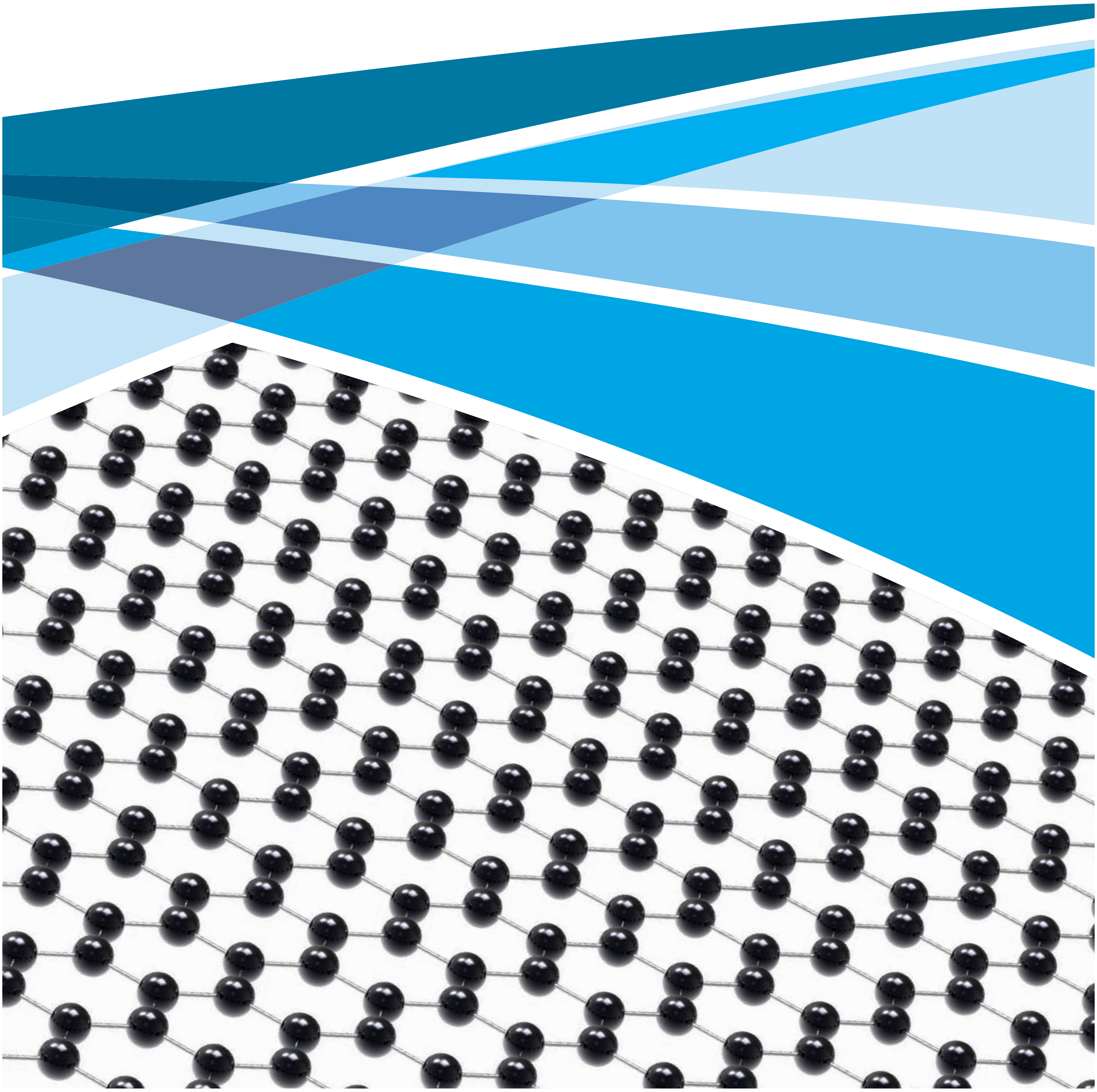
Intellectual Property Office

Graphene

The worldwide patent landscape in 2013



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Any enquiries regarding this publication should be sent to:

Patent Informatics Team
The Intellectual Property Office
Concept House
Cardiff Road
Newport
NP10 8QQ

Tel: 0300 300 2000
Minicom: 0300 0200 015
Fax: 01633 817 777

e-mail: pit@ipo.gov.uk

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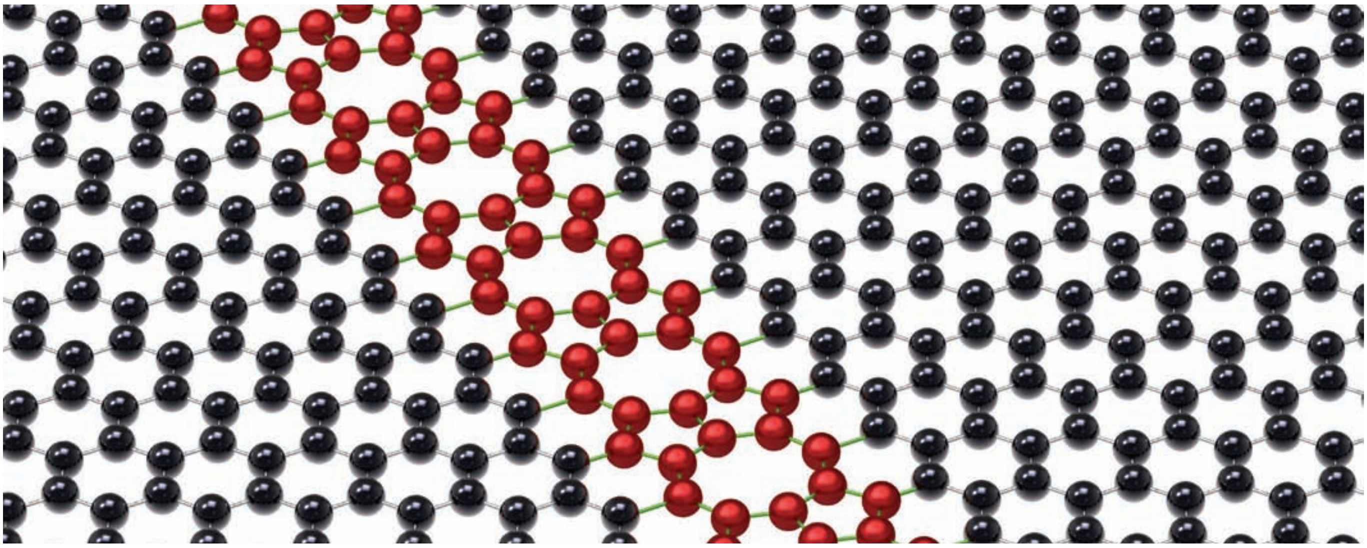
1 Introduction

Graphene is a nanomaterial consisting of single layer sheets of carbon atoms in a hexagonal arrangement[1]. The media refer to graphene as the "miracle material of the 21st Century"[2] and its 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"[3,4].

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[5]; 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[6].

In 2011 the Patent Informatics team at the Intellectual Property Office analysed patenting activity relating to graphene[7] 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[8]. Given the perceived imminent commercialisation and 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 2013 and how it has changed over the last couple of years.



1 H.P. Boehm, R. Setton and E. Stumpp, "Nomenclature and terminology of graphite intercalation compounds (IUPAC Recommendations 1994)", Pure Appl. Chem., 1994, Vol. 66, No. 9, pp. 1893-1901

2 http://news.bbc.co.uk/1/hi/programmes/click_online/9491789.stm

3 http://www.nature.com/news/2010/101007/full/news.2010.525.html

4 http://www.scientificamerican.com/article.cfm?id=geim-novoselov-physics-novel

5 http://arxiv.org/ftp/arxiv/papers/0906/0906.3799.pdf

6 http://www.zdnet.co.uk/news/emerging-tech/2011/06/10/the-10-strangest-facts-about-graphene-40093050/

7 http://www.ipo.gov.uk/informatic-graphene.pdf

8 http://www.bbc.co.uk/news/science-environment-20975580

2 The patent landscape

In July 2011 there were 3018 published patent applications relating to graphene worldwide. In the last 18 months this has almost tripled, with a total of 8416 published patent applications relating to graphene by February 2013[9].

The earliest mention of graphene appears in a patent published on 12 December 1994 with a priority dating back to 1991 and assigned to UCAR Carbon Technology Corporation[10]. No subsequent patent filings were made under this name. This document discusses intercalated graphite compounds, which are materials in which the layers of carbon in graphite have layers of another compound inserted between them. However, it was not until 1997 that graphene sheets are discussed in an isolated condition; in this instance as a step in the process of constructing carbon nanotubes[11].

The historical profile of patent publications in Figure 1 shows that following a slow take-off of patenting related to graphene in the early 2000s, there has been an almost exponential increase in worldwide patent publications since 2006. The red bars show the change in graphene patenting since the previous report was published in 2011.

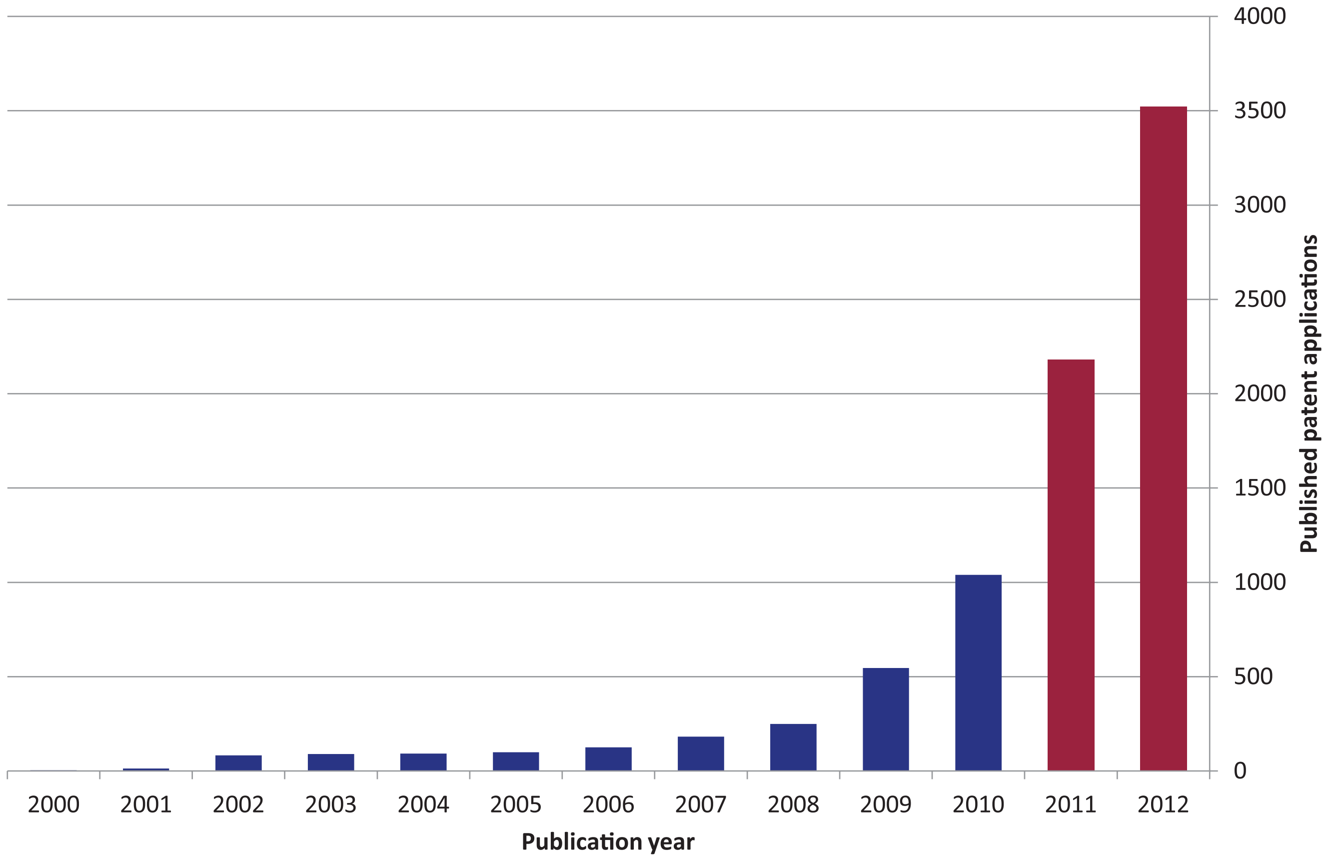


Figure 1: Worldwide patent publications by publication year

9 Further details can be found in the Appendix
10 US5376450 A (Published 27 December 1994)
11 WO98/39250 A1 (Published 11 September 1998)

Although Figure 1 shows the raw number of patent publications, a more accurate reflection on the level of innovation taking place can be seen by analysing patent families instead of patent publications. A patent family is one or more published patents with a shared priority. Analysis by patent family more accurately reflects the number of inventions present because generally there is one invention per patent family whereas analysis by patent publications inevitably involves multiple counting because one patent family may contain dozens of patent publications if the applicant files for the same invention in more than one country. Unless otherwise stated, all analysis in this report has been undertaken on patent families[12].

Figure 2 shows a comparison of the total number of published patent families by earliest priority year and the corresponding number of granted patents having the same priority year. For example, a patent family with an earliest priority date of 16 November 2008 will appear in the blue 2008 bar once it is published (approximately 18 months after the priority date) and then if a member of this patent family is granted at a later date (e.g. in 2011) then it will appear in the red 2008 bar once it is granted.

Although tempting, it would be wrong to conclude that the difference between the blue and red bars in Figure 2 necessarily represent 'failed' patent applications because a number of factors are at play in determining whether an application ever proceeds to grant. The patenting strategies of applicants may also contribute because applicants may file more applications than they ever intend to pursue. The inherent lag in patent grants, that varies from patent office to patent office, but which is generally measured in years, means that figures for patent grants are less up date and less indicative of current trends than applications, hence the 'tail-off' in the granted patents from 2006 onwards. Therefore, in general, the figures for published patents are considered a more current reflection of the level of innovation than the figures for granted patents.

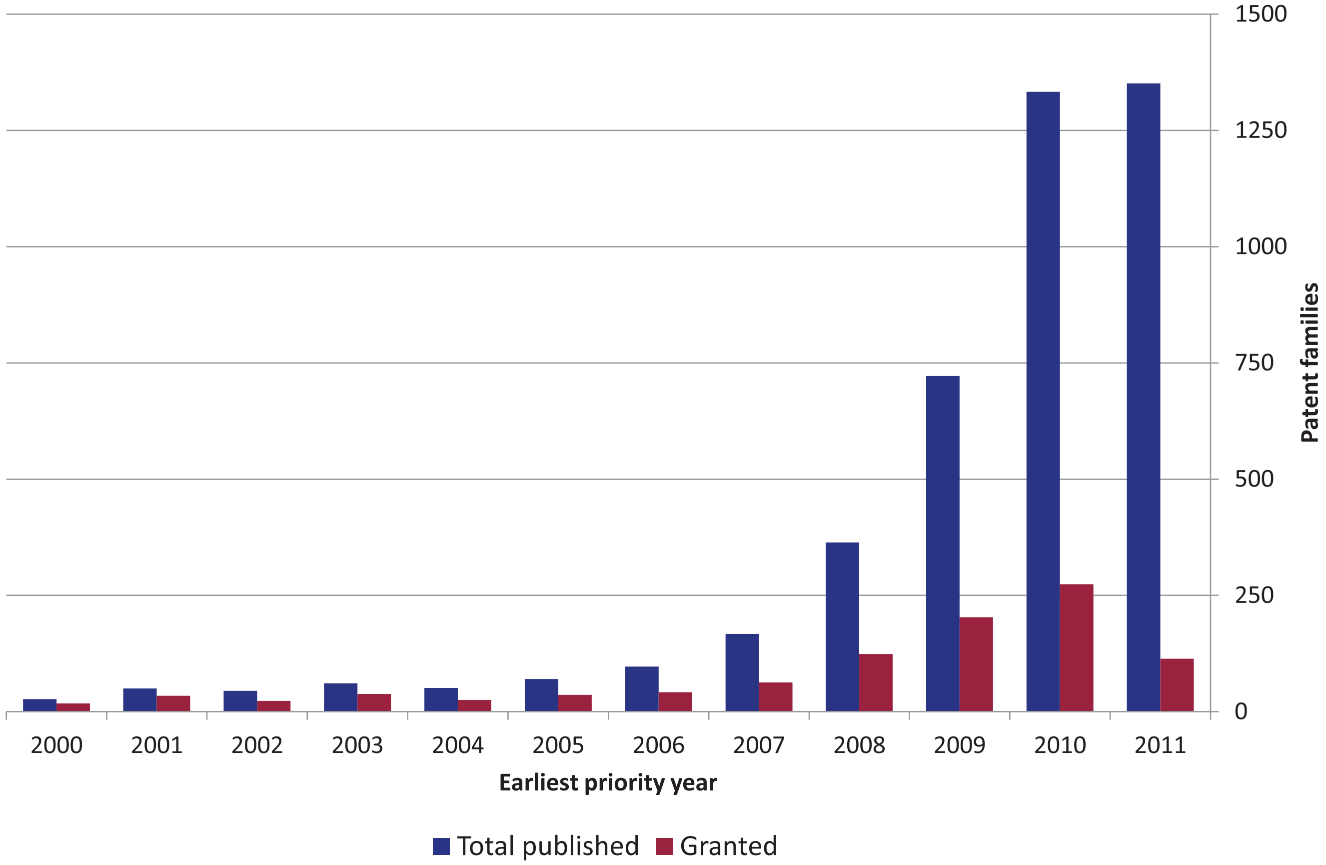


Figure 2: Comparison of published patent families and families with a granted family member by earliest priority year

12 Further details can be found in the Appendix

Figure 3 shows a chart of overall largest patent portfolios with Samsung being the clear leader with 210 patent families (inventions) in 405 published patent applications. The most notable change in the top applicants since the 2011 report[13] is the large influx of Chinese applicants. Only 8 of the top 20 applicants in the 2011 report remain the same with 8 of the 12 new entrants to the top 20 list coming from China. The highest ranked UK applicant is the University of Manchester with 6 patent families (inventions) in joint 163rd place.

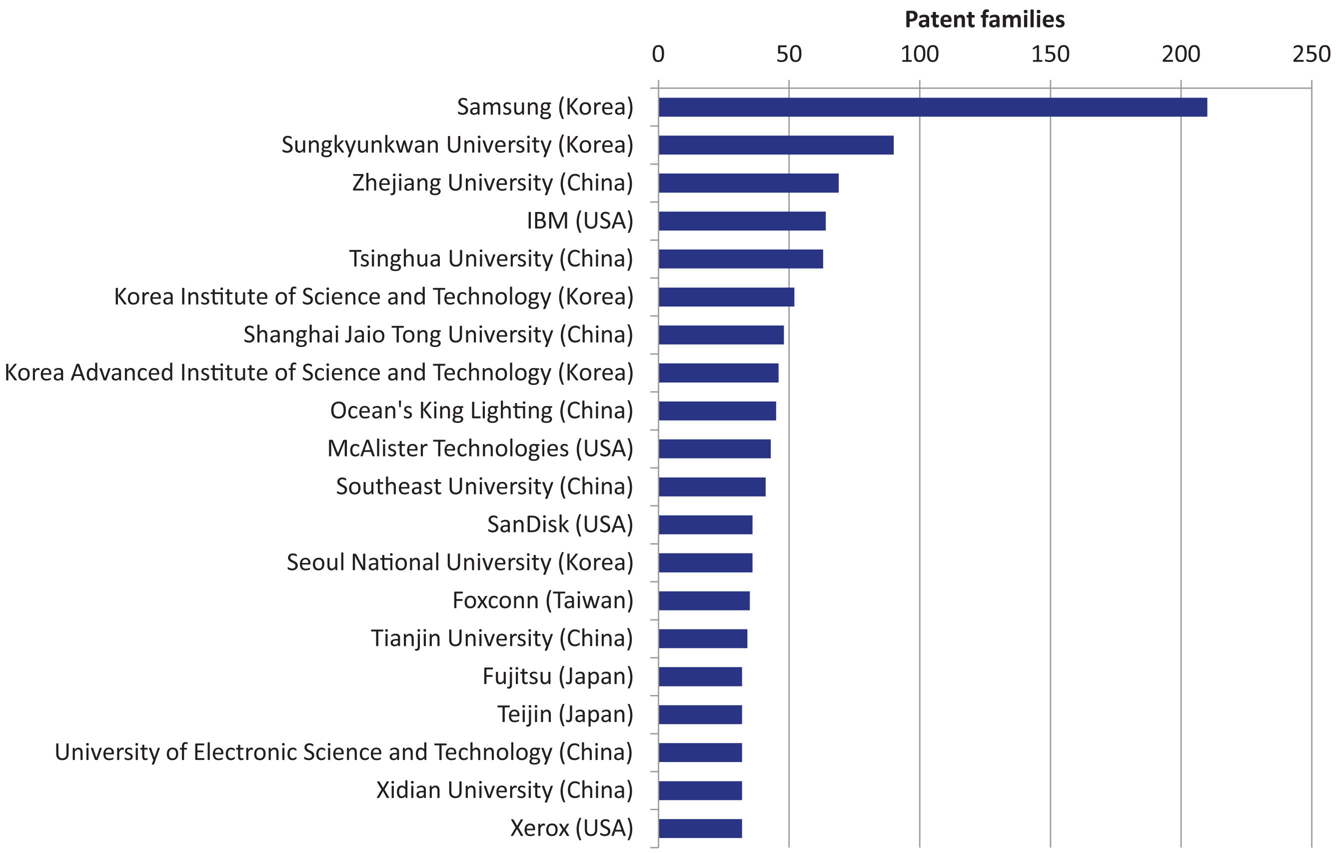


Figure 3: Number of patent families of the top 20 applicants

13 http://www.ipo.gov.uk/informatic-graphene.pdf

A large number of relatively new entrants in the list of top applicants is expected given the rapid take-off of patenting in graphene in the last five years. The applicant timeline for the top 20 applicants in Figure 4 illustrates this, and highlights the entry of the new Chinese applicants into this technology space.

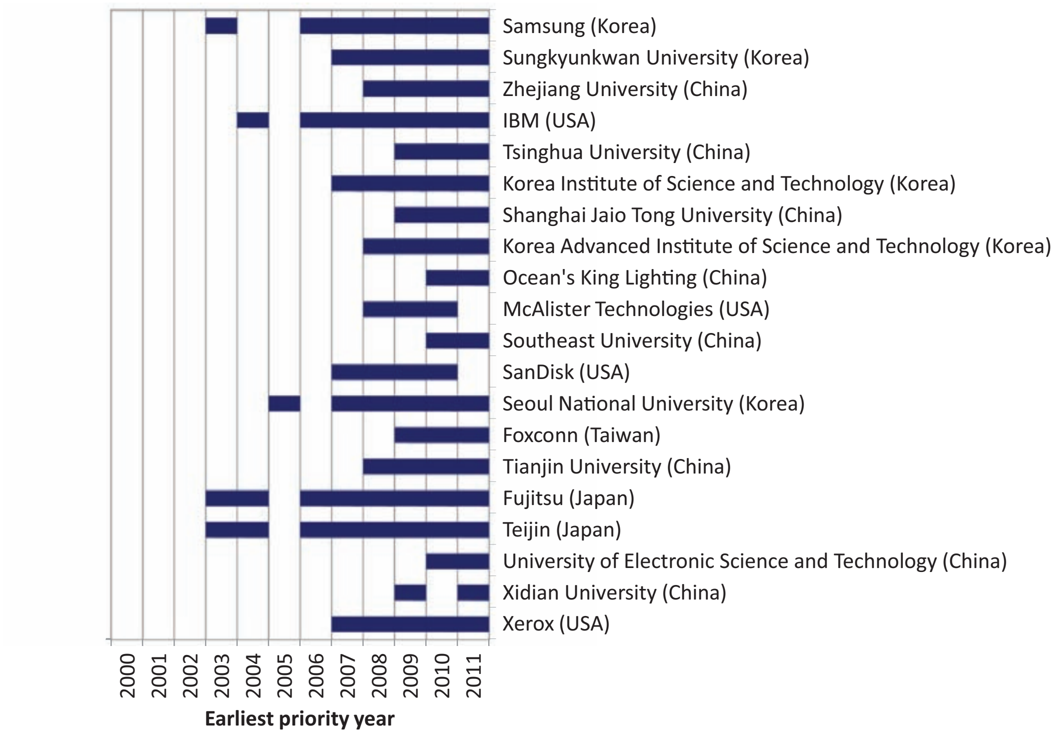


Figure 4: Applicant timeline of the top 20 applicants by earliest priority year

The spread of patent publication portfolio size shown in Figure 5 indicates that, in general, since 2011 applicants' patent portfolio sizes have increased significantly. *Prima facie* this indicates that many applicants who are already working on graphene-related technology are continuing to innovate in this space. However, when this is taken into context alongside Figure 3 and Figure 4, which show a large influx of new applicants holding big patent portfolios, it is not surprising that the shift in portfolio sizes suggests rapid patent portfolio growth given the preponderance of new large players in the technology space and the continued activity of the more established applicants. Comparison with the distribution of patent family (invention) portfolio size shown in Figure 6 supports this theory.

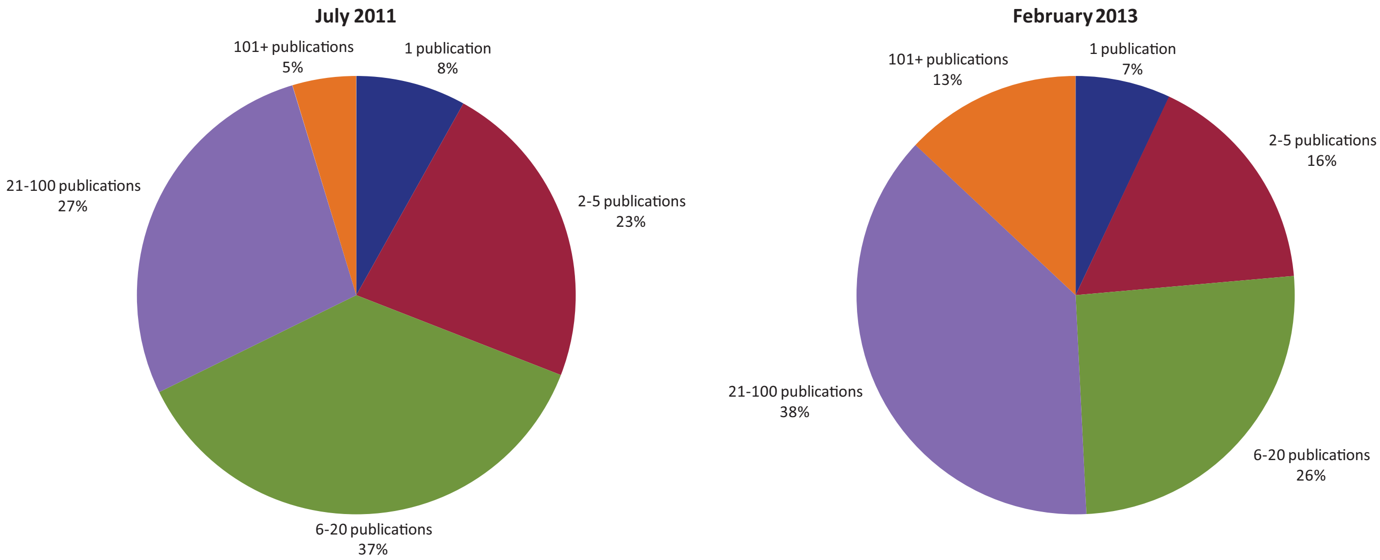


Figure 5: Patent publication portfolio sizes

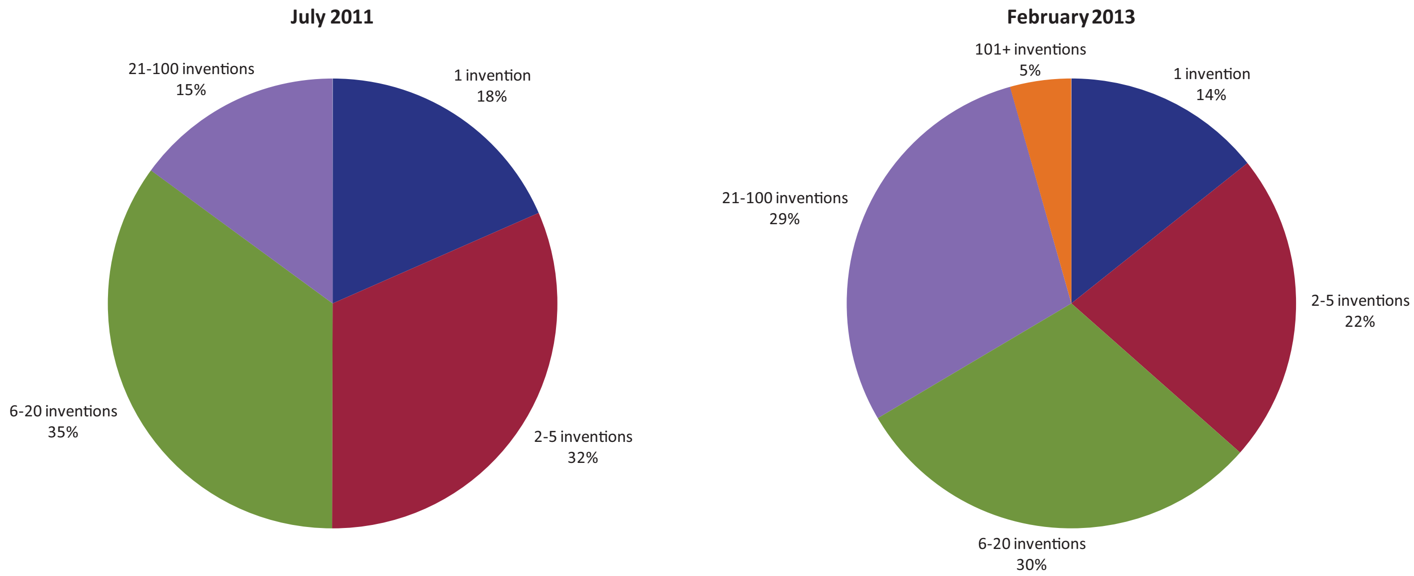


Figure 6: Patent family portfolio sizes

Figure 7 shows a patent landscape map for 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 (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. Different types of technology or different applications/uses can be grouped on patent landscape maps based on keyword or patent classification. The patent portfolio coverage of several of the top applicants within the graphene patent landscape is also highlighted.

With the exception of Samsung, the top corporations have a narrower technology focus than the top academic applicants. For example, despite SanDisk's large company size they have a narrow interest in graphene because as a flash memory device specialist they are only interested in graphene's potential uses in memory devices. Likewise IBM, Xerox, McAlister Technologies and Bayer are likely to have focused interests, whereas the academic institutions are likely to be interested in a wider range of potential applications by exploring different potential research directions. The exception to this is Rice University's concentrated interest in graphene for antenna-related uses, presumably reflecting the areas of interest of their research programmes.

Given the size of Samsung's graphene-related patent portfolio shown in Figure 3 (over four times larger than most of the other top 20 applicants) and the wide-ranging nature of their general business (from smartphones and televisions to refrigerators and air conditioning systems[14]) it is therefore not surprising that they are researching the potential application and uses of graphene in a wide range of technology areas as shown by their broader technology focus on the patent landscape map.

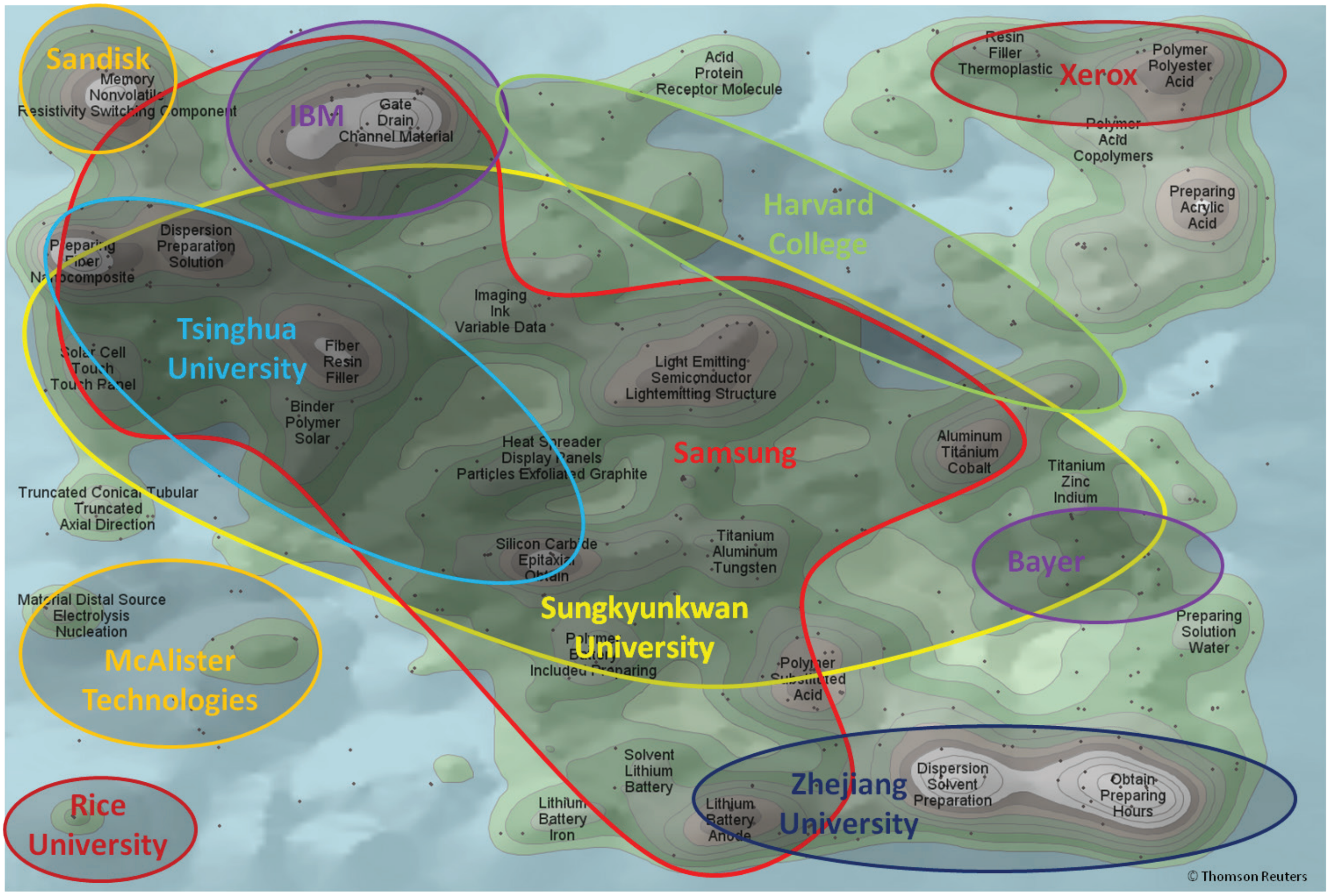


Figure 7: Graphene patent landscape map with selected top applicants highlighted

14 http://www.samsung.com/uk/

Figure 8 shows the breakdown of graphene patent applicants by sector. New high-tech technology areas are generally dominated by academia in the early stages of development and the corporate sector grows and dominates as the technology is commercialised, with a well-developed technology area having a corporate domination of about 80%[15]. It is therefore interesting to note the increasing dominance from academia and a decreasing corporate sector proportion since 2011, and at present the corporate and academia split is roughly the same. This supports the media reports[16] which suggest that graphene is struggling to make its first commercial breakthrough into a consumer application because it is hard to make it in large enough quantities for practical uses and that an increasing amount of research in academia is required to make this final step to commercialisation in real-world applications. The influence of Chinese academia, discussed in detail in section 5, will also have a noticeable effect on the data presented in Figure 8.

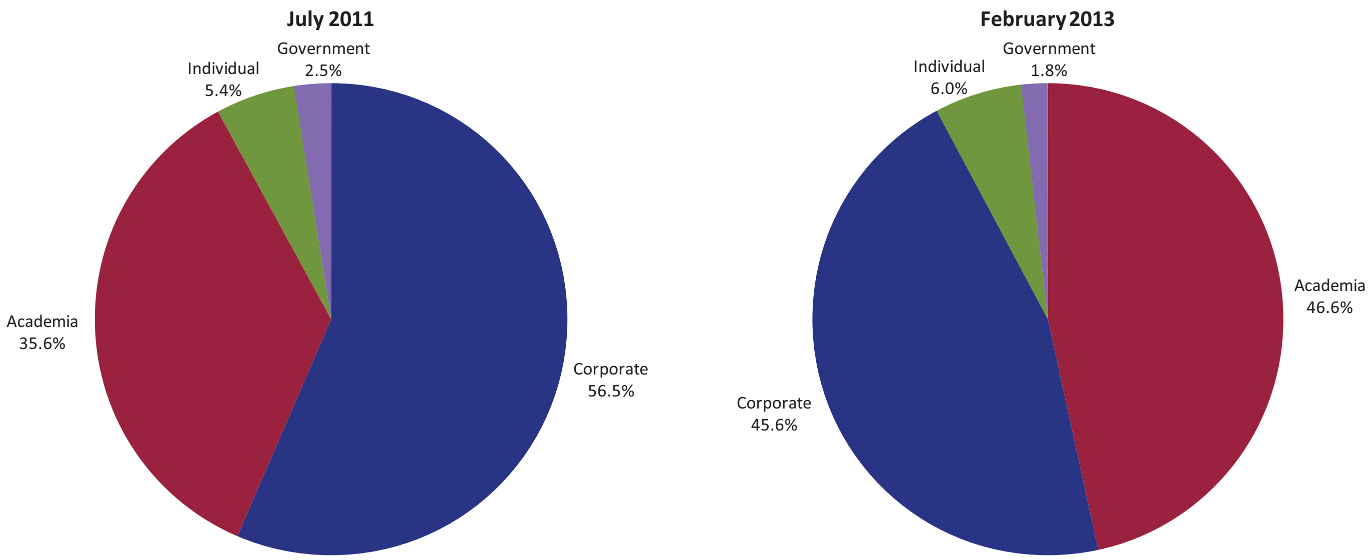


Figure 8: Patent families by sector

15 An example of this is shown on page 8 of http://www.ipo.gov.uk/informatics-3d.pdf

16 http://www.materialsforengineering.co.uk/engineering-materials-features/nanoscale-material-science/46809/

Figure 9 shows how the sector breakdown has changed over time and illustrates that proportionately the involvement from academia has increased steadily over the last five years. Inventions from academia made up over half of the patenting activity in 2011.

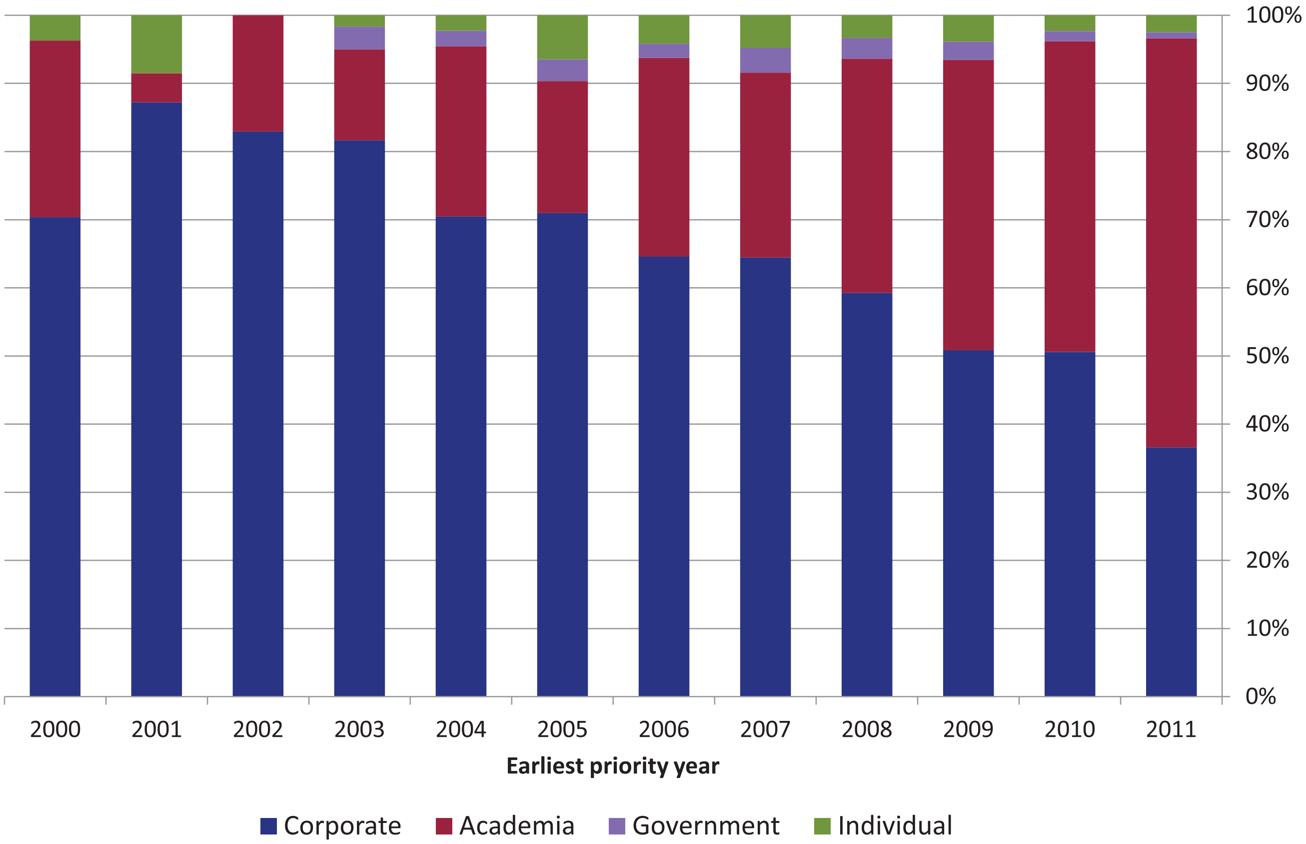


Figure 9: Patent family timeline by sector

The collaboration map shown in Figure 10 illustrates the patent families of the top 20 applicants and where they have co-applicants, as well as the patent families of these co-applicants. Around half of the top applicants have patent families with named co-applicants, suggesting that collaboration, or outsourcing of research and development to other organisations, is part of their innovation strategy.

Samsung, the most prolific applicant with 210 patent families, clearly does a lot of research and development in conjunction with many other applicants and 54 of Samsung's patent families having named co-applicants. Samsung has a strong collaboration with Sungkyunkwan University (SKKU), a private university in Seoul, Korea. This is not surprising given that Samsung offer a lot of financial support to SKKU in terms of faculty and degree course sponsorship and funding of specific research programmes including the 'Samsung-SKKU Graphene Research Center'[17].

As mentioned previously, graphene is elastic and can stretch up to 20% of its length, making it ideal for flexible displays. This particular property has been exploited by Samsung and Sungkyunkwan University and in 2010 this led to the prototype development of the world's largest flexible display, a 25" (63cm) flexible touchscreen made with graphene[18]. Nanotechology experts envisage that flexible touchscreens may be the first use of graphene in commercial terms[19], although it remains to be seen how long it is before they reach the marketplace; some predict it could be later this year[20].

Most of the Chinese applicants shown in Figure 10 exhibit no collaboration, but the University of Tsinghua has collaborated with Foxconn and its subsidiary Hongfujin Precision. Foxconn is a Taiwanese multinational that is a massive provider of electronics contract manufacturing with huge factories in mainland China. Notably Foxconn has recently made components for the iPad[21], iPhone[22], iPod[22], Kindle[23], PlayStation 3[24] and Wii U[25] and could therefore be a massive user of graphene if graphene replaces silicon in semiconductors in the future[26].

17 http://en.wikipedia.org/wiki/Sungkyunkwan_University
18 http://www.technologyreview.com/computing/25633/page1/
19 http://www.techeye.net/hardware/graphenes-first-commercial-use-will-be-in-flexible-touchscreens
20 http://www.bbc.co.uk/news/technology-20526577
21 http://www.sfgate.com/news/article/Apple-Adding-More-iPad-Production-Lines-To-Meet-2455806.php
22 http://online.wsj.com/public/article/SB118677584137994489.html?mod=blog
23 http://www.computerworld.com/s/article/9179759/Kindle_screen_maker_will_increase_capacity_to_meet_demand
24 http://www.dailytech.com/Sony+Sources+Foxconn+to+Help+Manufacture+PS3/article8894.htm
25 http://uk.ign.com/articles/2012/10/18/iphone-wii-u-manufacturer-admits-to-employing-children/
26 http://www.sciencedaily.com/releases/2012/09/120928085350.htm

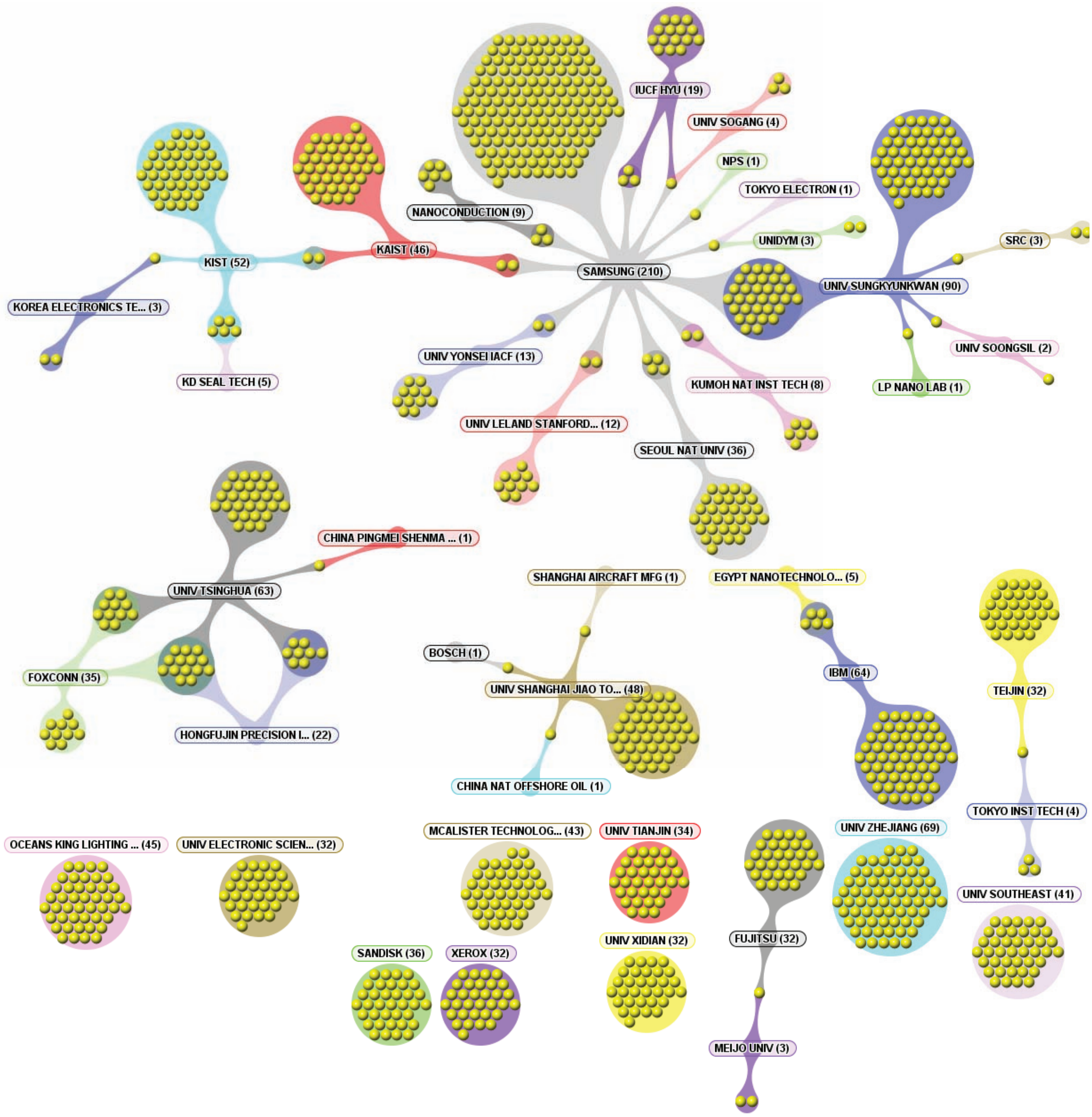


Figure 10: Patent family collaboration map showing the collaborations made by the top 20 applicants and their collaborators

3 The UK perspective

Figure 11 shows the same historical profile of patent publications shown in Figure 1 but highlights the negligible contribution of UK-based applicants and UK-resident inventors to the worldwide graphene patent landscape.

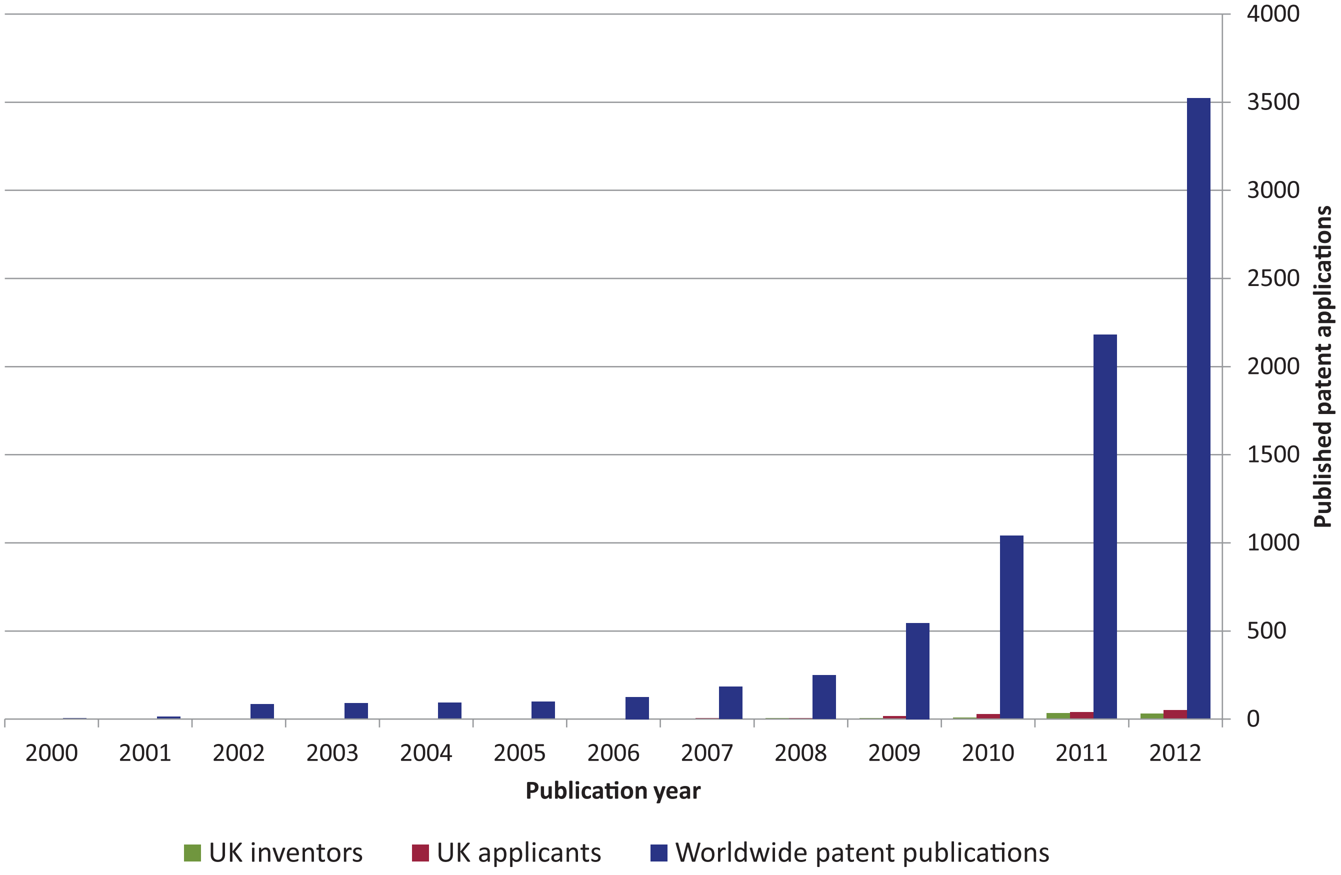


Figure 11: Comparison of worldwide patent publications and patent publications from UK applicants and UK inventors

Figure 12 shows that UK applicants hold the 6th largest number of patent families after Chinese, American, Korean, Japanese and German applicants. In terms of absolute levels of patenting in graphene-related technology, the 57 patent families (inventions) from UK applicants are orders of magnitude behind applicants from the top countries.

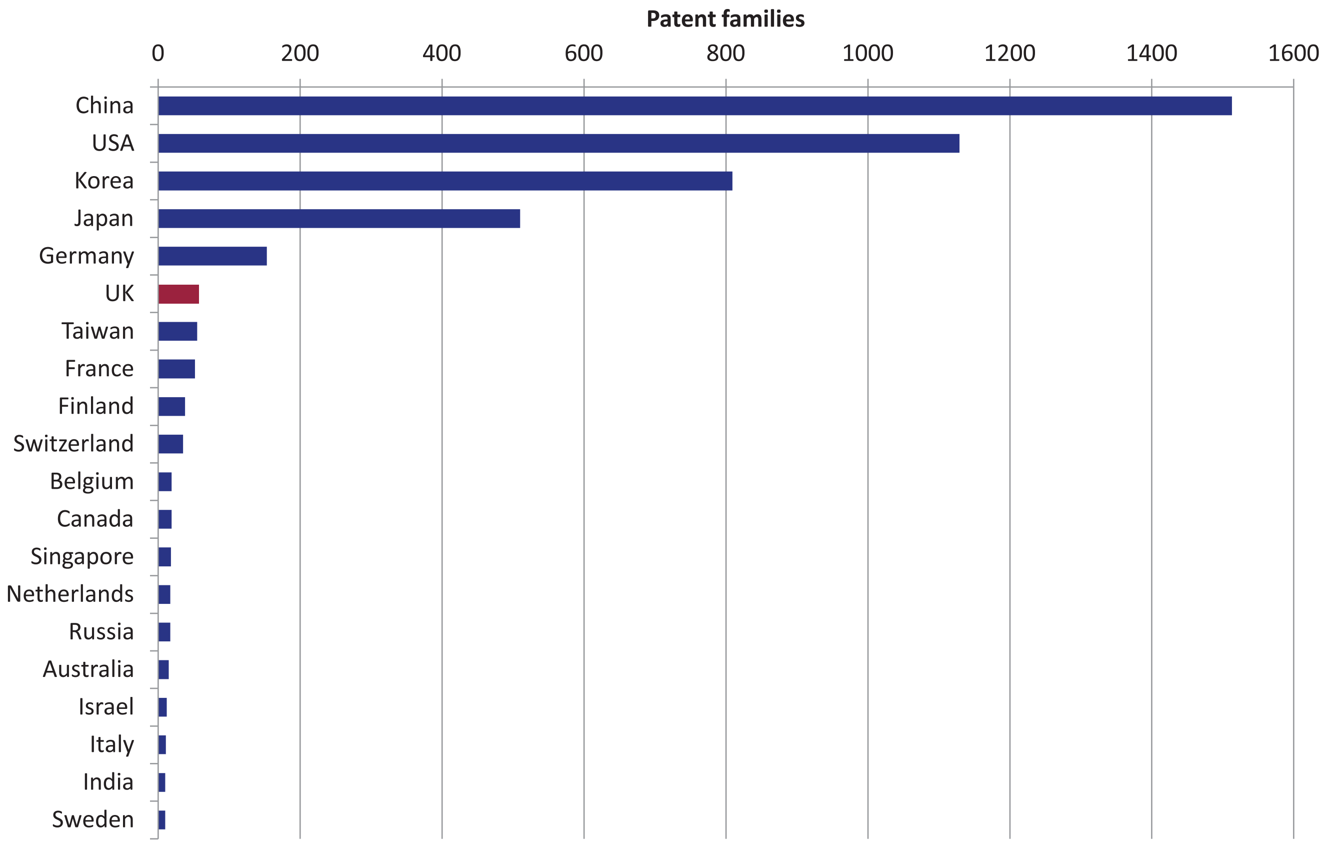


Figure 12: Applicant country distribution

However, it is well known that there is a greater propensity to patent in certain countries than others, and the trends shown in Figure 12 may change if the figures are corrected for this difference in behaviour. Therefore, the Relative Specialisation Index (RSI)[27] for each applicant country has been calculated to give an indication of the level of invention in graphene for each country compared to the overall level of invention in that country, and is shown in Figure 13.

The RSI shown in Figure 13 suggests a different picture to that shown in Figure 12, with the UK ranked 10th in the RSI chart compared to 6th in the applicant country chart. The USA shows a drop when the RSI is applied, highlighting the high absolute levels of patenting by American applicants and suggesting that the USA is not as specialised in the field of graphene as Singapore, China and Korea. The top RSI-ranked country, Singapore, shows much greater levels of graphene patenting than expected, despite their modest absolute levels of patenting (Singapore is ranked 13th in the top applicant countries), with most of Singapore's graphene-related patents coming from Nanyang Technological University and the National University of Singapore. Graphene patent families from UK applicants are below the level expected given the normal levels of patenting from UK applicants, with a negative RSI value of -0.46. The UK government has recently pledged £21.5m of funding to boost graphene research in the UK[28] and the results shown in Figure 13 suggest that this could not come at a better time to stop the UK falling even further behind the rest of the world when it comes to patenting of graphene research and development.

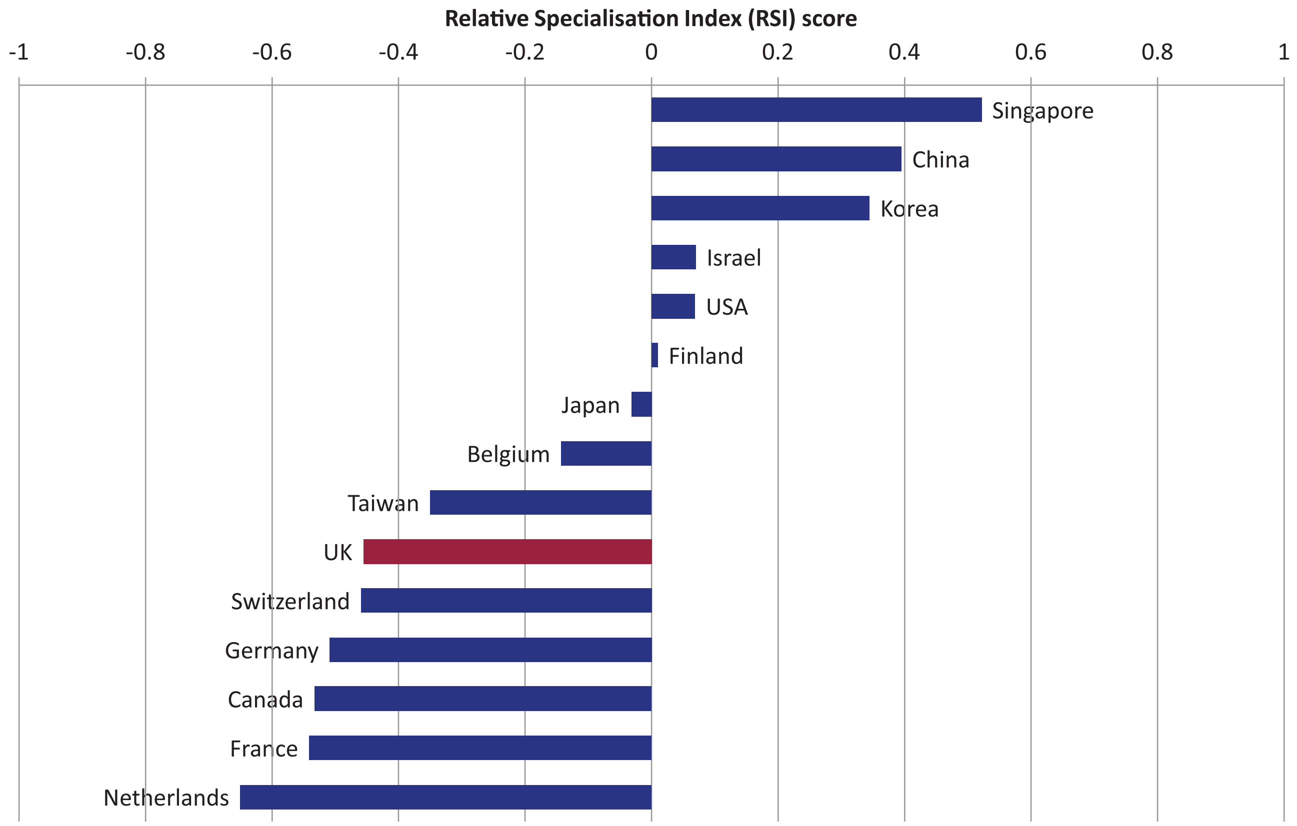


Figure 13: Relative Specialisation Index (RSI) by applicant country

27 Full details on how the Relative Specialisation Index (RSI) is calculated can be found in the Appendix
28 http://www.bbc.co.uk/news/science-environment-20846282

Figure 14 shows the top UK applicants with the University of Manchester owning the most (6) inventions relating to graphene. Hexcel Composites have the joint second highest (4) number of patent families (inventions) relating the graphene, but their patent families are larger than those from the University of Manchester, and Hexcel Composites have the most (26) published patent applications from UK applicants. Despite the fact that professors from the University of Manchester are credited with the discovery of isolating graphene[29], the University of Manchester did not appear as a listed patent applicant in the 2011 report[30] and their six patent families are all recent having been published in 2011 and 2012. These inventions relate to different nanocomposite materials comprising graphene and include fluorographene and graphene-based heterostructures for use in graphene-based transistors. In comparison, Hexcel Composite's patent families relate to the use of graphene in adhesive materials, and polymeric resins in particular. The sector split from UK applicants is similar to the worldwide sector split shown in Figure 8 with 51% of graphene patents coming from academia and 44% from the corporate sector.

Given the low absolute levels of graphene patenting in the UK, it is therefore not surprising that there is little collaboration involving the UK applicants, as shown in Figure 15. The top three UK applicants shown in Figure 14 have not collaborated with any other parties on any of their graphene patents, but Imperial Innovations (Imperial College) has collaborated domestically with UCL Business (University College London) and internationally with the National Taiwan University, both on one invention (patent family). The University of Southampton has also collaborated internationally on one patent family with Harvard College (USA), and the other domestic collaboration is between Smarter Energy Systems and the Questor Group, and QinetiQ and Advantage West Midlands, a former Regional Development Agency (RDA).

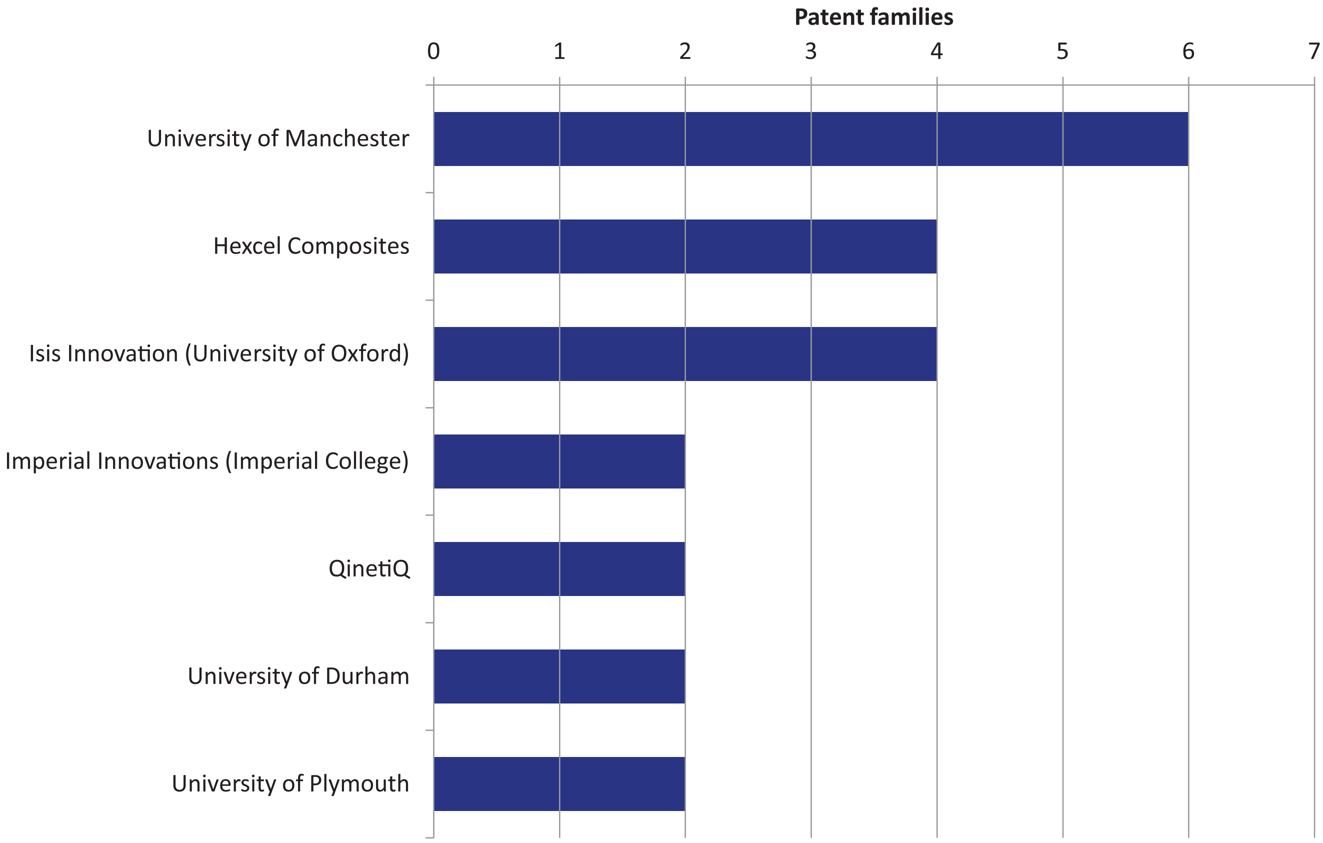


Figure 14: Patent families of top UK applicants

29 http://www.bbc.co.uk/learningzone/clips/the-discovery-and-uses-of-graphene/13761.html
30 http://www.ipo.gov.uk/informatic-graphene-uk.pdf

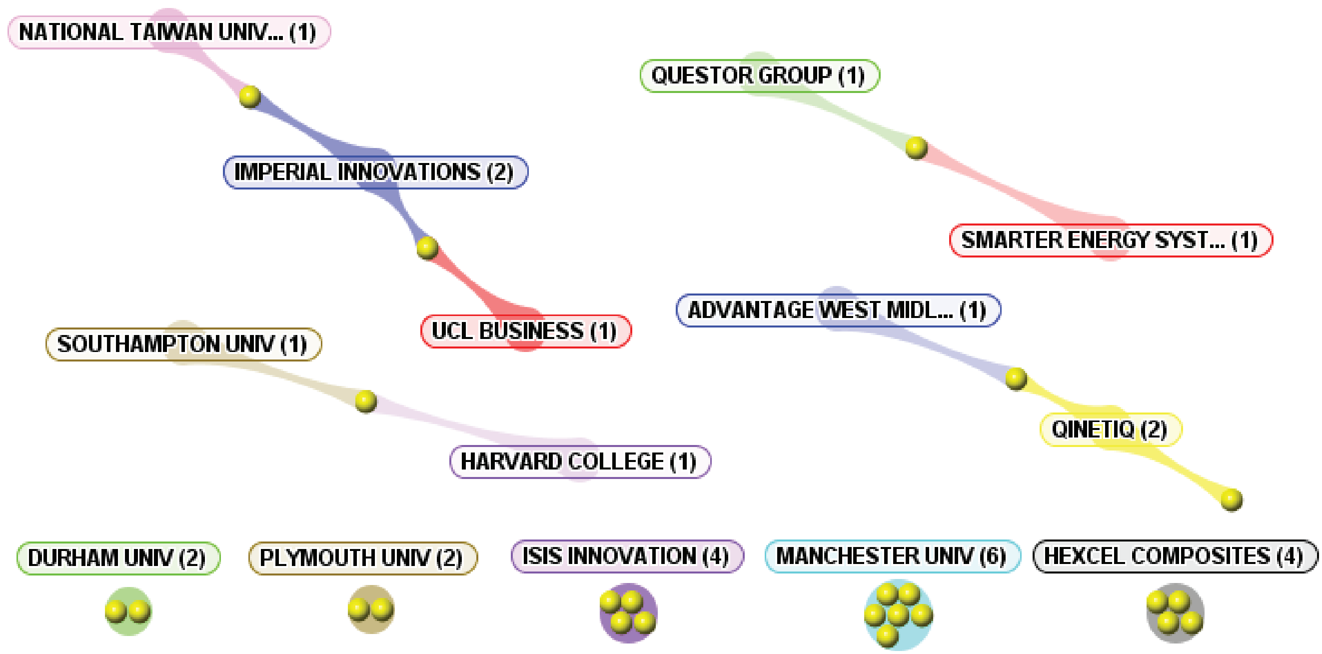


Figure 15: Patent family collaboration map showing the collaborations made by the top UK applicants and their collaborators

Figure 16 shows the patent portfolio size for applicants with the top named UK-resident inventors. Six of the top 10 largest portfolios come from non-UK applicants suggesting that a large proportion of British researchers in graphene are doing their research abroad or for a non-UK based applicant.

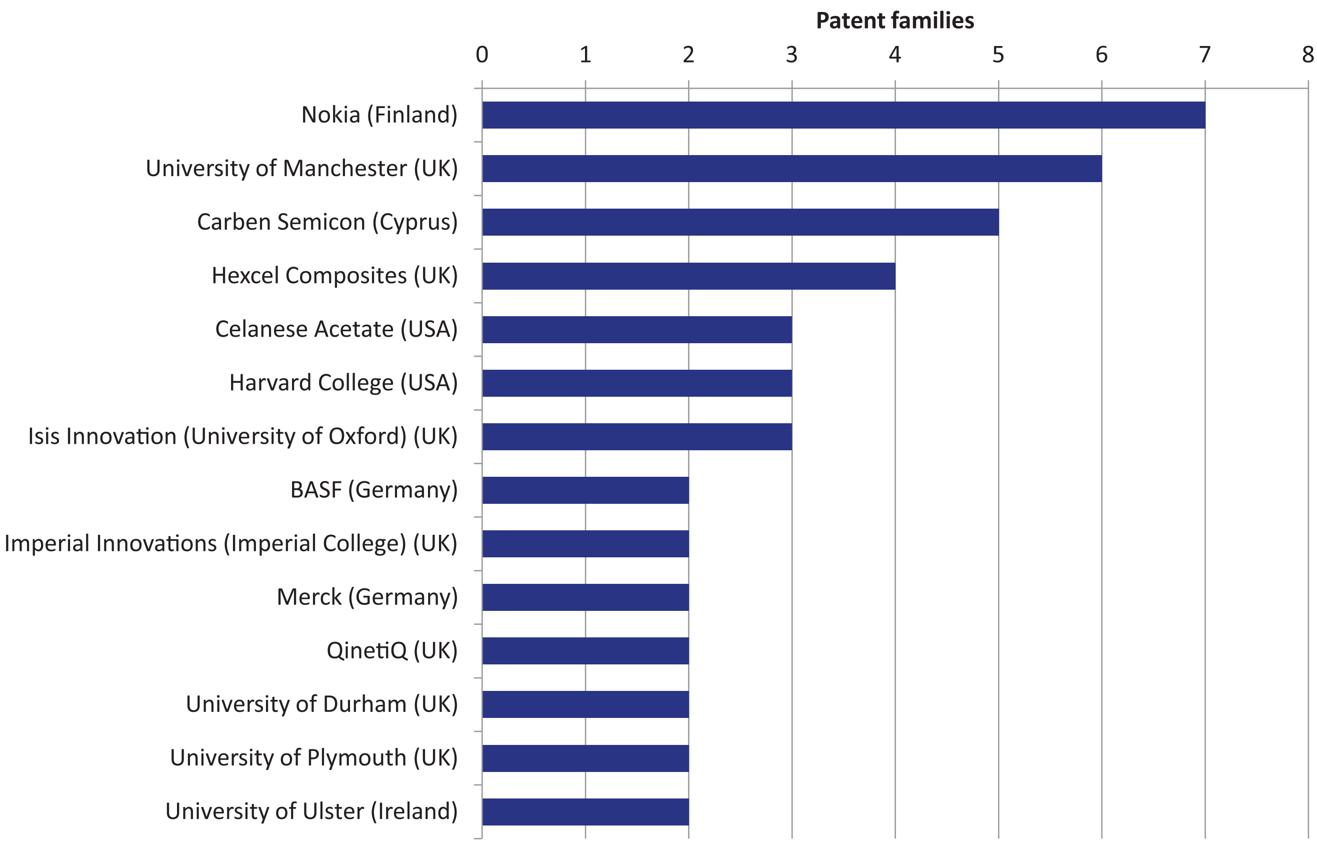


Figure 16: Patent families of applicants with the top named UK-resident inventors

In contrast to the comparatively negligible patent publication numbers for UK-based applicants shown in Figure 11, the number of academic research publications[31] made by UK institutions is large. Figure 17 shows that the UK institutions have published the 6th most academic papers (1150). Whilst this is still a considerable margin behind the countries whose academic institutions are most published (China (6660), USA (6651) and Japan (1926)), it compares much more favourably than the UK's position in terms of patent publications as illustrated in Figure 11, or patent families (inventions) as shown in Figure 12. It is also interesting to note that when the number of academic publications from all European Union countries are combined, the EU comes out on top with more academic publications related to graphene than China or the USA; when considering the EU as a whole, this could be considered a more accurate measure for comparison against China and the USA in terms of size and population.

Science-based innovations generally originate in academia and graphene is no exception; the first academic paper related to graphene[32] was published in 1947 when its band structure was theorised and calculated by PR Wallace. The much more recent explosion in graphene-related research has lead to the publication of 24,576 academic papers since 2002; this dwarfs the 8416 patent publications relating to 4740 patent families (inventions) published over a similar time frame.

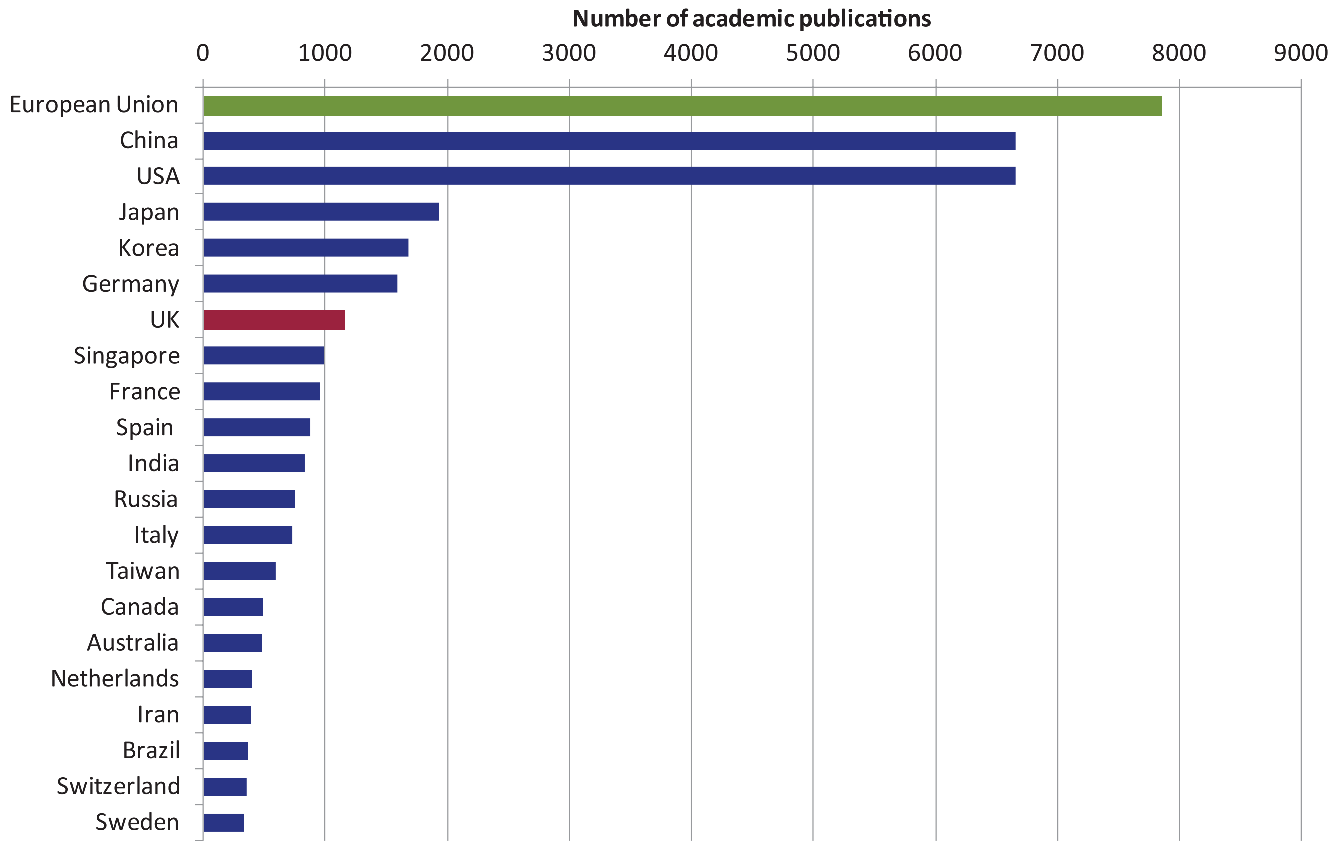


Figure 17: Academic publications related to graphene by country (including the EU)

31 Obtained from Web of Science and Conference Proceedings document collections in Thomson Innovation (provided by Thomson Reuters)

32 http://news.bbc.co.uk/1/hi/programmes/click_online/9491789.stm

Figure 18 shows the number of academic publications divided by Gross Domestic Product (GDP) including Purchasing Power Parity (PPP) calculations[33] which take into account the relative costs and the inflation rates of countries. Some of the top 10 countries could be thought of as punching above their economic weight in terms of academic research into graphene. However, although Figure 18 shows that Singapore and Korea (1st and 2nd respectively) are proportionately very active in academic research, this is also backed up by Figure 13 which shows they are also relatively specialised in graphene patenting and the development towards graphene commercialisation. When normalised by GDP, the UK's relative performance in terms of academic publications is broadly similar to that of many countries, including China, Germany and the USA.

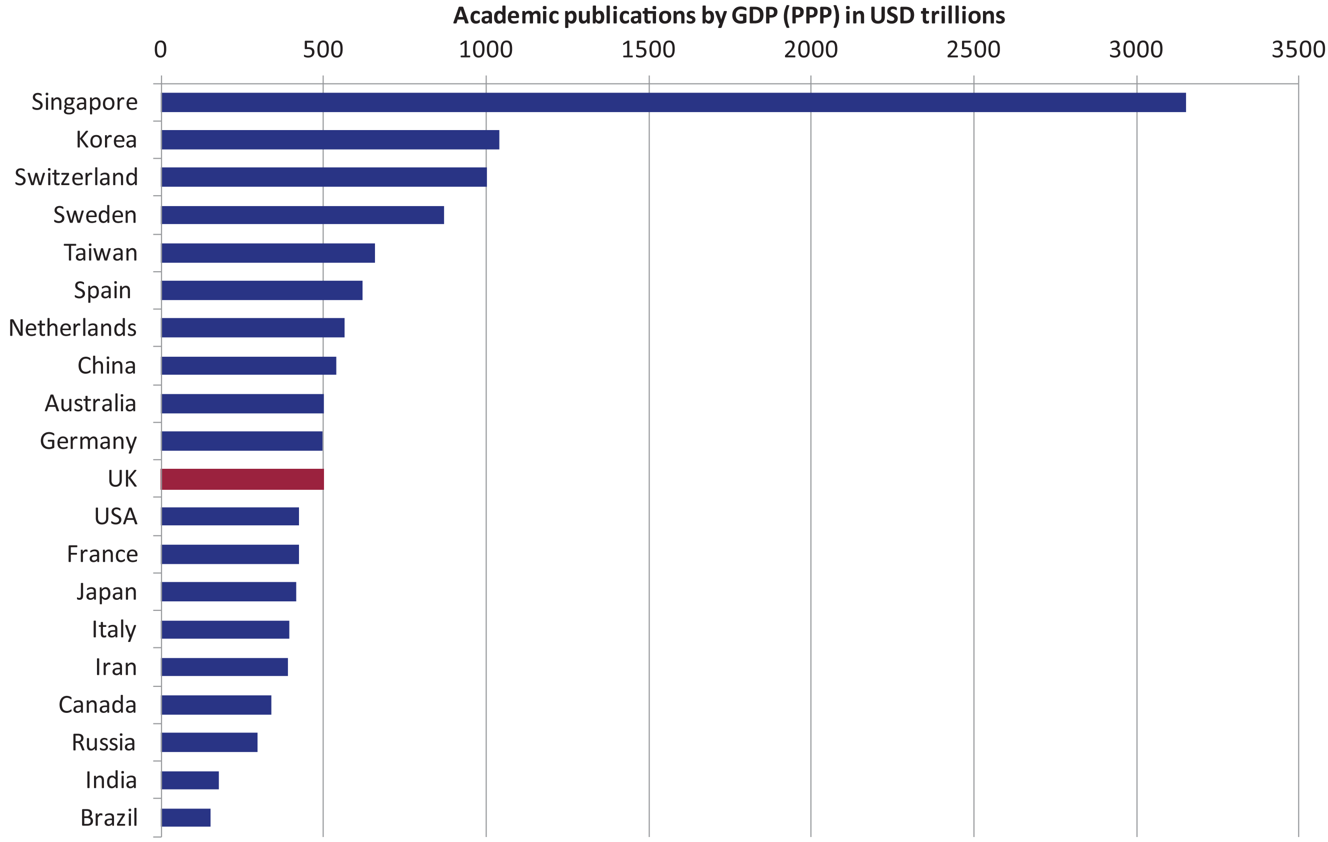


Figure 18: Academic publications/GDP (PPP) by country

33 As listed by the International Monetary Fund in October 2012 - http://en.wikipedia.org/wiki/List_of_countries_by_GDP_(PPP)

It is clear from the publication trends of UK institutions shown in Figure 19 that after a sluggish start into research related to graphene there has been a rapid increase in recent years. This trend seems likely to continue given the expected potential of graphene and the financial support being received from both the European Commission[34] and the UK government[35]. Graphene is already commercially available in some forms[36,37] and at increasingly reasonable prices[38]; it has been used in tennis racquets[39] and is reported[40] to have found another successful application in improving anodes for lithium-ion batteries which are due for commercial release by 2014 targeting the electric vehicle, consumer electronics and grid storage battery markets[41].

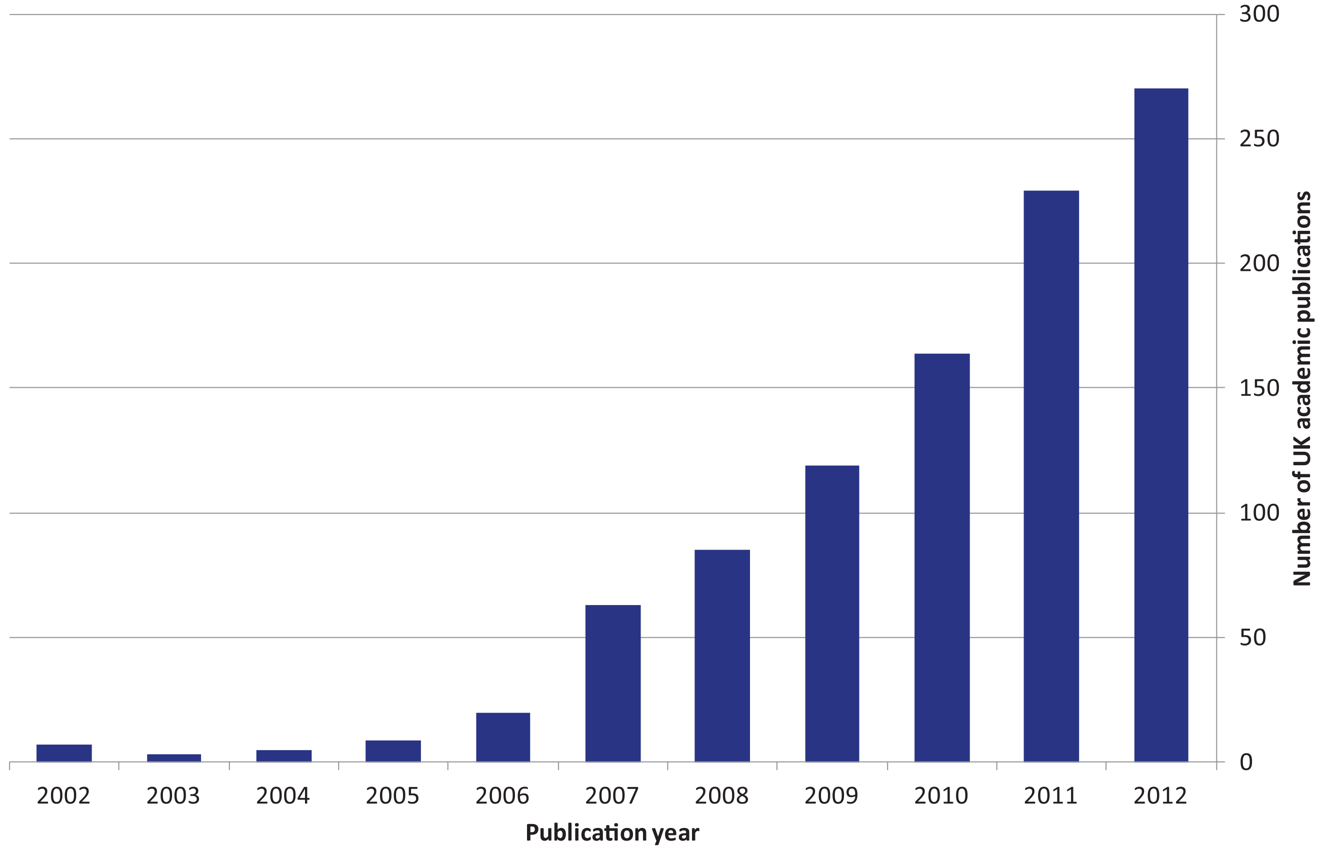


Figure 19: Graphene-related academic publications from UK institutions

34 http://www.manchester.ac.uk/aboutus/news/display/?id=9552
35 http://www.bbc.co.uk/news/science-environment-20846282
36 http://www.grapheneplatform.com/
37 http://www.acsmaterial.com/
38 http://blog.grabcad.com/2013/02/new-battery-technology-is-going-the-distance/
39 http://www.head.com/g/nz/graphene/
40 http://spectrum.ieee.org/nanoclast/semiconductors/nanotechnology/graphenesilicon-anodes-for-liion-batteries-go-commercial
41 http://www.clbattery.com/

4 The recent shift in graphene patenting activity

There has been a shift in the graphene patent landscape in the last couple of years and this is most noticeable when the data is time-sliced by patent families with an earliest priority date before 2010 and those since 1 January 2010.

Figure 20 shows how the split of patent families by publication country has changed in the last couple of years. The proportion of graphene patents published in Korea and via the PCT route has stayed roughly the same but there is a significant shift in the patents published in China with almost half of all graphene patents now being published in China; when Figure 12 above is compared to the minor influence of Chinese applicants in the July 2011 report[42] it is clear that this recent surge of Chinese graphene patents is coming from domestic (Chinese) applicants. Hence, the drop in the proportion of patents published in the USA, Japan, the EPO, and the rest of world shown in Figure 20 is not necessarily reflective of a large drop in their absolute levels of patenting but they are simply overshadowed by the effect of recent Chinese patent boom.

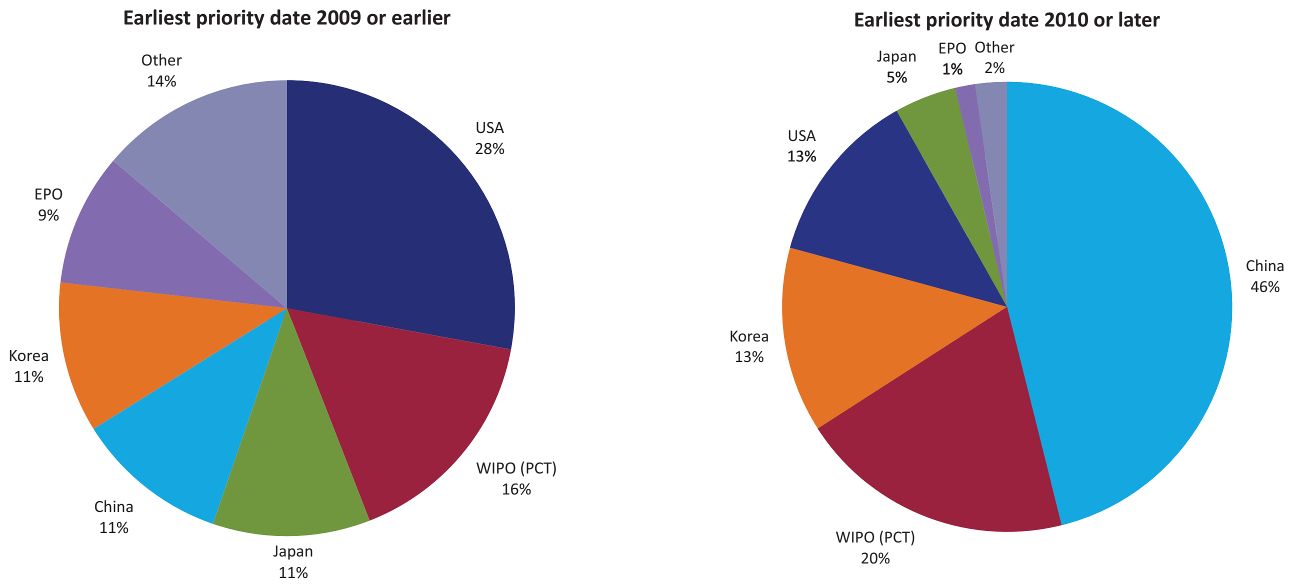
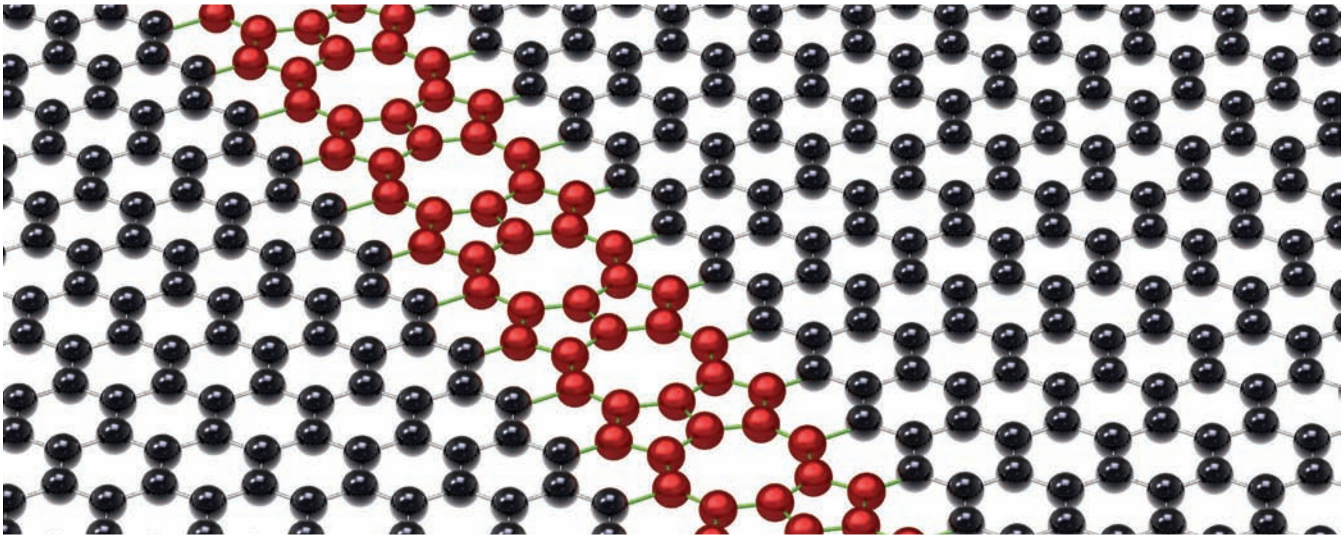


Figure 20: Comparison of patent family publication country distribution pre- and post-2010



42 http://www.ipo.gov.uk/informatic-graphene-uk.pdf

Figure 21 shows how the sector split has changed in the last couple of years. There were 567 graphene inventions from academia before 2010 but over double (1180) have been published since 2010; this translates to a shift in the proportion of academic inventions from 34% before 2010 to over 55% since 2010. When considered alongside Figure 20, this suggests that there has been a significant increase in the number of Chinese patent applications from Chinese academia in the last couple of years; this is investigated further in section 5.

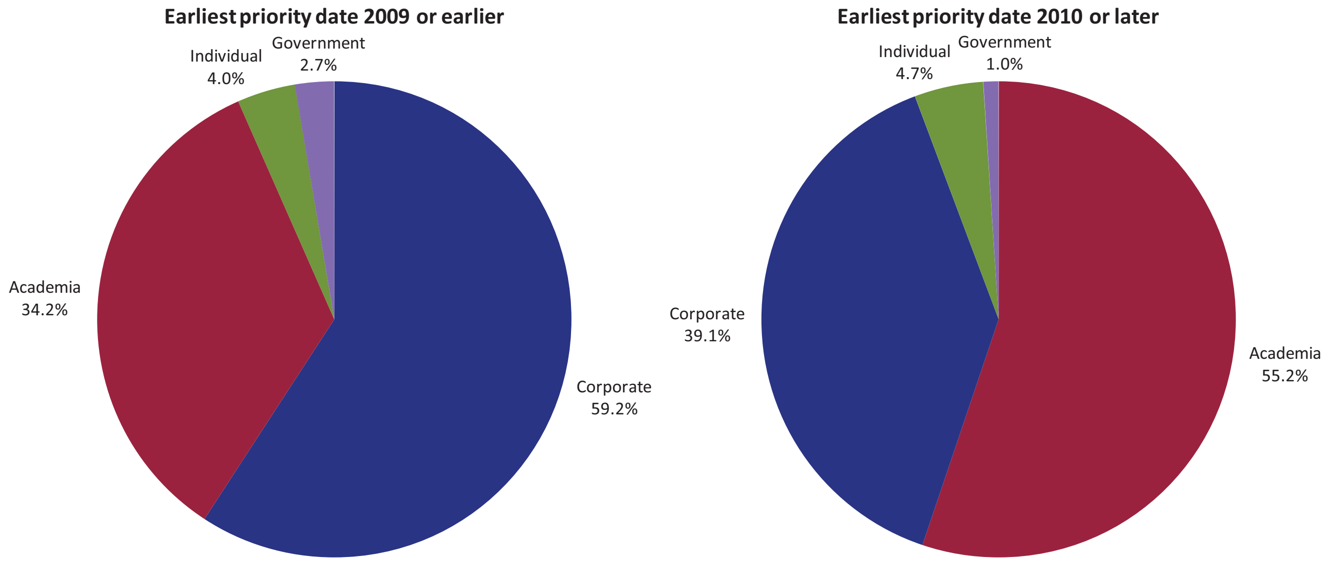


Figure 21: Comparison of patent family sector distribution pre- and post-2010

Table 1 shows the top 20 applicants from Figure 3 and compares how the patenting from these applicants has changed in recent years. The rise of the 8 Chinese applicants in the top 20 worldwide applicants is clear, with three of these having only entered the technology space since 2010. There is also an interesting decrease in graphene patenting in recent years from some major American and Japanese applicants.

As discussed earlier, Samsung has a very wide-ranging patent portfolio and their most recent graphene patents do not suggest that their focus has narrowed in any way; Samsung had over 100 patent families (inventions) published in 2012 and these range from graphene fabrication methods to using graphene as an electrode material in batteries. However, it is interesting to note that almost a quarter of Samsung's graphene patent published in 2012 relate to graphene-based LEDs (light emitting diodes). One advantage of adding graphene to LEDs is that it enables them to operate brighter with a dose of graphene oxide dissipating the extra heat that LEDs generate as they get brighter[43]. Another advantage is that a graphene quantum-dot light emitting material, as disclosed in a number of Samsung patents, is more eco-friendly than current materials with no health effects caused by the cadmium contained in the compound semiconductors[44]. Graphene's elastic properties could also help create stretchable LED arrays for use as backlights in flexible displays.

Zhejiang's University's recent patents are mostly focused on graphene preparation methods, including polymer-grafted graphene to be used in new graphene-based nanocomposites. Zhejiang's University's method patents are in stark contrast to IBM's most recent patents which are mostly application-based and include graphene-based solar cells, graphene-based optical sensors and graphene-based transistors and semiconductors.

Table 1: Comparison of the top 20 applicants pre- and post-2010

Applicant		Patent Families			
		Earliest priority date 2009 or earlier	Earliest priority date 2010 or later	Total	
1	Samsung (Korea)	73	137	↑	210
2	Sungkyunkwan University (Korea)	31	59	↑	90
3	Zhejiang University (China)	6	63	↑	69
4	IBM (USA)	22	42	↑	64
5	Tsinghua University (China)	6	57	↑	63
6	Korea Institute of Science and Technology (Korea)	18	34	↑	52
7	Shanghai Jaio Tong University (China)	3	45	↑	48
8	Korea Advanced Institute of Science and Technology (Korea)	12	34	↑	46
9	Ocean's King Lighting (China)	0	45	↑	45
10	McAlister Technologies (USA)	36	7	↓	43
11	Southeast University (China)	0	41	↑	41
12	SanDisk (USA)	33	3	↓	36
13	Seoul National University (Korea)	12	24	↑	36
14	Foxconn (Taiwan)	4	31	↑	35
15	Tianjin University (China)	9	25	↑	34
16	Fujitsu (Japan)	22	10	↓	32
17	Teijin (Japan)	25	7	↓	32
18	University of Electronic Science and Technology (China)	0	32	↑	32
19	Xidian University (China)	1	31	↑	32
20	Xerox (USA)	12	20	↑	32

43 http://www.smartplanet.com/blog/bulletin/the-key-to-led-brightness-graphene/12272
44 http://energy.korea.com/archives/28926

Figure 22 shows the graphene patent landscape map with each patent highlighted according to its priority date. There is a noticeable difference in the size and position of the clusters of green patents with a priority date between 2005 and 2009 compared to the red clusters of patents since 2010, possibly suggesting a change of focus in recent years.

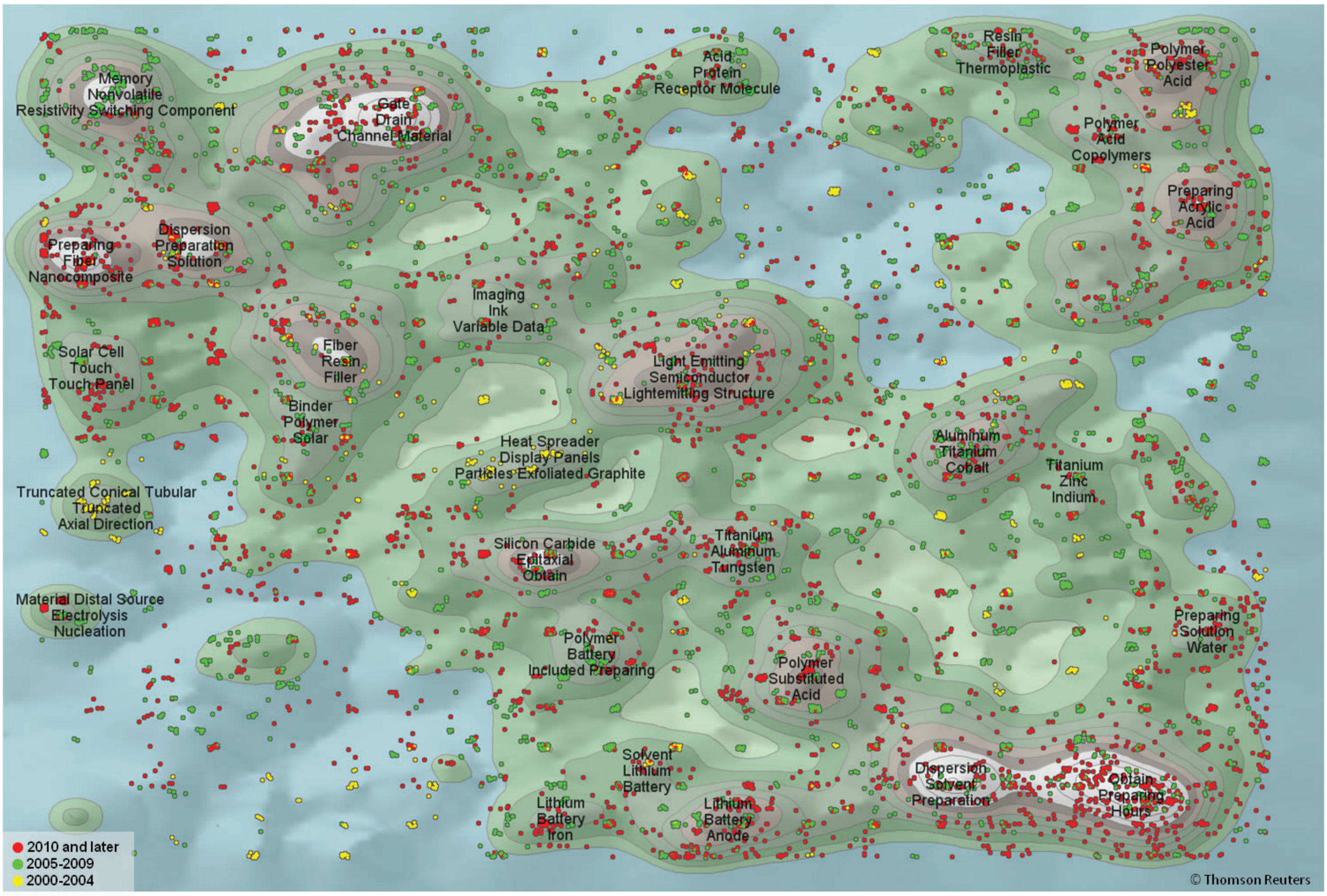


Figure 22: Graphene patent landscape map highlighting priority year

Figure 23 highlights the patents which have claimed priority since 2010 according to their sector type, with a high concentration of academic research being undertaken in the area of graphene preparation in the bottom right of the map.

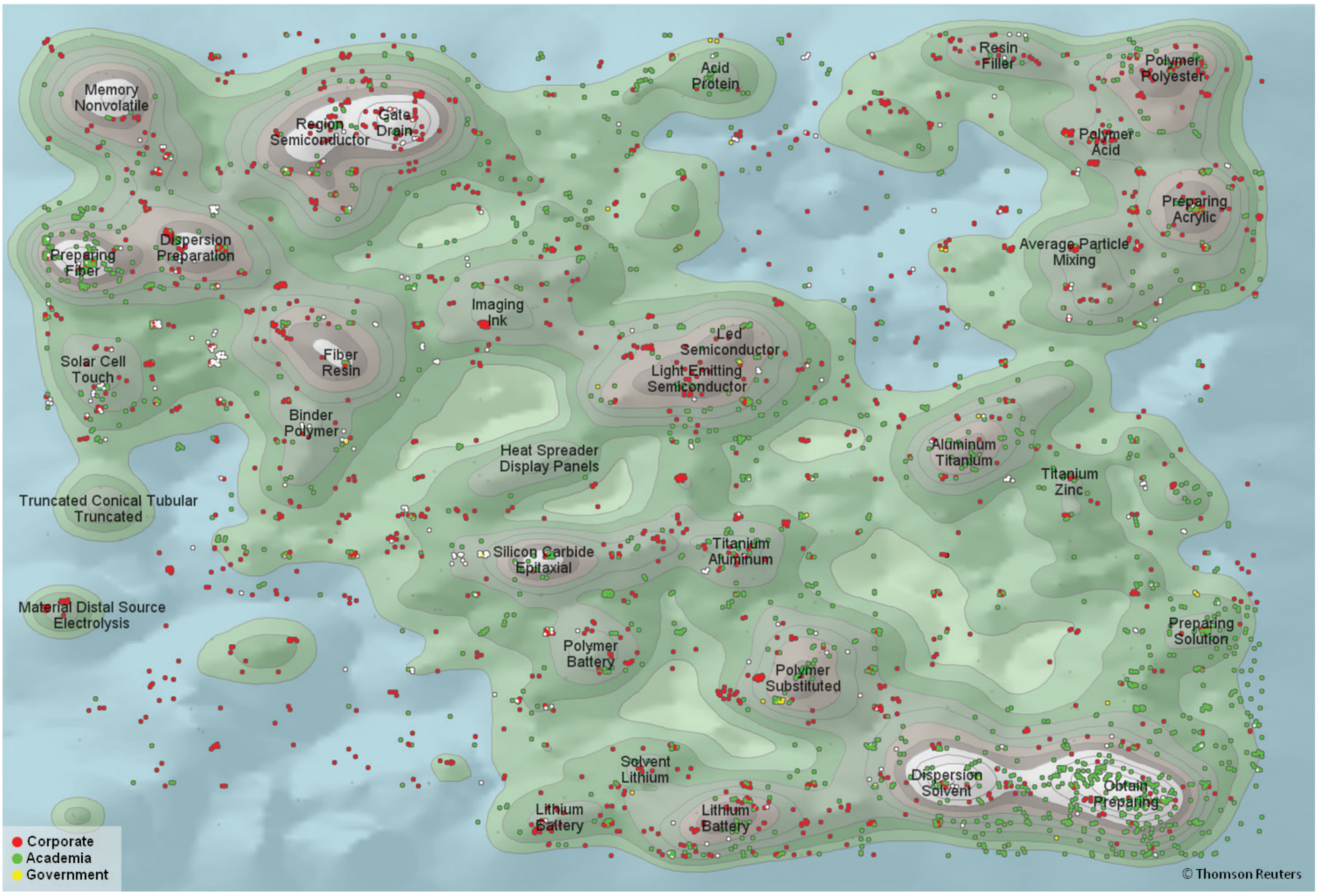


Figure 23: Graphene patent landscape map highlighting sector split since 2010

5 The Chinese impact in recent years

Several of the previous charts have highlighted the surge in Chinese patenting in graphene in the last few years. A subset of graphene patents from Chinese applicants was extracted for further analysis.

Figure 24 shows that in 2008 Chinese applicants made up 4% of the worldwide patent families and this increased to 49% in 2011. At present data for 2012 is incomplete due to the 18 month lag between the priority/filing date and the publication date, but the preliminary data for 2012 indicates that the Chinese domination within the graphene filing profile has continued to increase further and is now well over 50%.

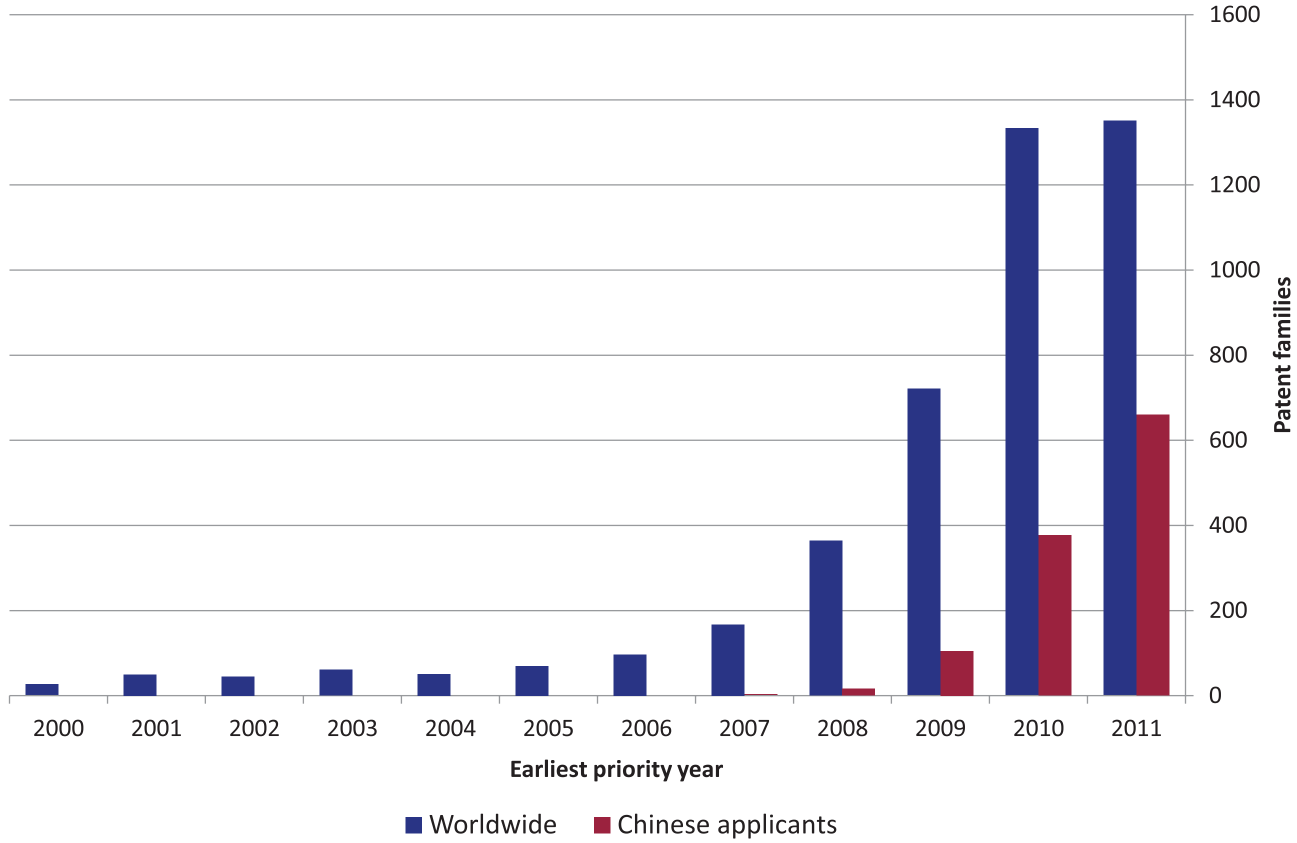


Figure 24: Worldwide patent families by earliest priority year highlighting families from Chinese applicants

Figure 25 confirms the suggestions made about the results shown in Figure 20 to Figure 23 and shows that over three-quarters of graphene patents from Chinese applicants come from academia. Considering that none of the Chinese universities have very large patent portfolios (as shown in Figure 3), when this is compared with the sheer volume of graphene patents coming from Chinese applicants since 2010 (Figure 24) it implies that there are a large number of separate Chinese universities undertaking research in graphene with moderate numbers in their patent portfolios.

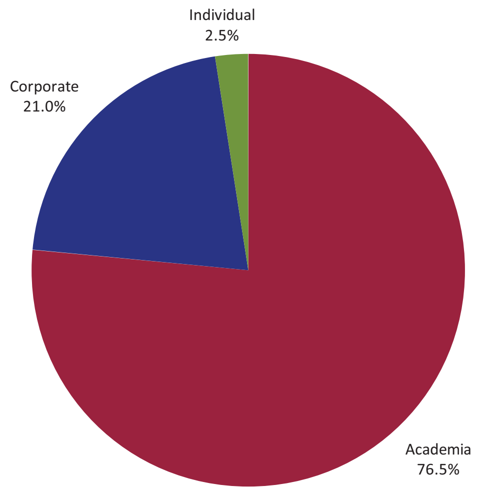
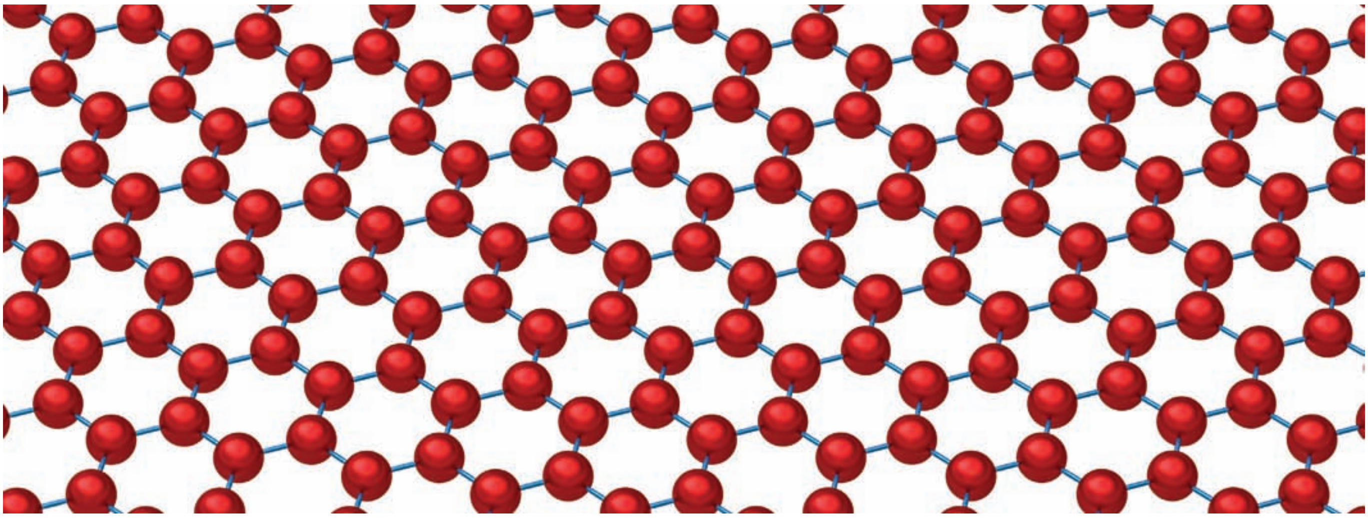


Figure 25: Patent families from Chinese applicants by sector



The graphene patent landscape map in Figure 26 highlights the Chinese and Korean patents since 2010. The comparison between the green dots in Figure 26 with the green academia dots in Figure 23 shows the sheer volume of patents from Chinese academia that are all narrowly focused on the preparation of graphene. This is perhaps because Chinese universities are searching for the 'major' breakthrough that will allow industrial quantities of graphene to be produced for global commercialisation.

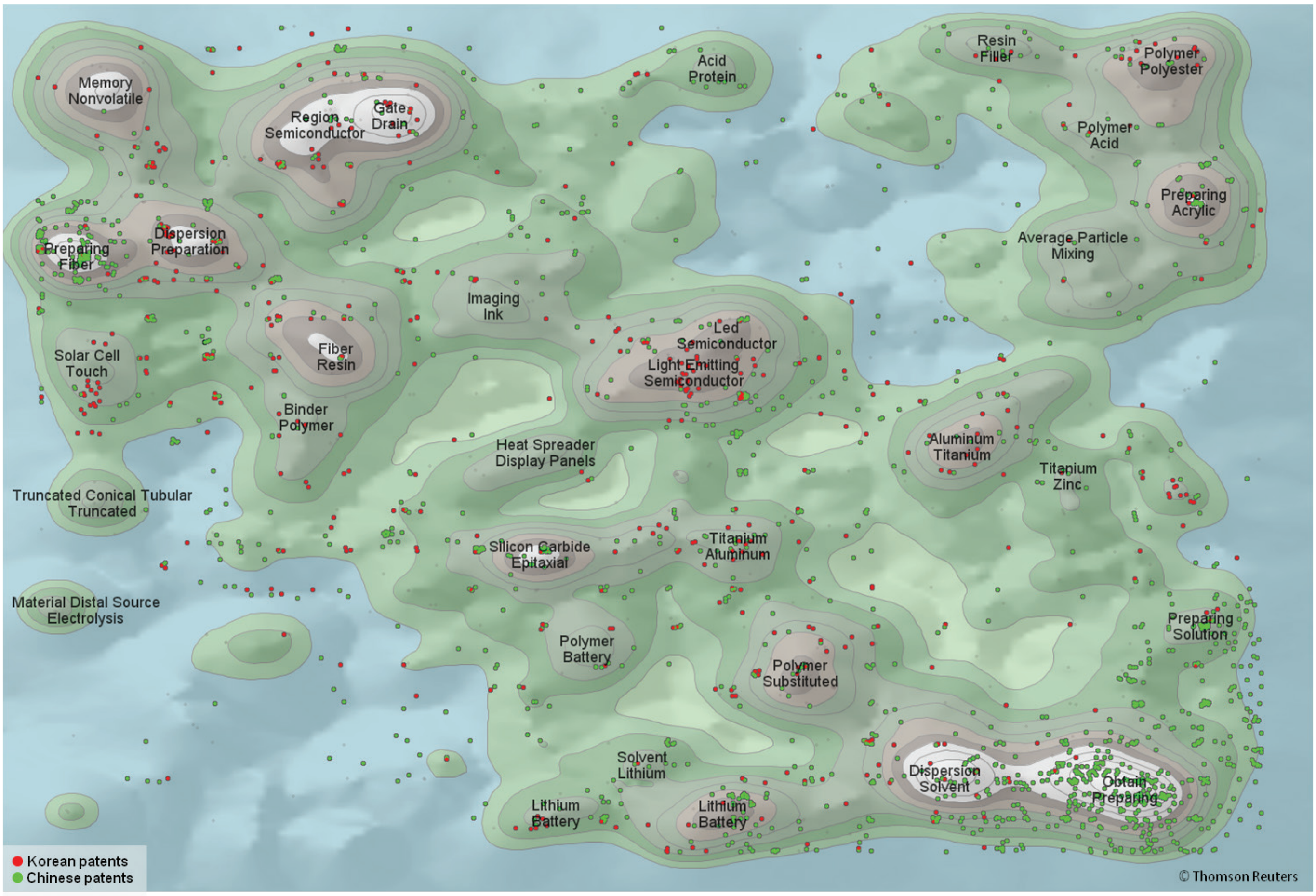


Figure 26: Graphene patent landscape map highlighting Chinese and Korean patents since 2010

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 have only one family member compared to 70% worldwide, and in over 98% of these patents the single family member is a Chinese patent application. In contrast, only 0.6% of graphene patents from Chinese applicants have more than five family members compared to 4.2% worldwide. This means that a lot of graphene patents from Chinese applicants are only going to have protection (once granted) in China and nowhere else worldwide.

In addition, Lei et al[45] have shown that there is a seasonal component to Chinese patent filings, with strong upward peaks in Chinese patents filed in December compared to the rest of the year suggesting a politically driven rather than innovation or commercially driven agenda in China; this seasonal component from Chinese patents is accurately reflected in the graphene patent data where the patent families filed in December are more than double the monthly average for the other 11 months of the year. Lei et al[45] 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. In general terms, the quality and 'value' of Chinese graphene patents compared those from the rest of the world is also unknown, but the interesting hypothesis put forward by Lei et al[45] should be borne in mind when considering the 'real' position of any worldwide patent landscape for any technology area.

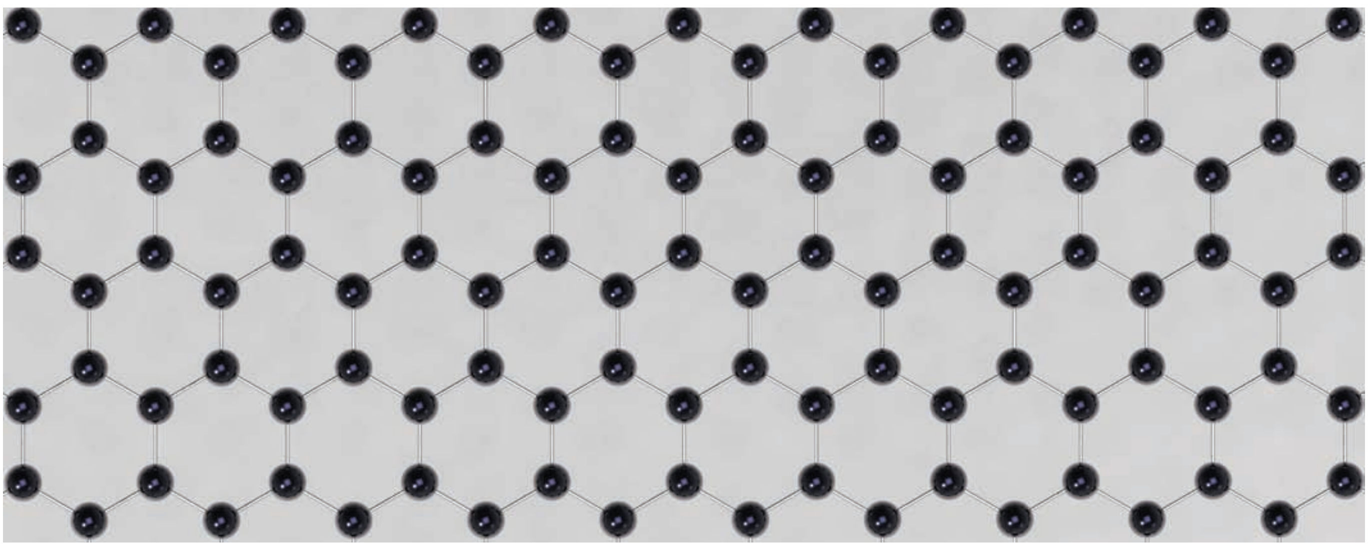
45 http://www.oecd.org/site/stipatents/4-3-Lei-Sun-Wright.pdf

6 Conclusion

Patenting in graphene has exploded in recent years; the number of published graphene patent applications worldwide between 2010 and 2012 has more than tripled and there has been an order of magnitude difference in the yearly publication figures over the last five years. Samsung holds the largest patent portfolio relating to graphene and given their substantial collaborative research with Sungkyunkwan University, who hold the second largest patent portfolio, these two applicants appear to be the market leaders. However, despite the apparent dominance of these two Korean organisations, the leading country in the field is China who has almost twice as many inventions relating to graphene than Korea.

The Chinese influence over the last couple of years has been extraordinary and they have taken graphene patenting extremely seriously with almost half of all graphene patents worldwide now coming out of China. However, one aspect that does not appear to have changed over the last 18 months is the lack of impact that the UK, both in terms of UK-based applicants or UK-resident inventors, is having on the world stage. Nonetheless, the Relative Specialisation Index (RSI) suggests that despite relatively low levels of patenting, the UK is still outperforming its major European competitors (France and Germany) when it comes to graphene patenting.

Graphene research is advancing at an alarming rate; several research papers are published every day and the amount of literature on graphene has developed a truly relentless pace[46]. Macroscopic analysis of the non-patent literature cannot currently be undertaken to the same level of detail as the patent landscape analysis which is made possible with access to good quality and complete worldwide patent databases. 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 beginning to understand commercial intent. The explosion of graphene patenting in the last few years shows just how many countries and major multinational corporations are investing heavily to try to successfully commercialise graphene and fulfil its theoretical potential, and in return reap the potentially vast financial rewards that a strong patent portfolio in this area could bring.



46 http://arxiv.org/ftp/arxiv/papers/0906/0906.3799.pdf

Appendix A – Interpretation notes

A.1 Patent databases used

For this project the Thomson Reuters World Patent Index (WPI) and the European Patent Office (EPO) EPODOC databases were interrogated, 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).

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

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

Filing 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 filing date, whichever is earlier. Depending on the jurisdiction, a patent is then given a 'B' or 'C' publication code when the patent 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)

The analysis presented in this report is primarily based on priority year to give the earliest indication of innovative activity.

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.

A.4 Patent documents analysed

The document dataset was identified through International Patent Classification (IPC) codes, European Classification (ECLA) codes (i.e. C01B31/04H+, H01L29/16G, M01B204/LOW, T01L29/16G) and word searching of abstracts in conjunction with patent examiner technology-specific expertise.

Any date attributed to a patent document is the priority date of that patent unless otherwise stated.

The applicant and inventor data is 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 package called *VantagePoint*[47] 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 patent landscape maps used in this report are produced using *Thomson Innovation*[48], a web-based patent analytics tool produced by *Thomson Reuters.*

47 http://www.thevantagepoint.com/
48 http://info.thomsoninnovation.com/

Appendix B – Relative Specialisation Index (RSI)

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, American and Japanese applicants 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 (in this study, Singapore in particular) 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 (up to 60,000 patents can be used for each patent map) 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’.

Appendix D – Graphene search strategy and classification

D.1 Epoquenet search strategy

..hi

File : EPODOC

SS Results

1	1191	/EC OR C01B31/04H+, H01L29/16G (*ECLA classification areas*)
2	3917	GRAPHENE+ (*keyword search*)
3	357	/ICO M01B204/LOW (*ICO code*)
4	45	T01L29/16G/ICO (*ICO code*)
5	4363	1:4
6	3902	*M4/PR/ALL
7	4622	*M4/PR/ALL
8	5108	*M4/PR/ALL
9	0	*M4/PR/ALL
10	0	*M4/PR/ALL
11	0	*M4/PR/ALL
12	1	*M4/PR/ALL
13	**8417**	5:12

D.2 ECLA classification

C01B31/04H	Carbon; graphite; graphene
H01L29/16G	Semiconductors comprising graphene
M01B204	*ICO code:* Structure or properties of graphene
T01L29/16G	*ICO code:* Semiconductors comprising graphene

Concept House
Cardiff Road
Newport
NP10 8QQ

Tel: 0300 300 2000
Minicom: 0300 0200 015
Fax: 01633 817 777
www.ipo.gov.uk

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