Modular Optical Quantum Computing

available on the cloud

Niccolo Somaschi – Chairman & CTO
niccolo.somaschi@quandela.com

15 December 2022
CINECA – Bologna (IT)
60 people dedicated to Quantum Computing & Quantum Photonics

>40 PhDs and engineers in semiconductors, quantum information theory, quantum optical technologies and computer science
Digital Quantum Computing Approaches

1. Matter Qubits: Ions, Superconductors, Cold Atoms...

   **Static qubits**: physically located in a QPU

   **Control Signals IN**

   **Read-OUT Signals**

   + Highly **EFFICIENT** 2-qubit GATES (deterministic)
   **BUT** Qubits have a physical size → Manufacturability roadblocks
   **BUT** Each qubit undergoes DECOHERENCE → errors with #qubits

2. Photonic Qubits

   Photons are **Flying Qubits** → moving through the QPU and through optical fibers

   **1 PHOTON IN 2 SPATIAL MODES (DUAL RAIL ENCODING)**

   Photon

   "|0>  |1>"

   **Sequence of n-qubit gates**

   - **Success probability** << 50%

   **+** ROBUST qubits (no decoherence)
   **+** MANIPULATION with classical elements (telecom, linear optics)
   **BUT** 2-qubit GATES are NOT EFFICIENT (probabilistic) → HARD to scale
Quandela exploits the efficient manipulation of optical qubits but tackle probabilistic nature of gates with a matter-based qubit generator.
Scalability & manufacturability with Photonic Quantum Computers

**Quandela’s OS:** classical control based on QC protocol + error correction

Feedback control (“FEED-FORWARD”)

READ-OUT electronics

QPU

Qubit GENERATOR → Qubit MANIPULATION → Qubit MEASUREMENT

*96% *

*99.54% purity **

→ 0.05 dB/cm

→ 99.9%

---


** "Near-optimal single-photon sources in the solid state": N. Somaschi at al, Nature Photonics, 10, 340, 2016 -
Cluster states generation for FTQC

MBQCs PROTOCOL

QUANDELA’S CLUSTER STATES GENERATOR

LINEAR OPTICAL ELEMENTES
- PROBABILISTIC
- 1000s of COMPONENTS

Cluster states generation for FTQC

**MBQCs PROTOCOL**

1D

2D

3D

**LINEAR OPTICAL ELEMENTS**

- PROBABILISTIC

- 1000s of COMPONENTS

**QUANDELA’S CLUSTER STATES GENERATOR**

A near-deterministic single-photon source

Massive reduction of overheads:

- 1 vs 1000s components

Generation rate \(> x 100\) higher than other quantum technologies (QDs & atom based)

N. Coste et al., "High-rate entanglement between a semiconductor spin and indistinguishable photons", arxiv:2207.09881, (2022)

**2024:**

Spin coherence time 10s ns & >98% purity

\( \rightarrow >5 \) photons cluster
On-premise & cloud accessible, optical QC - today

- Upgradability offered by modularity
- Scalability by the use of optical fibers and semi-conductor tech.
- Low energy consumption (~3 kW) with optimised and integrated cryostats, ready for deployment
Access to powerful “noisy” simulators (up to 15-20 photons) and real Quantum Processor Units

Generate and manage your tokens and keep track of your projects

Manage your company account and follow the activities of your collaborators

Intuitive Interface with Extensive Documentation

Optical QPUs in the cloud
https://cloud.quandela.com
Quandela is Delivering Real Life Use Cases for Customers Today

- **Cybersecurity**
  - Using quantum certified randomness to generate spy-proof hash keys
  - **Applications:** defense and security, post-quantum cryptography, banking industry

- **Molecular Design**
  - Using Variational Quantum Eigensolver (VQE) to resolve 3D-molecular configuration
  - **Application:** drug design in pharmaceuticals

- **Logistics**
  - Using state superposition to simultaneously explore a large number of paths to research solutions for NP-hard problems
  - **Application:** drone cohort flight planning

- **Time-Series Forecasting**
  - Using quantum forward propagation to detect weak signals in long time series
  - **Application:** finance & insurance industry

+ undisclosed users
**Quandela is Delivering Real Life Use Cases for Customers Today**

**Solving Partial Differential Equations**

- **Challenge** – reducing computing time and resources involved in PDE solving traditionally done on **HPC**

- Developed a **variational quantum circuit** by exploiting the quantum properties of photons

- Designed for **scaling-up** towards exponential **advantage** when compared to classical

- **Application**: to improve the **safety** of hydroelectric dams and **nuclear plant pipes**

**MBDA**

**Calculating the Behaviour of Polymer Materials**

- **Challenge** – improve accuracy of classical machine learning for classification tasks on large and complex datasets with huge dimension of parameters

- Developed **classical-quantum neural networks** to classify polymers with state-of-the-art results

- **Application**: to allow the **faster** and **more efficient prediction** of polymers’ properties (e.g., ductility, thermal stability)

Towards QC “advantage” via photonics

With $n$ photons, we count the particles in each $m$ mode, the size of the space is

$$\binom{n+m-1}{n}$$

Quandela’s 24-photon QPU is equivalent to $\sim 40$ qubits QC
Quandela - today

QPUs access on https://cloud.quandela.com & full-stack QC systems for on-premise deployment

State-of-the-art algorithms for tailored industrial use-cases

Demonstration of the most efficient generation of cluster states – resource for FTQC

"Thank you to Quandela for their ambition, their talent and for so many more projects yet to come! With confidence."

French President Emmanuel Macron
Semiconductor Quantum Devices & Quantum Photonics

Coste et al., “High-rate entanglement between a semiconductor spin and indistinguishable photons”, arXiv:2207.09881

Pont et al., “High-fidelity generation of four-photon GHZ states on-chip”, arxiv 2211:1562

Algorithms and Quantum Information


