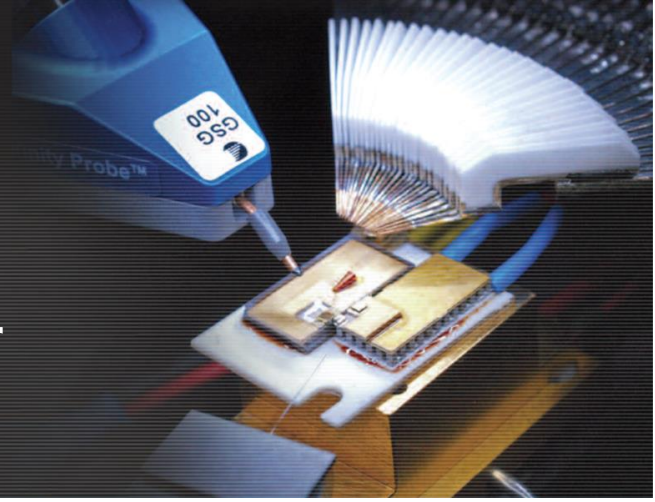
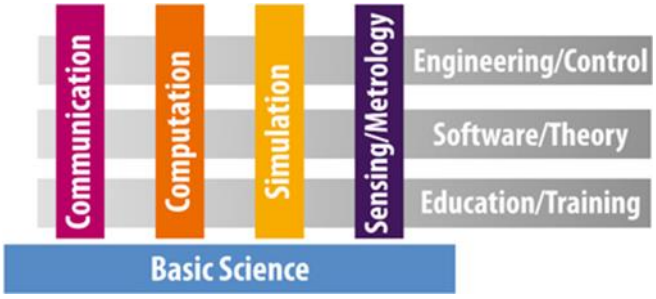


Photonic Integrated Circuits for Quantum Technology

Quantum Technology (QT) is required for the application of quantum mechanics in a wide variety of fields. The EU Quantum Flagship[1] identifies four application areas, namely Quantum Computing, Quantum Simulation, Quantum Communication, and Quantum Sensing and Metrology. A variety of techniques and systems can be considered for such quantum-based technologies, including those based on cold ions, diamond vacancies, Josephson junctions, and photons. Besides such core technological choices, any real-world quantum system would also need enabling technologies, such as, for example, cryostats and ultra-low-noise electronics.

The opportunities of QT are wide-ranging and with a potentially huge impact. Quantum computers hold the promise of solving problems with unprecedented speed, or to tackle problems that current computers cannot even handle nowadays, i.e., the quantum advantage. Although such applications might still be over a decade away, other applications of QT have now been deployed and are getting close to commercialization, such as secure communication based on quantum key distribution.



Strategic research agenda for the EU QT Flagship[2]

The opportunity for photonic integration

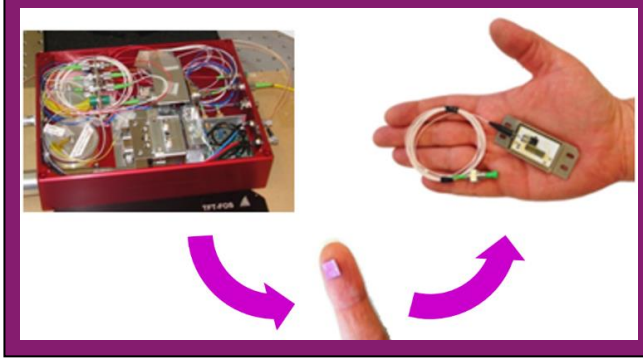
Photonic integrated circuits (PICs) offer some very concrete opportunities for QT. In quantum communication, PICs are foreseen to be critical elements in the near-term deployment of metropolitan quantum-key-distribution-based secure systems[2]. Individual and entangled photons can be generated, modulated and routed on the PIC. The existing use of PIC components and functionalities for wavelength-division multiplexed networks can be leveraged to enable practical quantum communication. Quantum entropy sources for gigabit-per-second random number generation are now being developed on a PIC by QuSide Technologies[3].

In quantum computing, photons can be used for the encoding of qubits. PICs can be used for ultra-low loss, large-scale scalable linear optical circuits for routing,

Photonic Integrated Circuits (PICs)

Also known as optical chips, PICs can contain tens to hundreds of optical components. While electronic ICs consist of transistors, capacitors and resistors, a PIC consists of, for example, lasers, modulators, photodetectors and filters, all integrated on a single substrate. These PICs are nowadays extensively used commercially, mainly in datacom and telecom.

PIC technology has now become accessible to users without a cleanroom, through so-called multi-project wafer runs and open foundries. For example, indium phosphide based technology is commercially available through SMART Photonics and Heinrich Hertz Institute, and silicon nitride technology through LioniX. Access is coordinated by the JePPIX platform: http://www.jeppix.eu/.



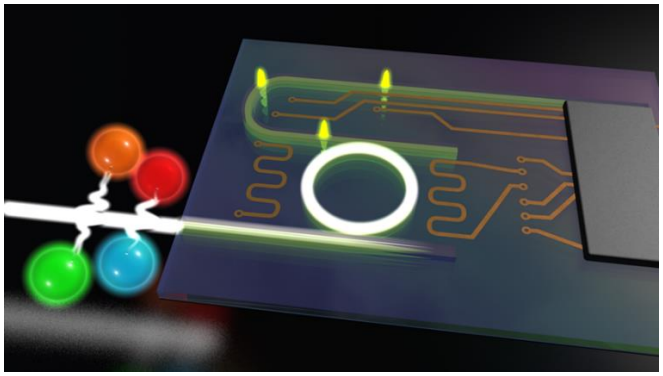
[1] https://qt.eu/

[2] https://doi.org/10.1088/1367-2630/aad1ea

[3] https://www.quside.com/

processing and analysis. The available nonlinearities can be utilized for photon pair generation. Based on such approaches, PsiQuantum is now building a general-purpose silicon photonic quantum computer[4]. QuiX has recently been founded to develop a single-purpose photonic quantum computer, based on silicon nitride PICs, for use in machine learning and quantum simulation applications[5]. Further integration of functionalities is possible, and, e.g., Xanadu is pursuing the integration of a squeezed light source on a PIC[6].

Beyond quantum communication and photonic quantum computing, photonics, and hence PICs, can play an important role for other quantum technologies. Communication with and control of cryogenically cooled QT systems is better achieved through optical fiber access, for reasons of compactness and heat capacity[7]. Arguably, microwave photonics can replace conventional microwave technology for low-interference and compact systems. More explorative opportunities include the on-chip integration of ion traps and their optical addressing[8].



Artist impression of photon pair generation using a PIC, by Michael Kues, Aarhus University.

Current technical developments

The PIC and overall system need to be carefully designed for the target application. Although the PIC technology platforms are mature, they have been developed mostly for telecom and datacom applications. QT might require a different design approach, based on a different trade-off. One critical difference is that many QT applications require ultra-low losses, with overall circuit insertion losses not exceeding the ~1-dB level. On the other hand, high-speed operation well above 1 GHz is typically not required.

In the current mature PIC platforms, controlled single-photon emitters and single-photon detectors, like avalanche detectors (SPADs), are not available yet. Hybrid approaches can be pursued, whereby SPAD arrays are coupled to silicon nitride PICs, for example. Packaging facilities to enable such hybrid approaches are now commercially available, e.g., as offered by PHIX and LioniX[9], and by the PIXAPP Photonic Packaging Pilot Line[10].

Discuss your application with us

If you are interested to know more about the use of PIC technology for QT applications, please contact Martijn Heck, coordinator of the PICs4All Application Support Center (ASC) at Aarhus University, Denmark, or Michael Kues. We have experience with all major PIC platforms, i.e., silicon, silicon nitride and indium phosphide, for application in QT and related fields. Specific expertise includes nonlinear photonics, laser diodes, and high-speed and ultra-low loss PIC design. We are set up to help you to do a feasibility study for the use of PICs for QT applications.

The PICs4All consortium[11] is funded under the Horizon 2020 framework and brings together expertise to support end-users, like academia, research institutes and industry, with PIC technology. The ASCs can help you connect to the eco-system of designers, foundries, packaging and test services.

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[4] https://psiquantum.com/
[5] https://nano-cops.com/news/cops-scientists-found-quantum-startup-quix
[6] https://www.xanadu.ai/
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[9] https://photonics.lionix-international.com/packaging-service/
[10] http://pixapp.eu/
[11] http://pics4all.jeppix.eu/