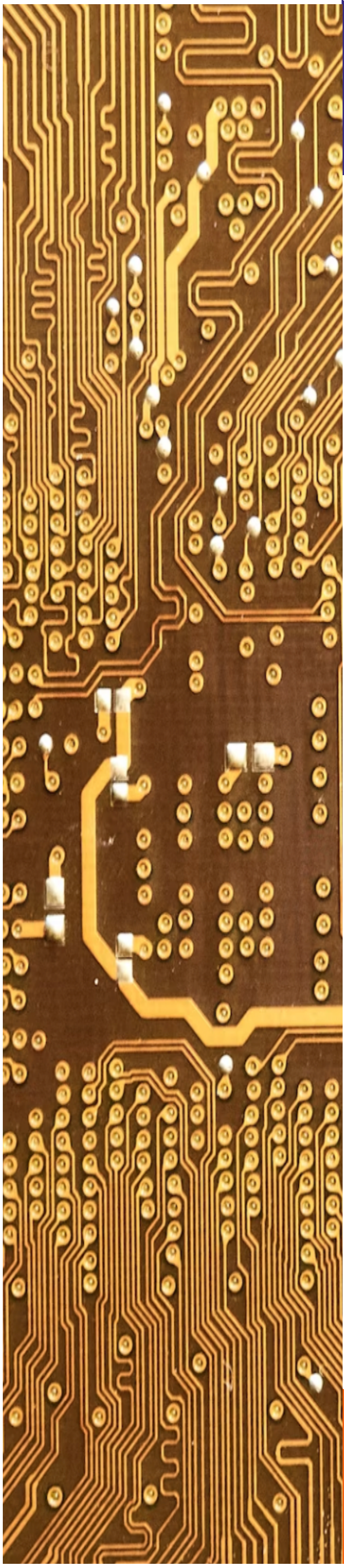

A Portrait of the Global Patent Landscape in Quantum Technologies

January 2024

QuIC
European Quantum Industry Consortium

Table of Contents

Introduction

1.1 Goal

This white paper presents an overview of the patent landscape in quantum technologies and provides some more details on **quantum computing**, **quantum communication** and **quantum sensing.** It will also review the **European position in relation to the USA and China**, and identify **the main actors and trends in quantum technologies**.

To this end, we will consider the following agenda in this white paper:

- First, we establish a **patent family landscape** in quantum technologies (i.e., patentable invention landscape), based on all alive patent families;
- Second, we focus on **"international patent families"**; these are patent families with at least one country of extension outside the country of origin, as **patent families of value are usually extended outside the country of origin**;
- Third, we zoom in on **European companies** and review the situation regarding patents and patent applications filed at the **European Patent Office**.

Important notes:
Note 1: *This study is based on alive patents and patent applications that were published before 30 June 2023. The reader should take into account that there is* ***an 18-month delay between the date of first filing and the date of first publication****. In other words, this study includes only patent families with a first filing* ***before 1 January 2022****.*

Note 2: The quantum technologies domain in particular is currently highly dynamic in terms of invention filings *and accordingly the number of patent families may be evolving quite significantly. IQM Finland, for example, released 10 first publications between July and November 2023, significantly increasing the size of its portfolio.*

Note 3: *For this study, Europe refers to "Geographical Europe": the 27 EU countries plus the United Kingdom, Switzerland, Norway and Iceland.*

1.2 What is the Quantum Revolution?

Here is how the European Commission describes the quantum revolution (Ref [1]):

- **In the first quantum revolution** during the early twentieth century, scientists learned to understand and apply the properties of quantum mechanics – the interactions of molecules, atoms, and even smaller particles like photons and electrons. This ultimately allowed them to create transistors, lasers and microprocessors: foundational technologies for computers, telecommunications, satellite navigation, smartphones, modern medical diagnostics, and much more.
- Now, **the second quantum revolution** is underway. Researchers can detect and manipulate individual particles and their physical interlinkages and interactions, and build new technologies and systems that make use of the properties of the underlying quantum mechanics. These developments have led to major technical advances in many different areas, including **quantum computing, sensors, simulations, cryptography and telecommunications**. A whole generation of new quantum technologies with the potential for far-reaching economic and societal impact is starting to emerge. Some are already in development, while many others will be developed in the coming decades.

For more information, see the full article at Quantum | Shaping Europe's digital future (europa.eu).

In this study, we will use the following segmentation:

- Quantum computing
- Quantum communication (quantum key distribution (QKD) & quantum internet)
- Quantum sensing

1.3 Overview of Quantum Computing

Please note that this paragraph has been extracted from the "QuIC – Strategic Industry Roadmap" (Ref [2]).

Quantum computing is a computational paradigm that exploits quantum effects such as **superposition, interference, and entanglement to solve problems by applying a quantum algorithm.** There are different variants of this paradigm. The most common is **digital gate-based quantum computing**, in which quantum algorithms are represented as quantum circuits – i.e., a sequence of quantum gates applied to qubits. Digital quantum computing is universal; that is, in principle a digital quantum computer can solve any quantum algorithm, although the currently available devices are still quite limited. An alternative paradigm is **adiabatic quantum computing**, in which the solution of the problem is encoded as the ground state of the system's Hamiltonian and the system evolves towards this solution through **continuous modulation of its tuneable parameters**. This is a variant of analogue quantum computing and is typically executed **on devices similar** to those used for quantum simulation. The equivalence between the **digital and adiabatic models** has been formally proven. Quantum simulation is a process that determines physical properties of quantum systems such as molecules or crystals by calculation methods or by studying a different quantum system with similar properties (as opposed to a direct measurement on the system of interest).

1.4 Overview of Quantum Communication

Please note that this paragraph has been extracted from the "Strategic Research & Industry Agenda" (Ref. [3]), a document published in November 2022 by the Quantum Flagship initiative. The Quantum Flagship is a large-scale initiative funded at the € 1b level on a 10-year timescale. The goal is to consolidate and expand European scientific leadership and excellence in this research area, to kick-start a competitive European industry in quantum technologies and to make Europe a dynamic and attractive region for innovative research, business and investments in this field.

The area of quantum communication aims at designing the tools and protocols to exchange quantum information among distant users.

Within a general progressive framework for quantum communication networks, where increasingly complex hardware and software give rise to more advanced functionalities, the field can at present be roughly divided into two domains:

1. **Near-term technology focusing primarily on QKD** and other applications attainable at a similar stage of functionality at relatively short distances. This technology has reached high Technology Readiness Level (TRL), and commercial products have already been brought to market. One of the main applications is the design of cryptographic schemes with security based on the laws of quantum physics.
2. **Long-term research and development** to unlock all the benefits of quantum communication for users around the globe, specifically enabling quantum communication over long distances, and offering higher levels of

functionality to the users. The long-term ambition is to build a **quantum communication infrastructure** (or **quantum internet**) that can provide fundamentally new technology by enabling quantum communication between any two points on earth. In synergy with the 'classical' internet that we have today, a quantum internet will connect quantum processors to achieve unparalleled capabilities that are provably impossible using classical communication.

The main components of such a network will be:

- Quantum repeaters: To connect many users at continental distances, a quantum repeater may be used to generate long-distance entanglement using fibre networks;
- Satellites: For ultra-long-distance backbones, satellites may be used to distribute entanglement between different points in the network;
- End nodes: The quantum analogues of laptops and phones connected to the internet, these are required to enable the execution of applications, and hence to make quantum internet technology available to end users.

1.5 Quantum Sensing and Metrology

Please note that this paragraph has been extracted from the "QuIC – Strategic Industry Roadmap" (Ref [2]).

Quantum sensing and quantum metrology are based on exploiting the quantum properties of nature, quantum phenomena, quantum states, their universality and intrinsic reproducibility, the quantisation of associated physical quantities, or their high sensitivity to environmental changes. Coupling a simple quantum system to an external physical quantity modifies the system's properties, thereby allowing the measurement of this quantity. In most cases, quantum sensors use the interference properties of simple quantum systems. In the very simplest case, these are qubits, i.e., systems with two basis states. The qubits are initialised in a prepared superposition state and then coupled to the external physical quantity to be measured. The coupling alters the phase of this superposition in a way that can be measured quantitatively. In many cases, these quantum measurements can then be mapped to the value of the external physical quantity, achieving increased absolute and relative accuracy compared to measurements by classical means. The wide variety of quantum systems used as sensors are typically classified into two main categories: gas and solid-state. All have specific properties and are sensitive to different physical quantities, which make them suitable for particular applications (e.g., **cold atoms** for gravimetry; **defects in diamond or silicon carbide** for high-resolution magnetometry).

Applications of quantum sensors are relevant in many different areas, including high precision spectroscopy, imaging, gravimetry or gyrometry, high-resolution microscopy, magnetometry, clocks and their synchronisation, positioning, or thermometry.

Global Patent Family Landscape of Quantum Technologies

2.1 Patent Family Landscape: General Trends

Details on the creation of the corpus of patent families are given in Appendix A.

We use the segmentation already defined:

- Quantum computing
- Quantum communication (QKD and quantum internet)
- Quantum sensing

The figure below shows the numbers of patent families and the respective weights for each of the three segments:

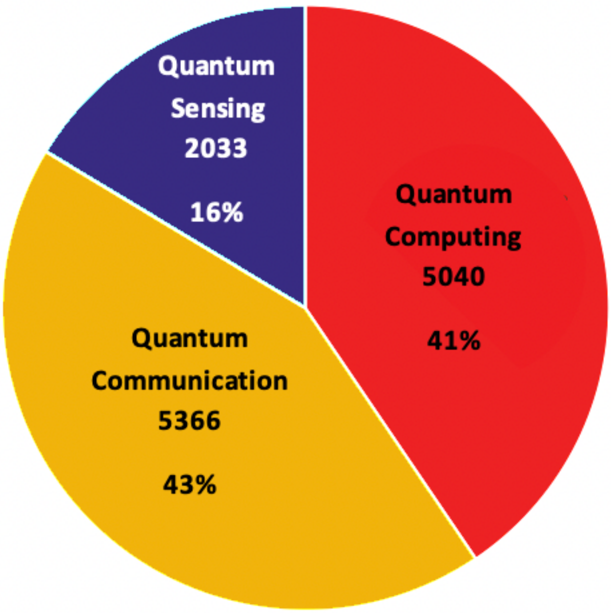

Figure 1: Number & weight of patent families by quantum technology segment

The next sections detail each of these three segments. Quantum computing and quantum communication are noticeably stronger than quantum sensing.

This effect is also clear from the graph of first filings by priority date:

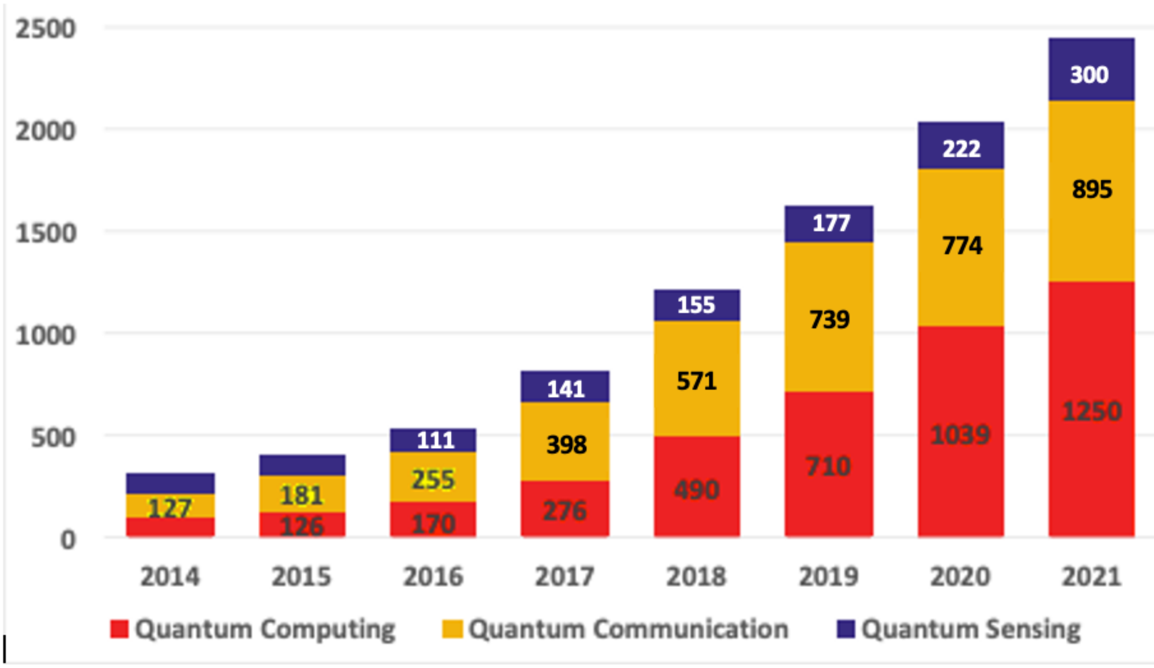

Figure 2: Global segmentation – number of patent families by priority date

The average growth per year is quite strong with around **35% overall for the 2016–2021 period** (indeed, as much as 50% for quantum computing!)

We can furthermore evaluate the relative contributions of each country or region for these segments:

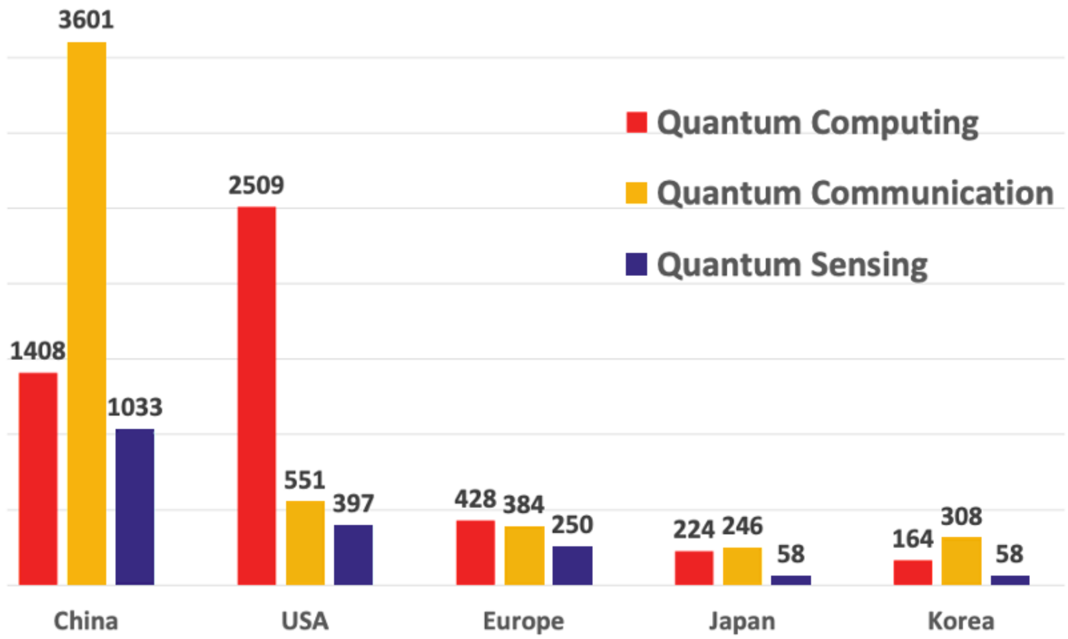

Figure 3: Number of patent families per quantum technology by country/region

Figure 3 shows that the USA and China are in fact investing mostly in two different segments:

- USA: primarily quantum computing
- China: primarily quantum communication

In Europe, there is no significant specific focus, and we observe that the three segments are quite well balanced (whereas in the other regions quantum sensing tends to lag behind).

We will now provide more details for each segment.

2.2 Quantum Computing: Patent Family Landscape

2.2.1 Main assignees by country

NB: The patent families identified in this segment are based only on the CPC code G06N-010 "Quantum Computing" (and not any of its subcategories).

We look first at the main assignees in quantum computing (the colour indicates the country of origin):

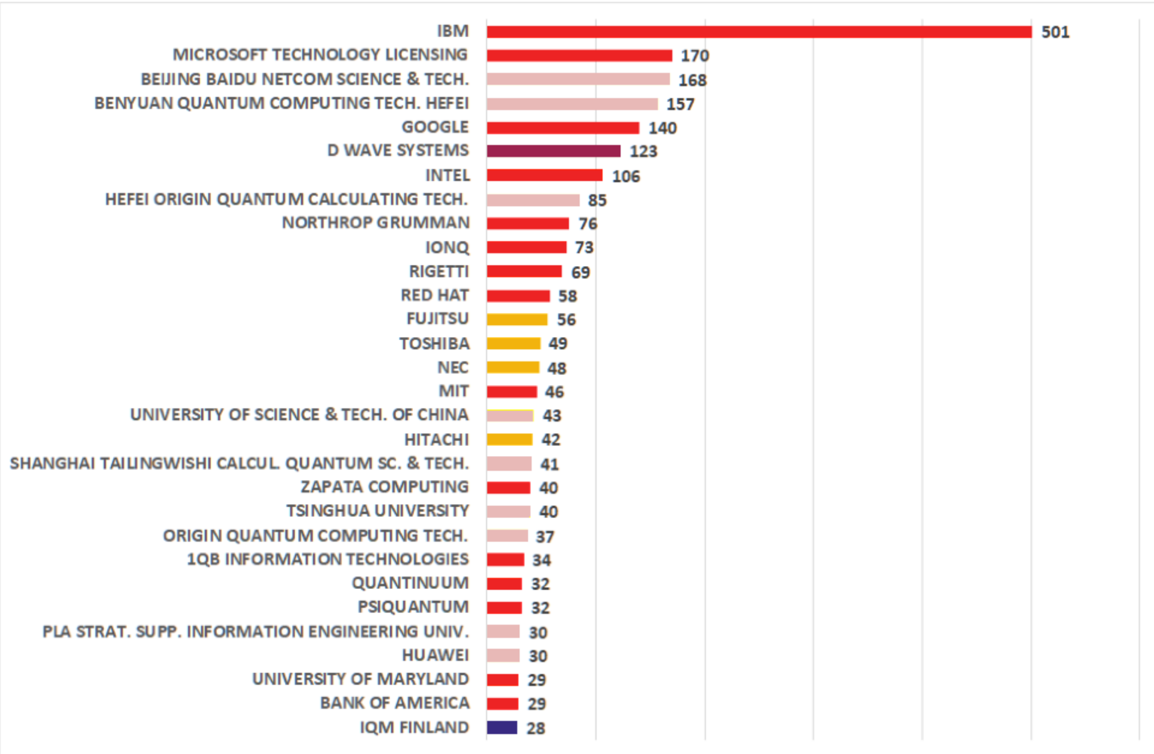

Figure 4: Main assignees in quantum computing, ranked by number of alive patent families

Legend: USA, China, Japan, Canada, Europe.

(Note: in this figure, we consider Quantinuum a US company as its headquarters are in the USA.)

It is clear that major US companies such as IBM, Microsoft, Google and Intel are leading the race in terms of number of patent families. From the Chinese side, Baidu and Origin Quantum are also vying for positions towards the top, and many Chinese academic institutions can also be seen on the list.

Turning to Europe, IQM makes an appearance at rank 30 for the number of patent families.

2.2.2 Focusing on Hardware Segmentation

Quantum computing hardware can be characterised both by the types of qubits supported and by the kind of computations the hardware can run. Most integrators focus on general-purpose quantum computing applications (gate-based systems). Quantum annealer systems generally have a narrow operational mode; however, many computing and simulation problems can be restructured to run on these systems.

Based on Ref [1], we use the following segmentation:

- Superconducting qubits
- Spin / silicon qubits
- Trapped ion quantum computer
- Neutral-atom / cold-atom quantum processor
- Photonic qubits

From among the alive patent families in the quantum computing domain, we selected the patent families associated with each of these hardware segments, associated with “qubit”. This search yielded around 31% of the alive patent families in quantum computing. This is of course indicative, but it clearly indicates the relative weight of these various technologies.

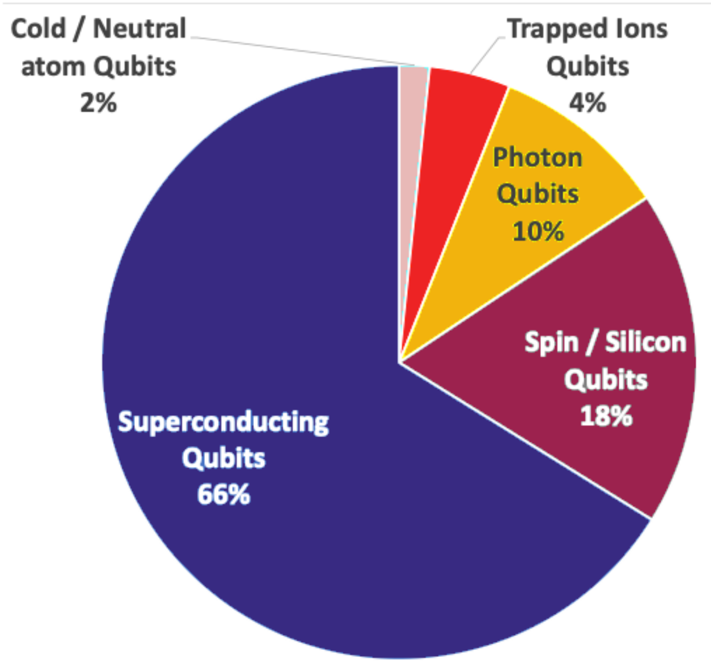

Figure 5: Number of patent families by hardware segment in quantum computing

In this corpus, **superconducting qubits currently represent two thirds of patent families** related to hardware quantum computing, with a strong lead from US companies.

If we focus on companies and academic institutions for just these hardware segments, we have the following picture:

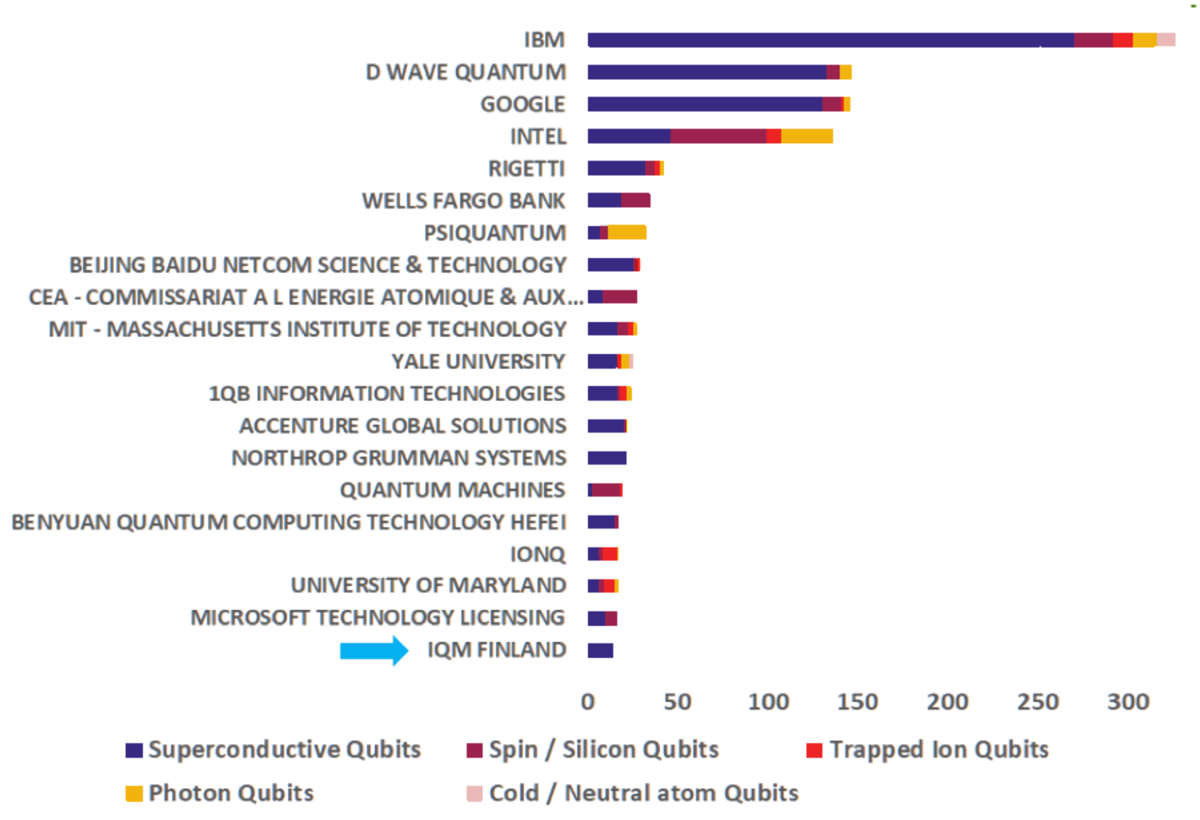

Figure 6: Main assignees within the quantum computing hardware segments

The race among assignees is led by US companies, with some "pure players" dedicated to quantum computing such as D-Wave Systems, IonQ, Rigetti, PsiQuantum.

It is worth noting that **IQM Finland is the only European company** in this graph, investing mostly in superconducting qubits.

However, we should be aware that many other startups are currently filing patent applications to widen their patent portfolio.

It is also important to remember that there is an 18-month delay between the date of first filing and the date of first publication.

Of course, there are also many other possible segmentations, e.g. using error detection/correction, type of quantum algorithm, etc.

2.3 Quantum Communication: Patent Family Landscape

As indicated in Section **Error! Reference source not found.**, quantum communication aggregates quantum cryptography (including QKD) and quantum internet. We **deliberately exclude "post-quantum cryptography"** as this describes classical technologies being able to resist potential crypto attacks from quantum computers.

The main assignees for the quantum communication segment are shown in the figure below (the colour indicates the country of origin):

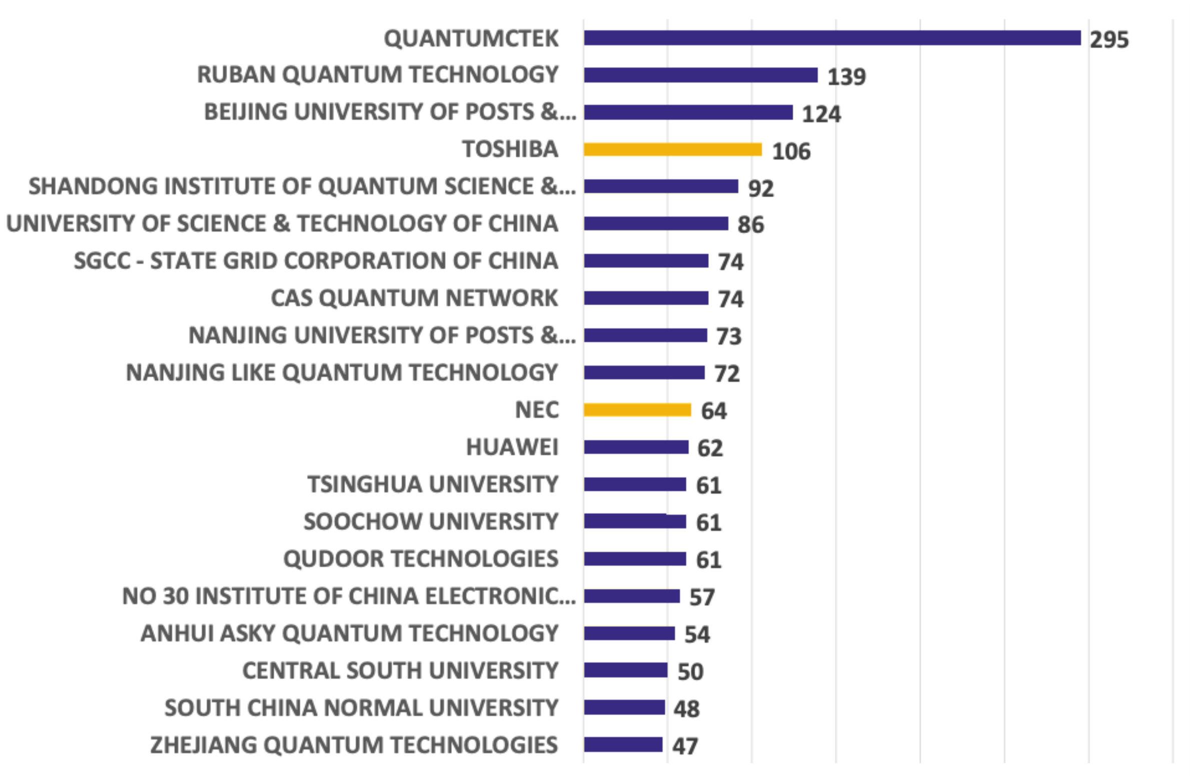

Figure 7: Main assignees in quantum communication, ranked by number of alive patent families

Legend: China, Japan.

It is clear that the quantum communication segment is overwhelmingly dominated by China and Japan.

Patent families related to QKD currently represent around 80% of all patent families (and quantum internet consequently has around 20%).

2.4 Quantum Sensing: Patent Family Landscape

The main assignees are shown in the figure below (the colour indicates country of origin):

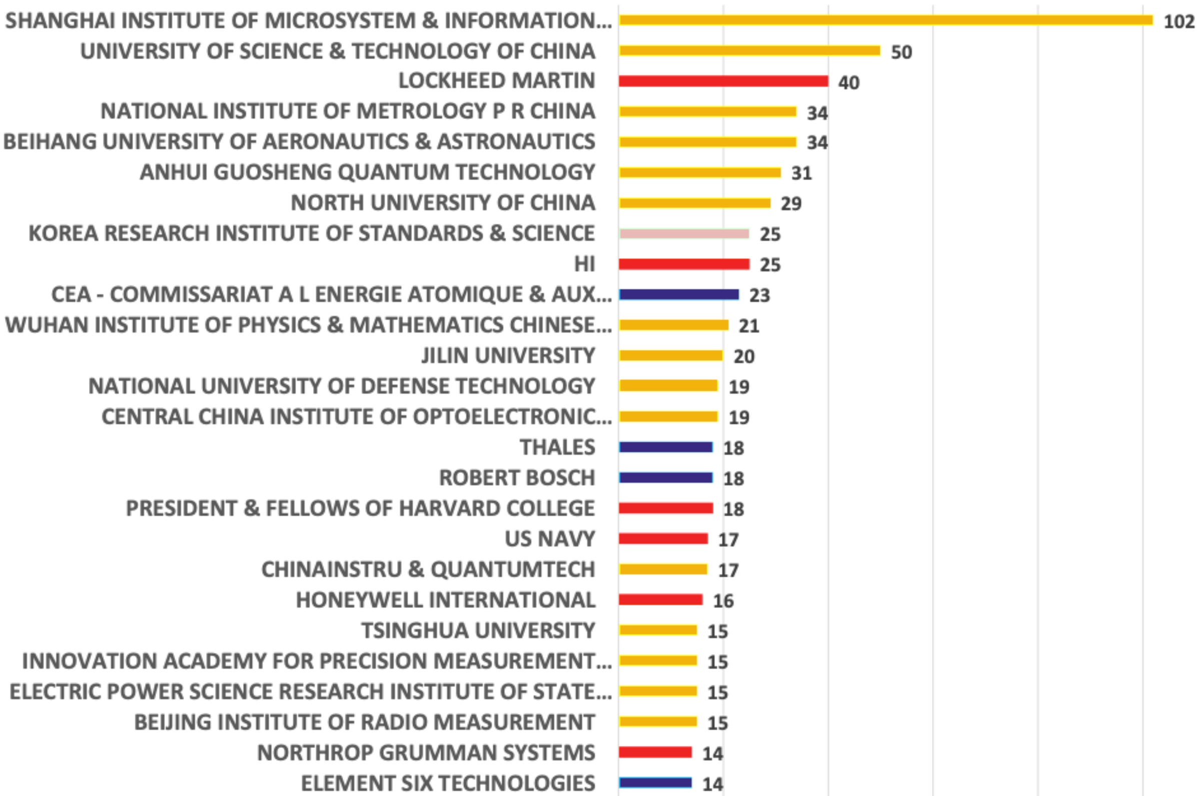

Figure 8: Main assignees in quantum sensing, ranked by number of alive patent families

Legend: USA, China, South Korea, Europe**.**

Among the European assignees are the CEA (French Alternative Energies and Atomic Energy Commission), Thales, Bosch, Element Six Technologies.

Based on Ref [1], we use the following segmentation:

- NV centres in diamond
- OPM
- SQUIDs / SQIFs
- Cold atoms
- Rydberg atoms

If we look at the relative weight for each of these segments for patent families with a first filing in 2021, we find the following:

NV centres	**37%**
SQUID, SQIF	**25%**
Cold atoms	**13%**
OPM	**8%**
Rydberg atoms	**6%**
Other	**10%**

Table 1: Relative weight of quantum sensing technologies, based on first filings in 2021

In terms of segmentation, NV centres represent today's leading technology. SQUID/SQIF technologies, based on the Josephson effect, remain quite active, although they can now be considered an "older" technology.

Landscape of 'International' Patent Families

It is important to consider that many patents or patent applications are for "domestic" use only. Patents and patent applications **of value are usually extended outside the country of origin.**

Accordingly, in this section, we will focus in particular on **international patent families**, with the following definition: an "international patent family" is a patent family having patent family members published by at least **two different patent authorities**. We also include in this category first filings submitted directly under the patent cooperation treaty. For Europe, we also require at least one patent authority **to be located outside Europe**.

It is clear from the table below that considering only international patent families changes the situation completely in terms of weight of countries/regions, **giving the USA a strong lead, with Europe moving up to position #2 and China shifting from first place to share third place with Japan:**

	Number of patent families per country of origin	Relative weight (% of all patent families)	Percentage of international patent families vs domestic patent families	Number of international patent families per country of origin	Relative weight (% of international patent families)
China	6022	*49%*	*7%*	444	*11%*
USA	3455	*28%*	*59%*	2025	*48%*
Europe	1051	*8%*	*88%*	926	*22%*
Japan	609	*5%*	*80%*	489	*12%*
Korea	522	*4%*	*35%*	183	*4%*
Other	720	*6%*	*20%*	143	*3%*
Total	**12,379**	***100%***	***34%***	**4210**	***100%***

Table 2: Relative weight by country – comparison with international patent families

Key points:

- **Only 7%** of Chinese patent families have been extended outside China. Most Chinese patent families are dedicated to domestic use only. Consequently, **the**

relative weight of Chinese patent families drops to 11% of all international patent families.

- By contrast, **the weight of US international patent families** relative to all international patent families **climbs to 48%**; the **European share also increases to 22%**.

The relative weights of each of our three segments also change significantly, as follows:

Relative weight	Of all patent families	Trend	Of international patent families only
Quantum computing	**41%**	↗	**60%**
Quantum communication	**43%**	↘	**25%**
Quantum sensing	**16%**	=	**15%**

Table 3: Relative weights of segments – comparison with international patent families

The change of relative weight is mostly due to:

- The number of quantum computing patent families coming from US assignees, with a relatively high level of international patent families;
- The number of quantum communication patent families coming from Chinese assignees, with a relatively low level of international patent families.

We will now examine the top 10 assignees for each segment.

For quantum computing, considering only international patent families, the top 10 assignees are shown below (the colour indicates the country of origin):

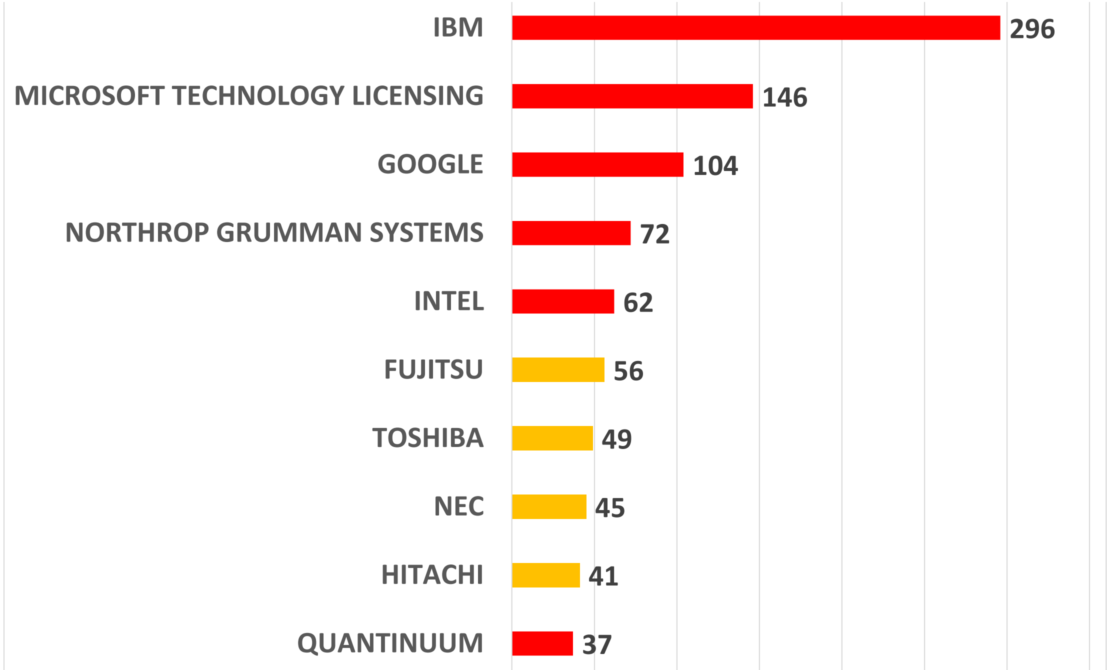

Figure 9: Quantum computing top 10 assignees, considering only international patent families

Legend: USA, Japan

A key point to note is that there are no European assignees among the top 10, while US companies have a very strong presence. In fact, this graph is quite similar to Figure 4: Main assignees in quantum computing, ranked by number of alive patent families, except that Chinese assignees are now at a lower rank.

For quantum communication, here are the top 10 assignees (the colour indicates the country of origin):

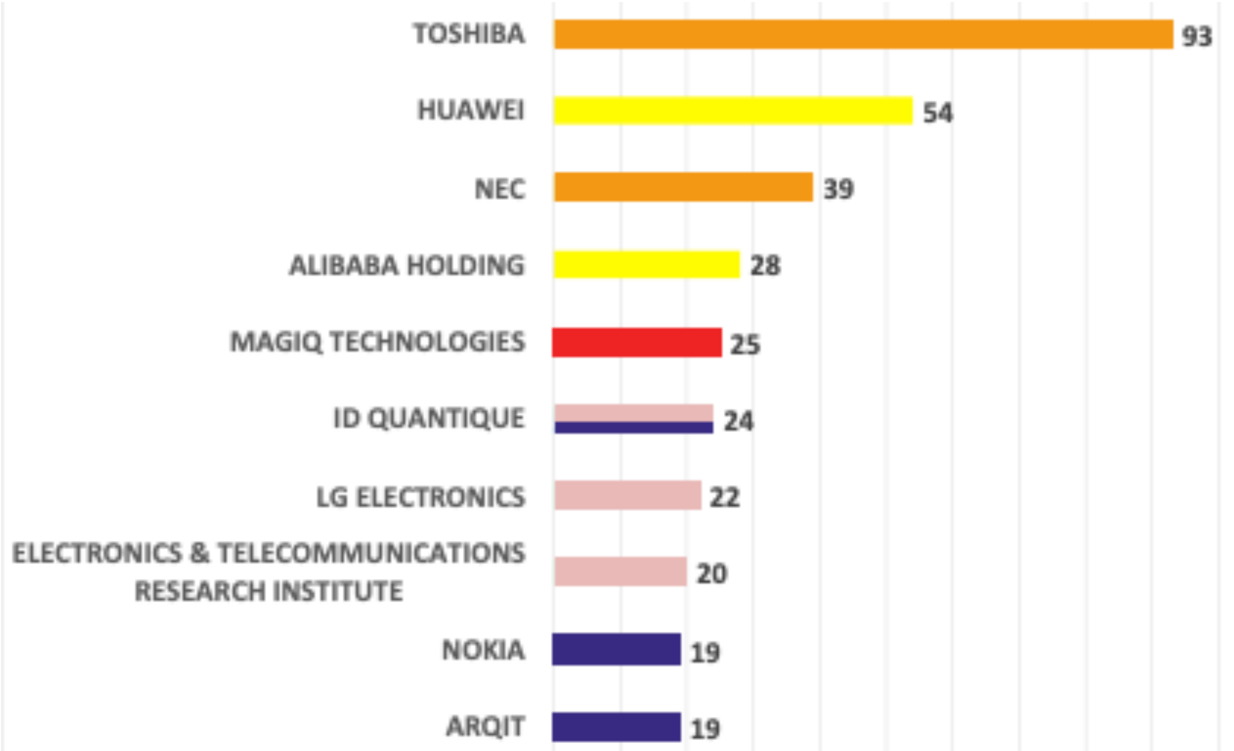

Figure 10: Quantum communication top 10 assignees, considering only international patent families

Legend: USA, China, Japan, South Korea, Europe

(Note: ID Quantique is a company based in Switzerland and owned by the South Korean company SK Telecom)

The picture here is quite different from Figure 7: no Chinese academic institutions are in this list, only some major Chinese companies, while Japanese companies take the lead. We can also now see some active companies in Europe.

Turning now to the **quantum sensing** sector, we have the following **top 10 assignees** (the colour indicates the country of origin):

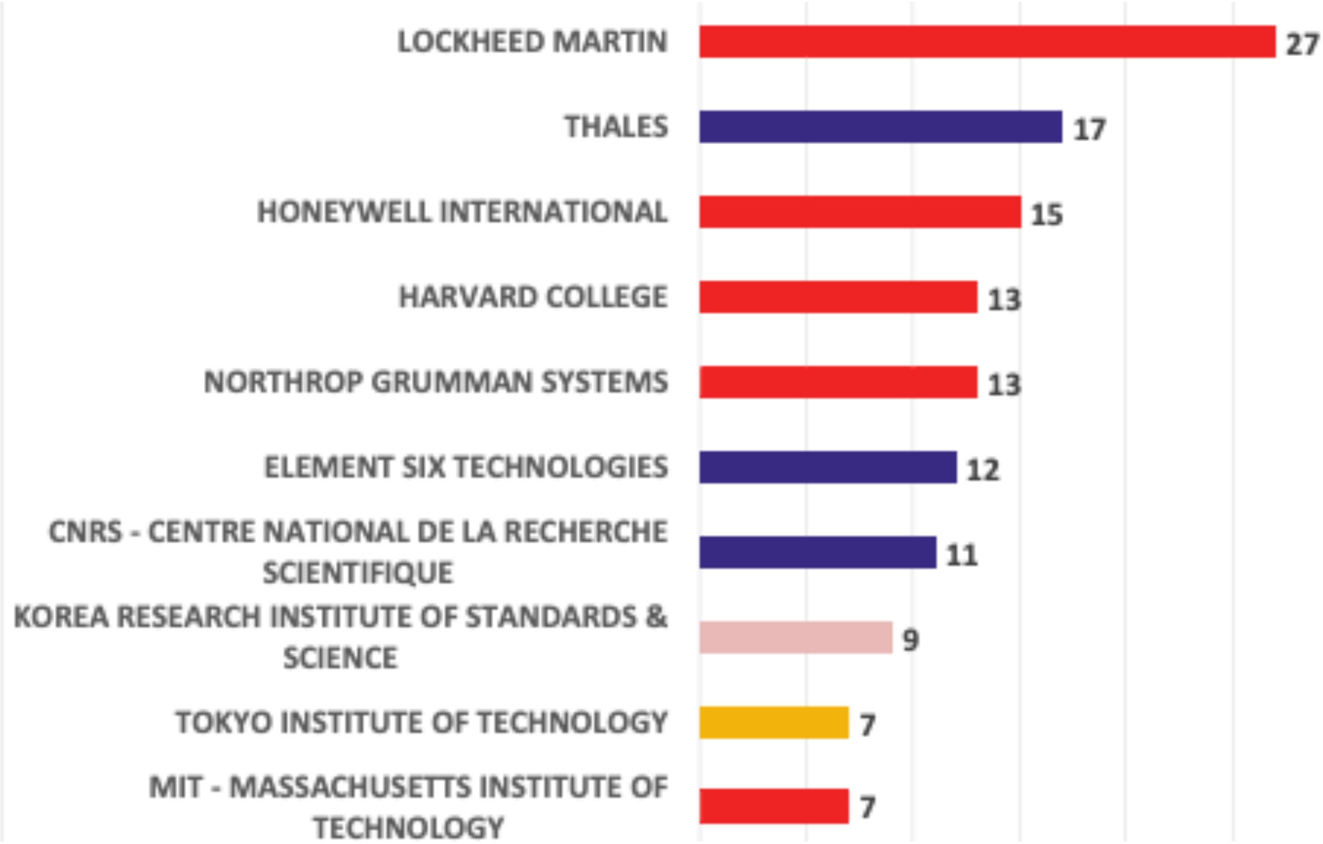

Figure 11: Quantum sensing top 10 assignees, considering only international patent families

Legend: USA, Japan, South Korea, Europe

In this ranking there are no more Chinese assignees. **Thales, Element Six Technologies and the CNRS** (French National Centre for Scientific Research) are among the top 10 assignees.

It is also worth noting that four of these top 10 assignees belong to the **Aerospace & Defence** domain.

European Situation for Patent Families in Quantum Technologies

4.1 European Leaders Based on the Number of Patent Families

The top 20 European assignees, based on their total number of alive patent families, are the following:

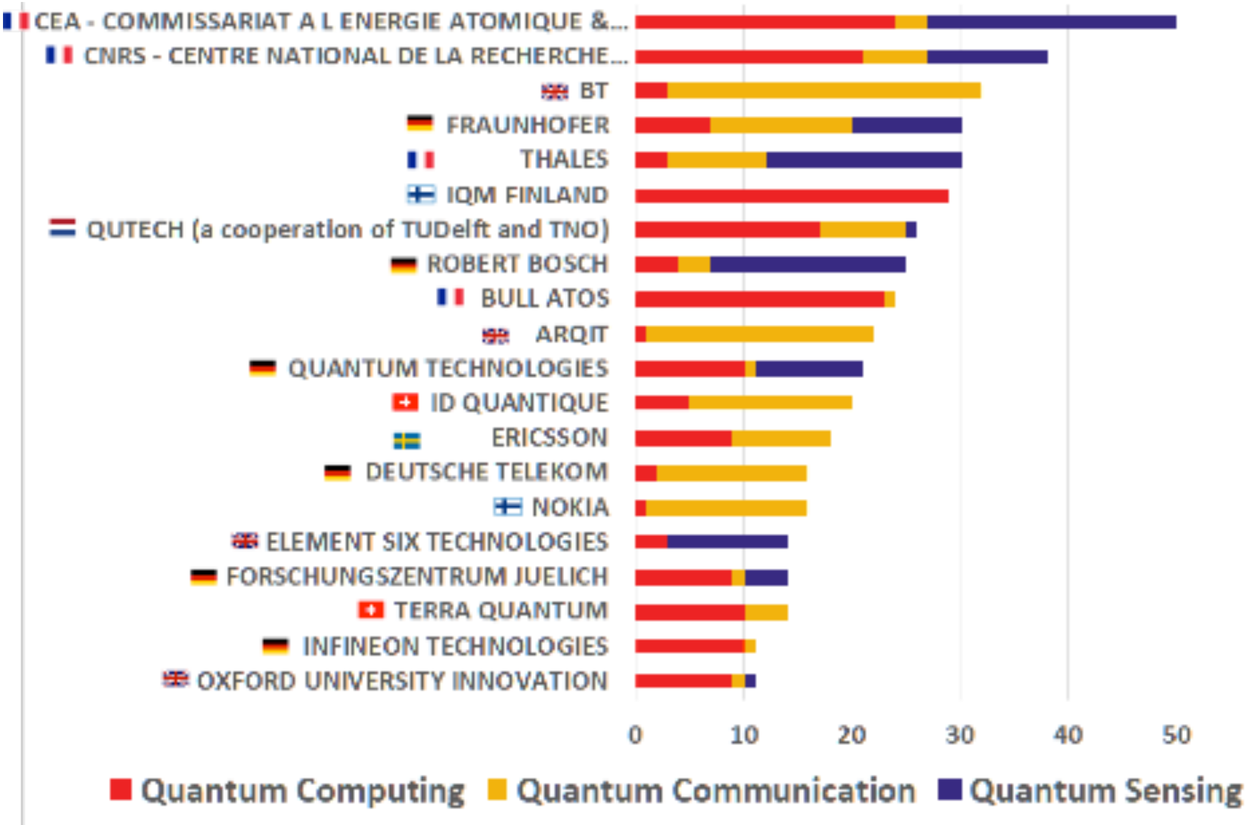

Figure 12: Top 20 European assignees, ranked by number of patent families

We can see that research & technology organisations have a strong presence on this list, in particular the CEA, the CNRS, Fraunhofer, QuTech (a collaboration between TU Delft and TNO), Forschungszentrum Jülich, IMEC (Interuniversity Microelectronics Centre, based in Belgium), Oxford University, Sorbonne University.

Companies:

- In quantum computing, **IQM Finland and Bull Atos** are leading the race, with the Bull Atos patent portfolio being unsurprisingly oriented more towards quantum simulation.
- In quantum communication, **BT, Arqit, Nokia, ID QUANTIQUE, Deutsche Telekom** all have strong portfolios.
- In quantum sensing, **Thales and Bosch** are leading the race for the most patent families.

Research & technology organisations:

- In quantum computing, the **CEA**, the **CNRS** and **QuTech** are leading the race.
- In quantum communication, currently no strong investment from RTOs, but **Fraunhofer** is most active.
- In quantum sensing, **CEA**, **Fraunhofer**, and **CNRS** are leading the race.

It is worth noting that all these assignees are members of QuIC except the CNRS, BT, Arqit, QinetiQ, Deutsche Telekom, Element Six Technologies, Oxford University Innovation.

4.2 Situation on the European Market: European Patents

Turning to focus on the European market, we will consider all the companies and academic institutions that have filed patents and patent applications to the European Patent Office, regardless of the country or origin of the first filing.

The chart below shows the top 25 assignees for European patents and patent applications filed to the European Patent Office (the colour indicates the country of origin):

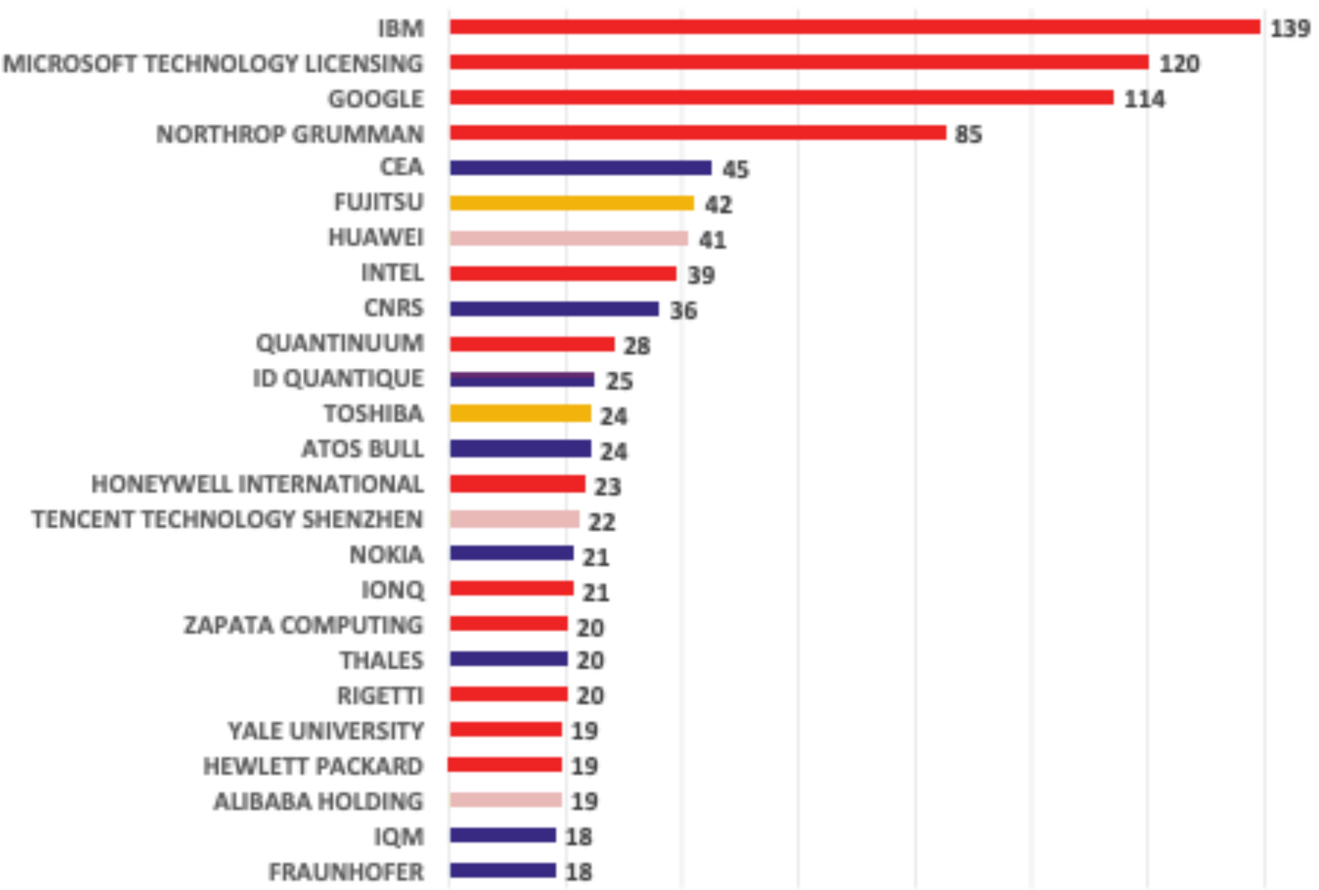

Figure 13: Top 25 assignees in Quantum Technologies ranked on number of European patents and patent applications

Legend: USA, China, Japan, South Korea, Europe

Among the top 25 assignees (patents or patent applications with the EPO), **12 out of 25 are based in the USA**, **which is driving the race with all the top four**.

European assignees are represented by three RTOs (French CEA and CNRS, German Fraunhofer) and four companies (Bull Atos, Nokia, Thales, IQM).

In fact, EPO patents or applications **originating from a European country** represent **only 31%** of all published European patents and patent applications in quantum technologies, while **US companies and academic institutions have a strong lead with 52%** of European patents and patent applications (see table below). We can compare this to patents filed in 2021 for all technology domains, where US assignees represent "only" 25% of patents filed at the EPO (versus 52% in quantum technologies), while European assignees represent 44% (versus 31% in quantum technologies).

	Percentage of total EPO alive patents or applications by country of priority in **quantum technologies**	Percentage of European patents and applications filed during 2022 by applicant residence[1] (all technology domains)
Europe	**31%**	**43%**
USA	**52%**	**25%**
China	5%	10%
Japan	6%	11%
Korea	1%	5%
Others	4%	6%

Table 4: Percentage of total EPO patents and patent applications by country of origin

Note 1: Source: EPO – 2022 Patent index - European patent applications filed with the EPO - Breakdown by applicant residence (cf [4])

The key point to note from this table is that European countries **have a much lower share in quantum technologies** than in technology overall, while the USA's share for quantum technologies is double its overall technology share.

Conclusion

Patents are a good indicator of the level of innovation and investment of academic institutions and companies in a given technology at country or regional level.

Currently, the quantum technology space for patented inventions is dominated:

- **By US companies and academic institutions** in quantum computing;
- **By Chinese and Japanese companies and academic institutions** in quantum communication (though very few of the Chinese patented inventions are extended outside China).

Europe is ranked in third place for inventions filed, **behind the USA and China** in any of the three segments (quantum computing, quantum communication and quantum sensing). However, **Europe's position in quantum sensing is more balanced than that of the USA or China**, in terms of inventions filed relative to the other two sectors.

The situation related to European patents and patent applications is alarming: **Europe is in second place in its own market**, with 31% of European patents and patent applications, while the **USA is ranked firmly in first place** with 51% of European patents and patent applications.

European companies may consequently be at risk, even in their own market, if they have to use protected technologies from non-European companies. **This could hinder the potential business from European companies.**

For Europe to achieve strategic autonomy in quantum technologies, European companies and RTOs need to reach the top ranking in terms of number of European patents & patent applications.

As such, we recommend:

- That more investments should be made by **European states and the European Union (EU)**, academic institutions companies and start-ups in quantum research and technology;
- That funding opportunities provided by European states or by the EU should be conditioned **by an ambitious policy related to intellectual property, with the filing of new inventions at the European Patent Office.**

For Europe and for the EU, ranking in first place in terms of filings with the European Patent Office is the only way to support strategic autonomy.

Related to the various segments (quantum computing, quantum communication and quantum sensing), it would be appropriate for **European states and the EU investments to target segments which are not currently over-dominated by the USA or China.**

References

Ref	Title	Authors
1	Shaping Europe's digital future: Quantum Quantum | Shaping Europe's digital future (europa.eu)	European Commission
2	QuIC – Strategic Industry Roadmap (December 2022) Public version https://www.euroquic.org/quics-strategic-industry-roadmap-is-now-available-to-the-public/	QuIC
3	Strategic Research & Industry Agenda https://qt.eu/news/2022/quantum-flagship-publishes-preliminary-strategic-research-and-industry-agenda	Published in November 2022 by the European Quantum Flagship under the supervision of the Strategic Advisory Board
4	European patent applications per country of origin https://report-archive.epo.org/about-us/annual-reports-statistics/statistics/2022/statistics/patent-applications.html#tab2	European Patent Office

Bibliography

Ref	Title	Authors
4	Quantum computing - Insight report – January 2023	European Patent Office
5	Landscape study on patent filing - Quantum metrology and sensing – September 2019	European Patent Office
6	Quantum Technologies: Patents, Publications & Investments	QuantX, Le Lab Quantique Michel Kurek

Glossary of Abbreviations

Abbreviation	Meaning
CPC	Cooperative Patent Classification
EPO	European Patent Office
NMR	Nuclear Magnetic Resonance
NV Centre	Nitrogen Vacancy Centre
OPM	Optically Pumped Magnetometer
QuIC	European Quantum Industry Consortium
RTO	Research and Technology Organisation
SQIF	Superconducting Quantum Interference Filter
SQUID	Superconducting QUantum Interference Device
TRL	Technology Readiness Level

Definitions

Term	Explanation
Priority Date	The Priority Date is the first filing date of a patent application, anywhere in the world (normally in the applicant's domestic patent office), to protect an invention (European Commission IP Helpdesk Website).
Priority Country	The Priority Country is the country where the patent is first filed before being extended to other countries (European Commission IP Helpdesk Website).
International Patent Family	An international patent family is a patent family having patent family members published by at least two different patent authorities. For Europe, we also require at least one patent authority to be located outside Europe. We also include in "international patent families" first filings submitted directly under the patent cooperation treaty.
Patent Family	A patent family is a collection of patent applications covering the same or similar technical content (EPO website).
Europe	EU27 + UK + Norway + Switzerland + Iceland
EPO member state	In addition to European countries, Türkiye is also an EPO member state (however, we find only six patent families

	related to quantum technologies with Türkiye as priority country).

Appendix A: Creating the Corpora of Patents and Patent Applications

We used "ORBIT INTELLIGENCE" (a patent search & analysis tool) from QUESTEL (https://www.questel.com) to perform our various searches and analyses relating to quantum technologies and to create the various corpora of patent families discussed in this white paper.

Please note that any Chinese Utility Model Patents returned by the various searches were excluded from the corpus.

Please note also that there is no "perfect corpus": there is always a trade-off between:

- Having the highest number of relevant patent families;
- Having an acceptable level of "noise" (patent families not directly related to the study).

For Quantum Computing and Quantum Simulation

We use the CPC code

- G06N-010: Quantum Computing; i.e., information processing based on quantum-mechanical phenomena.

Rationale:

The **rationale** for choosing only this CPC code is the following:

- Other patent studies use the same definition;
- The number of patent families is already quite significant (> 5000 patent families alive).

For Quantum Communication

We divide quantum communication into two parts. We use the following CPC codes for quantum cryptography:

H04L-009/0852	Quantum cryptography (transmission systems employing electromagnetic waves other than radio waves, e.g. light, infrared H04B 10/00; wavelength-division multiplex systems H04J 14/02; WDM arrangements H04J 14/03)

H04L-009/0855	… involving additional nodes, e.g. quantum relays, repeaters, intermediate nodes or remote nodes
H04L-009/0858	Details about key distillation or coding, e.g. reconciliation, error correction, privacy amplification, polarisation coding or phase coding

We use the following CPC code for quantum information networks:

H04B-010/70	Photonic quantum communication

We merge this search based on CPC code with a search based on keywords.

- For quantum cryptography

  ((QUANTUM CRYPTO+) OR (QUANTUM ENCRYPT+) OR (QUANTUM CRYPT+) OR (QUANTUM KEY) OR QKD)

  We exclude from this search **"post-quantum cryptography"** which does not use quantum-mechanical properties: ((POST QUANTUM CRYPT+) OR PQC)

- For quantum internet

((QUANTUM NETWORK?) OR (QUANTUM COMMUNICATION?) OR (QUANTUM INTERNET) OR (QUANTUM INFORMATION NETWORK?) OR (QUANTUM TELEPORTATION?))

Rationale

The **rationale** for choosing a mix of CPC code and text-based search is that CPC codes do not currently offer extensive coverage in this domain (a few hundreds of patent families).

For Quantum Sensing

We use the following CPC codes:

G01R-033/0354	SQUIDs
G01R-033/0356	… with flux feedback
G01R-033/0356	… coupling the flux to the SQUID
G01R-033/326	Arrangements or instruments for measuring magnetic variables …involving a SQUID

We combine this search with another search based on keywords:

(atomic vapor) or (cold cloud) or (trapped ion?) or (Rydberg atom+) or ((Bose Einstein) S condensate) or ((single spin?) and (NMR or (quantum dot?)) or (SQUID+) or (charge qubit?) or (flux qubit?)

We add the following searches as well:

- SQUID, SQIF
- Cold atoms: +COLD ATOM+
- NV Centres: (NV S CENT+) OR (NITROGEN VACANCY S CENT+) OR (NITROGEN DEFECT? S CENT+) OR (DIAMOND LATTICE?) OR (DIAMOND S NITROGEN VACANCY)

Finally, we restrict these searches to “Measurement” OR (MAGNETOMET+ OR INTERFEROMET+ OR GYRO+ OR ACCELERO+ OR radar? OR lidar? OR ladar? OR SENSOR? OR SENSING)

Rationale

Again, we use a mix of CPC code and text-based search since CPC codes do not currently offer extensive coverage in this domain (a few hundreds of patent families).