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Overview of Quantum Technologies

Technology Landscape Report

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December 2024

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Introduction

The technology landscape report provides an overview of the dynamic and rapidly evolving field of quantum technologies. Quantum technologies represent a revolutionary advancement in science and technology, with profound implications across multiple domains.

Quantum technologies rely on the properties of quantum mechanics to perform tasks that are otherwise impossible or unworkable with classical technologies.

To understand quantum technology in simple terms, let's consider an analogy[31] and think of quantum technology like a magical library. In this library, the books have incredible abilities:

- Superposition (Magical Books): Imagine each book can tell many different tales at once. When you open a book, it could be telling a tale about a knight or a princess or both at the same time. This is like a quantum bit (qubit) in a quantum computer that can be both 0 and 1 at the same time, unlike regular bits that are just 0 or 1.
- Entanglement (Paired Magical Books): Now, imagine two magical books that are connected. If you change the tale in one book, the tale in the other book changes instantly, no matter how far apart they are. This is like quantum entanglement, where particles become linked and instantly affect each other even across great distances.
- Quantum Tunnelling (The Magic Door): Imagine a magical door in the library that normally keeps you out. But sometimes, with a special key, you can walk right through it as if it's not there at all. This is like quantum tunnelling, where particles can pass through barriers that they shouldn't be able to, allowing for new kinds of technology and discoveries.

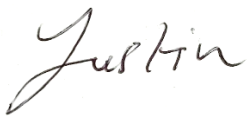
With the help of these magical properties of the books and the library, scientists can solve problems much faster, send messages that can't be intercepted, and uncover new mysteries about the world. Therefore, the technology developed using quantum technology is such as a library in which books are filled with magical doors and a keyboard. In this way, a person uses technology as if he had a magical library full of books to do impossible and amazing things!

Quantum promises to revolutionize industries by providing the highest computational power, uncrackable cryptography, sensors with high sensitivity, and ultra-secure communication networks.

This report delves into the three primary branches of quantum technologies: Quantum Communication, Quantum Computing, and Quantum Sensing.

But first, let's go back to explore the origins of quantum technology, tracing its development from early theoretical foundations to contemporary applications.

Please register your interest here Techconcierge@Dentons.com if you wish to attend our Webinar to be scheduled early 2025, in which Dentons and Clarivate will present highlights and discuss the quantum technology landscape in more detail.



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Co-Head IP, Dentons

Background

The origin of quantum technology can be traced back to the early 20th century with the advent of quantum mechanics. Key figures in this era include:

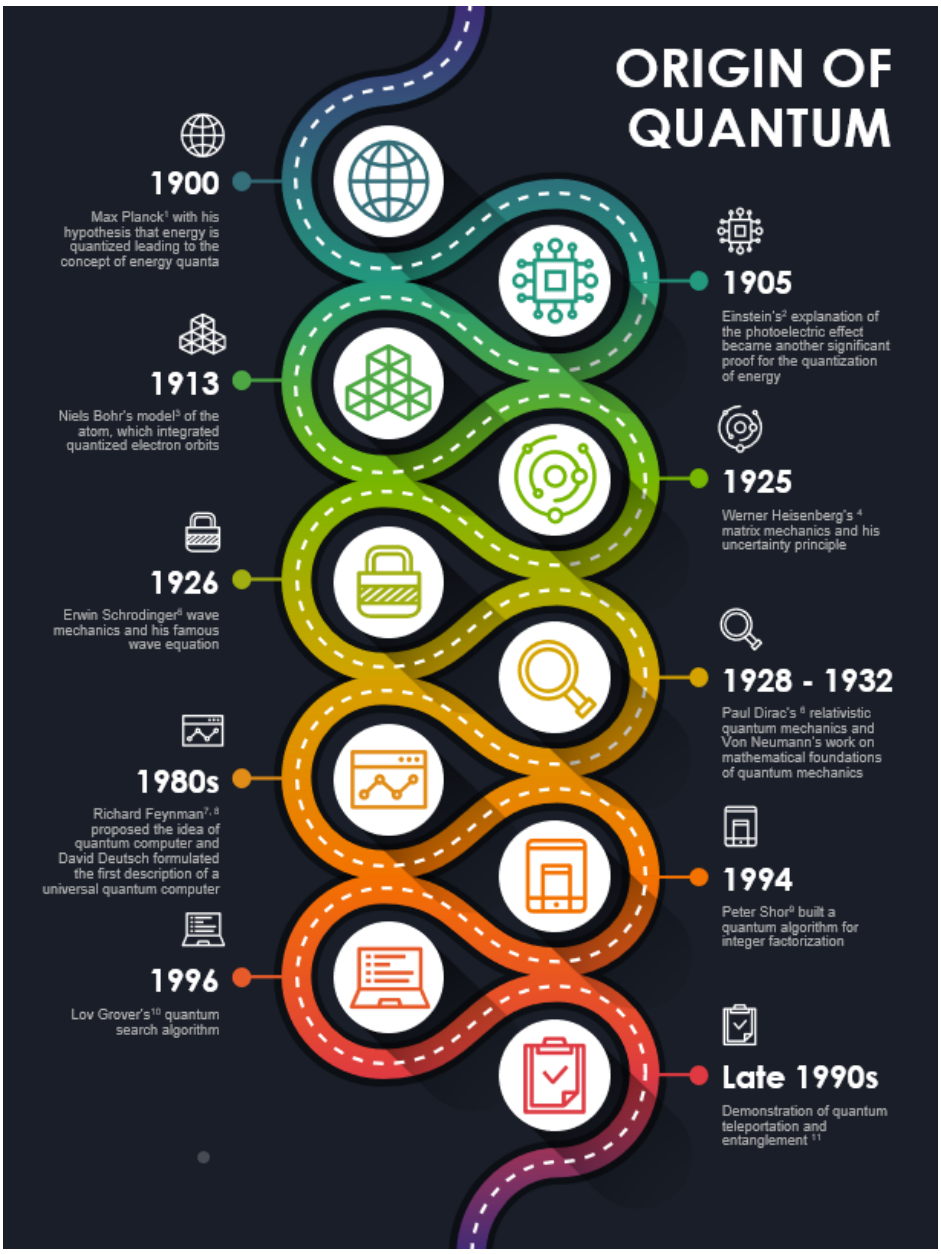

Figure 1: Origin of Quantum

The 21st Century: Towards Practical Quantum Technologies

The early 21st century has been characterized by rapid advancements in both theoretical and experimental quantum technologies:

- Quantum Communication[11, 14]: The development of quantum key distribution (QKD) protocols, such as BB84, has provided a method for secure communication guaranteed by the principles of quantum mechanics.
- Quantum Computing[12]: Great advances have been made in the development of scalable quantum computers, with various platforms being explored, including superconducting qubits, trapped ions, and topological qubits.
- Quantum Sensing and Metrology[15]: Quantum technologies have led to the development of highly sensitive sensors, with applications in fields ranging from medical imaging to navigation.

Problem Statement:

Classical computing[29] has reached its limits in addressing some of the most complex problems in science, cryptography, and big data. Quantum technologies, particularly quantum computing, offer a paradigm shift but face significant hurdles in development and implementation. Key problem areas in classical computing and quantum solution are summarised in the table below:

Challenges	Classical Computing	Quantum Solution
Computational Limits	Classical computers cannot efficiently solve problems like factoring large numbers or simulating quantum systems.	Improved qubits with probabilistic properties Quantum error correction
Security Threats	Vulnerable to quantum attacks and requires quantum-resistant algorithms	Quantum algorithms or hybrid system to solve practical problems beyond the capability of classical algorithms
Quantum Communication	Long distances communication security issue	Quantum key distribution (QKD) to secure communication channels Quantum repeaters to extend the range of quantum communication networks
Measurement Sensitivity	Traditional sensors' sensitivity cannot meet some applications' high precision requirements	Quantum sensors can optimize precision and beat current limits in all kinds of sensor technologies, from inertial sensors to quantum clocks.

Table 1: Challenges and Quantum Solution

Future Direction:

The future of quantum technologies is very promising, with several key areas of focus:

- Quantum Computing [13, 16]:
  - Fault-Tolerant Quantum Computers: Development of fault-tolerant quantum computers that can perform consistent and scalable computations.
  - Quantum Supremacy: Achieving and demonstrating quantum supremacy over classical supercomputers in practical applications.
- Quantum Communication Networks [19]:
  - Global Quantum Internet: Developing a global quantum internet that enables secure communication on a worldwide scale.
- Quantum Sensing and Metrology [20]:
  - Enhanced Sensors: Building quantum sensors with high levels of precision for applications in medicine, geology, navigation, and defence.
- Industry-Specific Applications [30]:
  - Healthcare: Quantum computing for drug discovery and personalized medicine.
  - Finance: Quantum algorithms for risk analysis and optimization.
  - Energy: Quantum systems for optimizing energy resources and discovering new materials.
  - Defence: Quantum technology can revolutionize defence strategies through enhanced data processing capabilities, unparalleled security via quantum communications, and quantum sensing providing enhanced detection and navigation.

Challenges:

Quantum technologies come with a set of challenges[16] that need to be resolved before their potential is fully unleashed:

- Technical Challenges:
    - Quantum Decoherence: Quantum states are incredibly fragile and prone to decoherence, resulting in the loss of information during the process of decoherence.
    - Error Rates: Quantum systems currently have high error rates that hinder practical computations.
    - Scalability: Scaling quantum systems to a large number of qubits while maintaining coherence and low error rates is challenging.
- Economic and Infrastructural Challenges:
    - High Costs: Quantum research and development require substantial financial investment.
    - Specialized Infrastructure: Quantum technologies need specialized infrastructure, including cryogenic systems and isolated environments.
- Human Resources:
    - Skill Gap: The number of experts with knowledge of multiple discipline areas of quantum technology are not sufficient for the development of quantum technology.
- Regulatory and Ethical Challenges:
    - Standardization: Lack of standards and benchmarks for quantum technologies.
    - Ethical Implications: Potential misuse of quantum technologies, particularly in surveillance and cryptography.

There are several challenges to make the shift to quantum technology from classical technology which can be overcome by Innovation. Thus, the next major section is on Patent Landscape on 'Quantum technology', as patents are a proxy to Innovation and an important ingredient to push the boundaries and accelerate the pace of Innovation to bring meaningful solutions. Patents are also an indicator to the investment by organizations in a technology area at country or regional level.

Executive Summary:

This study provides a comprehensive analysis of the patent landscape in the field of quantum technologies, focussing on 14,314 relevant inventions (DWPI patent families filed in the last 10 years. Key insights from the analysis are:

1. Overall Growth and trends:
    - Quantum technology domain experienced a compound annual growth rate **(CAGR) of 28%** from 2014 to 2022, with a particularly high growth **rate of 41% between 2015 and 2019** indicating the gain in importance of this technology.
    - Quantum computing exhibits a substantial growth trend, with patent **filings increasing roughly tenfold** over the study period.

2. Geography:
    - **China** is the leading source of innovation in quantum technology, with a strong focus on quantum communication (60% of Chinese inventions).
    - **United States** follows closely, with 80% of its inventions concentrated on quantum computing.
    - **Europe** is catching up with the recent investments in Quantum technology and may try to reduce the gap or get into Top 3.
    - The top three markets are China, the U.S., and Japan based on the patent protection.
    - Among European-based entities, German corporates and French academic institutions are leading innovators in quantum technologies

3. Players:
    - **IBM** is clearly leading the pack in patent filings with a huge margin with the second place Hefei Origin Quantum Computation within Quantum technologies
    - **65% of the top 25** patent applicants are China-based organizations.

4. Technology:
    - **70%** of the leading entities are research and academic institutions, predominantly located in China within Quantum sensing which indicates this area is in nascent stage.

Methodology and thanks

- Our partners in this joint study, Clarivate plc, are thanked for access to their market leading patent data, data analytics and contributions generally.

- The study is based on active unique patent applications (consolidated by the Derwent World Patents Index™ DWPI family*) first filed on or after 2014. It focuses on three main segments of quantum technologies*: quantum computing, quantum communication, and quantum sensing and metrology. The research has identified 14,314 inventions that are pertinent to this field. The emerging trend analysis employs the Derwent Strength Index™ (DSI*) to evaluate the patent's strength.

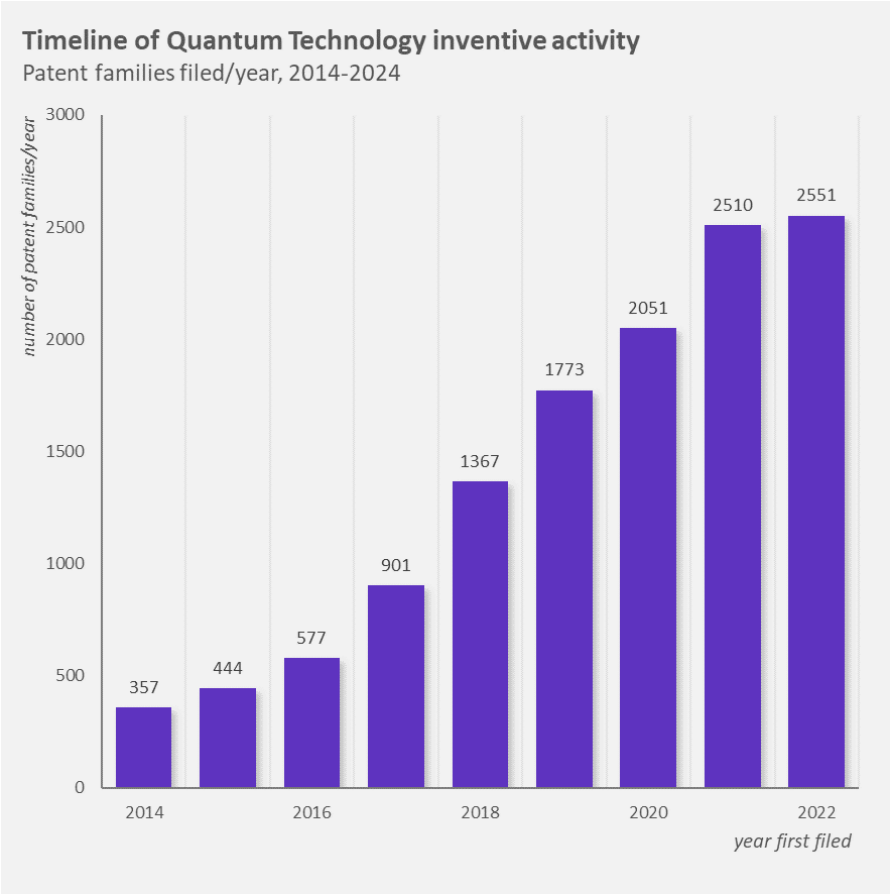

Figure 2: Patent Filing Trend in Quantum Technologies

The number of inventions for Quantum Technologies, considering the first filing year of 2014 and later, is displayed in the graph above. It shows a general upward trend that noticeably accelerated from 2016 to 2019. The U.S. filings are the primary source of growth during this time. Please note the filing numbers for 2023 and 2024 are incomplete due to the 18-month publication delay and therefore are not shown in the graph.

Table 2: Distribution of Quantum Technologies

Quantum Technologies	Count
1. Quantum Computing	6822
2. Quantum Communications	6542
3. Quantum Sensing	1844

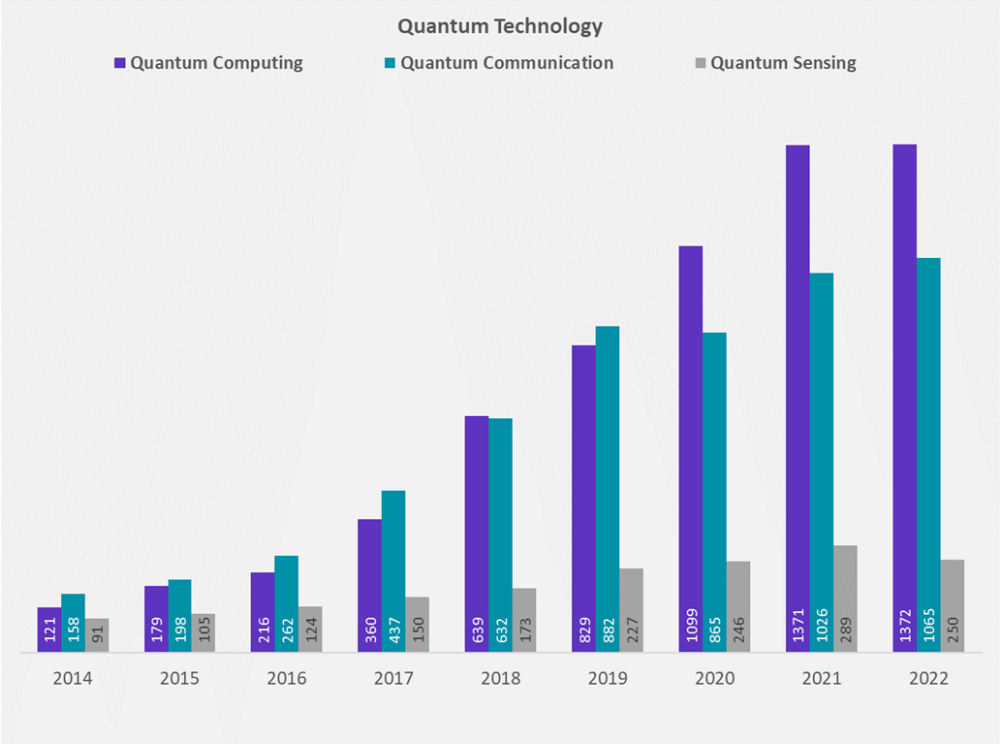

Figure 3: Filing trend of Quantum Computing, Quantum Communication and Quantum Sensing

As you can see in Figure 3, most quantum technology inventions fall within the quantum computing segment, while the second most popular technology segment is quantum communication. Quantum sensing inventions show lower and more consistent volumes over the longer term. The year-over-year filing trends for each category are further displayed in the bar chart. Throughout the course of the 10-year study, quantum computing has exhibited the strongest growth trend, with filings rising more than tenfold. During this same timeframe, inventions in quantum communication increased by roughly seven times, but since 2020, there has been a slowdown trend. Quantum sensing has experienced the least growth, with filings tripling.

Innovation sources by region

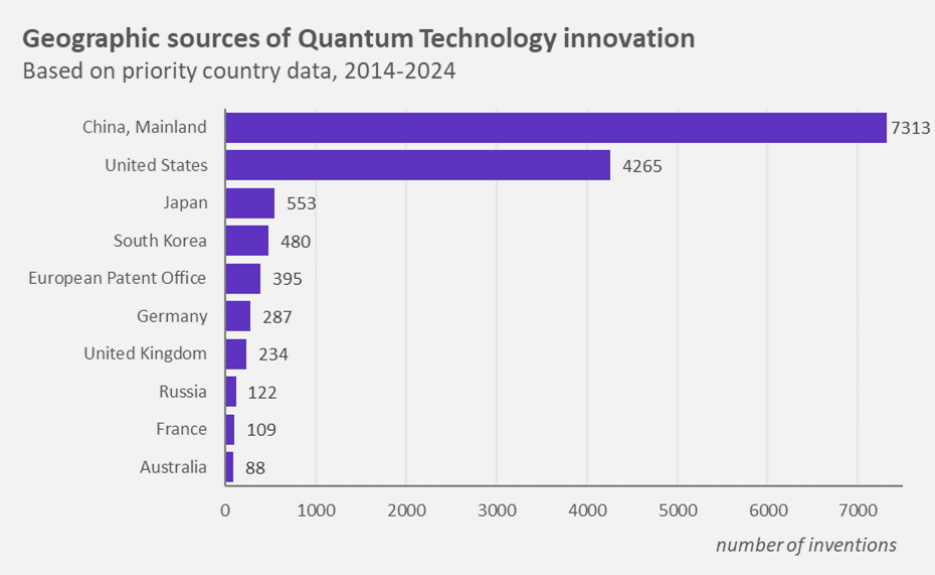

Figure 4: Source of Innovation for Quantum Technologies

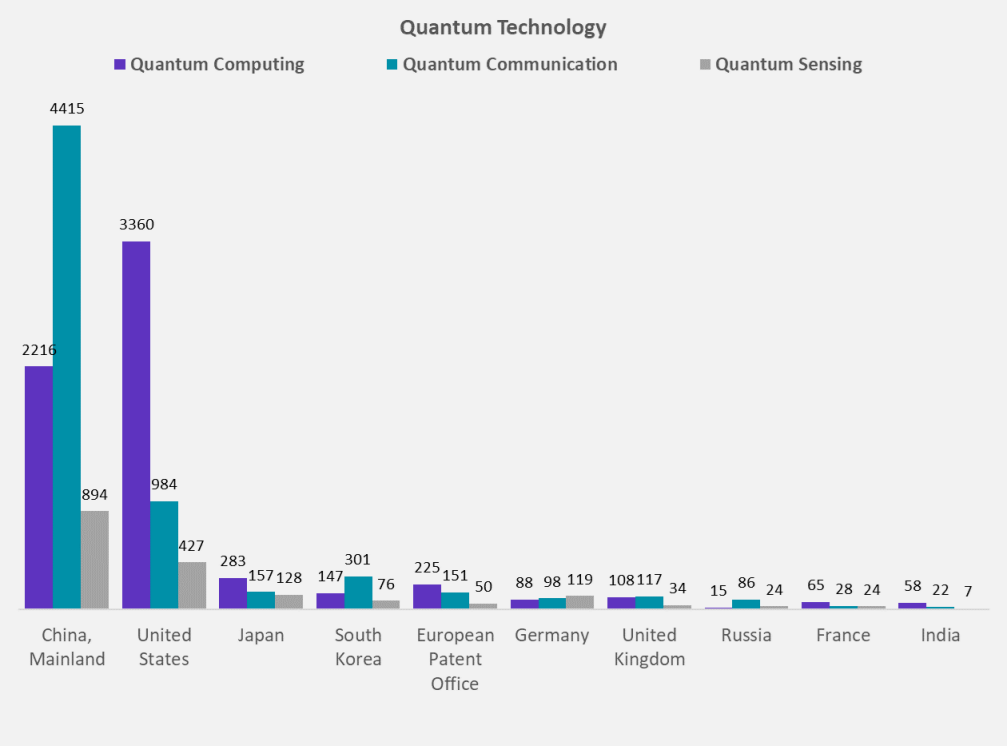

Figure 5: Source of Innovation for Quantum Computing, Quantum Communication and Quantum Sensing

China is the primary source of Innovation within Quantum Technology, with the United States following closely behind.

Each country/region has a different focus across three sectors. While nearly 80% of U.S. inventions are focused on quantum computing, about 60% of Chinese inventions are in the field of quantum communication. The filings seen in Germany are some of the most evenly distributed, with a slightly higher concentration in quantum sensing. Most filings within the United Kingdom relate to quantum computing and communication while most French inventions are in the area of quantum computing.

Protection country (market) analysis

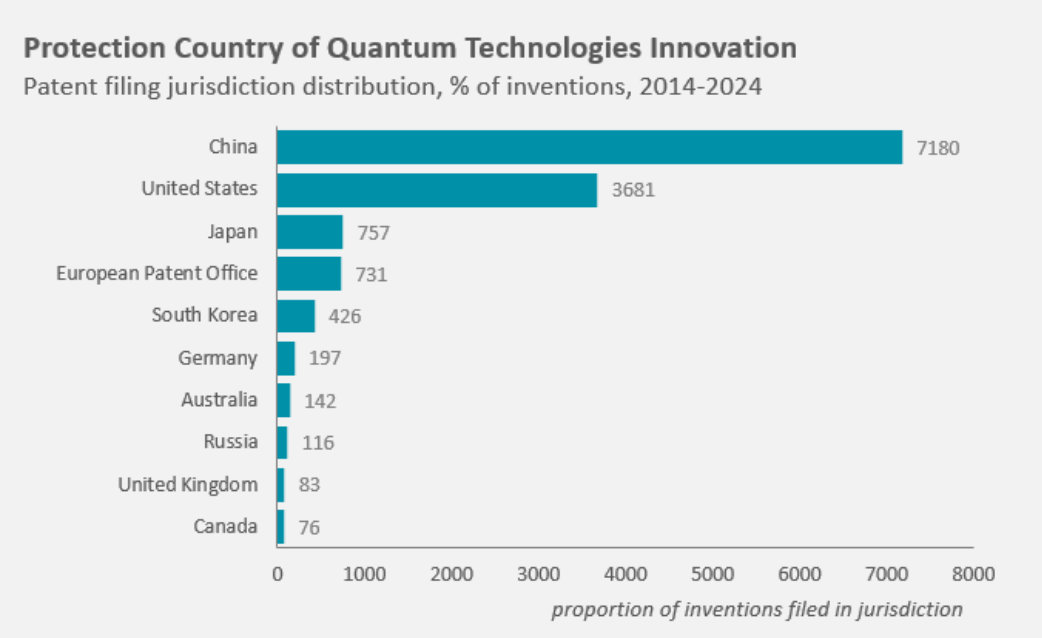

Figure 6: Patent Protection Country Analysis

The intended commercialization market may be represented by the publication country. The top three protected countries are China, the U.S., and Japan.

Global top applicants in Quantum Technologies

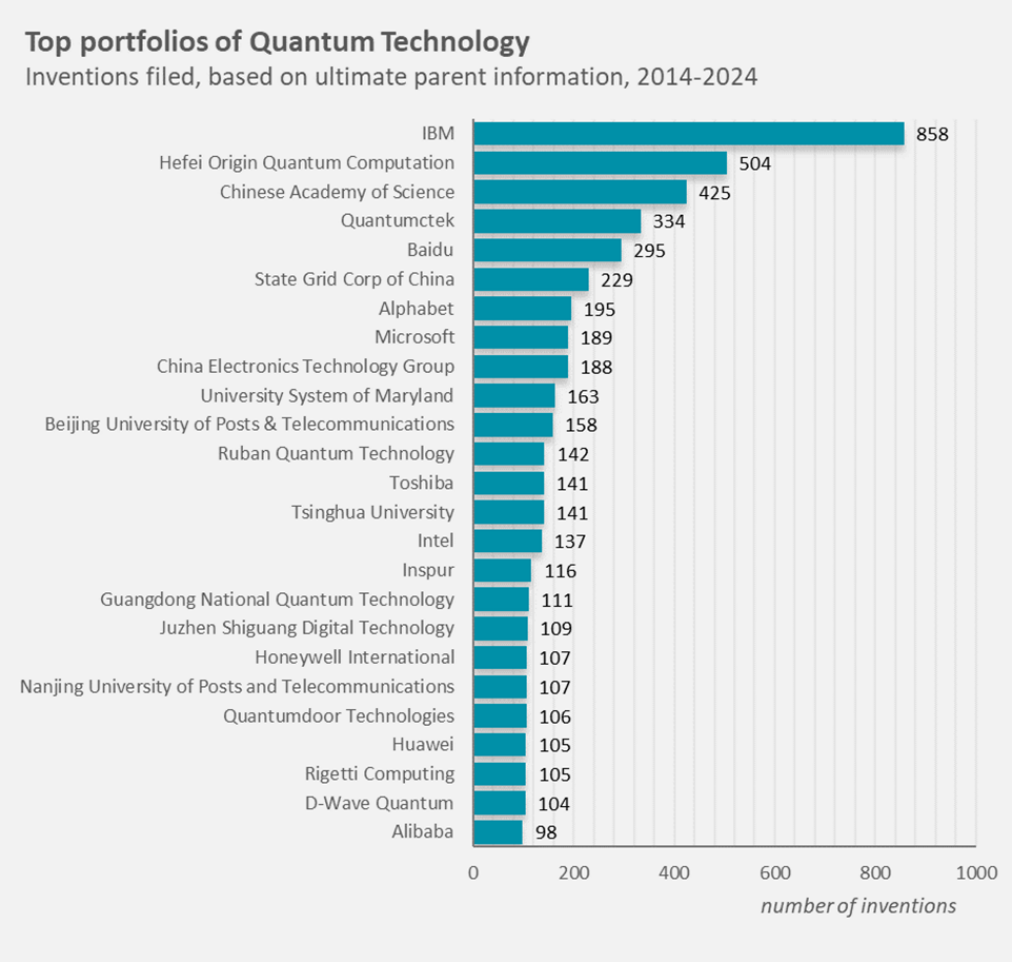

Figure 7: Top Players in Quantum Technologies

Quantum technology is a rapidly advancing field with significant contributions from both academic institutions and private companies around the world. The bar chart in Figure 7 shows the top 25 assignees with the most quantum technology inventions. Overall IBM has the highest number of inventions. Apart from IBM, Alphabet, Microsoft, University System of Maryland Intel, Honeywell, Rigetti Computing, and D-Wave are also among the top 25 applicants and all have headquarters in the United States. China-based companies have a prominent presence in this domain, with 16 of the top 25 companies/research institutions having headquarters in China.

Top global applicants in Quantum computing

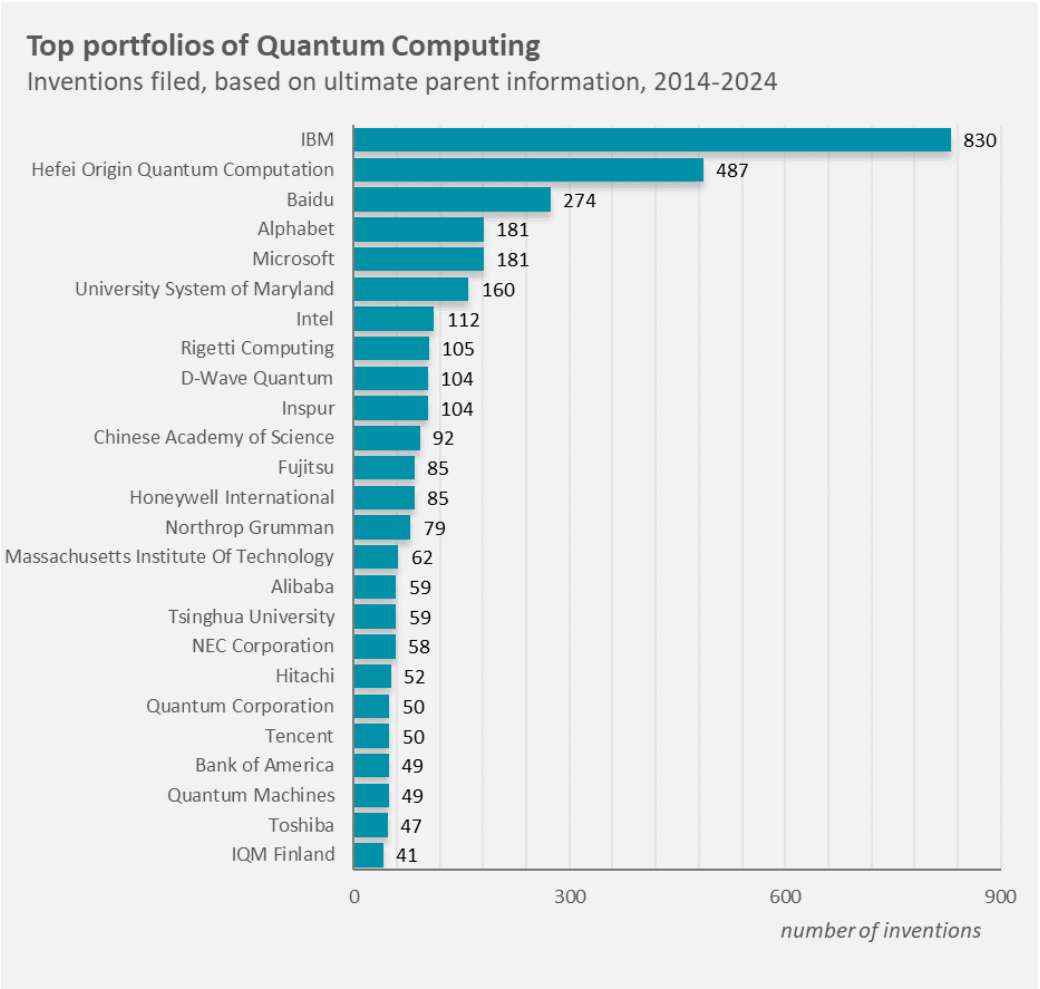

Figure 8: Top Players in Quantum computing

U.S. and China-based technology companies and academic institutions are at the forefront of quantum computing filings, with some competition from Japan-based companies.

Top global applicants in Quantum Communication

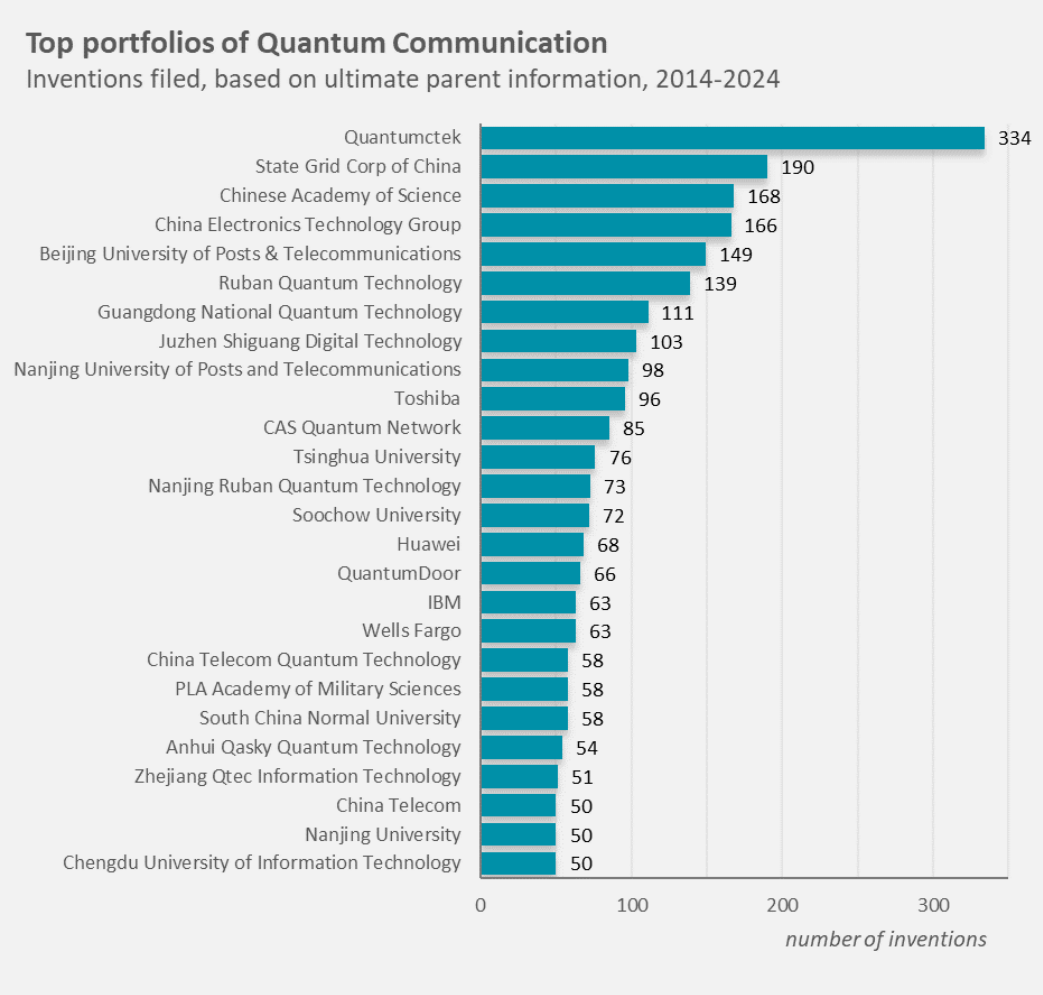

Figure 9: Top Players in Quantum Communication

In recent years, China has dominated the quantum communication patent landscape, with a significant number of filings originating from Chinese institutions and companies. China accounts for the top nine filing entities in this field. The United States and Japan also contribute substantially to the patent landscape in this field, driven by their leading tech companies and research institutions.

Top global applicants in Quantum Sensing

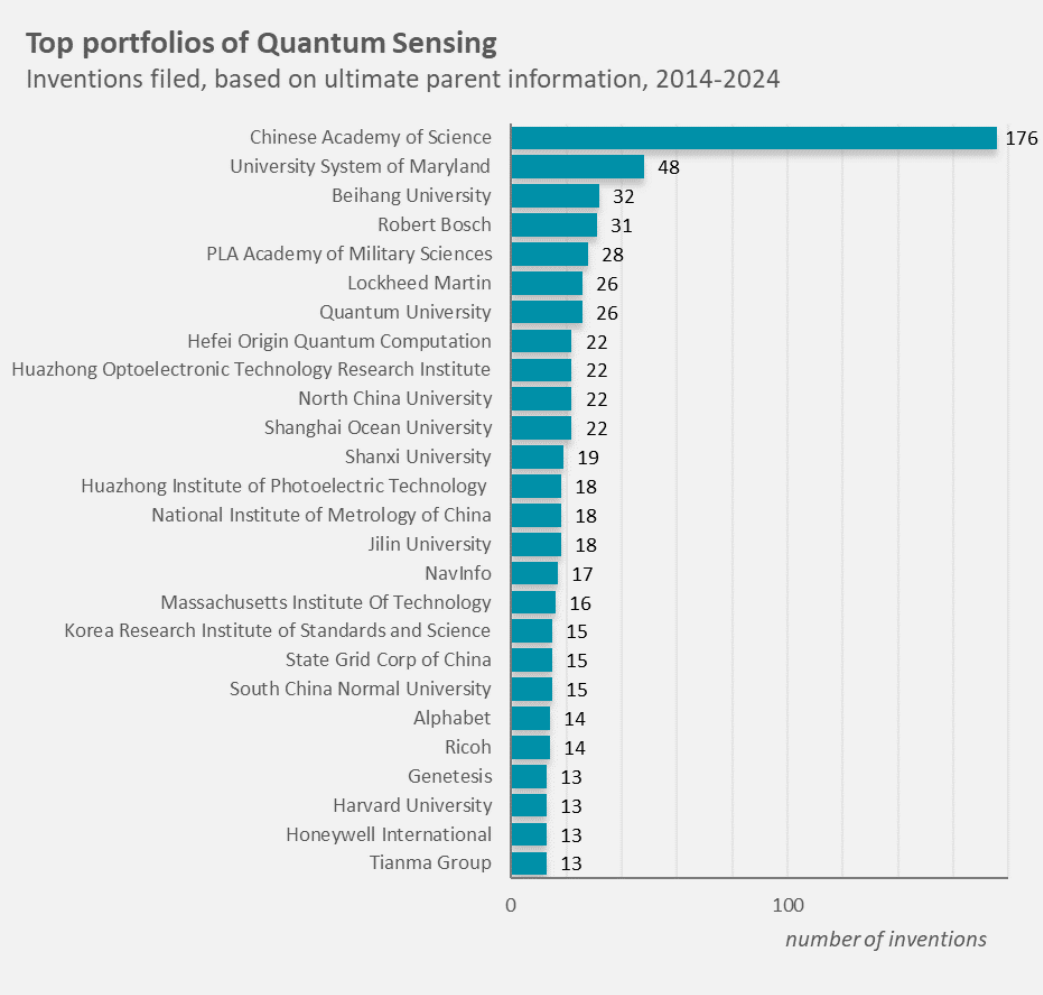

Figure 10: Top Players in Quantum Sensing

Seventy percent of the leading entities in the field of quantum sensing are research and academic institutions, the majority of which are based in China. Robert Bosch, the Germany-based multinational engineering and technology company, ranks fourth.

Europe filing trends

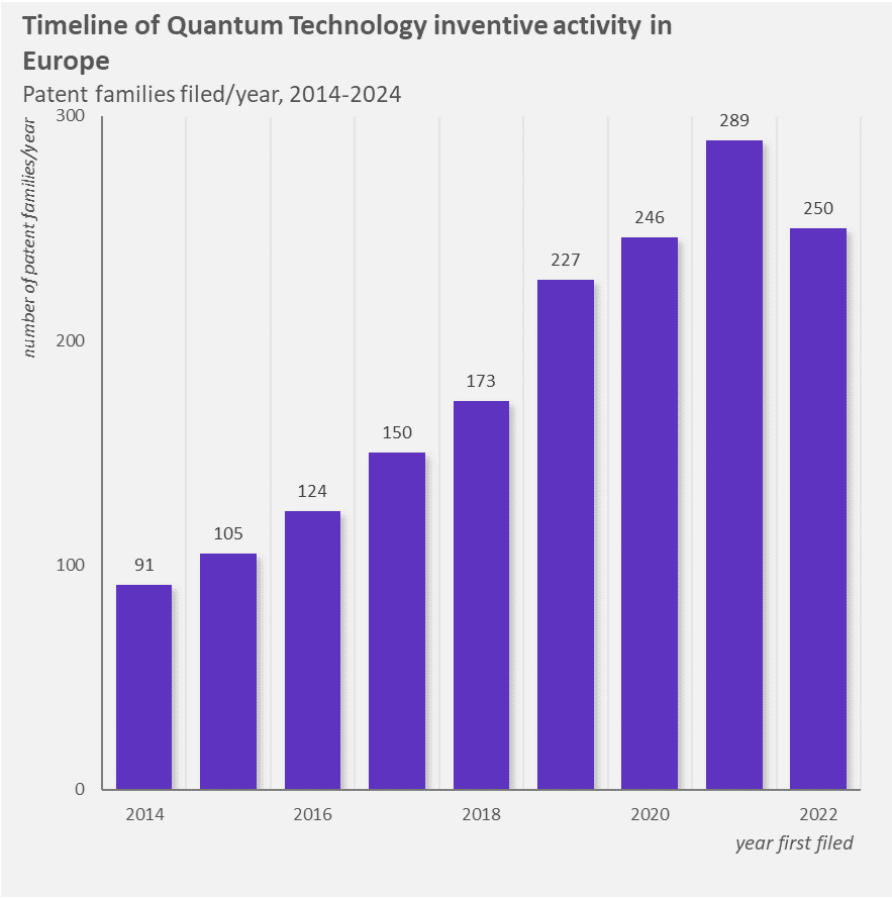

Figure 11: Patent filing trend in Europe

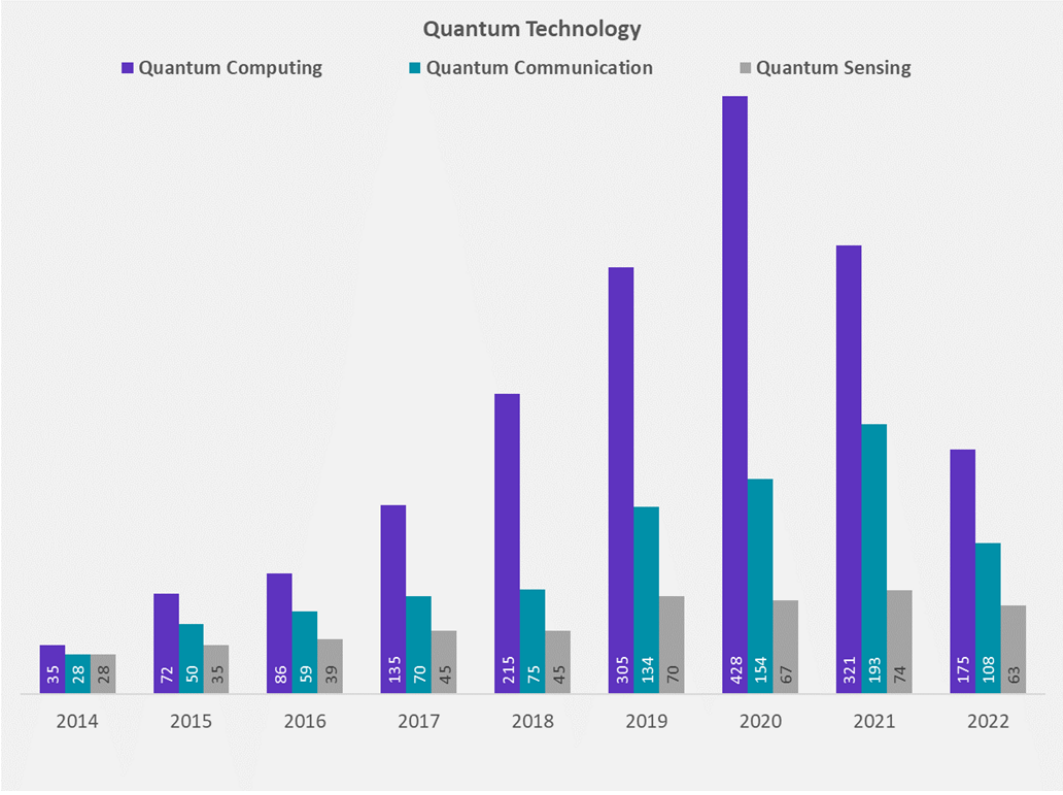

Figure 12: Patent filing trend within Quantum Computing, Quantum Communication and Quantum Sensing in Europe

The bar charts illustrate patenting activities in Europe, specifically focusing on inventions published within the European Patent (EP) region. The number of patent filings has been steadily increasing.

Following the global trend, quantum computing is the most filed topic in Europe which peaked in 2020 and has since shown a declining trend. Quantum communication filings progressively rise from 2014 to 2021 and decline in 2022. Since 2019, the number of quantum sensing filings has been consistently around 70 inventions per year.

Top applicants in Europe

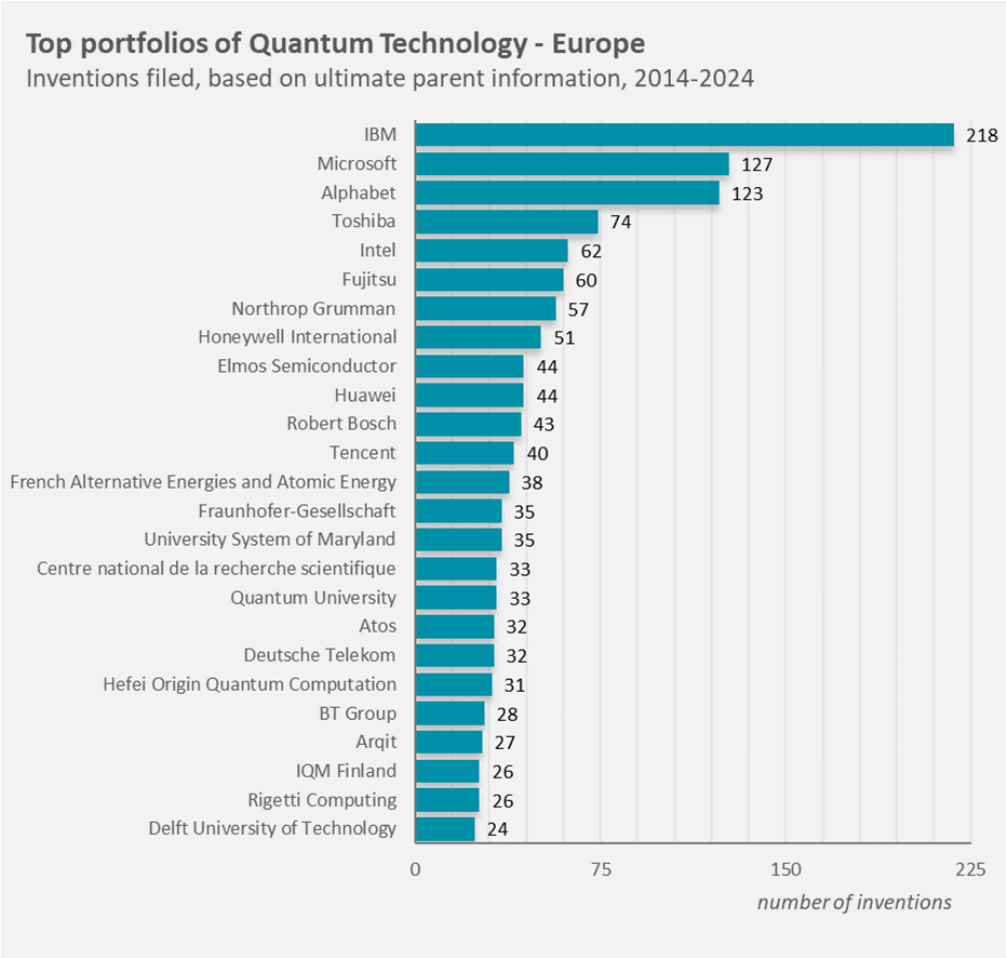

Figure 13: Top Players filing in Europe

The top 25 assignees with the greatest number of quantum technology inventions in European markets are displayed in the Figure 13 chart. Europe and US-based companies have a prominent presence in this dataset, with each having eight of the 25 companies having headquarters in European countries and the U.S. Europe and the U.S. are both strong players in the European patent filing market. Each is home to the headquarters of 8 of the top-filing companies within Europe.

Top Europe-based applicants

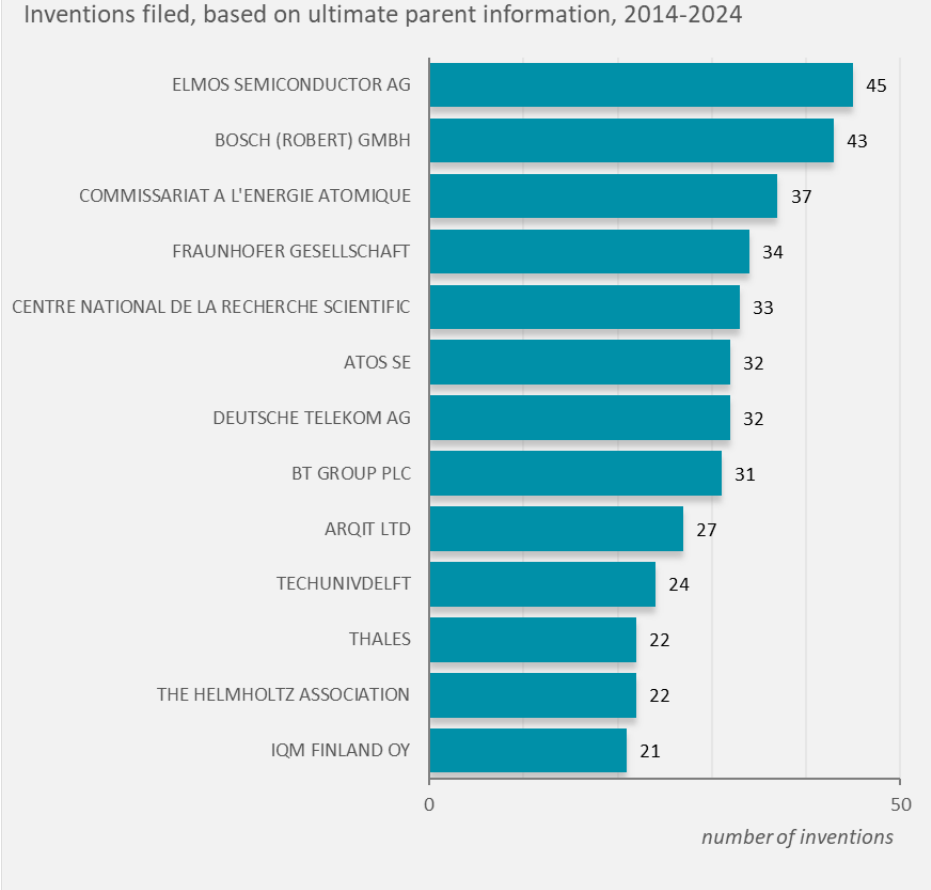

Figure 14: Top filers based in Europe with Quantum technology

The chart above further shows the European-based companies filing numbers in Quantum Technology. The top 2 portfolios are both German-based corporations Elmos Semiconductor and Bosch.

ThemeScape™ Map from Derwent Innovation

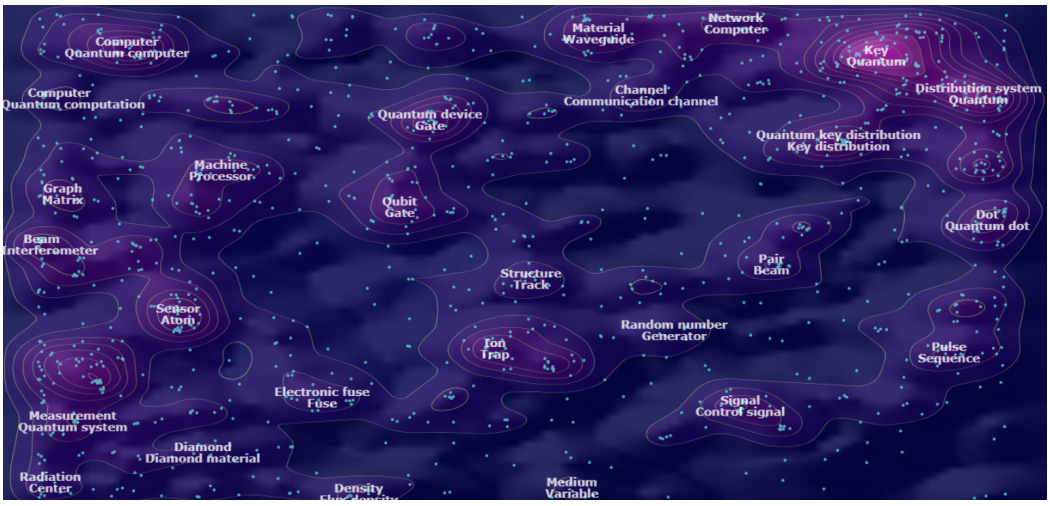

Figure 15: ThemeScape™ Map from Derwent Innovation

The concept map shown here uses advanced text analysis to summarize major concepts and subject matter within the E.P. inventions in the collection. The map was generated by analysing the Derwent - Use field.

Each patent family or "invention" is situated in a single location on the landscape map. Areas of higher density (light purple areas) represent technical topics shared across many inventions.

Globally, most common technology focus is on jet engine components such as key distribution, measurement, and signal control.

Emerging technologies in Europe

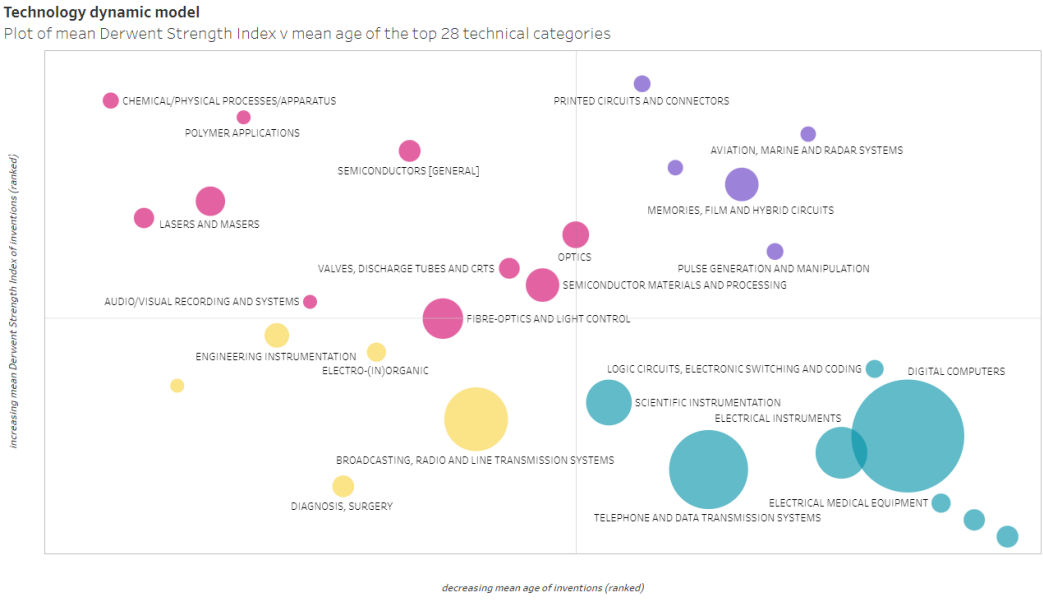

Figure 16: Emerging technologies in Europe

By analysing the strength and recency of inventions, the purple bubbles highlight emerging technologies

These emerging technologies include Aviation, Marine and Radar systems, Memories, Film and Hybrid Circuits, Pulse Generation and Manipulation and Printed Circuits and Connectors. These technologies may bring market interruption through future commercialization.

Conclusion

The growth in quantum technology showcases the brilliant discoveries of the physicists of the early 20th century and of the ability of the later generations of scientists and engineers to continuously create and reach new frontiers. Whether it be through the derivation of the main theoretical concepts by pioneers like Planck, Einstein, and Bohr or the practical accomplishments in quantum computing, communication and sensing, quantum technologies can disrupt many technologies. As research and development continue, the potential for quantum technologies to address some of the most challenging problems in science and engineering grows larger and more exciting.

Quantum technology is on the cusp of revolutionizing numerous industries with its unmatched capabilities. While significant challenges remain, ongoing research and innovation continue to push the boundaries, bringing us closer to a quantum-enabled future. The continual research and development efforts in Quantum Communication, Quantum Computing, and Quantum Sensing are the stepping stones to a future where communication is secured with supreme computational power, and having ultra-precise sensing which will be integral parts of our technological landscape.

This report aims to also provide a statistical overview on the patent landscape of quantum technologies with a focus on quantum communication, quantum computing and quantum sensors. The patent landscape covers innovation trend, geographic source of innovation, top applications, European based analysis, etc. The automated characterisation and statistical analysis of patent data is not an exact science our methodology inherently suffers "noise", for example where mention of "quantum" in a patent document is not identified in the correct context. Also keep in mind that many in these fields rely on trade secrets or are under mandatory secrecy and so the picture delivered from patent data alone is certainly incomplete. The vast potential of the technology makes various aspects and applications sensitive, and they remain out of public view. That said, the observed trends are informative and the we hope this report shines a light on this rapidly developing and fascinating field.

Since 2014, inventions in quantum technologies have shown a general upward trend, accelerating notably from 2016 to 2019, with the United States being the primary driver of this growth. Quantum computing exhibits the strongest growth, with patent filings increasing roughly tenfold over the past decade. Quantum communication filings increased about sevenfold but have slowed since 2020, while quantum sensing shows the least growth, with filings tripling during the study period. China, the U.S., and Japan are the three countries that have filed the most patent applications in this segment, indicating these as primary markets for commercialization. Globally, the most common technological focus is on jet engine components, key distribution, measurement, and signal control.

In Europe, patent filings have been steadily increasing, aligning with global trends. Quantum computing is the most filed topic in Europe, peaking in 2020 but declining since. US-based and European based corporations are the leading applicants in Europe. Among European-based entities, German corporations and French academic institutions are leading innovators in quantum technologies. The study also highlights emerging technology approaches from European entities, showcasing high strength and recent filings in areas such as aviation, marine and radar systems, memories, film and hybrid circuits, pulse generation and manipulation, and printed circuits and connectors.

By exploring the intricate details of quantum technologies and their transformative potential, this report underscores the importance of continued investment and ethical consideration in this rapidly evolving field.

Appendix

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Derwent Strength Index™ (DSI) A proprietary patent-scoring algorithm by Derwent. The DSI assesses the number of desirable characteristics a single invention has gathered to date. This is then aggregated across technologies and entities to identify trends and importance. The Strength calculation uses several factors in its model, including Impact, Investment, Success and Rarity.

In addition, the Strength Index also models the value of inventions over time as well as weighting for factors that accrue over time e.g., existence granted patent rights.

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Dr Justin Hill has assisted many of the world's leading technology companies with efficient global IP strategies and has dealt the full gambit of IP and commercial issues. Justin assists his clients with IP policy formulation and implementation, international portfolio management, highly efficient IP filing programs, competitive intelligence and positioning, revenue generation opportunities, and IP risk management. He also provides infringement and validity opinions, as well as being known for his successes in opposition and appeal proceedings before the European Patent Office. Justin spends a considerable amount of his time in IP negotiations and is a representative for patent litigation matters before the High Court and Unitary Patent Court.

Justin is a European patent attorney and listed by IAM 300 as Global Leader in IP Strategy . His team can advise on any area of technology from a network of 160 cities across 80 countries. He is well known among deep tech and investor communities.

Justin Hill – **Band 1** Intellectual Property: Patent & Trade Mark Attorneys for 10+ years **– *Chambers UK, 2024***

"Justin Hill is among the most strategic and commercially minded …. He is highly rated as a visionary value creator." **– *IAM 300 Global Leaders 2023***

"**Leader in Field** Justin Hill provides excellent commercial and strategic input." ***Legal 500 2023 – PATMA: Patent Attorneys***

"Justin Hill's track record is working with world-class technologies to generate portfolios of strategic importance" **– *IAM 1000***

Testimonials

Collated independently by Legal 500 research team.

'They are very efficient, knowledgeable and quick. They grasp concepts quickly and effectively.'

'The legal strengths of certain individuals coupled with the technical expertise of others is really pleasing to see. The Dentons representatives' ability to get into the details of software, how it works and review code is impressive. This is particularly important when discussing patent infringement where the lines of interpretation and equivalence can become blurred.'

'Fantastic, collaborative and friendly. The team becomes part of your team and immediately works alongside you, rather than away from you.'

'Justin Hill is a fantastic and calm leader who provides detailed oversight when needed.'

'Justin and his team really understand our business. This combined with their capabilities means the service we get is incomparable to other firms.'

'Justin Hill is extremely entrepreneurial.'

'We have a long-standing relationship with the team and have received excellent, well-thought-out strategic support over the years.'

'Not only is Justin Hill a grand master of IP strategy, but he is also an excellent and warm engagement partner that all strives to look after our best interests.'

Mitul Karaniya

Lead Product Manager, Clarivate

Mitul has 13+ years of experience in the field of IP and is an expert in Consulting and Project management. He has conducted research and analysis across a wide range of specialities and has worked with various technology/IP focused corporations, research institutions, and government organization to provide actionable intelligence that drives IP/Innovation strategy and achieves IP research objectives. He has leveraged country-level analysis to advise various ministries and organizations on crafting country-level IP policies impacting multi-billion-dollar investments into trending technical areas.

Chen Zhao

Lead Product Manager, Clarivate

Chen is responsible for managing global analytical projects and working with corporations, governments, and research institutions to deliver actionable insights and intelligence that drive R&D, IP and innovation strategy. Chen has over 7 years' experience in the field of IP analytics and searching. She holds a Master's degree in Environmental and Resource Engineering and BS in Materials Chemistry. She is well versed in English and Chinese (Mandarin) languages.

Gaurav Agnihotri

Associate Director, Clarivate

Experienced patent research professional and project leader with 15+ years of experience in IPR. He leads the patent analytics services team in the electronics, computing, and telecommunication domains, providing a wide range of patent services to global customers.

Ankur Bagul

Manager, Clarivate

Experienced patent research professional and project leader with 13+ years of experience in IPR. He has experience performing and executing landscape analysis, competitive intelligence, portfolio analysis, and technology assessments across a broad spectrum of technologies, including multiple projects in Quantum computing.

About Dentons

Across over 80 countries, Dentons helps you grow, protect, operate and finance your organization by providing uniquely global and deeply local legal solutions. Polycentric, purpose-driven and committed to inclusion, diversity, equity and sustainability, we focus on what matters most to you. www.dentons.com.

About Clarivate

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