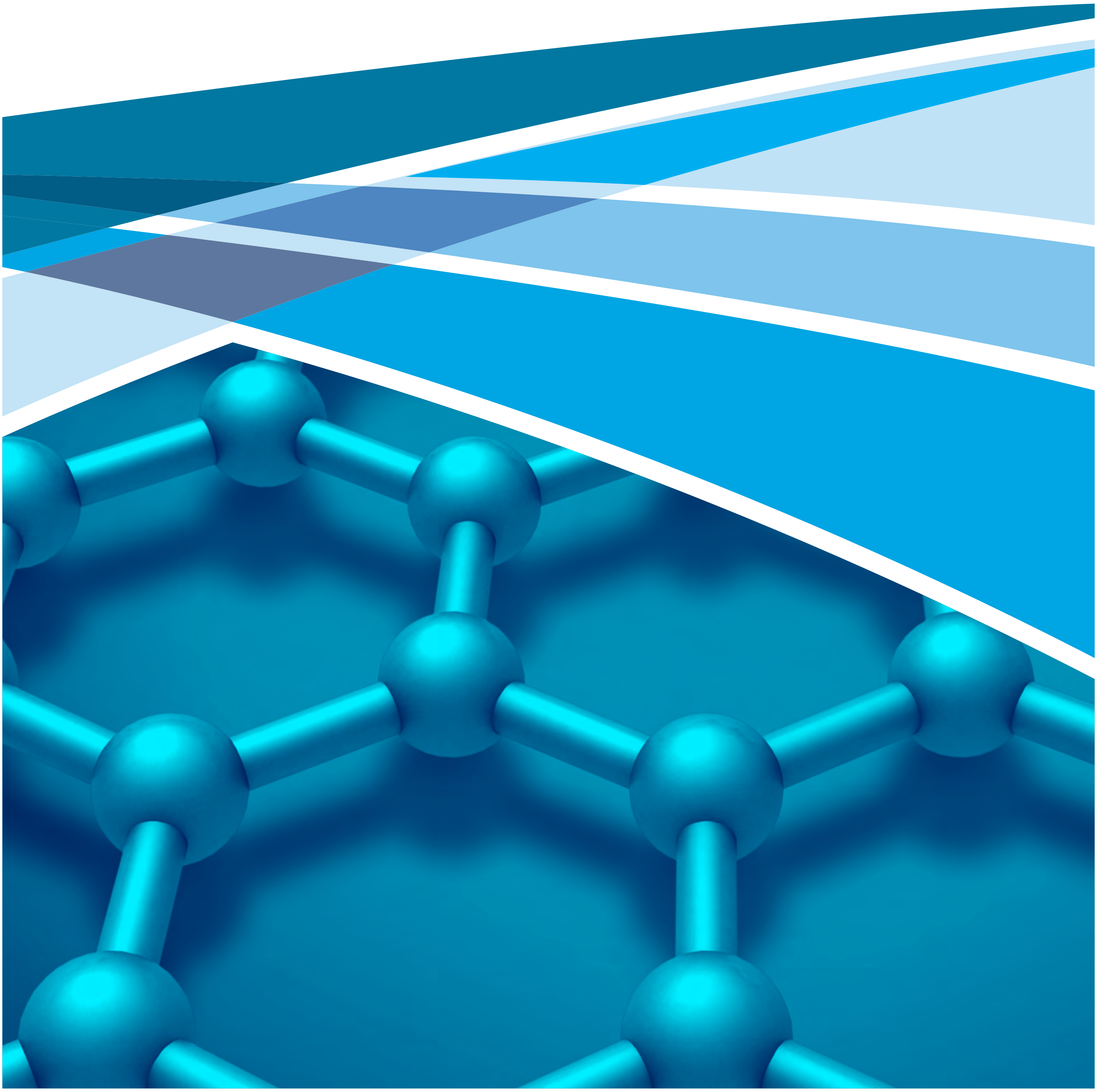
Intellectual Property Office

Graphene

The worldwide patent landscape in 2015



This report was prepared by the
UK Intellectual Property Office Informatics Team
March 2015

e-mail: informatics@ipo.gov.uk

Intellectual Property Office
Concept House
Cardiff Road
Newport
NP10 8QQ
United Kingdom

www.ipo.gov.uk/informatics

Contents

1 Introduction

Graphene is a crystalline form of carbon in which a single layer of carbon atoms are arranged in a regular hexagonal pattern[1]. It is very strong, light, and an excellent conductor of heat and electricity. It is also nearly transparent. The media refer to graphene as “the miracle material” and the public profile was boosted in 2010 when the Nobel Prize in Physics was awarded to Andre Geim and Konstantin Novoselov of the University of Manchester “for groundbreaking experiments regarding the two-dimensional material graphene”.

Graphene’s material properties are staggering; as a material it almost seems too good to be true, which explains why the media interest in it is so high. It is the thinnest known material in the universe and the strongest ever measured; for a crystalline structure it is elastic and can stretch up to 20% of its length; it is a very efficient electrical conductor and at room temperature it can sustain current densities six orders of magnitude higher than that of copper; its charge carriers have the highest intrinsic mobility; it has the best thermal conductivity of any material; and it is the most impermeable material ever discovered.

In 2011[2] and 2013[3] the Informatics team at the Intellectual Property Office analysed patenting activity relating to graphene, following a noticeable increase in the number of graphene-related patent applications filed in the UK. Since then the activity in this area has continued to grow in a seemingly exponential manner, as has the media hype surrounding it, with a predicted growth[4] in graphene markets from $20 million in 2014 to more than $390 million in 2024. Given this predicted growth, the continuing high-profile nature of graphene and its apparent interest to scientists, technologists and policy-makers alike, an updated report has been produced looking at the worldwide graphene patent landscape in 2015 and how it has changed since the last report.

[1] http://www.forbes.com/sites/tomkonrad/2013/09/18/graphene-stock-investing-what-the-pros-think/
[2] https://www.gov.uk/government/publications/graphene-a-worldwide-overview
[3] https://www.gov.uk/government/publications/graphene
[4] http://www.prnewswire.com/news-releases/graphene-markets-technologies-and-opportunities-2014-2024-300033012.html

2 Worldwide patent analysis

2.1 Overview

Table 1 gives a summary of the extracted and cleaned dataset used for this analysis of graphene. All of the analysis undertaken in this report was performed on this dataset or a subset of this dataset. The worldwide dataset for graphene published between 2005 and 2014 contains over 25,000 published patents, equating to over 13,000 patent families. Publications may be at the application or grant stage, so are not necessarily granted patents. A patent family is one or more published patents originating from a single original (priority) application. Analysis by patent family more accurately reflects the number of inventions present because generally there is one invention per patent family, whereas analysis by raw number of patent publications inevitably involves double counting because one patent family may contain dozens of patent publications if the applicant files for the same invention in more than one country. Hence analysis by patent family gives more accurate results regarding the level of inventive activity taking place.

Table 1: Summary of worldwide patent dataset for graphene

Number of patent families	13,355		
Number of patent publications	25,855		
Publication year range	2005-2014		
Peak publication year	2014		
Top applicant	Samsung (Korea)		
Field choices	**Field name**	**Number of entries**	**Coverage**
People	Inventors	23,284	99%
Applicants	Patent assignees	5184	99%
Countries	Priority countries	43	100%
Technology	IPC sub-group	7095	99%

Figure 1 shows the total number of published patents by publication year and suggests that patenting in graphene has grown quickly over the period, with the peak year showing as 2014. The data for 2013 and 2014 is shaded light blue to show the change since the previous report in 2013.

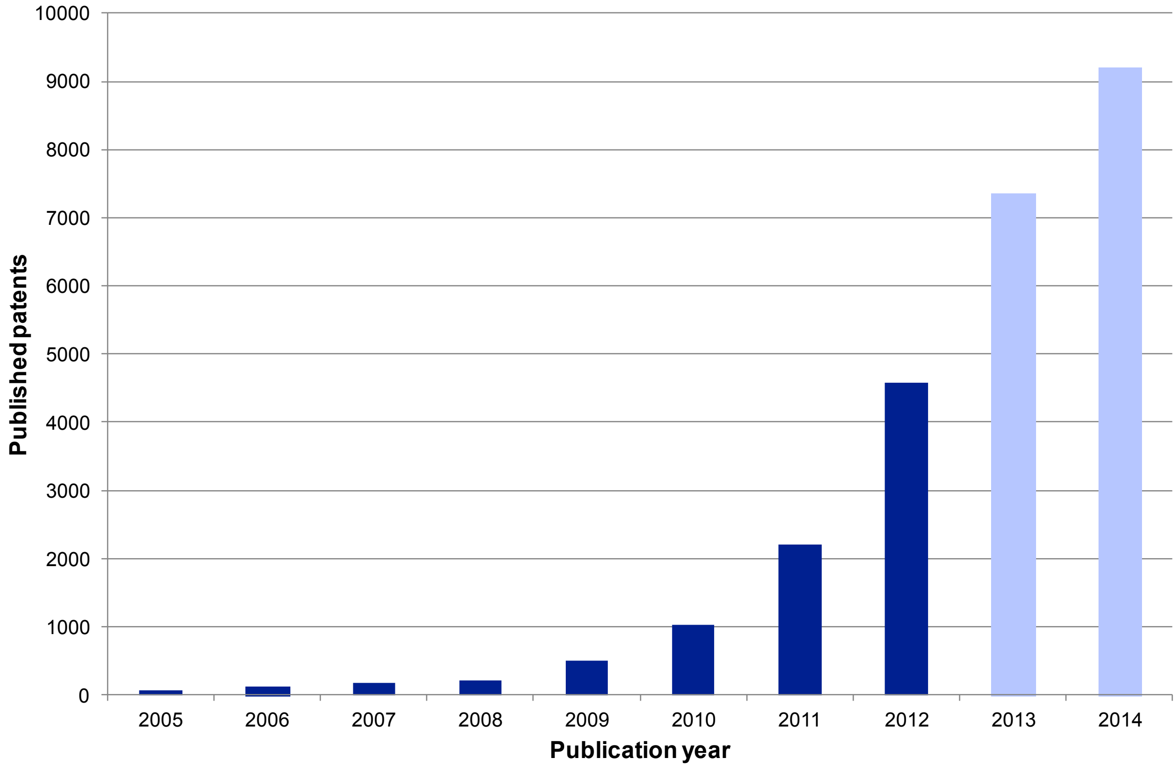


Figure 1: Patent publications by publication year

Figure 2 shows the total number of patent families by priority year but does not show patents published after 2012 since publication does not normally occur until eighteen months after the earliest of the priority date or filing (application) date. Hence, the 2013 and 2014 datasets are incomplete.

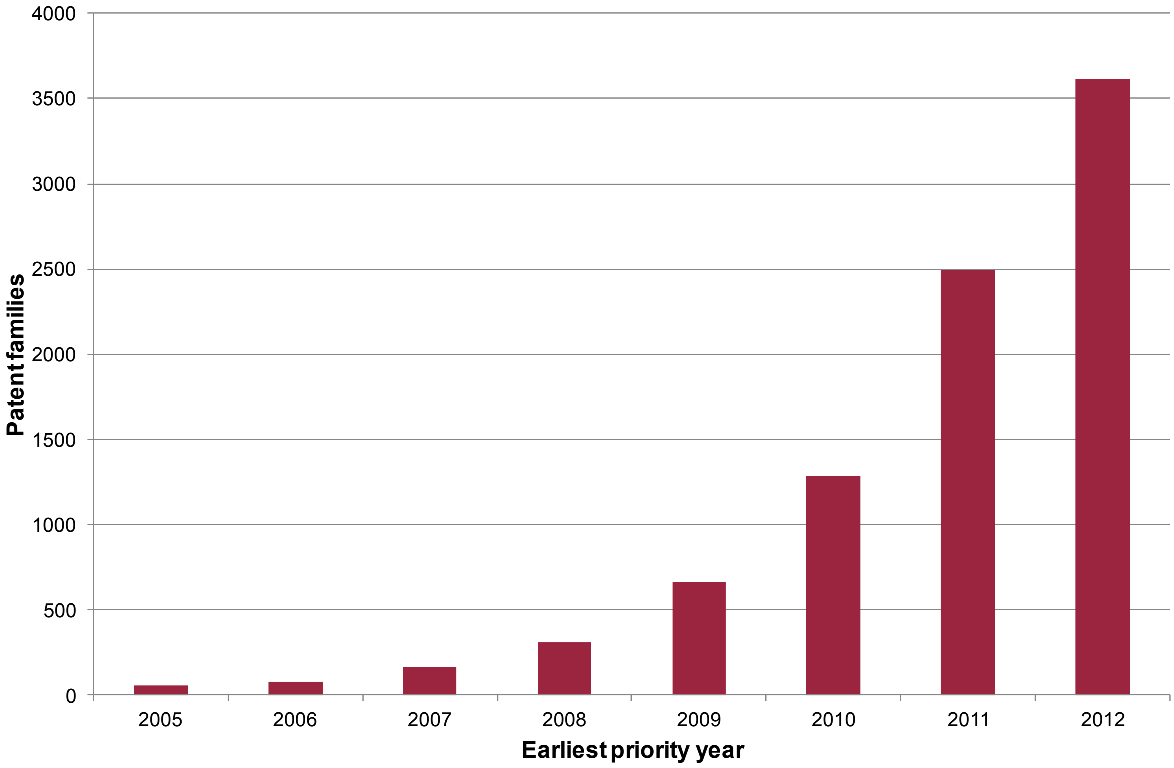


Figure 2: Patent families by priority year

General patenting levels globally have continued to grow at a steady rate. Figure 3 takes this growth into account by normalising the data shown in Figure 1 and presenting the annual increase in the size of the worldwide patent databases across all technologies against the year-on-year change in the size of the graphene dataset. For example, from 2008 to 2009 worldwide patenting across all areas of technology increased by 1.8% and this can be compared to a 124.9% increase in graphene patenting over the same time period. The trend shown in Figure 3 appears to follow the trends shown in Figure 1 & Figure 2 with a slow increase from 2005 followed by an explosion in patenting rates from 2008 onwards. Figure 3 also suggests that patenting in graphene is increasing at a considerably faster rate than patenting in general.

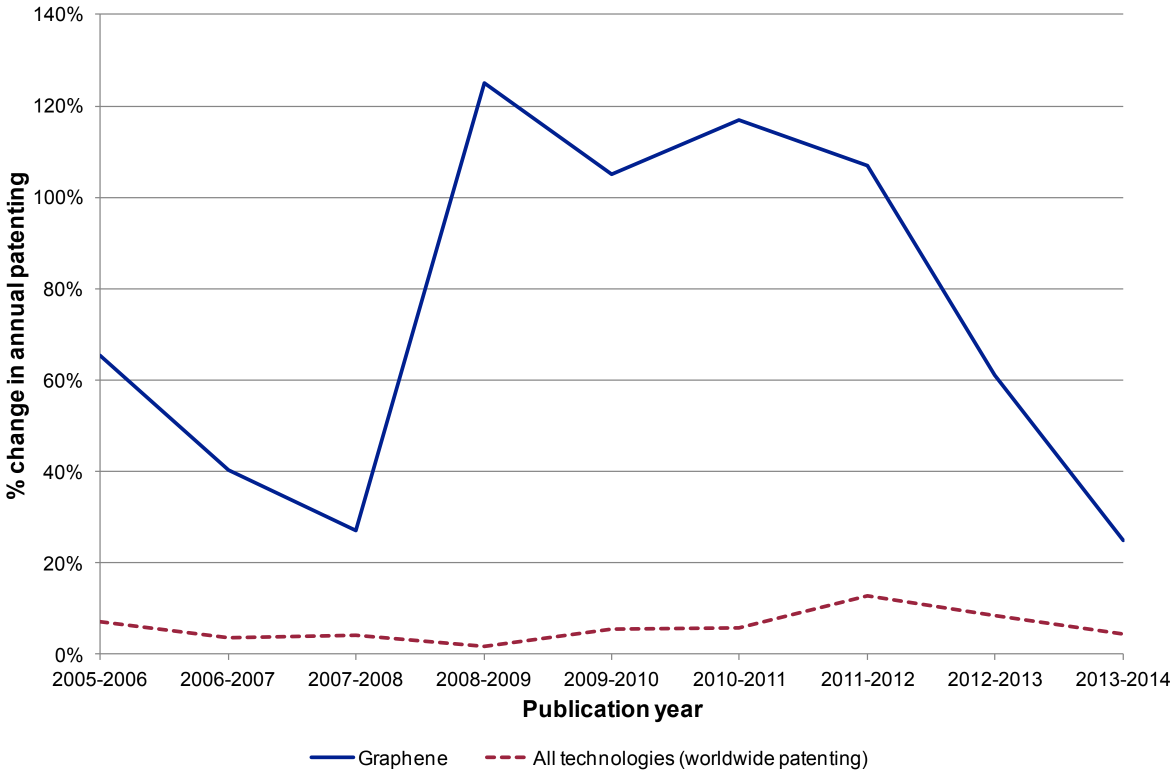


Figure 3: Year-on-year change in graphene patenting compared to worldwide patenting across all technologies

Figure 4 shows the priority country distribution across the dataset with almost half of graphene patents first filed in China. Less than 1% of graphene-related patents are first filed in the UK. Traditionally priority country analysis has been a good indicator of where the invention is actually taking place because many applicants will file patent applications first in the country in which they reside[5]. In recent years however, drawing firm conclusions from this data is harder because there may be other strategic reasons for an applicant choosing the country of first filing (*e.g*. tax treatment).

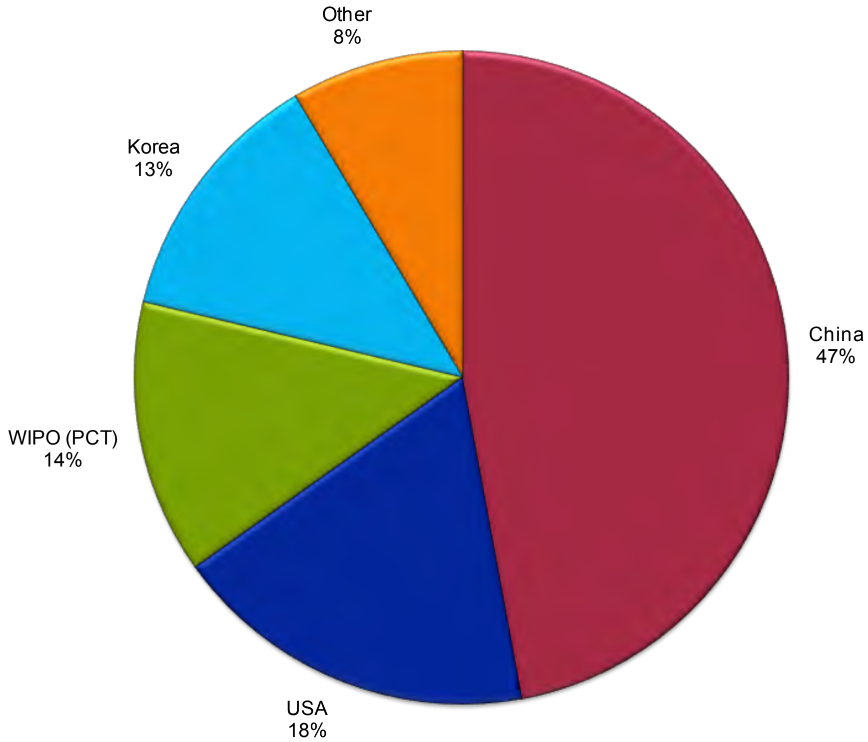


Figure 4: Priority country distribution

[5]In some countries this is/was a requirement (e.g. in the UK this was a requirement until 2005).

It is interesting to compare the priority countries over time. Figure 5 compares two periods of graphene patenting, the period prior to 2010 and the period after. It is interesting to see the growth in Chinese first filings between the two time periods, moving from just 7% in the earlier period to over 50% in the later period.

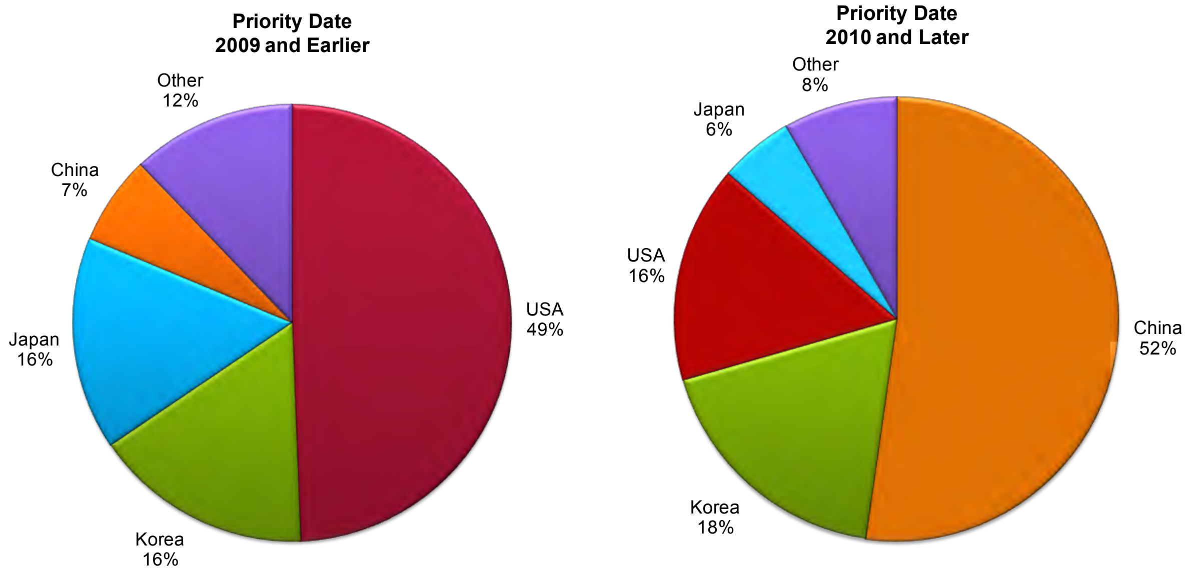


Figure 5: Priority country distribution over time

The applicant country distribution in Figure 6 shows a similar picture to the priority country distribution with China, Korea and the USA coming out as the top three countries. China does have a smaller representation with 29% of patent families having an applicant based in China as opposed to 47% of patent families having Chinese priority. As a result of this difference the remaining segments of the priority distribution are enlarged (including the “other” countries). Note that PCT filings[6] will exist as priority countries but not as applicant countries.

Overall it is clearly demonstrated that China has a significant role in the patenting of graphene.

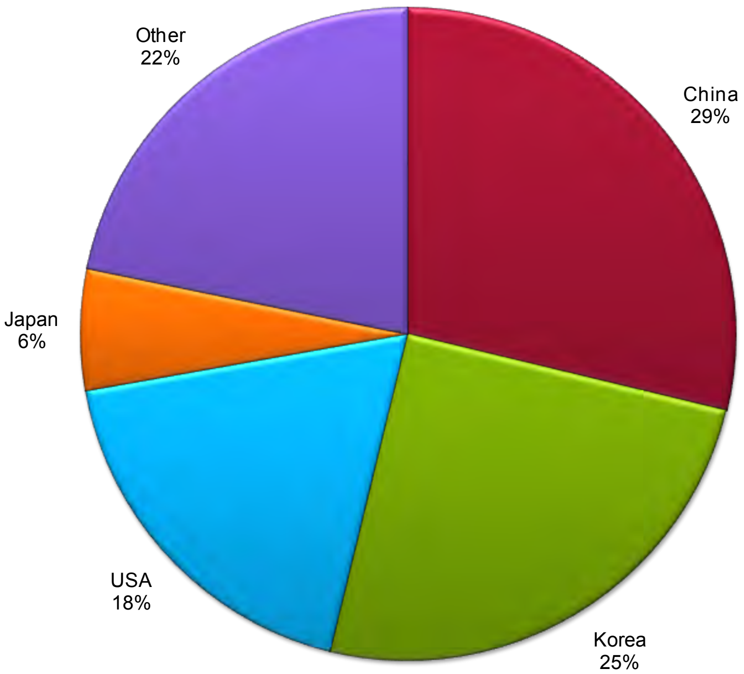


Figure 6: Applicant country distribution

[6] Alternative filing routes to single national patents, as outlined in Appendix A.3.

It is, however, well known that there is a greater propensity to patent in certain countries than others, and the trends shown in Figure 4, Figure 5 and Figure 6 may change if the raw data is corrected for this difference in behaviour. A Relative Specialisation Index (RSI)[7] for each applicant country has been calculated to give an indication of the level of invention in graphene technologies for each country compared to the overall level of invention in that country.

The RSI shown in Figure 7 indicates that, amongst others, the USA, Canada and the UK show a lower specialisation in graphene given the overall patent filings from these countries. Singapore, Korea and China, however, show high specialisations. Singapore in particular has a small share of applicants in absolute terms but this picture highlights their particular focus on graphene. China, on the other hand, has both a large share of applicants and a significant specialisation and is therefore quite dominant. The UK sits in ninth place on the RSI ranking, with a negative specialisation of just over -0.2 in graphene compared to other fields of patenting. It is clear, however, that the UK's specialisation in graphene has improved when compared to a score of approximately -0.4 reported in 2013[8].

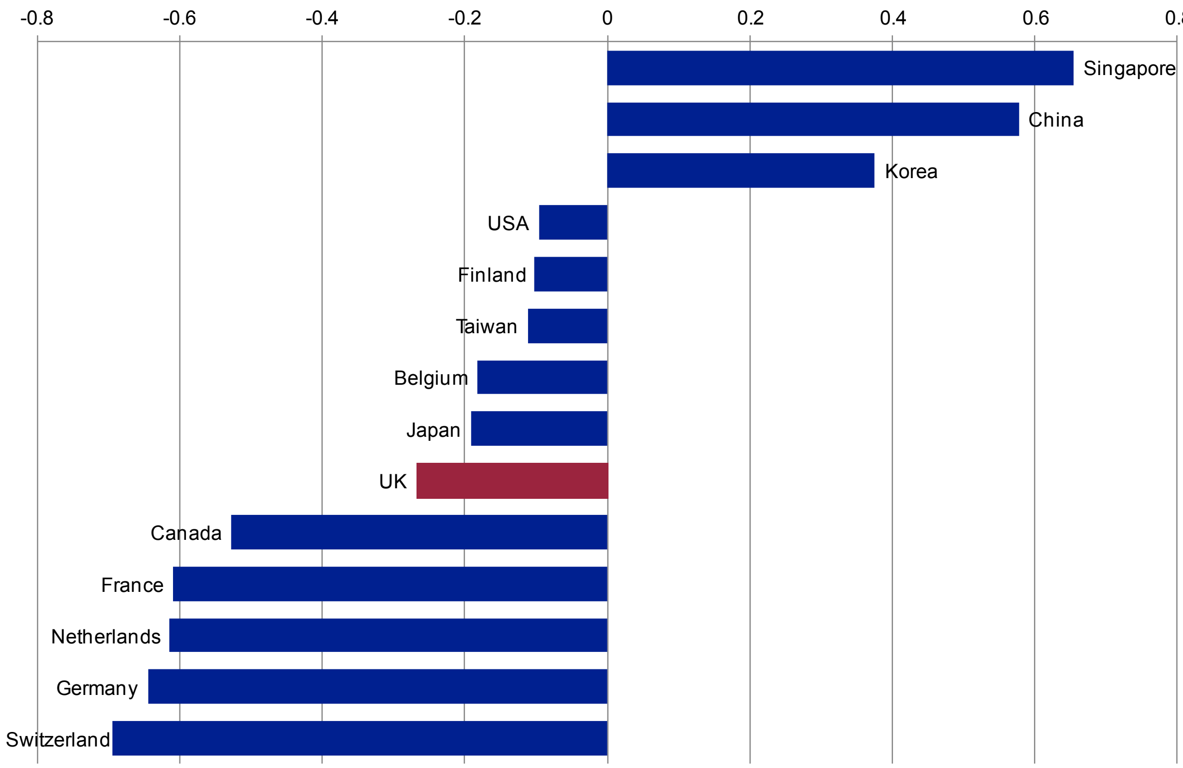


Figure 7: Relative Specialisation Index (RSI) by applicant country

---

[7] See Appendix B for full details of how the Relative Specialisation Index is calculated.
[8] https://www.gov.uk/government/publications/graphene

2.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[9]. Figure 8 shows the top twenty applicants in the graphene dataset.

As would be expected from the applicant distribution data already seen, many of the leading applicants are based in China. However, what is most striking is the number of academic institutions in this list, indicating that graphene continues to remain a highly research-based field as identified in the IPO reports of 2011 and 2013. It appears that the commercialisation of graphene has not yet been realised although it is believed that this is coming closer[10] and it is interesting to see the presence of three businesses in the top five applicants.

Samsung continues to lead the way as they did in 2013, with recent publications appearing to show a movement into flexible electronics[11] alongside energy storage[12]. A notable riser in the top graphene applicants is Ocean's King Lighting who were in ninth place in 2013 with fewer than fifty patent families but who have now risen to second place with an apparent interest in energy storage[13] and graphene preparation methods[14].

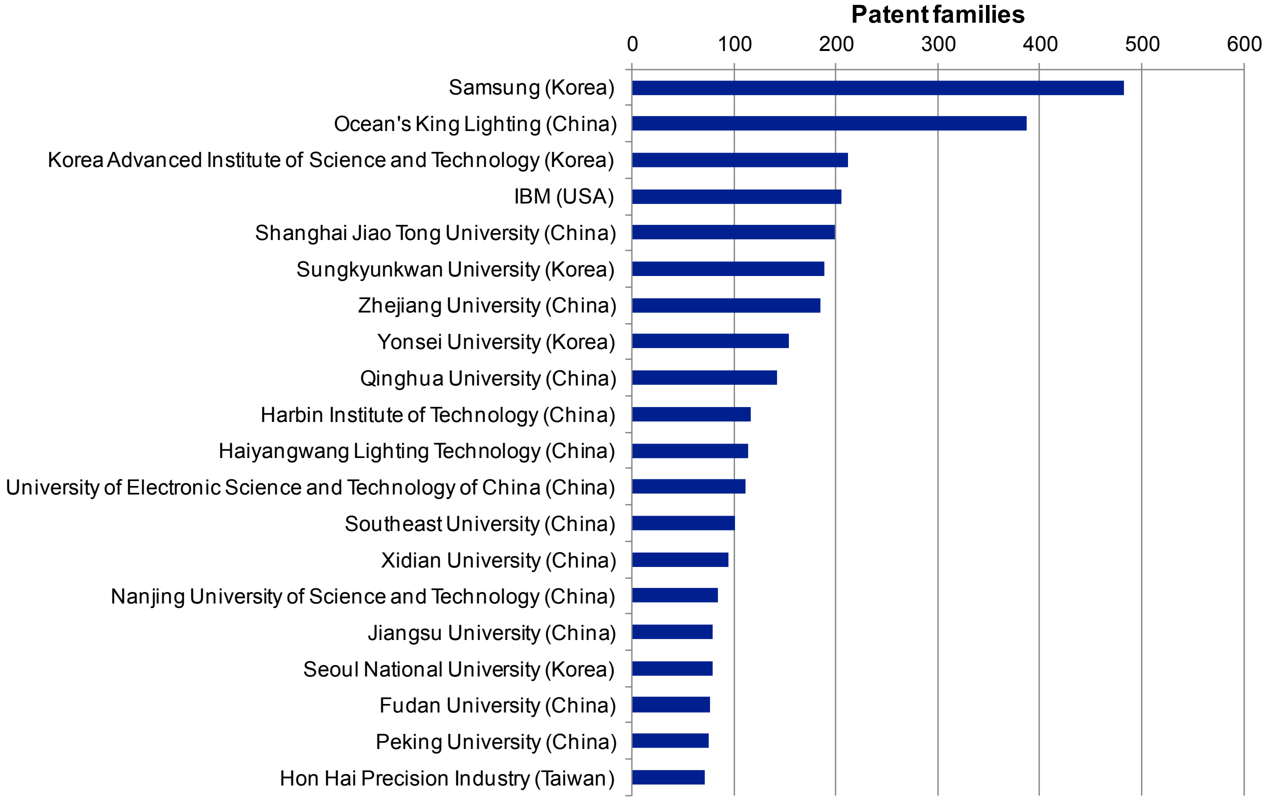


Figure 8: Top applicants

---

[9] See Appendix A.4 for further details
[10] http://www.extremetech.com/extreme/185737-researchers-may-have-solved-graphenes-production-problems-cleared-way-for-mass-production
[11] KR2014118512A
[12] KR2014104066A
[13] CN103682357A
[14] CN102923695B

Figure 9 is a bubble map showing a timeline for the top twenty applicants and shows the filing activity of these applicants in the last ten years. As can be seen, the majority of top applicants have been involved in graphene patenting in one way or another since at least 2010 and have seen a rapid growth in their patent portfolios since then For example, Samsung and Ocean's King Lighting show large growth in recent years, whereas the other applicants, perhaps with the exception of IBM and the Korea Advanced Institute, have filed consistent but comparatively low numbers.

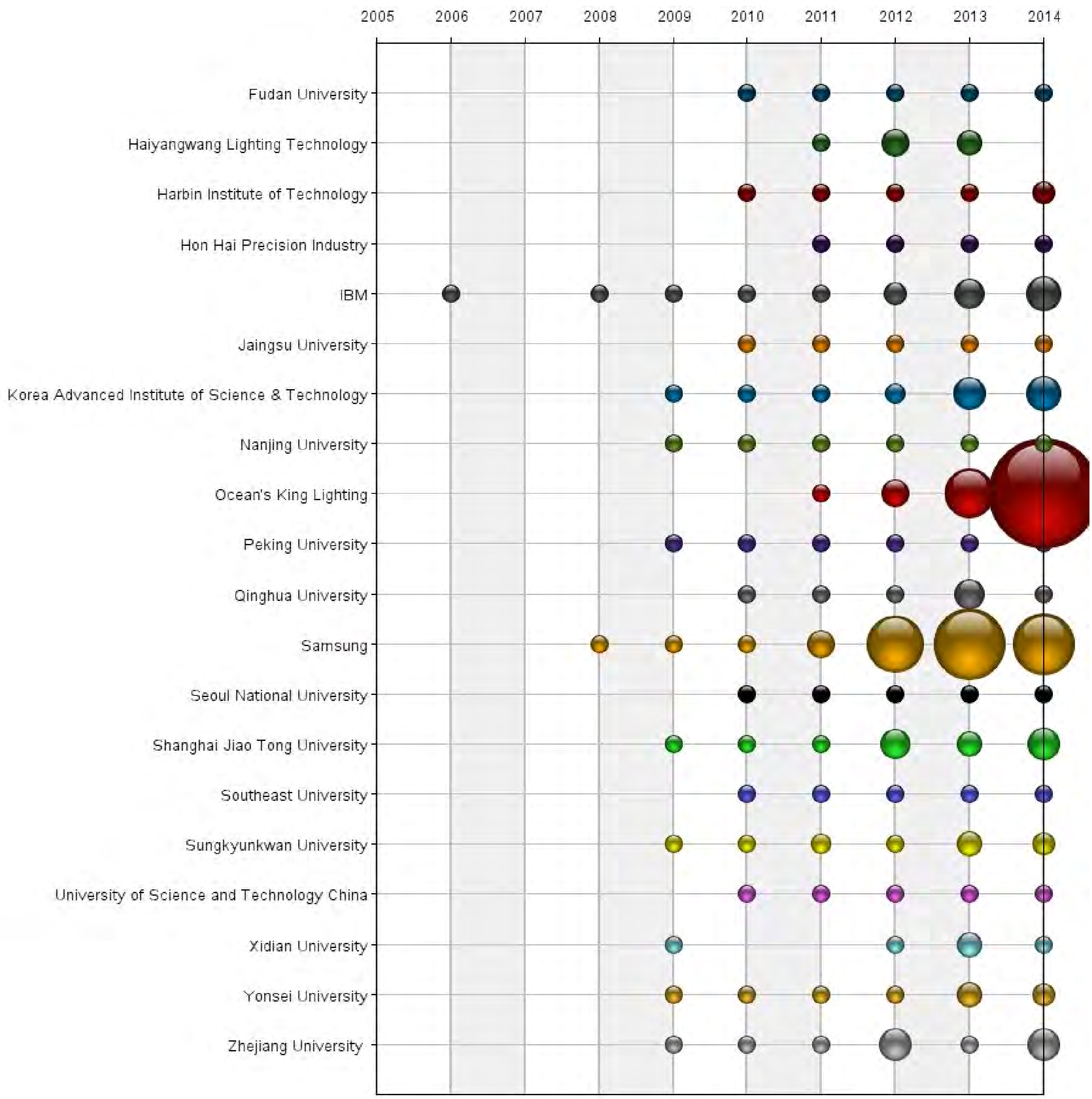


Figure 9: Applicant timeline of patent families by publication year

2.3 Collaboration

Figure 10 is a collaboration map showing where collaborations between the top applicants (shown in Figure 8) and their collaborators have taken place. The map has been restricted to applicants with at least five collaborations and each dot represents a patent family. Two applicants are considered to be linked together if they are named as joint applicants on a patent application. A collaboration map is a good indicator of technology transfer.

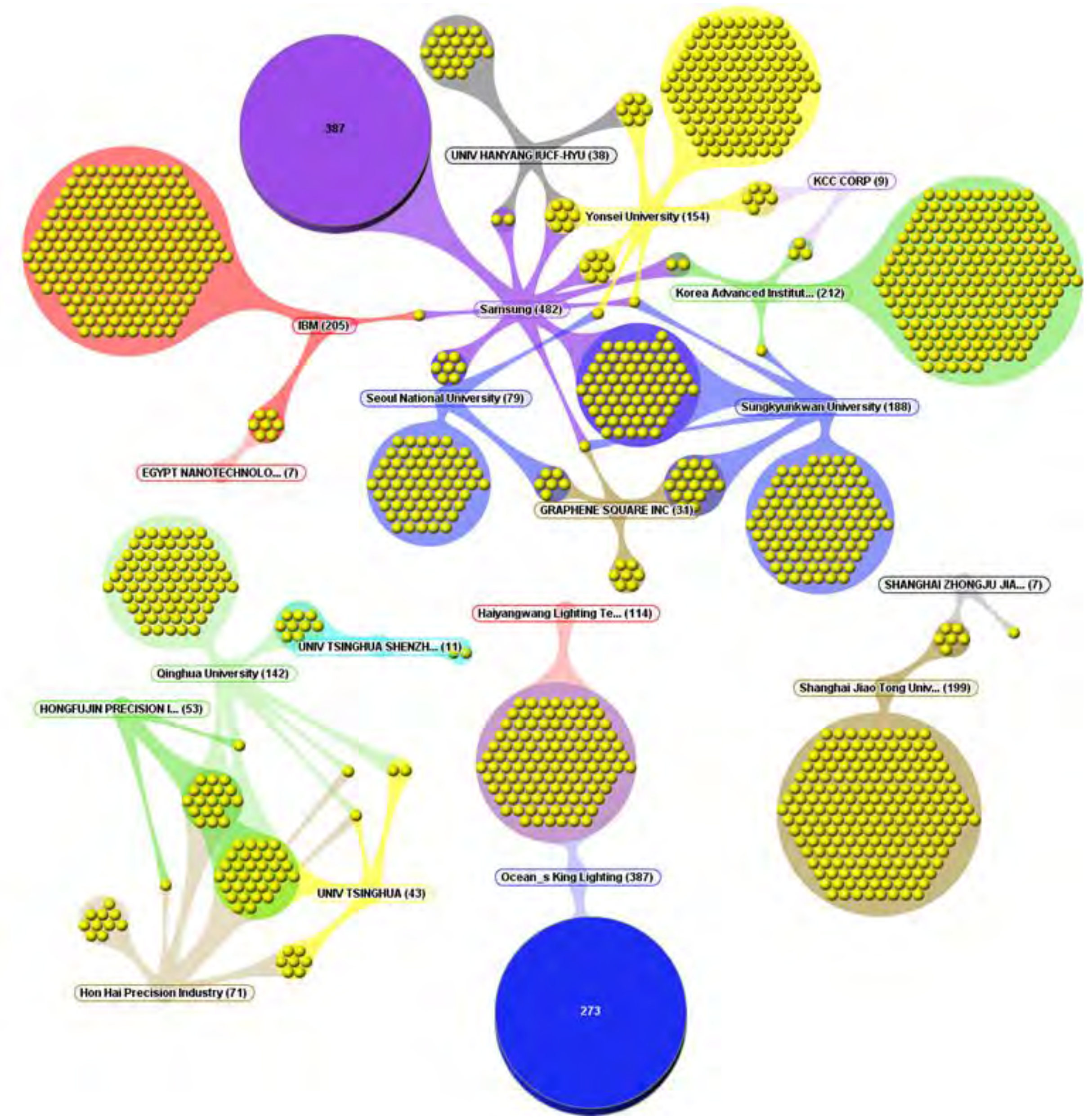


Figure 10: Collaboration map showing collaborations between the top 10 applicants and their collaborators where 5 or more collaborations have taken place.

Figure 10 reveals a remarkable amount of collaboration and knowledge flow within the graphene field. Of the top ten applicants, Samsung are the largest collaborators with ten different collaborations. Collaboration is seen between academic institutions, but also between academia and industry, and across differing countries.

3 Patent landscape map analysis

Figure 11 to Figure 14 are worldwide graphene patent landscape maps. Each map highlights one of the top four applicants in the area of graphene. A patent landscape map clusters similar patents together based on the occurrence of keywords in the title and abstract of each published patent application. Each patent is represented on the map by a dot (although not all dots are shown on a 'zoomed-out' map) and the more intense the concentration of patents (i.e. the more closely related they are) the higher the topography as shown by contour lines.

The maps provide a visual representation highlighting the areas in which Samsung, Ocean's King Lighting, Korea Advanced Institute of Science and Technology (KAIST) and IBM have been most active. Samsung's patents are generally spread out, though there does seem to be a change in focus from energy storage in 2013 to semiconductors and transistors in 2014. Ocean's King Lighting show two main areas of interest throughout 2013 and 2014, the first being energy storage and the second relating to graphene production methods. IBM, on the other hand, shows a strong focus in semiconductors over the entire period, across both years.

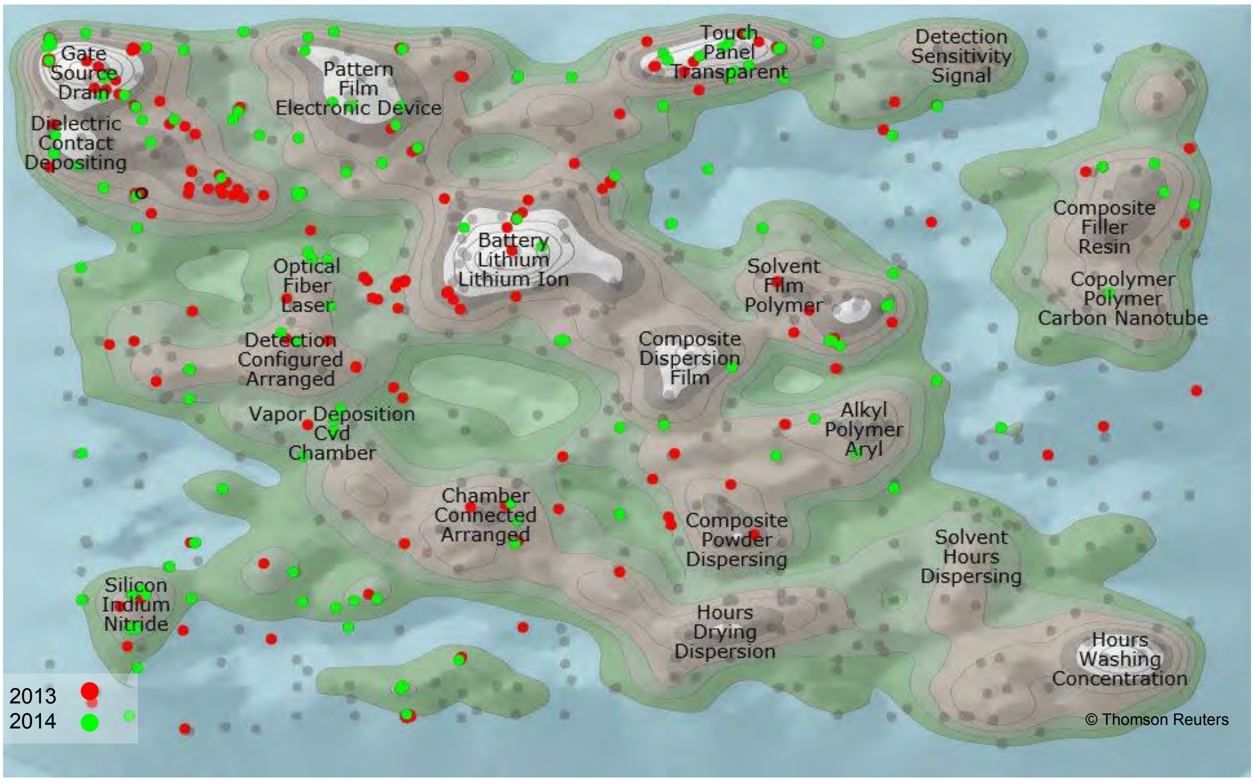


Figure 11: Graphene patent landscape map highlighting Samsung patents published in 2013 and 2014

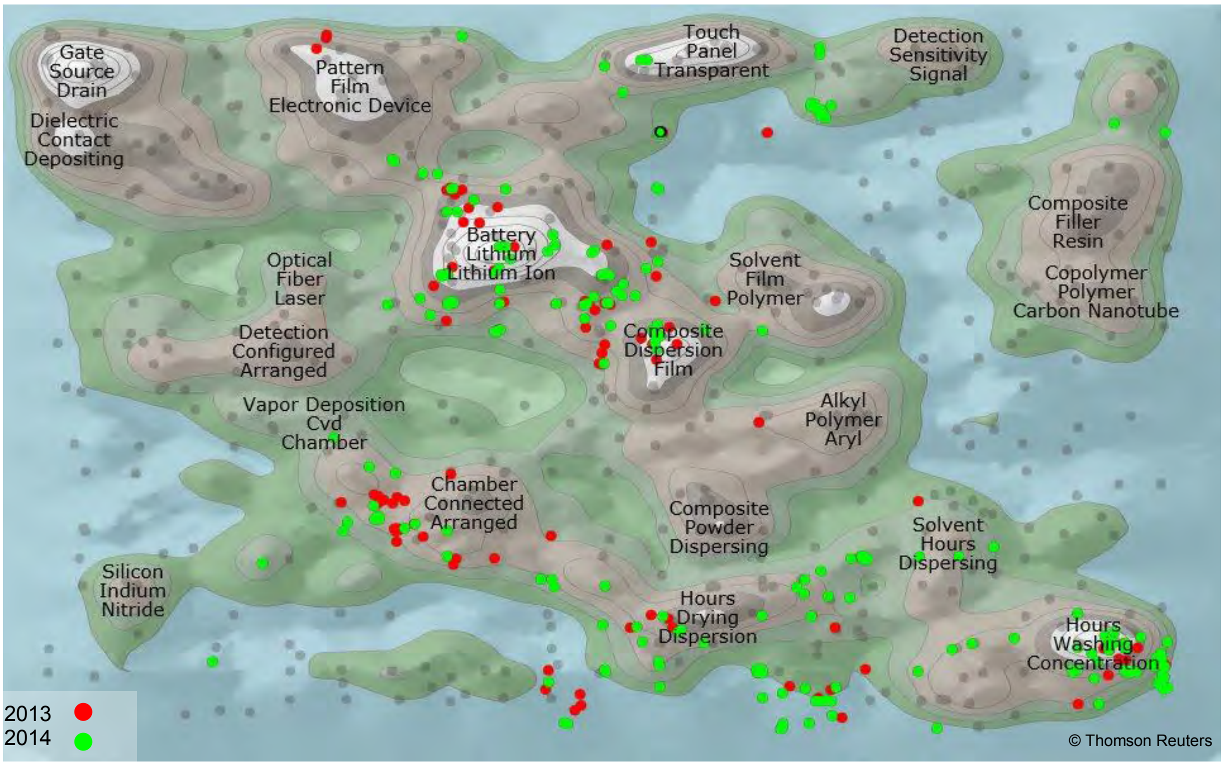


Figure 12: Graphene patent landscape map highlighting Ocean's King Lighting patents published in 2013 and 2014

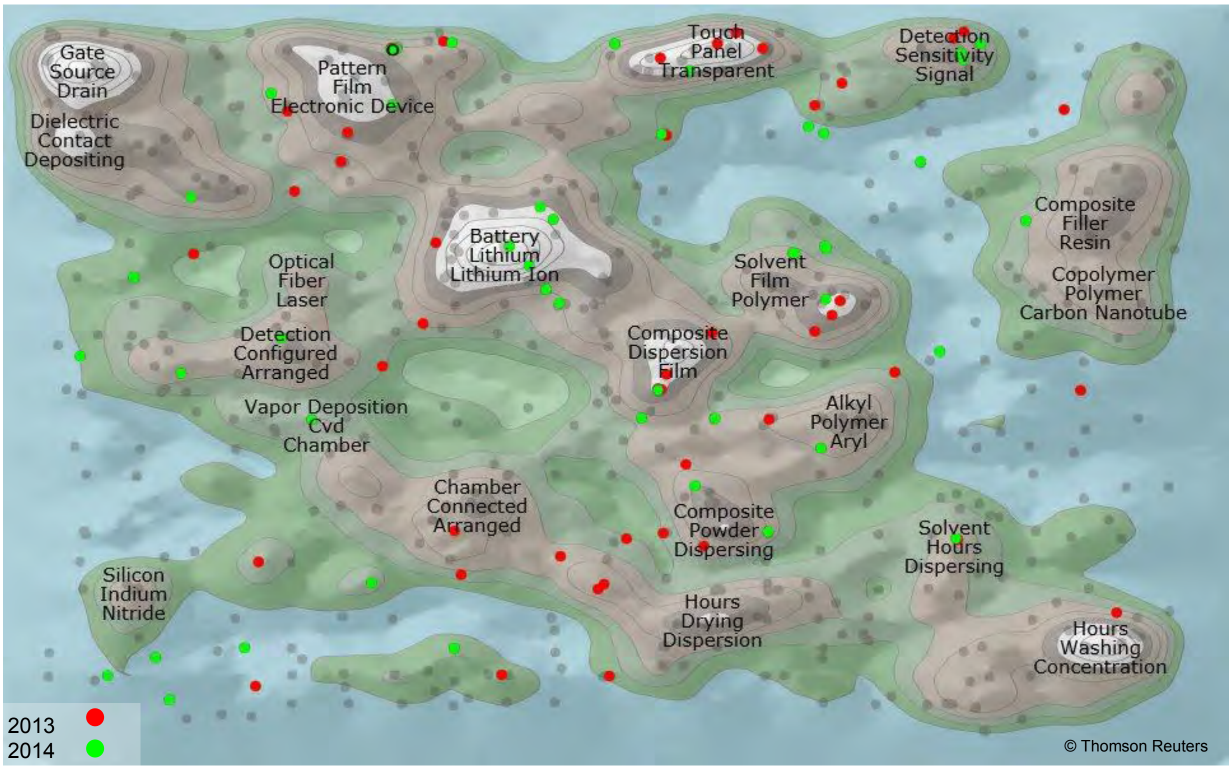


Figure 13: Graphene patent landscape map highlighting KAIST patents published in 2013 and 2014

Figure 14: Graphene patent landscape map highlighting IBM patents published in 2013 and 2014

4 The UK landscape

4.1 Top UK applicants

Figure 15 shows the top UK-based applicants within the graphene dataset. As for other countries, a large proportion of UK applications originate from academia, with the top three UK applicants all university-based and a further university in tied seventh place in the top ten. Currently, no UK companies appear to be in possession of large grapheme patent portfolios. Thus there would seem to be space and potential for further growth and the development of grapheme in the UK. With the Government announcing, in the 2014 Autumn Statement, the go-ahead for a £235m advanced material research centre to be based at Manchester University[15], the UK appears to be taking positive steps towards increasing their capability. It is also worth noting that the top 10 UK applicants contain an individual applicant, G S Kukard, in joint fourth position, indicating that graphene patenting is not solely in the hands of big business and academia within the UK.

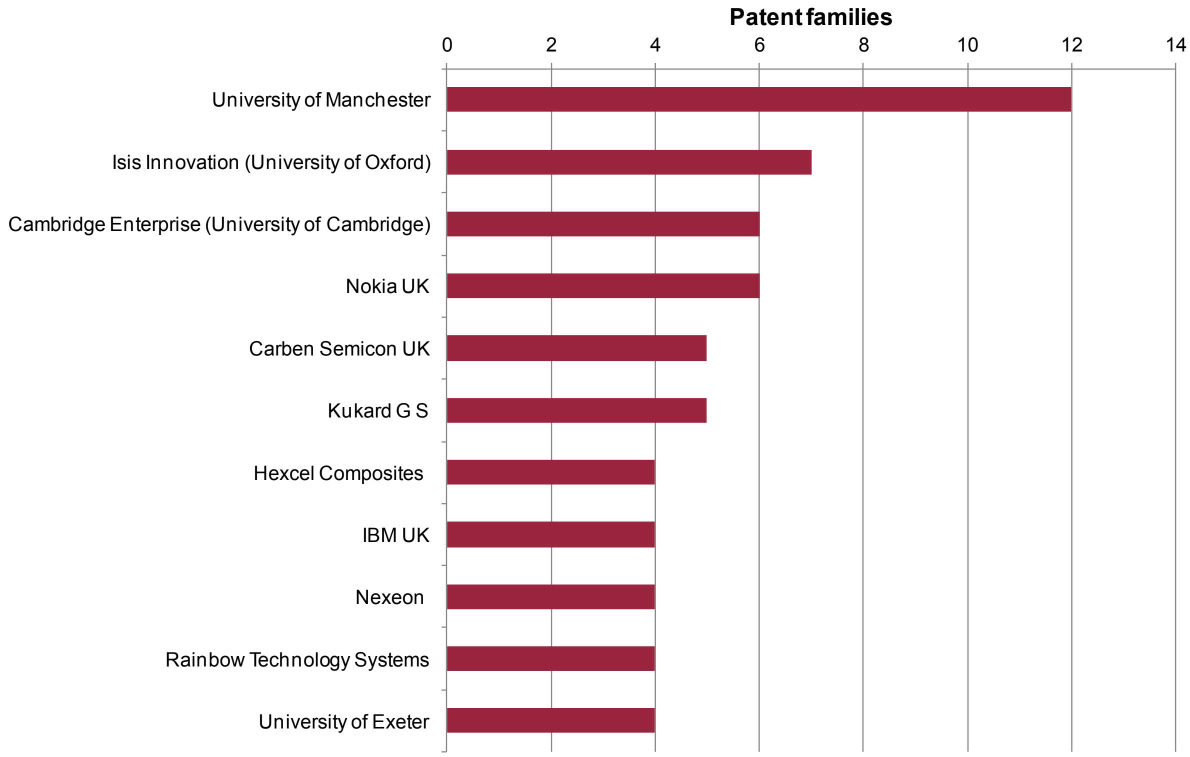


Figure 15: Top UK applicants

[15] http://www.bbc.co.uk/news/uk-england-30309451

4.2 UK inventor mobility

Figure 16 shows the top worldwide applicants with named UK inventors on their published patents. This list is largely a reflection of Figure 15 since all but three entries in the list are UK-based organisations. The exceptions are Nokia, based in Finland, Harvard College based in the USA and Carben Semicon of Cyprus.

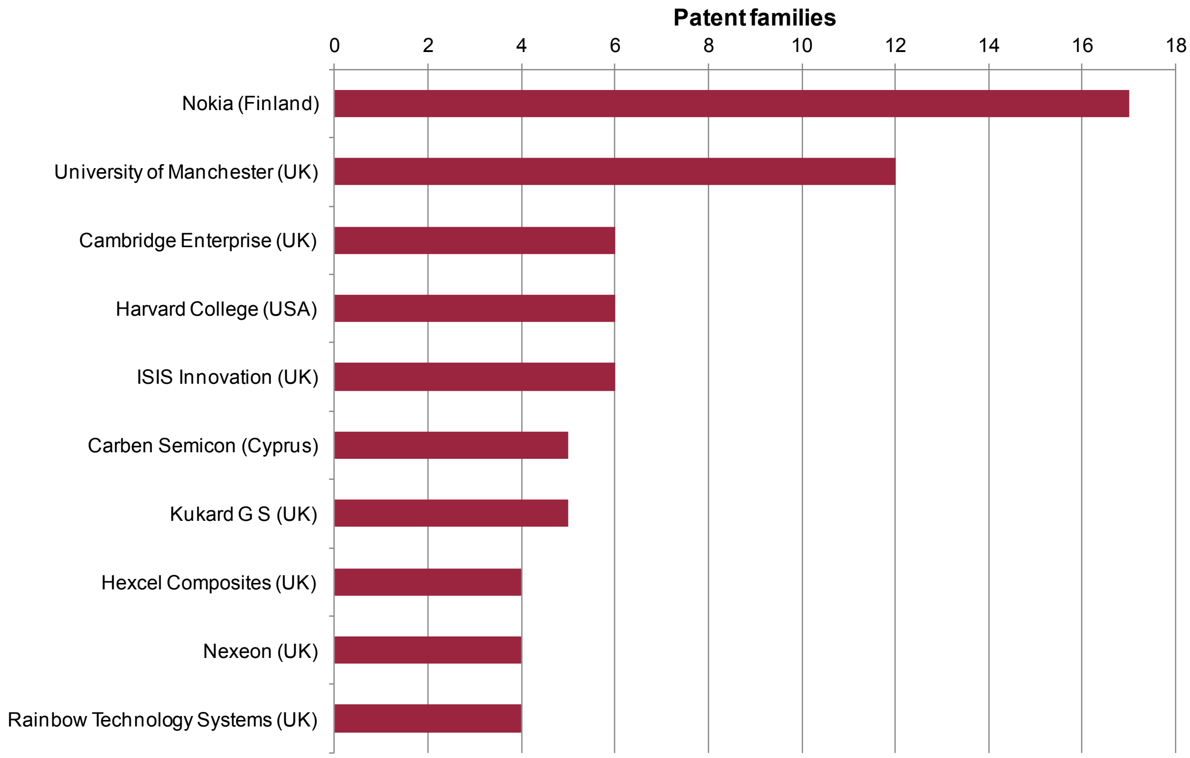


Figure 16: Top worldwide applicants with named UK-based inventors

4.3 How active is the UK?

A subset of the main worldwide dataset, designed to reflect all UK patenting activity, was selected. Figure 17 shows the year-on-year change in UK patenting activity against the worldwide year-on-year change in graphene patenting shown in Figure 3; this shows that, despite a negative RSI score in Figure 7, the UK has demonstrated a positive growth in patenting activity every year, with 2012-13 once again returning to growth rates in excess of worldwide levels. It is too early to tell what effect the UK Government's investment, since 2011,in advanced materials has had since any patents originating from this funding will take at least 18 months from date of filing to be published.

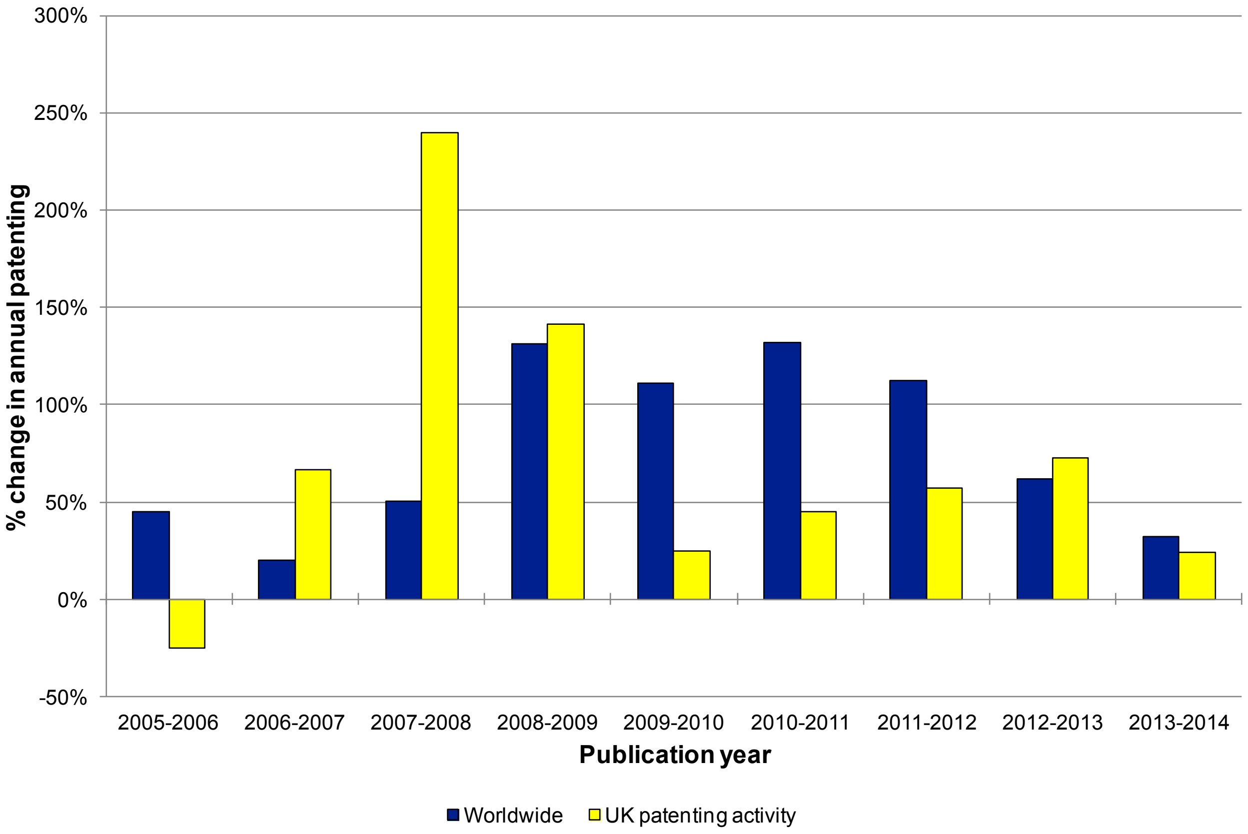


Figure 17: Year-on-year change in UK and worldwide graphene patenting

4.4 UK collaboration

Figure 18 reveals that collaboration trends for the UK are very similar to those seen worldwide, albeit on a smaller scale. There are a number of collaborations between UK applicants as well as with international applicants. As with the worldwide picture, collaborations take place both between academic institutions and between academia and industry. It is however, interesting to note that of the top applicants identified in Figure 15, only two applicants, Isis Innovation and Cambridge Enterprise, show collaborations although as university knowledge transfer companies this should, perhaps, come as no surprise.

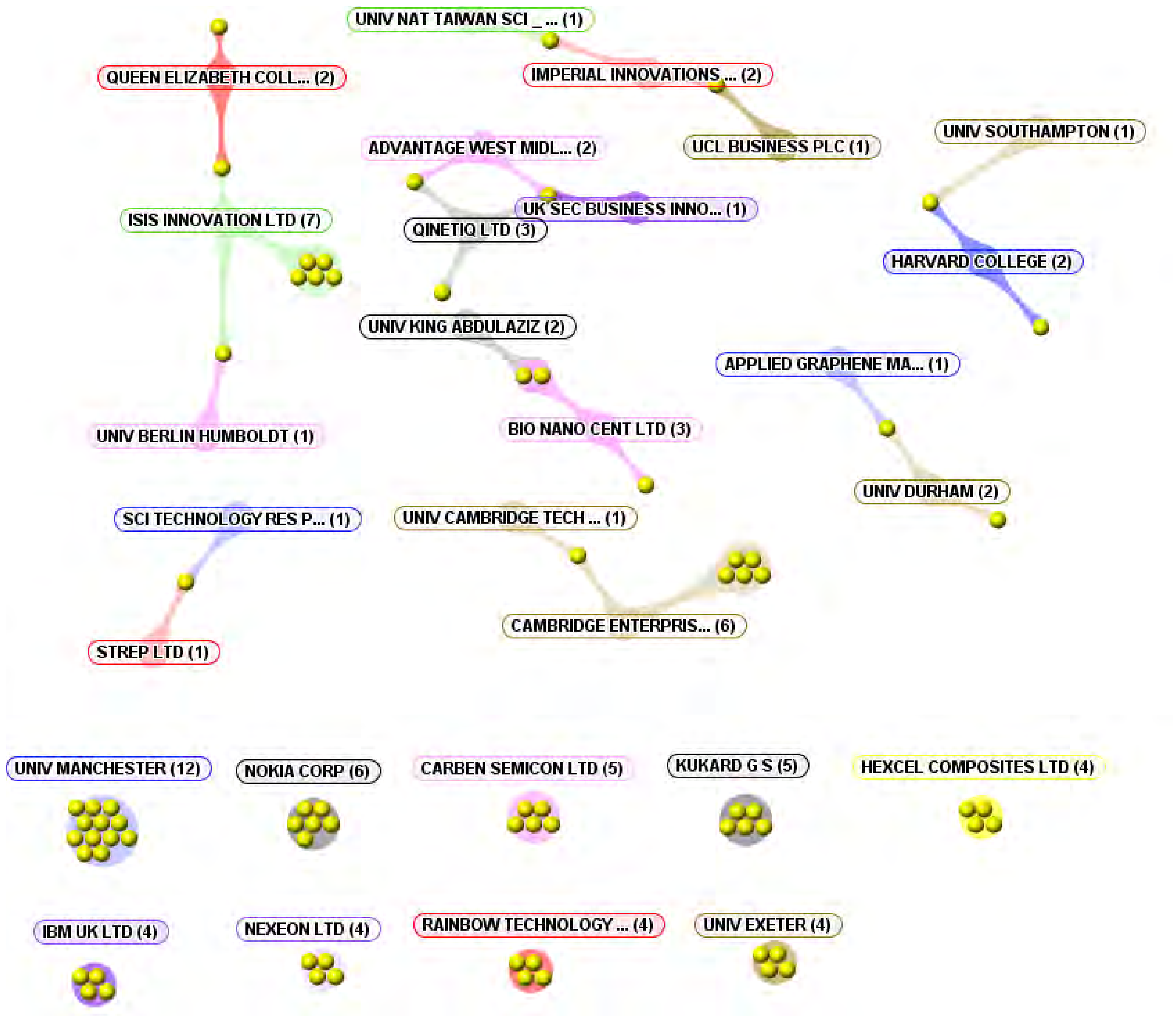


Figure 18: Collaboration map showing all collaborations between UK applicants and their collaborators

5 The Chinese landscape

Several of the previous charts have highlighted the continued rise in Chinese patenting in graphene since 2013. A subset of graphene patents from Chinese applicants was extracted for further analysis.

Figure 19 shows that in 2008 Chinese applicants made up 4% of the worldwide patent families, increasing to approximately 50% in 2012. At present, data for 2013 and 2014 is incomplete due to the eighteen month lag between the priority/filing date and the publication date, but the preliminary data for 2014 indicates that the Chinese domination within the graphene filing profile has continued to increase and is now well over 80%.

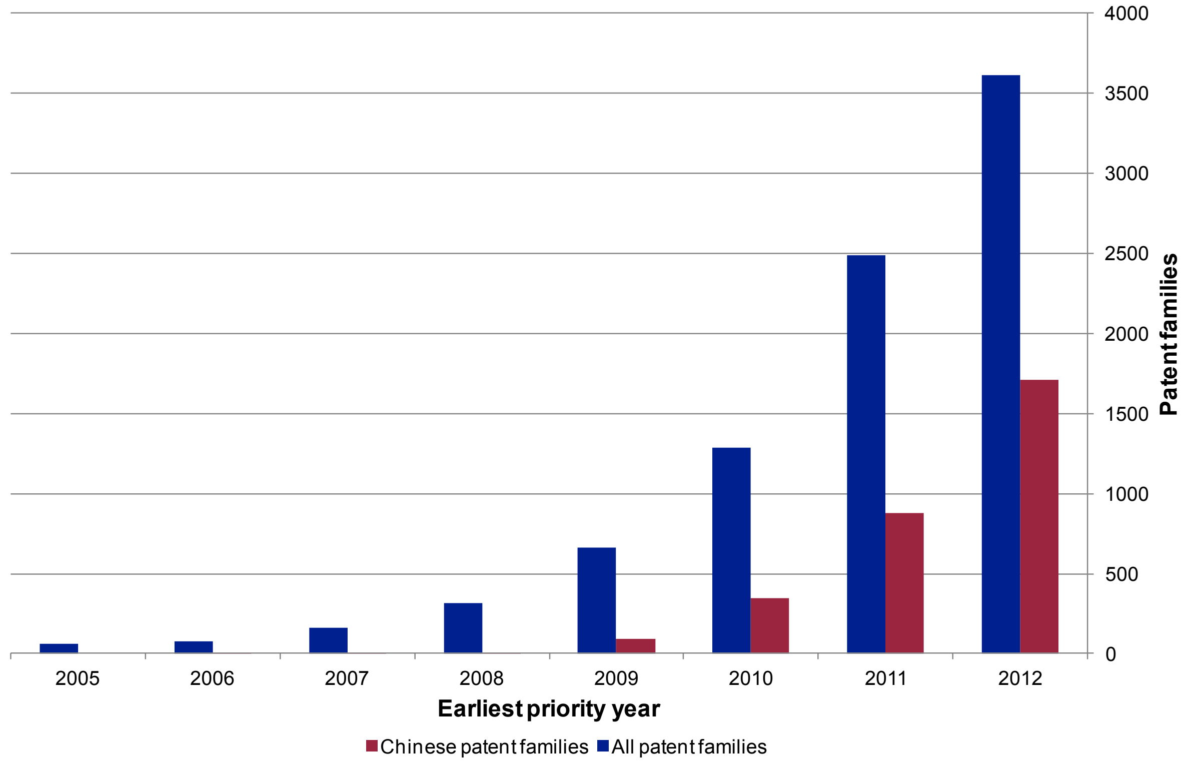


Figure 19: Worldwide patent families by earliest priority year against families from Chinese applicants

Figure 20 shows the top twenty Chinese applicants, seventeen of whom are universities. This chart supports the conclusions in the 2013 report that there are a large number of separate Chinese universities undertaking research in graphene with moderate numbers in their patent portfolios.

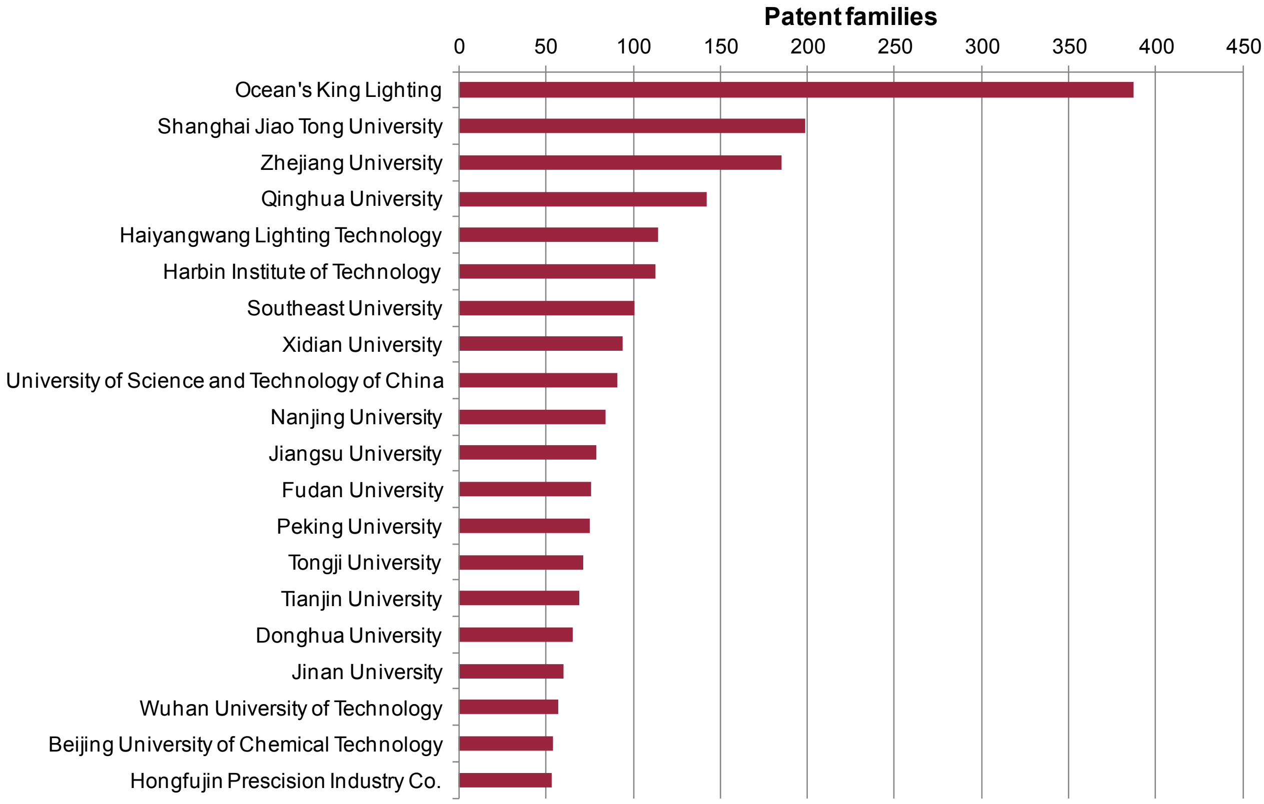


Figure 20: Top 20 Chinese applicants

An alternative viewpoint is to consider whether the sharp increase in the patenting of graphene in China in recent years is politically driven. 95% of graphene patents from Chinese applicants continue to have only one family member compared to 71% worldwide, and in over 98% of these patents the single family member is a Chinese patent application. Since 2013 there would appear to have been little change in overall trends across Chinese patent behaviour other than a growth in filings. This means that although there continues to be a growth in the number of published Chinese patent applications relating to graphene, many Chinese applicants are only seeking to protect their invention in China and will therefore have no worldwide monopoly.

As highlighted previously in the 2013 report, Lei et al[16] have shown there is a seasonal component to Chinese patents, with strong upward peaks in Chinese patent filing in December compared to the rest of the year. This suggests a politically driven, rather than innovation or commercially driven agenda in China; this seasonal component from Chinese patents was reflected in the data behind the 2013 graphene report, with almost a 250% increase in patent families filed in December compared to the monthly average for the other eleven months of the year. Lei et al[11] suggest that a plausible explanation of this phenomenon is that these Chinese patent applications are made under administrative pressure to meet yearly quotas set by the local Chinese governments. The fact that 95% of graphene patents from Chinese applicants only have one family member supports this theory, although there is no evidence to suggest the recent Chinese graphene patent surge is due to Chinese filing quotas. The quality and 'value' of Chinese graphene patents

[16] http://www.oecd.org/site/stipatents/4-3-Lei-Sun-Wright.pdf

compared those from the rest of the world is also unknown, but the hypothesis put forward by Lei et al[11] should be borne in mind when considering the ‘real’ position of any worldwide patent landscape for a particular technology area.

6 Conclusions

This is the third report in a series of graphene patent landscape analyses produced by the IPO as it continue to monitor developments in this high-profile technology. Patenting in graphene has risen rapidly in recent years; there has been an 802% increase in the number of published patents worldwide between 2010 and 2014. Samsung holds the largest graphene patent portfolio and, given its substantial collaborative research with Sungkyunkwan University (SKKU), who hold the sixth largest patent portfolio, together these two applicants would seem to be the market leaders. Despite the apparent dominance of these two Korean organisations, the leading country in the field continues to be China. The Chinese influence since 2013 has continued to grow and now almost half of all graphene patents worldwide originate from China.

As the technology space has developed there has been a considerable amount of collaboration, both domestically and internationally, continuing the trend identified in the IPO report published in 2013. However, one aspect that does not appear to have changed over the last 18 months is the lack of impact made by the UK, both in terms of UK applicants or UK inventors[17]; there has been an upturn in the UK's performance on the Relative Specialisation Index (RSI) since 2013 but it is too early to predict how the recent funding from the UK Government will have on UK patenting levels within this field.

Although the UK is clearly less dominant in the graphene field than countries such as China and the USA, the Relative Specialisation Index (RSI) would seem to suggest that despite its relatively low levels of patenting, the UK is still outperforming major European countries such as France and Germany with regard to its patenting of this technology.

Graphene research is advancing rapidly; several research papers are published every day and the growth in graphene literature shows no sign of abating. However, macroscopic analysis of the non-patent literature has not been undertaken on this report. Instead, with access to good quality worldwide patent databases, this report has been directed towards a reliable analysis of the underlying patent landscape. Patent statistics are not perfect and they do not directly translate to what is happening in the real world within a particular technology space but they do provide a sound basis for understanding commercial intent.

The continuation of trends identified in the IPO's report in 2013 have continued to show just how many countries and major multinational corporations are investing heavily to try to successfully commercialise graphene and fulfil its theoretical potential. There has been some movement in this area recently with Samsung alongside SKKU, becoming the first to grow a large-scale, impurity-free sheet of graphene capable of maintaining its electric properties[18]. Graphene has also been used in miniature ballistic tests[19] and it is hoped that layers of this material could be used in future to make bulletproof armour taking advantage of its inherent strength which, like for like, is stronger than steel[20].

---

[17] Although the UK has had a big impact in boosting graphene's public profile worldwide when two University of Manchester professors were awarded the Nobel Prize in Physics in 2010.
[18] http://www.htxt.co.za/2014/04/07/samsung-makes-graphene-breakthrough/
[19] http://www.bbc.co.uk/news/science-environment-30246089
[20] http://www.sciencemag.org/content/346/6213/1092

Appendix A Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) was interrogated using *Thomson Innovation*[21], a web-based patent analytics tool produced by *Thomson Reuters*. This database holds 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 the most recent patent trends.

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.2 Priority date, application date and publication date

Priority date: The earliest date of an associated patent application containing information about the invention.

Publication date: The date when the patent application is published (normally 18 months after the priority date or the application date, whichever is earlier).

Analysis by priority year gives the earliest indication of invention.

A.3 WO and EP 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 applications in each designated state or region, leading to a granted patent in each state or region.

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

[21] http://info.thomsoninnovation.com

A.4 Patent documents analysed

The graphene patent dataset for analysis was identified in conjunction with patent examiner technology-specific expertise. A search strategy was developed and the resulting dataset was extracted in April 2014 using International Patent Classification (IPC) codes, Co-operative Patent Classification (CPC) codes and keyword searching of titles and abstracts in the *Thomson Reuters* World Patent Index (WPI) and limited to patent families with publications from 2004 to 2013.

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.5 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[22] produced by *Search Technology* in the USA. The patent records exported from *Thomson Innovation* were imported into *VantagePoint* where the data is cleaned and analysed. The patent landscape maps used in this report were produced using *Thomson Innovation*.

[22] http://www.thevantagepoint.com

Appendix B Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patent families 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 graphene patents 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 of graphene patents in country i
n_{total} = total number of graphene patents in dataset
N_i = total number of patents in country i
N_{total} = total number of patents in dataset

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

Appendix C Patent landscape maps

A patent landscape map is a visual representation of a dataset and is generated by applying a complex algorithm with four stages:

i) **Harvesting documents** – When the software harvests the documents it reads the text from each document (ranging from titles through to the full text). Non-relevant words, known as stopwords, (e.g. “a”, “an”, “able”, “about” etc) are then discounted and words with common stems are then associated together (e.g. “measure”, “measures”, “measuring”, “measurement” etc).

ii) **Analysing documents** – Words are then analysed to see how many times they appear in each document in comparison with the words’ frequency in the overall dataset. During analysis, very frequently and very infrequently used words (i.e. words above and below a threshold) are eliminated from consideration. A topic list of statistically significant words is then created.

iii) **Clustering documents** – A Naive Bayes classifier is used to assign document vectors and Vector Space Modelling is applied to plot documents in n-dimensional space (i.e. documents with similar topics are clustered around a central coordinate). The application of different vectors (i.e. topics) enables the relative positions of documents in n-dimensional space to be varied.

iv) **Creating the patent map** – The final n-dimensional model is then rendered into a two-dimensional map using a self-organising mapping algorithm. Contours are created to simulate a depth dimension. The final map can sometimes be misleading because it is important to interpret the map as if it were formed on a three-dimensional sphere.

Thus, in summary, patents are represented on the patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map. Please remember there is no relationship between the patent landscape maps and any geographical map.

Please note that the patent maps shown in this report are snapshots of the patent landscape, and that patent maps are best used an interactive tool where analysis of specific areas, patents, applicants, inventors *etc* can be undertaken ‘on-the-fly’.

Intellectual Property Office
Concept House
Cardiff Road
Newport
NP10 8QQ
United Kingdom

www.gov.uk/ipo