Advances in Astronautics Science and Technology
https://doi.org/10.1007/s42423-020-00065-y

ORIGINAL PAPER

Nanomaterials in Space: Technology Innovation and Economic Trends

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Received: 8 August 2020 / Revised: 3 November 2020 / Accepted: 18 November 2020

Abstract

Nanomaterials and nanostructures have a broad impact on space missions and programs (e.g., launchers, planetary science, and exploration). Their main benefits are related to reduced vehicle mass improved functionality and durability of space systems and increased propulsion performance. For these reasons, in this paper, we would like to explore the recent evolutions of nanomaterials and nanostructures for space systems, with a focus on patents and market trends related to lightweight structures, damage-tolerant nanoscale systems, nanocoatings and adhesives, nanomaterials, and structures for thermal protection and control. Our analysis examines patent information from a database containing more than 54 M worldwide patent families and combines the data retrieved with market indicators. Such evaluation is useful to assess the technological trends and evaluate their current stage of maturity, within the overall Technology Life Cycle. Using specific sectoral keywords, our study takes into consideration about 3000 patent data on nanostructures, materials, and processes for space applications evaluating, among others, patents trends (2010–2019), International Patent Classifications, country distribution, top assignees, legal state, and forward and backward citations. As a result, we can assess which International Patent Classification is more common and which geographical area is more active. In the area under investigation, we identified that explosives and similar materials (C06B) are widely protected as well as heterocyclic compounds (C07D) and spacecraft and its related equipment (B64G). For what the geographical distribution is concerned, while China and United States confirm their predominance, it is worthwhile noticing that Canada, one of the ESA Member States, is highly active, as well. Our focus on the European patenting activity shows that Great Britain, Germany, and France are the most active countries. From the analysis of the other indicators (e.g., citations, assignees, etc.), we can assess which type of nanomaterial and nanostructure for space applications is growing more rapidly. Furthermore, patent indicators, integrated with market information, provide a clear evaluation of the related technology trends and readiness level. In conclusion, patent metrics provide a valuable asset to measure innovation performance. These data can also be used to monitor activities of worldwide players, create a performance evaluation system in R&D entities, and foresee specific technological trends. Thanks to this type of analysis, we can capture differences in innovation performances. The resulting indicators support strategic roadmapping and contribute to mapping knowledge and competences worldwide. In addition, they provide information on technological gaps and possible opportunities, measuring the results of space valorisation and technology transfer.

Keywords Patents · Nanotechnology · Technology transfer · Space application · Result valorisation

Abbreviations

ASI	Italian Space Agency
ESA	European Space Agency
IPC	International Patent Classification
MEMS	Micro Electro-Mechanical Systems
MOEMS	Micro Optoelectromechanical Systems
NASA	National Aeronautics and Space Administration
NEMS	Nanoelectromechanical System
R&D	Research & Development
WIPO	Worldwide Intellectual Property Organization

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Published online: 03 December 2020

1 Introduction

Nanotechnologies have a broad impact on space missions and programs (e.g., launchers, planetary science, and exploration), and they have proven to be beneficial in the space sector in terms of increased reliability, reduced costs and vehicle mass, increased propulsion performance, improved functionality, and durability of space systems. In addition, nanotechnologies are among those technologies with a significant transversal application across several space segments. Indeed, nanotechnology can be widely used, with high potential disruption, in different space activities such as the launcher industry, satellite manufacturing, satellite services, ground equipment, national security, crewed and robotic space science and exploration, space tourism, energy, mining, processing, and assembly [1]. Due to such transversal nature of nanotechnologies, we examined in this paper their progress in terms of patent evolution with a specific focus on topics of high interest for space, such as miniaturisation of devices and capabilities in structural, thermal, electrical, electromechanical, and optical performances. We grouped our results into the following three main areas of application: "Engineered Materials and Structures", "Sensors, Electronics and Devices", and "Energy Storage, Power Generation and Power Distribution".

2 Methodology

Using Orbit Intelligence patent database by Questel [2] containing about 54 Million worldwide patent families, we analysed more than 3000 space-related patents on nanomaterials, nanostructures, sensors, electronics and devices, energy storage, power generation, and power distribution, published between January 1, 2010 and December 31, 2019.

To provide a general overview of the most recent patent evolution of nanotechnology in the space sector, we combined two different taxonomies, namely the ESA Technology Tree v3.0 [3] and the ASI nanotechnology taxonomy developed in a previous study funded by the Agency in 2010 [4].

ESA Technology Tree provides a classification system for all technical know-how that is available in space programs. It has a three-level structure [3], as follows:

- *Technology Domain (TD)* A technology domain includes know-how relevant to a technical area that can be identified as being standalone and can therefore be considered independently of other TDs.
- *Technology Sub-Domain (TS)* A decomposition of a TD to provide a more accurate description of its content in terms of different but related technical areas.
- *Technology Group (TG)* A further decomposition of each TS to identify a technology that is relevant to a family of products but that is not the description of a product in itself.

ASI nanotechnology taxonomy has also a three-level structure [4], as follows:

- *Macro-Areas (MA)* it mainly refers to nanomaterials and nanodevices. Each of them can be considered independently of other areas.
- *Sub-Groups (SG)* this layer provides a more accurate description of the two macro-areas in terms of different functionalities.
- *Nanotechnology Group (NG)* further decomposition of each sub-group into detailed technological applications.

Table 1 shows a summary of the relations found at the first level of detail (TD & MA) between the two taxonomies. In particular, the columns report ASI Nanotechnology Taxonomy, while the rows show ESA Technology Domains. The cells ticked show the areas where a relation between space and nanotechnology was identified, as resulted from ASI study [4].

Starting from the results reported in Table 1, we selected those ESA Technology Groups (TG) mostly related to smart materials and adaptive structures applications. We clustered them into three (3) main sectors (see Table 2). Then, we built our queries, which are a combination of ESA Technology Groups with ASI Nanotechnology Groups (see Table 3).

Patent data analysis is a valuable resource to foresee technology and investment trends, innovation capacity, and potential markets, especially for space technologies, largely used not only in the space sector but also in a broad range of areas and applications. By combining the above-mentioned set of space and nanotechnology keywords, as identified above, we built a number of queries used for patent analysis.

In the patent analysis hereinafter presented, the data were analysed making use of Orbit Intelligence Database [2] with the aim of extracting information from patent files, such as titles, abstracts, claims, descriptions, and concepts to identify, among others:

- Investment Trends
- Legal State
- Technology Overview
- Classification Classes (IPC4)
- Top Players
- Market coverage and Competitors
- Players' dependency by citation.

The graphs elaborated and hereinafter presented are resulting from a specific aggregation of the raw data extracted from

Table 1 ASI nanotechnology taxonomy and ESA technology tree relations

		Nanomaterials			Nanodevices			
		Nanostructured coatings	Nanostructured materials	Fluids	Nanosensors	Nanomachines	Nanoelcectronics	Nanostructured photonic devices
1.	On-board data systems	×	×		×	×	×	×
2.	Space system software							
3.	Spacecraft electrical power	×	×	×	×	×	×	×
4.	Spacecraft environment and effects		×				×	
5.	Space system control		×	×		×	×	×
6.	RF payload and settings	×	×				×	×
7.	Electromagnetic technologies and techniques	×	×		×			×
8.	System design and verification							
9.	Mission operations and ground data systems				×		×	×
10.	Flight dynamic and GNSS			×	×	×	×	
11.	Space debris							
12.	Ground station system and network							
13.	Automation, Telepresence and robotics	×	×	×	×	×	×	×
14.	Life and physical sciences	×	×		×	×	×	×
15.	Mechanisms and tribology	×	×	×	×	×	×	
16.	Optics	×	×		×	×	×	×
17.	Optoelectronics	×	×		×		×	×
18.	Aerothermodynamics	×	×	×	×	×	×	
19.	Propulsion	×	×	×	×	×	×	×
20.	Structures and pyrotechniques	×	×	×	×	×	×	×
21.	Thermal	×	×	×		×		
22.	Environmental control life support (ECLS) and In-situ resource utilisation (ISRU)	×	×	×	×	×		
23.	EEE components and quality	×		×	×	×	×	×
24.	Materials and processing	×	×	×	×	×	×	×

Table 2 Technology groups (TG) from ESA technology tree

Technology sector	Technology groups
Engineered materials and structures	Spacecraft structure
	Inflatable structure
	Deployable structure
	EVA (Extra-Vehicular Activity)
	Pyrotechnic technology
	Spacecraft (S/C) Material & Processing
	S/C Ceramic structure
	S/C Metallic structure
Sensors, electronics, and devices	Optics, MOEMS, MEMS
	Optoelectronics/ Laser Technology/Detector Technology/Photonics
Energy storage, power generation, and power distribution	S/C Electrical Power
	Fuel Cell technology
	Energy storage technology
	Power conditioning and distribution
	Thermal power
	Heat transport technology
	Cryogenics & refrigeration
	Thermal protection/insulation
	Heat storage & rejection

Table 3 ASI nanotechnology groups (NG) from ASI nanotechnology taxonomy

Nanotechnology taxonomy
Nanomaterials
Nanostructured coatings
Tribological
Functional
Adhesives/sealants
Nanostructured materials
Nanocomposites
Carbon-based
Metal and ceramic-based
Polymer-based
Other
Fluids
Nanofluids
Dispersions
Nanodevices
Nanosensors
Electrical
Optical
Nanomachines
NEMS/piezomotors
Molecular machines
Nanoelectronics
CMOS integrated
New materials
Nanostructured photonic devices
Signal transmission
Signal generation

Questel database using the taxonomies described in the previous chapter.

Although the number of patents is not in itself a sufficiently accurate indicator of the capability of producing new knowledge, data on patent publications are very useful to characterise the technological profiles of the organisations and to identify possible knowledge spillovers [5]. The analyses of patent information, and the generation of technology intelligence reviews are increasingly required by both governmental agencies and corporate entities, to understand technology trends and foresights [6].

Patents analyses are fundamental to provide efficient access to a large collection of technologically focused data and to answer key questions aimed at understanding technology trend evolutions, or what type of organisation owns the patents and where, etc. This type of analysis is also often used by organisations exploring technology transfer and open-innovation opportunities, to understand what other organisations have invested in a particular area. “If another organisation has recently invested in a technology, there is a higher likelihood that they will be receptive to hearing about new developments, and potentially acquiring or licensing the technology” [7]. Both governmental and corporate environments use patent analyses as an essential tool for understanding the competitive environment around research areas of interest [6] and discovering whether groups interested in pursuing research initiatives have the freedom to do so. Once an initial understanding is gained, ongoing monitoring can also be established using patent analysis as a starting point. It is here worth noticing that some patents protect inventions that are completely unique; however, most cover incremental changes to inventions that already exist [7]. Patents are usually sought to establish a commercially useful monopoly that is related to one or more products or processes. There are also patent filing strategies where the main purpose is not to establish a commercially useful monopoly. In fact, “patent applications have been used to meet government targets, qualify for tax breaks, as a measure of academic/professional credibility or rank, or for a method of disclosure (defensive publication)” [7]. This demonstrates that it is important to understand what a patent represents and the extent to which patents are directly comparable.

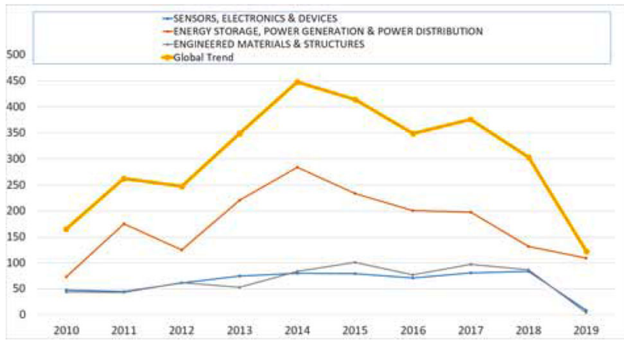

Fig. 1 Investment trend: count of patent families by first publication year

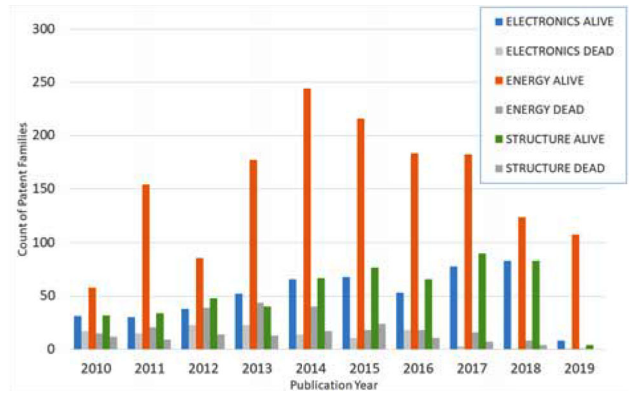

Fig. 2 Investment trend by legal state

3 Results and discussion

This paragraph presents the results obtained from the analysis of patent families published worldwide between January 1, 2010 and December 31, 2019. A patent family is a set of patents taken in various countries to protect a single invention. We extracted and analysed the dynamics of nanotechnology inventiveness in the three technology sectors related to "Engineered Materials and Structures", "Sensors, Electronics and Devices", and "Energy Storage, Power Generation and Power Distribution". Our analysis aims at withdrawing information on the following topics, which are further specified in the following paragraphs:

- Investment Trend;
- Technology Overview;
- Main Worldwide Key Players;
- Geographic distribution and target markets.

3.1 Investment Trend

The graph reported in Fig. 1 illustrates the evolution of patent publications over time (2010–2019), indicating the dynamics of inventiveness of the portfolio studied. The graph shows the investment trends, both global and by sector, for the period 2010–2014. We can clearly see a general non-linear growth of the Global Trend, which is highly determined by the patent publications in the "Energy Storage, Power Generation and Power Distribution". Such trend means that applicants were in the phase of construction of their patent portfolios. However, considering that the growth is not exponential, we can highlight the players' continued interest in this field without racing for the construction of massive portfolios.

For the 2014–2018 period, we can see a slight decline in the number of patents in "Energy Storage, Power Generation and Power Distribution". Such trend can be explained either by a potential disengagement of the players in this technological field or as a sign of market maturity.

For the overall period 2010–2019, it is worth noticing the steady trend in the number of patents filed in "Sensors, Electronics and Devices" and in "Engineered Material and Structure", that is a sign of maturity of these sectors. However, it is worth pointing out that the substantial decrease visible in the last two publication years is due to the 18-month delay between the filing of an application and its actual publication.

The graph in Fig. 2 shows the trends in the three sectors identified, focusing on the legal state of the patents retrieved. This kind of information is useful to understand if these patents are "Alive" (85% of the total amount) or "Dead" (15% of the total amount). For the sake of clarity, patents with no expiration events within their predicted term are considered "Alive". A family remains alive as long as it contains at least one record with an "Alive" status. Patents that pass their expiration date (20 years) and those with a terminal event (e.g., failure to pay maintenance fees) are considered "Dead".

Having considered in our analysis only a period of ten (10) years, the total amount of dead patents reported in Fig. 2 refers mainly to terminal events, such as patent withdrawal. The highest percentage of "Dead" patents is reported in 2017 for "Engineered Materials and Structures"; in 2018 for "Sensors, Electronics and Devices"; and in 2014 for "Energy Storage, Power Generation and Power Distribution".

3.2 Technology Overview

In our analysis, we used the IPC to carry out a technology overview of the areas where a greater patenting activity has been registered. Such analysis allows the identification of the main technological specialisation areas. The IPC hierarchical system, operationally managed by WIPO, is based on eight (8) technological main Sections: "A" (Human necessities); "B" (Performing operations, transporting); "C" (Chemistry, Metallurgy); "D" (Textiles; Paper); "E" (Fixed Constructions); "F" (Mechanical Engineering; Lighting, Heating; Weapons, Blasting); "G" (Physics); and "H" (Electricity).

Fig. 3 Technology overview

These are further divided into classes (number), sub-classes (letter), and groups (main and sub). For the purpose of our analysis, we considered the IPC4 (i.e., sub-class), to build a ranking of the technological areas with a higher level of patent protection.

The following graph (Fig. 3) shows the Technology Overview as emerged from the analysis of the first fifteen (15) International Patent Classification codes (IPC4) [8], considering all the three technology sectors.

In Appendix 1, a detailed list of the most frequent IPC4 codes resulting from our analysis is reported.

The following picture (Fig. 4) instead specifically focuses on the most frequent IPC4 codes within the Technology sectors. In particular, for "Energy Storage, Power Generation and Power Distribution", the most frequent IPC4 are:

- *F03G* Spring, weight, inertia, or like motors; mechanical-power-producing devices or mechanisms, not otherwise provided for or using energy sources not otherwise provided for
- *H01M* Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy
- *H01L* Semiconductor devices; electric solid-state devices not otherwise provided for

The most frequent IPC4 codes related to "Sensors, Electronics and Devices" are:

- *H01L* Semiconductor devices; electric solid-state devices not otherwise provided for
- *G02B* Optical elements, systems, or apparatus
- *G01N* Investigating or analysing materials by determining their chemical or physical properties

  The most frequent IPC4 codes related to "Engineered Material and Structure" are:
- *B64G* Cosmonautics; vehicles or equipment therefor
- *C07D* Heterocyclic compounds

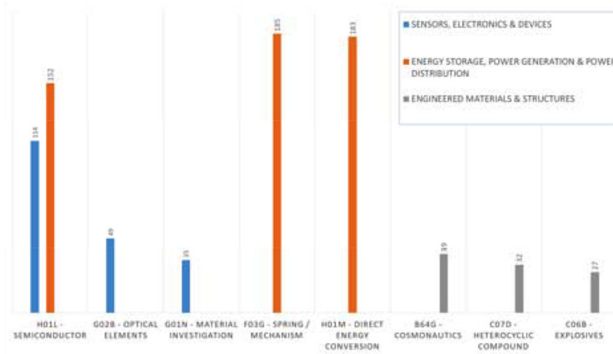

Fig. 4 Technology overview based on Top IPC4

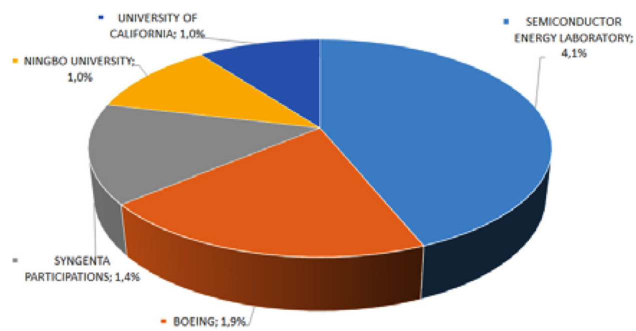

Fig. 5 Top key players

- *C06B* Explosive or thermic compositions; manufacture thereof; use of single substances as explosives.

3.3 Main Worldwide Key Players

Patents do not only provide a high level of detail on technologies, but they also highlight the organisations, the places, and the period of development of every patented invention [9].

The pie chart in Fig. 5 shows the top worldwide Key Players across the three sectors under examination, and namely the most frequent assignees in the patent set analysed. These data are a good indicator of the level of inventiveness of the most active players, mainly large corporations and universities, and their countries: Semiconductor Energy Laboratory in Japan (4.1% of the overall alive family patents), Boeing in USA (1.9%), Syngenta Participations in China (1.4%), Ningbo University in China (1%), and University of California in USA (1%). These first five (5) players worldwide cover almost 10% of the overall set of "Alive" patents examined. It is interesting to point out that large players and academia from different technological specialisations—not strictly related to the space sector—are involved in patenting activities that could provide significant contribution to space applications, also in terms of economic investments.

The chart in Fig. 6 depicts the top five (5) players with the largest number of patents in their portfolios in each technology sector under investigation, by volume of the topic

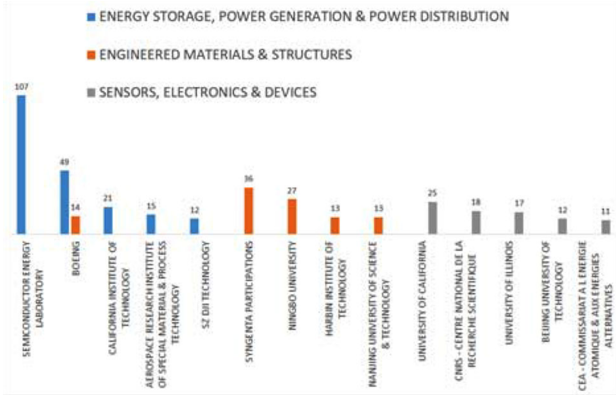

Fig. 6 Top Players by technology sector

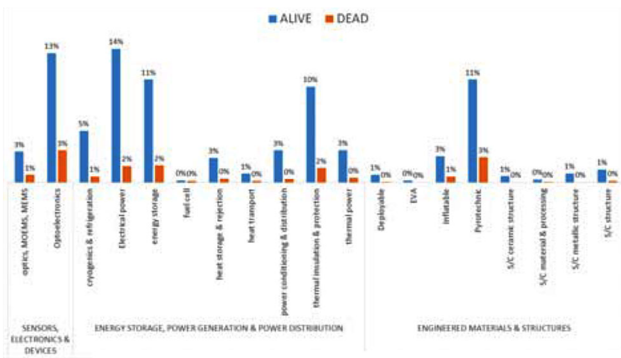

Fig. 7 Legal state by technology group

studied and their specialisation area. From this kind of analysis, we can identify that Semiconductor Energy Laboratory, Boeing, and California Institute of Technology have a strong specialisation in "Energy Storage, Power Generation and Power Distribution". Boeing is also strongly active and has a deep specialisation in "Engineered Materials and Structures" together with Syngenta Participations and Ningbo University. The University of California, CNRS (Centre National de la Recherche Scientifique), and University of Illinois have a strong specialisation in "Sensors, Electronics & Devices".

The chart in Fig. 7 illustrates a detailed picture of the patents analysed in the different sectors according to their legal state. The most active Technology Groups are related to Electrical power (14%), Optoelectronics (11%), Energy storage (11%), Pyrotechnic (11%), and Thermal insulation and protection (10%). Conversely, the highest rate of dead patents is related to optoelectronics (3%) and pyrotechnics (3%).

3.4 Geographic Distribution and Target Markets

The map in Fig. 8 illustrates the geographical distribution of alive patents protected in the various national patent offices.

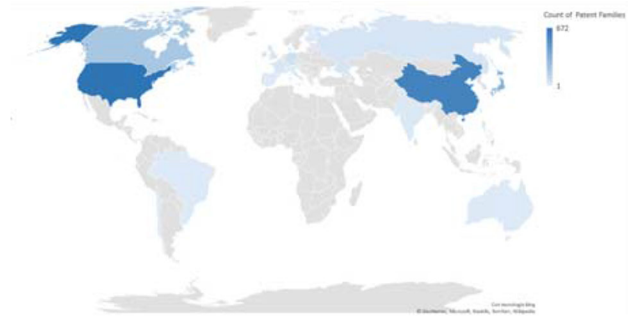

Fig. 8 Market and competitors' location

It also provides information on the commercial strategies of the players in the sectors studied, as the national filings are a good indicator of the markets that need to be protected. In addition, many players protect the geographical areas where the manufacturing sites of their competitors are located.

The top ten (10) markets with the highest patenting activity in the period 2010–2019 are shown in Fig. 9. In this pie chart, we can see the overall patenting activity for the mentioned period related only to "Alive" patents. More in detail, US maintains its hegemony (27% alive family patents) followed by China (24%) and Japan (13%). It is worth noticing that, if we consider both "Alive" and "Dead" patents, China patenting activity (27%) exceeds the US (25%) for the same period (2010–2019). This result is particularly interesting when compared to the results obtained for the period 2000–2009, reported in Fig. 10, where we can see that US, a country traditionally related to the space sector, was already positioned as first country worldwide in its patenting activity with 37% of alive patents, while China was far below US with a percentage of alive patents of only 5%. Such trend clearly shows how patenting policies have changed in the Chinese industrial sector. This result confirms the general trend for the period under analysis, as already highlighted in [10, 11]. In highly competitive markets, Chinese firms needed to acquire strategic assets to compete successfully, particularly in the global marketplace. China's domestic and outbound technology acquisition regime, as well as its IP system more generally, has therefore become more formalised, predictable, and rules-driven.

From the two graphs, we highlight that Canada (8%), one of the ESA Member States, is also highly active in patenting activity, although it also decreased from 14% (2000–2009) to 8% (2010–2019).

It is, however, worth highlighting that the overall patenting activity worldwide in all three Technology Groups is quite relevant and involves many other countries, such as: Japan, EU countries (DE, IT, FR, ES), Korea, Great Britain, and Russia.

If we examine the European countries, the overall trend is quite steady in both periods (2000–2009) and (2010–2019).

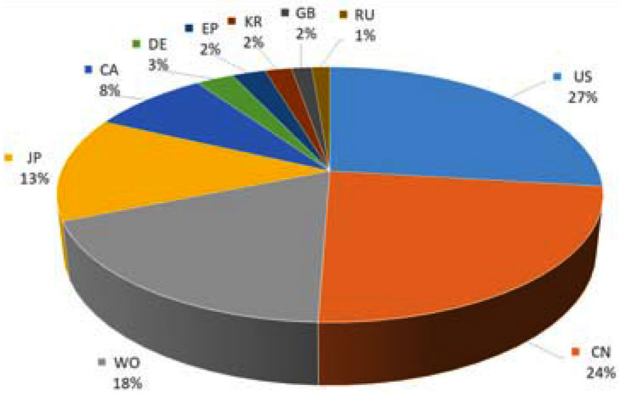

Fig. 9 Top 10 markets and competitors—alive patents (2010–2019)

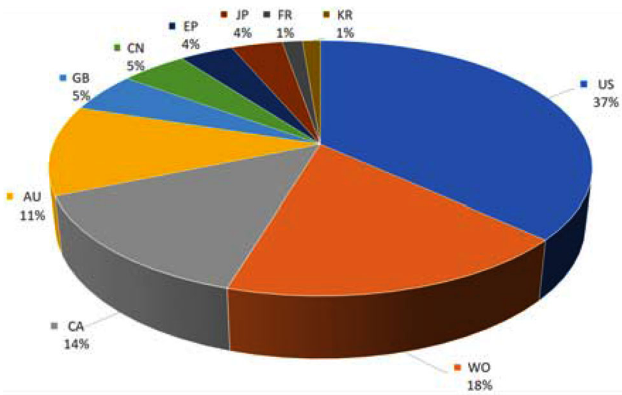

Fig. 10 Top 10 markets and competitors—alive patents (2000–2009)

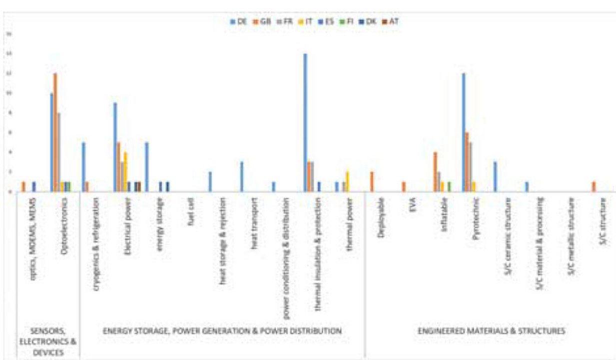

Fig. 11 EU focus: markets coverage by technology group

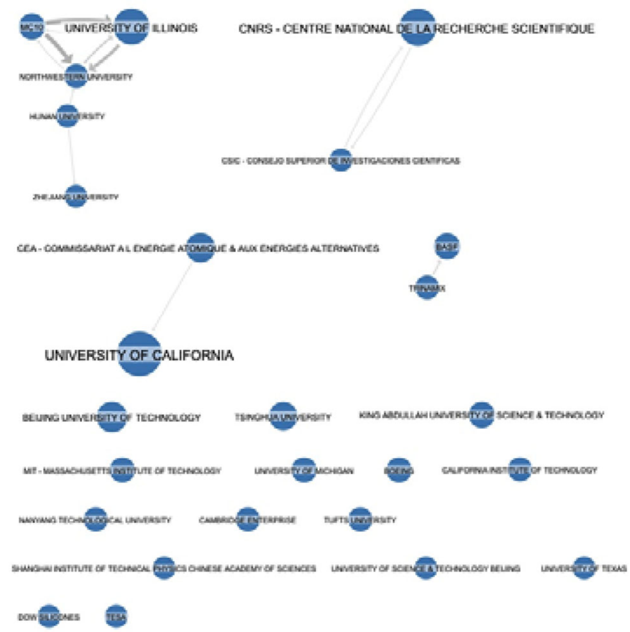

Fig. 12 Sensors, electronics, and devices—player dependency by citation (Source: Questel-Orbit Intelligence®)

The chart in Fig. 11 illustrates a European focus on patents and market coverage in the last 10 years. Such focus on the European patenting activity shows that Germany, Great Britain, France, Italy, and Spain are the most active European countries. It is also worth observing that Germany, Great Britain, and France have a very broad and transversal expertise in almost all the considered Technology Groups (TG).

Conversely, the other countries analysed display a more vertical and sector-based expertise.

Patent data are not static [9]; in fact, a dynamical view can also be provided by the citations of both antecedents and descendants of patented inventions. Indeed, the overall portfolio shows more than 70,000 cited patents and more than 26,000 citing patents. More specifically, the graphs in Figs. 12, 13, and 14 explain the players' dependency by citation in the three sectors considered. This kind of information identifies those patent portfolios that have strong interactions with each other. A portfolio that is strongly cited by most players is likely to be a pioneering or a blocking portfolio. The representations given hereinafter are a good indicator of the applicants' inclination to collaborate and they also depict their preferred partners.

The broadest citation dependency in the "Sensors, Electronics and Devices" sector (Fig. 12) is shown by the Top Key Players (University of Illinois, CNRS—Centre National de la Recherche Scientifique, and University of California). It is interesting to notice the significant interaction between University of California and CEA (Commissariat à l'énergie atomique et aux Énergies Alternatives).

In the "Energy Storage, Power Generation, and Power Distribution" sector (Fig. 13), the most relevant citation cluster is shown by University of California, Boeing, and CNRS (Centre National de la Recherche Scientifique).

In the "Engineered Materials and Structures" sector (Fig. 14), the broadest citation dependence is shown by Syngenta Participation.

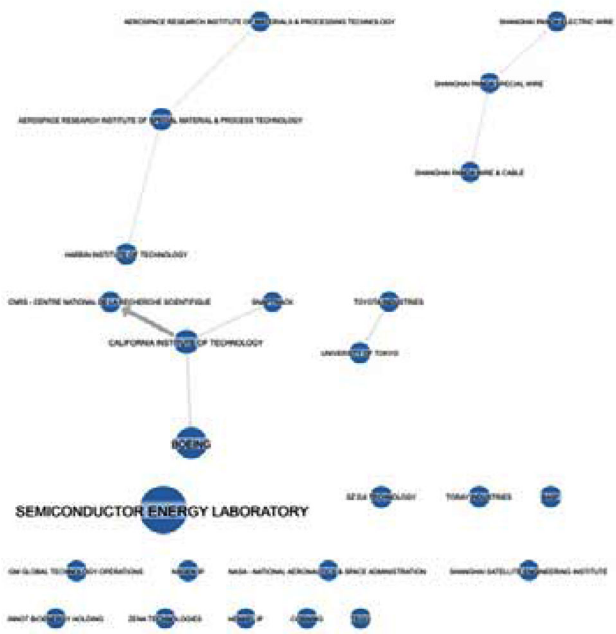

Fig. 13 Energy storage, power generation, and power distribution—-player dependency by citation (Source: Questel-Orbit Intelligence®)

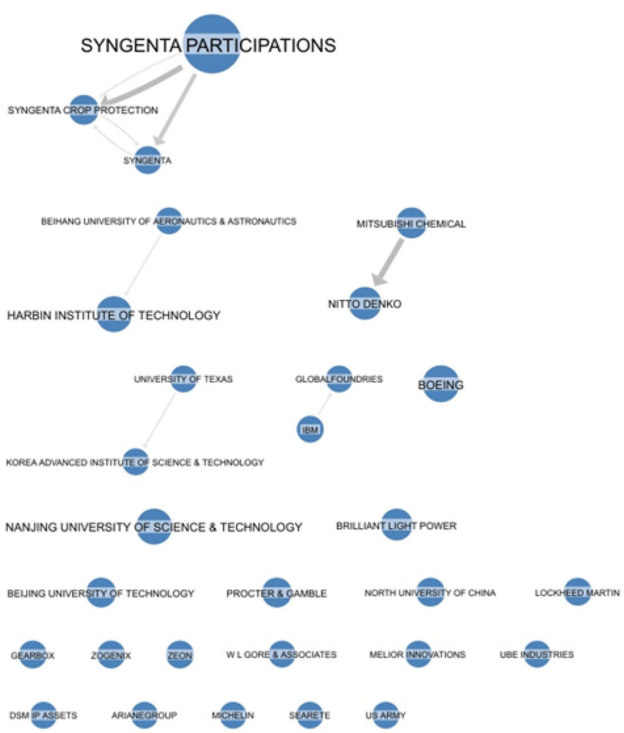

Fig. 14 Engineered materials and structures—player dependence by citation (Source: Questel-Orbit Intelligence®)

4 Conclusions

Following the above-presented analysis, we can draw some conclusions. As shown in this document, space-related patents cover a wide range of nanotechnology knowledge, since their applications may include nanoparticles, nanocomposites, and nanostructures, and may be applied in energy conversion, storage systems, and in electronics and sensors. Indeed, the patent analysis carried out on over 3000 worldwide family patents, which confirmed that nanotechnologies play a significant role in all space technology sectors considered.

In particular, our analysis focused on three nanotechnological areas relevant to the space sector, namely: "Sensors, Electronics and Devices", "Energy Storage, Power Generation, and Power Distribution", and "Engineered Materials and Structures".

The overall interest in the protection of the patent families considered is very high, since 85% of the total amount is still "Alive".

Using the IPC4 taxonomy, we built a ranking of the most frequently protected technological areas. Such ranking includes: semiconductors (H01L), energy direct conversion (H01M), mechanical devices (F03G), optical elements (G02B), material analysis (G01N), spacecraft (B64G), heterocyclic compounds (C07D), and explosives (C06B).

Our analysis also included the most frequent assignees in the patent portfolio analysed to assess the level of inventiveness worldwide. The most active players, which are mainly large corporations and universities from China and US, cover almost 10% of the overall set of patents.

From a market point of view, US confirms its highest positioning with 27% of alive family patents, followed by China (24%). However, if we consider also "Dead" family patents, China exceeds the US. This result is particularly interesting when compared to the results obtained for the period 2000–2009, in which China was far below US. The overall patenting activity worldwide in all the areas examined is quite relevant and involves many other countries, such as: Japan, Canada, EU countries (DE, IT, FR, ES), Korea, Great Britain, Russia, India, Taiwan, Israel, Brazil, and Australia.

From the analysis of the backward and forward citations, it is interesting to highlight that the overall portfolio of over 3000 family patents examined is not static since more than 70,000 cited patents and more than 26,000 citing patents have been retrieved.

Finally, on the basis of the results obtained, we can assess that the "Energy Storage, Power Generation, and Power Distribution" is the area with the highest patenting activity (~1700 patent families) with an investment trend for the past ten (10) years that has seen a general non-linear growth.

For what the "Sensors, Electronics and Devices" (~600 patent families) and "Engineered Materials and Structures" (~650 patent families) are concerned, we found that the investment trend for the same period has been generally slow and steady.

Our results, far from being exhaustive, present an innovative technology overview where the specific combination of a space taxonomy (ESA Technology Tree) and a nanotechnology taxonomy (ASI Nanotechnology Taxonomy) proved to be valuable in identifying the trends of emerging and existing technologies. However, a thorough analysis will be performed integrating other kinds of data, such as bibliometrics and market indicators.

Appendix 1

IPC4 Codes

IPC4	Description
B01J	CHEMICAL OR PHYSICAL PROCESSES, e.g., CATALYSIS OR COLLOID CHEMISTRY; THEIR RELEVANT APPARATUS
B32B	LAYERED PRODUCTS, i.e. PRODUCTS BUILT-UP OF STRATA OF FLAT OR NON-FLAT, e.g., CELLULAR OR HONEYCOMB, FORM
B64G	COSMONAUTICS; VEHICLES OR EQUIPMENT THEREFOR
C01B	NON-METALLIC ELEMENTS; COMPOUNDS THEREOF
C04B	LIME; MAGNESIA; SLAG; CEMENTS; COMPOSITIONS THEREOF, e.g., MORTARS, CONCRETE OR LIKE BUILDING MATERIALS; ARTIFICIAL STONE; CERAMICS; REFRACTORIES; TREATMENT OF NATURAL STONE
C06B	EXPLOSIVE OR THERMIC COMPOSITIONS; MANUFACTURE THEREOF; USE OF SINGLE SUBSTANCES AS EXPLOSIVES
C07D	HETEROCYCLIC COMPOUNDS
C08G	MACROMOLECULAR COMPOUNDS OBTAINED OTHERWISE THAN BY REACTIONS ONLY INVOLVING CARBON-TO-CARBON UNSATURATED BONDS
C09K	MATERIALS FOR APPLICATIONS NOT OTHERWISE PROVIDED FOR; APPLICATIONS OF MATERIALS NOT OTHERWISE PROVIDED FOR
F01K	STEAM ENGINE PLANTS; STEAM ACCUMULATORS; ENGINE PLANTS NOT OTHERWISE PROVIDED FOR; ENGINES USING SPECIAL WORKING FLUIDS OR CYCLES
F03G	SPRING, WEIGHT, INERTIA, *or like motors*; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR
G01N	INVESTIGATING OR ANALYSING MATERIALS BY DETERMINING THEIR CHEMICAL OR PHYSICAL PROPERTIES
G02B	OPTICAL ELEMENTS, SYSTEMS, OR APPARATUS
G02F	DEVICES OR ARRANGEMENTS, THE OPTICAL OPERATION OF WHICH IS MODIFIED BY CHANGING THE OPTICAL PROPERTIES OF THE MEDIUM OF THE DEVICES OR ARRANGEMENTS FOR THE CONTROL OF THE INTENSITY, COLOUR, PHASE, POLARISATION OR DIRECTION OF LIGHT, e.g., SWITCHING, GATING, MODULATING OR DEMODULATING; TECHNIQUES OR PROCEDURES FOR THE OPERATION THEREOF; FREQUENCY-CHANGING; NON-LINEAR OPTICS; OPTICAL LOGIC ELEMENTS; OPTICAL ANALOGUE/DIGITAL CONVERTERS
H01L	SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES NOT OTHERWISE PROVIDED FOR
H01M	PROCESSES OR MEANS, e.g., BATTERIES, FOR THE DIRECT CONVERSION OF CHEMICAL ENERGY INTO ELECTRICAL ENERGY

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