Graphene patent and technology landscape analysis

Making sense of an industry-disrupting material
About this report

Graphene—a single layer of carbon atoms held together in a honeycomb structure—boasts extraordinary properties that could radically change our world, through transformational applications in electronics, telecommunications, aerospace, food packaging and virtually every other industry that can exploit its unique features.

In an attempt to delineate the current evolutionary state of graphene, provide adequate insight into global R&D investment and pinpoint technological areas for future development, the present patent landscape analysis was drafted. Patents are a unique source of information reflecting the level of current research and technology, long before a product reaches the market. Patent landscape is a search to understand a particular technology that provides a snapshot of the patent activity either within a given country or region, or globally. Depending on the case, hundreds or even thousands of patent records are screened. The results of this analysis are visualized in a way that allows for meaningful conclusions to be drawn.

This report was originally prepared for one of our clients and as such contained confidential information relating to strategic directions for capitalizing on the emerging technological potential of graphene. All this information has been excluded from the current version of the report.
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Graphene basics
Graphene basics

Graphene is a single planar sheet of sp2-bonded carbon atoms. The carbon atoms are densely structured in honeycomb networks, arranged in 2-dimensional, hexagonal patterns called “benzene rings”. This honeycomb network is the basic building block of three-dimensional graphite.

Graphene is very strong, light and an excellent conductor of heat and electricity. Scientists claim that graphene’s extraordinary properties could be exploited in several industries and potentially lead to a technological revolution.
Graphene’s properties

Graphene is:

**Strong**
200 times stronger than steel

**Thin**
The thinnest material on earth – 1 million times thinner than a human hair

**Conductive**
The world’s most conductive material

**Two-dimensional**
The world’s first 2D material

Source: [http://www.graphene.manchester.ac.uk/explore/what-can-graphene-do/](http://www.graphene.manchester.ac.uk/explore/what-can-graphene-do/)

Graphene can be stretched by a quarter of its length and it’s stiffer than diamond. Because it’s only one atom thick, a gram of graphene can cover an entire football field. Graphene also demonstrates a high biocompatibility and can be used in biomedical applications. It also absorbs 2.3% of white light.
Graphene potential applications

**Solar industry**
Ultra-thin, lightweight solar cells, produced by using stacked sheets of graphene, could revolutionize the solar industry. Such solar cells have the potential to surpass any substance, aside from reactor-grade uranium, with respect to the energy produced per pound of material.

**Bulletproof armor**
Researchers conducted miniature ballistic tests on sheets of graphene by firing a tiny silica sphere at it. A layer just an atom thick can absorb eight to ten times the impact that steel can.

**Telecommunications**
Graphene allows for a particularly fast conversion of light into electrical signals. The use of graphene in optical data transmission could revolutionize telecommunications.

**Sensors**
More sensitive and robust biotech sensor devices, environmental monitoring, oil and gas sensors.

**Computers**
More efficient transistors based on graphene could result in thinner computer chips which use less energy and work faster.

**Cameras**
Graphene’s response to light makes it an ideal material for camera sensors. Graphene could be a game changer for the world of photography as it contains the ability to absorb light over a broad range of wavelengths.

**Buildings**
Ultra-thin graphene surfaces could one day be used to develop a coating on the outside of buildings that would absorb sunlight and generate enough electricity to power all the appliances inside.
Patent landscape analysis
Methodology

Understand
- Reading background art
- Identifying main components
- Compiling keywords list

Search
- Keyword based
- Class based
- Applicant based
- Country based
- Citation study

Analyze
- Filtering
- Analyzing relevant records
- Advanced patent analytics
The following table presents a summary of the extracted and cleaned patent dataset used in the report. Numerous patent databases were utilized to compile the patent pool. Several analyses contained in the report are based on PatentInspiration.

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Number of patent publications</td>
<td>28,396</td>
</tr>
<tr>
<td>Number of patent families</td>
<td>20,858</td>
</tr>
<tr>
<td>Publication year range</td>
<td>01/01/2005 - 05/10/2016</td>
</tr>
<tr>
<td>Top applicant</td>
<td>SAMSUNG ELECTRONICS CO LTD (637 patents)</td>
</tr>
<tr>
<td>Country with most publications</td>
<td>China (8,272 patents)</td>
</tr>
<tr>
<td>Year with most publications</td>
<td>2015 (7,245 patents)</td>
</tr>
<tr>
<td>Main group with most publications</td>
<td>B82Y30/00; Nano-technology for materials or surface science (3,230 patents)</td>
</tr>
</tbody>
</table>
Patent landscape analysis

This graph shows the total number of published patents per year. The upward trend suggests that patenting in graphene has rapidly increased over the period (the numbers in the past two years (2015 and 2016) are under-represented, since patent applications may remain unpublished for up to 18 months).

The number of patents published per year about a technology is linked to the so-called S curve of that technology. When the curve is going up, the technology is evolving very fast and still in an early, if premature, phase. A decline in patenting activity may be a sign that the technology has advanced to a more mature state and could be exploited in additional commercial applications.
This graph presents a timeline for the top 20 applicants’ publication activity (numbers for 2015 and 2016 may be under-represented). The different color shades designate the number of patents per applicant (the darker the color, the higher the number of patents published).

The graph shows a peak of patent publications in 2014 by Ocean’s King Lighting. However, Samsung remains the most active applicant.

The relatively high number of universities and research institutes in the top applicants list indicates that graphene is still in an exploratory research phase.
Patent landscape analysis

Connections

This figure shows which applicants have cooperated with one another on graphene-related patents. The lines interconnect the applicants (line thickness corresponds to the number of patents in cooperation). The size of the applicant name indicates how many patents they have individually. The bigger the dot size, the more collaborations for an applicant.

We can see from this analysis that connections between industry and academia are quite pronounced (e.g., Samsung - Georgia Tech - Sungkyunkwan University - MIT etc.). This is consistent with the fact that graphene-based technologies have yet to reach the point of full-scale commercialization.

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Patent landscape analysis

CPC code

CPC (Cooperative Patent Classification) is a joint effort from the EPO and the USPTO to unify their classification systems. Classification codes are assigned by patent officers to patents at the time of application, to classify them according to their technical content.

The donut chart shows the top main group occurrences in the patent pool. These codes give a quick insight in the technological content of the patents and thus may hint at applications linked to graphene. Nano-technology for materials and manufacture of nano-structures are two main groups with particularly high numbers of patents.

- B82Y30/00: Nano-technology for materials or surface science
- B82Y40/00: Manufacture or treatment of nano-structures
- Y02E60/122: Lithium-ion batteries
- H01L29/1606: (Graphene)
- C01B31/0484: (After-treatments)
- C01B31/0446: (Preparation)
- B82Y10/00: Nano-technology for information processing
- Y02E60/13: Ultracapacitors
- H01M4/625: (Carbon or graphite)
- C01B31/0453: (by CVD)
- Others
Graphene vs. related codes (trend)

This chart plots the graphene patenting activity trend against the activity of a pool comprising all patent records of the relevant codes presented in the previous figure (the trend lines were constructed using simple moving averages of the patent publications per quarter for each patent pool).

As it was made obvious from the previous analyses, the number of graphene patents rose exponentially during the last years, to the point of surpassing (in 2015) the cumulative patent pool of ten relevant main groups.
Patent landscape analysis

Graphene vs. related codes (patent value)

Taking the previous analysis one step further to investigate the potential of graphene, comparing the value of the two patent pools, we can see that overall graphene patents (in pink) score higher than the rest under the related codes.

For this analysis a patent value index was used, which is calculated based on text analytics and the number of forward citations a patent has received. The size of the bubbles represents the size of the patent families.
Patent landscape analysis

This graph shows the patent application country distribution across the dataset. Each patent record has a field that mentions the country of the patent/applicant/inventor. If there are multiple applicants/inventors based in different countries for one patent, the patent will be included in each of the country counts.

Since the address of the patent usually corresponds to the R&D center of the applicant, this analysis can give an overview of where knowledge hubs are located in the world.

It is self-evident that China dominates the graphene patent landscape (about one-third of graphene patent records are Chinese).

- China (8243 patents)
- United States (5631 patents)
- Republic of Korea (3599 patents)
- Japan (1802 patents)
- Taiwan (882 patents)
- Germany (600 patents)
- United Kingdom (414 patents)
- France (311 patents)
- Others
The map shows a snapshot of the patent application activity per country for the period 01/01/2005-31/12/2010. Juxtaposing this map with the one shown in the next page can be quite enlightening as to the exponentially increasing interest for graphene, whose tremendous properties and potential applications were not fully realized back in 2010.
Patent applications per country, as of 5 October 2016. Chinese applicants/inventors have vastly increased in number. There have been quite significant increases in US, Korean, Japanese and Taiwanese patents as well. The overall trend per country can be seen in the next chart.
Patent landscape analysis

Patent application trend

The patent application trend per geographical region showcases the increasing interest for graphene-related patents (numbers for 2016 are under-represented), as well as the Chinese domination. The chart also indicates that Europe may be late to the graphene party with a thin, moderately increasing patenting activity.
As with the overall patent publication activity, the number of European patent publications progresses in an upward trend, peaking in 2015. However, it is also noticeable, as previously described, that the rise is not as intense (designated by the trend line’s slope).
Germany accounts for nearly 25% of European patent applications. Traditionally, country analysis has been a good indicator of where the invention is actually taking place. In recent years, however, drawing conclusions from these data can be challenging, as strategic reasons (e.g. tax deductions) may influence the applicant’s decision regarding the country of filing.
### European patent landscape

#### Patent publications per applicant per year

Patent publication timeline for the top applicants in Europe. Research institutes and academia also have a strong presence.

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<th>BASF AG</th>
<th>BAYER AG</th>
<th>BELENOS CLEAN POWER HOLDING AG</th>
<th>BOSCH GMBH ROBERT</th>
<th>CENTRE NAT DE LA RECH SCIENT</th>
<th>COMMISSARIAT ENERGIE ATOMIQUE</th>
<th>ECOLE POL FED DE LAUSANNE</th>
<th>GLOBALFOUNDRIES INC</th>
<th>IBM</th>
<th>IMEC</th>
<th>INFINEON TECHNOLOGIES AG</th>
<th>KONINKL PHILIPS NV</th>
<th>MAX PLANCK GESELLSCHAFT</th>
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European patent landscape

Top applicants (companies)

This tag cloud presents the companies with the most patents in the European patent pool. The larger the font size, the more patent applications for a company.

Nokia and BASF are the most significant entries.
European patent landscape

Top applicants (research institutes and academia)

Similarly, this figure shows the most active European universities and research institutes. The CNRS (France) and the University of Manchester (where graphene, as we know it today, originated from) are the most significant entries.
Advanced patent analytics

Fields

This sunburst diagram maps the fields mentioned in the graphene patent pool.

To compile this analysis, synonyms to specific words linked to each field are extracted from the patent texts. Then, the most recurring words are translated into the main fields where graphene has applications.

The chart can be particularly valuable if processes or functions are being explored, or if problems need to be solved. It gives an overview of possible ways to realize something and can introduce new trains of thought for a problem solving process.
Similar to the fields analysis, the technologies chart shows the key technologies and industries described in the patent pool (technology fields are defined according to Schmoch’s classification (WIPO, 2010) and rely on the International Patent Classification (IPC) codes contained in the patent documents).

This analysis can be correlated to the CPC chart as well.
Advanced patent analytics

This analysis plots out the different domains found within the graphene patent pool. Each color and approximate position relates to a larger domain. The classification codes are extracted at subclass level and clustered into the domains.

This analysis indicates which domains are described in your patent pool. You can find different domains that are similar to yours based on their classification code combinations. If you have a specific problem, you could find which other similar domains have already solved your problem.
Advanced patent analytics

Materials
The most frequently used materials (as these are described in the patent documents) are extracted from the texts. Materials are shown in different slices of main categories with one or more subcategories. This chart can hint at material combinations and applications that may be used by companies in relation to graphene.
Advanced patent analytics

Unit fields
This analysis searches within the patent texts for symbols expressing units of measurement related to size, temperature, pressure, current, voltage, frequency, power etc.
The findings may provide interesting hints in regards to the quantities and features that inventors are working on.

- Size
- Time
- Voltage
- Pressure
- Power
- Frequency
- Temperature
- pH
- Current
- Viscosity
- Speed
- Volume Flow Rate
- Sound
- Mass Flow Rate
- Illumination
Advanced patent analytics

<table>
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<th>Increase</th>
<th>Decrease</th>
<th>Change or stabilize</th>
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<td>agent (1145)</td>
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<td>concentration (452)</td>
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<td>energy (323)</td>
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<td>material (349)</td>
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</table>

<table>
<thead>
<tr>
<th>Modifier</th>
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</table>
| This figure shows an overview of the topics that inventors are working on. The results are shown in three separate tag clouds (the larger the font size, the more patents related to the word—the exact number of patents is shown in the parentheses).

A list of synonyms is used to look within the patent pool for the things that inventors want to increase, decrease or stabilize.

This analysis, accompanied by the previous ones, can provide valuable insight for problem solving or ideation.

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Advanced patent analytics

The last step for acquiring the whole picture in regards to the major topics and technological issues that arise from the patent pool, is the so-called value equation, shown below:

\[
\text{Value} = P - (H + I + C)
\]

where
- \( P \): Performance
- \( H \): Harm
- \( I \): Interface
- \( C \): Cost

A list of synonyms and phrases for describing the four components of the equation is searched throughout the patent texts. The results are then presented in the form of four tag clouds (the larger the font size, the more patents related to the word).
Advanced patent analytics

Self

Extending the previous analysis, the actions—deriving from the patent pool—that are done automatically are identified.

Value can be perceived through the notion of a self-operating system (i.e. a system that requires zero user involvement). This is linked to the general trend in technologies towards higher intelligence and automation.

By searching for functions that are done automatically, it is possible to pinpoint the attributes than can help lower the interface, thus creating more value.
Advanced patent analytics

White space analysis

This final analysis maps the standard properties of the graphene patent pool. These standard properties provide us with a roadmap informing us where we need to look for the future solutions most likely to deliver the ideal outcomes. This graph can be used to extrapolate existing solutions into the future and speculate on likely graphene-related solutions.

Each of the spokes represents a relevant property and all of the white space indicates jumps that are known from other technologies that haven’t been made within the graphene field, yet. The untapped evolutionary potential allows us to get a sense of what future generic solutions may look like.

Note: graphene’s evolutionary potential (as depicted in the current white space analysis) derives solely from the patent pool under scrutiny. A dedicated and more focused investigation can be conducted using the EvPot+ tool, which is part of the Systematic Innovation™ problem solving suite. Based on the Russian TRIZ problem solving methodology, the EvPot+ tool, through 3.7 million data-points, can give a clear insight into which technology types will ultimately win the evolutionary race to the ideal solution. For more information contact us.
Areas for future development
As previously stressed, graphene yields extraordinary properties that could be linked to applications with significant technological novelty. However, large-scale production still poses considerable risks and drawbacks. It is estimated that over two thirds graphene-producing organizations employ “top down” production methods (i.e. graphene made from the exfoliation of graphite by various patented methods to produce nano-platelets). The remaining third manufactures graphene by the “bottom up” method, i.e. growing graphene as a layer on a substrate of copper or silicon dioxide/carbide.

From this perspective, it’s safe to speculate that research around graphene, in the short and mid term, will primarily focus on the following:

- Development of new processes that achieve large economies of scale.
- Production of graphene in forms that address critical market needs.
- Production of large sheets of graphene on a continuous process.
Areas for future development

Utilizing the findings from the patent landscape analysis, we estimate that in the next 5 years, the technological areas and applications with the largest potential for graphene will be:

- Production of graphene sheets and lightweight products with amazing electrical and thermal properties.
- Graphene-based super capacitors, the initial use will be within handheld devices and mobile phones.
- Graphene can be used in sensors as functionalized sensor element or as transparent electrodes.
- RFID (radio frequency identification); graphene ink can be used for printed antennas.
- Smart packaging, including printing interconnects and functional inks, utilizing graphene inks.
- High strength composite materials.

For more information regarding the areas for future development, please contact us.
About Seven Sigma

Who we are

We are an innovation consulting firm focused on helping our clients envision and build the future, instead of being overrun by it.

Leveraging proven methodologies and valuable expertise, our team of accomplished consultants works with organizations to outflank their toughest innovation challenges, skyrocket their innovation performance and ultimately boost their competitiveness and profitability.
About Seven Sigma

Who we work with
Organizations connect with us for:
- Developing an innovation culture and advancing their innovation capabilities
- Creating a winning innovation and technology strategy
- Designing and implementing idea and product portfolio management processes

Our consulting network expands across the globe in the fields of creativity, inventive problem solving and change management. We also work with a large number of academic and research institutes – operating across a wide spectrum of domains – that can contribute their knowledge to addressing your challenges.
Thank you for your attention