EPIC Online Technology Meeting on
Quantum Computers

EPIC
EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

INSTITUT d'OPTIQUE GRADUATE SCHOOL ParisTech | université PARIS-SACLAY

NAQUIDIS CENTER atomQtrl

PHOTONICS AS A KET FOR QUANTUM COMPUTING : AN INTRODUCTION

Johan Boullet – Institut d'optique Graduate school, France

johan.boullet@institutoptique.fr

Statement

Optics and photonics are a core enabling element of quantum technologies, as many of the systems require very precise control of light

Quantum technology presents various innovation opportunities for the optics and photonics community, and there is a large ecosystem of component, system, and service players with various requirements for their respective architectures...

Who could be the key players of this QT European Ecosystem?

What is the true market of QT for photonics actors?

How to build together a pereign & mature Quantum Photonics Market

Quantum Computing

There are classes of problems that are exponentially difficult to deal with depending on the number of particles with a classical computer but which can be solved in polynomial time with a quantum computer.

Shor factorization algorithm for example.
Deutsch-Jozsa algorithm.

Considerable potential applications in materials science and condensed matter, chemistry, protected communications, etc.
Optimization problems, the traveling salesman,…

The power of the quantum computer comes from entanglement but
its weakness comes from the fragility of superpositions of states with N particles

Quantum Technology

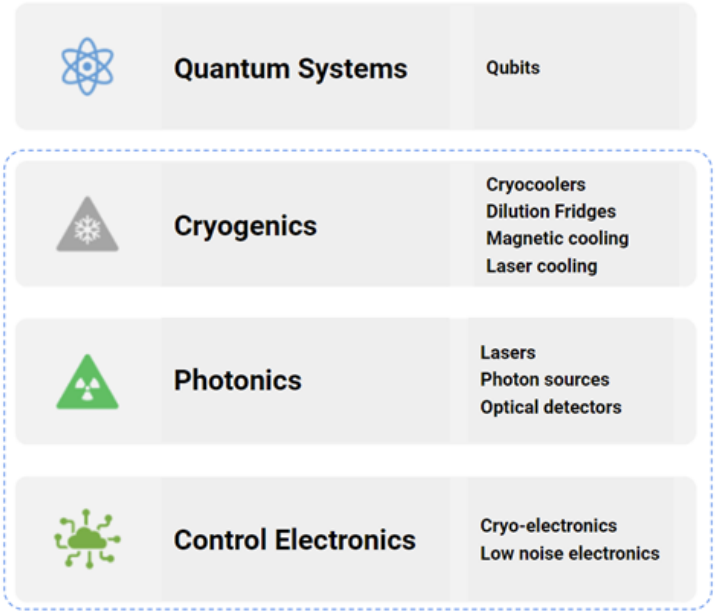
EPIC Online Technology Meeting on Quantum Computers

Quantum Systems

- Atoms & Ions
- Superconducting & Semiconductors
- Hybrid
- Topological
- Molecular
- Color Centers
- Photonic

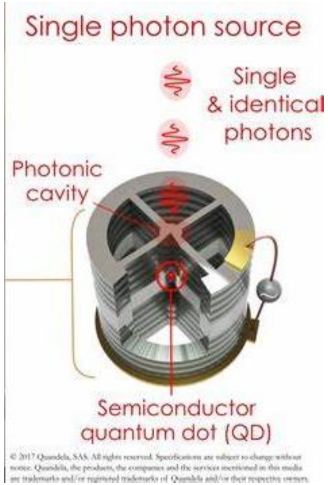
Essential Enabling Technologies

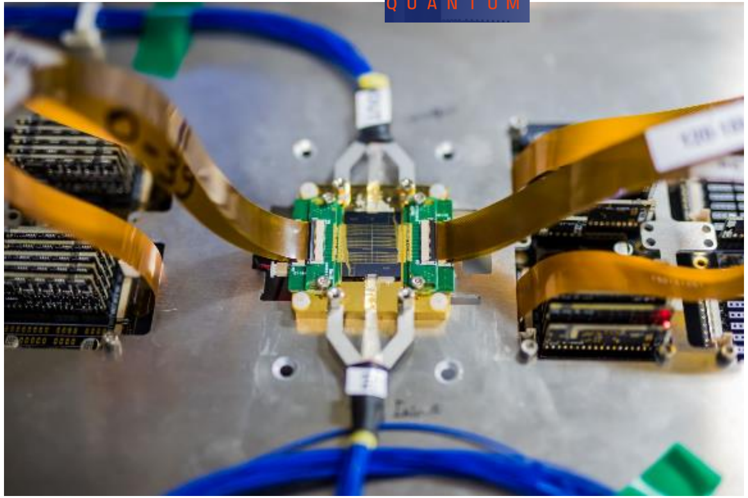
- Cryogenics
- Photonics
- Control Electronics



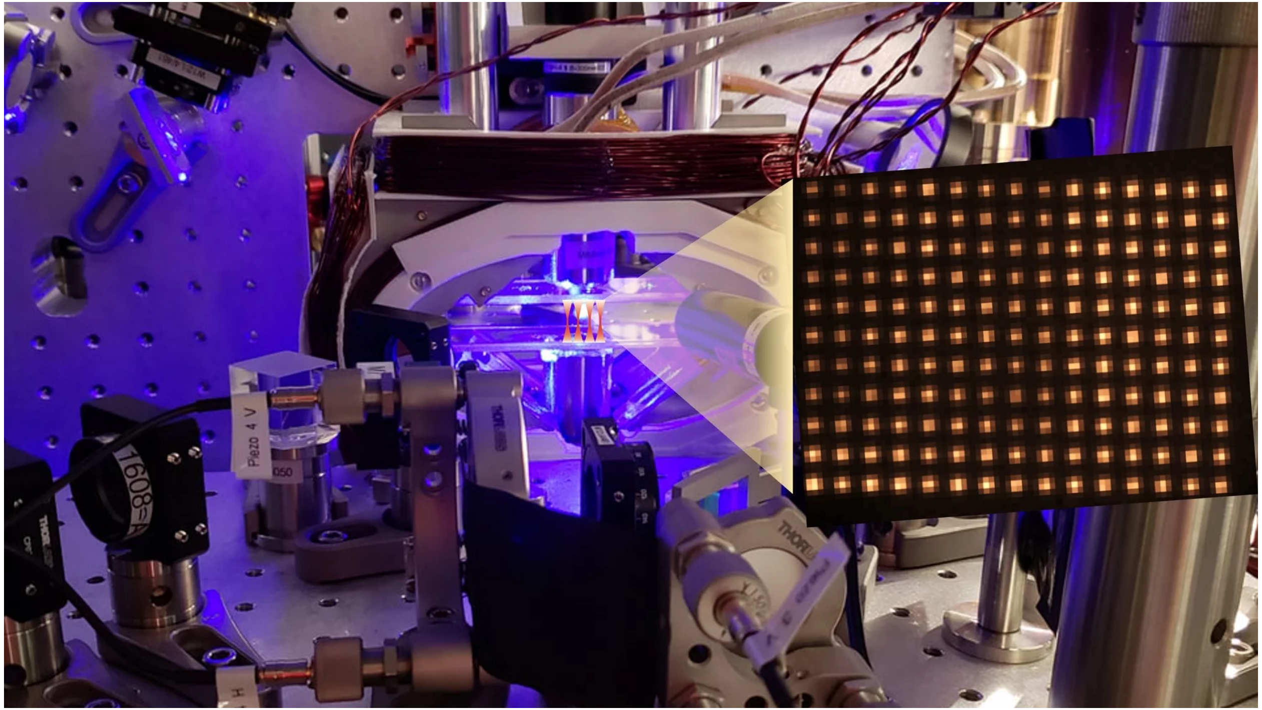
PIC & SPP


QUANDELA


Single photon source
Single
& identical
photons
Photonic
cavity
Semiconductor
quantum dot (QD)



Quantum computing with atoms



Quantum computing with ions

nature

Explore content | About the journal | Publish with us

nature > articles > article

Article | Published: 21 October 2020

Integrated multi-wavelength control of an ion qubit

R. J. Niffenegger, J. Stuart, C. Sorace-Agaskar, D. Kharas, S. Bramhavar, C. D. Bruzewicz, W. Loh, R. T. Maxson, R. McConnell, D. Reens, G. N. West, J. M. Sage & J. Chiaverini

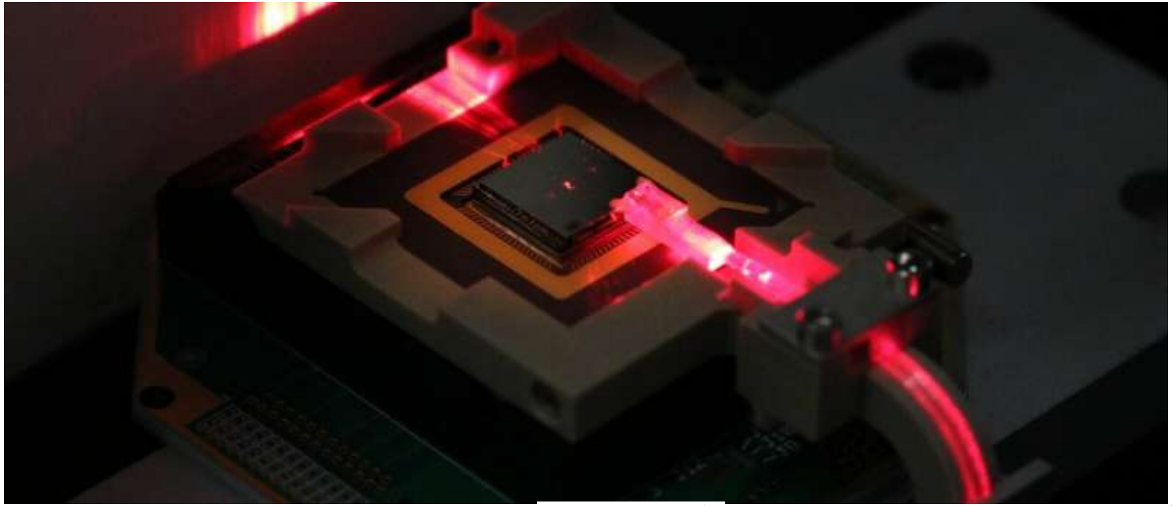
Nature **586**, 538–542 (2020) | Cite this article

A Publisher Correction to this article was published on 19 January 2021

OCTOBER 22, 2020

Control ions for quantum computing and sensing via on-chip fiber optics

by Kylie Foy, Massachusetts Institute of Technology



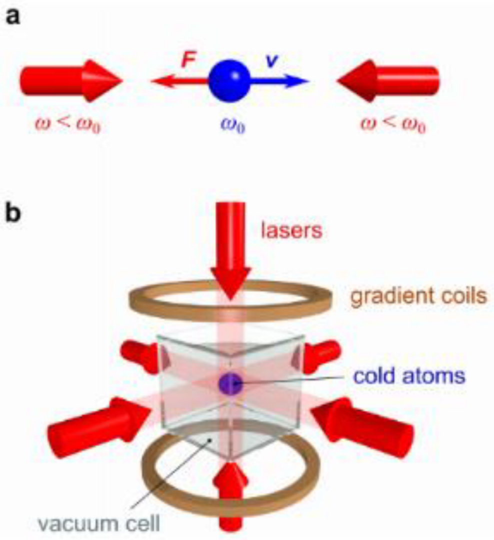
INSTITUT d'OPTIQUE GRADUATE SCHOOL

NAQUIDIS CENTER

atomQtrl

Photonics as KET : lasers

Élément		Longueur d'onde (nm)	Accordabilité (nm)	Puissance (Watts)
37 85.468 Rb Rubidium	Refroidissement, Piège, Capteur, Détection	780	± 0.1	1 - 2
		815-850	Non	2 - 10
		1560	Non	5 - 15
	Rydberg	420	Non	1 - 2
		1013	± 2	50 - 100
		1013	± 2	0.2
	Qbit	795	± 1	3 - 10
		795	Modulé	1
		1590	± 0.5	0.1
38 87.620 Sr Strontium	Refroidissement, Piège	461	± 0.01	1 - 3
		813	± 0.5	5
	Capteur	689	± 0.01	1
	Rydberg	317 – 320		1
	Qbit	707	± 0.1	1
		679	± 0.1	1
	Détection	408	± 0.01	1
70 173.04 Yb Ytterbium	Refroidissement	399		1-5
		556		0.5-1
		649		<0.1
		770		<0.1
	Alternative	1388		<0.1
	Capteur	578		<0.1
	Piège	759		1-10



The laser quality and performance are very important:

- Wavelength is related to the atomic transition used
- Laser power
- Laser stability and linewidth
- Agility
- Tunability
- …

➔ **$LiNbO_3$ modulators and special fibers are used….**

Quantum computing with supra

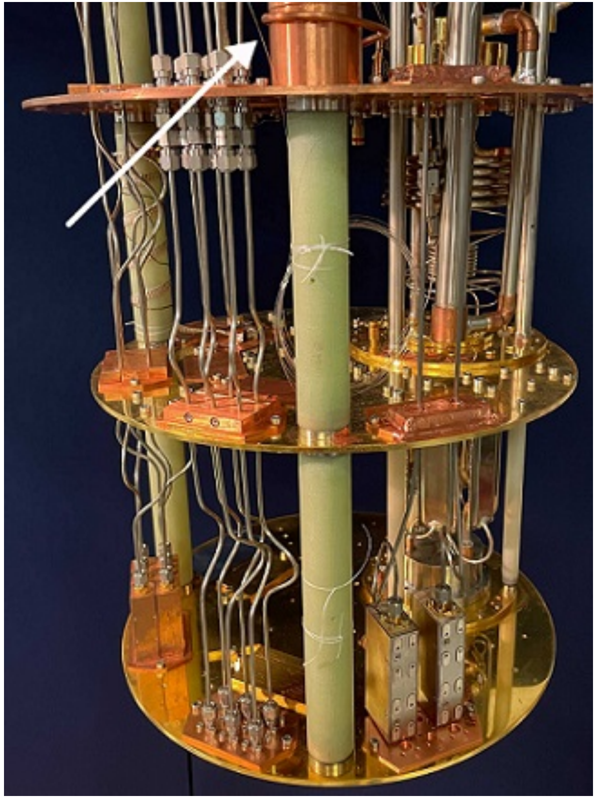
- chip @ 50 mK, wire @ 300K…
- RF can be


Article | Published: 24 March 2021

Control and readout of a superconducting qubit using a photonic link

F. Lecocq, F. Quinlan, K. Cicak, J. Aumentado, S. A. Diddams & J. D. Teufel

Nature **591**, 575–579 (2021) | Cite this article



A ROAD TO QUANTUM INTERNET?

Quantum communications leverages the properties of quantum state preparation and measurement as well as intrinsic quantum phenomena such as entanglement and squeezing to create secure communications networks…

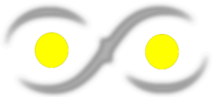
How to overcome propagation losses

- Major challenge : propagation loss in optical fibers : 0.2 dB/km → 99% loss for 100 km
- No signal reamplification possible in contrast with the classical Internet …

- **1st approach : intermediate trusted nodes**
  - Decryption / Re-encryption with another key

Ex. of 2000 km Chineese quantum communication network with 32 trusted nodes

- **2[nd] approach: intermediate untrusted quantum relays**
  - Requires photon entanglement



Road to 2035: Near-Term (2025 – 2029)

Lasers
- Power, wavelength range, low noise etc
- SWAP reduction
- Higher TRL

Single-photon sources
- Higher efficiency sources

Photonics / Optics
- EU sovereignty for components (free space, fiber, crystals, diodes etc)

Advanced optical detectors
- Higher efficiency telecom detectors
- Larger detectors for space

Integrated Photonics
- New production facilities
- Cryogenic compatibility
- Loss reduction
- Source, detector, and modulator integration
- On-chip single photons and squeezed light

Road to 2035: Long-Term (2030 – 2035)

Lasers

- Further SWaP Reduction of lasers, stabilized lasers, optical frequency combs etc
- Cost reduction
- Reduce necessary user interaction

Single-photon sources

- Improve miniaturisation

Advanced optical detectors

- Real photon-number-resolving detectors;
- Higher count rates
- Ultralow time jitter

Integrated Photonics

- High-end foundry fabrication
- Assembly lines photonic integrated circuits

Dual Use of QT : EU recommandation, 10/2023

European Commission - Press release

Commission recommends carrying out risk assessments on four critical technology areas: advanced semiconductors, artificial intelligence, quantum, biotechnologies

Strasbourg, 3 October 2023

Today, the Commission adopted a Recommendation on critical technology areas for the EU's economic security, for further risk assessment with Member States. This Recommendation stems from the Joint Communication on a European Economic Security Strategy that put in place a comprehensive strategic approach to economic security in the EU.

This Recommendation relates to the assessment of one of four types of risks in that comprehensive approach, namely technology risk and technology leakage. The risk assessment will be objective in character, and neither its results nor any follow-up measures can be anticipated at this stage. In the Recommendation, the Commission puts forward a list of ten critical technology areas. These technology areas were selected based on the following criteria:

- Enabling and transformative nature of the technology: the technologies' potential and relevance for driving significant increases of performance and efficiency and/or radical changes for sectors, capabilities, etc.;
- The risk of civil and military fusion: the technologies' relevance for both the civil and military sectors and its potential to advance both domains, as well as risk of uses of certain technologies to undermine peace and security;
- The risk the technology could be used in violation of human rights: the technologies' potential misuse in violation of human rights, including restricting fundamental freedoms.

QT enabling industry needs worldwide market

- Not a **<u>fundamental lack of supply</u>** -> Europe is the home for the best suited laser sources & photonics systems for QT and serves maybe 60 to 80% of the current global market demand for quantum.

- On the other hand, there can be a **<u>fundamental discrepancy</u> between the expectation of the not-laser-savvy <u>quantum customers and their SWaPc requirements</u>** on one side and the existing photonics companies in the field on the other side.

- **<u>Lack of realism on the market size</u>** as far as the transition effort to bridge such discrepancy is concerned.

- Mastering the demand **<u>in small volume today by testing the quality in limited series</u>** is a tricky thing...

• <u>From small volume and high cost to largest volume and low cost we need a consistent longterm market</u> (not funding alone with its wavy political uncertainties), **<u>in non-European markets</u>**, that we cannot address due to understandable European souvereignity concerns.

- **Capital investment** is needed.

- **Government / European contracts** (compare to USA)