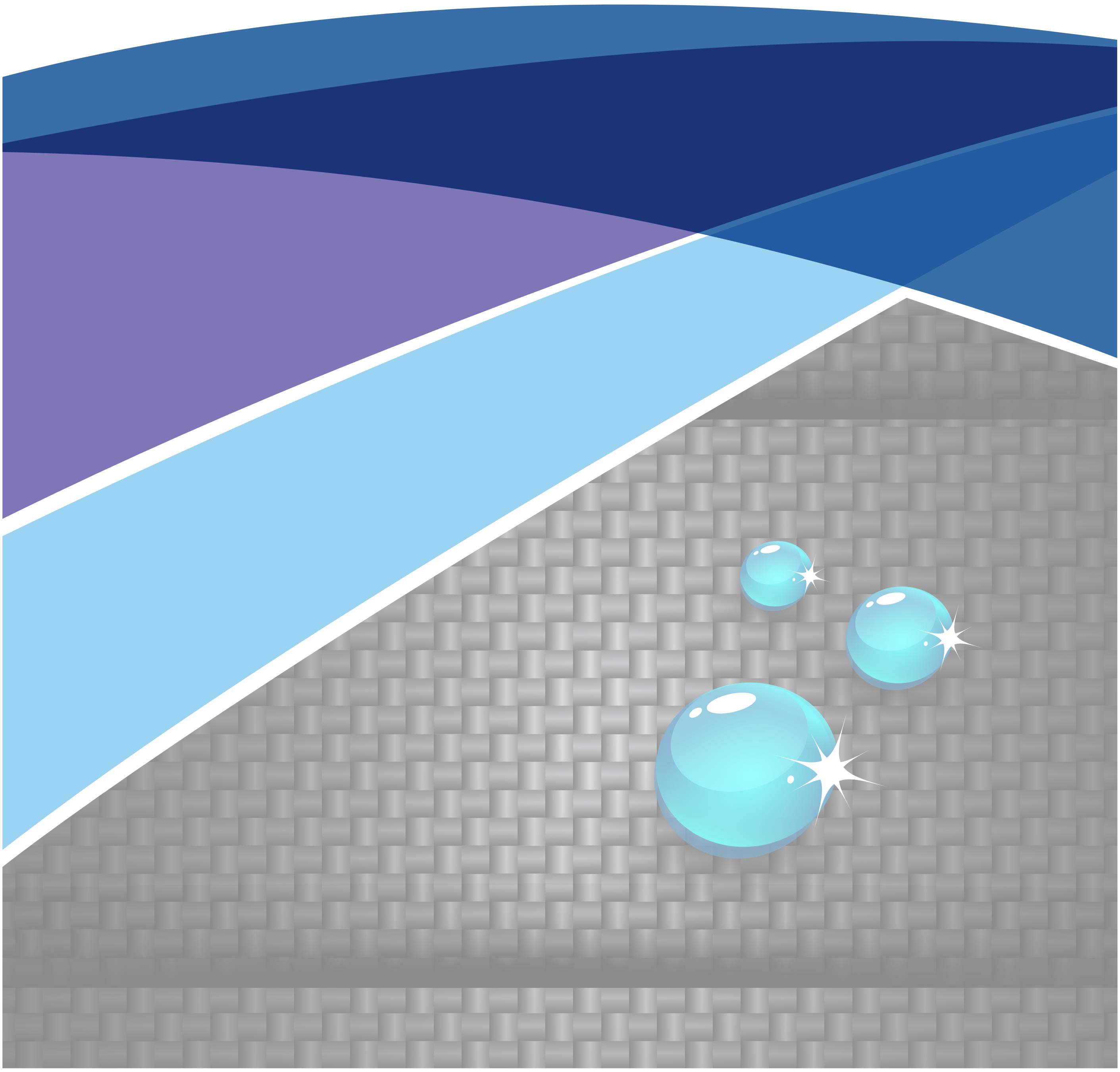
Intellectual Property Office

Eight Great Technologies

Advanced Materials

A patent overview



#8Great

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Contents

1 Introduction

The UK Government has identified ‘eight great technologies’ plus a further two which will propel the UK to future growth. These are:

- the big data revolution and energy-efficient computing;
- satellites and commercial applications of space;
- robotics and autonomous systems;
- life sciences, genomics and synthetic biology;
- regenerative medicine;
- agri-science;
- advanced materials and nanotechnology;
- energy and its storage;
- quantum technologies;
- the internet of things.

Patent data can give a valuable insight into innovative activity, to the extent that it has been codified in patent applications, and the IPO Informatics team is producing a series of patent landscape reports looking at each of these technology spaces and the current level of UK patenting on the world stage. As an aid to help people understand the eight great technologies and to consider the direction of future funding, the IPO is offering a comprehensive overview of patenting activity in each of these technologies.

This report analyses the worldwide patent landscape for technology directed towards advanced materials. Advanced materials and nanotechnology provides a very wide ambit for the construction of a meaningful search of relevant patent documentation. Therefore the current report is divided into four separate parts, each of which is examined in turn, in an attempt to give a broad overview. The four areas taken from the area of advanced materials and nanotechnology are: forms of carbon i.e. graphene and nanostructures, metamaterials, renewable energy enabling materials technology and wearable technology. The dataset relating to metamaterials would have been completely overshadowed by other subject areas within the search, if it had not been divided out, as it is so small in size relative to the forms of carbon dataset. There are many published patents worldwide relating technologies such as graphene and additive manufacturing[1], but the datasets

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[1] More information can be found in our 2013 reports giving overviews of the worldwide 3D Printing (Additive manufacturing) patent landscape http://www.ipo.gov.uk/informatics-3d-printing.pdf and graphene patent landscape http://www.ipo.gov.uk/informatics-graphene-2013.pdf

used for this report were limited to the specific subject areas listed above. These data subsets have also formed separate sections in the current report.

The datasets used for analysis were extracted from worldwide patent databases following detailed discussion and consultation with patent examiners from the Intellectual Property Office who are experts in the field and who, on a day-to-day basis, search, examine and grant patent applications relating to the technologies involved. Published patent application data was analysed rather than granted patent data. Published patent application data gives more information about technological activity than granted patent data because a number of factors determine whether an application ever proceeds to grant; these include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

2 Worldwide Patent Analysis

2.1 Forms of carbon

2.1.1 Overview

The dataset for forms of carbon does not include any specific search for polymeric compounds as this search is beyond the remit of the current report. The search has been limited to classifications which are used in the locations of patents which relate to particular types of carbon, usually in a "pure" form such as alternative allotropes[2] of carbon such as graphene and carbon fibre.

Table 1 gives a summary of the extracted and cleaned dataset used for this analysis of the forms of carbon patent landscape. All of the analysis undertaken in this section of the report was performed on this dataset or a subset of this dataset. The worldwide dataset for forms of carbon patents published between 2004 and 2013 contains more than 35,329 patent families equating to over 112,282 published patents. Published patents may be at the application or grant stage, so are not necessarily granted patents. A patent family is one or more published patent originating from a single original (priority) application. Analysis by patent family more accurately reflects the number of inventions present because generally there is one invention per patent family, whereas analysis by raw number of patent publications inevitably involves 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. Hence analysis by patent family gives more accurate results regarding the inventive effort that patenting activity represents.

[2] The term allotrope refers to one or more forms of an elementary substance. An example would be: Graphite is an allotrope of carbon. Oxygen (diatomic O_2) and ozone, (O_3), are allotropes of oxygen. A definition is available from: http://chemistry.about.com/od/dictionariesglossaries/g/defallotrope.htm

Table 1: Summary of worldwide patent dataset for forms of carbon

Number of patent publications	35,329
Number of patent families	112,282
Publication year range	2004-2013
Peak publication year	2013
Top applicant	Bridgestone Corp (Japan)
Number of patent assignees	121,340
Number of inventors	185,585
Priority countries	52
IPC sub-groups	13,788

Figure 1 shows the total number of published patents by publication year (top) and the total number of patent families by priority year (bottom – considered to be the best indication of when the original invention took place. Figure 1 suggests an increase in forms of carbon patenting over the time period of the dataset but since 2012 this steady rate has further accelerated. The patent family chart in red does not show any patents filed after 2012 because a patent application is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2013 and 2014 data is incomplete and has been ignored.

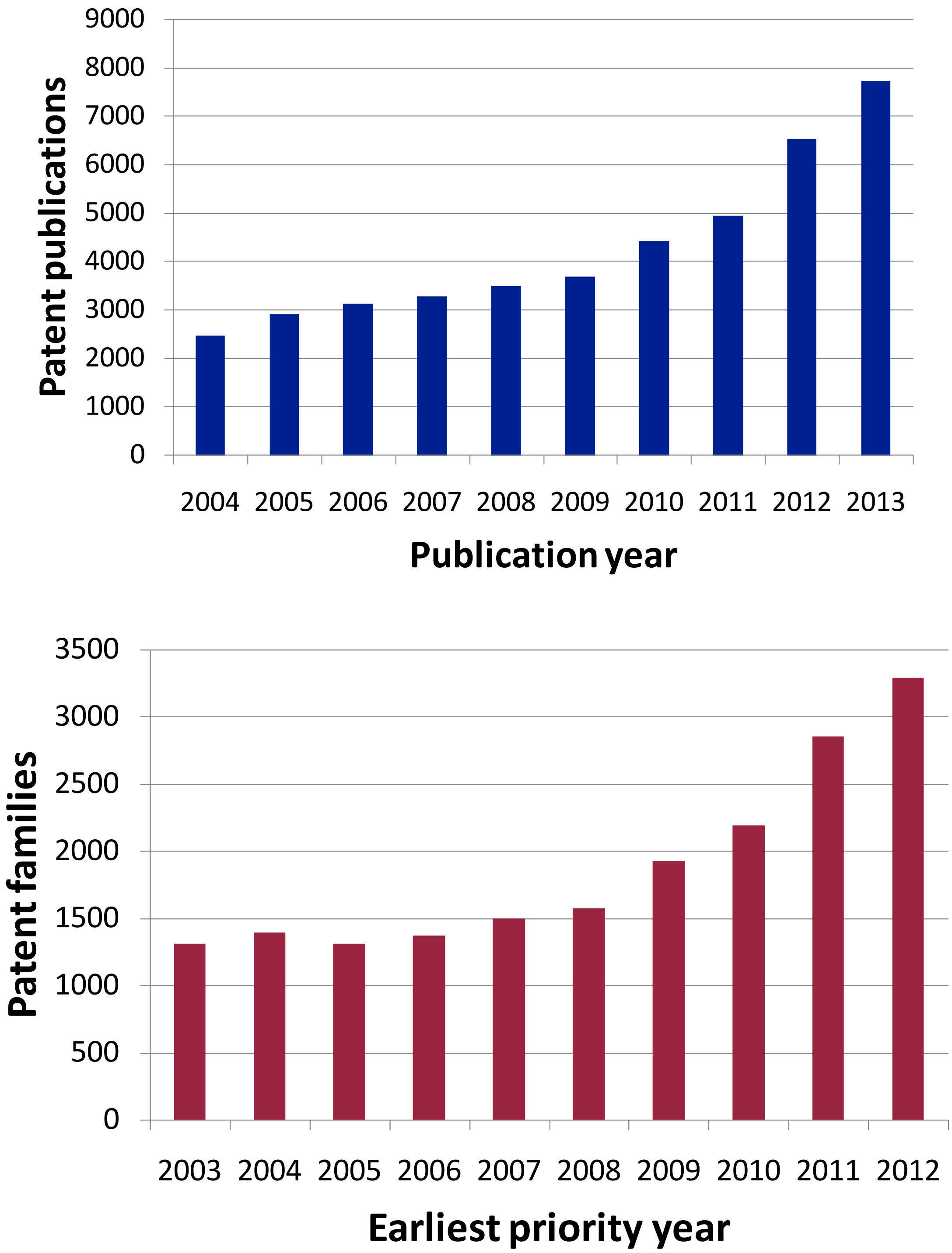

Figure 1: Patent publications by publication year (top) and patent families by priority year (bottom)

In real-world terms, only limited information can be gleaned from the generally upward trends shown in Figure 1 because overall patenting levels globally continue to grow at an ever-increasing rate. Figure 2 addresses this issue by normalising the data shown in Figure 1 and presenting the annual increase in the size of worldwide patent databases across all technologies against the year-on-year increase in the size of the forms of carbon dataset. For example, between 2012 and 2013 worldwide patenting across all areas of technology increased by 8.55% and this can be compared to a 32% increase in form of carbon patenting over the same time period.

Figure 2 shows that the increase in forms of carbon patenting (shown in Figure 1) is generally above the overall increase in the size of the worldwide patent databases across all technologies. This analysis served to highlight the importance of this area of technology worldwide.

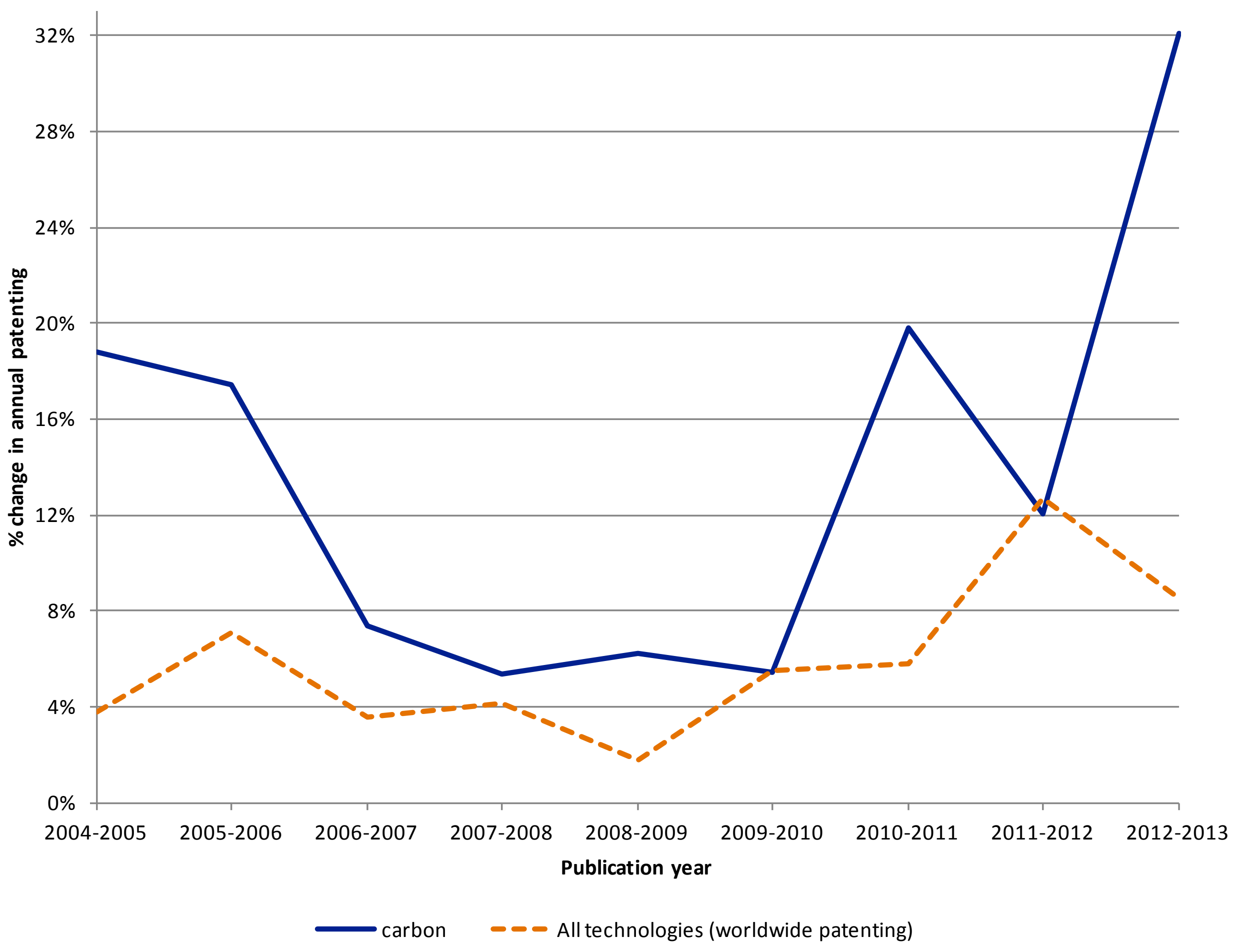

Figure 2: Year-on-year change in carbon patenting compared to worldwide patenting across all technologies

It is very difficult to draw accurate conclusions from simply presenting data based on the country of residence of patent applicants because there is a greater propensity to patent in certain countries than others. However the Relative Specialisation Index (RSI)[3] for each applicant country (Figure 3) has been calculated to give an indication of the level of invention in forms of carbon patenting for each country compared to the overall level of invention in that country.

The RSI shown in Figure 3 shows that Germany, Korea and the UK are relatively specialised in the field of forms of carbon with considerably more forms of carbon patents filed in these countries compared to the overall level of invention in those countries. The UK is ranked third with an RSI value of 0.295, suggesting that there are more form of carbon patents filed by UK applicants compared to the overall level of patenting from UK applicants across all technology areas.

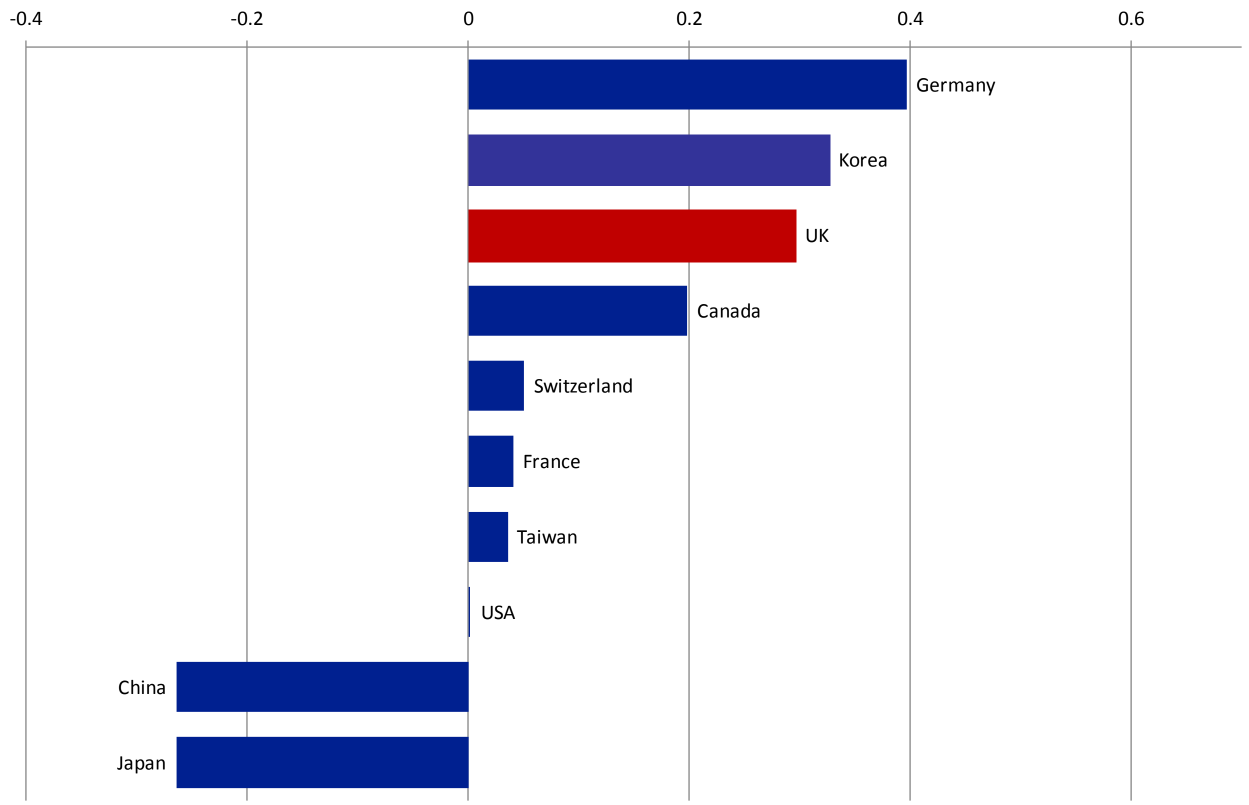

Figure 3: Relative Specialisation Index (RSI) by applicant country

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[3] See Appendix B for full details of how the Relative Specialisation Index is calculated.

2.1.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[4]. Figure 4 shows the top 20 applicants in the dataset with mostly major multinational companies; some of the patent applications are for tyre compositions such as those from Bridgestone and Sumitomo, relating to tyre compositions containing carbon black. Carbon black is a material that has many uses and can be included in tyre compositions as a reinforcing filler. It may also be used as a colour pigment or for modelling diesel oxidation experiments[5].

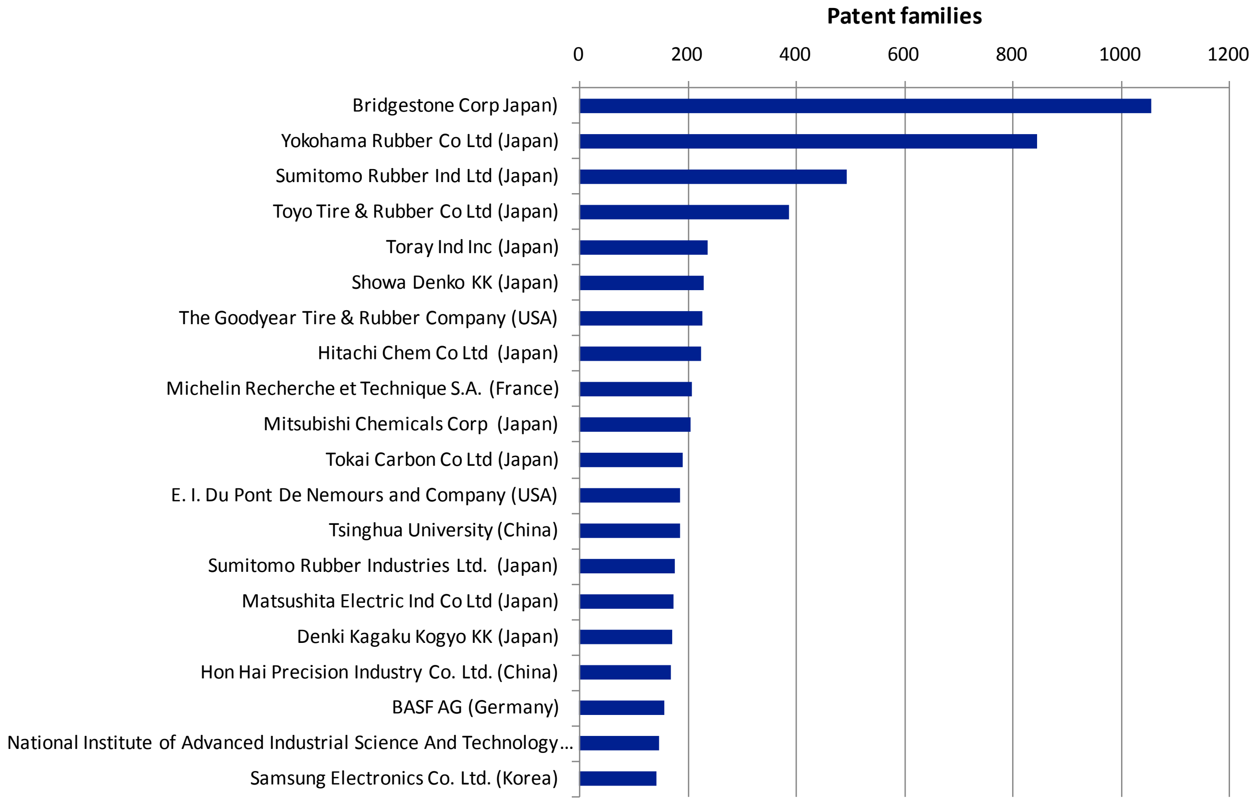

Figure 4: Top applicants

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[4] See Appendix A.4 for further details.

[5] A general list of information is available from: http://en.wikipedia.org/wiki/Carbon_black and http://www.cdc.gov/niosh/docs/81-123/pdfs/0102.pdf "Occupational Safety and Health Guideline for Carbon Black: Potential Human Carcinogen" (PDF). Centers of Disease Control and Prevention, National Institute for Occupational Safety and Health.

2.1.3 Technology breakdown

Figure 5 shows the top International Patent Classification (IPC) sub-groups and Table 5 lists the description of each of these sub-groups. The IPC provides for a hierarchical system of language-independent symbols for the classification of patent applications according to the different areas of technology to which they pertain. The tyre-related content is highlighted by some of the IPC terms listed i.e. B60C.

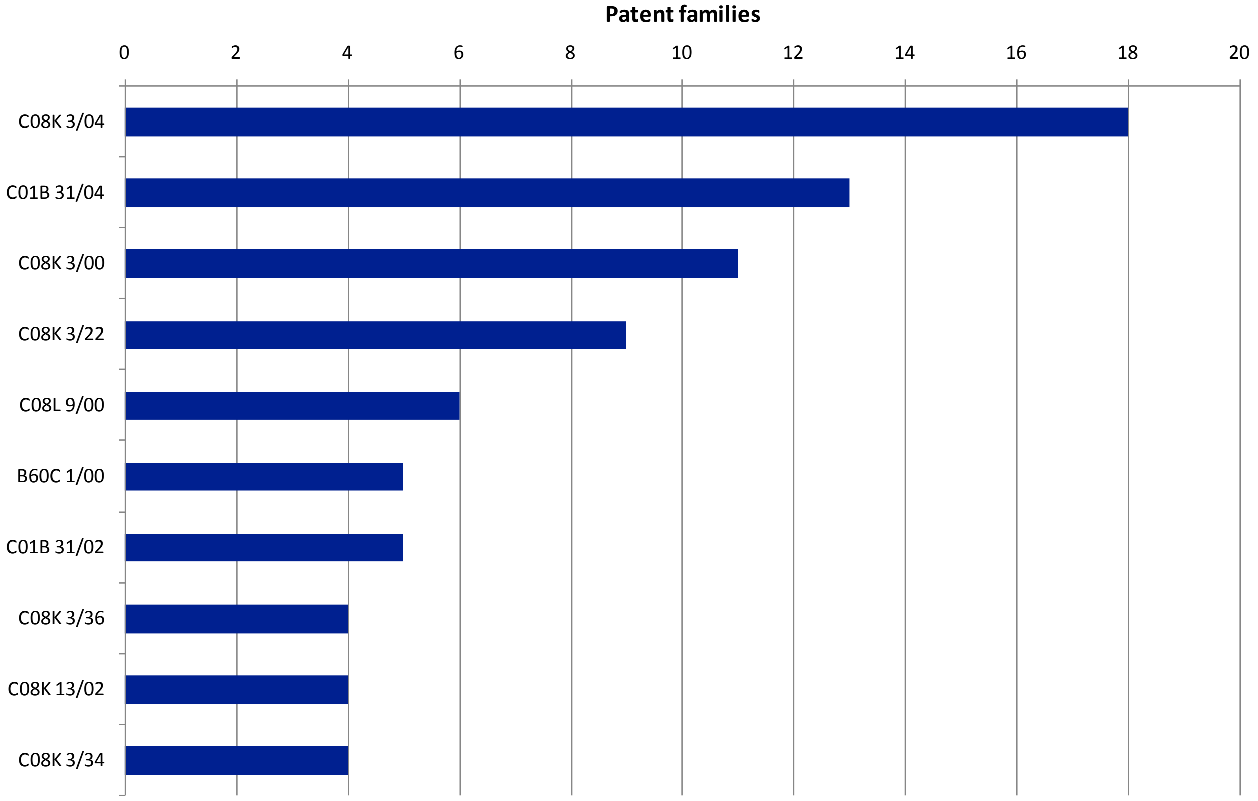

Figure 5: Top IPC sub-groups

Table 2: Key to IPC sub-groups referred to in Figure 5

C08K 3/04	Use of inorganic ingredients -> Elements -> Carbon
C01B 31/04	Carbon; Compounds thereof -> Preparation of carbon; Purification -> Graphite
C08K 3/00	Use of inorganic ingredients
C08K 3/22	Use of inorganic ingredients -> Oxygen-containing compounds, e.g. metal carbonyls -> Oxides; Hydroxides -> of metals
C08L 9/00	Compositions of homopolymers or copolymers of conjugated diene hydrocarbons
B60C 1/00	Tyres characterised by the chemical composition or the physical arrangement or mixture of the composition
C01B 31/02	Carbon; Compounds thereof -> Preparation of carbon; Purification
C08K 3/36	Use of inorganic ingredients -> Silicon-containing compounds -> Silica
C08K 13/02	Use of mixtures of ingredients not covered by any single one of main groups , each of these compounds being essential
C08K 3/34	Use of inorganic ingredients -> Silicon-containing compounds

2.2 Metamaterials

2.2.1 Overview

One of the defining characteristics of metamaterials is that the electromagnetic response results from combining two or more distinct materials in a specified way that extends the range of electromagnetic patterns.

Metamaterials can be defined as: "*macroscopic composites having a manmade, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation*"[6]

This means that metamaterials can be thought of as manmade materials with unusual properties not found in nature. Dr Driscoll[7] has created arrays of minuscule 'elements' that bend, scatter, transmit or otherwise shape electromagnetic radiation in different ways that no natural material can do.

Metamaterials are already known for some of the following attributes:

- Negative refractive index (invisibility cloaks)[8,9]
- Sound deadening cloaks[10]
- Cheaper satellite communications[11]
- Thinner smartphones [12]
- Ultrafast optical data processing[13]

Table 3 gives a summary of the extracted and cleaned dataset used for this analysis of metamaterial patent landscape. All of the analysis undertaken in this section of the report was performed on this dataset or a subset of this dataset. The dataset itself is relatively small but exhibits rapid growth in the numbers of patents. The worldwide dataset for

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6 The term was coined in 1999 by Rodger M. Walser of the University of Texas at Austin.
7 Dr Driscoll, currently working for Intellectual Ventures on meta materials: http://www.intellectualventures.com/insights/archives/dr.-david-r.-smith-joins-iv-to-commercialize-metamaterials-inventions/
8 Institute of Physics, Metamaterials, available from: http://www.iop.org/resources/topic/archive/metamaterials/
9 Invisibility Cloak Made From Silk, Discovery News (2013), available from: http://news.discovery.com/tech/silk-invisibility-cloak.htm
10 Metamaterials make 3D acoustic cloaking device, The Engineer, (2014), available from: http://www.theengineer.co.uk/channels/design-engineering/news/metamaterials-make-3d-acoustic-cloaking-device/1018181.article
11 http://www.kymetacorp.com/
12 Exotic optics: Metamaterial world, Billings, (2013) available from: http://www.nature.com/news/exotic-optics-metamaterial-world-1.13516
13 "Metamaterials manipulate light on a microchip." Penn State Materials Research Institute ScienceDaily. ScienceDaily, (2012). available from: http://www.sciencedaily.com/releases/2012/11/121124090509.htm

metamaterials patents published between 2004 and 2013 contains 328 published patents equating to 124 patent families. As stated earlier in Section 2.1.1, published patents may be at the application or grant stage, so are not necessarily granted patents. It should also be noted that the analysis is performed via patent family for reasons already set out in Section 2.1.1.

Table 3: Summary of worldwide patent dataset for metamaterials

Number of patent publications	328
Number of patent families	124
Publication year range	2004-2013
Peak publication year	2012
Top applicant	Kuang- Chi (China)
Number of patent assignees	137
Number of inventors	324
Priority countries	20
IPC sub-groups	352

Figure 6 shows the total number of published patents by publication year (top) and the total number of patent families by priority year (bottom – considered to be the best indication of when the original invention took place). Figure 6 suggests a general increase in metamaterials patenting between 2008 and 2012 but since 2012 this seems to have declined with a smaller number of publications in 2013. The patent family chart in red does not show any patents filed after 2012 because a patent application is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2013 and 2014 data is incomplete and has been ignored.

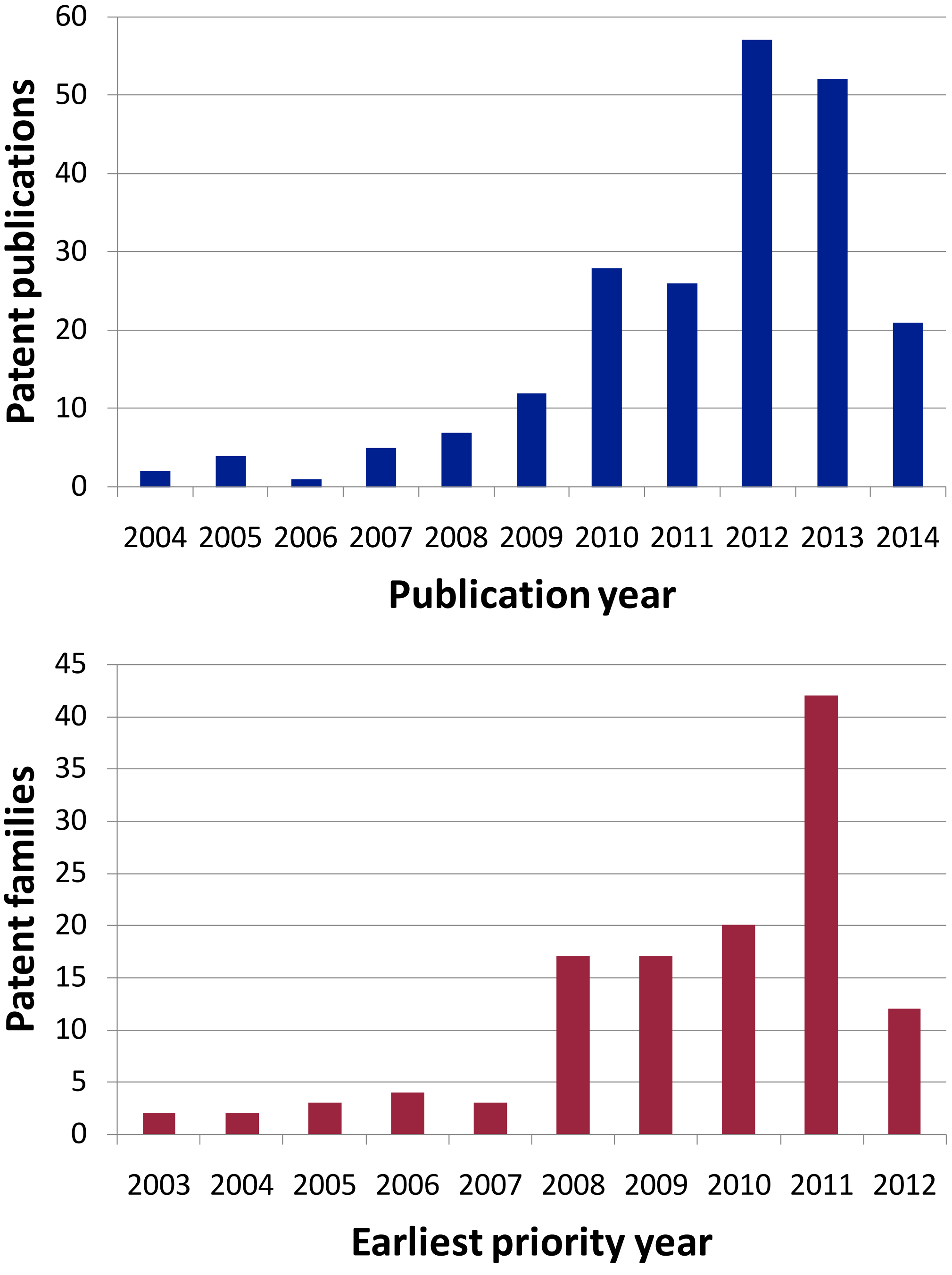

Figure 6: Patent publications by publication year (top) and patent families by priority year (bottom)

In real-world terms only limited information can be gleaned from the generally upward trends shown in Figure 6 because overall patenting levels globally continue to grow at an ever-increasing rate. However, a comparison with worldwide patenting in this field was not practicable given the small size of the dataset and has thus not been reproduced here.

For the same reasons data comparing RSI values cannot be presented. It is interesting to note that the numbers are all negative, suggesting that this area is still relatively emerging.

2.2.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[14]. Figure 7 shows the top 20 applicants in the dataset with a mixture of major multinational companies such as IBM and Boeing alongside academic institutions such as Isis Innovation, MIT and the University of Southampton.

The top applicant, Kuang-Chi from China, combines private scientific research and academic research institution. It is a series of research and innovation platforms of science and technology. It also helped establish the State Key Laboratory of Metamaterial Electromagnetic Modulation Technology, which focuses on research into metamaterials and electromagnetic modulation[15].

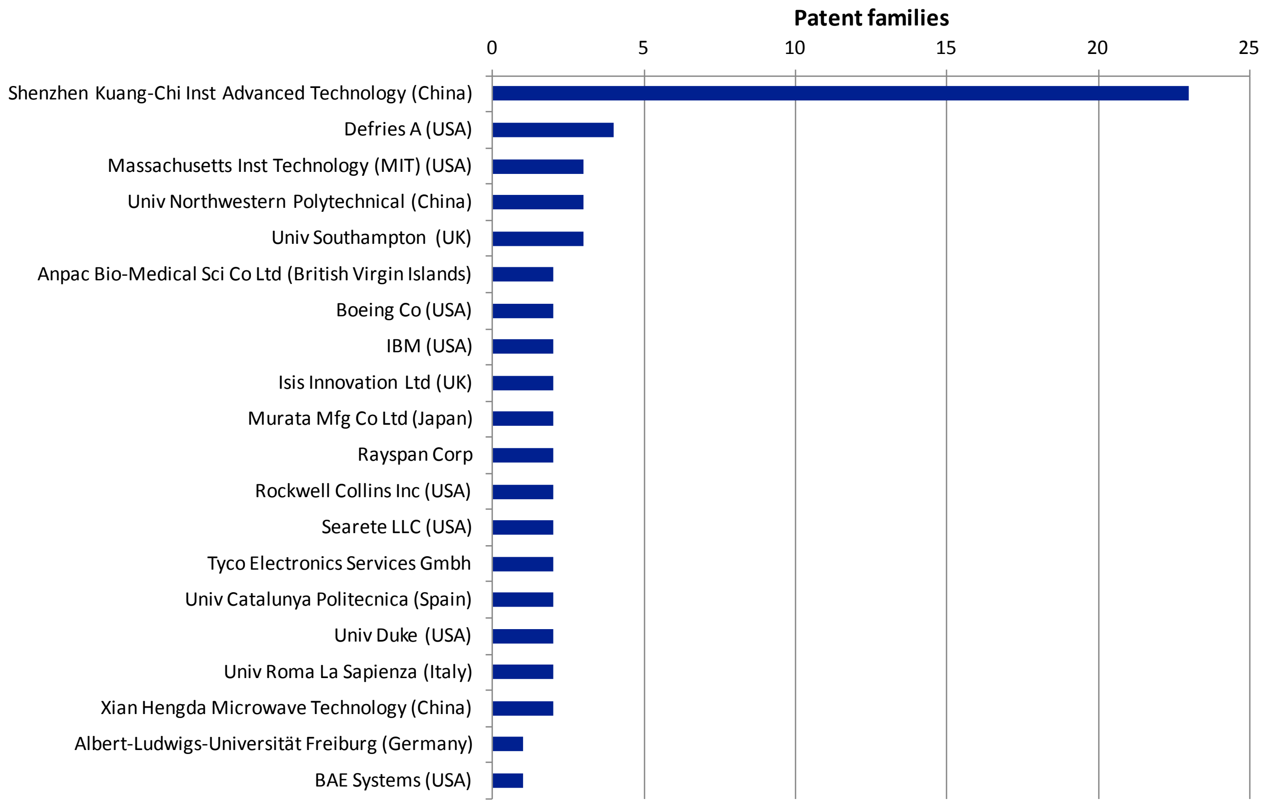

Figure 7: Top applicants

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[14] See Appendix A.4 for further details.

[15] The website gives more details, (last accessed 12 July 2014) http://www.kuang-chi.com/htmlen/about/

2.2.3 Technology breakdown

Figure 8 shows the top International Patent Classification (IPC) sub-groups and Table 4 lists the description of each of these sub-groups. The IPC provides for a hierarchical system of language-independent symbols for the classification of patent applications according to the different areas of technology to which they pertain. The marks mostly relate to optics but there is also a wide range of other technology areas highlighted, including nanotechnology.

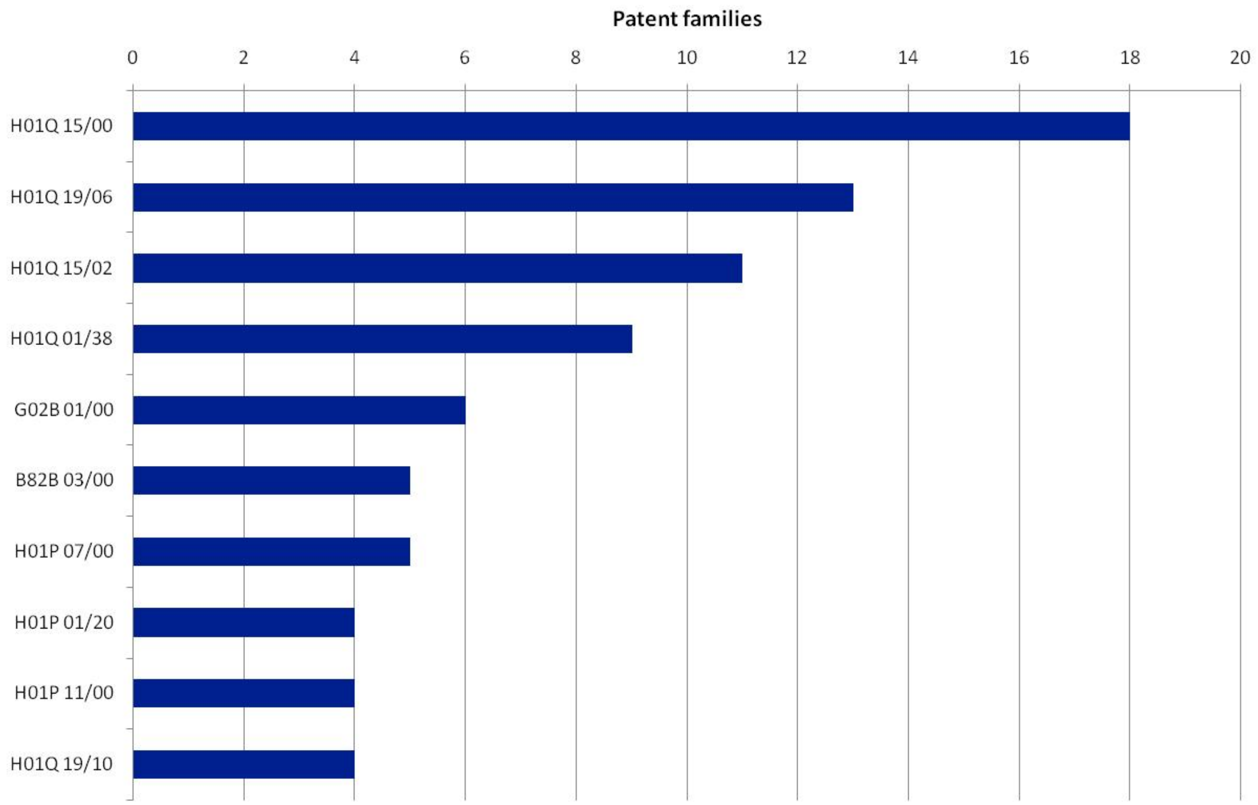


Figure 8: Top IPC sub-groups

Table 4: Key to IPC sub-groups referred to in Figure 12

H01Q 15/00	Devices for reflection, refraction, diffraction, or polarisation of waves radiated from an aerial, e.g. quasi-optical devices
H01Q 19/06	Combinations of primary active aerial elements and units with secondary devices, e.g. with quasi-optical devices, for giving the aerial a desired directional characteristic -> using refracting or diffracting devices, e.g. lens
H01Q 15/02	Devices for reflection, refraction, diffraction, or polarisation of waves radiated from an aerial, e.g. quasi-optical devices -> Refracting or diffracting devices, e.g. lens, prism
H01Q 01/38	Details of, or arrangements associated with, aerials -> Structural form of radiating elements, e.g. cone, spiral, umbrella -> formed by a conductive layer on an insulating support
G02B 01/00	Optical elements characterised by the material of which they are made; Optical coatings for optical elements
B82B 03/00	Manufacture or treatment of nano-structures by manipulation of individual atoms or molecules, or limited collections of atoms or molecules as discrete units
H01P 07/00	Resonators of the waveguide type
H01P 01/20	Auxiliary devices -> Frequency-selective devices, e.g. filters
H01P 11/00	Apparatus or processes specially adapted for manufacturing waveguides or resonators, lines, or other devices of the waveguide type
H01Q 19/10	Combinations of primary active aerial elements and units with secondary devices, e.g. with quasi-optical devices, for giving the aerial a desired directional characteristic -> using reflecting surfaces

2.3 Renewable energy enabling materials

2.3.1 Overview

Table 5 gives a summary of the extracted and cleaned dataset used for this analysis of the renewable energy materials patent landscape. All of the analysis undertaken in this section of the report was performed on this dataset or a subset of this dataset. The worldwide dataset for the renewable energy enabling materials patents published between 2004 and 2013 contains more than 80,000 published patents equating to over 23,000 patent families. As stated earlier in Section 2.1.1, published patents may be at the application or grant stage, so are not necessarily granted patents. It should also be noted that the analysis is performed via patent family for reasons already set out in Section 2.1.1.

Table 5: Summary of worldwide patent dataset for renewable energy enabling materials

Number of patent publications	80,302
Number of patent families	23,502
Publication year range	2004-2013
Peak publication year	2012
Top applicant	Sharp (Japan)
Number of patent assignees	8,353
Number of inventors	30,313
Priority countries	41
IPC sub-groups	7,102

Figure 9 shows the total number of published patents by publication year (top) and the total number of patent families by priority year (bottom – considered to be the best indication of when the original invention took place. Figure 9 suggests an increase in renewable energy enabling materials patenting over the time period of the dataset but since 2012 this steady rate has further accelerated. The patent family chart in red does not show any patents filed after 2012 because a patent application is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2013 and 2014 data is incomplete and has been ignored.

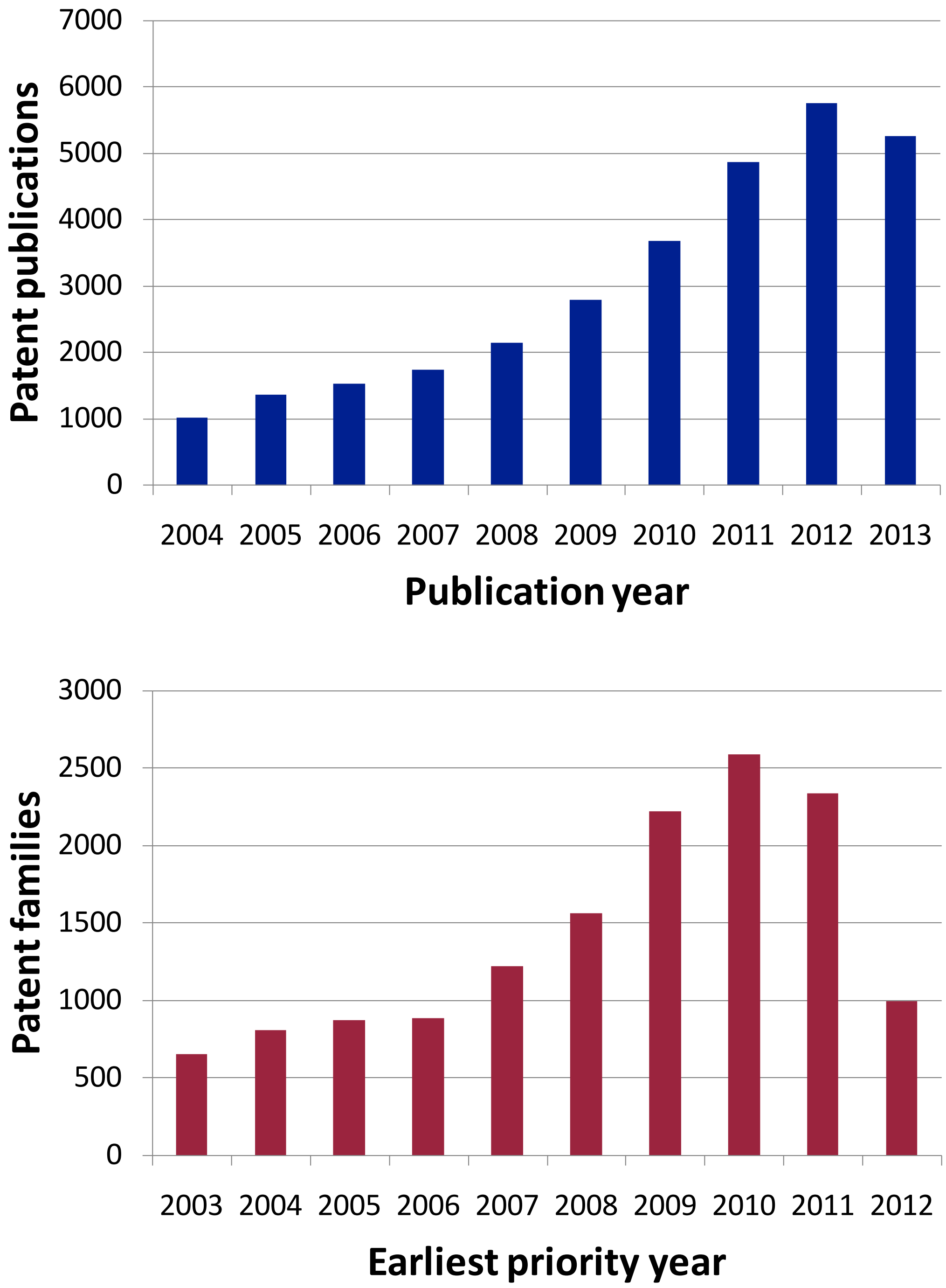


Figure 9: Patent publications by publication year (top) and patent families by priority year (bottom)

In real-world terms only limited information can be gleaned from the generally upward trends shown in Figure 9 because overall patenting levels globally continue to grow at an ever-increasing rate. Figure 10 addresses this issue by normalising the data shown in Figure 9 and presenting the annual increase in the size of worldwide patent databases across all technologies against the year-on-year increase in the size of the renewable energy enabling technologies dataset. For example, between 2010 and 2011 worldwide patenting across all areas of technology increased by about 6% and this can be compared to a 32% increase in renewable energy enabling technology patenting over the same time period.

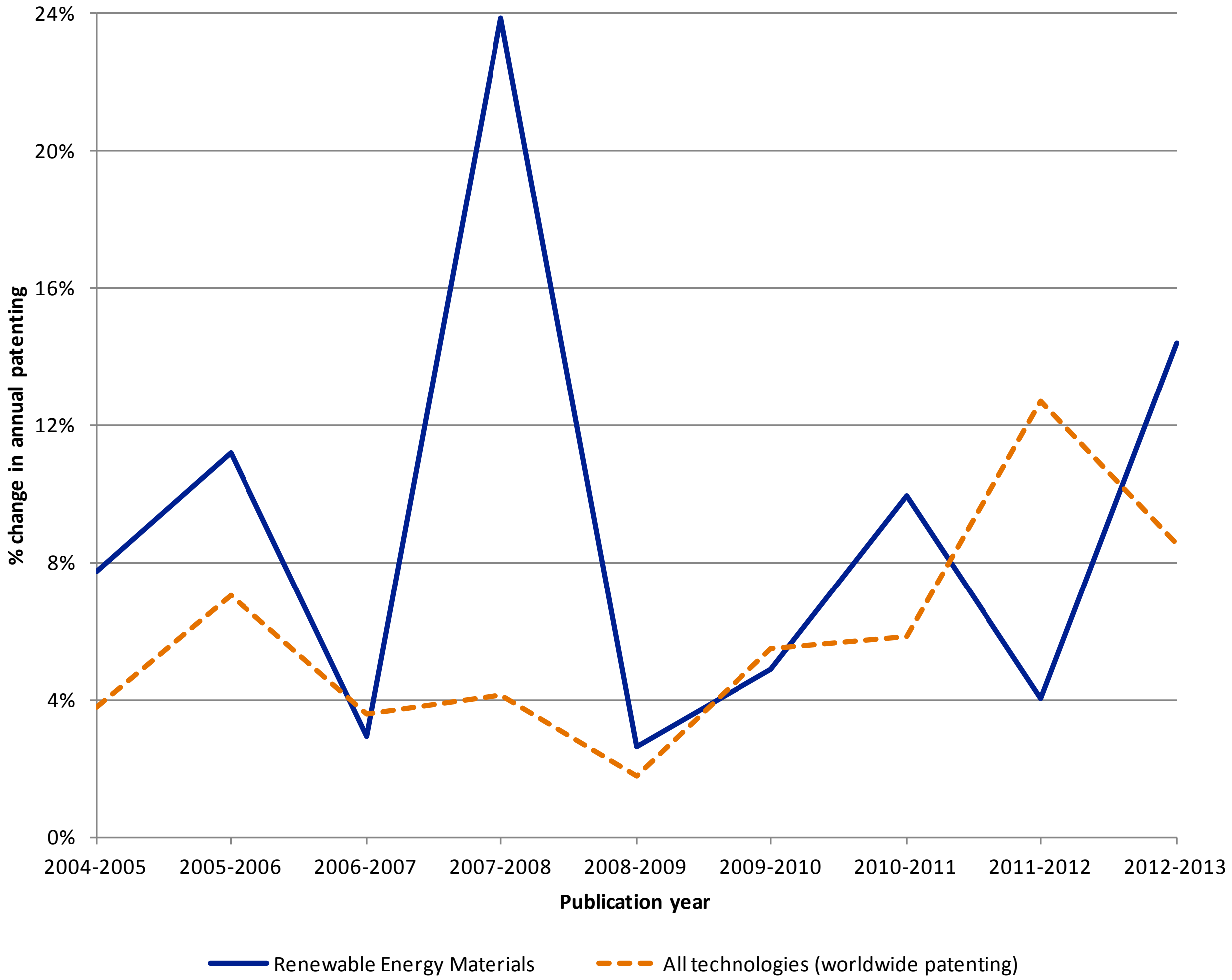


Figure 10: Year-on-year change in wearable technology patenting compared to worldwide patenting across all technologies

Figure 10 shows that there is an overall increase in patenting in the area of renewable energy enabling technology patenting (shown in Figure 9) and is on average, above the general increase in the size of the worldwide patent databases across all technologies.

It is very difficult to draw accurate conclusions from simply presenting data based on the country of residence of patent applicants because there is a greater propensity to patent in certain countries than others. However the Relative Specialisation Index (RSI)[16] for each applicant country (Figure 11) has been calculated to give an indication of the level of invention in renewable energy materials patenting for each country compared to the overall level of invention in that country.

The RSI shown in Figure 11 that both France and the UK are relatively specialised in the field of renewable energy materials with considerably more patents in renewable energy materials filed in these countries compared to the overall level of invention in those

[16] See Appendix B for full details of how the Relative Specialisation Index is calculated.

countries. The performance of the UK suggests that there is more interest in this area of activity from UK applicants compared to the overall level of patenting from UK applicants across all technology areas.

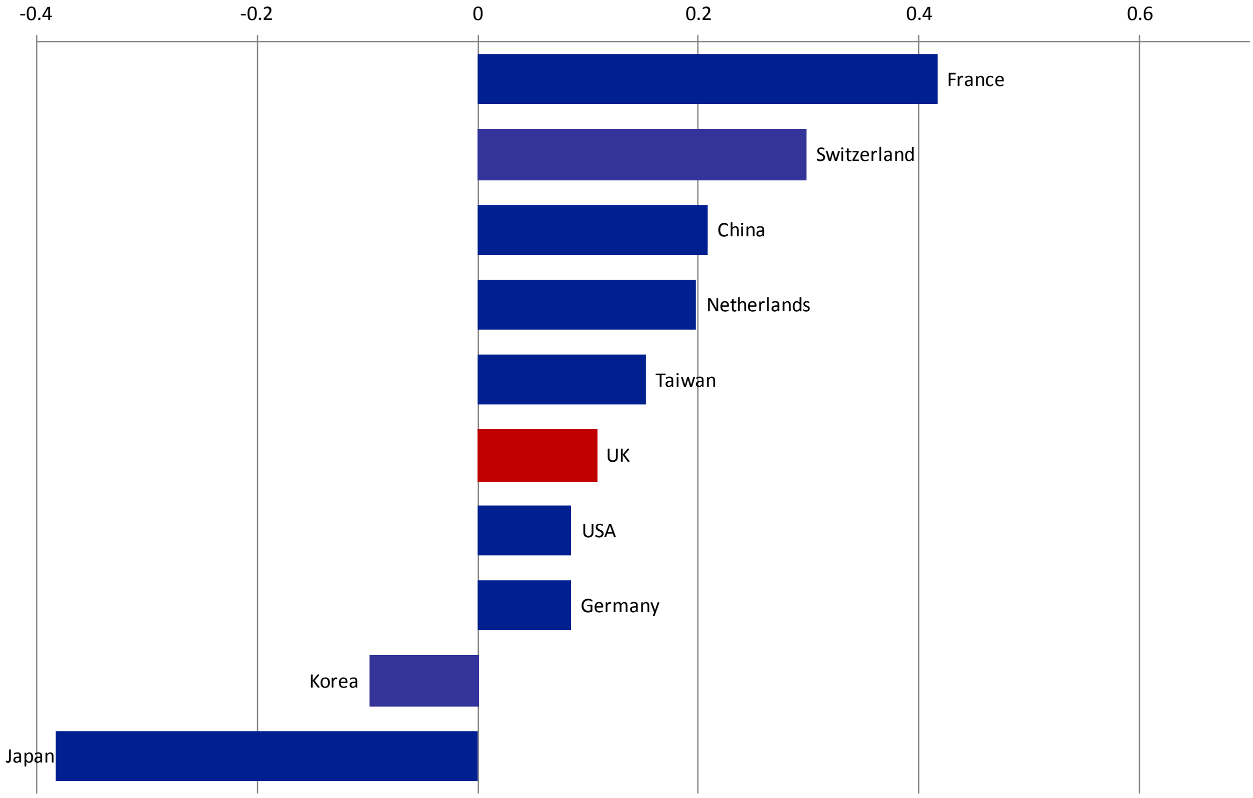


Figure 11: Relative Specialisation Index (RSI) by applicant country

2.3.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[17]. Figure 12 shows the top 20 applicants in the dataset with many major multinational companies such as Sharp and Mitsubishi.

This plot emphasises the different technologies which are encompassed within the current search as is evident from the list of top applicants; many of the patents in this dataset include methods of forming films for solar cells.

[17] See Appendix A.4 for further details.

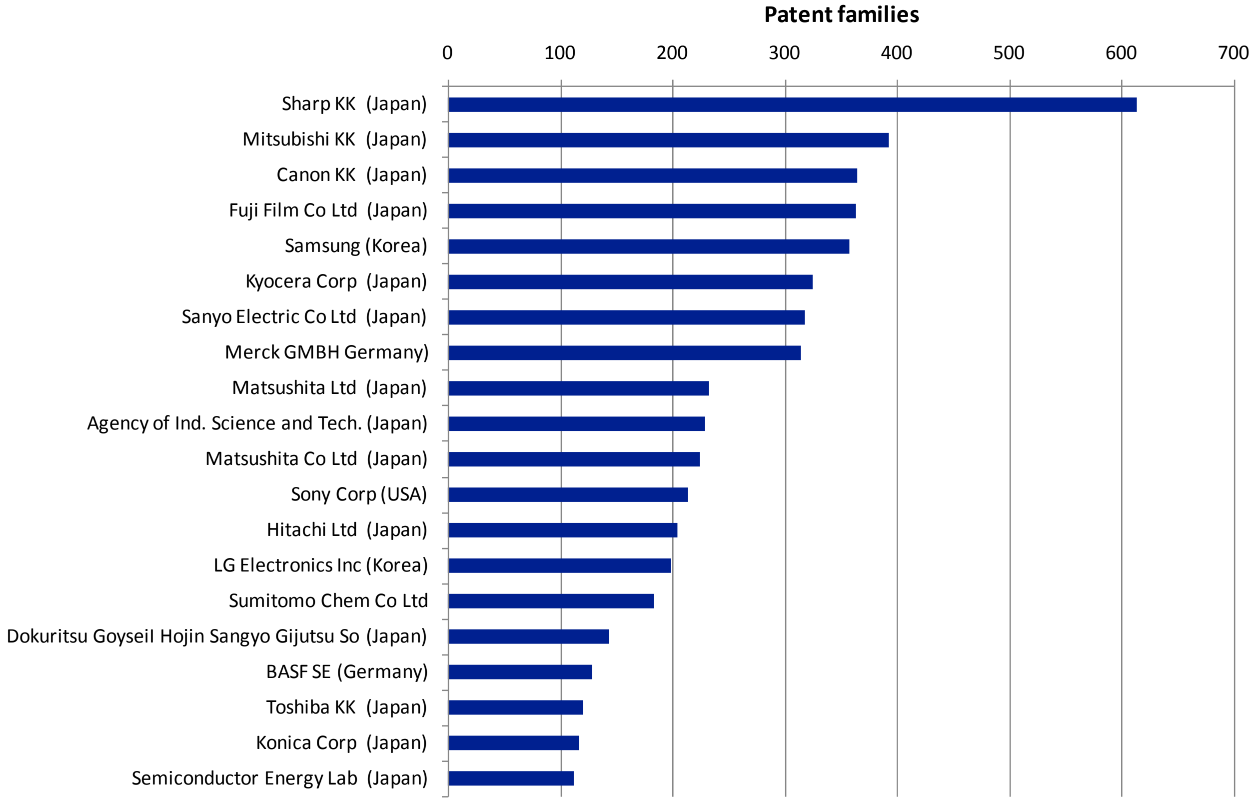


Figure 12: Top applicants

2.3.3 Technology breakdown

Figure 13 shows the top International Patent Classification (IPC) sub-groups and Table 6 lists the description of each of these sub-groups. The IPC provides for a hierarchical system of language-independent symbols for the classification of patent applications according to the different areas of technology to which they pertain. There is a concentration of IPC terms that relate to gas purification. This dataset also contains a large amount of data relating to semiconductors and their use in solar cells.

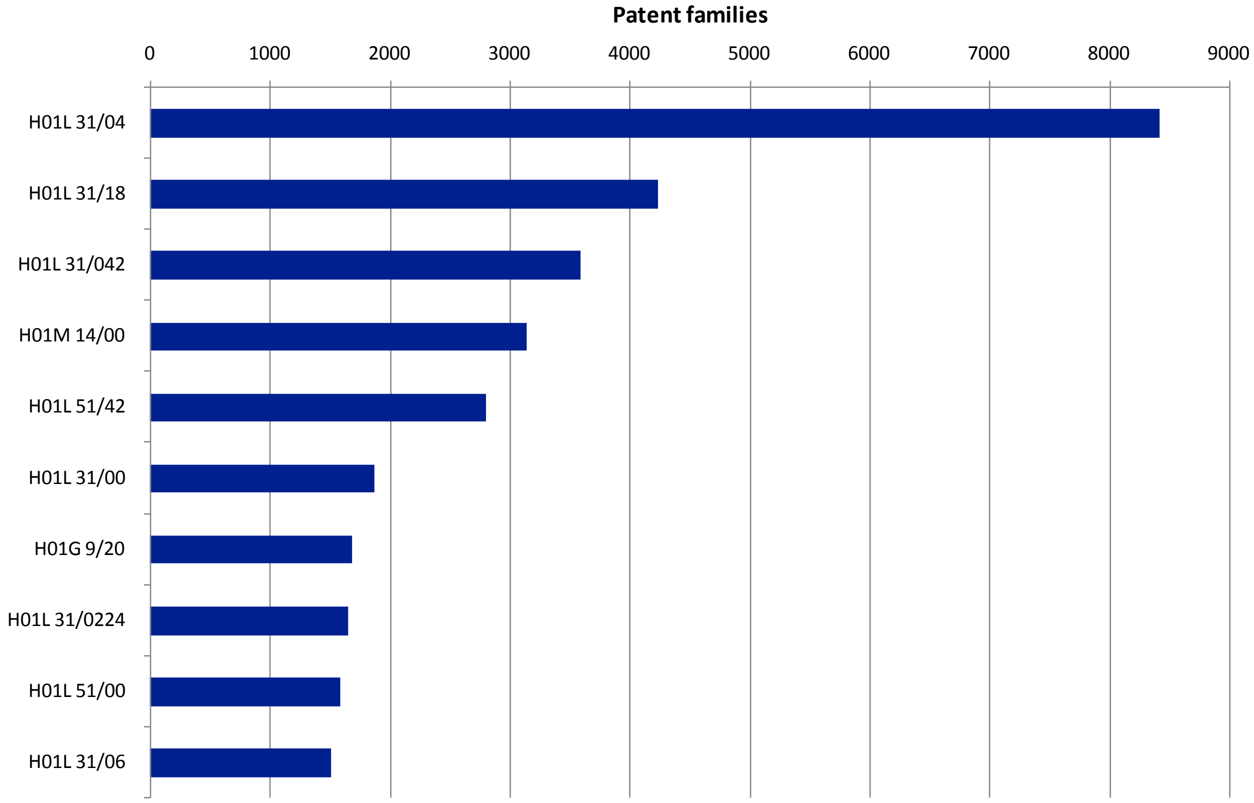


Figure 13: Top IPC sub-groups

Table 6: Key to IPC sub-groups referred to in Figure 13

H01L 31/04	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof -> adapted as conversion devices
H01L 31/18	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof -> Processes or apparatus specially adapted for the manufacture or treatment of these devices or of parts thereof
H01L 31/042	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof -> adapted as conversion devices -> including a panel or array of photoelectric cells, e.g. solar cells
H01M 14/00	Electrochemical current or voltage generators not provided for; Manufacture thereof
H01L 51/42	Solid state devices using organic materials as the active part, or using a combination of organic materials with other materials as the active part; Processes or apparatus specially adapted for the manufacture or treatment of such devices, or of parts thereof -> specially adapted for sensing infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation; specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation
H01L 31/00	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof
H01G 9/20	Electrolytic capacitors, rectifiers, detectors, switching devices, light-sensitive or temperature-sensitive devices; Processes of their manufacture -> Light-sensitive devices
H01L 31/0224	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy

	of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof -> Details -> Electrodes
H01L 51/00	Solid state devices using organic materials as the active part, or using a combination of organic materials with other materials as the active part; Processes or apparatus specially adapted for the manufacture or treatment of such devices, or of parts thereof
H01L 31/06	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof -> adapted as conversion devices -> characterised by at least one potential-jump barrier or surface barrier

2.4 Wearable technology

2.4.1 Overview

Wearable technology is also an area where there is increasing levels of interest. This is in part due to the media coverage and interest in high profile launches of such technologies[18,19.] This technology also has potential health and sport uses[20,21,22]

Table 7 gives a summary of the extracted and cleaned dataset used for this analysis of the wearable technology patent landscape. All of the analysis undertaken in this section of the report was performed on this dataset or a subset of this dataset. The worldwide dataset for wearable technology patents published between 2004 and 2013 contains more than 40,000 published patents equating to over 18,000 patent families. As stated earlier in Section 2.1.1, published patents may be at the application or grant stage, so are not necessarily granted patents. It should also be noted that the analysis is performed via patent data for reasons already set out in Section 2.1.1.

Table 7: Summary of worldwide patent dataset for wearable technology

Number of patent publications	40,477
Number of patent families	18,491
Publication year range	2004-2013
Peak publication year	2013
Top applicant	Seiko (Japan)
Number of patent assignees	15,711
Number of inventors	35,777
Priority countries	64
IPC sub-groups	12,575

[18]The Glass Explorer Programme. Now in the UK, more details are available from: https://www.google.co.uk/intl/en/glass/start/

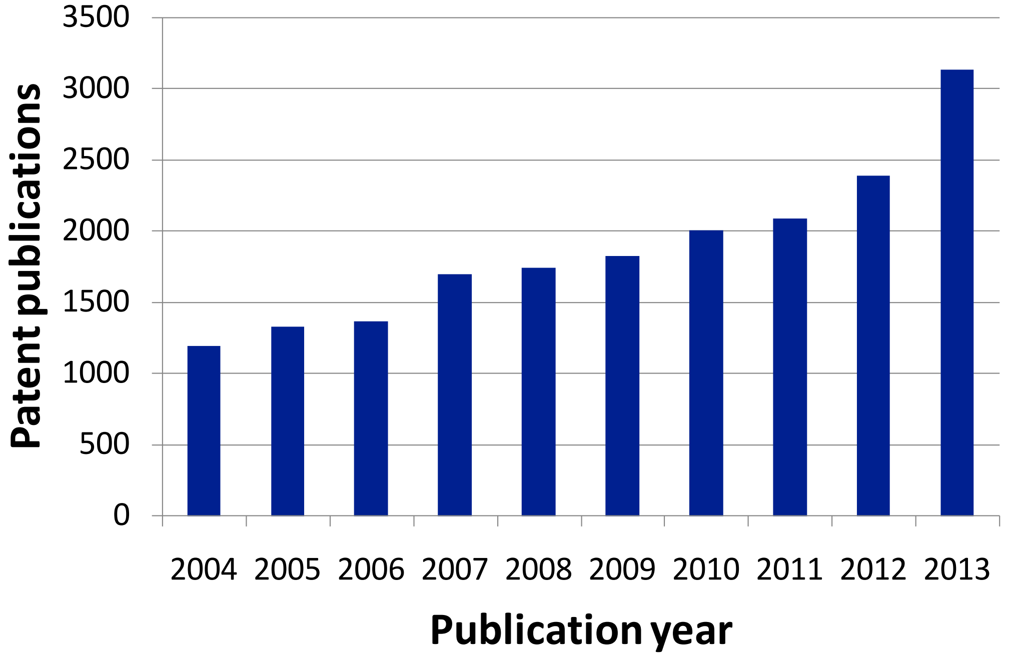
[19] Samsung Introduces GALAXY Gear, a Wearable Device to Enhance the Freedom of Mobile Communications, (2013), available from:http://www.samsung.com/us/news/21647

[20] Apple's Nike+iPod Sport Kit to drop this week, a combined shoe sensor and smartphone app, (2012) available from: http://forums.appleinsider.com/t/64829/apples-nike-ipod-sport-kit-to-drop-this-week

[21] Football shirt with on board computer, (2001) BBC available from: http://news.bbc.co.uk/1/hi/education/1678754.stm

[22] High tech football shirt measures players' work rate in £50m Spurs deal (2011) CNET, available from: http://www.cnet.com/uk/news/high-tech-football-shirt-measures-players-work-rate-in-50m-spurs-deal/

Figure 14 shows the total number of published patents by publication year (top) and the total number of patent families by priority year (bottom – considered to be the best indication of when the original invention took place). Figure 9 suggests an increase in wearable technology patenting between the time period of the dataset but since 2012 this steady rate has further accelerated. The patent family chart in red does not show any patents filed after 2012 because a patent application is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2013 and 2014 data is incomplete and has been ignored.



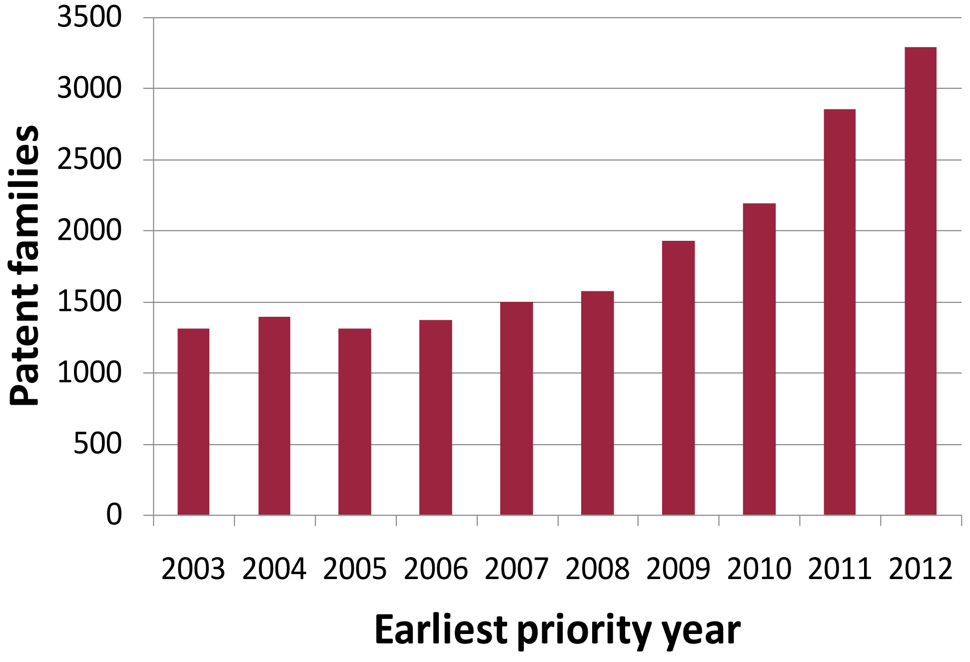


Figure 14: Patent publications by publication year (top) and patent families by priority year (bottom)

In real-world terms only limited information can be gleaned from the generally upward trends shown in Figure 14 because overall patenting levels globally continue to grow at an ever-increasing rate. Figure 15 addresses this issue by normalising the data shown in Figure 14 and presenting the annual increase in the size of worldwide patent databases across all technologies against the year-on-year increase in the size of the wearable technology dataset. For example, between 2012 and 2013 worldwide patenting across all areas of technology increased by 8.55% and this can be compared to a 32% increase in wearable technology patenting over the same time period.

Figure 15 shows that the increase in wearable technology patenting in the first half of the last decade (shown in Figure 1) is well above the general increase in the size of the worldwide patent databases across all technologies. This analysis also serves to highlight the high levels of innovation in wearable technology captured in patents.

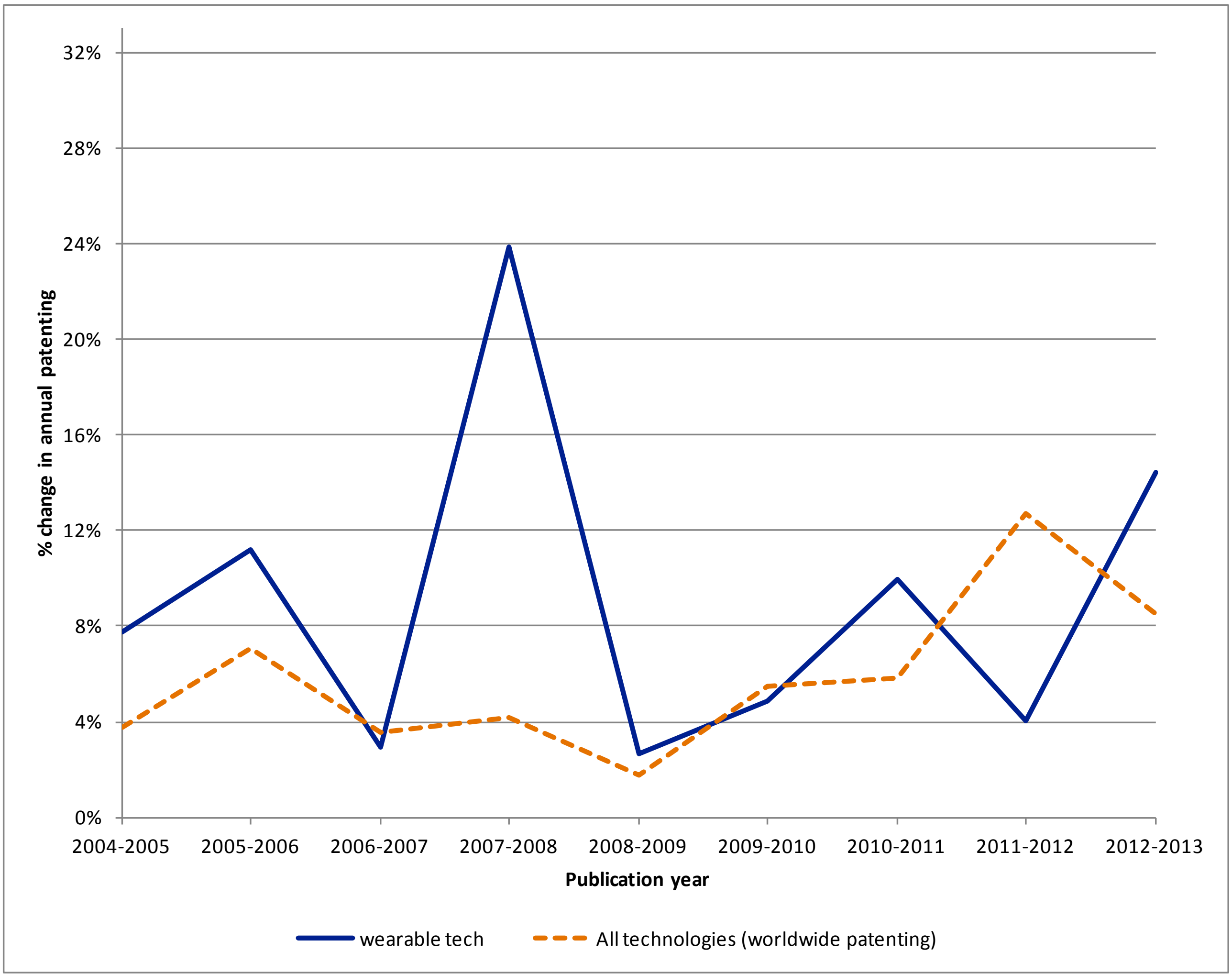


Figure 15: Year-on-year change in wearable technology patenting compared to worldwide patenting across all technologies

It is very difficult to draw accurate conclusions from simply presenting data based on the country of residence of patent applicants because there is a greater propensity to patent in certain countries than others. However the Relative Specialisation Index (RSI)[23] for each applicant country (Figure 16Figure 11) has been calculated to give an indication of the level of invention in renewable energy materials patenting for each country compared to the overall level of invention in that country.

The RSI of in Figure 16 shows that both China and Germany are relatively specialised in the field of wearable technology materials with considerably more patents in wearable technology materials filed in these countries compared to the overall level of invention in those countries. The UK is listed in the top ten countries according to RSI value.

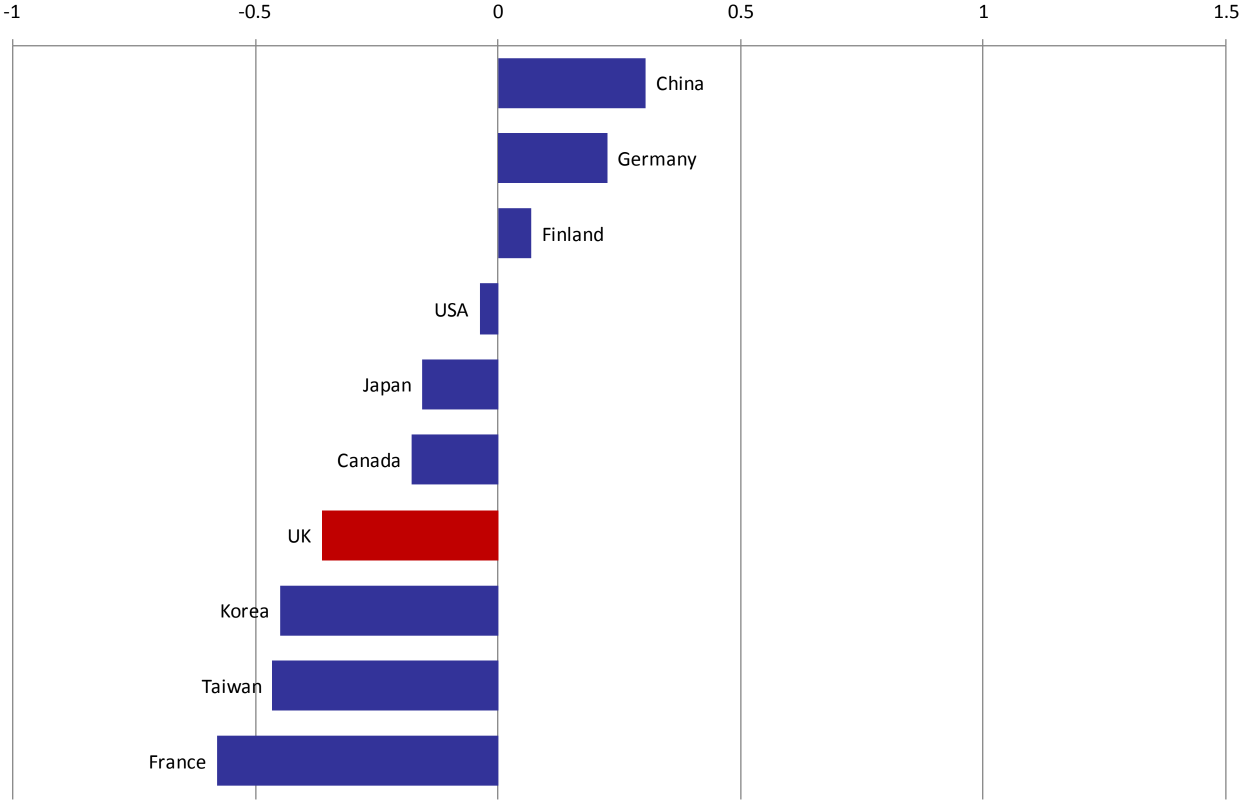


Figure 16: Relative Specialisation Index (RSI) by applicant country

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[23] See Appendix B for full details of how the Relative Specialisation Index is calculated.

2.4.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[24]. Figure 17 shows the top 20 applicants in the dataset with many major multinational companies such as Seiko Epson, Ricoh and Samsung. It is notable that most of these applicants are Japanese. There are already exhibitions/conference relating to wearable technology occurring in Japan[25].

Epson have created "smart glasses" which allow images projected by a drone to be transferred in real time to rescue workers on the ground as well as glasses that may be used in more urban settings[26]. This plot is restricted to large multinational companies. There are no wholly UK based applicants.

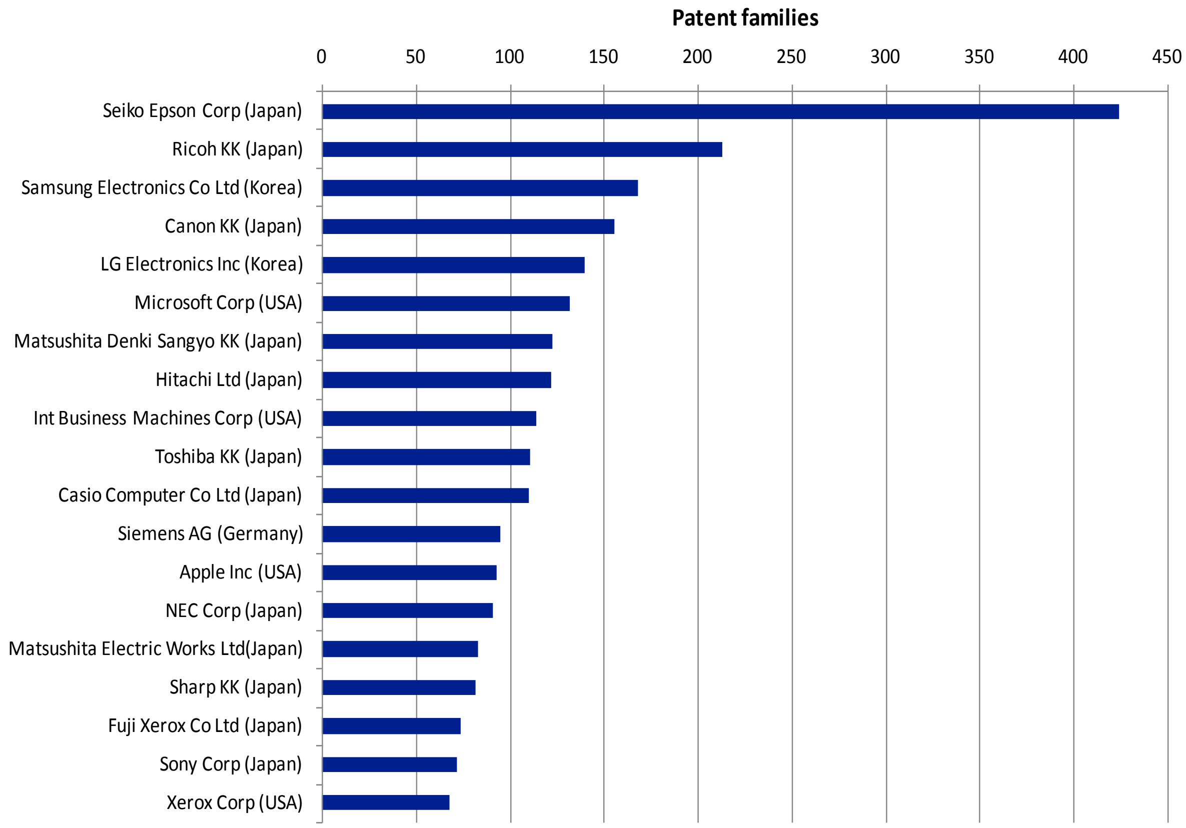

Figure 17: Top applicants

[24] See Appendix A.4 for further details.

[25] More information is available from the following links (2014): https://www.wearabletechjapan.com/, http://www.techinasia.com/tag/wearable-tech/ http://fortune.com/2014/04/02/japans-tech-startups-bet-on-wearables-in-the-u-s/

[26] Epson's Moverio Smart Glasses Tested in Disaster Response System, (2014) available from: http://global.epson.com/innovation/technology_articles/201406_01.html and http://www.youtube.com/watch?v=zAY9fcgSH2U&list=UUhYlBwEOeAKUHNfjw0b_BjA

2.4.3 Technology breakdown

Figure 18 shows the top International Patent Classification (IPC) sub-groups and Table 6 lists the description of each of these sub-groups. The IPC provides for a hierarchical system of language-independent symbols for the classification of patent applications according to the different areas of technology to which they pertain.

The IPC marks and the technologies to which they relate are shown in Figure 18 and Table 7. For instance the top IPC mark relates to optics and liquid crystal displays. The next two marks relate to television receiver circuitry.

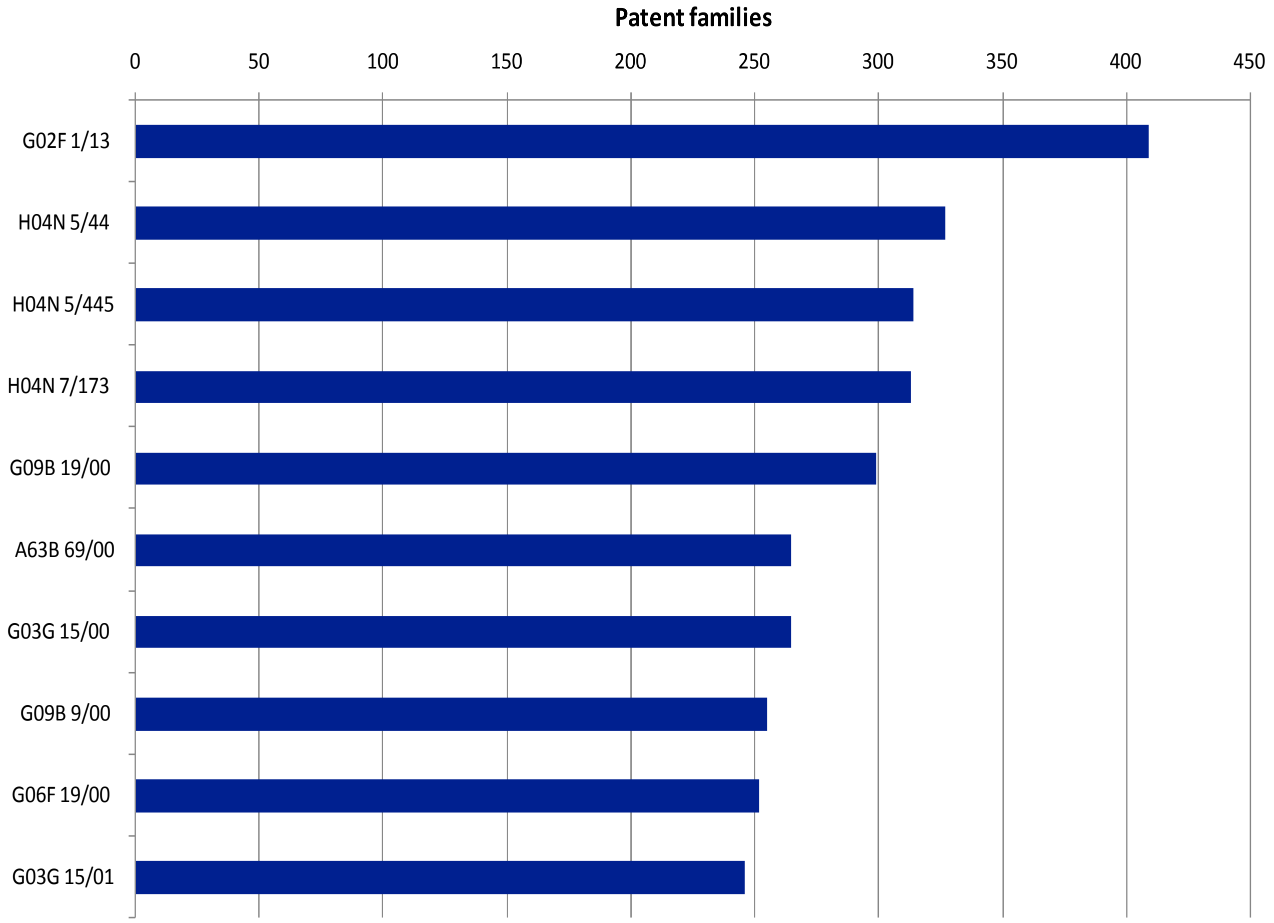

Figure 18: Top IPC sub-groups

Table 8: Key to IPC sub-groups referred to in Figure 18

G02F 1/13	Devices or arrangements for the control of the intensity, colour, phase, polarisation or direction of light arriving from an independent light source, e.g. switching, gating or modulating; Non-linear optics -> for the control of the intensity, phase, polarisation or colour -> based on liquid crystals, e.g. single liquid crystal display cells
H04N 5/44	Details of television systems -> Receiver circuitry
H04N 5/445	Details of television systems -> Receiver circuitry -> for displaying additional information
H04N 7/173	Television systems -> Analogue secrecy systems; Analogue subscription systems -> with two-way working, e.g. subscriber sending a programme selection signal
G09B 19/00	Teaching not covered by other main groups of this subclass
A63B 69/00	Training appliances or apparatus for special sports
G03G 15/00	Apparatus for electrographic processes using a charge pattern
G09B 9/00	Simulators for teaching or training purposes
G06F 19/00	Digital computing or data processing equipment or methods, specially adapted for specific applications
G03G 15/01	Apparatus for electrographic processes using a charge pattern -> for producing multicoloured copies

3 The UK landscape

3.1 Forms of carbon

3.1.1 Top UK applicants

Figure 16: Relative Specialisation Index (RSI) by applicant country shows the top UK-based applicants within the forms of carbon dataset. There is considerable academic interest[27] (partially from university technology transfer companies) in this area from Cambridge, Oxford (Isis Innovation[28] is the name of the technology transfer group of Oxford University) and Manchester Universities. The IPC marks relating to this sub dataset (Table 9) shows that UK strengths lie in the area of nanotechnology. The Aerospace interest (Airbus and BAE) focuses on nano-sized carbon elements for use in composites. A number of multinationals are listed in Figure 19.

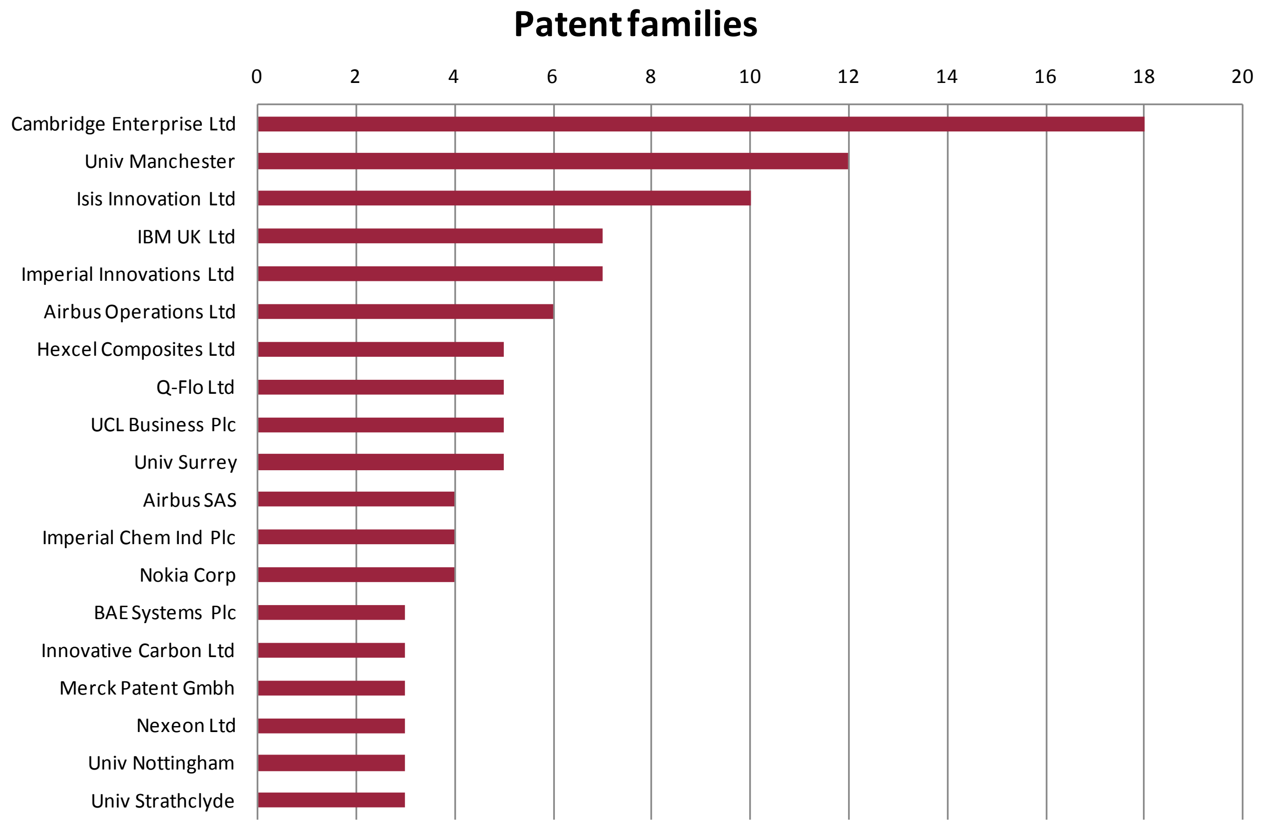

Figure 19: Top UK applicants

[27] Britain's big bet on graphene, Brumfiel, (2012)Nature, available from http://www.nature.com/news/britain-s-big-bet-on-graphene-1.11124, Graphene, Manchester University, (2014) available from: http://www.graphene.manchester.ac.uk/ , Graphene research at the University of Oxford, available from (2014) :http://fng.materials.ox.ac.uk/Main/NanotubesAndGrapheneProjects

[28] More information is available from: http://www.isis-innovation.com/ (2014)

Table 9: Top IPC marks of UK applicant data

C08K 3/04	Use of inorganic ingredients -> Elements -> Carbon
C01B 31/02	Carbon; Compounds thereof -> Preparation of carbon; Purification
B82Y 30/00	Nano-technology for materials or surface science, e.g. nano-composites
C01B 31/04	Carbon; Compounds thereof -> Preparation of carbon; Purification -> Graph
C08K 3/00	Use of inorganic ingredients
C01B 31/00	Carbon; Compounds thereof
B82Y 40/00	Manufacture or treatment of nano-structures
B82B 3/00	Manufacture or treatment of nano-structures by manipulation of individual atoms or molecules, or limited collections of atoms or molecules as discrete units
C08J 5/00	Manufacture of articles or shaped materials containing macromolecular substances
H01B 1/24	Conductors or conductive bodies characterised by the conductive materials; Selection of materials as conductors -> Conductive material dispersed in non-conductive organic material -> the conductive material comprising carbon-silicon compounds, carbon, or silicon

3.1.2 Collaboration

Figure 20 is a collaboration map showing all collaborations between the top ten UK applicants in the dataset and other members of the top ten applicants. Each dot on the collaboration map represents a patent family and two applicants are linked together if they are named as joint applicants on a patent application. A collaboration map indicates instances where joint work in solving a problem has resulted in a shared application for a patent.

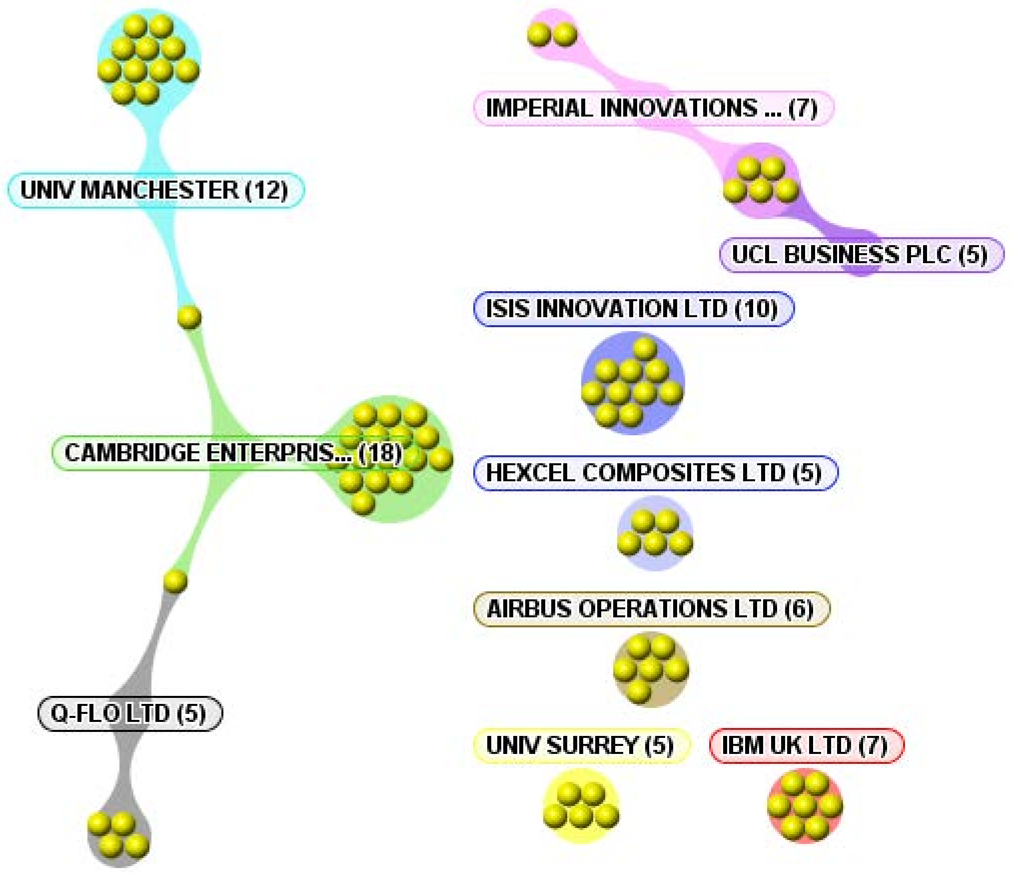

Figure 20: Collaboration map showing all collaborations between the top 10 UK applicants

Figure 20 shows that most of the large multinationals in the top 10 have not collaborated together. However, a few of the top applicants (Manchester, Cambridge, Imperial and UCL Universities) have worked together on joint patent applications.

3.1.3 How active is the UK?

A subset of the main worldwide patent dataset designed to reflect UK patenting activity was selected, Figure 21 shows the annual change in forms of carbon patenting arising from UK patenting activity against the worldwide year-on-year change in this field (Figure 2). The worldwide forms of carbon patenting activity is greater than that in the UK for five of the nine data points plotted in Figure 21. The UK does not appear to have any entry over the time period 2007-2008 and is not therefore listed on the plot.

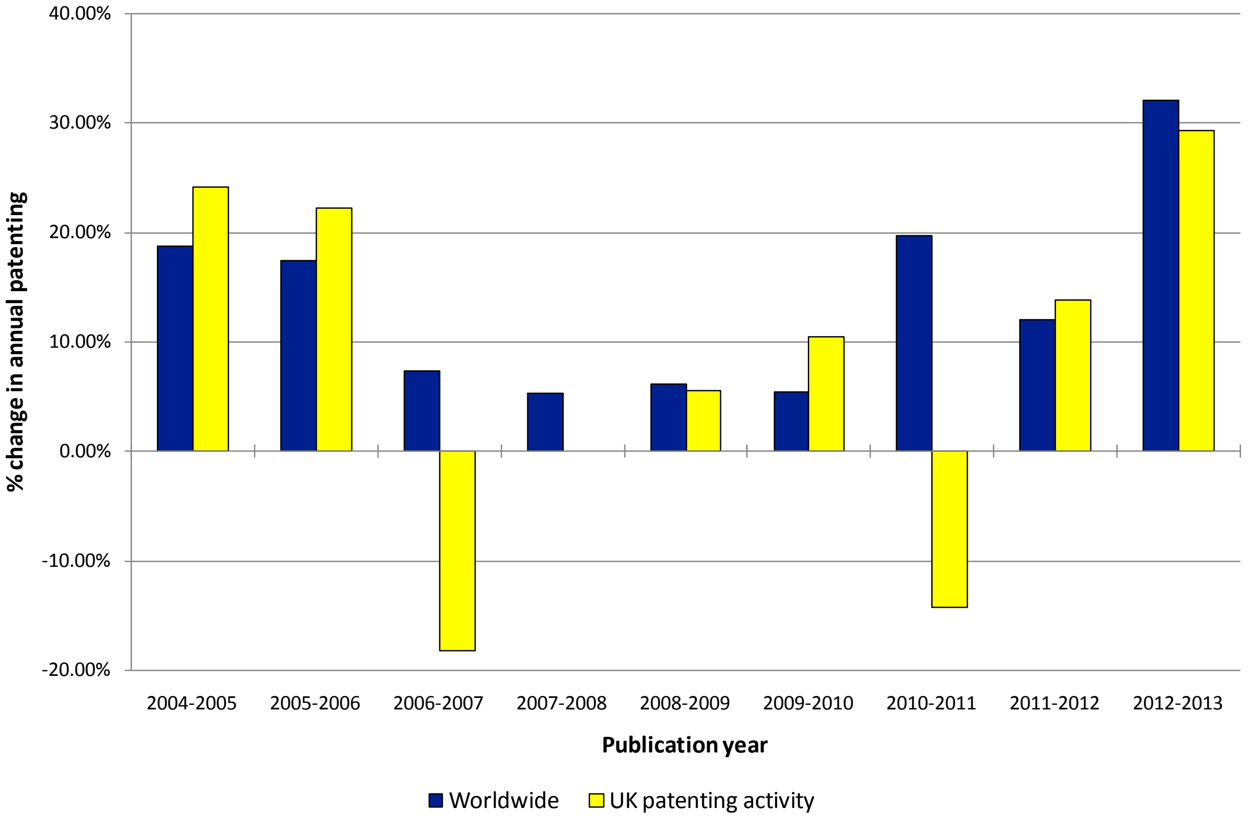

Figure 21: Year-on-year change in UK and worldwide patenting

Similar patent subsets were created to reflect patenting activity taking place in several comparator countries (France, Germany, USA, Japan and China) to produce the comparison chart shown in Figure 22. China and France appear to have the greatest changes in patenting activity over the time period of this dataset. The difference in increase in numbers of patents is notably 2012-2013 in the Chinese data.

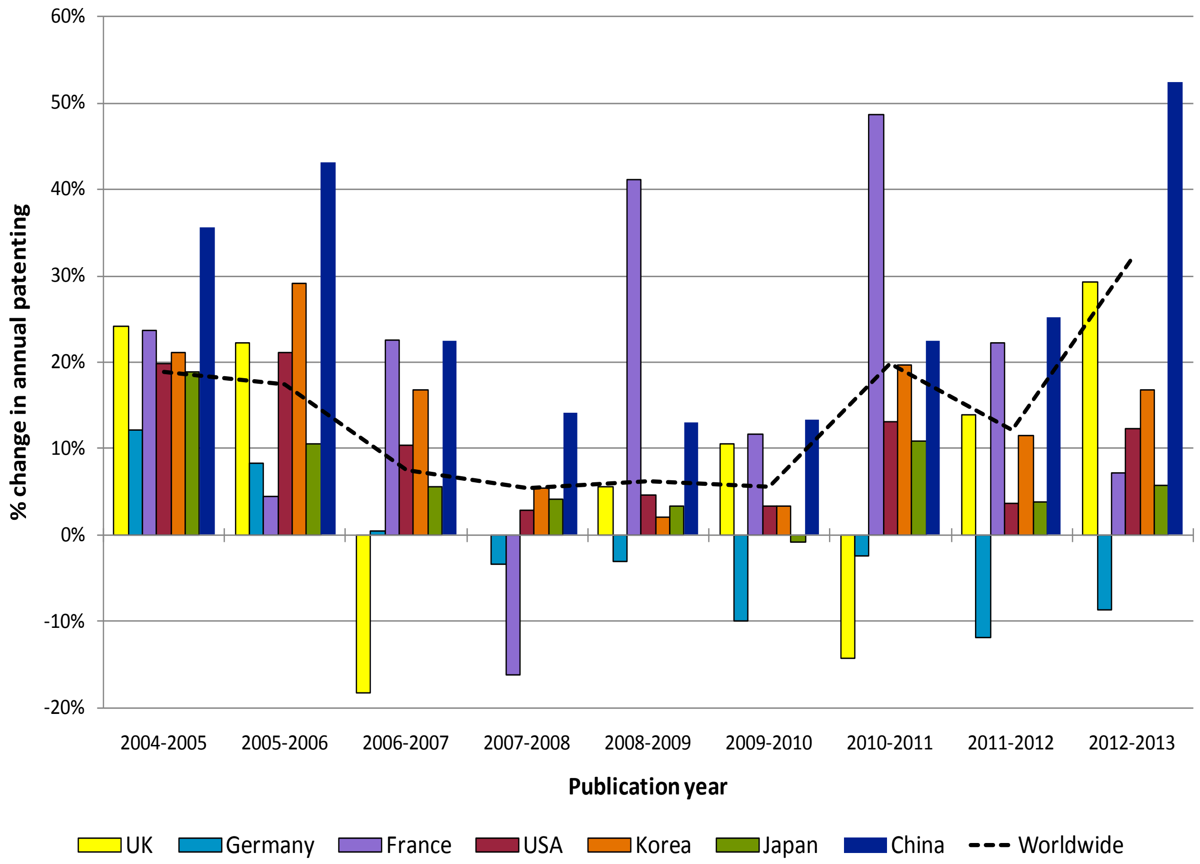

Figure 22: Year-on-year change in UK forms of carbon patenting against comparison countries

3.2 Metamaterials

3.2.1 Top UK applicants

This technology field has produced a very small dataset such that it cannot be used for detailed analysis. This figure demonstrates that there is interest from the UK in this area of technology, but that it is not by UK based companies, but companies based elsewhere with UK-based inventors.

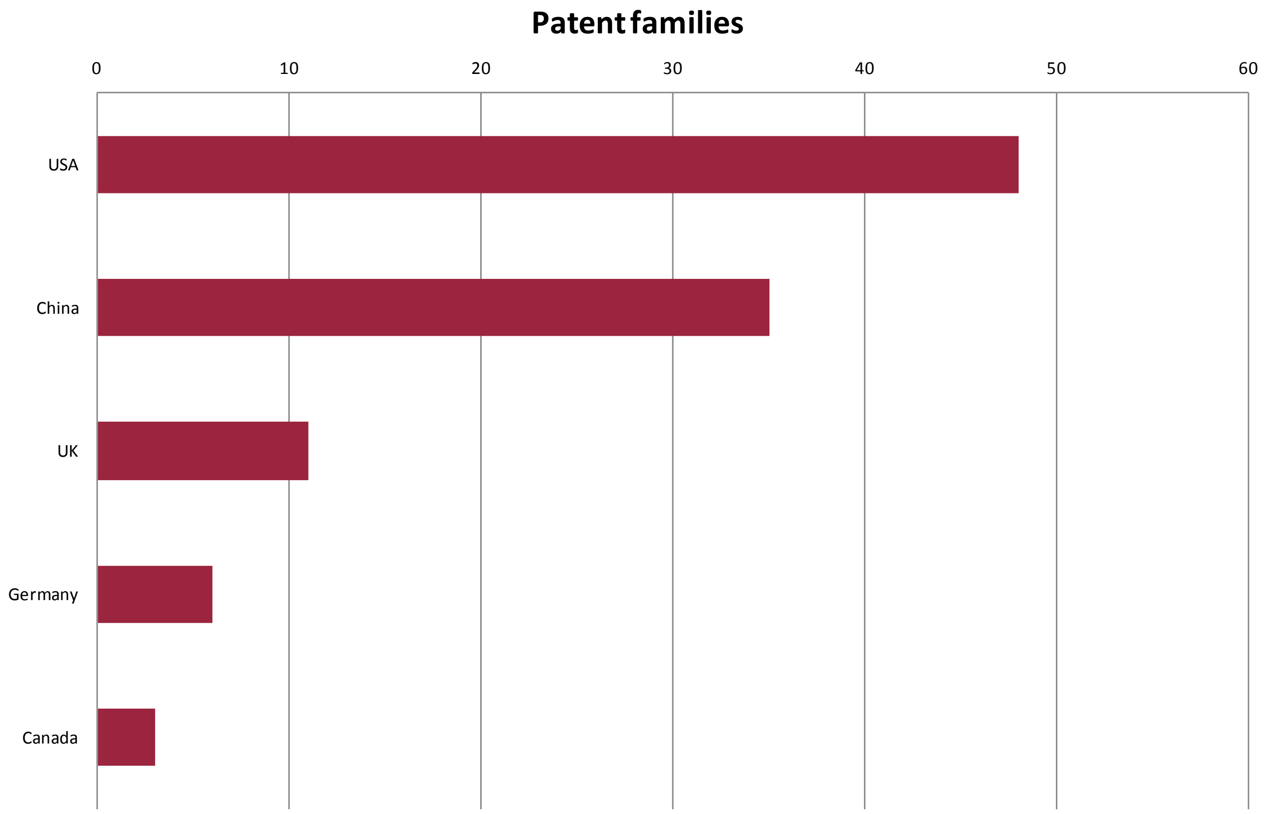

Figure 23: Metamaterials UK-based inventors

These applicants include:

- Datalase,
- EADS (UK),
- Imperial Innovations,
- Isis Innovation,
- Lamda Guard,
- Queen Mary and Westfield College,
- Seaerte and

University of Southampton are working on a variety of technologies in this area. For example Isis is using metamaterials in transformers, EADS is working in field of optical devices, as is University of Southampton.

No analysis has been performed on this dataset as it is of too small a size to present relevant information via patent landscape analysis

3.3 Renewable energy materials

3.3.1 Top UK applicants

Figure 24 shows the top UK-based applicants within the renewable energy enabling materials dataset. It is immediately evident that there is considerable academic interest in this area from Cambridge, Oxford and Imperial Universities. It is not surprising that Merck is listed as this company is head quartered in Germany; a country which has seen rapid development in the area of renewable energy.

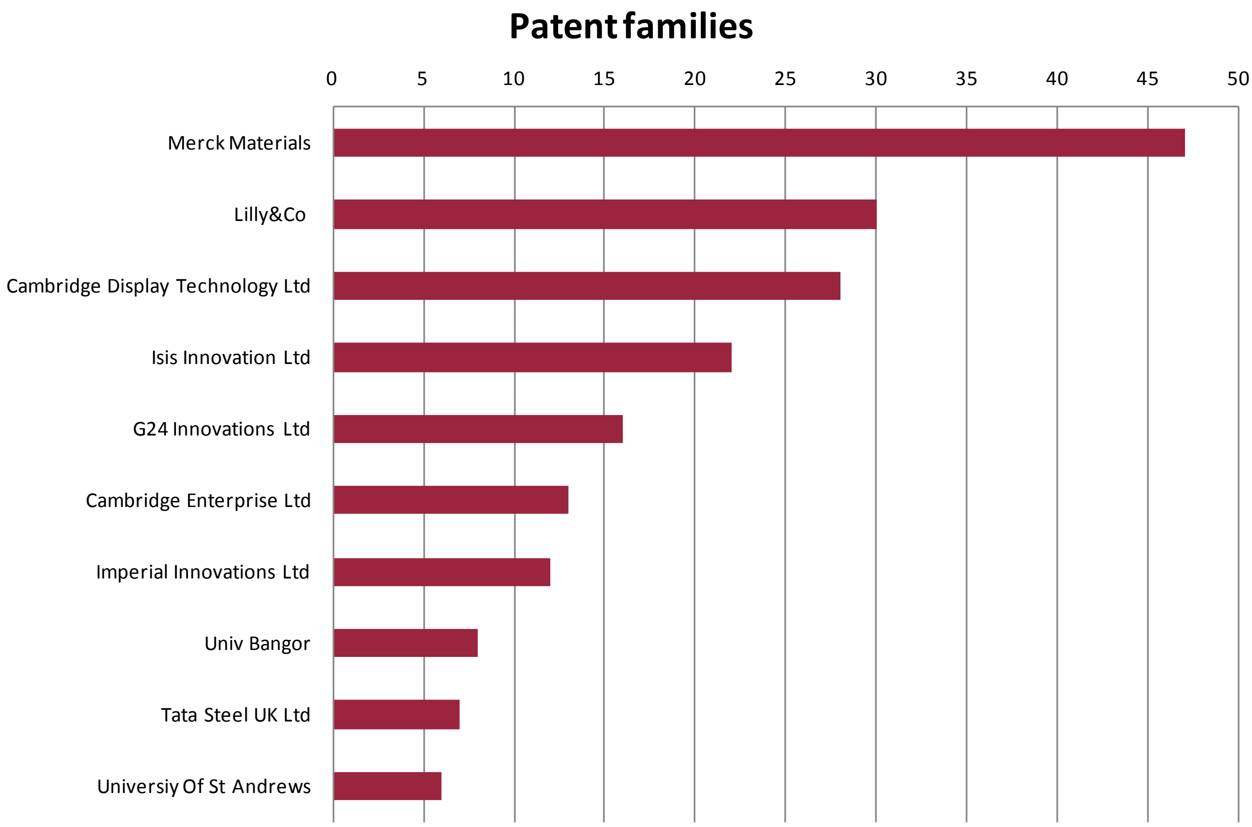

Figure 24: Top UK applicants

3.3.2 Collaboration

Figure 26 is a collaboration map showing all collaborations between the top ten UK applicants in the dataset and other members of the top ten applicants. Each dot on the collaboration map represents a patent family and two applicants are linked together if they are named as joint applicants on a patent application. A collaboration map indicates instances where joint work in solving a problem has resulted in a shared application for a patent.

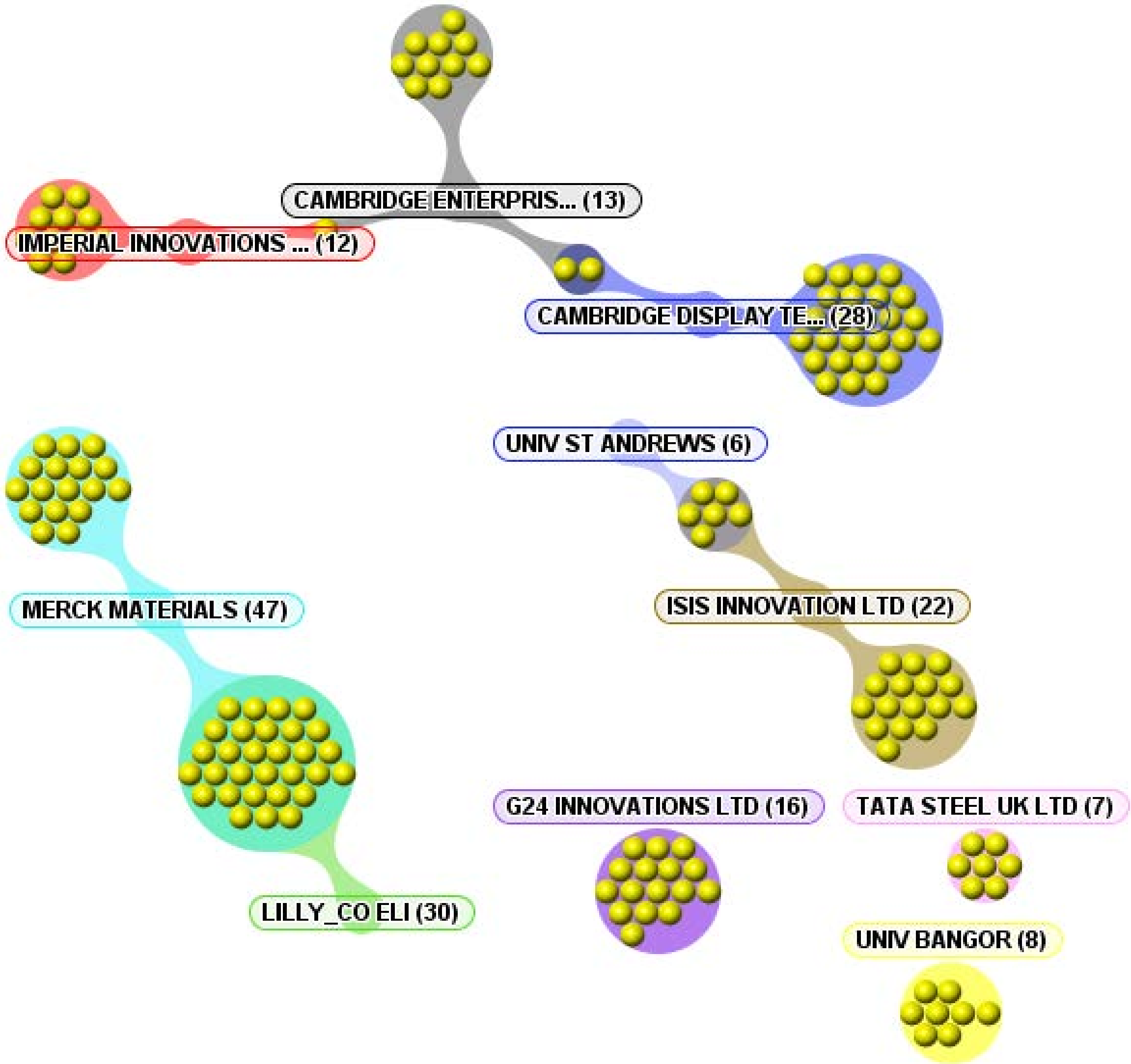

Figure 25: Collaboration map showing all collaborations between the top 10 UK applicants

Figure 25 shows there are collaborations between the top 10 UK applicants in the dataset. Again it is noticeable that collaboration appears more in companies with an academic background i.e. university technology transfer companies.

3.3.3 How active is the UK

A subset of the main worldwide patent dataset designed to reflect UK patenting activity was selected. Figure 21 shows the annual change in renewable energy enabling materials patenting arising from UK patenting activity against the worldwide year-on-year change in this field shown in Figure 15: this shows that UK patenting activity in renew worldwide renewable energy enabling materials patenting activity for five of the nine data points plotted in Figure 26. There does not appear to be any overall trend in UK patenting volumes over this time period.

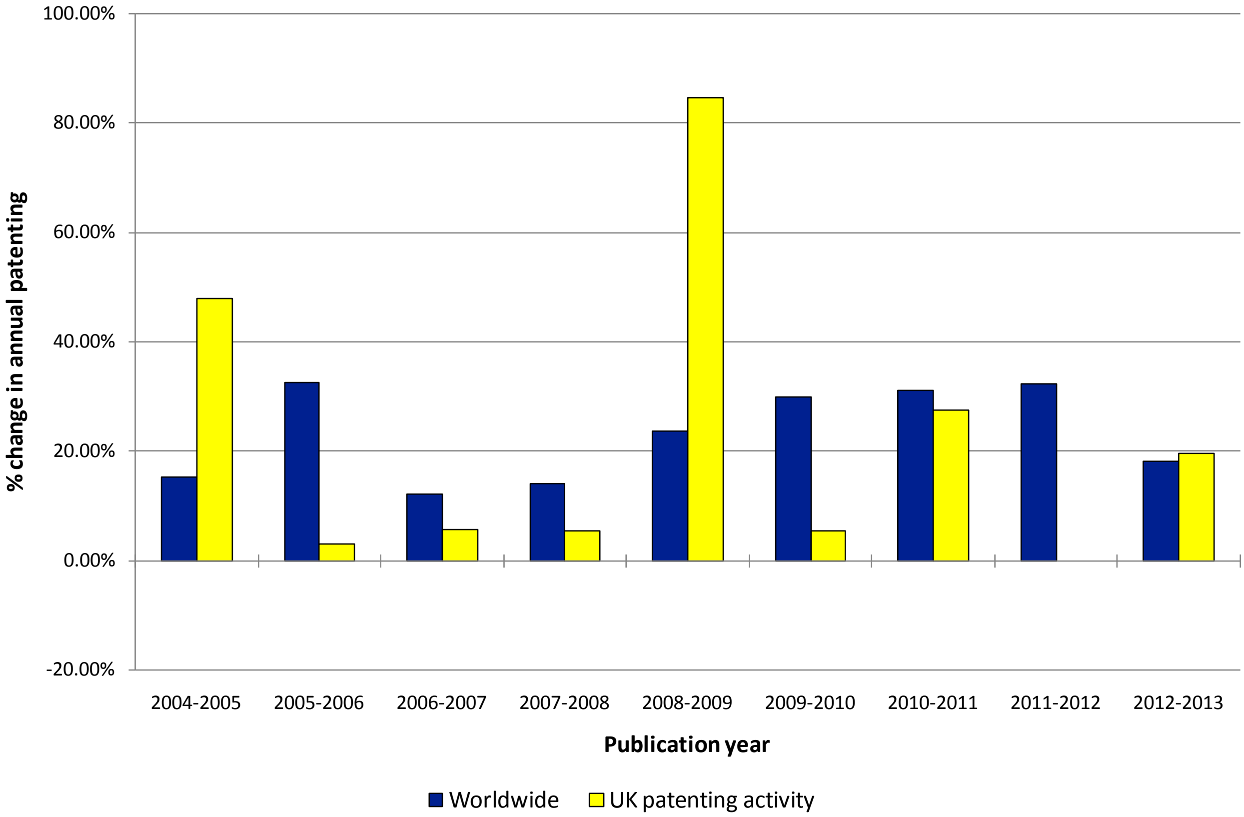

Figure 26: Year-on-year change in UK and worldwide patenting

Similar patent subsets were created to reflect patenting activity taking place in several comparator countries (France, Germany, USA, Japan and China) to produce the comparison chart shown in Figure 27. The dataset in Figure 27 is dominated by Chinese patent activity and highlights a remarkable increase in activity over specific time periods in the dataset. Growth in French patenting is also high.

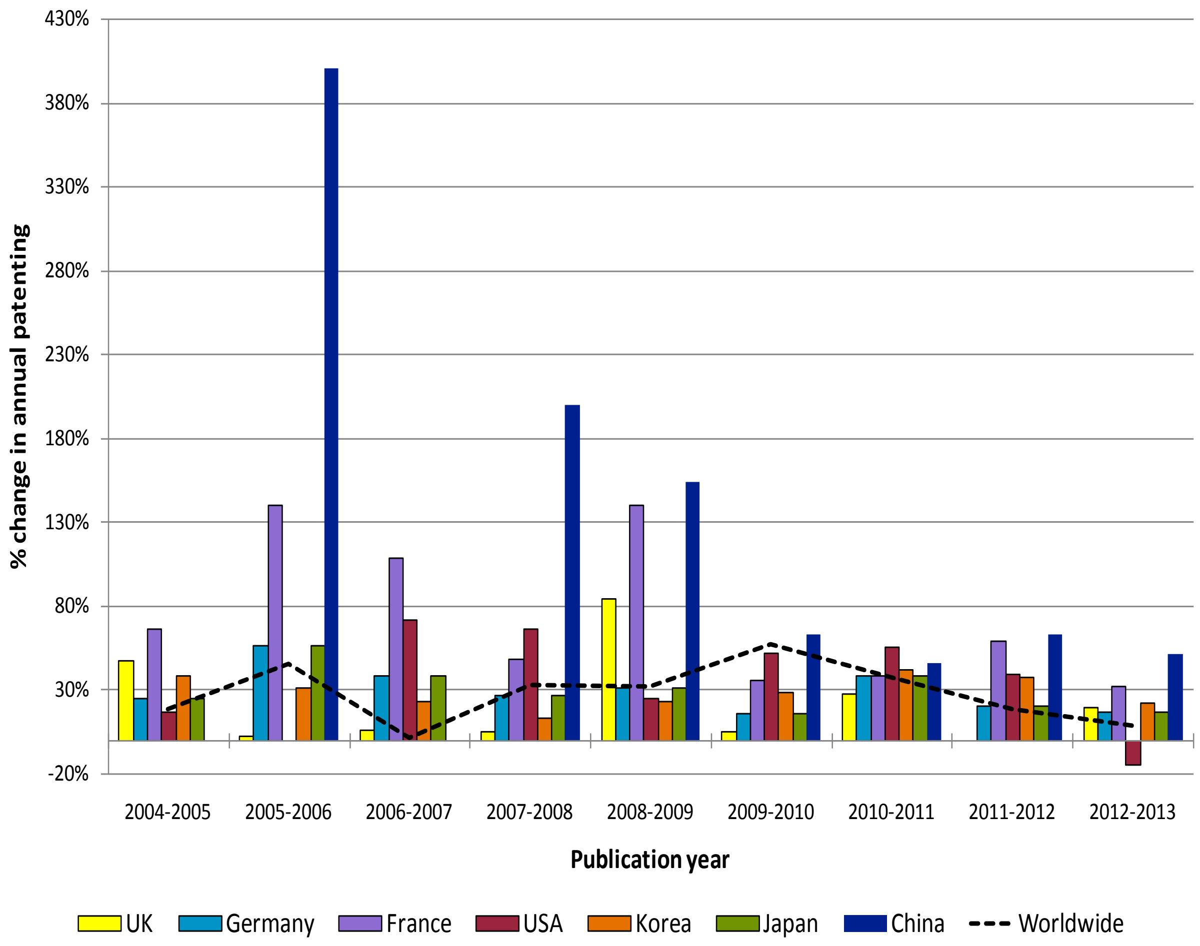

Figure 27: Year-on-year change in UK renewable energy enabling materials patenting against comparison countries

3.4 Wearable technology

3.4.1 Top UK applicants

The dataset for UK applicants was so small that it was not possible to produce a list of top UK applicants. A low number of UK patent owners were noted including ARM and Cambridge Display Technology.

Many patents in this area do have UK based inventors named on the documents rather than UK based applicants as illustrated below:

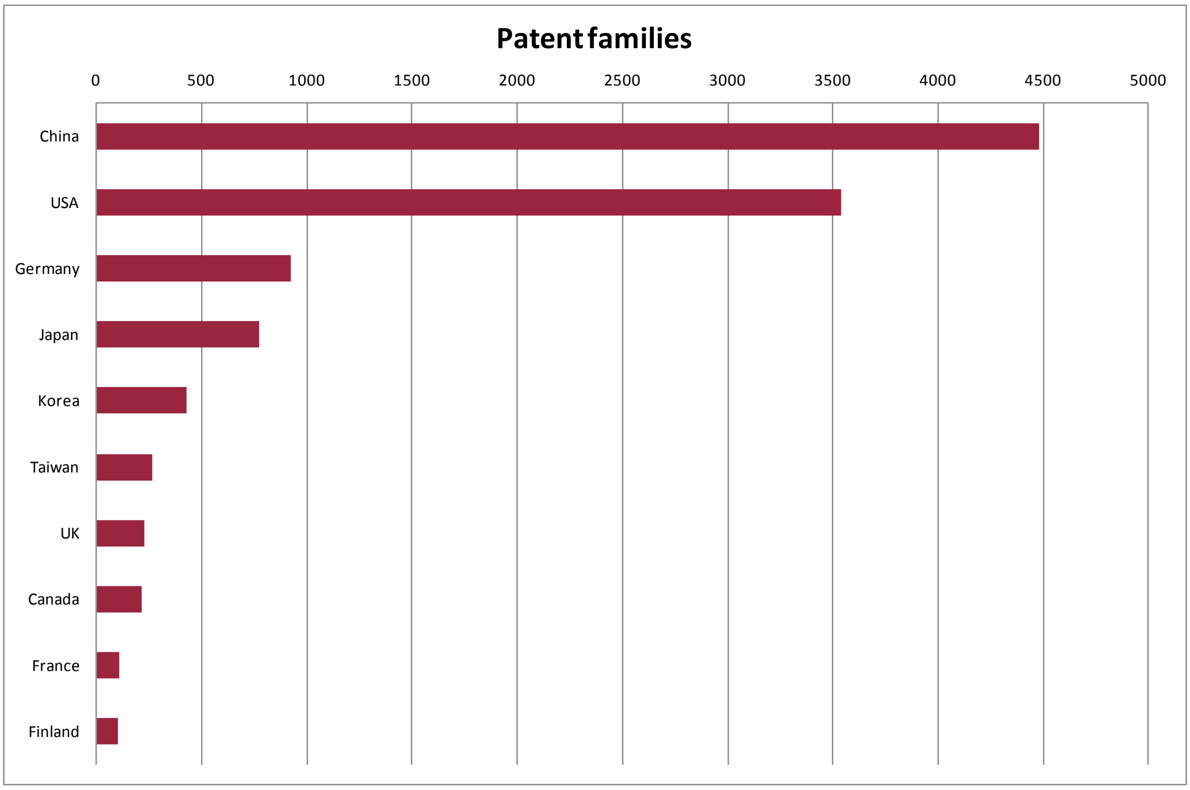

Figure 28: Top inventor countries

No collaboration map has been produced for UK applicants given the low volume of patenting. However, this has been completed for the worldwide dataset, showing a lack of collaboration amongst the top applicants.

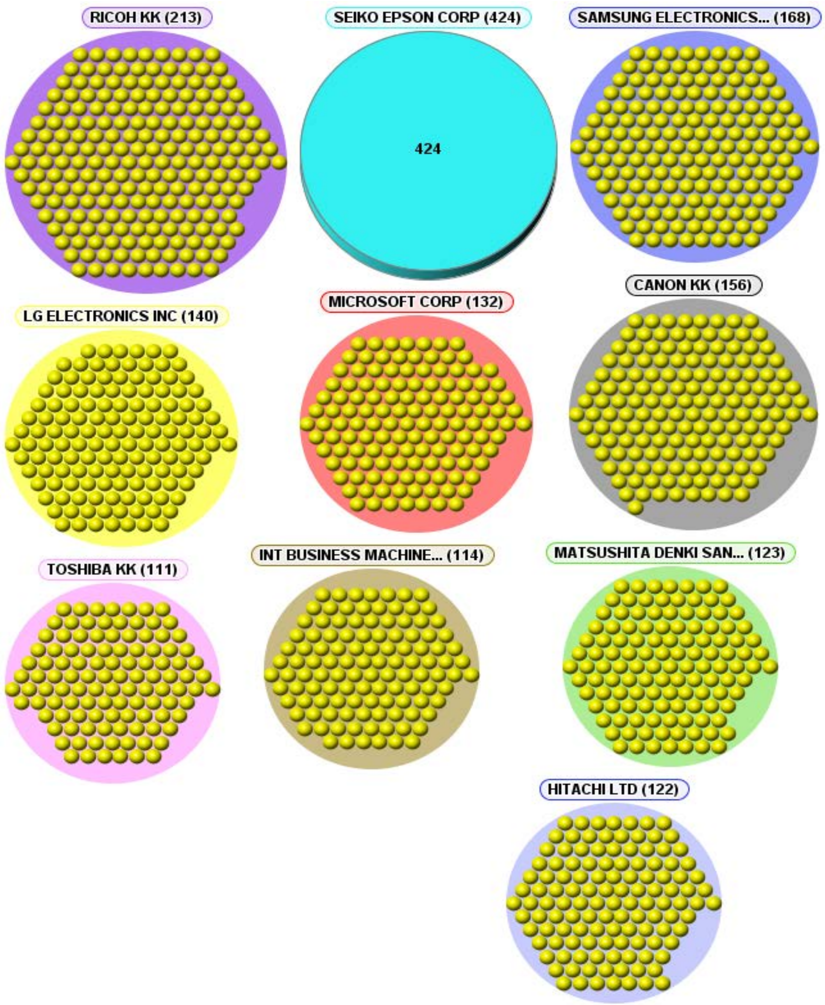

Figure 29: Collaboration map showing all collaborations between the top 10 worldwide applicants

3.4.2 How active is the UK?

Figure 30 shows the annual change in UK wearable technology patenting arising from UK patenting activity against the worldwide year-on-year change in this field shown in Figure 15; UK patenting activity wearable technology has been lower than the worldwide change in wearable technology patenting activity for six of the nine data points plotted in Figure 30. The general trend in patent activity is up for the UK and the world in recent years but this is not firmly established.

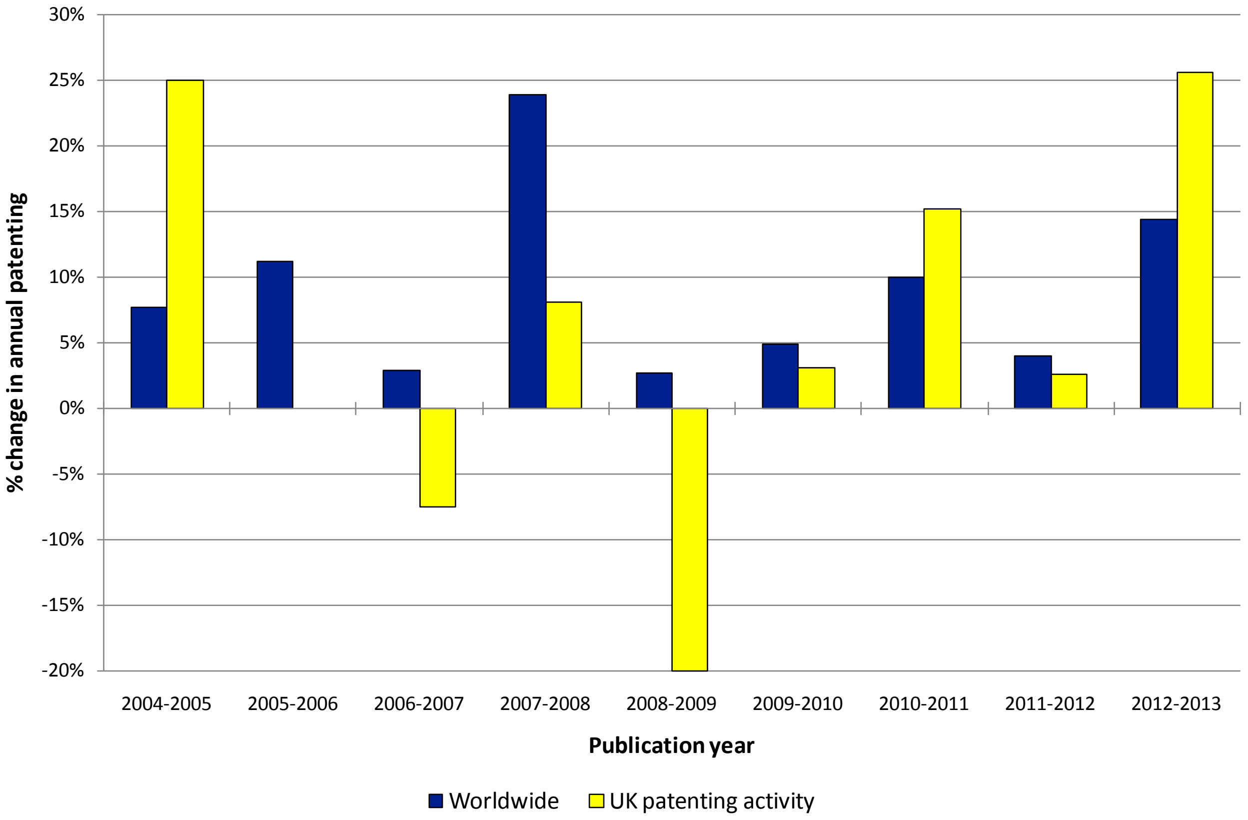

Figure 30 Year -on-year change in UK and worldwide patenting

Similar patent subsets were created to reflect patenting activity taking place in several comparator countries (France, Germany, USA, Japan and China) to produce the comparison chart shown in Figure 31. The dataset in Figure 31 is dominated by Chinese patents for the time period 2006-2008 but this peak increase dies down in subsequent time periods in the dataset.

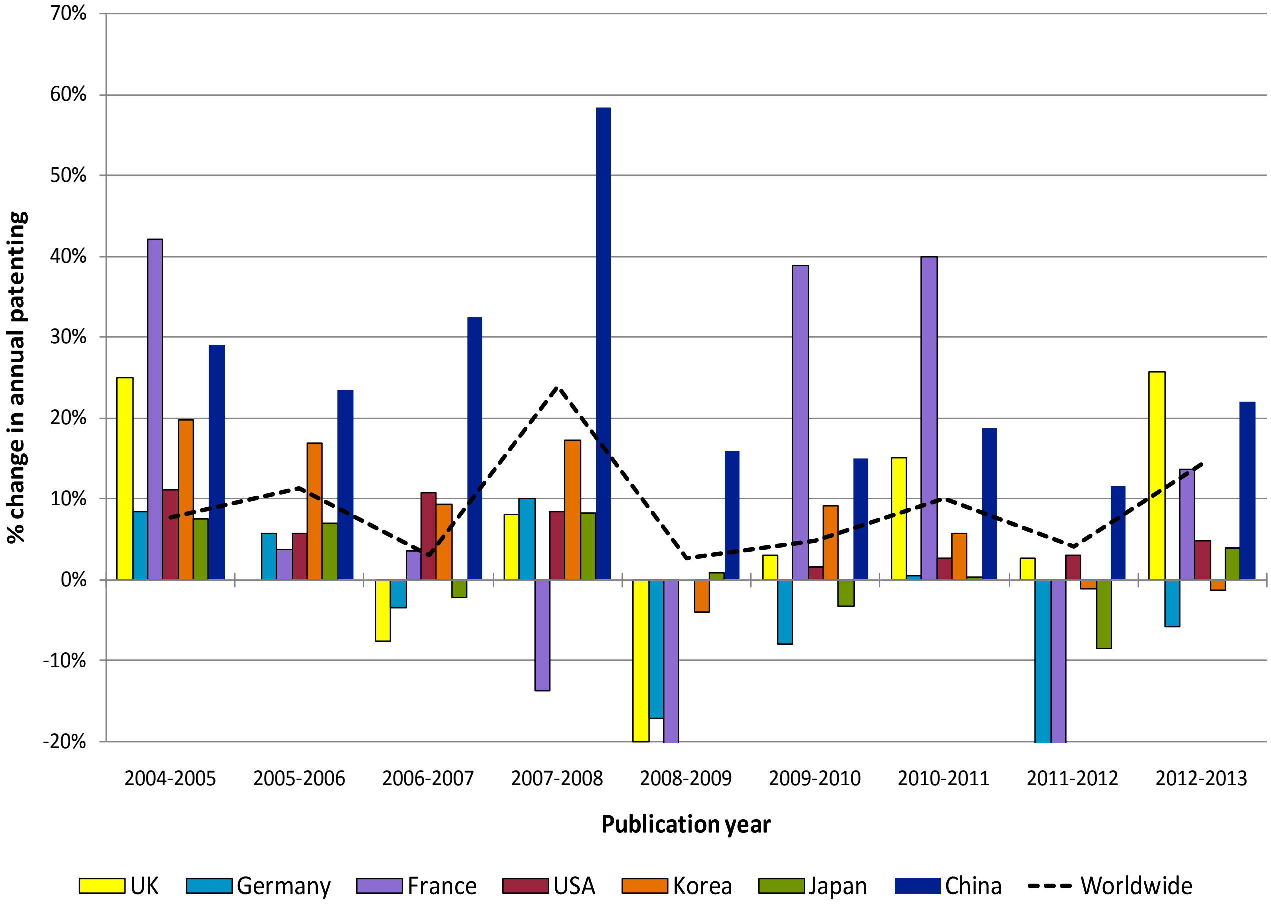

Figure 31: Year-on-year change in UK wearable technology patenting against comparison countries

4 Patent landscape map analysis

4.1 Forms of carbon

In order to give a snapshot as to what the patent landscape looks like for this technology space, a patent map provides a visual representation of the dataset. Patent families are represented on a 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[29].

Figure 32 shows a patent landscape map. There is major interest in tyres. The map also shows the diversity of the uses for forms of carbon.

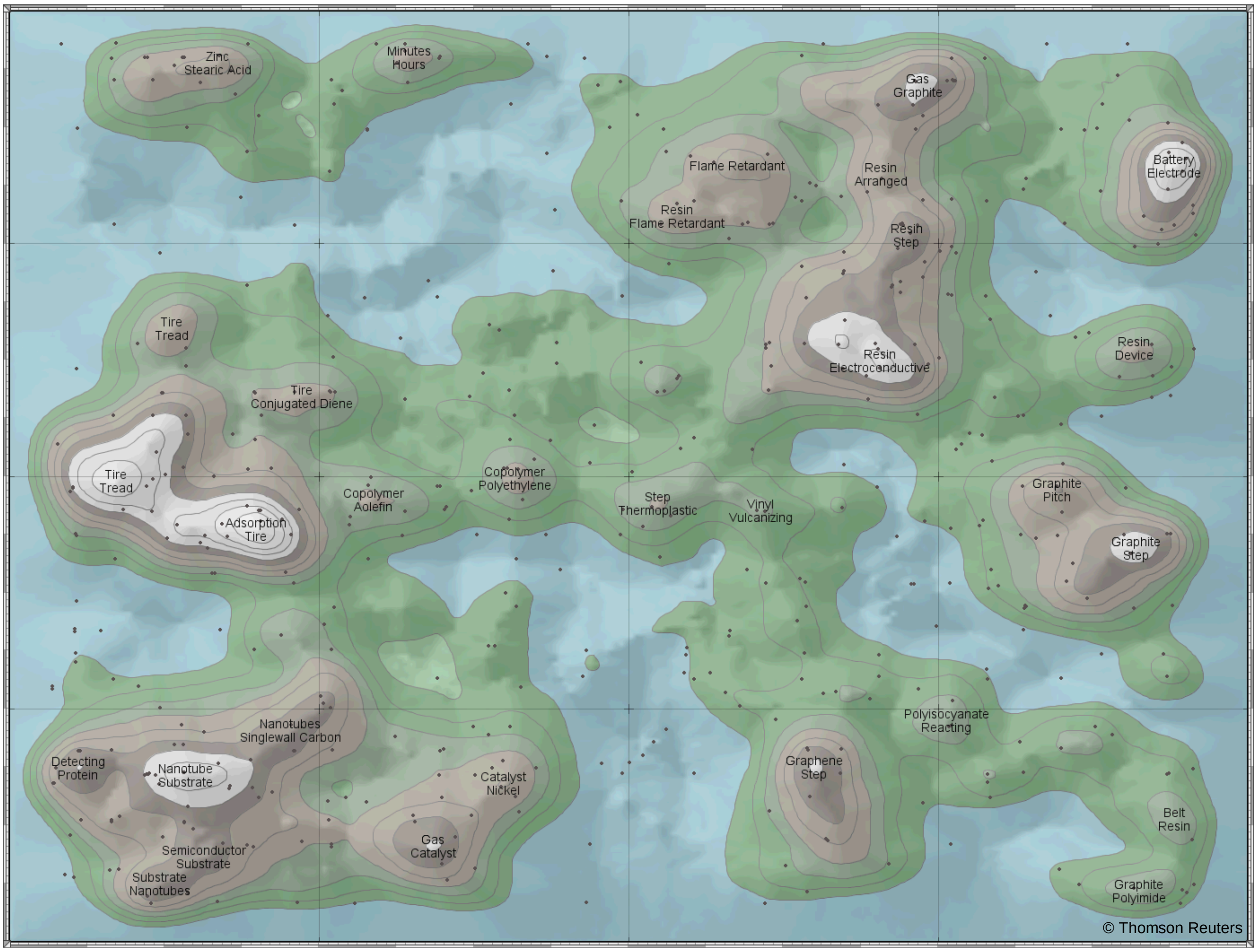

Figure 32: Patent landscape map of all patent families relating to forms of carbon

Manchester University was chosen as an applicant of interest as it had already appeared on the list of top UK applicant in Figure 19 and is well known for having had the Nobel prize presented too two members of the research faculty there, Geim and Novoselov. for

[29] Further details regarding how patent landscape maps are produced is given in Appendix C.

the discovery of the graphene form of carbon[30]. Figure 33 shows the patents where Manchester University has been highlighted as an assignee. Given the research this university have been doing in the area of graphene this is not unsurprising. However, if the map (Figure 34) is examined for patents that use/manufacture graphene[31] it can be seen that this area has expanded beyond the initial research that was completed at Manchester. These uses include: energy storage, photovoltaic cells, ultrafiltration, optical electronics and biological engineering.

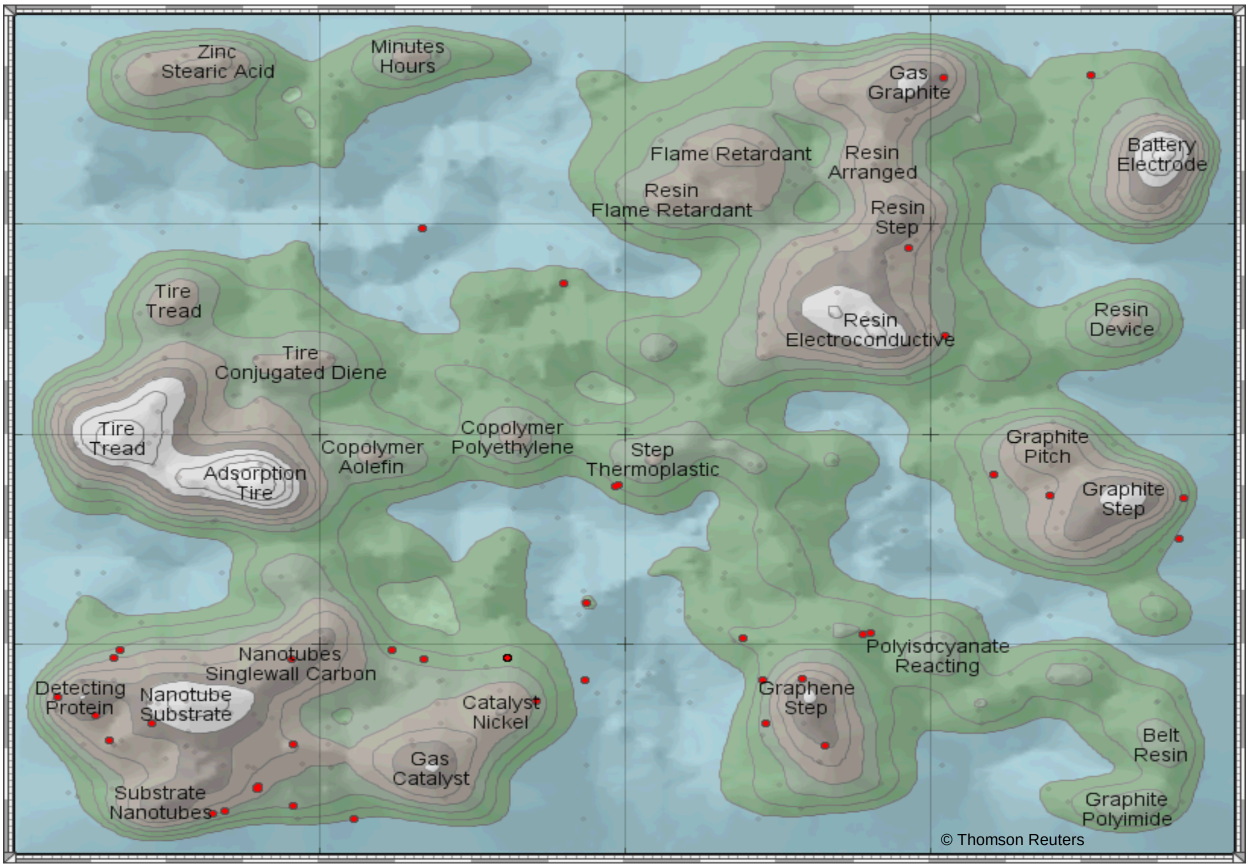

Figure 33: Patent landscape with Manchester University patents highlighted (in red)

30 The graphene story: how Andrei Geim and Kostya Novoselov hit on a scientific breakthrough that changed the world... by playing with sticky tape, The Indepdent,(2013) Available from: http://www.independent.co.uk/news/science/the-graphene-story-how-andrei-geim-and-kostya-novoselov-hit-on-a-scientific-breakthrough-that-changed-the-world-by-playing-with-sticky-tape-8539743.html

31 List of potential uses of graphene available from: http://www.graphenea.com/pages/graphene-uses-applications

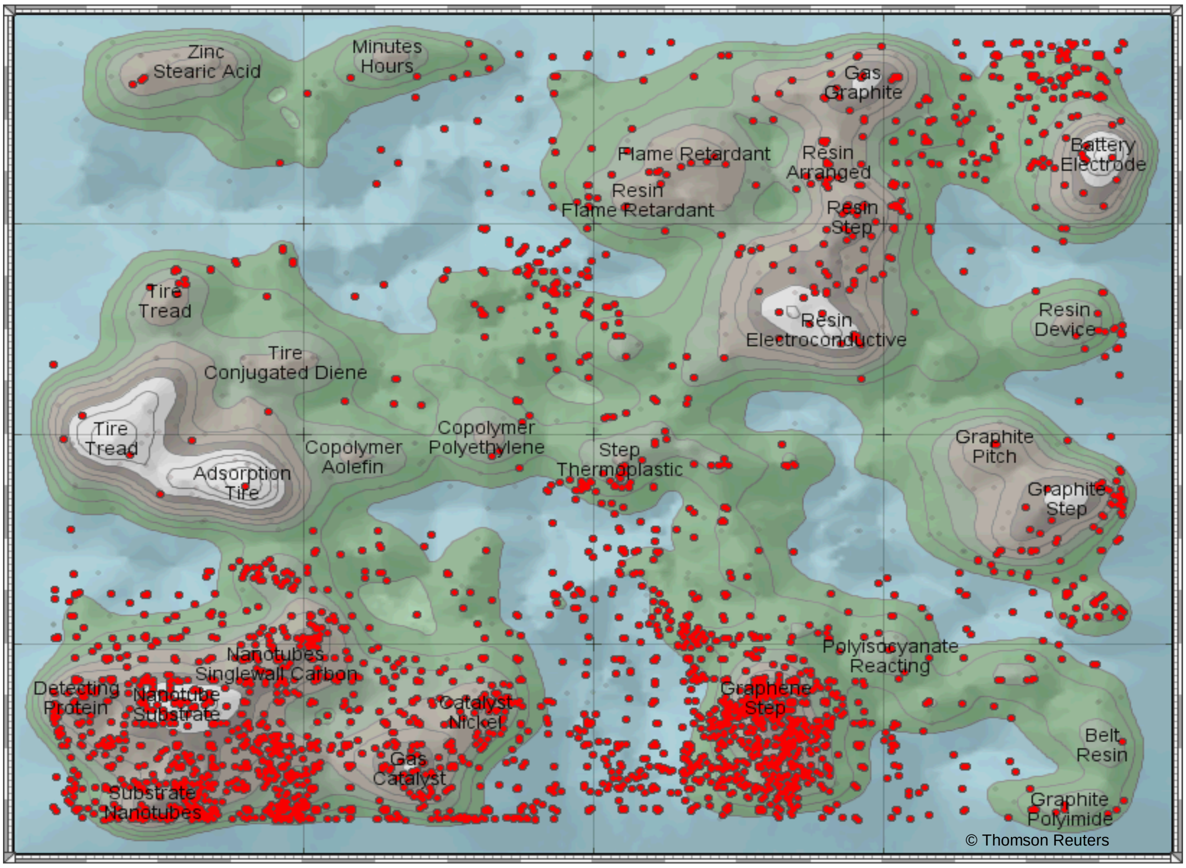

Figure 34: Patent landscape with graphene patents highlighted (in red)

4.2 Renewable energy enabling materials

As explained earlier in Section 4.1, the dataset relating to renewable energy enabling materials was "landscaped"[32].

Figure 35 shows a patent landscape map of the renewable energy enabling materials patent families. The technology in the patent landscape is skewed towards production of solar cells, as noted earlier.

[32] Further details regarding how patent landscape maps are produced is given in Appendix C.

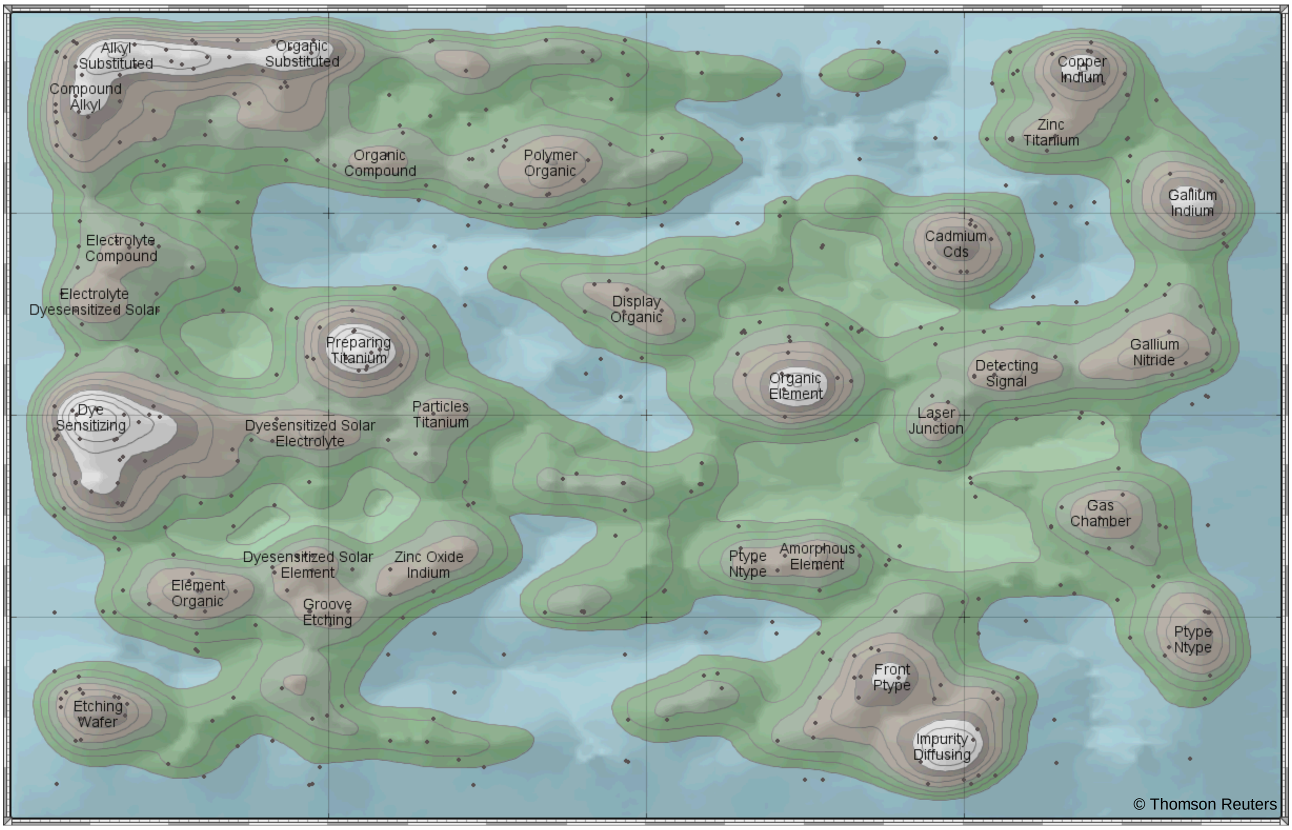

Figure 35: Patent landscape map of all patent families relating to renewable energy enabling materials

Figure 36 is the same landscape map as shown here in Figure 35 but it now shows patents where some UK applicants (Cambridge, Isis Innovation and Imperial Innovations) highlighted on the map. It is evident that a diversity of UK research is occurring in this area.

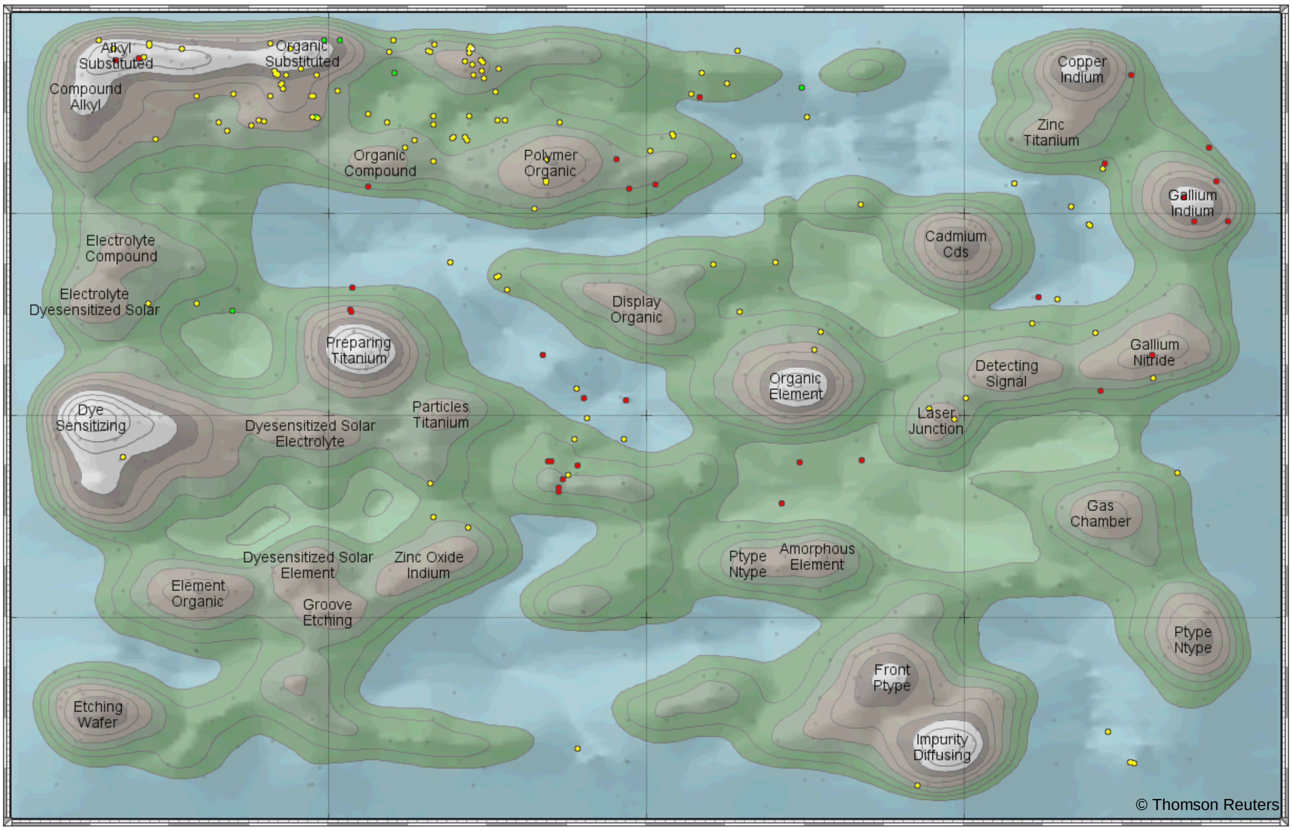

Figure 36: Renewable energy enabling technology patent landscape map with Cambridge (yellow), Isis Innovation (green) and Imperial Innovations (red) patent assignees highlighted

4.3 Wearable technology

As explained in Section 4.1, the dataset relating to wearable technology was "landscaped"[33].

Figure 37 shows a patent landscape map of the wearable technology patent families. The map shows that patented research can be divided between computations/software-based patents and more "mechanical/enabling" patents.

[33] Further details regarding how patent landscape maps are produced is given in Appendix C.

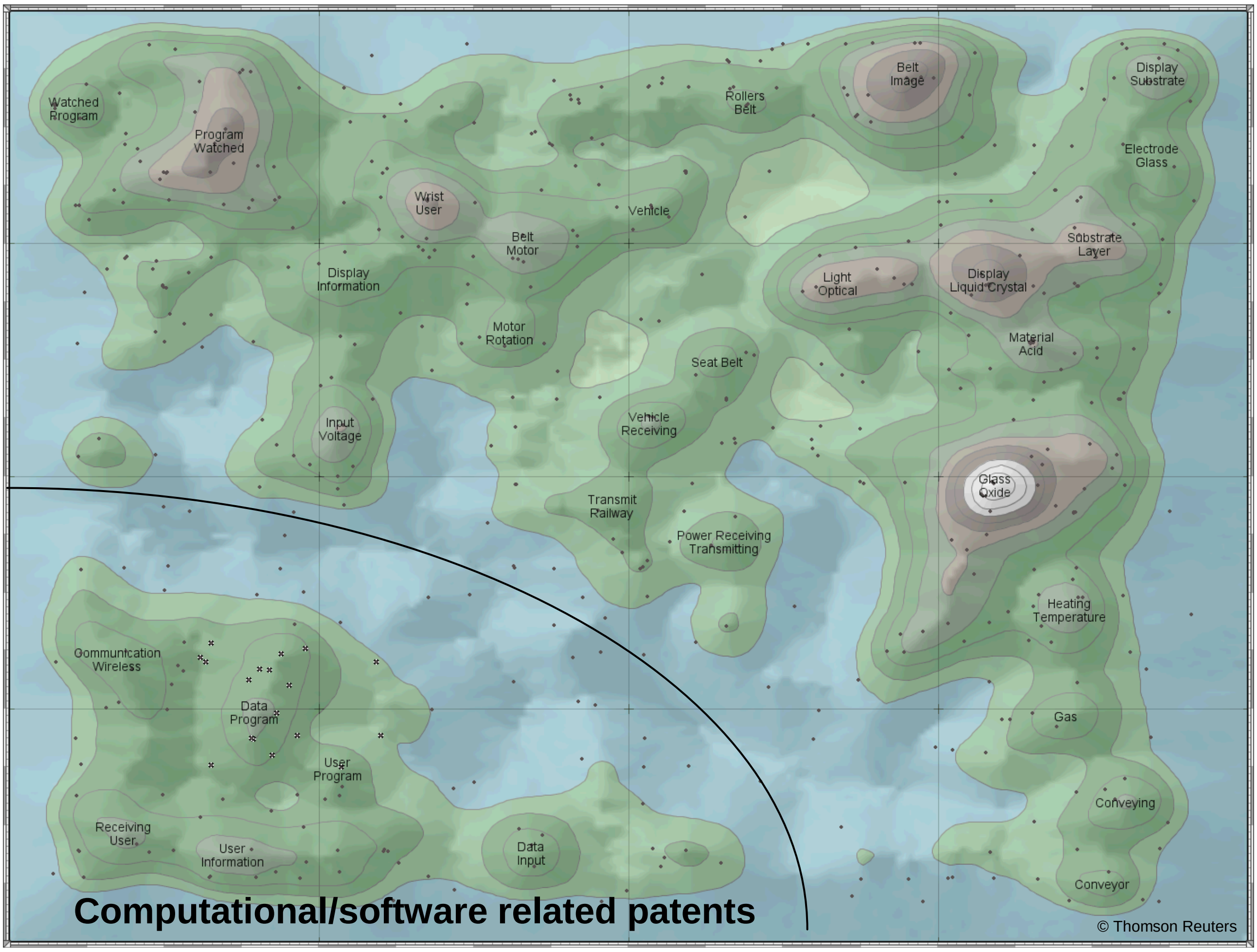

Figure 37: Patent landscape map of patent families relating wearable technology

The patent landscape map shown in Figure 38 is the same patent map shown in Figure 37, but with specific patent assignees (dots) highlighted. The map in Figure 38 highlights patent families filed by well known applicants in the wearable technology sector, namely Apple and Google. There is a relatively tight grouping of patents from these applicants suggesting multiple inventions.

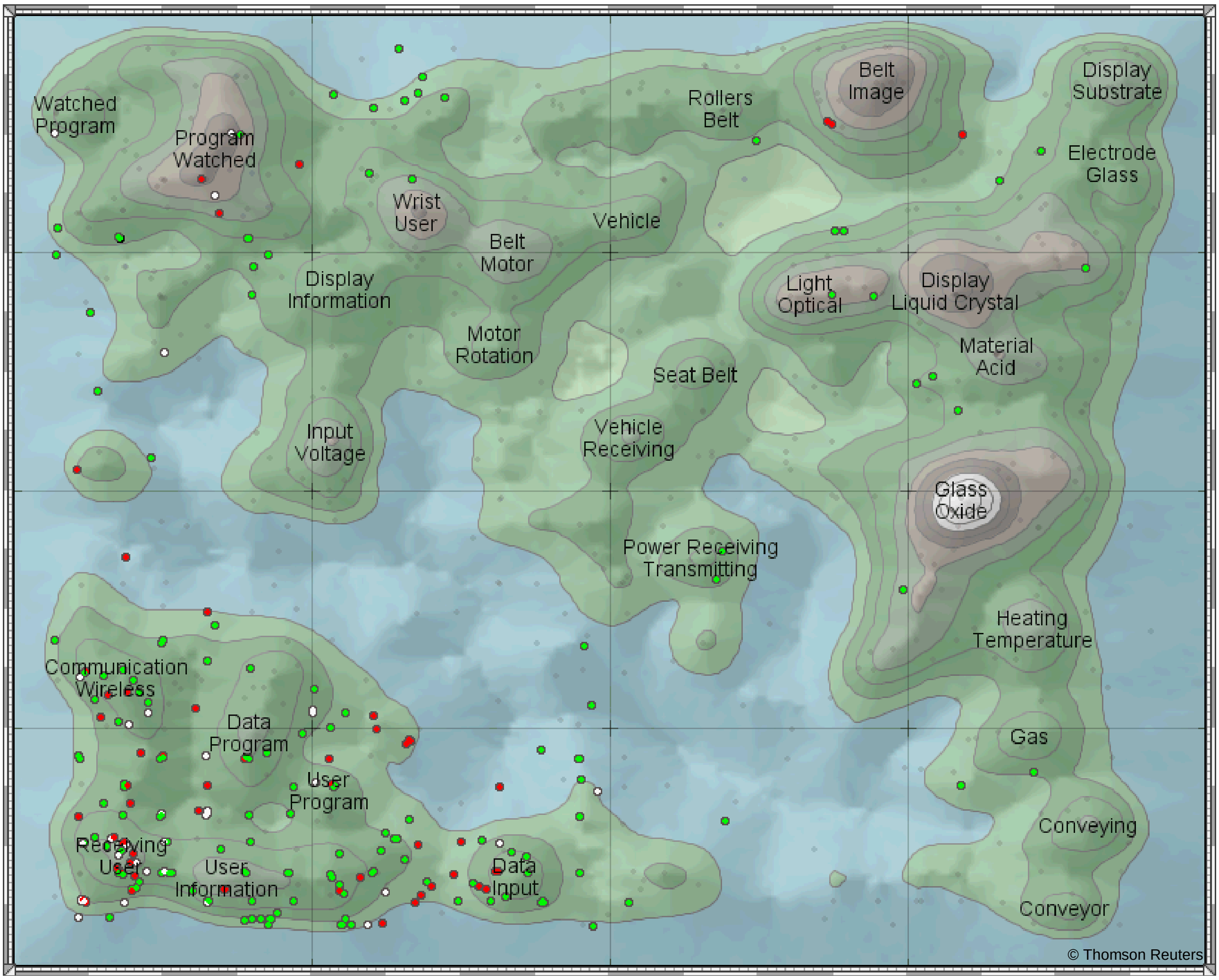

Figure 38: Wearable technology patent landscape map with both Apple (green) and Google (red) patent assignees highlighted

5 Overall Conclusions

The area of advanced materials and nanotechnology is a very wide one. What technologies fall within the term "advance materials and nanotechnology" is not well defined. Consequently this report has selected four areas that are commonly considered to fall squarely within the term. These are: forms of carbon, renewable energy enabling technology, metamaterials and wearable technology.

The forms of carbon dataset showed that the UK has a good research base[34] and a high degree of interest in this technology. Following on from the initial research into graphene it can be seen that the UK has continued with work in the area of nanotechnology[35]. There is considerable academic interest in this area from Cambridge University, Oxford and Manchester Universities in the general area of nanotechnology. In aerospace, Airbus and BAE are working in use of nano-sized carbon elements for use in composites.

The area of metamaterials is developing but appears to be in its early stages (due to the low number of patents); there is significant Chinese patent activity, relative to other countries' patents occurring in this area. There are many potential commercial applications for this technology. In the UK Isis Innovation (Oxford University) is using metamaterials in transformers, and EADS is working in the field of optical devices, as is University of Southampton.

Renewable energy enabling technologies is a growing area. In the UK, Merck is the biggest patent filer. There is also academic interest in this area from Cambridge, Oxford and Imperial Universities. There is a mixture of UK applicant types in this dataset with some multinationals, academic (or technology transfer companies with an academic base) and small to medium enterprises present.

The wearable technology "space" appears to be dominated by a number of multinational companies, some of which employ UK inventors, who are not based in the UK, some of which employ UK-based inventors. However, this is a fast moving technology area and should be regularly reviewed in order to ensure that relevant information about the development of this field is used to promote UK interests. There are few UK based patenting organisations; patenting in this area is dominated by Japanese based multinationals.

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[34] Britain's big bet on graphene, Brumfiel, (2012)Nature, available from http://www.nature.com/news/britain-s-big-bet-on-graphene-1.11124, Graphene, Manchester University, (2014) available from: http://www.graphene.manchester.ac.uk/ , Graphene research at the University of Oxford, available from (2014) :http://fng.materials.ox.ac.uk/Main/NanotubesAndGrapheneProjects

[35] For more information please see the Graphene 2013 IPO report available from: http://www.ipo.gov.uk/informatics-graphene-2013.pdf

Appendix A Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) was interrogated using *Thomson Innovation*[36], a web-based patent analytics tool produced by *Thomson Reuters*. This database holds bibliographic and abstract data of published patents and patent applications derived from the majority of leading industrialised countries and patent organisations, *e.g.* the World Intellectual Property Organisation (WIPO), European Patent Office (EPO) and the African Regional Industry Property Organisation (ARIPO). It should be noted that patents are generally classified and published 18 months after the priority date. This should be borne in mind when considering 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 and publication date

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

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

Analysis by priority year gives the earliest indication of invention.

A.3 WO and EP patent applications

International patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

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

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

A.4 Patent documents analysed

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

The applicant and inventor data was cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation (Ltd, Pty, GmbH *etc*.), or equivalence (Ltd., Limited, *etc*.).

A.5 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[37] produced by *Search Technology* in the USA. The patent records exported from *Thomson Innovation* were imported into *VantagePoint* where the data is cleaned and analysed. The patent landscape maps used in this report were produced using *Thomson Innovation*.

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

Appendix B Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patent families in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of advanced materials subset 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 the relevant technical area patent publications in country i
n_{total} = total number of relevant technical area patent publications in dataset
N_i = total number of patent publications in country i
N_{total} = total number of patent publications in dataset

The effect of this is to highlight countries which have a greater level of patenting in a relevant technical area than expected from their overall level of patenting, and which would otherwise languish much further down in the lists, unnoticed. Please not that India is **not** included in the RSI measure because the worldwide patent databases have poor coverage of Indian applicant address (applicant country) data.

Appendix C Patent landscape maps

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

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

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

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

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

Thus, in summary, published 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’.

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