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Workshop 22 - Quantum photonics: From optical table to chip

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Participants

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- Moderator: Prof. Rogério de Sousa (University of Victoria, Canada)

What is the biggest challenge in quantum photonic circuit integration and scalability?

- Need different types of devices. Switches, detectors, resonators. It's not obvious that they can coexist in the same platform. Photonic Inc. perspective: T-center may not survive fabrication processes. Need process compatible technologies or integrate different chips and have them all work together.
- Similar challenges at Xanadu. Components are easy to optimize when they are not together. Optical loss is the challenge for integration. Things can coexist, but additional losses take place. Common theme in composite chips as well as single layer SiN. Additional loss: coupled light between channel and microring. Oxide in waveguides filling causes additional loss. The other problem is uniformity across devices. Need uniform control link and coupling ratio. Strategies to migitate nonuniformity cause loss.
- For resonators, problem hidden in "elevator effect". Enhance the process you want (Purcell, etc) but automatically enhances other process such as loss. Advantage of integration is also a curse because you need to control the processes that you don't want. From a theoretical point of view there is no reason why we can't get 1km of waveguide with low loss. Fundamentally loss can in principle be several orders of magnitude less than what we have in current fabrication. In the beginning of integrated optics, we got 1 dB/cm. With new fabs we get 0.01db/cm, so we can be optimistic for the future.

From audience: Any new tricks from quantum photonics to mitigate these effects?

- Electro-optic modulation has not been optimized for quantum photonics. In classical photonics, low V_pi is the focus. For quantum photonics, loss may be more important than a low V_pi.

Photonic QC requires integration of sources, nonlinear crystals, and photon detectors in the same chip. How do we ensure seamless integration without introducing losses?

- You don’t need to necessarily co-integrate everything. You can connect modules with optical fiber. E.g. SSPD.
- Vertical integration with LNO. To increase coupling . Preparation of the surfaces and interfaces are important. Integrating III—V or optical fiber to SiN waveguide. Happen with surface preparation in the clean room. Recipe development level. We are riding on topics that come from classical photonics telecom.
- A lot of the work happens in the clean room to reduce losses. Photonic ensures that we have an architecture that is resilient to losses . Loss slows down QC. Approach from opposite direction: Integrate first and then fine tune recipe to reduce losses.
- When devices are close together you minimize loss. Pack devices in really small spaces to reduce waveguide loss.
- Avoid complete integration. Photonic QC will not be a single wafer. Need to solve problem of loss between moduli. If you try to integrate everything you will have to solve all losses mechanisms yourself. Modularity allows you to optimize devices individually. Difference in specs across industry is a problem.

Two-qubit photonic quantum gates are probabilistic. Is that a barrier for scalability? What are the most promising methods to increase their success rate?

- Two qubit gates are NOT probabilistic if you use GKP states and exploit more than single photon approach. In linear optic QC you can not avoid non-deterministic gates. If you rely on detector-induced nonlinearities you will be probabilistic and will have to parallelize and store output in buffer. We don't think that is a promising approach.
- Xanadu uses precursors and then refineries to increase prob of success. Lower loss allows higher probability. This is how it works for GKP/cluster approach.
- Many groups working on concepts about deterministic gates. Dwell time in resonators is ms. Increases prob but decreases speed.
- In dual rail, if you loose a photon you loose your state. Thah is why we use different encodings. Increasing success rate in these other approaches is done at the expense of the speed.
- Currently photonic is at mHz rate for entanglement of T-centres. Our estimates indicate 2kHz is achievable by parallelization. Horizontal scaling of interconnects.

What are the opportunities and challenges for different technologies/modalities to interface with each other?

- There is this view that we are competing with each other and we have competing platforms. There is no fundamental reason why we can't have photonic QCs interacting with spin-based QCs. You have to solve the transduction problem and I see in the future companies working with each other.
- I don't think transduction has a business case. Some small links might work but for straight QC application such as Qchemistry I don't think hybrid QCs will be realistic in the future.
- Photonic carrier is essential because you want to interface QCs with each other. But not because you want two different architectures to coexist.

How do you imagine the Q internet? Different companies with different tech interacting.

- My opinion: Qinternet is SciFi. Qubits should be close together in order to have advantage. Quantum intranet is powerful, Q internet I don’t see the point. Blind QC and security is interesting. But according to one of the big companies Blind QC will ruin business model.

From a systems perspective, what does having access to a quantum memory change how we think about building a quantum computer?

- The benefit of having a q memory is to have a state that is protected and will not necessarily decohere when you have qubit-qubit interaction. When you have QCs communicating over long distances. Cross talk will be a problem. If you have memories that can talk with photons you can get rid of this challenge.
- Our architecture does not rely on memory. If we had memory it would make it cheaper and we would not need to consume so many clock cycles.

What is the most promising route for photonic circuit programability?

- Reliable low loss fast optical modulators would have great impact on programmability. Speed is not necessarily that important but you want low loss. Microheater is not compact, leads to crosstalk, and consumes too much energy.
- Company iPronix is working on a FFPGA for versatile universal chip design to programmable chips.

How can we manage finite device yields in integrated devices?

- During one of the panels they were talking about mitigating finite yields like they do in CPUs. If a region of the CPU fails, you go to other region. So the way to tackle is to make extra devices and use optical switches or fab to route to the parts of the circuits that work.
- Difficult to do monolithic integration, reduces yield. Screen the chips and get rid of the ones that do not work.
- Very relevant question for economic feasibility. For Xanadu, make chips as small as possible and take advantage of modularity. Small chips with few devices tolerate low yields. At semiconductor factories a lot of chips get rejected. We do the same thing in Qphtonics. For large chips, we rely on the fact that not everything needs to work. As long as they are in the few places that have to work (failure at the bottom of the tree is critical, but in the top is not a problem). The requirement for photonic circuits is not as high as in CPU semiconductor industry.
- Depends on the value of the yields. Some devices are more robust to imperfection. This is why groups have used ring resonators instead of photonic crystals. The yield is much higher. E.g. two rings, it's still ok if the rings are not identical. Even if the directional couplers are not 50/50 it can still work because it uses symmetry. Smart Design can help! Many tricks to work well with what we have now.

Outlook for students

- If you are a student in photonics pay attention to performance. Go beyond break even, and look at it holistically and with practicality.
- At the moment there is no serious reason that photonics will not be a great platform for QC. Loss can be solved.
- Anyone interested in optics/q optics : Most interesting time for you to be in this field because we are in the 1950’s era of the quantum revolution. No matter which modality wins, you will have to interconnect your devices using photonic interconnects.