why this University?
  - High reputation, has research and expertise in advanced electronics relevant for Rockley Photonics
  - Rockley needed additional resources and expertise to augment and de-risk existing development efforts
- Method: Committed multi-year funding from Rockley, high level SOWs with end deliverables only
  - A bit less detailed planning up front, more flexibility
- Resources: 1 PhD student per project
- IP: Joint patents generated during the projects
- Results and postmortem:
  - Project 1: 1 device run, design and fabout completed on schedule, preliminary testing showed not all performance requirements met, discontinued due to Rockley priority changes, student graduated
  - Project 2: 1 device run, design and fabout completed on schedule, testing slow due to student inexperience, but eventually good performance demonstrated, valuable for next-gen products
  - Publications: 1 conference presentation and 1 journal paper in progress (project 2)

Lessons - Industry and Academia Challenges

1. Direction changes
   - Industry needs can sometimes change faster than academia (especially in startups)
2. Contract management
   - Statements of work (SOWs) and terms and conditions (Ts&Cs) need to be worked out in advance
   - SOWs need to include deliverables, specifications, budget in statements of work for productive projects
3. IP
   - Ownership and tracking of IP, different terms if government funding involved
   - Negotiating licensing for previously existing IP
   - Risk of IP leakage/contamination due to lack of IP experience or policies
   - Can be managed but consumes time and energy from both parties
4. Need for publishing
   - industry has need for confidentiality/secrecy
   - Timing and priority of paper/conference publishing may clash
5. Export Control

Summary

1. Industry and Academia can have symbiotic relationship
   - Academia provides economical fundamental research which is high risk but high reward
   - Academia provides value also in fab and design services using their specialized expertise
   - Industry provides funding for industry-oriented research, market guidance, commercial exploitation

2. Rockley Photonics has many R&D projects with academia which have been overall successful and provide value
   - Most successful examples were prototyping projects using mostly known materials and processes, but for next gen or alternate applications (not for short term products)
   - Fundamental research projects can take many years before payoff is realized (results are still TBD)
   - Industry needs to remember differing needs and conditions of academia and visa versa, plan ahead with SOWs and contracts

THANK YOU