NanOQTech

Nanoscale Systems for Optical Quantum Technologies

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D4.6 Dissemination and Exploitation Plan

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Version history

Version	Date	Author(s)	Description
V1	04/08/2017	D. Serrano (CNRS-CP)	Draft
V2	11/08/2017	D. Serrano, P. Goldner (CNRS-CP)	Revised draft
V3	20/09/2017	D. Serrano, P. Goldner (CNRS-CP) and all Partners	Final version

Table of Contents

Deliverable Description

This deliverable establishes a "Dissemination and Exploitation Plan" (DEP) for NanOQTech's outputs. Dissemination and exploitation strategies are strongly linked since developing efficient dissemination channels opens the pathway for subsequent societal and economical exploitation of the project's results.

Dissemination

Dissemination actions have the objective of making the advancements achieved through NanOQTech available to a broad audience in order to promote further scientific developments, and raise awareness about their social impact and exploitation potential.

The main dissemination actions which are planned to be carried out during NanOQTech and after its end are summarized in Table 1.

Action	Leading partner	Targeted audiences	Indicators
Publication of results in peer-reviewed journals	All	Scientific community	Impact factor, citations, downloads
Website	CNRS-CP	Scientific community, industrials, institutional actors, general public	Visitor analytics
Newsletter	CNRS-CP	Scientific community, industrials, institutional actors, general public	Number of subscribers, analytics
Events	CNRS-CP	Scientific community, industrials, institutional actors, general public	Organized: number of attendees, satisfaction surveys Attended: number of invited talks, oral presentations and posters
Social media	CNRS-CP	scientific community, industrials, institutional actors, general public	Number of followers
Leaflet	CNRS-CP	Scientific community, industrials, institutional actors, general public	Contact requests, demonstrations of interest
Logo	CNRS-CP	Scientific community, industrials, institutional actors, general public	Logo recognition, number of times displayed

Table 1: Dissemination actions.

The Dissemination timeline planning will span the entire length of the project and extend beyond (Table 2).

	NanOQTech contract			Post NanOQTech contract				
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Publications								
Conferences								
Website								
Newsletter								
Events								
Social Media								
Leaflet								
Logo								

Table 2: Roadmap for dissemination actions.

Publication of scientific results in peer-reviewed journals

The aim of this action is the communication of NanOQTech's results to the scientific community. Therefore, it primarily targets a specialized scientific audience although manuscripts and data[1] will be made available to everyone on an open access platform: zenodo.org[2]. Through this dissemination action, the value of the scientific results will be immediately quantified by the journals' impact factors and, in the long term, the number of citations and number of manuscript downloads.

NanOQTech has already given rise to several publications (Table 3), a scientific production which is expected to increase during the upcoming years, with a maximum output between the last year of contract and the immediate subsequent years.

[1] See the "Data Management Plan" (deliverable 4.4) for more details.

[2] The totality of NanOQTech contents uploaded to zenodo.org will be available in open access no more than 6 months after their publication.

Title	Partners	Journal	Impact factor
Dispersive coupling between light and a rare-earth-ion–doped mechanical resonator	CNRS-IN CNRS-SY AU	Physical Review A *(Phys. Rev. A 94, 053804, 2016)*	2.92
Optical Line Width Broadening Mechanisms at the 10 kHz Level in Eu3+:Y2O3 Nanoparticles	CNRS-CP	Nano Letters (*Nano Lett.*, *17* (2), 778, 2017)	13.78
Nuclear spin coherence properties of 151Eu3+ and 153Eu3+ in a Y2O3 transparent ceramic	CNRS-CP	Journal of Physics: Condensed Matter (*J. Phys. Cond. Matter* 29 (12), 2017)	2.65
Dispersive heterodyne probing method for laser frequency stabilization based on spectral hole burning in rare-earth doped crystals	CNRS-IN CNRS-SY CNRS-CP	Optics Express *(Opt. Exp. 25 (13), 15539, 2017)*	3.31

Table 3: Publications related to NanOQTech.

Project website

The website, **www.nanoqtech.eu** has been used from the early beginning of the project as the main communication platform for NanOQTech's activities. It is therefore periodically updated with all news related to NanOQTech, including published papers (with their corresponding open access links), events, deliverables, details about the every-day-life of the project, open position offers, contact information, as well as outreaching posts. It is therefore designed for the largest audience, from scientists to general public interested in the emergent quantum technologies. The website also provides information about the NanOQTech's goals, consortium and EU funding, as well as background information on quantum technologies.

The website host[3] provides detailed analytic services, which are used to evaluate web performance.

Newsletter

With a similar objective as the website, the newsletter aims at raising awareness about the project's activities, outputs, achievements and their potential social impact. In contrast to the website, it provides a way to actively target particular sectors of audience, professionals, industrials or potential investors. The first NanOQTech's newsletter appeared in June 2017 with a new edition planned every six months.

[3] NanoQTech website is hosted by wix.com.

The first newsletter was sent to 359 recipients. It was opened 462 times and generated 63 clicks. The same web provider is used for the website and newsletter, with the same analytic services.

Events

Events organization and participation constitute another dissemination strategy in NanOQTech. This includes both specialized events, like scientific congresses or workshops, and general public events, like outreaching conferences. Therefore, conferences, workshops and other training events have mainly a knowledge dissemination objective, while general public events are aimed for improving the project visibility and social impact awareness.

Event's attendance:

NanOQTech members regularly attend scientific conferences in order to disseminate NanOQTech's results within the scientific community while following the updates in the field. Thus, a specialized scientific audience is mainly targeted, although international conferences can also provide good opportunities for knowledge exchange between scientists, industrial exhibitors and other attendants.

Up to now, NanOQTech partners have presented 2 plenary, 12 invited and 3 contributed talks, as well as 4 posters in national and international conferences, workshops and seminars (see Annex I).

Event's organization:

During the first year of contract, two main NanOQTech events have been organized:

- **NanOQTech mini-summer school**

  The NanOQTech mini-summer school took place on May 2-4, 2017 in Paris. The main objective was to provide a custom-designed training and exchange meeting centered on NanOQTech's topics. It was therefore primarily meant for the NanOQTech's consortium members and collaborators, but it was also advertised and made openly accessible for any interested researchers, undergraduate and graduate students. The attendance reached 30 participants[4].

- **Public conference by Klaus Moelmer**

  Klaus Moelmer (AU) accumulates a long experience in outreaching conferences on quantum physics and quantum information. Taking advantage of this, a general public conference was organized in Paris on May 3, 2017 entitled "The quantum computer" in which he presented the principles of this long-time dreamed machine, in front of more than 300 attendees.

[4] See deriverable 4.4 report for more details.

Two other events have been or are organized in relation to NanOQTech:

- S. Kröll (ULUND) organized two breakout sessions on rare earth quantum technology related issues at PQE-2017, Invited speakers at these sessions were, Mikael Afzelius, University of Geneva; Andrei Faraon, Caltech; David Leibrandt, NIST; Charles Thiel, Montana State University and from NanOQTech consortium: Philippe Goldner, CNRS-PC; David Hunger, KIT; Yann Le Coq, CNRS-SY;
- D. Hunger (KIT) is organizing an International Workshop on Rare Earth Doped Crystals for Quantum Information Processing in Karlsruhe (27-28 September 2017). About 50 researchers are attending the workshop in which NanOQtech will be advertised by talks from the Consortium (CNRS-CP, CNRS-SY, CNRS-IN, KIT, ICFO-QP, ULUND, AU) and distribution of the leaflet.

Social media

NanOQTech is currently active on social media through a LinkedIn group[5]. Given the professional character of LinkedIn network, the main objective of this group is to gain broad visibility within the scientific, industrial and institutional sectors.

Leaflet

A 4-page leaflet (see Annex II) has been designed to be distributed by the NanOQTech partners during their attendance to scientific, outreach and industrial activities. Conceived for all-public, the main objective of the leaflet is to increase the visibility of the project, providing context, objectives and links to the project's website and contacts for further information.

Logo

NanOQTech's logo is systematically used in all dissemination actions to provide the project with a visual identity.

Exploitation

The Exploitation strategy's objective is to put the project’s results into practical uses. To achieve this, we plan to patent results that have commercial potential, look for possible industrial partners besides Keysight Technologies to exploit results and/or create start-up companies.

Market analysis and business opportunities

Currently, we are witnessing a strong increase in the development of quantum technologies. To the strong public efforts (Figure 1), have to be added the investments of large industrial actors in the telecommunications, micro-electronics and information technology sectors. Some companies that are active in quantum technologies are listed in

[5] https://www.linkedin.com/groups/8590350

Annex III. Promising markets are expected in the fields of quantum sensing, computing and communications[6].

NanOQTech goals have potential disruptive impacts in quantum technologies. Moreover, highly demanding technological challenges that need to be overcome to reach these goals may also lead to multiple exploitable outputs in other fields.

A number of identified exploitable outputs and potential users is listed as follows:

Quantum technologies

1. Quantum memories for light
    - application: quantum cryptography for secure internet exchanges, quantum networks.
    - users: communication, information technology, defense companies; government institutions.
2. Quantum force sensing
    - application: imaging, gravitation measurements, charge and spin sensing.
    - users: bio-medical and research instrumentation companies.
3. Single-photon source
    - application: quantum cryptography, computing, imaging, random number generators.
    - users: communication, information technology, photonics and research instrumentation companies.
4. Quantum opto-electronics
    - application: ultra-compact opto-electronics circuits and sensors.
    - users: micro-electronics and photonics companies.

Other fields

1. Cryogenics
    - application: low temperature nano-positioning systems with active control of vibrations.
    - users: research instrumentation companies.
2. Laser stabilization
    - application: ultra-narrow lasers.
    - users: photonics and research instrumentation companies.
3. Fluorescent nano-materials
    - application: biological probes, lighting.
    - users: chemical and bio-medical companies.
4. Real-time control software and hardware
    - application: signal processing.
    - users: electronics and photonics companies.

[6] The Economist, https://www.economist.com/news/leaders/21718503-strangeness-quantum-realm-opens-up-exciting-new-technological-possibilities-quantum

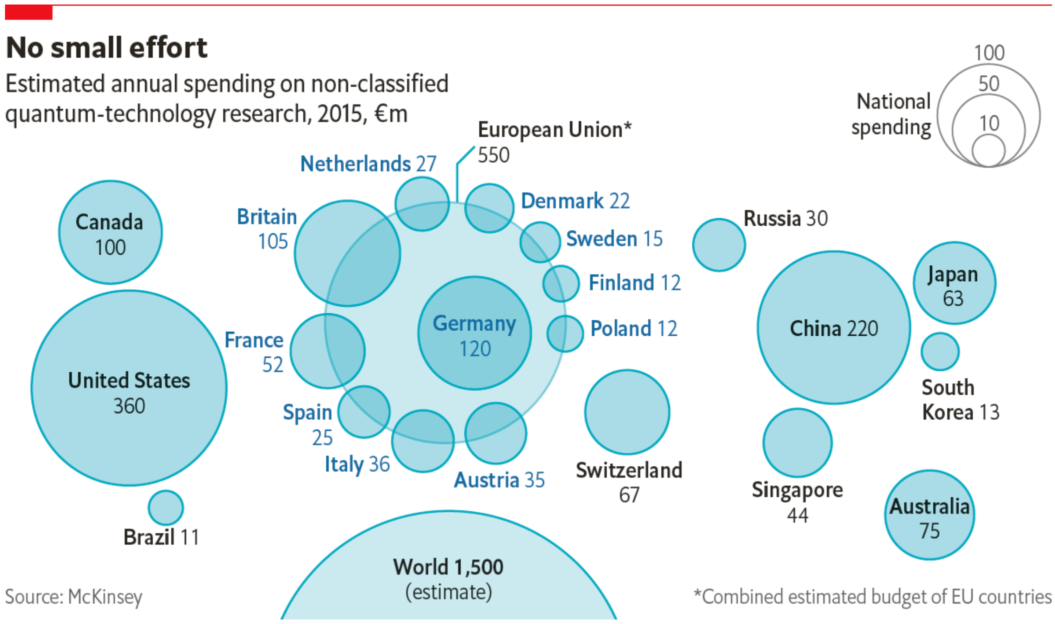

Figure 1: Public efforts in the development of quantum technologies (source "The Economist")

Several systems are currently studied to achieve the functionalities in quantum technologies that are targeted in NanOQTech (cf. table 4). The rare-earth nano-systems we investigate have potentially important competitive advantages over these other approaches.

NanOQTech is based on rare earth doped nanostructures, which we expect to have the following key properties for quantum technologies:

- long coherence lifetimes for optical and spin transitions, although at liquid helium (LHe) temperatures
- stable centers (physically, chemically and with respect to optical and spin properties) embedded in solid-state structures
- wide range of rare earth concentrations
- visible and infrared transitions, including telecom wavelength
- wide range of compositions, structure sizes and forms (particles, films).

To our knowledge, this combination of properties is unique among systems for quantum technologies. It translates into competitive advantages that are summarized in the table below.

Application	Competing systems	NanOQTech advantage
Quantum memories for light	Bulk rare earth crystals	Access to single ions for processing capabilities
	NV centers in diamond	Multimode storage, telecom wavelength, long term stability
	Atomic vapors	Long storage time, easy to handle solid-state system
Quantum force sensing	Cold atoms	High sensitivity, long term stability, sensor built in the oscillator
	NV centers in diamond	High sensitivity, long term stability
Single photon source at telecom wavelengths	Carbon nanotubes Semi-conductors	Narrow band photons for interactions with quantum memories
Quantum opto-electronics	NV centers in diamond Semi-conductors nanocrystals	High density of emitters and telecom wavelength

Table 4: Competing systems and NanOQTech's competitive advantages.

Developments on competing systems and teams will be closely followed and a review will be made at each project's meeting or sooner if necessary.

Intellectual property protection

The consortium agreement defines the management of intellectual properties among the partners. It was signed in September 2016 prior to the start of the project.

Roadmap and business model

The exploitation of NanOQTech's results is planned first through patents. When applicable, patentable results will be first discussed with exploitation services of the different partners' institutions and then filled in compliance with the consortium agreement.

The business models favored in NanOQTech are patent licensing and/or creation of start-up companies, depending on the industrial context of the results to be exploited. These matters will be discussed with the Keysight team involved in the project, which is originally a spin-off of the partner ICFO and has a very useful experience to share.

Participations into industry workshops will raise the awareness about the project's results (see dissemination), may enable to set up partnerships with new companies, and importantly will allow us to periodically assess the needs of the users in terms of functionalities and performances. It can be noted that several companies active in or related to quantum technologies have expressed their interest in NanOQTech (Thales, Id Quantique and Attocube). Along the same line, we will organize an industry workshop in the 3rd year of the project (D.4.8) and a report on quantum technologies is also scheduled in the first year of the project (D4.4). All these activities will support our business model, i.e. the research of partners for licensing NanOQTech results and/or creating start-up companies. A tentative roadmap of these different actions is shown in Table 5.

Exploitation training

NanOQTech partners will be encouraged by the project and exploitation coordinators (see below) to participate in exploitation training sessions. All partner's institutions organize such training on a regular basis. We will also aim at attending training specifically designed for FET OPEN projects, like the workshops organized by the fet2rin consortium[7].

	NanOQTech contract			Post NanOQTech contract				
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Patents								
Industry workshops, meetings, fairs								
Exploitation training								
NanOQTech industry workshop								
NanOQTech report on quantum Technologies								
Start-up companies								

Table 5: Roadmap for exploitation actions.

Risks and challenges

As previously mentioned, there exists multiple scientific and technical challenges to be overcome by NanOQTech's partners in order to meet the quantum technologies market demands. Therefore, NanOQTech's time frame (3 years) could be a too short period to

[7] http://www.fet2rin.com

solve all technical issues to immediately achieve commercially exploitable devices. Nevertheless, important outputs are expected, and the increasing public funding on quantum technologies for the upcoming years sets a perfect context for continuing developing NanOQTech's achievements towards exploitation. As mentioned above, we will also periodically check the industrial needs to ensure that our goals are consistent with market and technology evolutions.

Indicators

We identify the following indicators to assess the exploitation plan:

- number of participations by NanOQTech members to industrial events related to quantum technologies meetings, workshops, fairs, etc.
- number of participants at NanOQTech industrial workshop classified by their origin (e.g. academics, industrials, investors…)
- number of participations to training events for improving exploitation (e.g. fet2rin project)
- number of patents
- number of start-up companies

Monitoring and management of the activities

The project coordinator (PC) and the project manager (PM), both at CNRS-CP, perform the monitoring of the dissemination activities, in close contact with the WP leaders. The project-wide dissemination actions (website, logo, flyers, summer school, newsletters etc.) are mainly produced and updated by the PM with the input of all partners. The partners are responsible for dissemination in their respective fields and institutions.
The industrial partner (Keysight Technologies) is the exploitation coordinator. It monitors the exploitation plan in contact with the PC and the WP leaders. It also manages IP protection and look for patent opportunities in the project's activities. It is the project contact point for potential industrial partners and will organize an industrial workshop to promote NanOQTech results and discuss possible commercial exploitations. All partners will be active in identifying potential stakeholders, companies, competing approaches, as well as new opportunities in relation with NanOQTech.

Conclusion

The dissemination strategy for NanOQTech relies on a number of agreed actions, having as a main objective the communication of the project's outputs to the most suitable audiences in order to raise awareness about their potential economical and societal impact. In the context of an emerging quantum technological market, the subsequent exploitation of identified outputs is planned by means of patents, active seek of industrial partners and creation of start-up companies.

Annex I: Talk and Poster Presentations

Title	Type	Partners	Conference
Towards cavity enhanced single-rare-earth-ion detection	Contributed	KIT	DPG-Frühjahrstagung (DPG Spring Meeting), Mainz, Germany, 6 – 10 March 2017
Towards cavity enhanced single-rare-earth-ion detection	Contributed	ICFO-QP	Single Photons Single Spins (SPSS) Meeting, Troyes, France, 29 – 1 September 2017
	Invited	KIT	PQE Conference 2017, Snowbird, USA, Jan 2017
	Invited	KIT	Seminar of Institute of Applied Physics, University of Bonn, Germany, 2017
	Invited	KIT	Seminar, QUTech, TU Delft, The Netherlands, 2017
	Invited	KIT	CEWQO Conference 2017, Lyngby, Denmark, 2017
	Invited	KIT	Quantum Information Workshop, Hong Kong, China, 2017
Strain-coupled hybrid quantum systems with rare-earth doped crystals	Invited	CNRS-IN	Quantum Engineering Science and Technologies Symposium, November 2016, Singapore. *in the presence of Pr. Paul Indelicato (French Ministery for Education and Research) animating a discussion on the Quantum Engineering EU-flagship.*
Optomechanics with rare-earth doped crystals	Invited	CNRS-IN	Foundations and Applications of Nanomechanics, September 2017, Trieste, Italy
Strain-coupled hybrid quantum systems with rare-earth doped crystals	Invited	CNRS-IN	Nanyang Technological University (NTU), Physics department, Singapore, August 2017
Strain-coupled hybrid quantum systems with rare-earth doped crystals	Invited	CNRS-IN	National University of Singapore (NUS), Centre for Quantum Technologies, Singapore, August 2017
High Precision Phase and Frequency Measurements in Rare Earth Doped Crystals at Cryogenic Temperatures for	Poster	CNRS-SY, CNRS-IN	European Frequency and Time Forum, Besançon, France, July 2017

Probing Nanoresonators Behavior			
Quantum applications and spin off discoveries in rare earth crystals	Invited	ULUND	Initiative seminar on Quantum Technology, Chalmers, Göteborg, Sweden, Dec 2016
Quantum information, quantum optics and laser frequency stabilization based on rare earth doped crystals	Plenary	ULUND	PQE-2017, Snowbird, USA, Jan-17.
Towards bulk crystal coherence times in Eu3+:Y2O3 nanocrystals	Poster	CNRS-CP	Workshop on quantum information: fundamentals and applications, Paris, 2016
Rare Earth Doped Nanostructures: Quantum Leaps for Optical Technologies	Plenary	CNRS-CP	International Conference on Luminescence 2017, João Pessoa, Brazil, August 2017
Étude des propriétés de cohérence de nanoparticules de Eu3+:Y2O3	Poster	CNRS-CP	French Workshop on crystals for optics, Paris, France, Sept. 2017
ALD deposition of Er and Eu-doped yttrium oxide thin films for quantum technologies	Poster	CNRS-CP	French Workshop on crystals for optics, Paris, France, Sept. 2017
Narrow Optical and Spin Linewidths in Rare Earth Doped Micro- and Nano-Structures	Invited	CNRS-CP	PQE-2017, Snowbird, USA, Jan-17
Optical detection and control of spin coherences in rare earth doped crystals	Invited	CNRS-CP	International workshop on Impurity Spins for Quantum Information and Technologies, Okinawa, Japan, 2017

Annex II: Leaflet

Institut de Recherche de Chimie Paris — Centre National de la Recherche Scientifique
IRCP/Chimie ParisTech: Coordination, material development.

Néel Institut — Centre National de la Recherche Scientifique
Institut Néel: Nano-resonator hybrid systems.

l'Observatoire de Paris – SYRTE — Centre National de la Recherche Scientifique
SYRTE: Nano-resonator hybrid systems.

KIT — Karlsruher Institut für Technologie
Quantum Optics Group: Spin-atom-photon interfaces using micro-cavities.

ICFO The Institute of Photonic Sciences — The Institute of Photonic Sciences ICFO
Quantum Photonics Group: Single photon sources.

ICFO The Institute of Photonic Sciences — The Institute of Photonic Sciences ICFO
Quantum Nano-Electronics Group: Hybrid graphene devices.

Aarhus University — Aarhus University
Dpt. of Physics: Theoretical developments.

Keysight Technologies — Keysight Technologies
Real-time control systems.

Lund University — Lund University
Quantum Information Group: Quantum gates.

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NanOQTech

Nanoscale Systems for Optical Quantum Technologies

European Commission | Horizon 2020 European Union funding for Research & Innovation

NanOQTech is a European Union Horizon 2020 project funded through the FET Open programme. Seven European partners join their forces in the aim to build nanoscale hybrid quantum devices that strongly couple to light. Such devices are expected to lead to major advances in quantum communication quantum sensing and quantum opto-electronics

Our vision

Quantum technologies are developed to overcome classical limits in communication and processing but also in new areas like sensing, imaging and simulations. They will impact all aspects of life by allowing e.g. ultra-secure communications, simulation of complex drug molecules, or new bio-medical imaging techniques.

Many quantum systems are investigated for specific tasks. The next major challenge is to overcome the limits of single systems by associating radically different quantum systems in hybrid architectures, each selected for its specific properties. Interconnection of these systems will also be necessary to further develop functionalities like distributed processing or extremely secure data exchange, in a global 'quantum internet'.

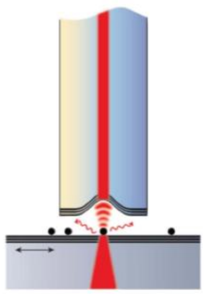
Our vision is that RE nanostructures will play a pivotal role in this scheme by offering a solid-state platform that can be coupled to other quantum systems, while incorporating a coherent spin-photon interface.

The FET OPEN programme

FET Open supports the early-stages of the science and technology research and innovation around new ideas towards radically new future technologies. It also funds coordination and support actions for such high-risk forward looking research to prosper in Europe.

Aims of the project

- to develop rare earth nanostructures with long optical and spin coherences
- to couple these structures to optical micro-cavities
- to demonstrate single-ion optical quantum memories, two-qubit gates and deterministic narrowband single photon sources at 1.5 µm
- to build hybrid RE-graphene devices to achieve plasmon mediated ion-ion interactions
- to fabricate hybrid RE nano-resonators to reach the strong coupling regime
- to guide the experimental effort and prepare further advances by developing comprehensive theoretical tools.



NanOQTech data

The project started on October 1st, 2016 and will last for 3 years with a budget of 3.38 M€.

www.nanoqtech.eu

Annex III: Some companies involved in quantum technologies

Company	Sector	Headquarters
1QBit	Computing	Vancouver, Canada
Accenture	Computing	
Airbus	Computing	Blagnac, France
Aliyun (Alibaba Cloud)	Communication	Hangzhou, China
Anyon Systems Inc.	Computing	Dorval, Canada
Artiste-qb.net	Computing	Toronto, Canada
AT&T	Communication	Dallas, TX, USA
Atos	Communication	Bezons, France
Bosch	Sensing	Germany
BT	Communication	London, UK
Cambridge Quantum Computing Ltd.	Computing	Cambridge, UK
D-Wave	Computing	Burnaby, Canada
EvolutionQ	Communication	Waterloo, Canada
ISARA	Communication	Waterloo, Canada
Quantum Valley Investments	Computing/Communication	Waterloo, Canada
CipherQ	Communication	Toronto, Canada

Fujitsu	Communication	Tokyo, Japan
Google	Computing	Mountain View, CA, USA
h-bar	Computing/Communication	Melbourne, Australia
HP	Communication, computing	Palo Alto, CA, USA
Hitachi	Computing	Tokyo, Japan
Honeywell	Computing	Morris Plains, NJ, USA
HRL Laboratories	Computing	Malibu, CA, USA
Huawei	Communication	Shenzhen, China
IBM	Computing	Armonk, NY, USA
ID Quantique	Communication	Geneva, Switzerland
Infosec Global	Communication	Zurich, Switzerland
ionQ	Computing	
Intel	Computing	Santa Clara, CA, USA
KPN	Communication	The Hague, Netherlands
Lockheed Martin	Computing	Bethesda, MD, USA
MagiQ	Communication	Somerville, MA, USA
Microsoft	Computing	Redmond, WA, USA
Mitsubishi	Communication	Tokyo, Japan

NEC Corporation	Communication	Tokyo, Japan
Nokia Bell Labs	Computing	USA
Northrop Grumman	Computing	West Falls Church, VA, USA
NVision	Sensing, imaging	Germany
NTT Laboratories	Computing	Tokyo, Japan
NuCrypt	Communication	Evanston, IL, USA
Psiquantum	Computing	United Kingdom
QC Ware	Computing	Palo Alto, CA, USA
Quantika	Computing/Communication	Milan, Italy
QuantumCTek	Communication	Hefei, China
Quantum Circuits	Computing	New Haven, CT, USA
Quantum Diamond Technologies	Sensing	Somerville, MA, USA
Qubet	Communication	York, UK
Qubitekk	Computing/Communication	Vista, CA, USA
QuintessenceLabs	Communication	Deakin, ACT, Australia
QxBranch	Computing	Washington, D.C., USA
Raytheon	Computing/Communication	Cambridge, MA, USA
Rigetti Computing	Computing	California, USA

RIKEN	Computing	Wako, Japan
Sparrow Quantum	Communication	Copenhagen, Denmark
Toshiba	Communication	Tokyo, Japan