commentary

Exploiting carbon flatland

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Seven years after isolation of the first graphene sheets, an analysis of the densely populated patent landscape around the two-dimensional material reveals striking differences between universities' patenting activities and illustrates the challenges of a fast-moving technology space.

In the past 15 years the attitude of academic researchers in physics, materials science and chemistry towards patents has changed enormously. One of the most notable changes has been how researchers now value patents as an information resource[1]. Indeed, taken together, the more than 50 million patents globally form a 'library' that not only contains examples of technology application, but also information about the scale and the scope of the commercial interest in different technologies. These data form an important reference for researchers who intend to commercialize their findings and can reveal in-depth insights into emerging technology trends.

At CambridgeIP, we have analysed the patent landscape around graphene with a particular focus on the impact of universities and academic institutions, as these, in terms of scientific publications, have shown a surge in activity in recent years. To arrive at our graphene patent landscape, we undertook a literature review focused on past patent studies[2,3], interviewed graphene technology and industry experts, made broad and inclusive searches in the patent literature, conducted a semi-automated and expert-validated analysis on our systems to remove false positive search results, then generated data sets and undertook further analysis to produce our report[4]. Importantly, our search strategy was aimed at exploring the wider patent space around graphene and included patents on manufacturing processes, purification techniques, modelling techniques, integration with other systems and innovations around end-use.

One of the striking features of the graphene patent landscape is what is not present. Andre Geim, one of the two winners of the 2010 Nobel Prize in Physics "for groundbreaking experiments regarding the two-dimensional material graphene"[5] is not listed as an inventor on any published graphene patent application. Konstantin Novoselov, who shared the prize with Geim, is an author on just one patent application[6]. And Geim's and Novoselov's employer, the University of Manchester, has applied for significantly fewer graphene patents than its university and research institute peers[4]. In fact, by the number of patents filed it ranks far behind other institutions such as the Massachusetts Institute of Technology, Rice University and Sungkyunkwan University.

When Richard Smalley and his colleagues won the Chemistry Nobel Prize in 1996 "for their discovery of fullerenes"[7], Rice University had already filed a significant number of patents in relation to nanotechnology and carbon nanotubes. The rate of patent applications only increased further after the award of the Chemistry Nobel Prize[8], and, by numbers of graphene patent applications filed to date, Rice University ranks in the top 10 overall after corporations such as Samsung, Sandisk and IBM.

> One of the striking features of the graphene patent landscape is what is not present. The University of Manchester has applied for significantly fewer patents than its peers.

Clearly, the attitude of universities and academics towards patenting their inventions varies widely. In an interview for *Nature News*[9] Andre Geim said he had refrained from filing patents in the graphene area because of concerns over potential law suits from "a major electronics company" and over a lack of specific industrial applications and industrial partners for his developments.

These are important points raised by many researchers. However, experience teaches us that it is rather unlikely a sensible consumer electronics company would risk suing a major university or a leading researcher. The negative impact on the company brand and sales performance would be too great. In fact, a university is much more likely to be sued over patent infringement by another university. And, at least in the United States, universities bring patent infringement actions against corporations fairly frequently — often at the behest of the university's corporate partners who in turn agree to meet legal costs arising. Nonetheless, there are other valid reasons to delay filing a patent or to refrain from patenting altogether. A lack of industrial applications and partners is one such reason. Many universities simply do not have the funds to file speculative patent applications, particularly over early-stage technologies that may take many years and require much additional investment before reaching commercial end-use. Moreover, the intensity of corporate engagement with universities, and university attitudes towards patenting, vary from country to country and between universities within the same country. Also, many individual academics wish to donate developments to the global community rather than see their developments owned by corporations.

In the graphene patent landscape, there has been a surge in patent filings around the world in recent years. Figure 1 presents the development of the total number of graphene-related patents over the past few years together with selected scientific publications on the preparation and application of graphene. In particular from around 2007, when graphene became more widely known in the science and industrial research communities, we observe a spike in numbers of patent applications both from corporations and academic institutions.

The overall picture that emerges resembles that of the semiconductor and biotechnology industries and some early-stage technology spaces, including nanotechnology, which experience particularly high levels of patent activity. Such high activity is not without risk, as it can lead to what commentators term 'patent thickets'[10]. A patent 'gold rush' can lead to simultaneous filings of very similar innovations from a number of researchers in different countries around the world. Such overlapping granted patents can be a reason for increased litigation, and they have caused many governments and experts to study the possible impacts, both positive and negative, of the patent system on innovation[11].

Early signs in the graphene patent area are positive, with many patent applications being granted. This is encouraging as nascent technology areas, such as nanotechnology, often struggle to arrive at a coherent terminology for technology components[12]. Quite simply, different patent applicants can call the same component by different names. Graphene is a 2D form of crystalline carbon, which gives rise to additional challenges in distinguishing it from other forms of nanocarbon in the patent literature, including carbon nanotubes and fullerenes. In fact, many patent authorities even decided to employ specialist nanotechnology patent examiners to check nanotechnology applications, and to create special classification codes. The European Patent Office, for example, has already created graphene-specific patent classifications.

Across all years, there is a relatively high patent contribution from universities and research institutes, consistent with other relatively early-stage and research-intensive technology spaces. Table 1 highlights the most active inventors with university affiliations or collaborations, and shows strong track records of industry–university collaborations in both South Korea and the United States. The contribution of multinational corporations to the graphene patent landscape is and remains significant. There are a number of possible reasons for this, including the fact that many of the end-use industries for graphene developments are notoriously patent-intensive. Another reason may simply be that the material is perceived as easier to work with and to scale up than many other nanomaterials, including carbon nanotubes, that have seen considerable commercial interest. And some major corporations have gained in-house expertise in nanotechnology, perhaps easing their switch to graphene. There is evidence in the patent literature of corporations simply hedging their bets by adding graphene claims to current patent families around existing technologies, and there are signs that some corporations are engaging in 'portfolio maximization' and 'portfolio optimization' strategies observed in information technology, electrical engineering, biotechnology and other sectors relying on complex technology systems[13]. It has, for example, become relatively common practice for patents to claim graphene as one of a long list of potential nanomaterials that could deliver a desired result.

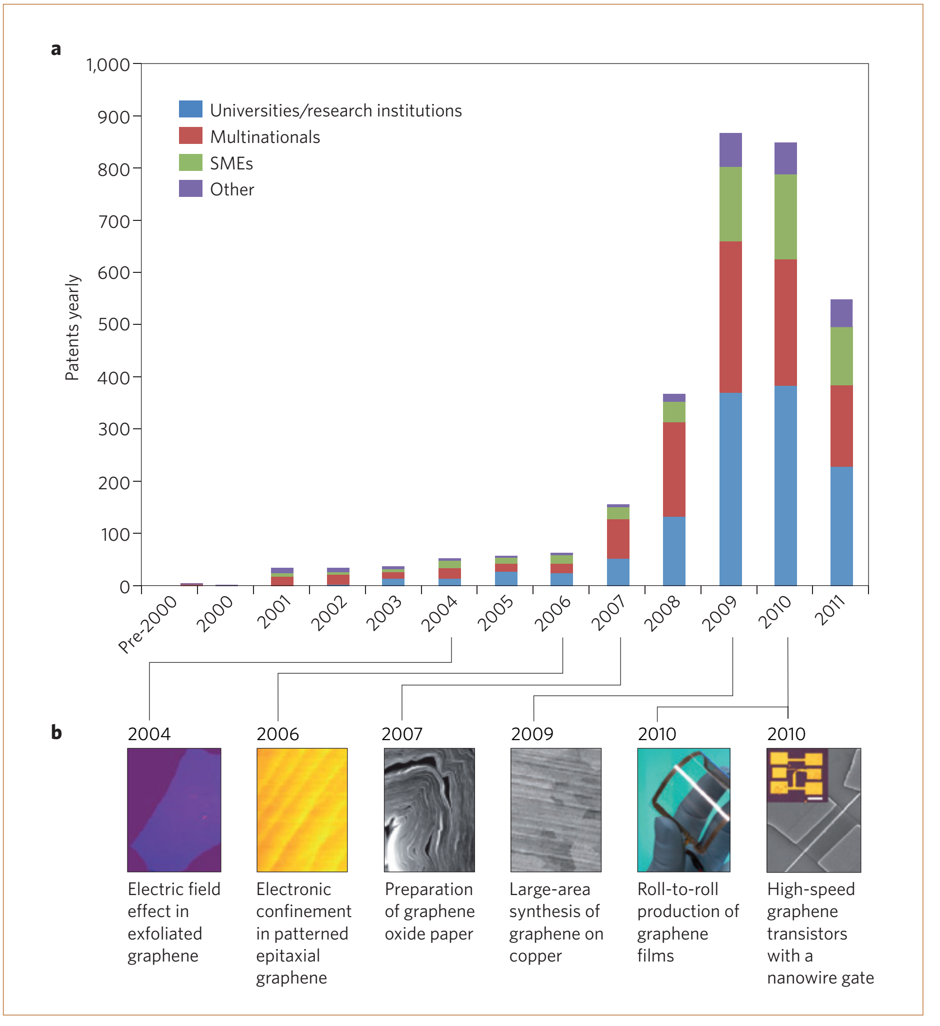

Figure 1 | Development of graphene science and technology. **a**, The number of patent applications by year. Patent applications may be unpublished for 18 months or more. Therefore the number of patents for the past two years may be underrepresented. **b**, Timeline of some representative scientific discoveries. Images reproduced from (left to right): ref. 18, © 2004 AAAS; ref. 19, © 2006 AAAS; ref. 20, © 2007 NPG; ref. 21, © 2009 AAAS; ref. 22, © 2010 NPG; ref. 23, © 2010 NPG.

The largest corporate patent portfolios in the graphene patent landscape are held by Samsung and Sandisk, reflecting clear industrial interests in semiconductor- and memory-related applications. Key differences in corporate research and development (R&D) focus and commercial strategies can be inferred from the corporate patent filings. Samsung has a broad set of application interests and a wide set of collaborators including several leading universities and research institutes around the world (Fig. 2a). By comparison, Sandisk has a more highly focused patent portfolio and relatively few collaborators (Fig. 2b).

Naturally, analysis of the patent data can reveal R&D collaborations as well as the focus of specific groups and individuals. Moreover, individual patent documents can help readers to identify specifications around particular industrial applications. Assessing abandoned patents, comparing journal articles and the patent literature in specific spaces, and undertaking analysis of areas where patents are not filed ('white space' or 'gap' analysis) can also give researchers useful clues about 'dead ends' to avoid and areas where commercially viable solutions are required. Unfortunately, the graphene patent landscape is not mature enough yet to show these characteristics reliably, but they should soon emerge if patenting rates continue to rise.

As the first 2D crystal discovered, and with such unusual electronic, optical and mechanical properties, it is easy to see why graphene is of such broad interest across industry fields ranging from semiconductors to biotechnology. And, like it or not, patents underpin R&D strategies and commercial strategies in a great many industries relevant to graphene research deployments. In the current economic environment, the chance of receiving an investment of sufficient working capital to take a graphene research project, scale it up and roll out a commercial application is much less than in the past. This funding squeeze means that smaller players are less likely to be able to afford to 'do it alone'. Finding corporate strategic partners with experience, scale and contacts is now even more important at an even earlier stage. And, whatever the nature of the patent landscape in a given area, it is notoriously difficult for innovators to assess the possible rewards of taking out a patent and to balance these against the costs and risks of doing so. For these and other reasons, it is leading practice at university technology-transfer offices to seek corporate partners as early as possible in the patenting process. Our graphene patent landscape indicates that university collaborations with industry and industrial sponsorship of university research are common in the graphene space. There is a high level of university and corporation graphene patent co-ownership. Samsung, for example, co-owns graphene patents with Hanyang University, Kumoh National Institute of Technology, Leland Stanford Junior University, Seoul National University and Sungkyunkwan University (Fig. 2a).

The chance of an academic inventor receiving an investment to roll out a commercial graphene application is less than in the past. Finding corporate strategic partners is now even more important.

Many universities have been successful in developing graphene technologies themselves and then licensing out patents covering these technologies to industrial players. As the World Intellectual Property Organization says, "licensing not only creates an income source for the patentee, but also establishes the legal framework for the transfer of the technology to a wider group of researchers and engineers, who may, in turn, further contribute to the development of the technology"[14]. Massachusetts Institute of Technology, for example, advertises around 30 graphene technologies as available for licence on its Industrial Liaison Program website. And a search of the Rice University technology transfer website brings up 14 advertisements for graphene technology available for licence, the most recent being for "Growth of graphene from food, insects, and waste"[15].

The UK's Chancellor of the Exchequer, George Osborne, has recently announced a £50 million grant to support UK-based graphene research and "fund a national research programme that will take this Nobel Prize-winning discovery from the British laboratory to the British factory floor"[16]. In response, Konstantin Novoselov said that the £50 million investment was "a 'smart move' that, if spent wisely, would

Table 1 | Top 10 ranking of university-related inventors by number of patents filed, together with affiliations and example patent titles.

Rank	Name	Number of patents	Organizational affiliations in inventor's graphene patents	Example patent number on Boliven.com	Example patent title
1	Jae-young Choi	62	Kumoh National Institute of Technology; Samsung; Sungkyunkwan University	US20110127497A1	Organic light-emitting device using graphene
2	Hyeon-jin Shin	43	Samsung; Sungkyunkwan University	US20090308520A1	Method for exfoliating carbonization catalyst from graphene sheet, method for transferring graphene sheet from which carbonization catalyst is exfoliated to device, graphene sheet and device using the graphene sheet
3	Seon-mi Yoon	39	Samsung; Sungkyunkwan University	US20090071533A1	Transparent electrode comprising graphene sheet, and display and solar cell including the electrode
4	Ilhan A. Aksay	35	Battelle Memorial Institute; Princeton University; Vorbeck Materials Corporation	US20100096595A1	Functional graphene–polymer nanocomposites for gas-barrier applications
5	Hyun-jong Chung	34	Samsung; Seoul National University; Sungkyunkwan University	US20110089995A1	Graphene device and method of manufacturing the same
6	Sun-ae Seo	33	Samsung; Seoul National University; Sungkyunkwan University; Leland Stanford Junior University	US20110108521A1	Methods of manufacturing and transferring larger-sized graphene
7	Byung Hee Hong	28	Samsung; Sungkyunkwan University	US20110195207	Graphene roll-to-roll coating apparatus and graphene roll-to-roll coating method using the same for graphene
8	Yun-sung Woo	21	Samsung; Seoul National University; Sungkyunkwan University	US20110108609	Methods of fabricating graphene using alloy catalyst
9	Robert K. Prudhomme	21	Princeton University; Vorbeck Materials Corporation	US20110042813A1	Printed electronics
10	Rodney S. Ruoff	20	Graphene Energy; Northwestern University; Texas Instruments; University of Texas	WO2008143829A2	Graphene oxide sheet laminate and method
11	James M. Tour	20	University of Texas; William Marsh Rice University	US20110059871	Graphene compositions and drilling fluids derived therefrom
12	John S. Lettow	18	Princeton University; Vorbeck Materials Corporation	US20110049437	Coatings containing functionalized graphene sheets and articles coated therewith

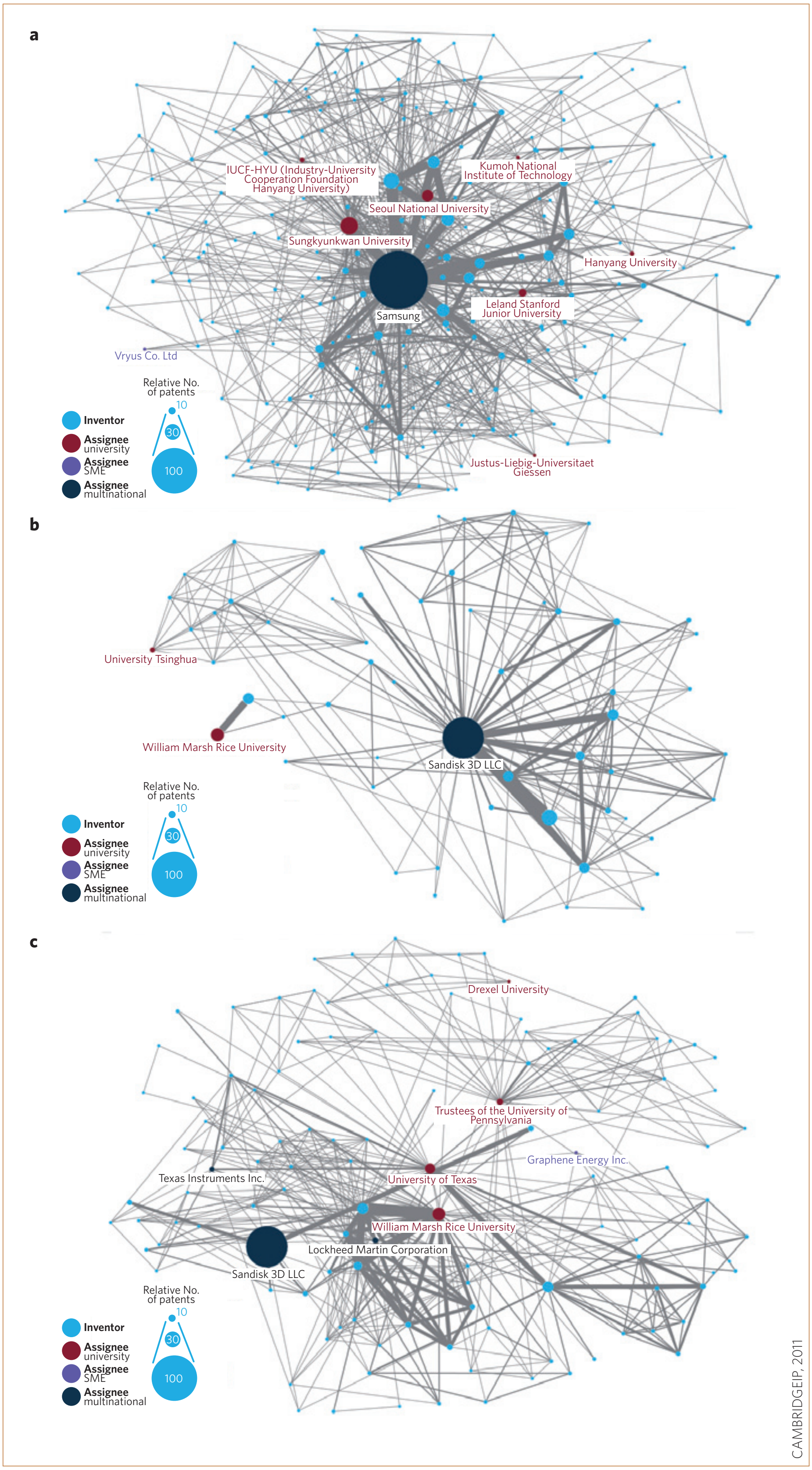

Figure 2 | Graphene patent networks for **a**, Samsung, **b**, Sandisk and **c**, Rice University. The nodes in the graphs represent individual inventors and organizational assignees such as universities, multinationals, and small and medium enterprises (SMEs). The lines between the nodes correspond to mutual patent filings.

reap economic dividends"[17]. Consequently, whatever the reasons behind the decision not to file more graphene-related patents thus far, I expect to see many more graphene patents from the University of Manchester and its industrial partners over the next several years, if only to meet the expectations of private-sector partners and public-sector stakeholders. Of course, in addition to graphene other '2D' materials exist, and the patent literature could soon provide evidence of forays into these new flatlands. Whether you think the information in patents assists the scientific discovery process or you feel that the business interests revealed in patents impede scientific aims, I am confident that you will agree with me how fascinating it will be to observe 'patenting in the flatlands' over the next few years. ❐

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