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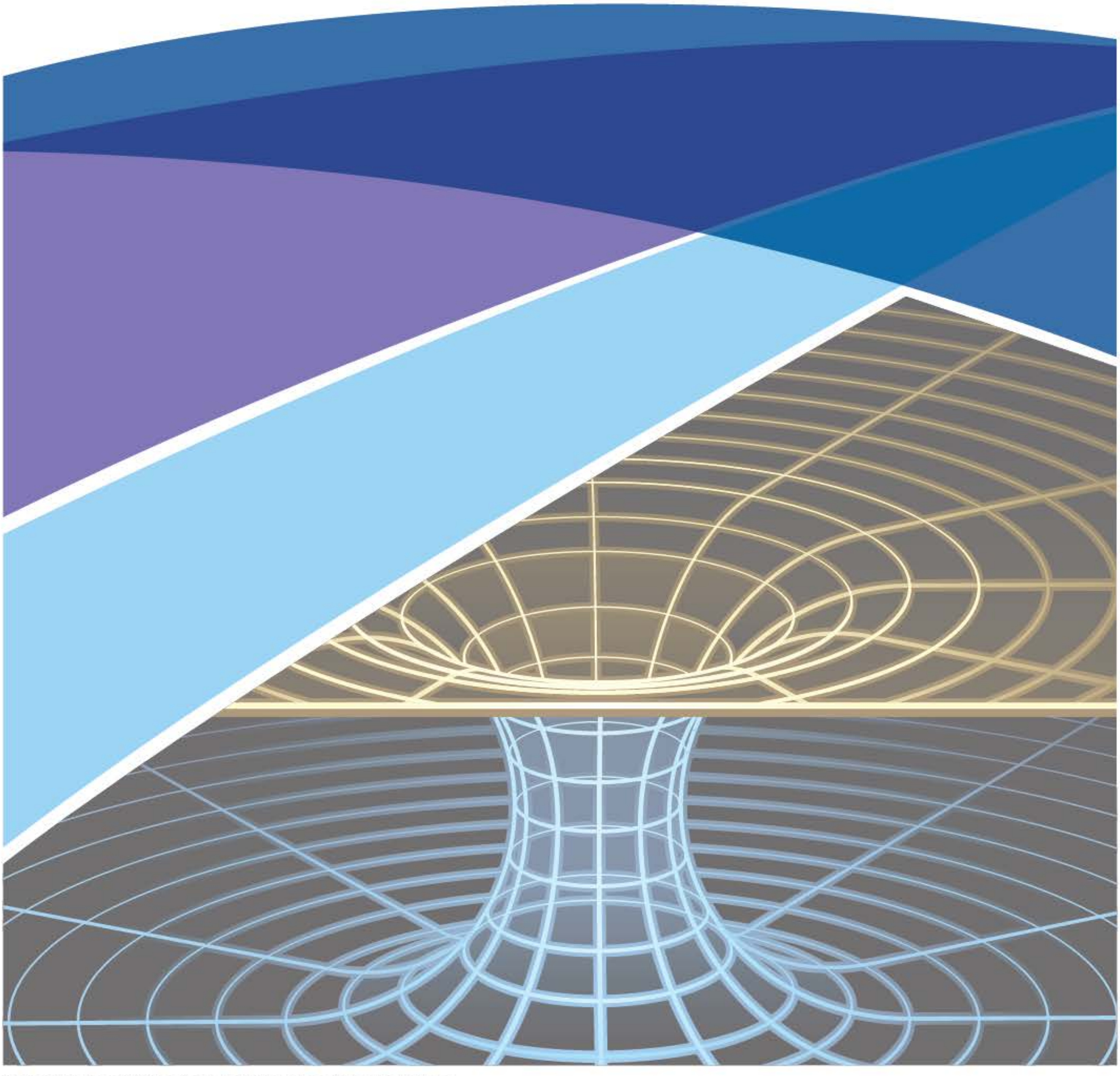
Quantum Technologies

A patent review for the Engineering and Physical Sciences Research Council (EPSRC)

October 2013



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Executive Summary

Overall the patent data shows that the UK is strong in quantum technologies, more particularly of the four areas of quantum technology analysed, it is strong in quantum secure communications and quantum computation. There is not enough patent data to meaningfully analyse the strengths of countries in quantum metrology and sensors or quantum simulators. Quantum secure communications and quantum computation are both areas of technology that exhibit a low but significant level of patenting activity. Commercial interest, evidenced by increased patent filing, in both areas began in 2000 and a steady and continued level of activity has existed since 2005. The patent data shows a strong UK presence in these two technology areas, with the proportion of inventors based in the UK being notably high. Quantum metrology and sensors patent activity is very slight at present, but exhibits a defined year-on-year growth. The preponderance of academic organisations in this dataset suggests that the technology is not mature. The commercialisation of further developments in this technology space has the potential to disrupt current sensor/metrology markets.

Quantum secure communications: This is a fledgling technological area with a low but significant overall level of patenting activity; a total of around 200 applications were published each year since 2006. Patent publication trends suggest that commercial interest in research into this technology space started at the beginning of the last decade.

The UK is ranked third highest after the USA and Japan in terms of priority patent publications by country, patent applicant country and inventor country. The UK is relatively well placed in quantum secure communications technology. The numbers for the UK are much closer to those of the US and Japan for inventor country than for priority publications or applicant country, which emphasises the strength that UK expertise has in quantum secure communications research. The Relative Specialisation Index[1] chart clearly illustrates that quantum secure communications is an area of UK strength, with patenting well above the level that would be expected for the UK in general. Analysis of academic publications also shows a strong UK research base in this technology space.

European Union (EU) priority patents and patent applicants are not far behind Japanese and US priority patents and applicants. The EU is only marginally in second place to the US in terms of inventor countries and places significantly ahead of Japan. EU academic publications are approaching twice the level of the nearest other publishers. This is a strong showing for the EU in quantum secure communications, which is based largely on the strength of the UK in this technology.

The top organisations are predominantly US and Japanese multinationals. British organisations British Telecom and QinetiQ appear in sixth and tenth place respectively. The lack of a strong presence from academic organisations indicates a commercial bias that points towards this being a reasonably mature technology area which is already commercially viable.

Quantum metrology and sensors: Analysis of patenting activity reveals a very small dataset (184 patent publications) which appears to have the hallmarks of a very early stage emerging technology that has yet to be commercialised fully and has potential to be disruptive. There is a small but steady increase in worldwide patenting activity which continues through the most recent year (2012).

The chart of top organisations, Figure 9, contains a large portion (7 of 20) of academic organisations, suggesting that the technologies have yet to be fully commercialised. This shift might disrupt established markets in sensing/metrology.

[1] More details can be found in Appendix C: Relative Specialisation Index

The UK appears in this tiny dataset, but by no means dominates it. However, the numbers of patents related to quantum metrology and sensors are very small so it is difficult to draw any solid conclusion about the relative strengths of the UK, Europe and other countries.

Quantum simulators: Worldwide published patent data reveals only 8 inventions that relate to quantum simulators. Of these, 4 claim priority in the United States, 2 in Japan, 1 at the European Patent Office (EPO), and 1 in China. None of the applicants or inventors on these patents are recorded as being based in the UK. Lack of patent publications in this technology area is perhaps unsurprising, given that generic methods of simulation and modelling are not regarded as patentable subject matter by many patent authorities, such as the UK and the EPO.

Quantum computation: The patent trends in this technology area reveal a low but significant overall level of patenting activity based on a relatively small absolute level of patenting (around 60 patent publications a year since a peak of 85 applications in 2005). This suggests a constant amount of research and development in this technology area year-on-year. This can be seen to illustrate commercial interest in research into quantum computation beginning at the turn of the millennium and subsequently continuing at a significant and steady level.

D-Wave systems are trailblazing ahead in terms of patents per organisation. There are no UK companies amongst the top 20 organisations for patenting in quantum computing technologies. However, the UK is well represented (3rd strongest country) in terms of priority patent applications and in terms of patent applicant and inventor countries (4th strongest country). The UK is relatively strong in this technology area, both in terms of its above average patenting activity and the high volume of academic publications that it generates.

The EU is also relatively strong in terms of patenting in the quantum computing area, especially in terms of inventor country where it is second only to the USA. This potentially reflects a large academic research base of expertise in the EU, which is confirmed by the fact that the EU tops the academic publications chart by some margin.

Contents

1 Introduction

The EPSRC is investigating UK funding of quantum technologies to build on the capabilities developed over the last decade and to take advantage of existing strengths to establish the UK as a leading player in a developing quantum technologies industry. Patent data can be a valuable indicator of innovation activity. As part of this investigation the Intellectual Property Office attended a roundtable discussion regarding quantum technologies and provided input on patent filings and the patent landscape in these exciting technology areas.

This report provides the background data behind the view expressed at the roundtable. It analyses the worldwide patent landscape in the quantum technology areas discussed at the roundtable and as defined by the EPSRC's working group on quantum technologies. More specifically, the worldwide patent landscapes in the fields of quantum secure communications, quantum metrology and sensors, quantum simulators and quantum computing are analysed. Comparisons are drawn between the positions of the UK and Europe in these technology spaces and the positions of other countries.

The datasets used for analysis in this report were extracted[2] from worldwide patent databases following consultation with patent examiners from the Intellectual Property Office who are experts in the field and who search, examine and grant patent applications relating to quantum technologies.

[2] Further details on the search strategy used can be found in Appendix B: Search strategy.

2 Quantum Technologies: Definitions

The EPSRC's working group on Quantum Technologies defined the technologies of interest as follows:

- Quantum secure communications;
- Quantum metrology;
- Quantum sensors;
- Quantum simulators;
- Quantum computation.

However, because of the structure of patent classification keys and the overlap in meaning of the relevant keywords, it was not possible to make a meaningful distinction between metrology and sensors for patent landscaping purposes. Therefore these areas have been combined for patent landscaping and this report analyses four quantum technology areas[3]:

- **Quantum secure communications:** which offer the prospect of fundamentally secure communication channels (as one could prove through the laws of quantum physics that no information was intercepted). This includes patents relating explicitly to encryption, e.g. quantum key distribution (QKD), as well as transmission systems and components that are specific to quantum communications;
- **Quantum metrology and sensors**: where quantum effects such as entanglement or superposition are exploited in the undertaking of high-resolution and highly sensitive measurements of physical parameters;
- **Quantum simulators:** which enable the accurate modelling of real molecules and materials;
- **Quantum computation**: information processing by using quantum superposition, coherence, decoherence, entanglement, nonlocality and/or teleportation.

[3] Further detail of the definition of these areas is apparent from the detail of the search strategies which can be found in Appendix B: Search strategy.

3 Quantum secure communications

Number of patent families	912		
Number of patent publications	2107		
Publication year range	1992-2013		
Peak publication year	2007		
Top country	USA		
Top applicant	MagiQ Technologies (USA)		
Field choices	**Field name**	**Number of entries**	**Coverage**
People	Inventors	1586	91%
Applicants	Patent assignees	997	88%
Countries	Priority countries	26	100%
Years	Publication years	22	99%

Table 1: Summary of worldwide patent dataset for quantum secure communications

Table 1 indicates that quantum secure communication is a fledgling technological area with a relatively low absolute level of patenting activity.

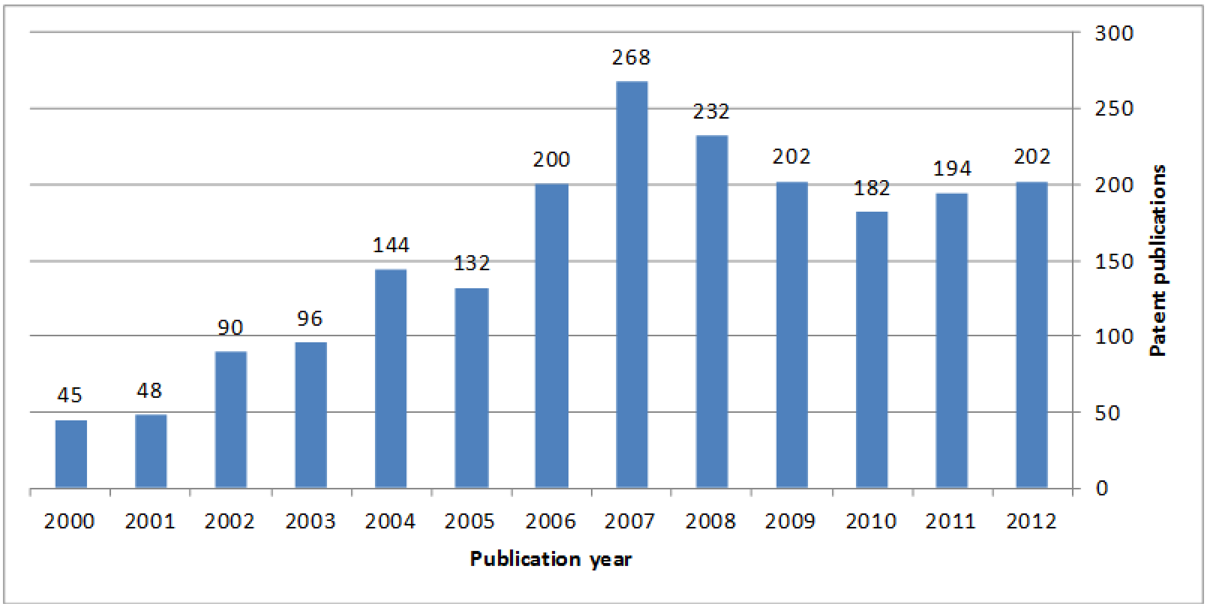

Figure 1 : Patent publications by publication year for quantum secure communications

Figure 1 confirms that there is a low but significant overall level of patenting activity. The level is steady with a worldwide total of around 200 patents being published in each year since 2006. This suggests a constant amount of research and development in this technology area year-on-year. There is an eighteen month delay between patent filing and publication and the associated research and development will typically have happened in the years before filing the patent applications. With this in mind, Figure 1 can be interpreted as illustrating that commercial interest in research into quantum secure communications began at the beginning of the last decade, and that there has subsequently been a significant and steady level of research interest.

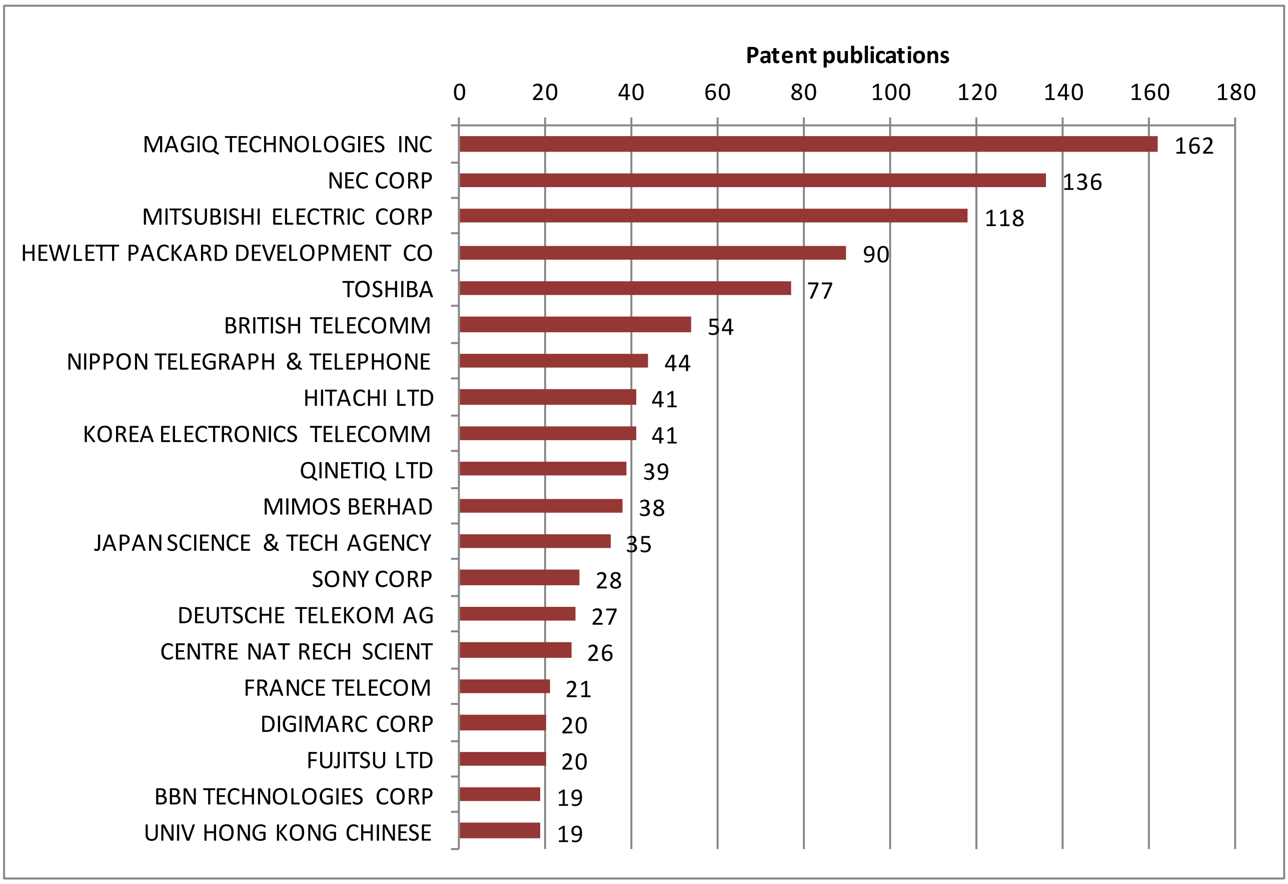

Figure 2 : Top 20 organisations for quantum secure communications

The top organisations, Figure 2, are dominated by US and Japanese multinationals. British organisations British Telecom and QinetiQ appear in sixth and tenth place respectively. These companies, however, have published less than half the number of patent than any of the top 3 organisations, and less than a third of the number that MagiQ technologies have published.

Very few academic organisations appear within the top 20 organisations. This commercial bias may indicate this technology area is relatively mature and commercially viable.

The UK is the third highest ranked country after the USA and Japan in terms of the location of filing priority patent applications as shown in Figure 3. Direct comparison of the numbers of priority applications is potentially misleading as it is accepted that the propensity to patent varies country-to-country according to filing habits and idiosyncrasies in different patent systems. US applicants, for example, typically file more patent applications per invention than the applicants at European patent offices. Even without factoring this in, Figure 3 illustrates that the UK is relatively well placed in quantum secure communications technology. China and the UK’s nearest European rivals have, at best, half as many priority patent applications as the UK.

Discounting 'WO' priority applications (applications made at the World Intellectual Property Office (WIPO)), the European Union, with UK priority applications making up almost half its total, places second between the USA and Japan.

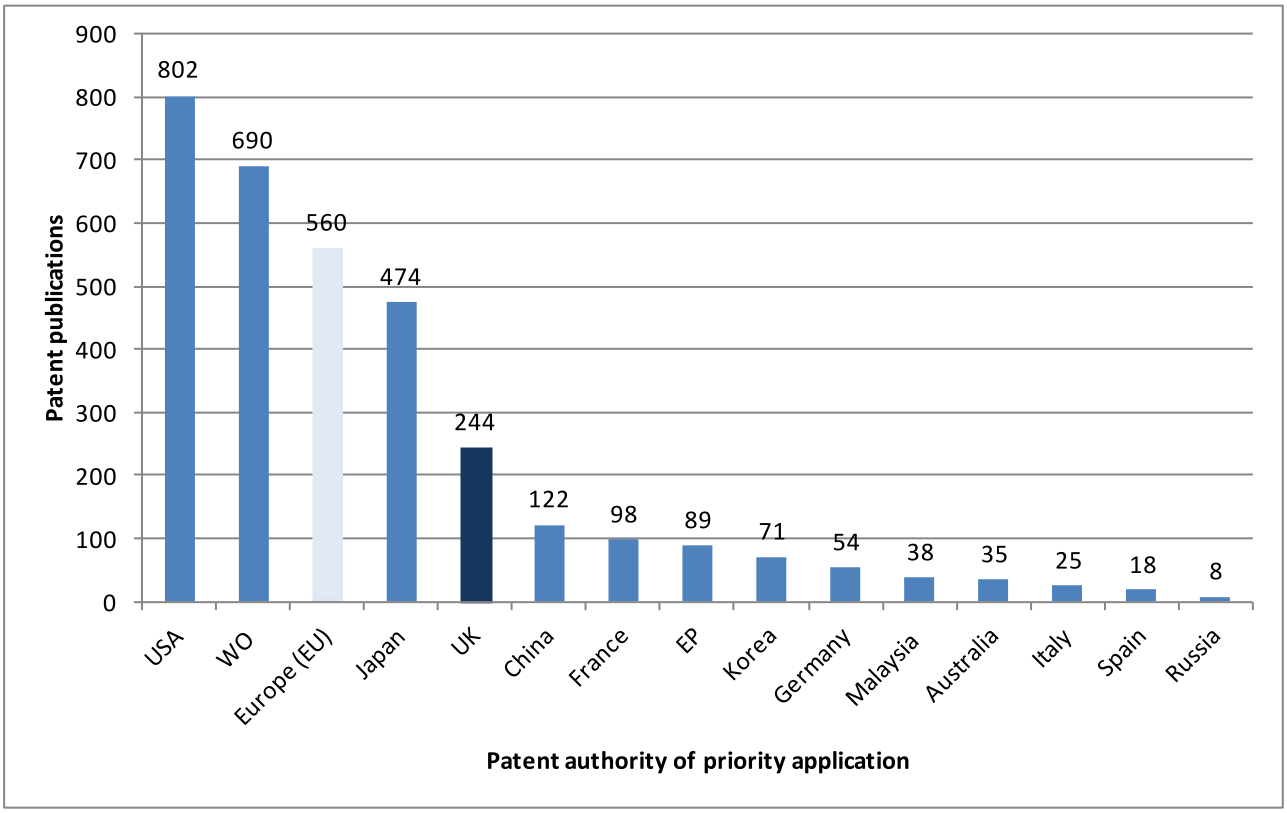

Figure 3 : Top authorities for priority applications of patent publications for quantum secure communications

Japanese applicants come out top in the applicant country chart, Figure 4, which is not a surprise given the preponderance of Japanese multinationals making up the top 20 organisations as shown in Figure 2. European Union (EU) based patent applicants are not far behind Japanese and US based applicants, whilst the UK places as the third highest country and is well ahead of its other nearest competitors France and China.

The UK also places as third strongest country in terms of inventor country as shown in Figure 5. Interestingly, the numbers of patents having a UK based inventor are much closer to those of patents having inventors located in Japan or the USA than the equivalent comparison using applicant country. This suggests that the quantum secure communication research done by some non-UK based patent applicants is carried out by researchers based in the UK. The same comparison for EU based inventors shows that the EU surpasses Japan and almost equals the US in terms of inventor country. This is a very strong showing for the EU which is based predominantly on the strength of the UK in quantum secure technologies.

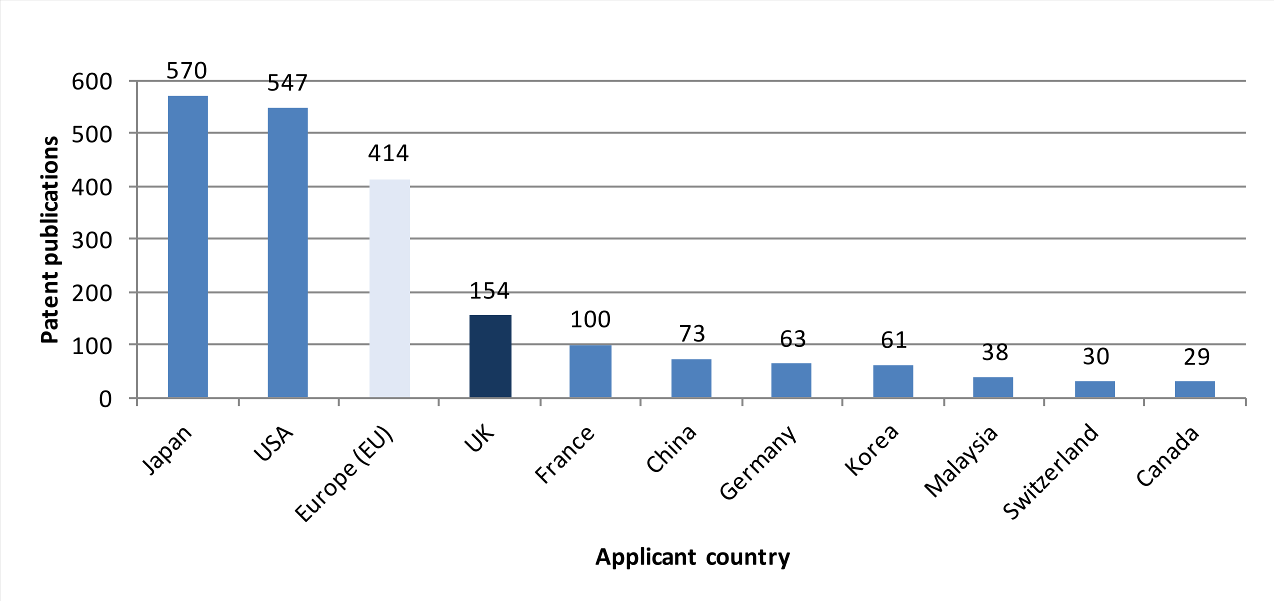

Figure 4 : Top applicant countries for quantum secure communications

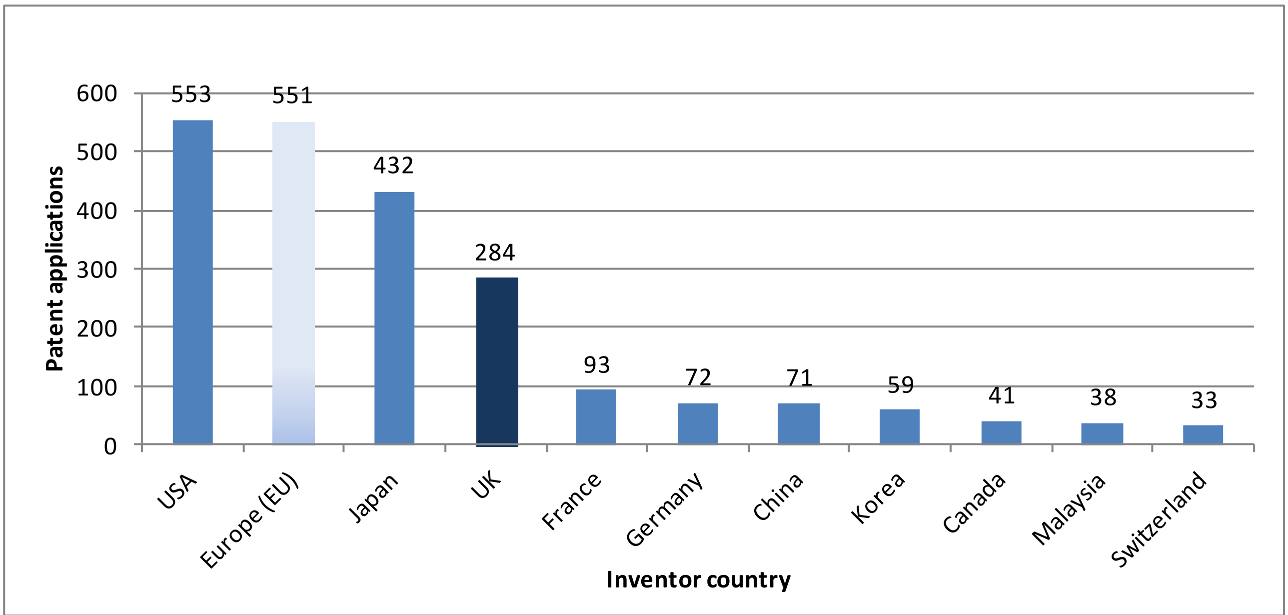

Figure 5 : Top inventor countries for quantum secure communications

The RSI[4] chart, Figure 6, normalises the patent application numbers from patent applicants from the main countries in the quantum secure communications dataset to remove the bias created by country-to-country variations in the propensity to patent. This clearly illustrates that quantum secure communications is an area of UK strength, with patenting well above the level that would be expected for the UK in this technology space.

Academically, according to the numbers of publications in journals and conference proceedings from UK based organisations (Figure 7), the UK is strong in quantum secure communications research. The high volume of academic publications coming from China is

[4] More detail in Appendix C: Relative Specialisation Index

contrary to what might be expected from their placement in the patent analysis of this technology area. EU countries are also placed very highly this area.

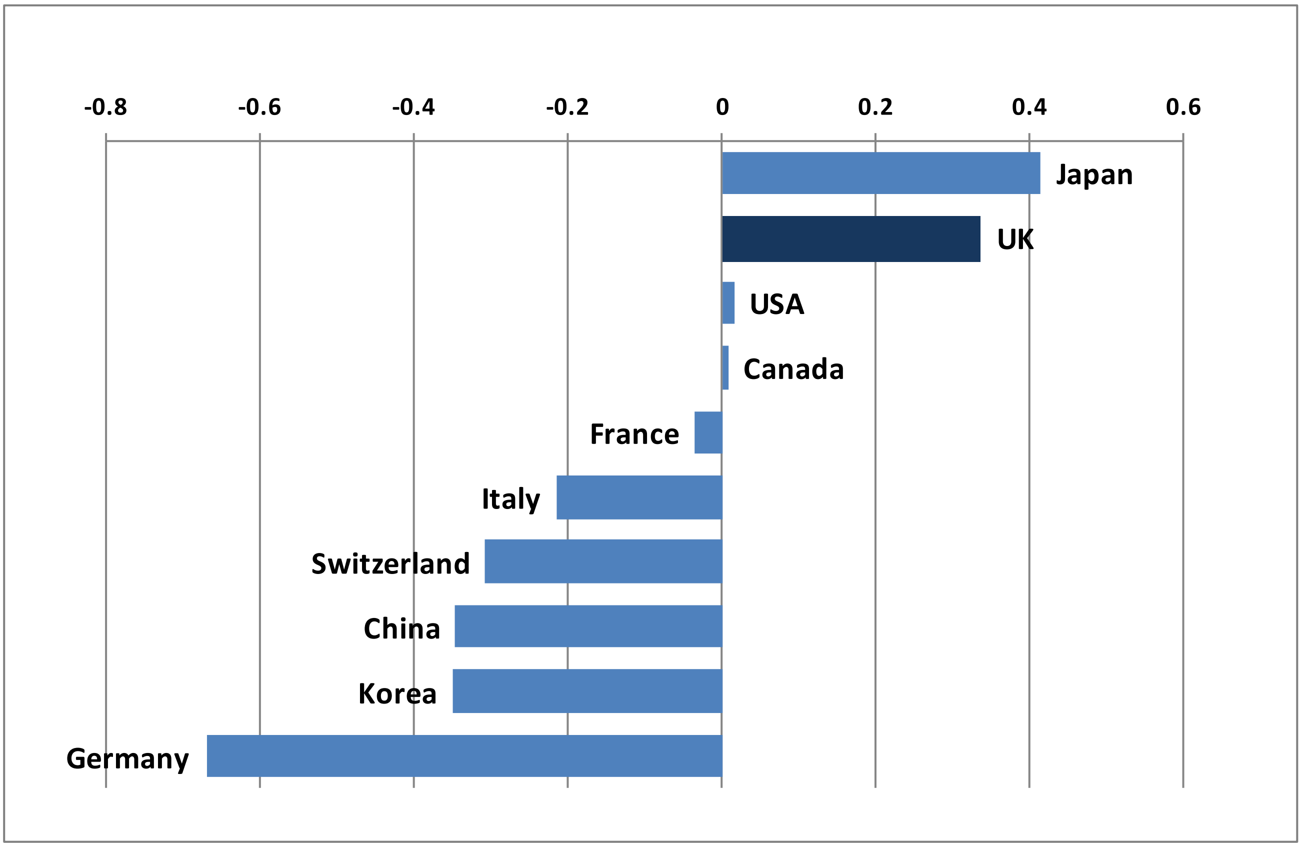

Figure 6: Relative Specialisation Index (RSI) chart for quantum secure communications

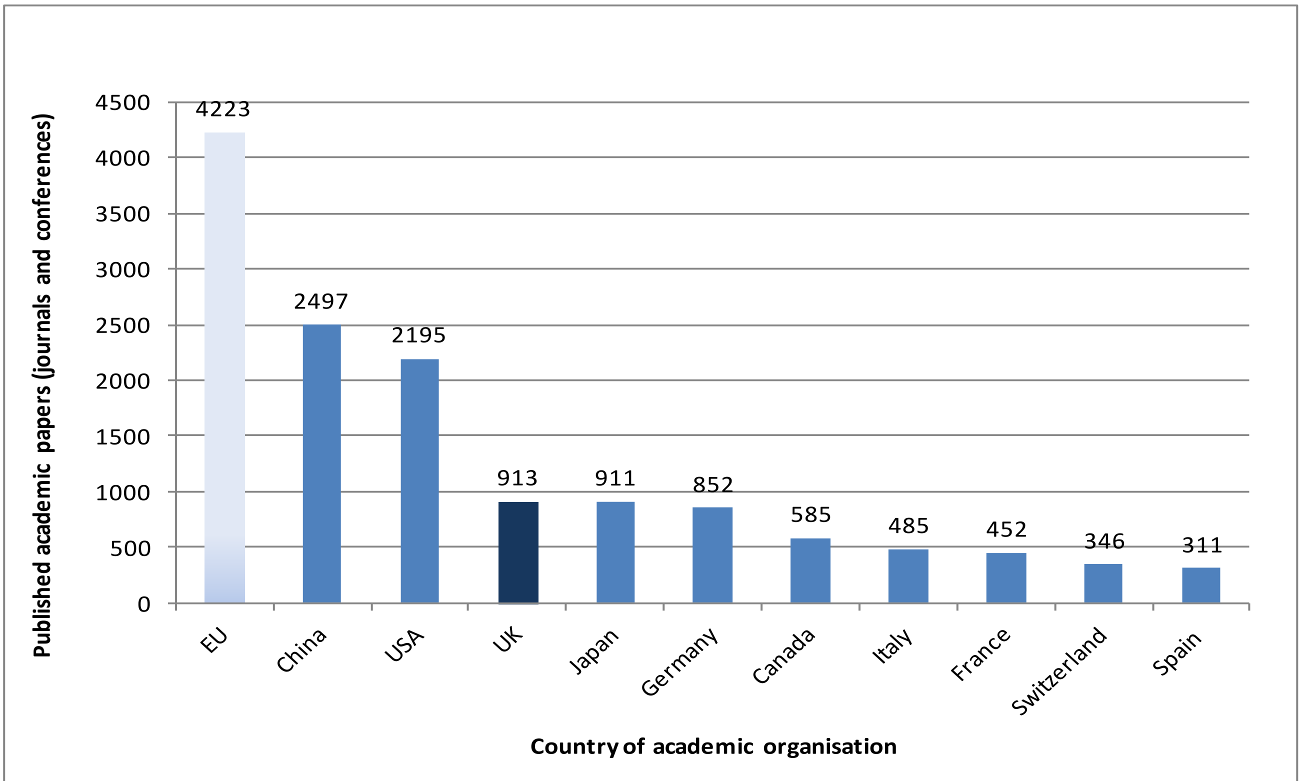

Figure 7: Academic publications from Web of Science 2002-2012 for top countries in quantum secure communications

4 Quantum metrology and sensors

It is difficult to define a search strategy for this technology area as metrology and sensors based on quantum effects have disparate applications and are also very new technologies. These factors mean that patents related to this technology area are potentially distributed widely in the patent classification schemes and are likely to contain very different keywords. A broad approach was taken[5] which aims to capture patents that use words that are definitively associated with quantum effects in their titles and or abstracts and which are also classified in patent classification areas that relate to measurement/sensing.

Number of patent families	119		
Number of patent publications	184		
Publication year range	1994-2013		
Peak publication year	2012		
Top country	USA		
Top applicant	University of Michigan State (USA)		
Field choices	**Field name**	**Number of entries**	**Coverage**
People	Inventors	311	100%
Applicants	Patent assignees	168	92%
Countries	Priority countries	13	100%
Years	Publication years	20	100%

Table 2: Summary of worldwide patent dataset for quantum metrology and sensors

Table 2 illustrates that this is a very small dataset, suggesting a very early stage emerging technology.

[5] See also Appendix B: Search strategy

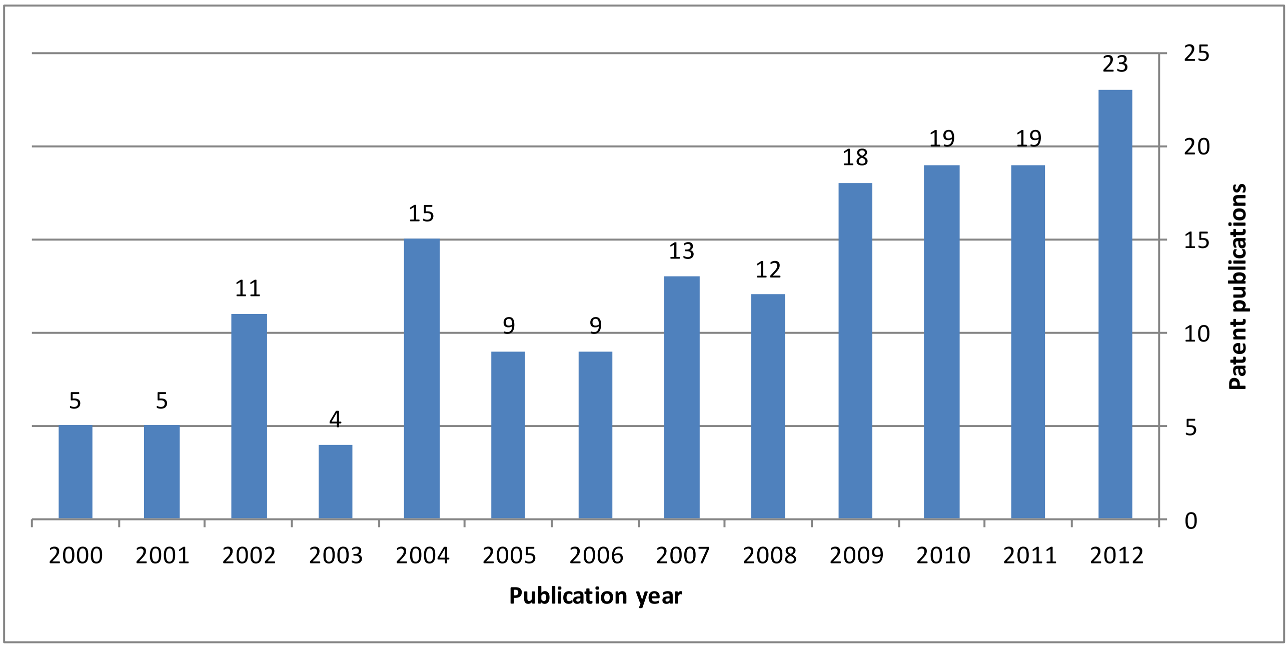

Figure 8 : Patent publications by publication year for quantum metrology and sensors

Figure 8 illustrates a defined small but steady increase in worldwide patenting activity which continues through the most recent year (2012).

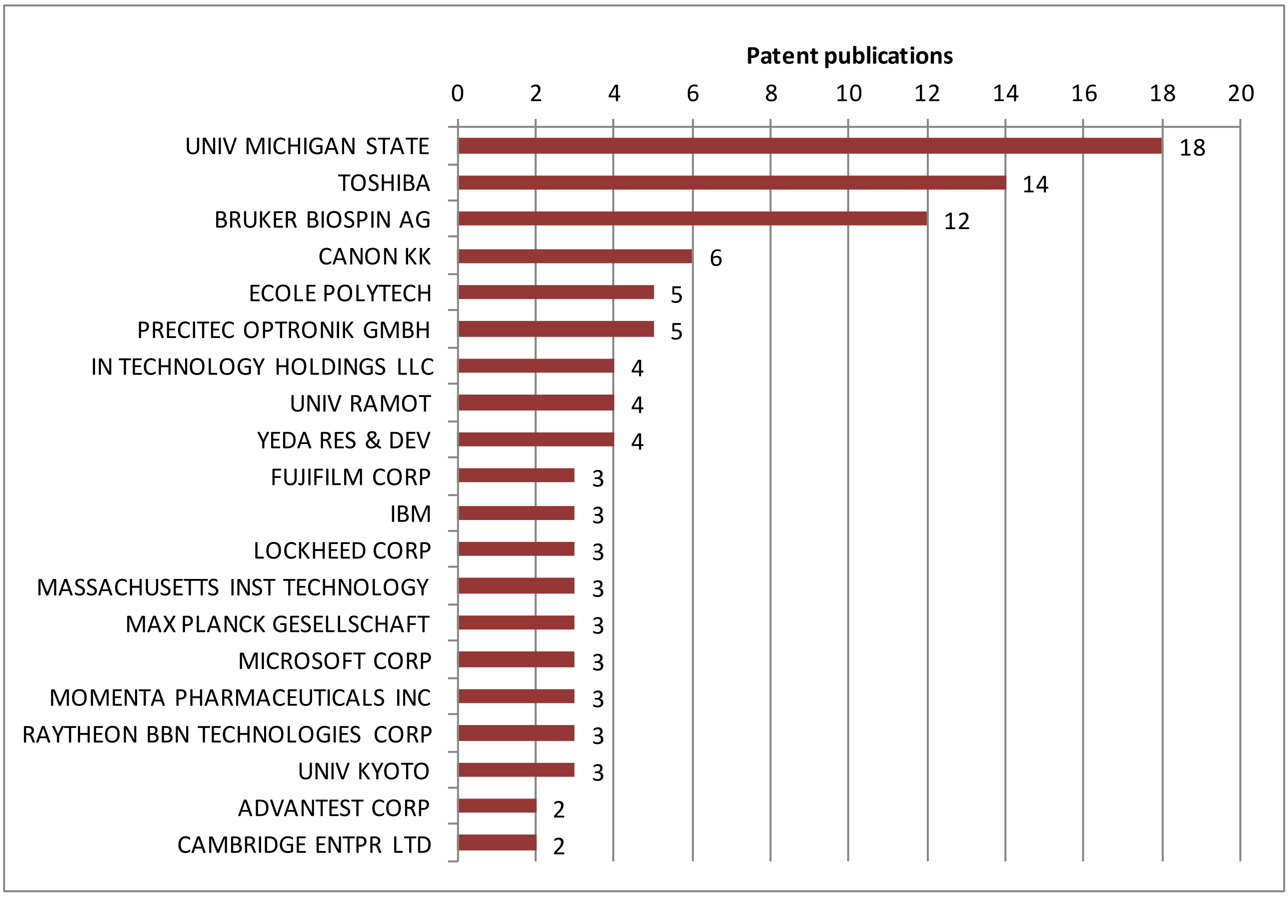

Figure 9 : Top 20 organisations for quantum metrology and sensors

Notably, the chart of top organisations shown in Figure 9, contains a large portion (7 of 20) of academic organisations. This illustrates that these technologies are early in their development and may only recently have graduated from being of purely academic research interest to commercially applicable sensor/metrology technologies. The shift of the types of organisation patenting in a technology area from academic to commercial is also theorised[6] as being a characteristic of the patenting trend of a disruptive technology area. Therefore the increase in patent publications coupled with the relatively high proportion of academic organisations may indicate that this technology area has potential to be disruptive as patenting increases and becomes more commercially focused.

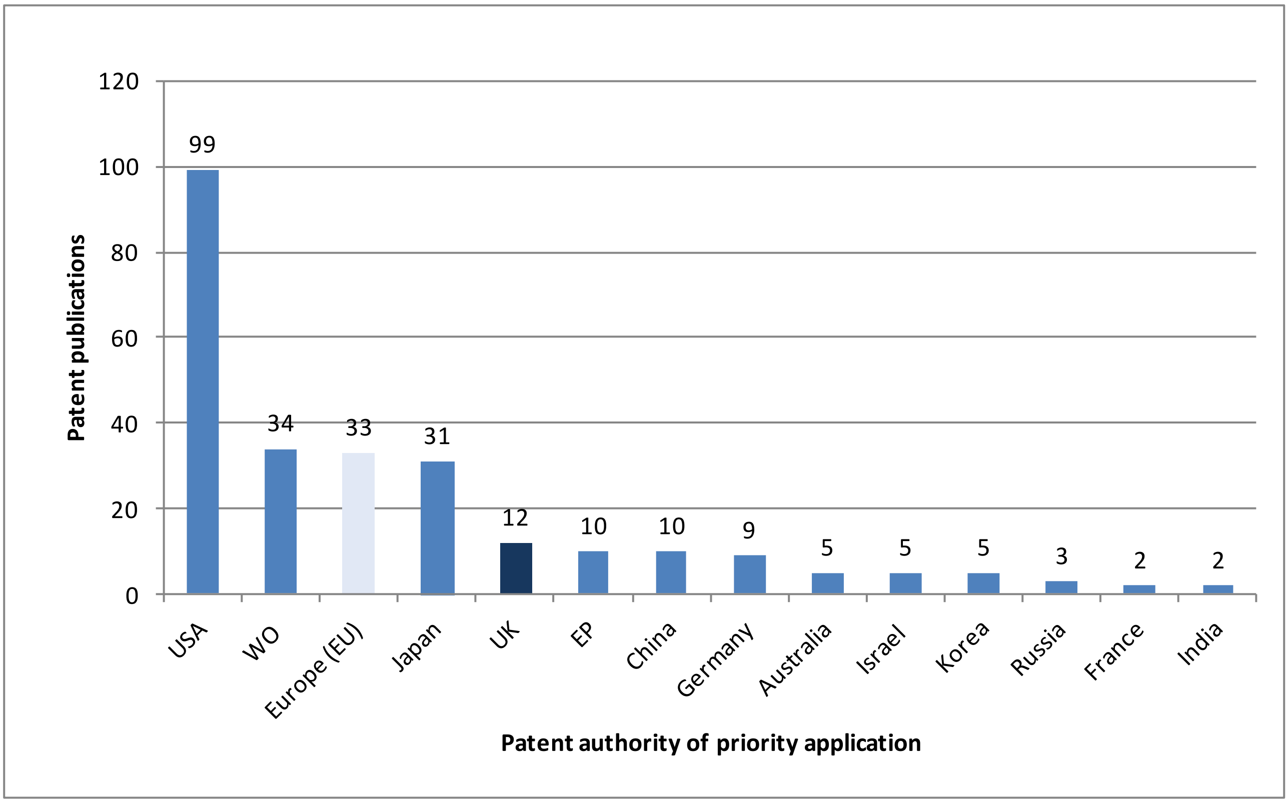

Figure 10 : Top authorities for initial patent publications for quantum metrology and sensors

Though Figure 10 indicates that the UK is lagging the USA and Japan in terms of priority patent filings, it is still leading amongst European and other countries in the quantum metrology and sensors technology space. However, despite this apparent lead, it is clear from the numbers of UK based applicants and inventors shown Figures 11 and 12, that the UK is not well represented in patenting activity in the quantum metrology and sensors technology space.

The numbers of patents related to quantum metrology and sensors are very small so it is difficult to draw any conclusion about the relative strengths of the UK and Europe. Furthermore it is possible that key areas of related UK research activity were not caught by the search statement, for example if there are specific technology areas that the EPSRC are aware of and have in mind as examples of these technologies but which might not have been caught by the keywords used.

What the data for quantum metrology and sensors does appear to show is that this is an emerging technology area that at this very early stage exhibits potential to disrupt existing sensors and metrology markets.

[6] “Double-boom cycles and the comeback of science-push and market pull”, Ulrich Schmoch, 21 June 2007, Elsevier.

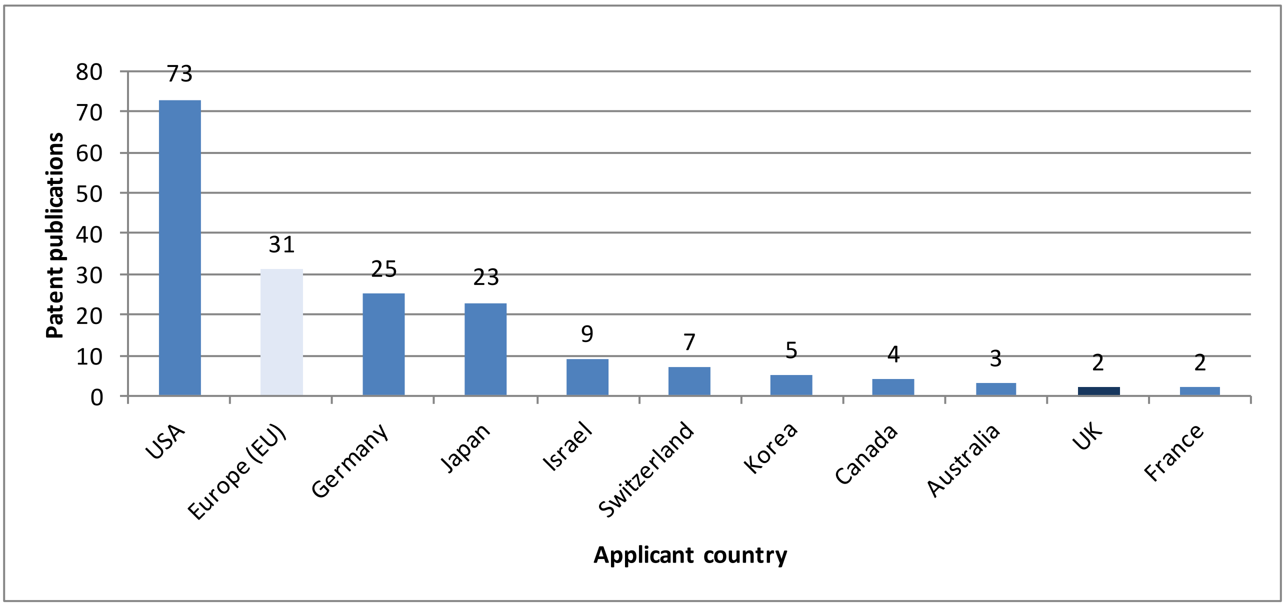

Figure 11 : Top applicant countries for quantum metrology and sensors

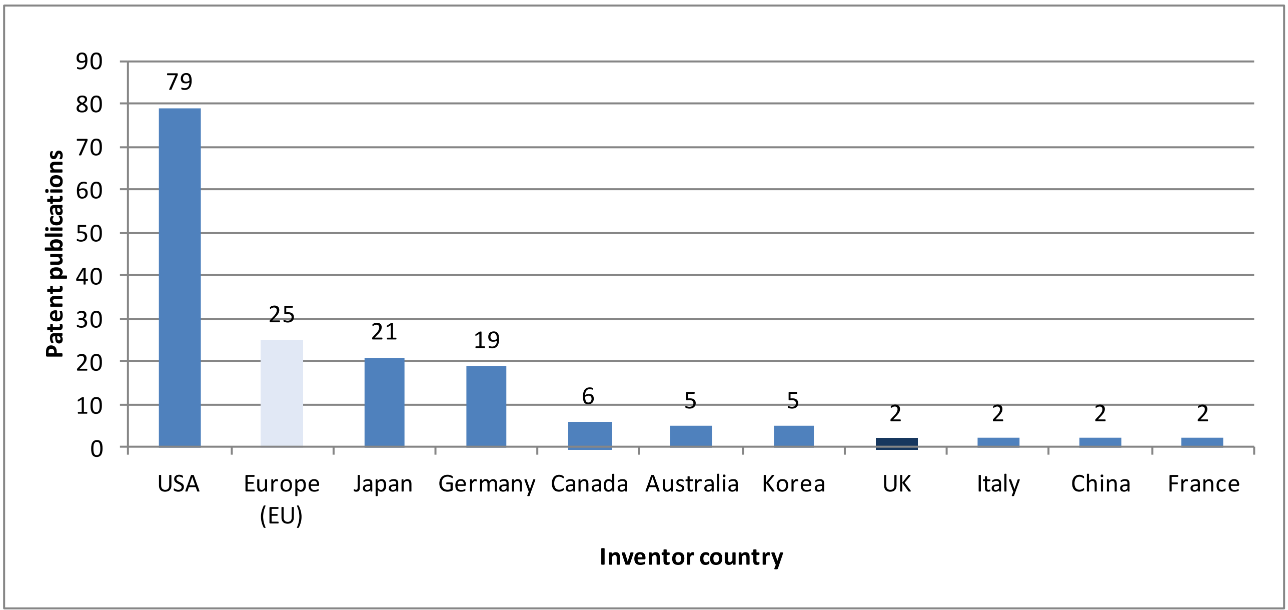

Figure 12 : Top inventor countries for quantum metrology and sensors

The numbers of patents in the quantum metrology and sensors dataset are too low to make an RSI analysis meaningful.

The research falling into this area of technology in the academic literature is very diverse. Furthermore, there is no classification key which could be used to replicate the patent literature search strategy within the tool for researching academic publication numbers. These factors mean that it is not possible define an equivalent dataset in non-patent literature upon which analysis of academic publications might be performed.

5 Quantum simulators

Worldwide published patent data contains very few quantum simulators. Looking through the patents identified as relevant by the search strategy[7] yields only 8 inventions (8 distinct families of patent applications) that relate to quantum simulators. Of these, 4 claimed priority in the United States, 2 in Japan, 1 at the European Patent Office (EPO) and 1 in China. None of the applicants or inventors recorded on these patents from the UK.

Lack of data in this technology area, even if it were an active one academically, is perhaps not surprising given that methods of simulation and modeling, especially when they are generic (as would be the case for general simulation of quantum effects), are not regarded as patentable subject matter by many patent authorities, including the UK and the EPO.

Others at the roundtable are better placed to advise on the progress of quantum simulation technology from an academic perspective.

[7] See Appendix B: Search strategy

6 Quantum computation

Number of patent families	839		
Number of patent publications	1995		
Publication year range	1985-2013		
Peak publication year	2005		
Top country	USA		
Top applicant	DWAVE SYS INC		
Field choices	**Field name**	**Number of entries**	**Coverage**
People	Inventors	1755	91%
Applicants	Patent assignees	860	87%
Countries	Priority countries	23	92%
Years	Publication years	29	100%

Table 3: Summary of worldwide patent dataset for quantum computation

Table 3 indicates that quantum computation has a relatively low absolute level of patenting activity.

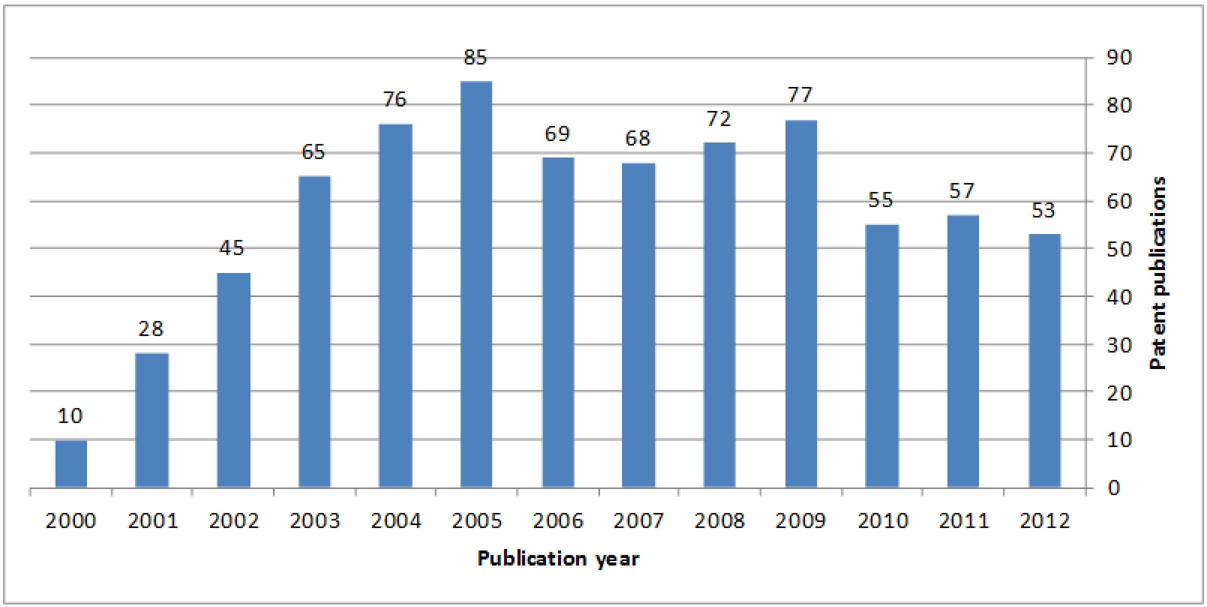

Figure 13 : Patent publications by publication year for quantum computation

With similarity to the quantum secure communication area, the publication year chart shown in Figure 13, for quantum computation confirms that there is a low but significant overall level of patenting activity. The level of publications has been reasonably steady since the peak in 2005, with a worldwide total of around 60 patents being published in each year. This suggests a constant amount of research and development in this technology area year on year. Given the 18 month delay between patent filing and publication, coupled with fact that the research and development will have happened in the years before filing the patent applications, Figure 13 can be interpreted as illustrating that the start of commercial interest in research into quantum computation the turn of the millennium has been followed by a significant and steady level of research interest.

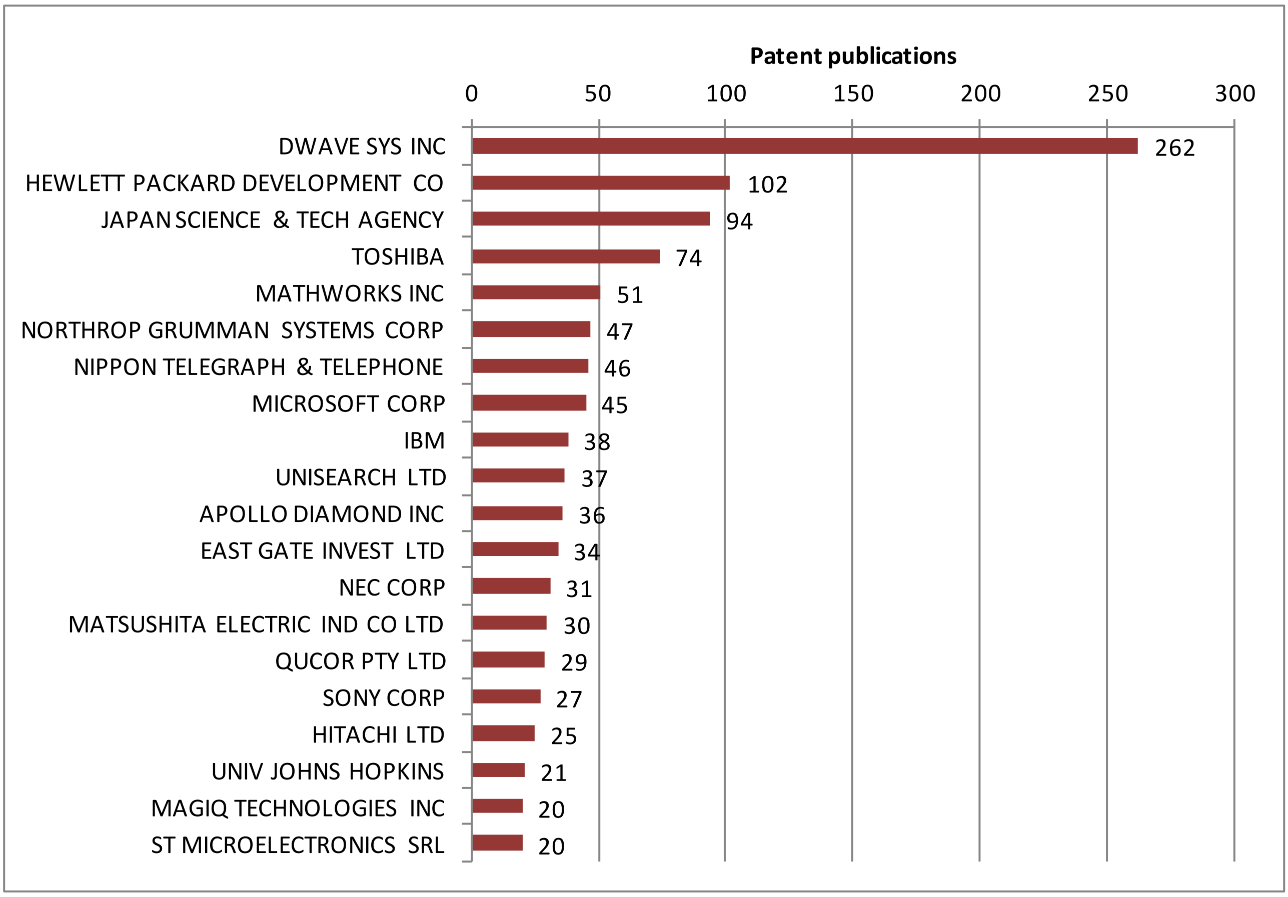

Figure 14: Top patent organisations for quantum computation

Figure 14 shows that D-Wave systems are clearly way out ahead in terms of patents per organisation. This should not come as a surprise given their commercial success in marketing what is arguably the first quantum computer[8], and is certainly a computational device that utilises quantum effects.

There are no UK companies amongst the top 20 organisations for patenting in quantum computing technologies. However, the UK is well represented (3rd strongest country) in terms of priority patent applications as shown in Figure 15, and patent applicant and inventor countries (4th strongest country) as shown in Figures 16 and 17.

The RSI score chart shown in Figure 18 and academic publications chart shown in Figure 19, also indicate that the UK is strong in this technology area, both in terms of above average patenting activity and placement amongst other countries in terms of academic publications.

The EU is also relatively strong in terms of patenting in the quantum computing area, especially in terms of inventor country where it is second only to the USA as shown in Figure 17. This potentially reflects a large academic research base of expertise in the EU and this

[8] "D-Wave sells first commercial quantum computer", 01 June 2011, PHYS.ORG, available here: http://phys.org/news/2011-06-d-wave-commercial-quantum.html
& "Nasa buys into 'quantum' computer", 16 May 2013, BBC News, available here: http://www.bbc.co.uk/news/science-environment-22554494

also appears the case given that the EU tops the academic publications chart as shown in Figure 19, by some margin.

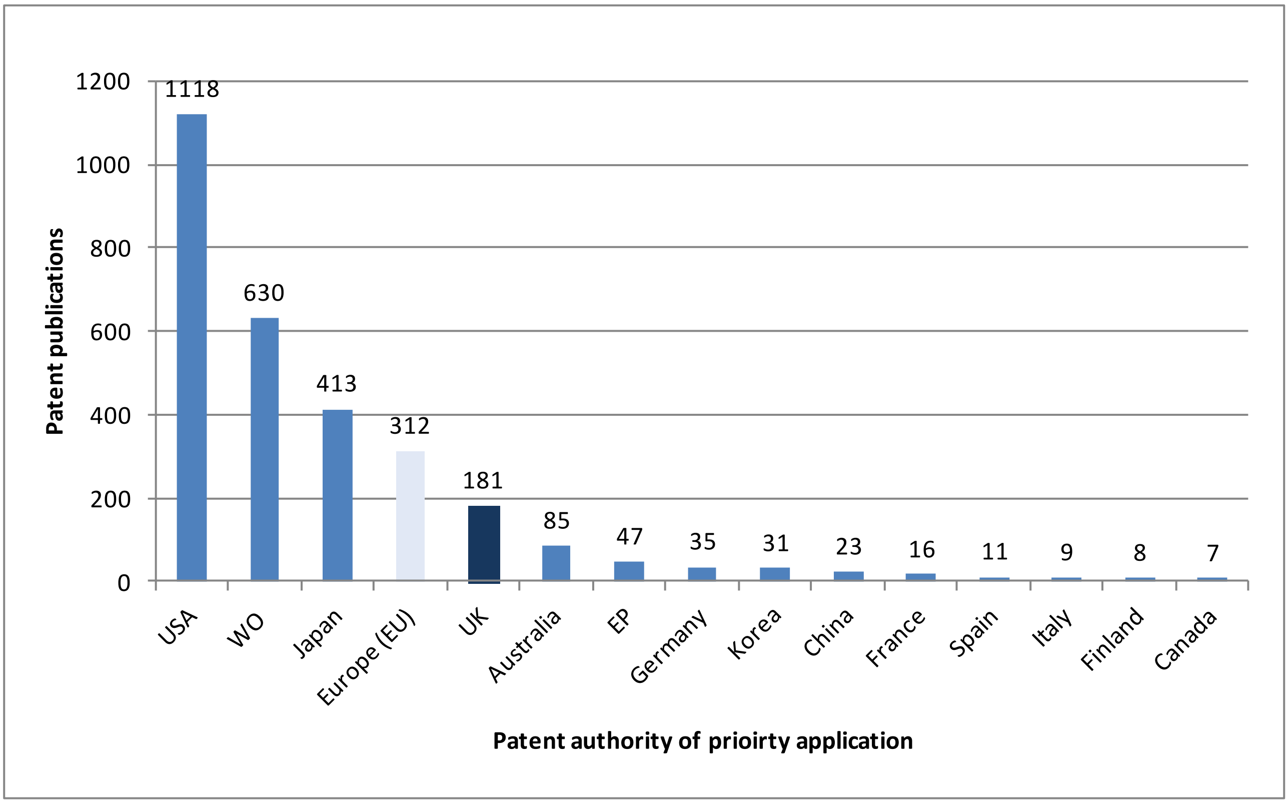

Figure 15: Top authorities for initial patent publications for quantum computation

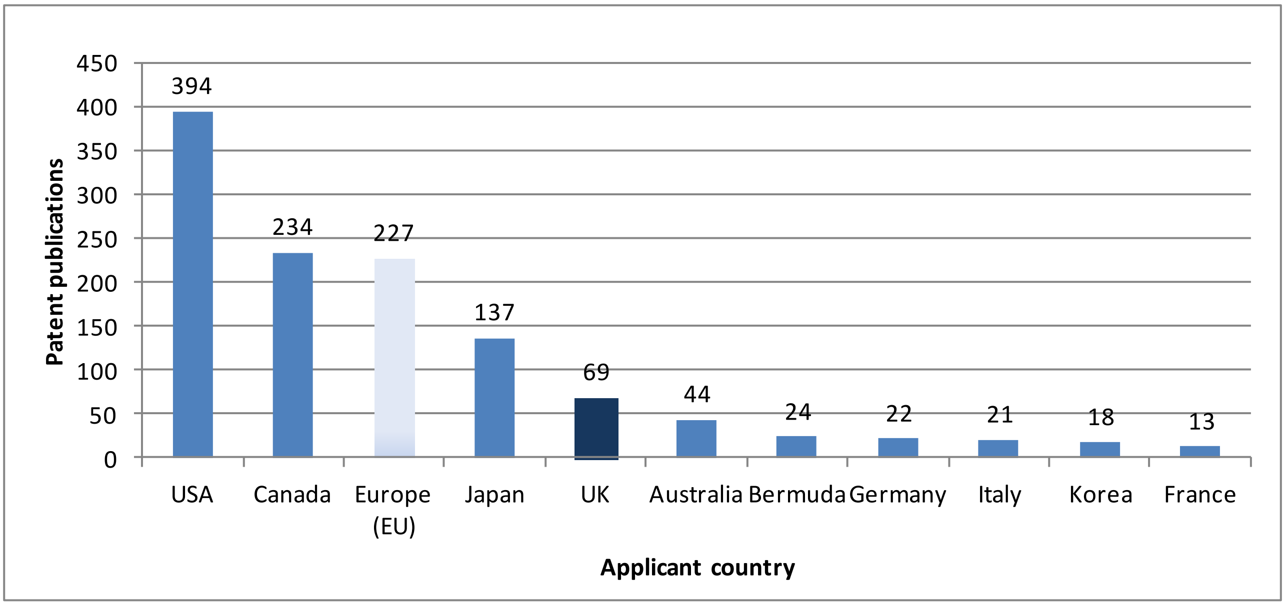

Figure 16 : Top applicant countries for quantum computation

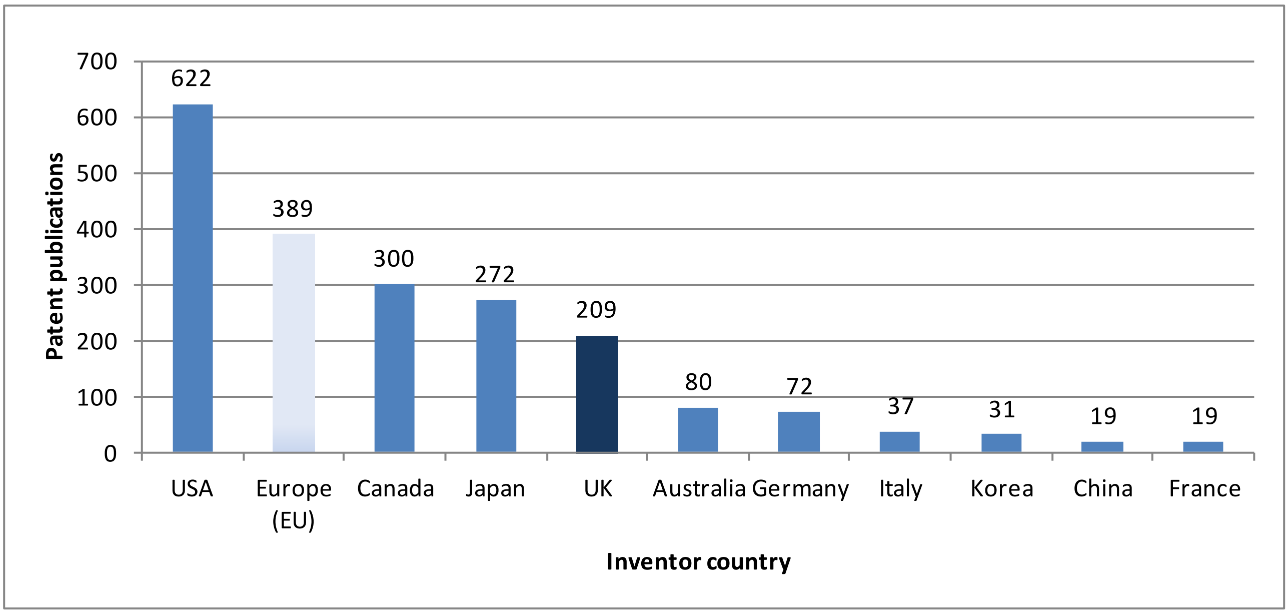

Figure 17 : Top inventor countries for quantum computation

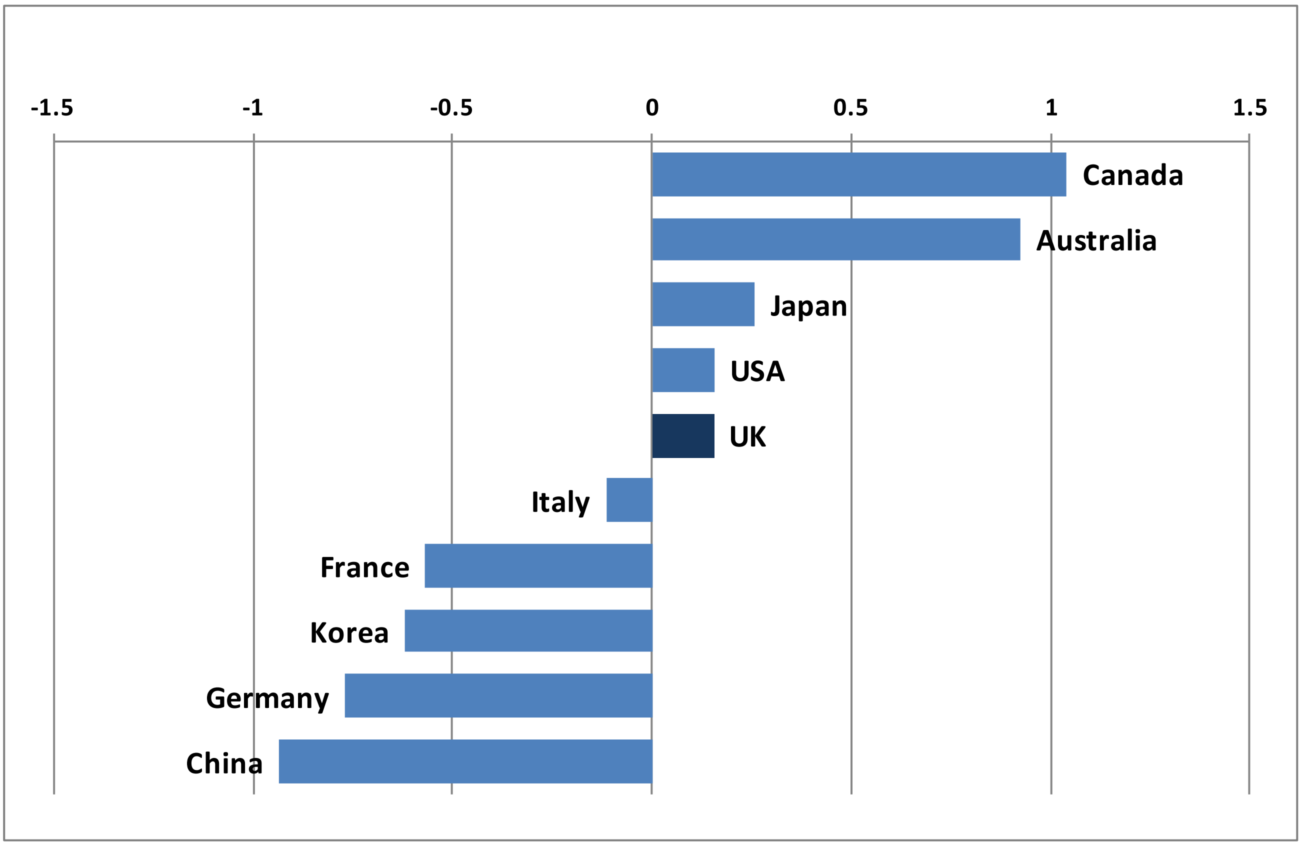

Figure 18: Relative Specialisation Index (RSI) chart for quantum computation

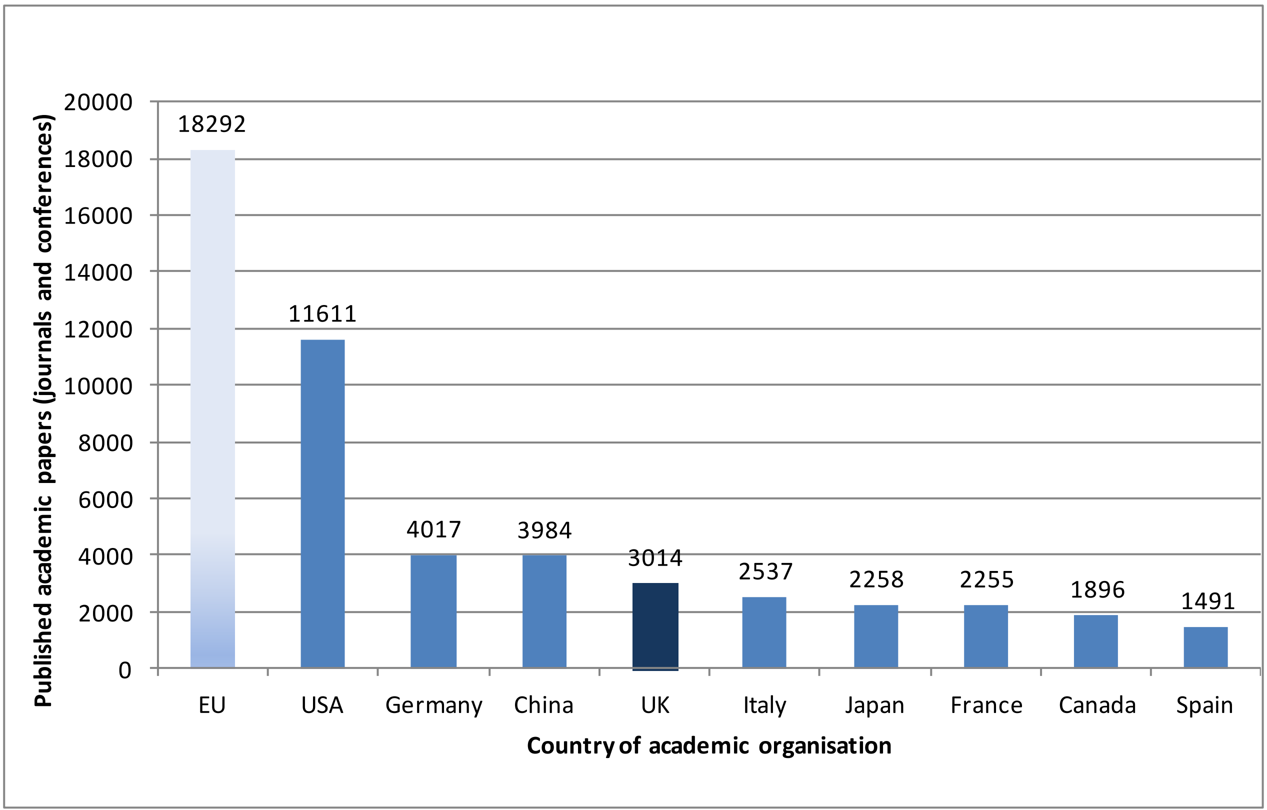

Figure 19: Academic publications from Web of Science 2002-2012 for top countries in quantum computation

7 Appendix A: Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) and the European Patent Office (EPO) EPODOC databases were interrogated, both of which hold bibliographic and abstract data of published patents and patent applications derived from the majority of leading industrialised countries and patent organisations, *e.g.* the World Intellectual Property Organisation (WIPO), European Patent Office (EPO) and the African Regional Industry Property Organisation (ARIPO). It should be noted that patents are generally classified and published 18 months after the priority date. This should be borne in mind when considering recent patent trends (within the last 18 months).

A.2 Priority date, application date and publication date

There are generally three dates which can be associated with a patent application as follows:

Application date: The date on which a physical application was made for a patent. This enables an accurate temporal reflection of the technical content of a patent application.

Priority date: A patent can claim priority from an earlier application. This usually happens for two reasons: a) when an application is filed in one country, international convention dictates that the applicant then has 12 months to file a corresponding application abroad. Thus the patent application would then have a priority date, which indicates the earliest date attributed to the invention; b) an earlier application may contain part of a subsequent invention so a subsequent application, made within 12 months of filing, may claim priority from the earlier application. However, in the new application, this date is only valid for that part of the invention which appears in the earlier application. Care should therefore be taken when analysing the priority date of an invention.

Publication date: The date when the patent application was published. A patent is normally first published (‘A’ publication) 18 months after the priority date or the application date, whichever is earlier. Depending on the jurisdiction, a patent is then given a ‘B’ or ‘C’ publication code when it is granted. Any further publications (*e.g.* following correction) are given a numbered publication code in a most jurisdictions (*e.g.* ‘A1’, ‘A2’, ‘B1’, ‘B2’ *etc*).

Patent family: The WPI database contains one record for each patent family. A patent family is defined as all documents directly or indirectly linked via a priority document. This provides an indication of the number of inventions an applicant may hold, as opposed to how many individual patent applications they might have filed in different countries for the same invention.

A.3 Explanation of the figures used in this report

If patent applications are assumed to be the result of research and development activity, they can be viewed as a proxy for innovation in the technology area that is being analysed. With this in mind, in each of the four technology areas analysed (where enough data exists) the following charts are included for analysis of the technology landscape:

Patent publications by publication year (for 2000-20012): This chart plots the first publication year of each patent application against number of patent applications. This broadly shows the evolution of patenting in a technology area, for example illustrates peaks and troughs in the level of patenting and general trends of increasing or decreasing levels of patenting, as well as giving a feel for the overall number of patent applications involved.

Top 20 organisations: This illustrates the organisations that are filing the most patent publications in the technology area. Taking patent applications as a proxy for innovation and research and development, this can give insight into which organisations are the main players in a technology area.

Top 15 publication authorities for priority applications: This chart illustrates where the initial patent applications (i.e. the priority applications) are filed. Working on the assumption that patents are most likely to be filed for first in the country in which the research and development is carried out, this chart can reveal geographical information about the origin of the innovative activity behind a patent applications in a technology area. However, it is dangerous to compare absolute numbers of priority applications as filing habits are different in different patent authorities, for example the propensity to patent is typically higher in Japan and the USA than in individual European countries and at the (EPO).

Top 10 patent organisation countries: The address of the assignee(s) is recorded on patent applications and this chart uses this to plot, for top 10 patent assignee countries, the country of the assignee against the number of patent applications. The patent applications may be made in any patent authority. So for example, a patent application filed at the US Patent and Trademark Office (USPTO) by an organisation having a Japanese address, would appear in the Japan column.

Top 10 inventor countries: The address of the inventor(s) is recorded on a patent application and this chart uses this to plot, for the top 10 inventor countries, the country of the inventor against the number of patent applications. The patent applications may be made in any patent authority. So for example, a patent application filed at the US Patent and Trademark Office (USPTO) by an inventor resident in the UK, would appear in the UK column.

Relative Specialisation Index (RSI): Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patents in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of patents in the technology area of interest found in each country to the fraction of patents found in that country overall. More information on the calculation can be found in Appendix C.

Top 10 countries for academic publications (Web of Science) between 2002 and 2012: Technology area data extends beyond just patent data, so to look beyond what patent filings illustrate in these technology areas, where it was possible, academic publications from the last ten years were analysed. The result is a plot which illustrates the number of academic publications for the ten most active countries in the technology area over the ten year time frame. Organisation address data from *Web of Science* and *Conference proceedings*[9] and suitable key words from the search strategies[10] were used to count academic publications.

A.4 WO, EP and EU patent applications

International patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent

[9] Both of which are *Thomson Reuters* services/products, more information in part A.6 of Appendix A: Interpretation notes.
[10] As defined in Appendix B: Search strategy

applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications (EP) are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

Figures for patent applications with WO and EP as priority country have been included for completeness although no single attributable country is immediately apparent.

Europe (EU), where it exists in the figures, is an amalgamation of patents from each of the countries of the European Union and EP patents. This is included to provide a comparison between very large economies such as USA and Japan with the Europe. It is highlighted in the charts with a gradient fill to distinguish it from the countries and patenting authorities.

A.5 Patent documents analysed

Appendix B provides full details of the search strategy used to extract the dataset used for analysis. The applicant and inventor data was cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation (Ltd, Pty, GmbH *etc*.), or equivalence (Ltd., Limited, *etc*.).

A.6 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[11] produced by *Search Technology* in the USA. The patent records exported from the EPODOC and WPI patent databases are imported into *VantagePoint* where the data is cleaned and analysed. In addition, the “top countries for academic publications” data that is used in this report was produced using *Thomson Innovation*[12], a web-based patent and academic publication analytics tool produced by *Thomson Reuters*. The academic publications that were used in *Thomson Innovation* are the *Web of Science* and *Conference proceedings* which are both *Thomson Reuters* services/products.

[11] http://www.thevantagepoint.com
[12] http://info.thomsoninnovation.com

8 Appendix B: Search strategy

Based on the technology areas as defined by the EPSRC's working group on quantum technologies, patent datasets were identified in conjunction with patent examiner technology-specific expertise. Search strategies were developed (see below) and the resulting datasets were extracted on 17 September 2013 using International Patent Classification (IPC) codes, Co-operative Patent Classification (CPC) codes, and the Japanese Patent Office's File Index System (FICLA) and keyword searching of titles and abstracts in the *Thomson Reuters* World Patent Index (WPI) and the European Patent Office (EPO) EPODOC databases. The datasets were not date limited.

Quantum secure communications:

- H04L9/0852, 0855 & 0858 /CN
- OR
- (H04L9) /CN/IC/FI AND (((QUANTUM+ OR ENTANGL+) AND +CRYPT+) OR QKD OR (QUANTUM W KEY?+))
- OR
- H04B10/70/CN/IC
- OR
- H04K1/CN/IC/FI AND (QUANTUM+ OR ENTANGLE+)

Quantum metrology and sensors:

- G01/CN/IC/FI AND QUANTUM+ AND (ENTANGL+ OR SUPERPOSIT+ OR +COHERENCE? OR NONLOCALIT+ OR TELEPORT+)

Quantum simulators:

- (SIMULAT+ OR MODEL+) AND ((QUANTUM+ OR PHOTON+ OR ELECTRON?) 4D (ENTANGL+ OR SUPERPOSIT+ OR SPIN?))
- OR
- G06F17/50/CN/EC/FI AND QUANTUM+
  (SMALL RESULT SET OF 68 PATENT FAMILIES VIEWED MANUALLY TO EXCLUDE FALSE HITS)

Quantum computing:

- G06N99/002/CN
- OR
- BY10/00/CN AND (QUANTUM 1D (COMPUT+ OR (DATA W PROCES+)))
- OR
- (/IC/CN/FI OR G06N, H01L, G06F, G02F, H03K) AND (QUANTUM 1D (COMPUT+ OR (DATA W PROCES+)))

9 Appendix C: Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patents in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of patents in the technology area of interest found in each country to the fraction of patents found in that country overall. A logarithm is applied to scale the fractions more suitably. The formula is given below:

$$\log 10 \left(\frac{n_i / n_{total}}{N_i / N_{total}} \right)$$

where
n_i = number patents in the technology area of interest in country i
n_{total} = total number of patents in dataset of patents related to the technology of interest
N_i = total number of patents in country i
N_{total} = total number of patents from all of the countries

The effect of this is to highlight countries which have a greater level of patenting in the technology area of interest than expected from their overall level of patenting, and which would otherwise languish much further down in the lists, unnoticed.

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