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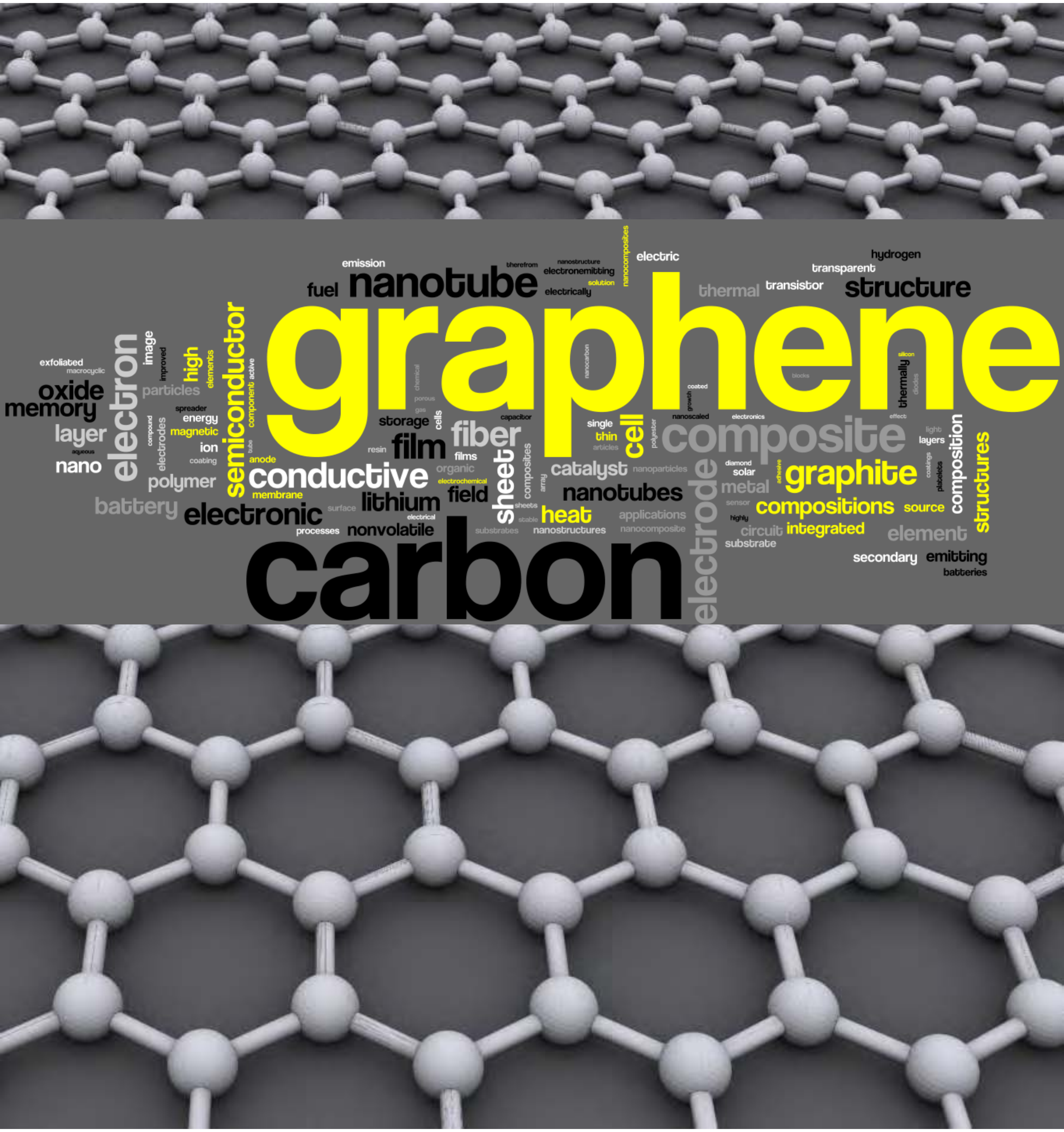

# An Analysis of Worldwide Patent Filings Relating to Graphene

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The patenting of graphene-related technology took off rapidly in the 2000s. The largest patent portfolio is held by Samsung, and the top two applicants have only been active in the field since 2007. Half of the applicants hold patents relating to fewer than five inventions, illustrating the youth of this emerging technology. Developments are still relatively research-based, with a large portion of academic participation, although consumer applications such as flexible touchscreen displays are getting closer to reality. A range of different research strategies are evident from patent collaborations; Samsung exhibits a reasonable amount of collaboration whilst other top applicants show none. In contrast to the specialism evident from most applicants, Samsung is active in a very diverse range of graphene-related technology. Inventions are classified in a wide range of International Patent Classifications (IPCs), though the majority of these relate to its chemistry and processing; the others define a varying range of potential applications for graphene. Though this is a rapidly emerging technology, the trends in the current patent data indicate that it will not prove to be disruptive in itself.

## Introduction

Graphene is considered a nanomaterial as it consists of sheets of carbon atoms a single layer thick in a hexagonal arrangement [1]. The number of graphene-related patent applications received at the IPO has increased over the last few years since applications in electronics, opto-electronics, and photonics devices have been discovered and are in development. The media refer to graphene as the "miracle material of the 21st Century" [2] and its public profile was recently boosted when the Nobel Prize in Physics 2010 was awarded to Andre Geim and Konstantin Novoselov of Manchester University "for groundbreaking experiments regarding the two-dimensional material graphene" [3].

The media buzz around graphene is not surprising given some of its properties – it is the thinnest known material in the universe and the strongest ever measured [4]; for a crystalline structure it is elastic and can stretch up to 20% of its length; it is a very efficient electrical conductor and can sustain current densities six orders of magnitude higher than that of copper at room temperature; 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 [5].

## General Patenting Trends

Searching in the EPODOC and WPI patent databases in July 2011 yielded 3018 published patent documents which are related to graphene. The earliest mention of graphene appears in a patent published 12 December 1994, having a priority dating back to 1991 and assigned to UCAR Carbon Technology Corporation [6]. 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 is 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 [7].

The historical profile of patent publications (Figure 1) shows that there has been a rapid take-off of patenting related to graphene since 2000.

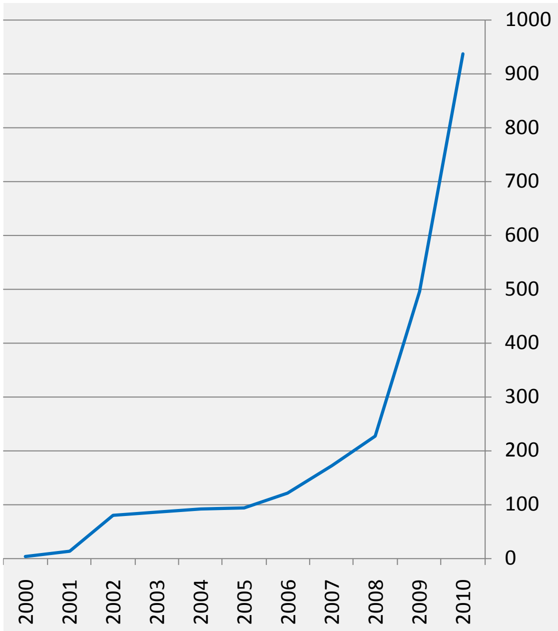


**Figure 1: Historical filing profile by publication year**

## Applicant Trends

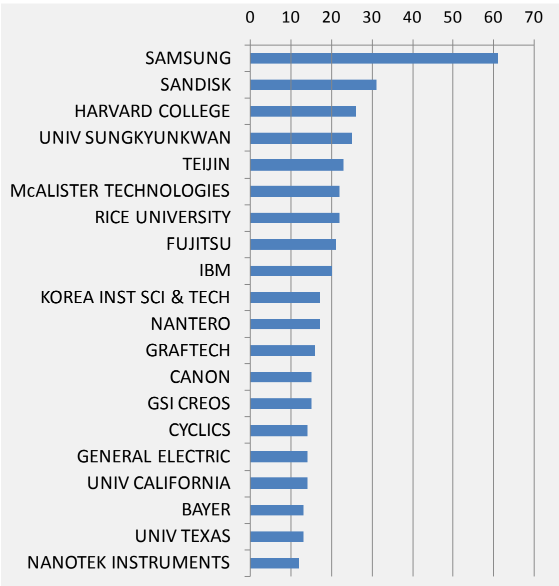


**Figure 2: Number of patent families of the top 20 applicants**

The chart of overall largest patent portfolios (Figure 2), shows the leader as Samsung (61 patent families) by a clear margin over Sandisk (31 patent families). Unusually these top two applicants are new entrants to this technology as far as patent data is concerned having been active only since 2007. As might be expected from the rapid take-off of patenting in this area, there are a considerable number of new entrants in the applicants holding the most patent families (Figure 3).

Other relatively new entrants include the University of Sungkyunkwan, McAlister Technology, Korea Institute of Science and Technology, Bayer, and the University of Texas. In contrast, many of the other applicants with the largest portfolios have a longer history, although Graftech, Canon, GSI, and Cyclics have shown no activity since 2007.

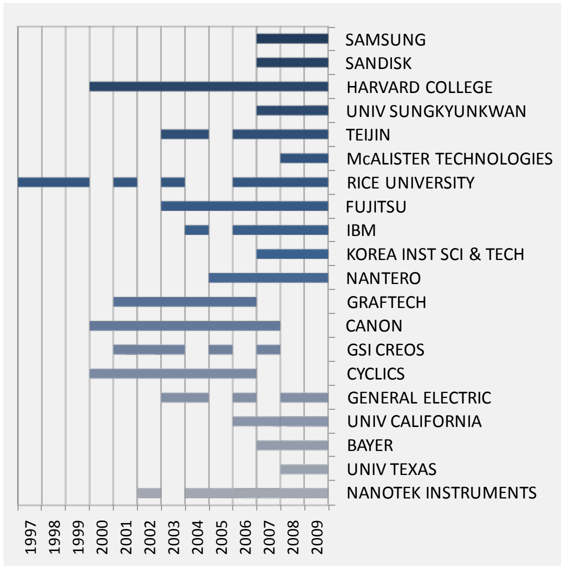


**Figure 3: Applicant timeline by priority date**

The spread of patent publication portfolio size (Figure 4) indicates that there are relatively few patents (8%) belonging to applicants with only one patent, in contrast with the expected pattern for emerging technologies in which a large proportion of new names appear, and the turnover of applicants is high. Comparison with the spread of invention portfolio size (Figure 5) indicates that the low proportion of applicants with small patent publication portfolios could at least partially be an artefact of filing strategies since half of the applicants have five or fewer inventions, with almost a fifth of the inventions held by applicants holding only one patent family, *i.e.* a monopoly for only one invention.

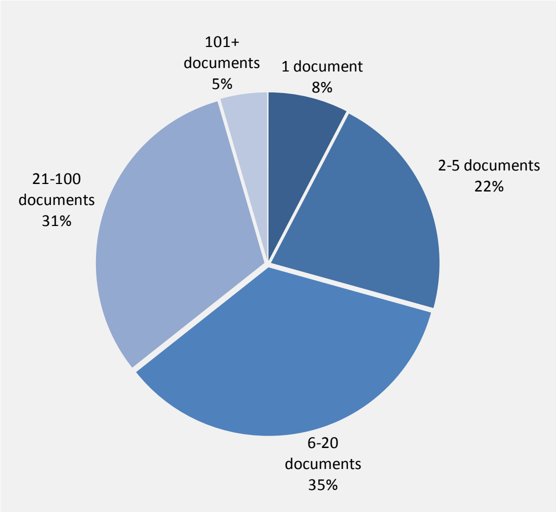


**Figure 4: Patent publication portfolio sizes**

Having said that, a large proportion of the applicants with fewer patents in graphene technology have robust patenting strategies; strategies which pursue protection in multiple markets.

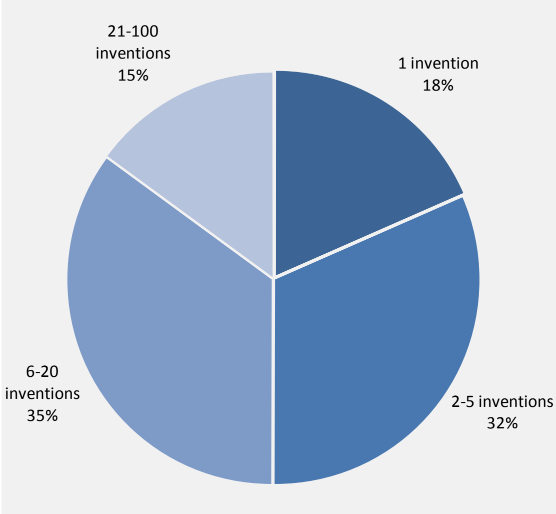


**Figure 5: Patent family portfolio sizes**

Figure 6 is a global map showing patent priority country density for graphene-related patents. The strength of the colouring represents the proportion of patent publications. Priority country information is a good indicator of where the innovation is taking place; for graphene it is clear that the USA leads the way, followed by the Far East (Japan, Korea and China).

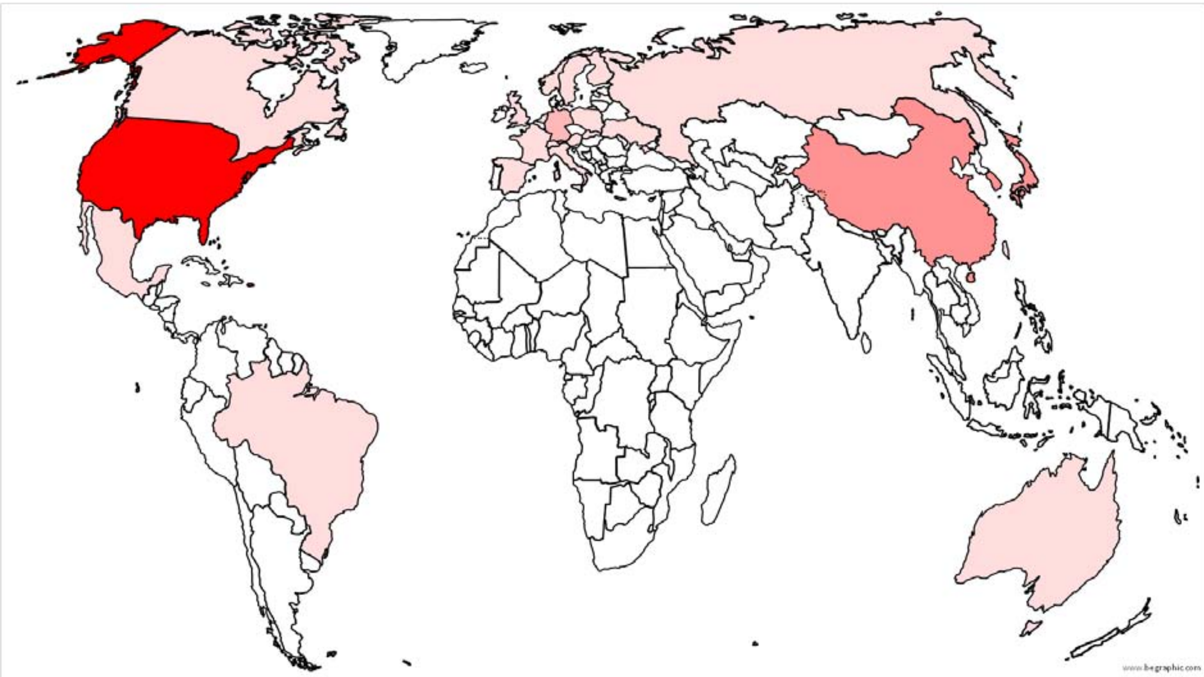

**Figure 6: Patent priority country distribution density - www.begraphic.com**

Another explanation of the prevalence of families rather than one-off national filings can be gleaned from Figure 7, which illustrates a low proportion of individuals (5%) in the applicant type. It is clear that research in a complex technology area such as this is likely to be dominated by big players who have the necessary resources and technical expertise. A consequence of this is that the majority of applicants will be established entities which are patent-savvy in that they are likely to seek international protection for anything they see as worth patenting.

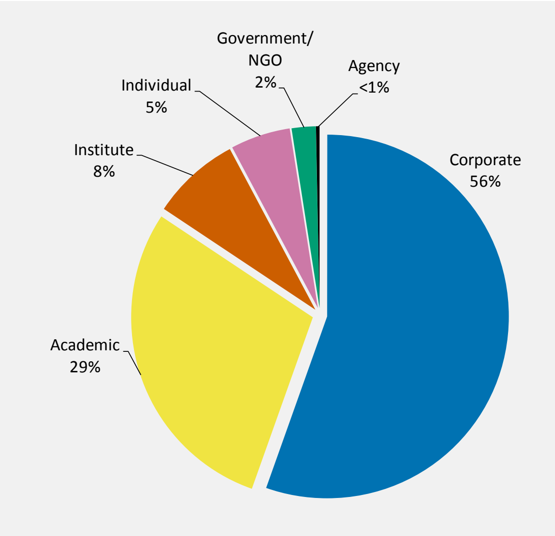


Figure 7: Sector breakdown

The research-based nature of this technology is reflected by the level of academic, institute, and government applicant types present, pushing the corporate balance down to 56%, which is far below the expected level in a patent dataset for a specific technological area (normally >80%). This pattern suggests that the scientific research is still ongoing to a significant degree, although the work of commercialising the research into products in the marketplace has great potential and is getting ever closer to reality.

This is further supported by the evolution of corporate and academic involvement (Figure 8) which indicates that the recent increase in patenting is paralleled by an increasing proportion of participation from academia, suggesting that more research is required before graphene can be fully exploited in real-world applications.

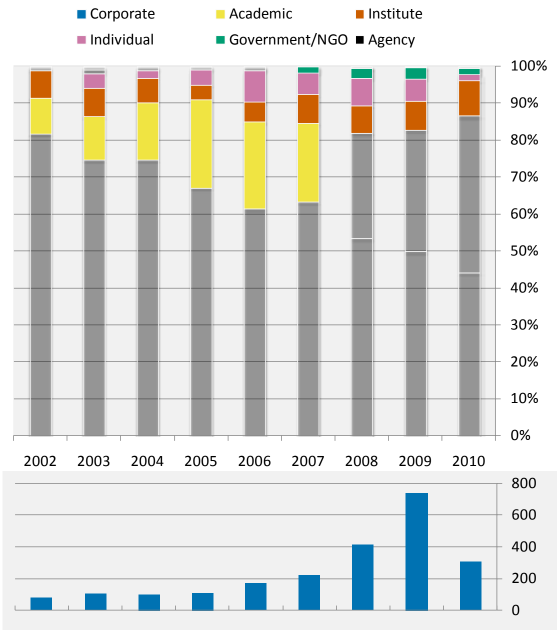


Figure 8: Timeline by sector (top) and publications by priority year (bottom)

## Applicant Collaboration

Figure 9 illustrates the collaborations made by the top five applicants and their collaborators. The top patent filer in the field of graphene, Samsung, exhibits a reasonable amount of collaboration, as would usually be the case for a large multinational corporation. This includes joint-research with academia, including collaboration on seven patent applications with Sungkyunkwan University (SKKU) Foundation for Corporate Collaboration, who are also one of the top five applicants. SKKU is a private university in Seoul, Korea, and collaboration with Samsung is not surprising given that Samsung offer a lot of financial support to SKKU in terms of faculty and degree course sponsorship and funding different research programmes [8], including the 'Samsung-SKKU Graphene Research Center'.

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 SKKU and in 2010 this led to the prototype development of a 25" (63cm) flexible touchscreen made with graphene [9]; this is the world's largest flexible display.

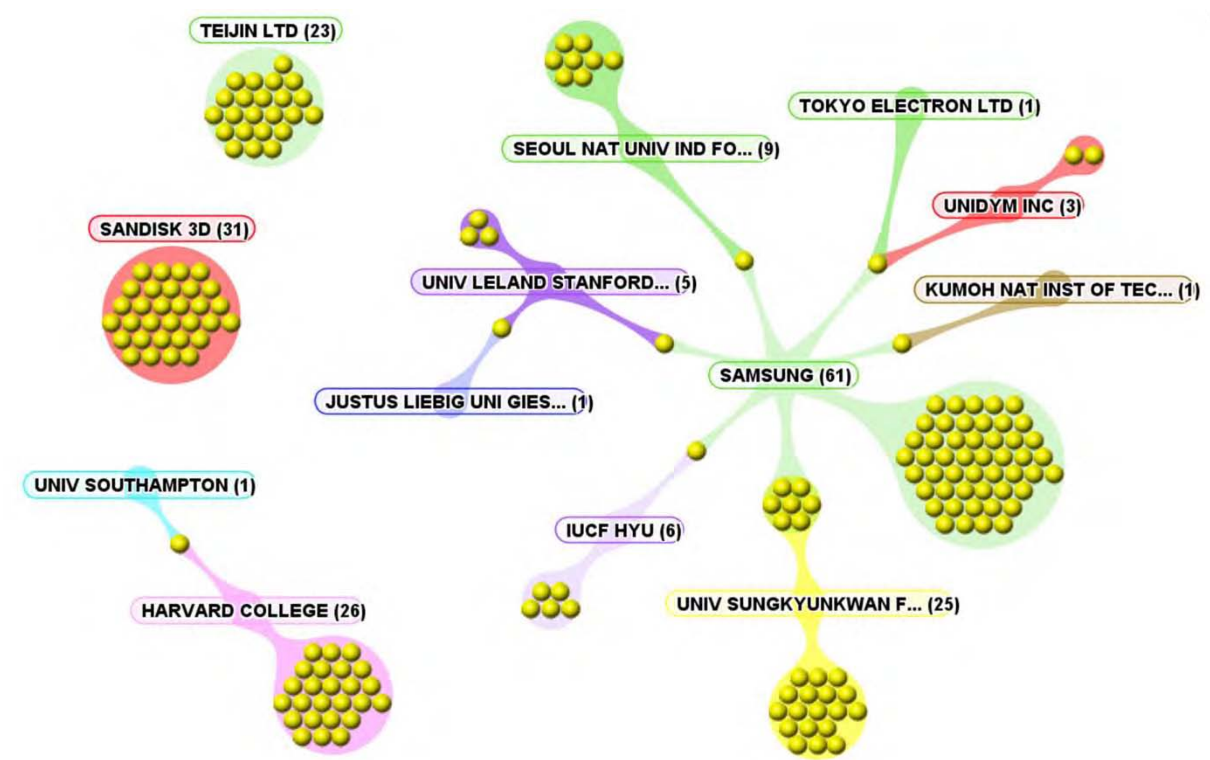


**Figure 9: Collaboration map showing the collaborations made by the top five applicants and their collaborators**

Nanotechology experts envisage that flexible touchscreens will be the first use of graphene in commercial terms, although it remains to be seen how long it is before they reach the marketplace. Some predict it could be as soon as 2013 [10].

Figure 9 also shows no collaboration from Sandisk and Teijin, potentially highlighting their research or patenting strategy.

## Technology Trends

Graphene has been explicitly catered for in the European Patent Office's Classification scheme (ECLA) since early in 2011. A table of the relevant ECLA classifications can be found in the Appendix. Currently there is no place unique to graphene-related technologies within the International Patent Classification (IPC). Figure 10 illustrates the IPC sub-groups which occur most frequently on patents relating to graphene.

The most common classification given to graphene patents under the International Patent Classification (IPC) at the main sub-class level is C01B *(Carbon; compounds thereof)*. This is followed by main sub-classes B82B *(Nano-structures formed by manipulation of individual atoms, molecules, or limited collections etc)* and C08K (*Use of inorganic or non-macromolecular organic substances as compounding ingredients)*.

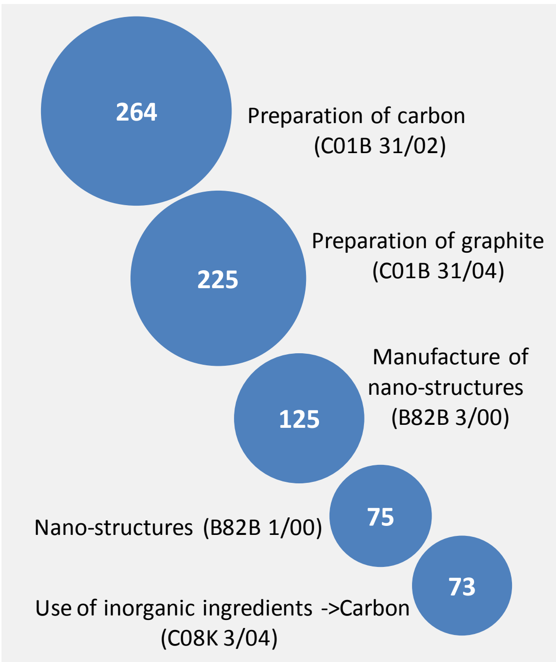


**Figure 10: Top IPC sub-groups by number of publications**

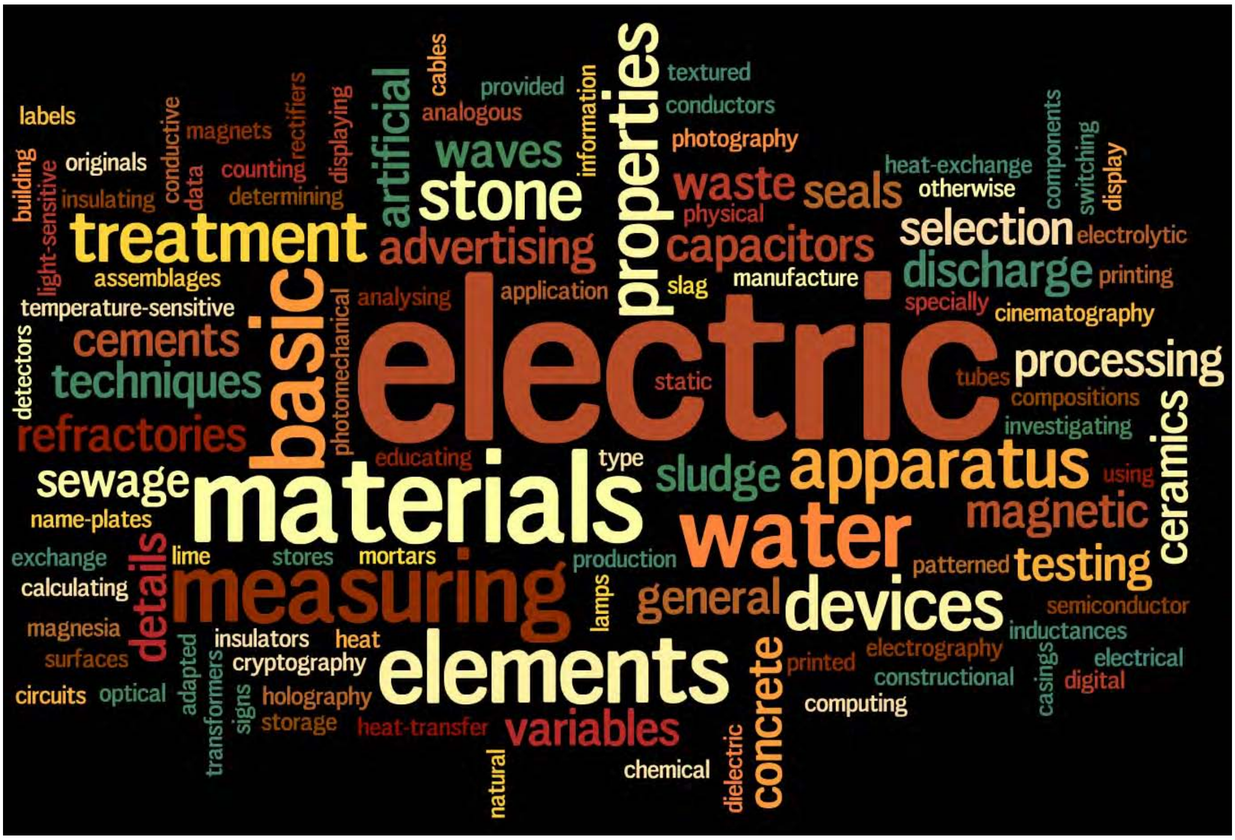


**Figure 11: A proportional illustration of the words occurring in the top application-based IPCs**

The classification of patents can give an indication of the applications of the underlying technology: the applications that graphene is used for should be evident from the IPCs occurring in the dataset of graphene-related patents.

Among the most frequently occurring IPC sub-groups, most are ways of producing or manipulating materials, *i.e.* graphene. However a diverse range of classifications for the applications of graphene also appear, including basic electric elements (H01) such as discharge lamps, capacitors, rectifiers, diodes, and light or temperature sensitive devices of the electrolytic type, as well as heat exchange (F28F), treatment of water/waste (C02F), and electrical digital data processing (G06F).

Figure 11 proportionately illustrates words occurring in the top application-based IPCs.

## The Technology Landscape

Figure 12 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 (although not all dots are shown) 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 IPC. The patent portfolio coverage of several of the top graphene applicants within the graphene patent landscape is shown in Figure 12. The top applicant, Samsung, has been left off the map because their patents are spread across the entire map, highlighting that they appear to be researching and developing technologies in most areas of graphene.

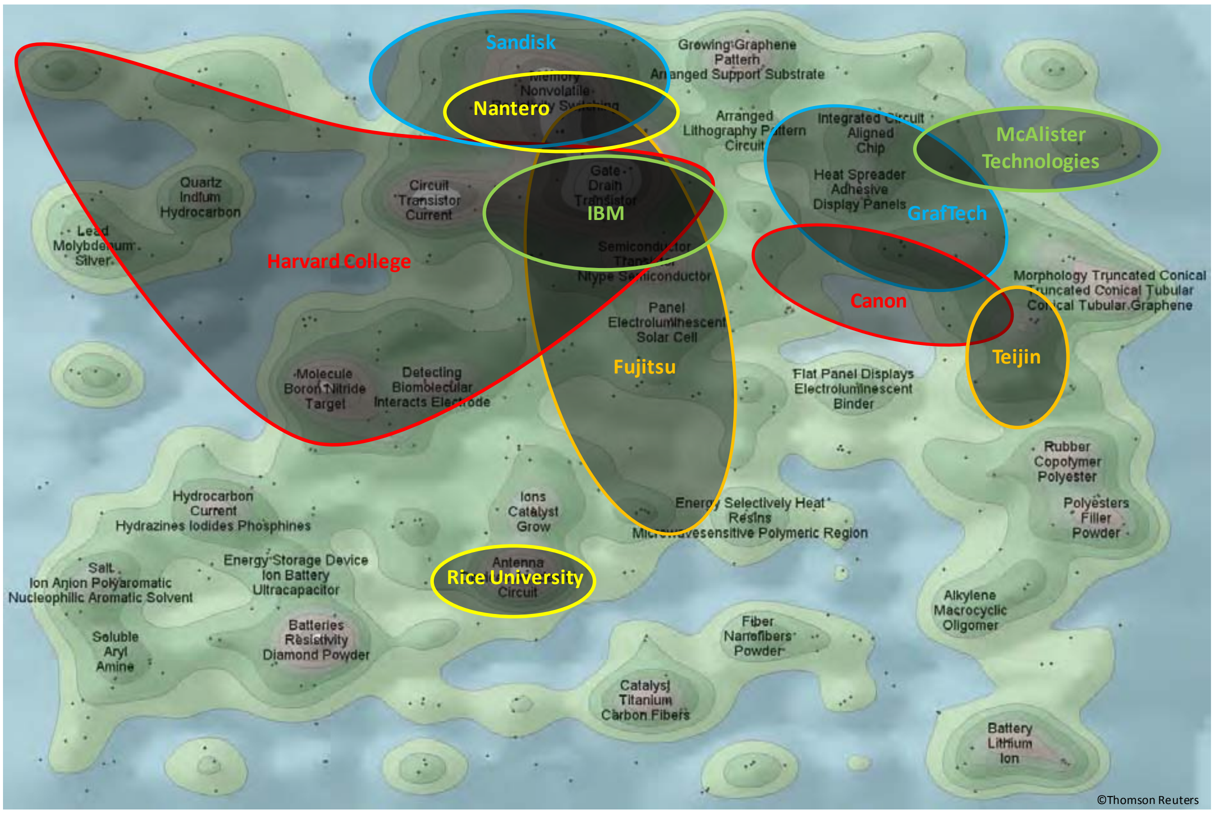


**Figure 12: Graphene patent landscape map with selected top applicants highlighted**

Sandisk and Harvard College are the second and third highest filing applicants in graphene. It is interesting to note that Sandisk are quite concentrated in one small area at the top of map whereas Harvard College have wider coverage. A possible explanation for this is that although Sandisk are a large organisation they may only have a narrow interest in graphene because as the specialist in flash memory devices they are only interested in graphene's potential uses in memory devices, whereas Harvard College are one of the world's leading research universities and are likely to be interested in a wider range of potential applications. Another explanation is possible when considering Figure 12 together with Figure 3, which shows that Harvard College have filed graphene-related patents every year since 2000, before the current research boom following the isolation of graphene in 2004 by Andre Geim and Konstantin Novoselov of Manchester University [2], and Harvard College have therefore experimented with a wider range of ideas and research areas whereas Sandisk have only entered the graphene development arena since 2007 with specific interest in graphene's potential uses in memory devices.

It is also interesting to note Rice University's concentrated interest in graphene for antenna-related uses, reflecting the areas of interest of their research programmes. Similar conclusions can be drawn about the interests of other companies based on their location within the graphene patent landscape.

## Disruptive Technology?

It is clear from the patenting trends in graphene-related patents, Figure 1, and the applicant portfolio and activity, Figures 3-5, 7 and 8, that this is a rapidly emerging research-based area of technology. Looking at the trends in the classification of patents, this technology is now finding application in a diverse range of technological areas.

The rapid emergence of key technologies can disrupt established hierarchies in a technology or market sector. Examples of such disruptive technologies include microwave heating [11], flash memory [12], fibre reinforced plastics [13] and analogue to digital conversion [14].

By analysing the historical published patent data that was available during the fledgling stage of such recognised disruptive technologies we have developed a prototype toolkit of metrics which gives an indication of whether a technology has disruptive potential [15].

Graphene patent fillings have already surpassed the fledgling stage, but applying the prototype toolkit retrospectively to the appropriate point in the evolution of patent filings, identified by the toolkit as 2003, suggests that graphene-based technology is fast emerging and research-based, but not disruptive. That is not to say that one or many specific applications of graphene will not disrupt an established technology or a market.

However, the prototype toolkit was trained using technologies which do not exhibit the same characteristics as graphene, *e.g.* researched by large organisations as opposed to university spin-outs. The rest of this paper suggests that graphene is probably a disruptive technology in some way, so perhaps the prototype toolkit requires further development based on an even wider range of different technologies.

Given the properties which have already been established and the degree of research by major applicants, a significant disruption may be just a matter of time. It will be interesting to see where such applications are found and how the technology evolves. The mass production of graphene appears to be the biggest obstacle at the moment, but it has been predicted that graphene nanoplatelets could be produced for under £6/kg ($5/lb) [16]; if these costs can be achieved it may provide a major disruption in the nanocomposites marketplace. More detailed analysis of the use of graphene in particular applications would also be an interesting follow up of this research.

## Conclusion

The first patent mentioning graphene was published in 1994 and the patenting of graphene-related technology took off rapidly in the 2000s. The largest patent portfolio is held by Samsung, and surprisingly the top two applicants are new entrants in the field. Half of the applicants hold patents relating to fewer than five inventions, illustrating the youth of this emerging technology. The majority of these inventions are protected internationally, perhaps illustrating the commercial importance of potential applications of the technology.

The development of this technology is still largely research-based, with a relatively large portion of academic participation, although real-world consumer applications such as flexible touchscreen displays are getting closer to reality and could be widely available within the next few years. Graphene-related technologies are classified in a diverse range of places in the IPC and though the majority of sub-groups relate to the chemistry and processing of graphene, there are a significant and diverse range of application-specific classifications applied. Varying research strategies of the applicants are evident from the patent collaborations; Samsung exhibits a reasonable amount of collaboration, whilst other top applicants such as Sandisk and Teijin, show none. The different nature of the top applicants is further highlighted by the technology landscape which reveals that, in contrast to the specialism evident from most applicants, Samsung is active in a very diverse range of graphene-related technology.

Though graphene is a rapidly emerging technology, the trends in the patent data indicate that it will not prove to be a disruptive technology. Over the coming years it will be interesting to see if graphene fulfils its potential as the “miracle material of the 21$^{st}$ Century” [2].

## References

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[16] http://nextbigfuture.com/2011/04/commercialization-of-graphene.html

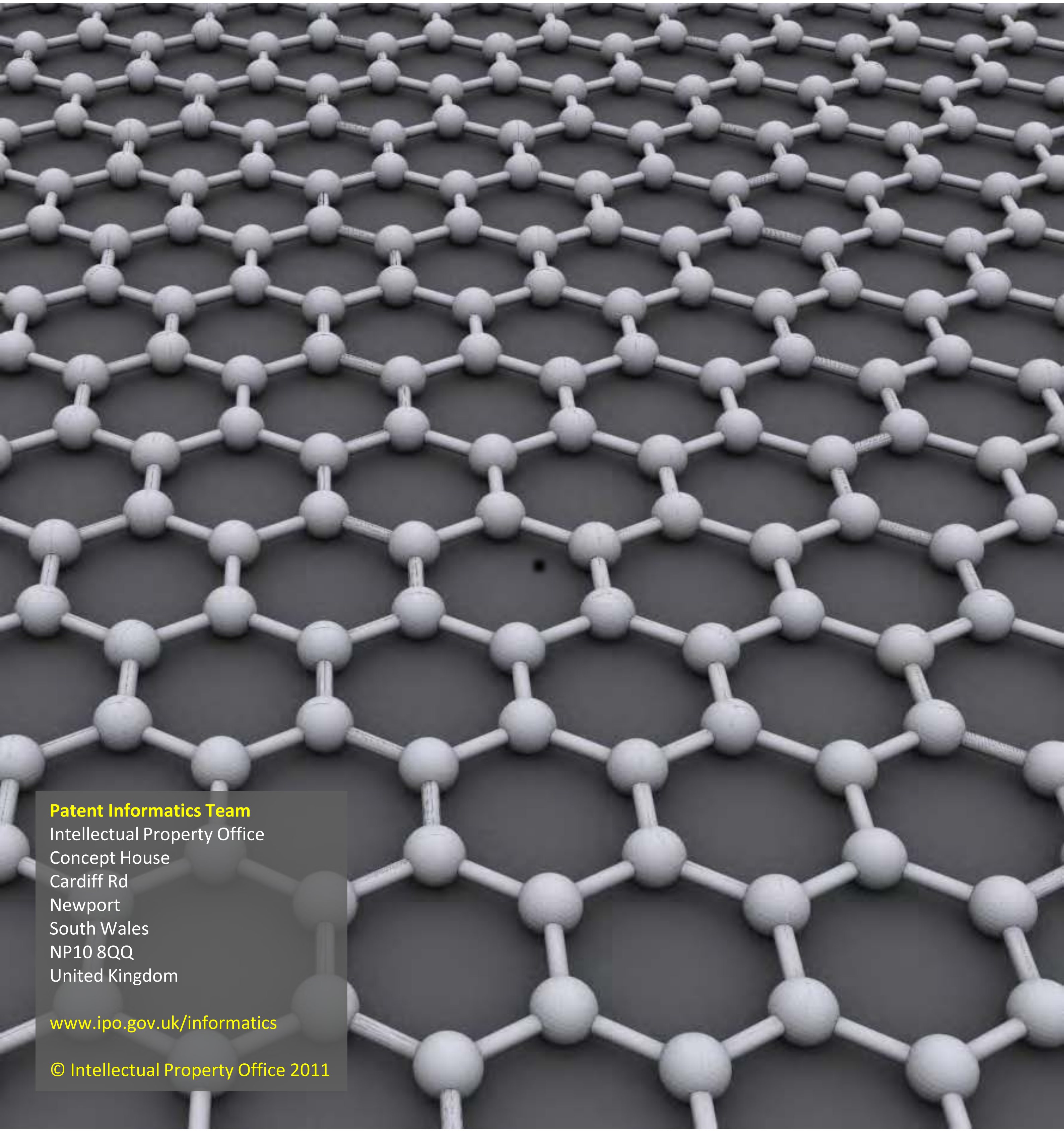
## Appendix

**Table 1: ECLA classifications relating to graphene**

| | |
|---|---|
| C01B | Carbon; Compounds thereof |
| C01B 31 | . Preparation of carbon; Purification |
| C01B 31/04 | . . Graphite, including modified graphite |
| **C01B 31/04H** | **. . . (Graphene)** *(Introduced April 2011)* |
| **C01B 31/04H2** | **. . . . (Preparation)** |
| **C01B 31/04H2B** | **. . . . . (by CVD)** |
| **C01B 31/04H2D** | **. . . . . . (by epitaxial growth)** |
| **C01B 31/04H2F** | **. . . . . . (by exfoliation)** |
| **C01B 31/04H2F2** | **. . . . . . . (starting from graphitic oxide)** |
| **C01B 31/04H4** | **. . . . (After-treatments)** |
| **C01B 31/04H4B** | **. . . . . (Purification)** |
| H01L | Semiconductor devices; electric solid state devices not otherwise provided for |
| H01L 29 | Semiconductor devices adapted for rectifying, amplifying, oscillating or switching, or capacitors or resistors with at least one potential-jump barrier or surface barrier, e.g. PN junction depletion layer or carrier concentration layer; Details of semiconductor bodies or of electrodes thereof |
| H01L | . Semiconductor bodies |
| H01L 29 | . . characterised by the materials of which they are formed |
| H01L 29/16 | . . . including, apart from doping materials or other impurities, only elements of the fourth group of the Periodic System in uncombined form |
| **H01L 29/16G** | **. . . . (Graphene)** *(Introduced February 2011)* |

**Table 2: ECLA indexing terms (ICO terms) relating to graphene**

| | |
|---|---|
| **M01B 204/00** | **Structure or properties of graphene** *(Introduced April 2011)* |
| **M01B 204/02** | **. Single layer graphene** |
| **M01B 204/04** | **. Specific amount of layers or specific thickness** |
| **M01B 204/06** | **.Graphene nanoribbons** |
| **M01B 204/06B** | **. . characterised by their width or by their aspect ratio** |
| **M01B 204/20** | **. Graphene characterised by its properties** |
| **M01B 204/22** | **. . Electronic properties** |
| **M01B 204/24** | **. . Thermal properties** |
| **M01B 204/26** | **. . Mechanical properties** |
| **M01B 204/28** | **. . Solid content in solvents** |
| **M01B 204/30** | **. . Purity** |
| **M01B 204/32** | **. . Size or surface area** |
| T01L | Semiconductor devices; electric solid state devices not otherwise provided for |
| T01L 29 | . Semiconductor devices adapted for rectifying, amplifying, oscillating or switching, or capacitors or resistors with at least one potential-jump barrier or surface barrier, e.g. PN junction depletion layer or carrier concentration layer; Details of semiconductor bodies or of electrodes thereof |
| T01L 29/12 | . . characterised by the materials of which they are formed |
| T01L 29/16 | . . . Including, apart from doping materials or other impurities, only elements of the fourth group of the Periodic System in uncombined form |
| **T01L 29/16G** | **. . . . Graphene** *(Introduced February 2011)* |



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