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Patent Landscape Analysis

Buckypaper

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1. Introduction

1.1 Background on the subject

Buckypaper is a paper of about 25-µm thickness made from Carbon Nanotube ("CNT") fibers. The thickness of CNT fibers' is about 1/50,000thof the diameter of a single human hair. These nanotubes form atomic bonds powerful enough to make them twice as hard as diamonds. When sheets of buckypaper are stacked together, the resulting composite material is 10 times lighter than steel while being 250 times stronger. The vast potential of such a material in industry is mind boggling. For instance, in the aviation industry, dramatic improvements can be made to aero structures, can increase payloads, and also improve fuel efficiency.

Also, unlike conventional composite materials, buckypaper conducts electricity about as well as silicon and disperses heat like steel. Instead of the metal mesh currently used in the structure of the composite aircraft to disperse lightning strikes, buckypaper, with its high current-carrying capacity, would allow lightning's electrical charge to flow around the plane and dissipate without causing damage.

This material has flame retarding properties and could one day help prevent fires on aircraft, ships and other structures. Its strength-to-weight ratio might also prove ideal when making protective gear, including helmets and body armor, for the military and police, as well as create improved and more comfortable prosthetics for wounded veterans.

> *When sheets of buckypaper are stacked together, the resulting composite material is 10 times lighter than steel while being 250 times stronger.*

Such features would explain why the US Air Force and companies like Raytheon and Lockheed Martin have been heavily investing in R&D of the material to fulfill its promise. Florida State University has also been doing research in this field and they have also developed a prototype[1]. Buckypaper can be used to grow biological tissue, such as nerve cells. Buckypaper can be electrified or functionalized to encourage growth of specific types of cells. It could act as a filter membrane to trap micro particles in air or fluid. As the nanotubes in buckypaper are insoluble and can be functionalized with a variety of functional groups, they can selectively remove compounds or act as a sensor.

> *This sheet has variety of applications, ranging from growing biological tissue to fabrication of the television picture tubes.*

[1] Future planes and cars may be made of paper '500 times stronger than steel' [LINK]

This wonder material could even be used to illuminate computer and television screens. It has the potential to be more energy-efficient, lighter, and more effective in producing uniform brightness in screens than current cathode ray tube (CRT) and liquid crystal display (LCD) technology.

Figure 1: Buckypaper developed at Florida State University [LINK]

1.2 Purpose of the Analysis

The upward trends in finding a better replacement for steel, has led to exploration of carbon nanotube films or sheets which are thinner and stronger.

The current patent landscape study explores the recent developments in the research of Buckypaper (Carbon Nano Tube film). The focus is to capture patents published since 2005, with some of them taking priority from 1996, in countries such as India, China, Taiwan, USA, Australia, France, Italy and so forth.

Four main technological avenues exist for the Buckypaper market:

1. Fabrication methods of Carbon nanotubes/ Buckypaper
2. Modification of CNT films by patterning and doping
3. Properties of the CNT films
4. Application areas of CNT films/ Buckypaper

Instead of considering the ups and downs of this technology, this study aims to establish a panorama of the industrial property and research in fabrication and applications of Carbon Nanotube films.

2. Market analysis

2.1 Hon Hai Precision Industry Co. Ltd.

2.1.1 Profile

Hon Hai Precision Industry Co. Ltd., trading as Foxconn Technology Group, is a Taiwanese multinational electronics contract manufacturing company headquartered in Tucheng, New Taipei, Taiwan. It is the world's largest electronics contract manufacturer measured by revenues. Foxconn is primarily an original design manufacturer and its clients include many top American, European, and Japanese electronics and information technology companies. Notable products that the company manufactures include the iPad, iPhone, iPod[2], Kindle, PlayStation 3, and Wii U.

2.1.2 Patent Portfolio

Hon Hai Precision Industry Co. Ltd., has 204 patents related to Buckypaper in our portfolio. The patents mainly focus on touch screen displays (used in iPad, iPhone, etc.), transistors, capacitors, diodes, etc. (used in motherboards).

2.1.3 Financial Analysis

The company has been able to grow revenues from $114.7 billion USD (2011) to $129.7 billion USD (2012)[3]. Net Income also increased from 2.71 billion USD (2011) to 3.15 billion USD (2012).

2.2 Samsung Electronics Co. Ltd.

[2]Apple Adding More iPad Production Lines To Meet Holiday And 2011 Demand [LINK]
[3] Hon Hai precision industry(2317:Taiwan) [LINK]

2.2.1 Profile

Samsung Electronics Co., Ltd. is a South Korean multinational electronics company headquartered in Suwon, South Korea. It is the flagship subsidiary of Samsung Group and has been the world's largest information technology company by revenues since 2009. Samsung Electronics has assembly plants and sales networks in 88 countries and employs around 370,000 people. Samsung has previously been known for its position as a manufacturer of components such as lithium-ion batteries, semiconductors, chips, flash memory and hard drive devices for clients such as Apple, Sony, HTC and Nokia. Since 2010, Samsung has been one of the largest vendors in the mobile phone and smartphone markets. Samsung has been the world's largest maker of LCD panels and the world's largest television manufacturer since Samsung Electronics displaced Apple Inc. as the world's largest technology company in 2011[4] and has been a major part of the Economy of South Korea.

2.2.2 Patent Portfolio

Samsung Electronics Co., Ltd., has 17 patents related to Buckypaper in our portfolio. The patents mainly focus on touch screen displays (used in LCDs, smartphones, etc.), transistors, capacitors, diodes, etc. (used in processors, memory flash devices).

2.2.3 Financial Analysis

The company has been able to grow revenues from $144.48 billion USD (2011) to $176.07 billion USD (2012)[5]. Net Income also increased from 11.72 billion USD (2011) to 20.31 billion USD (2012).

2.3 Nantero Inc.

2.3.1 Profile

Nantero is a technology company based in Woburn, Massachusetts dedicated to developing a new form of non-volatile RAM, called Nano-RAM, or NRAM(R).[6] It was founded in 2001 by Greg Schmergel, Thomas Rueckes, and Brent M. Segal.

[4]Samsung reports best sales ever, expects PC deals in Q4 [LINK]
[5] Samsung electronics co ltd (005930:Korea SE) [LINK]
[6] Nantero [LINK]

2.3.2 Patent Portfolio

Nantero Inc. has 9 patents related to Buckypaper in our portfolio. The patents mainly focus on transistors, capacitors, diodes, etc. (used in processors, memory flash devices).

2.3.3 Financial Analysis

It is a privately held firm. In August of 2008, Lockheed Martin Corp. acquired Nantero's government business unit, and entered into an exclusive license arrangement with Nantero for government applications of Nantero's intellectual property portfolio. A radiation-resistant version of NRAM, developed jointly by Lockheed Martin[7] and Nantero, was tested on Space Shuttle mission STS-125 in May 2009, proving that NRAM can function even in harsh conditions of space. Nantero began collaboration with the Belgian Nano electronics research center (IMEC) in October 2012 to develop high-density carbon-nanotube memories with features smaller than 20 nanometers in size. In November 2012, Nantero received series D funding to advance NRAM into commercial production. Nantero completed series D with an investment by Schlumberger Limited, in May 2013.

2.4 Other Key Players

2.4.1 Intel Corporation

Intel Corporation[8] is an American multinational semiconductor chip maker corporation headquartered in Santa Clara, California. Intel is the world's largest and highest valued semiconductor chip maker, based on revenue It is the inventor of the x86 series of microprocessors, the processors found in most personal computers. Intel Corporation, founded on July 18, 1968, is a portmanteau of Integrated Electronics (the fact that "Intel" is the term for intelligence information was also quite suitable). Intel also makes motherboard chipsets, network interface controllers and integrated circuits, flash memory, graphic chips, embedded processors and other devices related to communications and computing.

[7] Lockheed buys Nantero's government unit [LINK]
[8] Intel Annual Report [LINK]

No. of Patents	Patent Focus
5	All the patents mainly focus on increasing the thermal conductivity of thermal interface using Carbon Nano Tubes films.

2.4.2 Fuji Xerox Co., Ltd.

Fuji Xerox Co., Ltd. is a joint venture partnership between the Japanese photographic firm Fuji Photo Film Co. (75%)[9] and the American document management company Xerox (25%) to develop, produce and sell xerographic and document-related products and services in the Asia-Pacific region. Its headquarters is in Midtown West in Tokyo Midtown, Akasaka, Minato, and Tokyo, Japan. Fuji Xerox is the world's longest running joint venture between a Japanese and an American company.

No. of Patents	Patent Focus
5	They have filed the patents in variety of domains, ranging from solar cell to electronic devices

2.4.3 Eastman Kodak Company

Eastman Kodak Company is an American multinational imaging and photographic equipment, materials and services company headquartered in Rochester, New York, United States and incorporated in New Jersey. It was founded by George Eastman in 1888. Kodak is best known for photographic film products. During most of the 20th century Kodak held a dominant position in photographic film, and in 1976 had a 90% market share of photographic film sales in the United States. The company's ubiquity was such that its tagline "Kodak moment[10]" entered the common lexicon to describe a personal event that demanded to be recorded for posterity.

[9] Fuji Xerox Unveils Its First Corporate Identity Change In 13 Years [LINK]
[10] The end of our Kodak moment [LINK}

No. of Patents	Patent Focus
4	All the patents mainly focus on manufacturing touch screen panels using Carbon Nano Tubes films.

2.4.4 Lockheed Martin

Lockheed Martin is an American global aerospace, defense, security, and advanced technology company with worldwide interests. It was formed by the merger of Lockheed Corporation with Martin Marietta in March 1995. It is headquartered in Bethesda, Maryland, in the Washington Metropolitan Area. Lockheed Martin employs 123,000 people worldwide. Lockheed Martin is one of the world's largest defense contractors as is evident from the fact that in 2009, 74% of Lockheed Martin's revenues came from military sales. It received 7.1% of the funds paid out by the Pentagon[11].Lockheed Martin operates in five business segments. These comprise Aeronautics, Information Systems & Global Solutions, Missile and Fire Control, Mission Systems and Training, and Space Systems. In 2009, US Government contracts accounted for $38.4 billion (85%), foreign government contracts $5.8 billion (13%), and commercial and other contracts for $900 million (2%) in revenues. In both 2009 and 2008 the company topped the list of US Federal Contractors.

No. of Patents	Patent Focus
5	They have filed the patents in variety of domains, ranging from ballistic fabrics to capacitors and two terminal switch

2.4.5 Toray Industries

Toray Group fuses nanotechnology into its operations, using organic synthetic chemistry, polymer chemistry and biotechnology as its core technologies. In addition to the Foundation Businesses of fibers & textiles and plastics & chemicals[12], Toray likewise promotes the global development of IT-related products,

[11] Is Lockheed Martin Shadowing You? [LINK]
[12] Toray Industries [LINK]

carbon fiber composite materials, pharmaceuticals and medical products, environment & engineering including water treatment and progress in other pivotal business fields.

No. of Patents	Patent Focus
6	All the patents mainly focus on manufacturing touch screen panels using Carbon Nano Tubes films.

3. Global Overview of Buckypaper Patents

The aim of this section is to study the overall environment of the intellectual property concerning the development of Buckypaper.

The “patents” search was conducted using a series of key words including: Carbon, nanotube, sheet, layer, film, cover, paper, buckypaper, bucky, etc., based on publication date since 2005, some of them taking priority from 1996. This search, conducted for patents in US, Canada, Mexico, South America, Europe, Japan, China, and India jurisdictions, led to the extraction of around 2546 patent applications published till June 2013. Out of these, a total of 639 relevant patent families have been analysed.

3.1 Priority& Publication Trend

Until 2002, the number of filings remained stable at around 4-6 applications a year, followed by a rise in the number of filings reaching levels of around 12-14 patent application filings a year. More recently, this already dynamic sector has surged further ahead, with more than 100 patent applications in 2008. This rise in the filing of patent applications is due to the increase in the sales of smartphones, as CNT films are used in the display panel of these devices and because most of the applications are related to the fabrication of touch screen displays panels which are used in the smartphone industry.

Patents published after 2005 are considered for the analysis. The predicted figures for the number of published patents in the 2013 and 2014 are 197 and 234 respectively. As of June, 96 patents have been published in the year 2013.

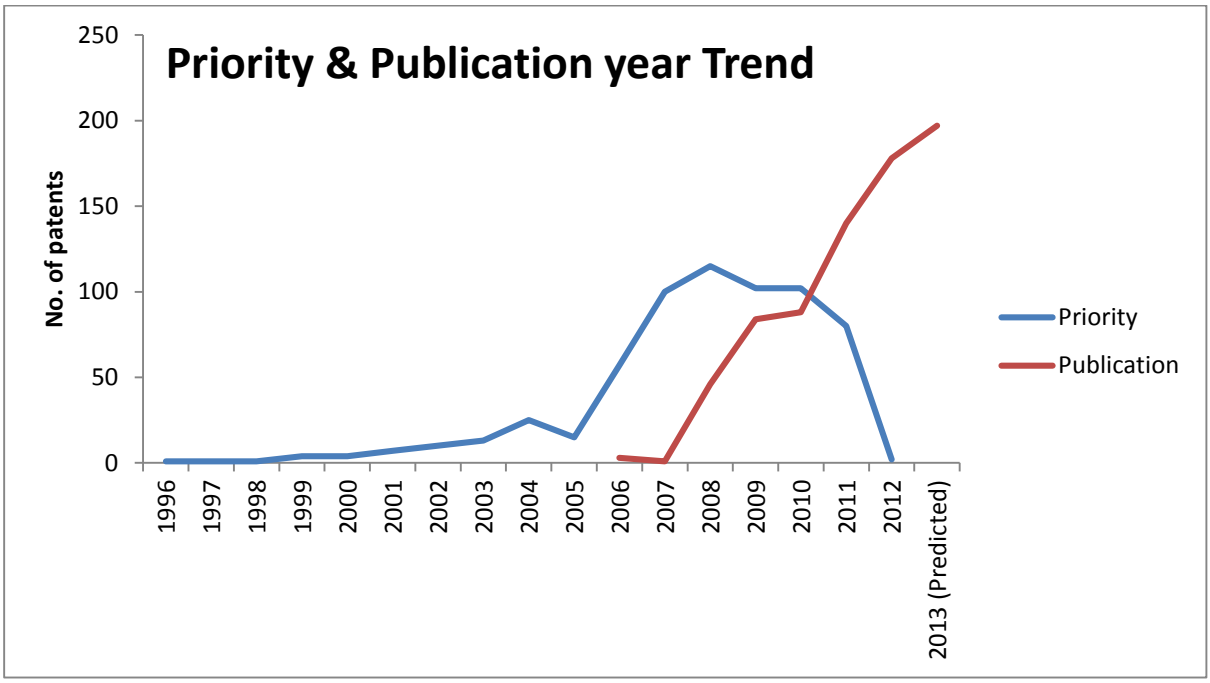


Figure 2: Evolution over time of priority and publications made in the buckypaper field

3.2 Priority Country Distribution

An analysis of the location of the filings of patent applications is shown in the **Figure 3**. The figures give an overview about all the countries that have initiated R&D related to Buckypaper. It can be observed that, USA is the country with most number of priority filings (368 patent families). China is in second place with 213 patents. Some of the newly published patents take priority from Singapore, China, U.S., and Taiwan.

Among the applicants, it is interesting to note that numerous patent portfolios have been built up by academic institutions, such as that of the Tsinghua University (133 patent applications), William Marsh Rice University (8 patents) and University Of Florida Research Foundation Inc. (5 patents). These universities can be easily targeted for technology transfer or patent acquisitions when looking to build a strong portfolio.

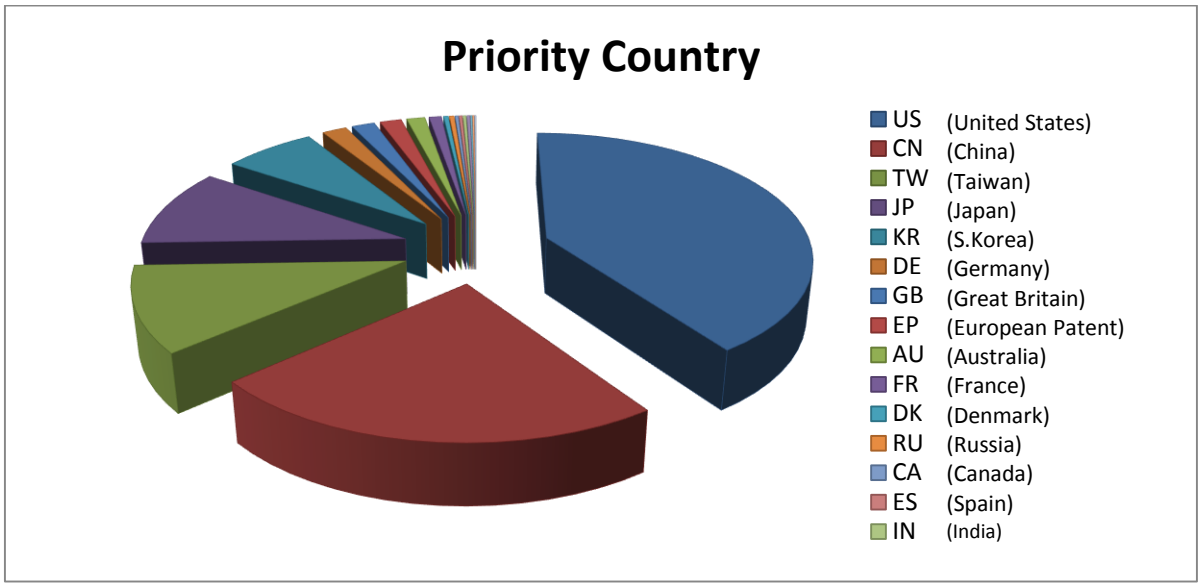


Figure 3: R&D initiation made globally in the Buckypaper technology

3.3 Segmentation of patents by IPC code

We have highlighted the IPC codes that are the most represented in the patent applications filed since 2005. This segmentation is given in the **Figure 4**.

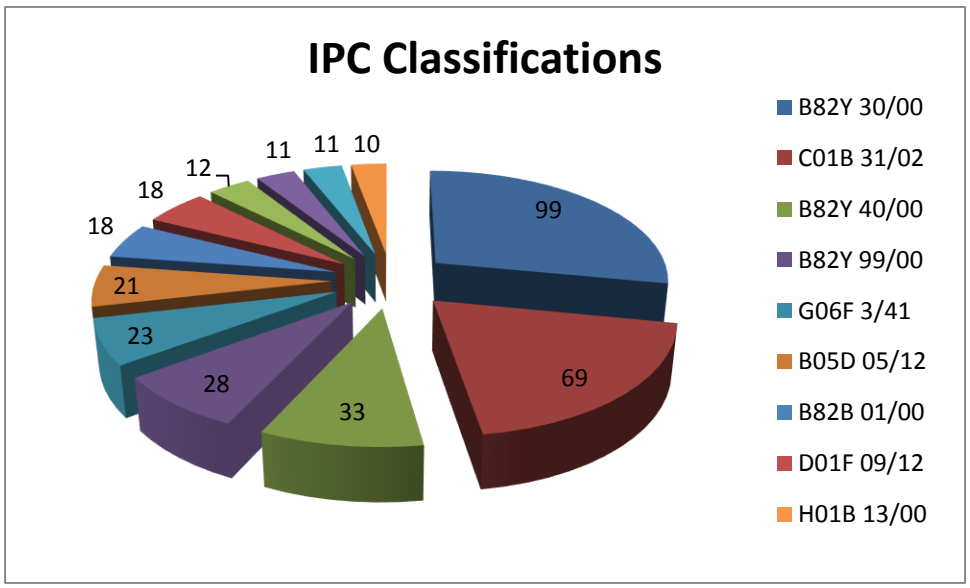


Figure 4: Key International patent classes that have maximum patent filings in this portfolio

3.3.1 Major IPC Classes and their Definitions

The main IPC codes are stable over time and are particularly representative of this sector.

IPC Code	Description
B82Y 30/00	Performing operations; transporting: Nano-Technology: Specific uses or applications of nano-structures; measurement or analysis of nano-structures; manufacture or treatment of nano-structures: Nano-technology for materials or surface science
C01B 31/02	Chemistry; Metallurgy: Inorganic chemistry: Non-metallic elements; compounds thereof: Carbon; compounds thereof: Preparation of carbon; Purification
B82Y 40/00	Performing operations; transporting: Nano-Technology: Specific uses or applications of nano-structures; measurement or analysis of nano-structures; manufacture or treatment of nano-structures: Manufacture or treatment of nano-structures
B82Y 99/00	Performing operations; transporting: Nano-Technology: Specific uses or applications of nano-structures; measurement or analysis of nano-structures; manufacture or treatment of nano-structures
G06F 3/041	Physics: Computing; calculating; counting: Electric digital data processing: Input arrangements for transferring data to be processed into a form capable of being handled by the computer; Output arrangements for transferring data from processing unit to output unit: Input arrangements or combined input and output arrangements for interaction between user and computer: Arrangements for converting the position or the displacement of a member into a coded form: Digitizers
B05D 5/12	Performing operations; transporting: Spraying or atomizing in general; applying liquids or other fluent materials to surfaces, in general: Processes for applying liquids or other fluent materials to surfaces, in general: Processes for applying liquids or other fluent materials to surfaces to obtain special surface effects, finishes or structures: like electrical properties
B82B 1/00	Performing operations; transporting: Nano-Technology: Nano-structures formed by manipulation of individual atoms, molecules, or limited collections of atoms or molecules as discrete units; manufacture or treatment thereof: Nano-structures formed by manipulation of individual atoms or molecules, or limited collections of atoms or molecules as discrete units
D01F 9/12	Textiles; paper: Natural or artificial threads or fibers; spinning: Chemical features in the manufacture of these artificial elements; apparatus specially adapted for the manufacture of carbon filaments: Artificial filaments or the like of other substances; manufacture thereof; apparatus specially adapted for the manufacture of carbon filaments: Of inorganic material: Carbon filaments; apparatus specially adapted for the manufacture thereof
H01B 13/00	Electricity: Basic electric elements: Cables; conductors; insulators; selection of materials for their conductive, insulating or dielectric properties: Apparatus or processes specially adapted for manufacturing conductors or cables

Table 1: Major IPC classifications

3.4 Segmentation of patents by USPC code

We have highlighted the USPC codes that are the most represented in the patent applications filed since 2005. This segmentation is given in the **Figure 5**.

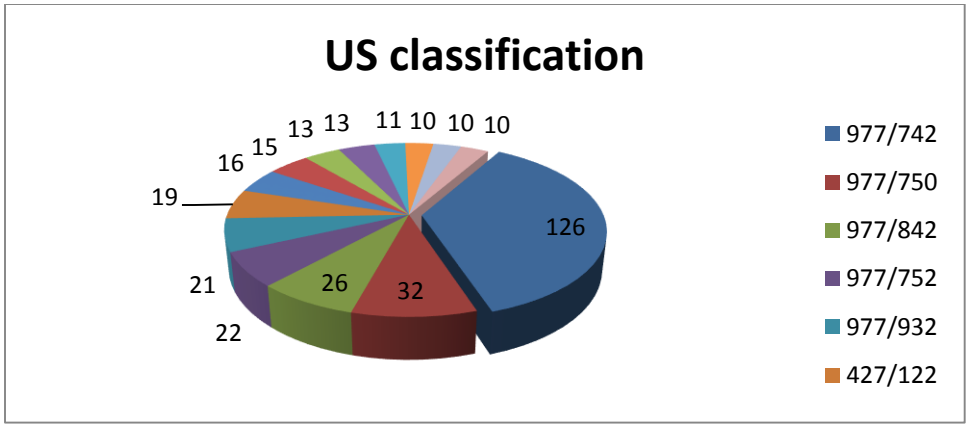


Figure 5: Key US patent classes that have maximum patent filings in this portfolio

3.4.1 Major US Classes and their definitions

USC Code	Description
977/742	Nanotechnology: Nanostructure: Fullerenesor fullerene-like structures: Carbon nanotubes
977/750	Nanotechnology: Nanostructure: Fullerenesor fullerene-like structures: Carbon nanotubes: Single-walled
977/842	Nanotechnology: Manufacture, treatment, or detection of nanostructure: For carbon nanotubes or fullerenes
977/752	Nanotechnology: Nanostructure: Fullerenesor fullerene-like structures: Carbon nanotubes: Multi-walled
977/932	Nanotechnology: Specified use of nanostructure: For electronic or optoelectronic` application
427/122	Coating processes: Electrical product produced: Carbon coating
345/173	Computer graphics processing and selective visual display systems: Display peripheral interface input device: Touch panel
428/408	Stock material or miscellaneous articles: Self-sustaining carbon mass or layer with impregnant or other layer
977/948	Nanotechnology: Specified use of nanostructure: For electronic or optoelectronic` application: Energy storage/generating using nanostructure

Table 2: Major US classifications

4. Key Applicants in the field of Buckypaper

4.1 Major Applicants

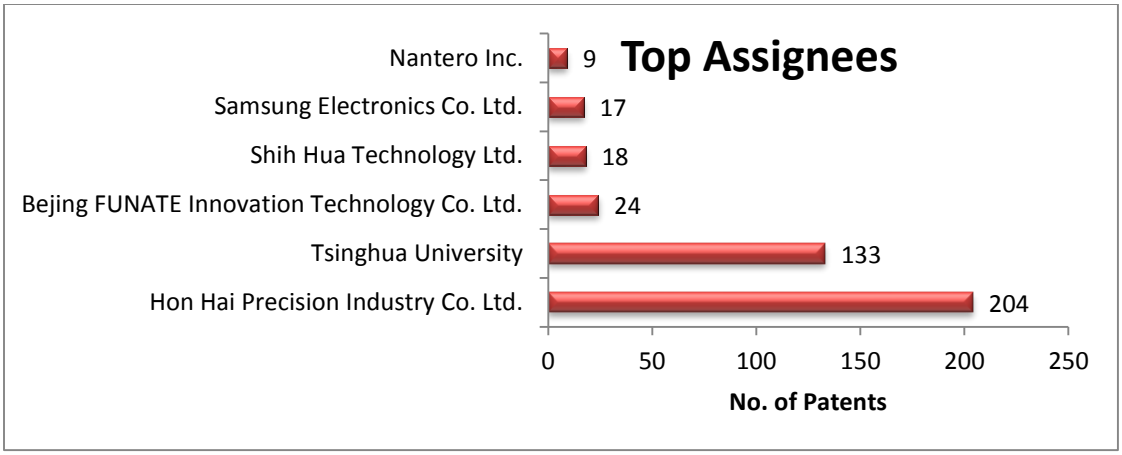


Figure 6: Major assignees in the given field

Hon Hai Precision Industry Co. Ltd. holds the maximum number of patents (204) in the overall portfolio. Fan, Shou-Shan with 174 Patents is the most prolific inventor for this company. All of the patents have been published since 2008. Hon Hai Precision Industry Co. Ltd. is a Taiwanese firm and is the largest contract manufacturer in the world. Term of the patent life in Taiwan and U.S. is 20 years. Hence, most of the patents are in their early stages and ensures that the firm has a strong patent portfolio.

Tsinghua University has 133 patents and they have collaboration with Hon Hai Precision Industry Co. Ltd. (Not shown). Most of the patents are related to flat panel displays or the touch display panels of the touchscreen devices.

Beijing FUNATE Innovation Technology Co. Ltd. also has 24 patents with some of the patents jointly assigned to. Hon Hai Precision Industry Co. Ltd.

Taiwanese firm Shih Hua Technology Ltd has 18 patents, all filed 2011 onwards, related to Touch screen panels.

4.1.1 Geographical analysis of Major Applicants

S. No.	Assignee	Geographical Location	US	CN	TW	JP	KR	EP	AU	WO
1	Hon Hai Precision Industry Co. Ltd.		145	139	81	77	6	12	0	0
2	Tsinghua University		133	129	19	74	6	16	0	0
3	Beijing FUNATE Innovation Technology Co. Ltd.		18	18	5	2	0	0	0	0
4	Shih Hua Technology Ltd		18	3	16	1	0	0	0	0
5	Samsung Electronics Co. Ltd.		15	7	1	5	15	8	0	1
6	Nantero Inc.		6	2	3	1	3	4	2	4

Table 3: Geographical analysis of Major applicants

Maximum patents are filed in US and China because of the dominance of the smartphones and electronic devices industry. American companies have either set up their own manufacturing plants in China or they

have contracted manufacturing to local vendors. For e.g. all the touch panel displays of Apple devices are manufactured by Hon Hai Precision Industry Co. Ltd.

4.2 Key Inventors

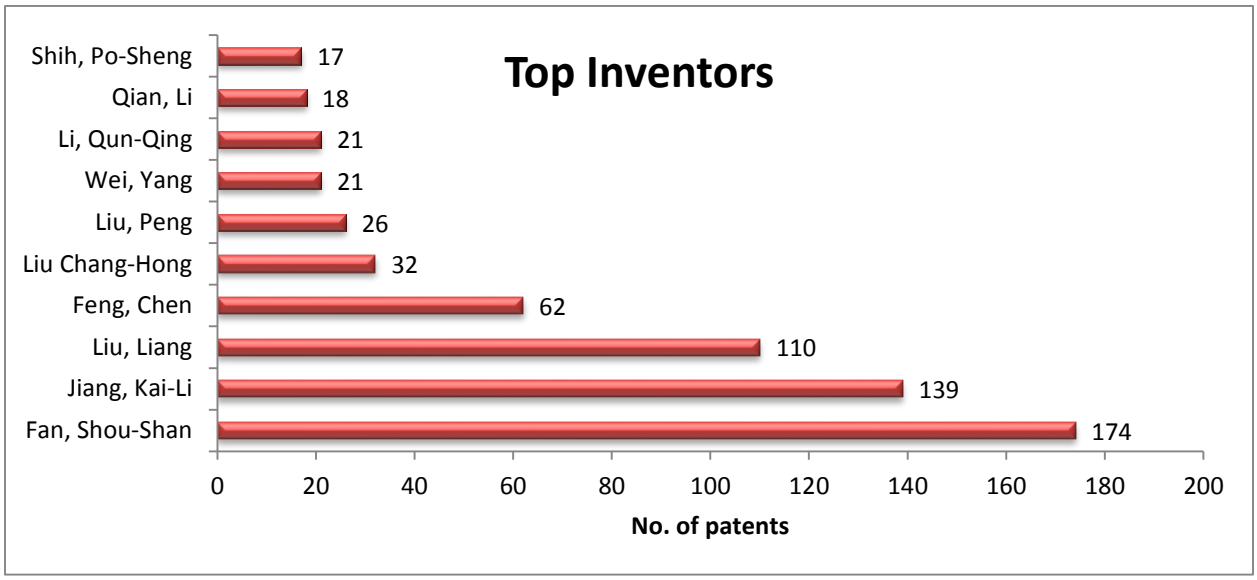


Figure 7: Key inventors that have filed patents related to given field

The inventors identified in IEC patent portfolio have been classified into three separate classes:

The most prolific inventors in terms of filings are Fan, Shou-Shan (Hon Hai Precision Industry Co. Ltd., 174 Patents), and Jiang, Kai-Li (Hon Hai Precision Industry Co. Ltd., 139 Patents). Also, something noteworthy is that both these inventors started filing patents 2007 onwards.

Other inventors are Liu, Liang (110 patents), Feng, Chen (62 patents), Liu Chang-Hong (32 patents), Liu, Peng (26 patents), all of whom work for Hon Hai Precision Industry Co. Ltd.

The emerging inventors described hereafter possess a lower number of patent applications filed, but are more recent. For instance, Veeraswamy, Vijayen, S. (Guardian Industries Corp.) is an inventor with a portfolio of 2 patent applications; Shih, Po-Sheng has filed 2 patent applications for Shih Hua Technology Ltd., while Lin, Yu-Ming has 1 patent application for International Business Machines Corporation.

5. Topology of patents in the field of Buckypaper

5.1 Most Cited Patent Family

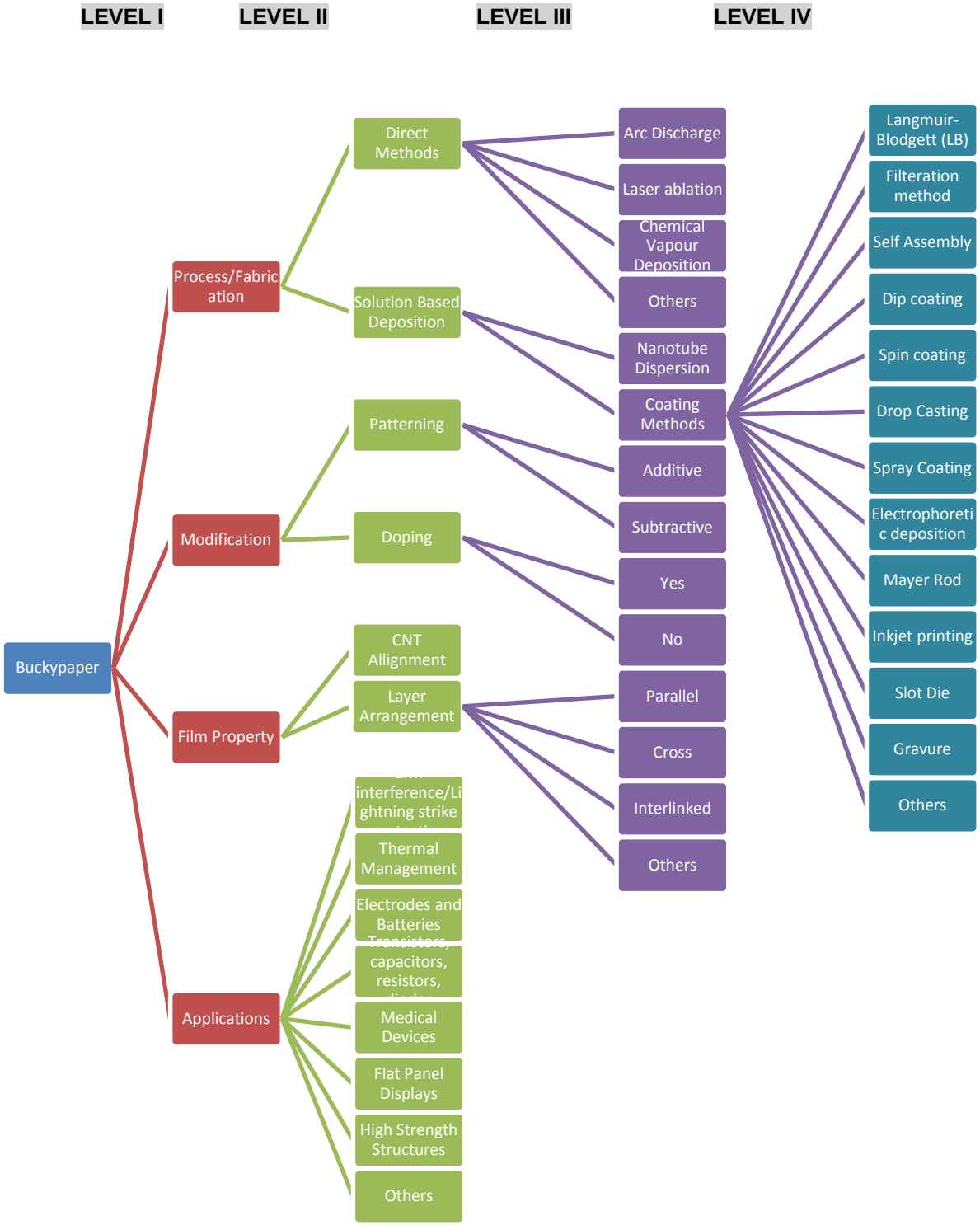
The table below mentions details of the patents that have been cited the most:

Family Id.	Title	Assignee	Number of Citations
20030130US20030021141A1	Carbon nanotube films, layers, fabrics, ribbons, elements and articles	Nantero Inc.	928
19980911CA2283502A1	Array of fullerene nanotubes	William Marsh Rice University	839
19980212WO1998005920A1	Macroscopically manipulablenanoscale devices made from nanotube assemblies	William Marsh Rice University	525
20070208AU2005335123A1	Fabrication and Application of Nanofiber Ribbon and Sheet, and Twisted and Non-Twisted Nanofiber Yarn	University Of Texas	385
20000321CA2280234A1	Device comprising a carbon nanotube field emitter structure and process for forming device	Lucent Technology	301
19990506AU1999PP9764D0	Multilayer carbon nanotube films	Commonwealth Scientific And Industrial Research Organization	248
20021227WO2002103737A2	Field emission devices using carbon nanotubes modified by energy, plasma, chemical or mechanical treatment	Hyperion Catalysis International, Inc.	217

Table 4: Most cited patent family

6. Technology Segmentation

6.1 Taxonomy



6.2 Segmentation of Patents by Technology

6.2.1 Fabrication Methods

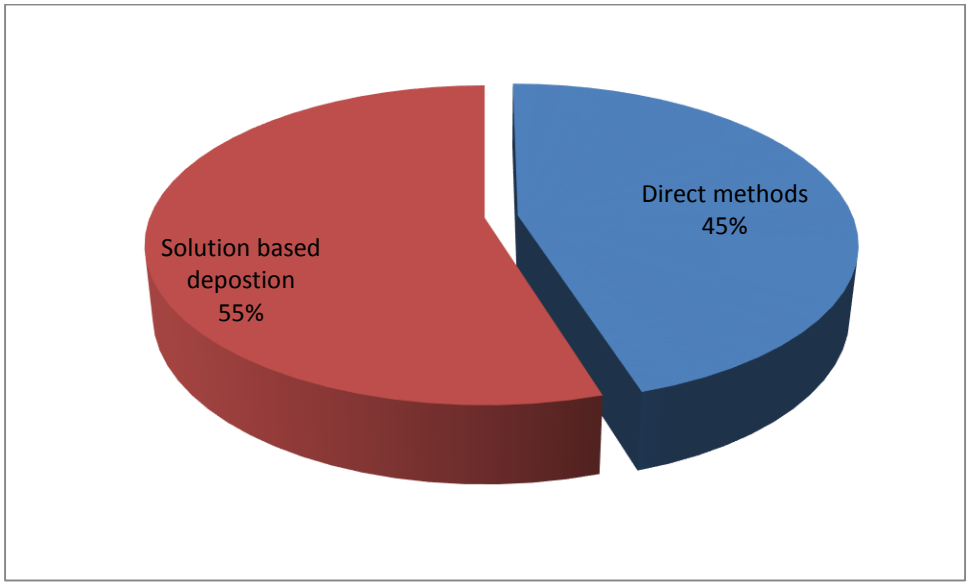


Figure 8: distribution of type of fabrication methods

As seen in **Figure 9**, there are mainly 2 kinds of fabrication methods. Direct methods are the methods in which the CNT layers are formed directly over the substrate by employing various techniques. Solution based methods are the methods in which a solution containing CNTs is deposited on the substrate. Solution based deposition is used in 282 patents whereas direct methods are used in 233 patents for the fabrication of the Carbon Nano tube films over the substrate. Solution based deposition fabrication methods do not require any high vacuum system and it can be done at low temperatures. Hence, solution based deposition methods are used in more number of patents.

6.2.1.1 Type of Direct Methods:

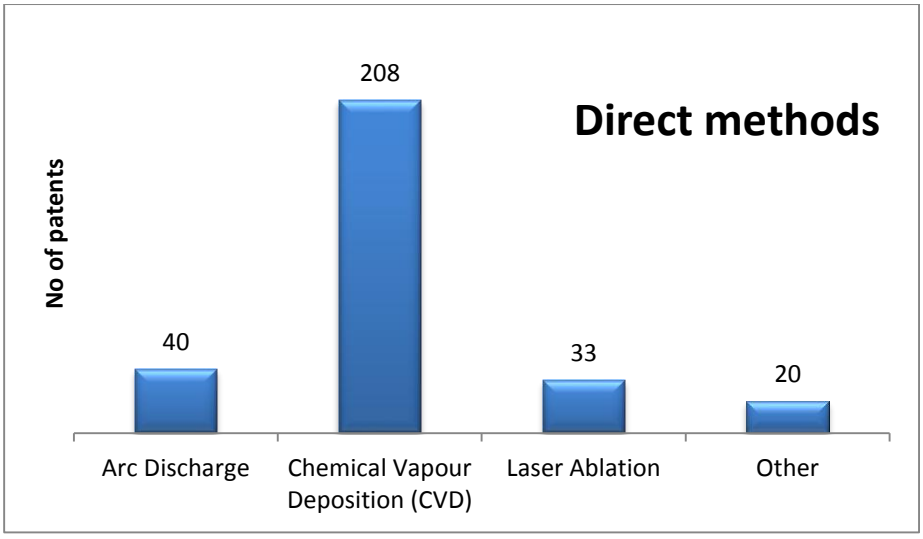


Figure 9: Patent distribution of type of direct methods

Chemical Vapor Deposition (CVD) is the most common among all the direct methods. This is due to the fact that macroscopic quantities of CNTs or sub monolayer densities can be grown through CVD. The density of the CNTs film can be controlled by the catalyst density and growth time.

6.2.1.2 Solution based deposition Coating Techniques:

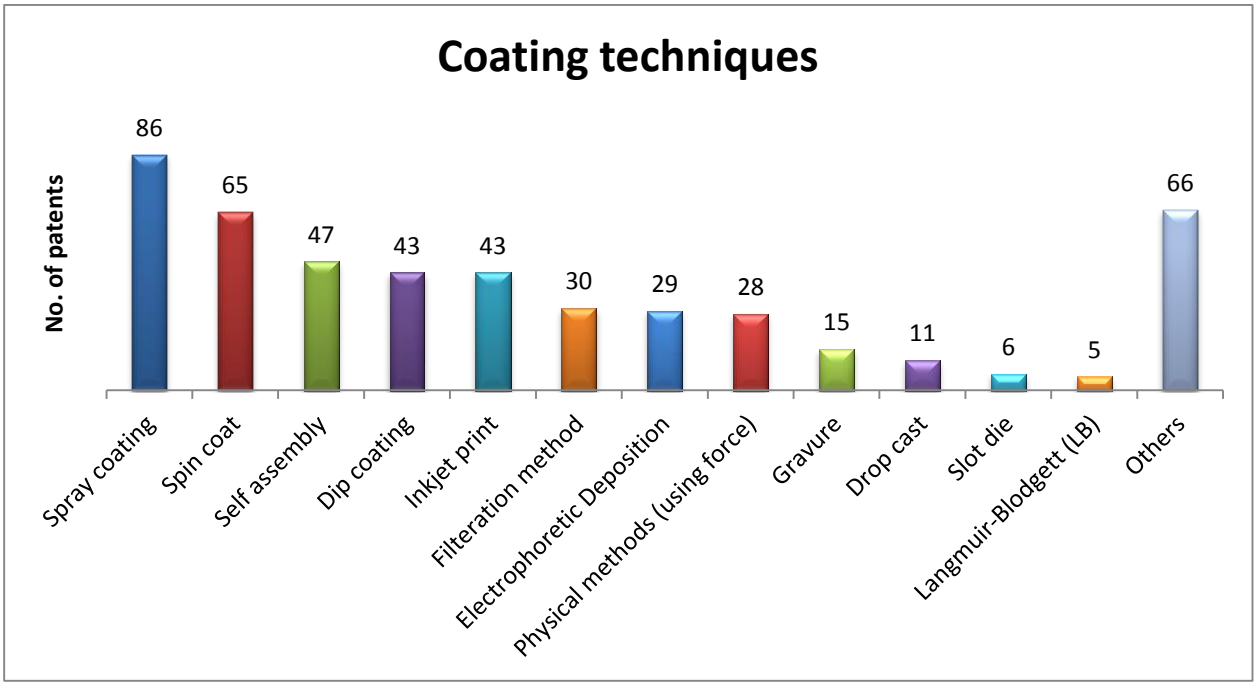


Figure 10: Patent distribution of type of coating techniques

Spray Coating is the most used type of coating technique. Spray coating is popular because of its simplicity and this method takes comparatively less time than other methods for the fabrication of carbon nano tube films. Other methods of coating techniques include kiss coating, knife coating, coating through flocculation, etc.

6.2.2 Film Modifications

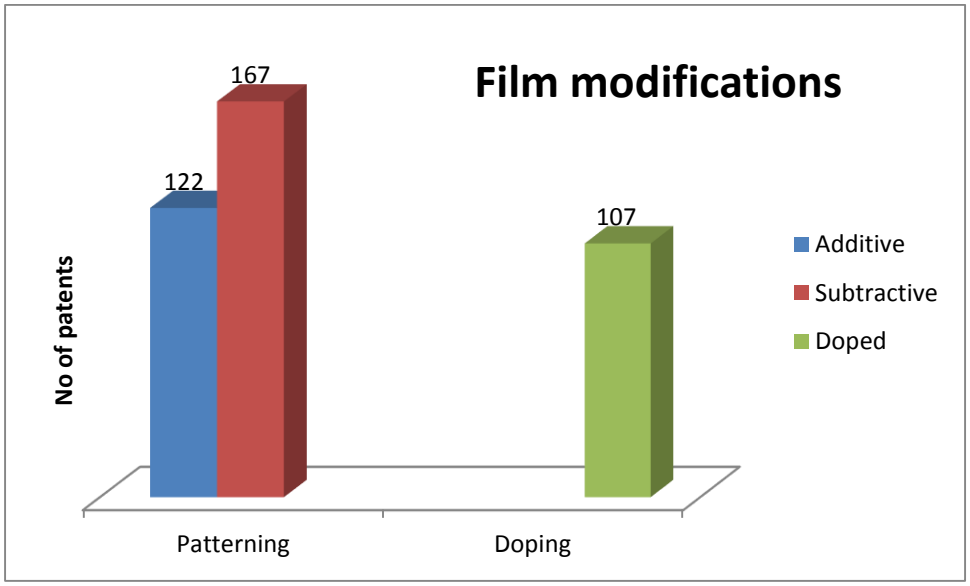


Figure 11: Patent distribution of type of film modifications

Patterning is generally done in the carbon nanotube films which are fabricated by solution based deposition. Most of the patents having additive patterning correspond to the patents which are fabricated through Inkjet printing method. Similarly the CNT films in patents having subtractive patterning are fabricated through spin coating and self-assembly methods.

Doping of CNT thin films is attractive and essential for further performance improvement and modifications. Doping the CNTs increases the charge carrier number for high electrical conductivity. Hence for the fabrication of transistors, doping of the carbon nanotube films is preferred.

6.2.3 Film Property

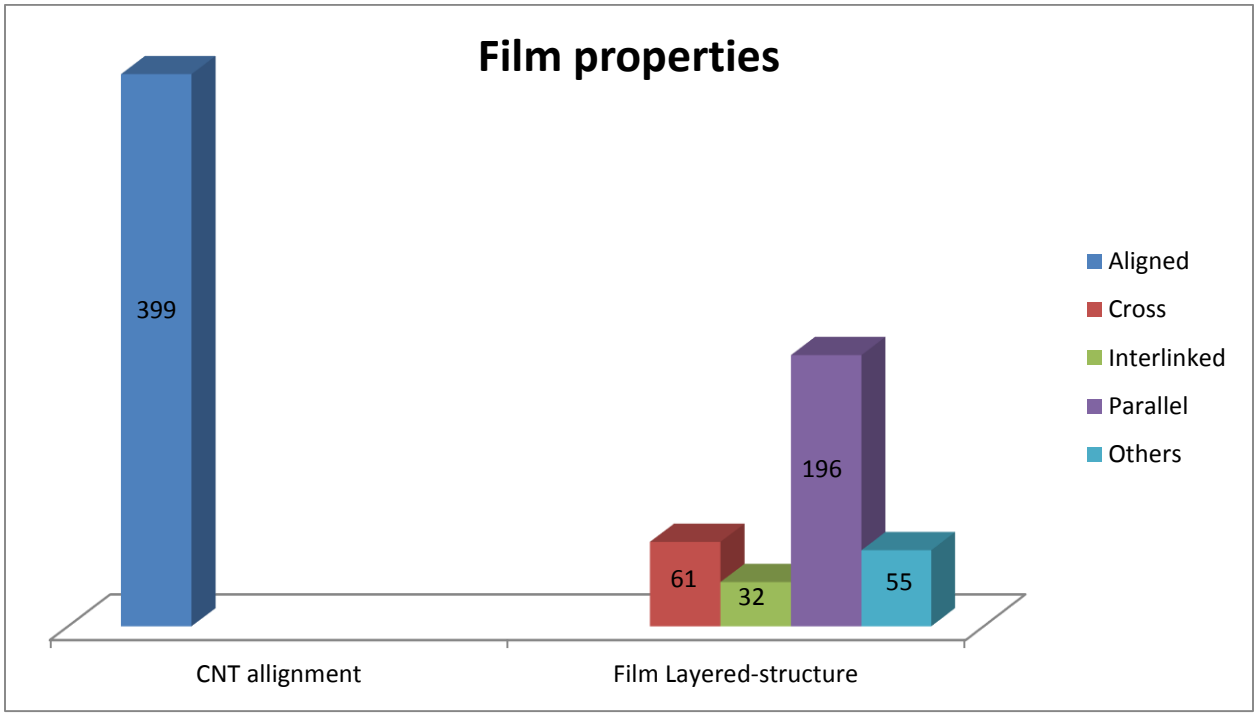


Figure 12: Patent distribution of type of film properties

Aligned CNT films which are stacked in a parallel structure result in the best thermal and electrical conductivity of the structure. Hence for multi-layered film structure, parallel configuration with aligned carbon nanotubes are incorporated in most cases.

6.2.4 Application Areas

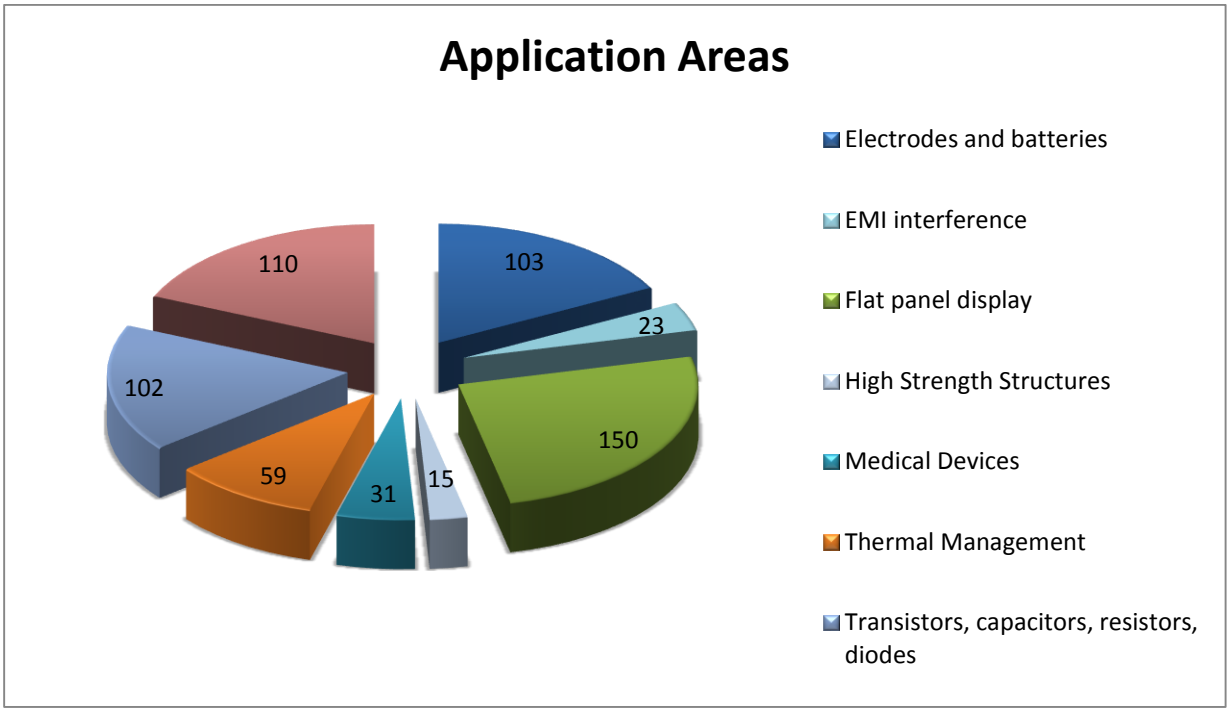


Figure 13: Patent distribution of various application areas

Buckypaper, carbon nanotube films, can be used for variety of applications ranging from fuel cells and electrodes for batteries to flat panel display touch panel display.

Maximum patents correspond to flat panel displays as the major assignee, Hon Hai Precision Industry Co., Ltd., manufactures the touch panel displays for one of the largest manufacturers of smartphones.

6.3 Application areas v/s Key Assignees

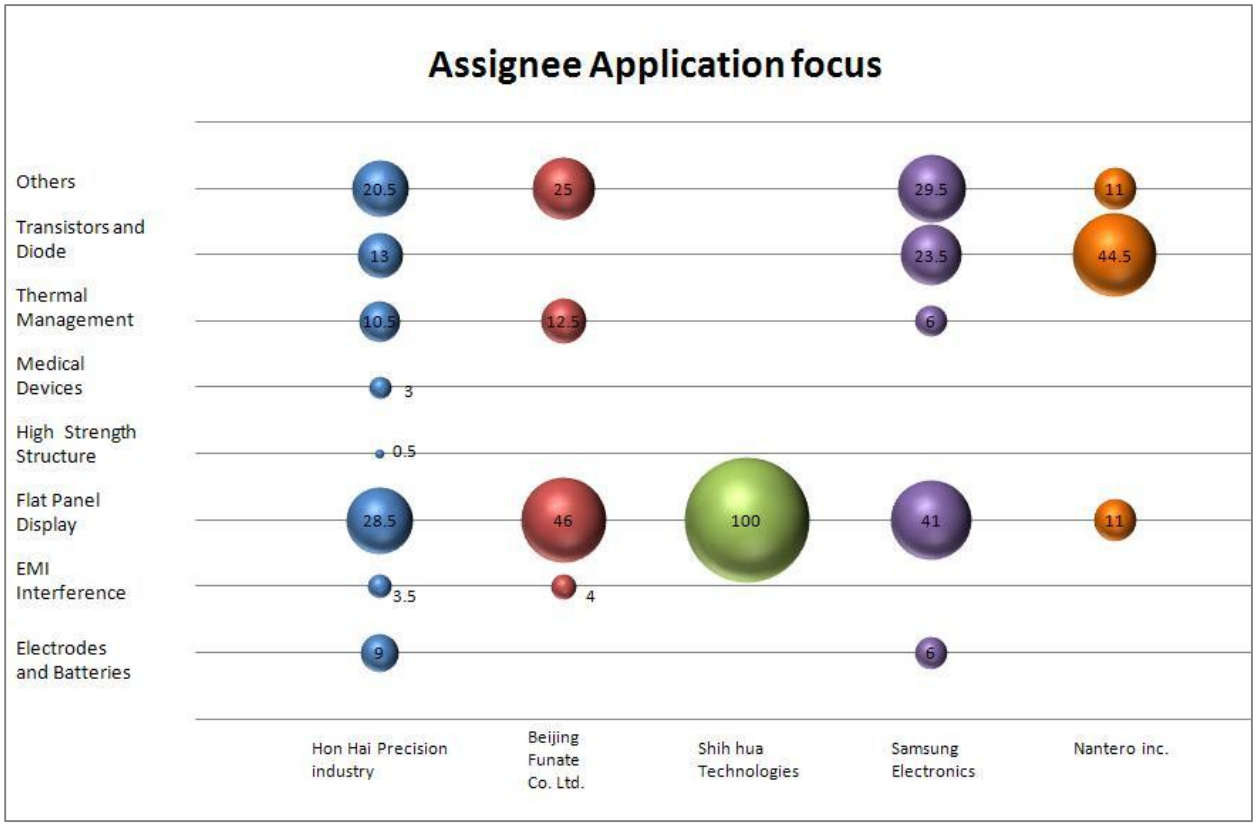


Figure 14: Distribution of Application area amongst top assignees (percentages)

Figure 15 depicts focus of major assignees in various listed applications of the CNT technology, e.g. Shih Hua Technologies patents are only focused on flat panel or touch panel displays. The data represents percentage of analyzed patents focused on a listed application. Tsinghua University patents data has been merged with Hon Hai Precision Industry as all of the patents assigned to Tsinghua University have Hon Hai as co-assignee.

6.4 Technology v/s Key Assignees

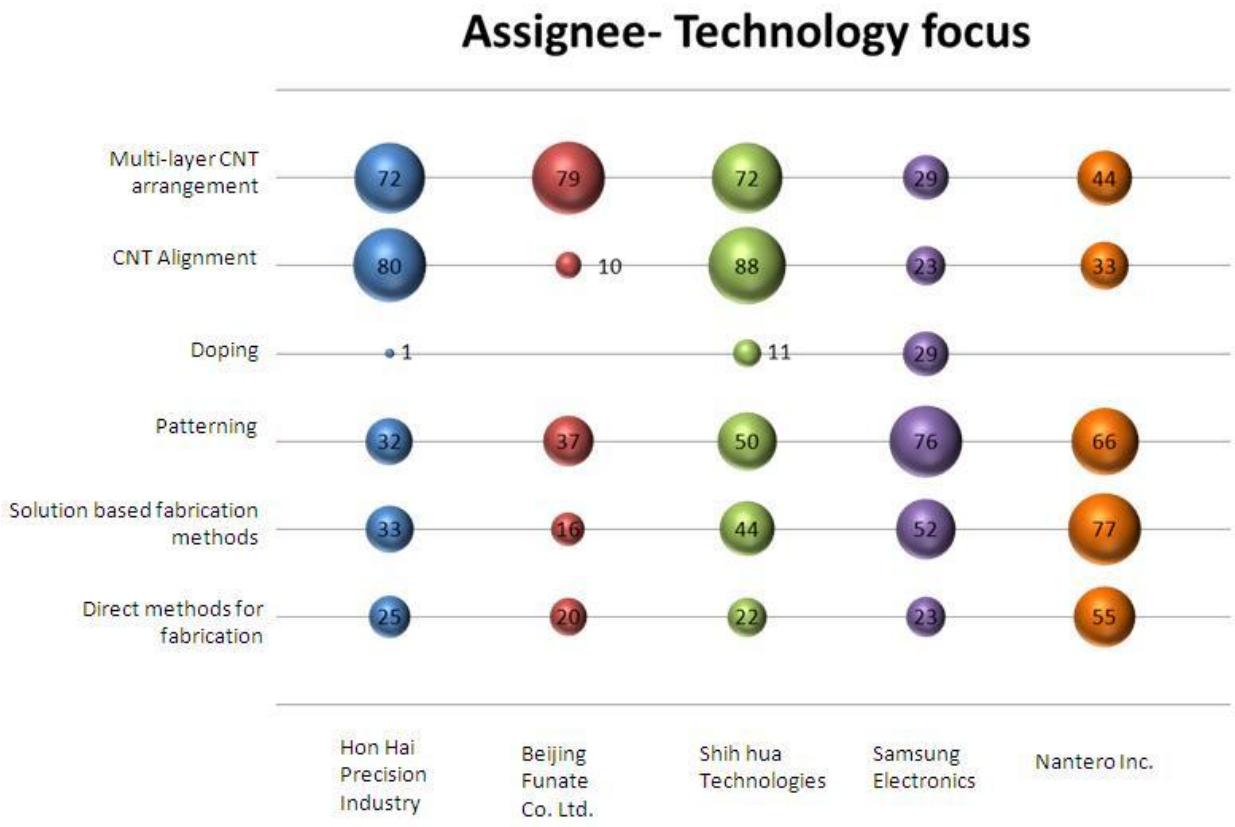


Figure 15: Assignee - Technology Focus

Hon Hai Precision industry Co. Ltd (Assignee) focuses in the technology domains of Multi-layer CNT arrangement and CNT alignment technology which is reflected in **Figure 16** with 80 percent of its patents related to multi-layer CNT arrangement and 72 percent to CNT alignment. 29 percent of the patents assigned to Samsung Electronics disclose doping technology. Samsung Electronics data holds its significance as most of the Samsung Electronics patents are related to transistors technology and doping forms an integral part of transistors technology.

6.5 Evolution in filings by Technology

6.5.1 Evolution in Fabrication methods

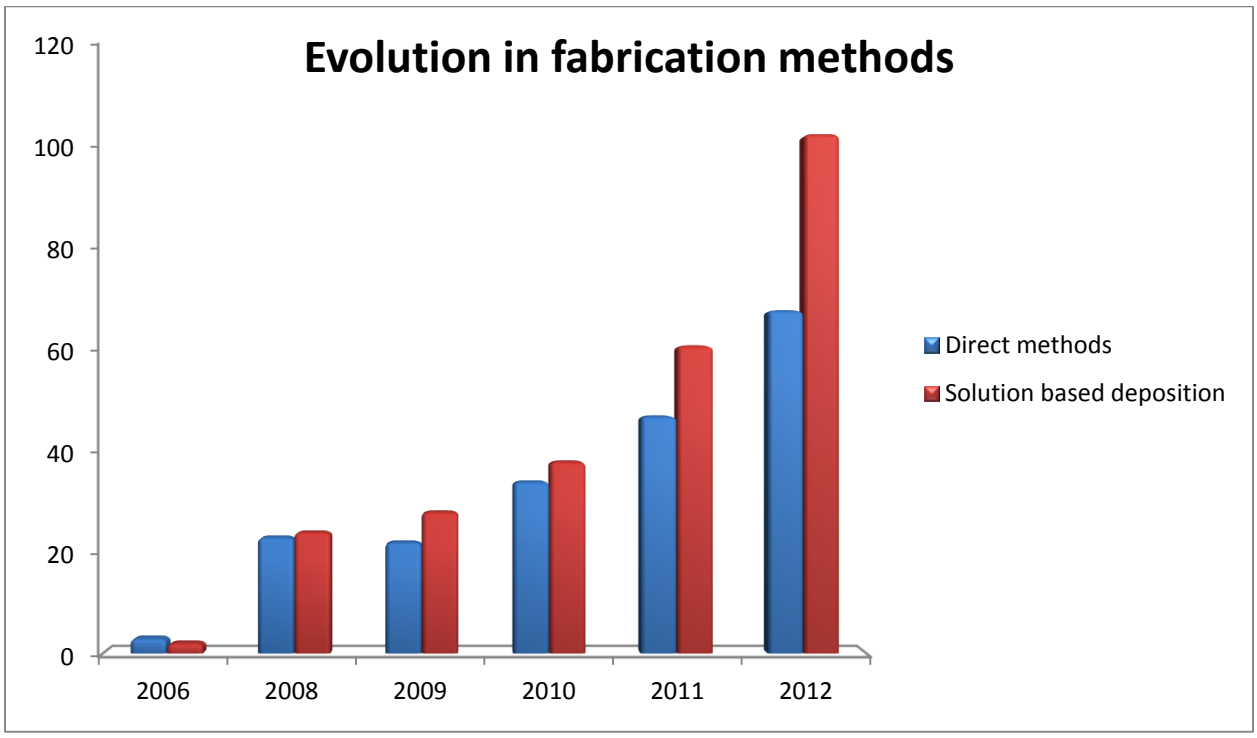


Figure 16: Evolution in fabrication method of CNT film

Recently, solution-based film coatings have found widespread interest in both industry and academia. When compared to direct growth methods for film deposition, a solution-based process has several advantages. It is a low temperature (<100°C) process, compatible with plastic substrates; it does not need a high-vacuum system, thereby reducing costs significantly; and the deposition occurs at high speeds up to 200ft./min using roll-to-roll techniques.

6.5.2 Evolution in Film Properties

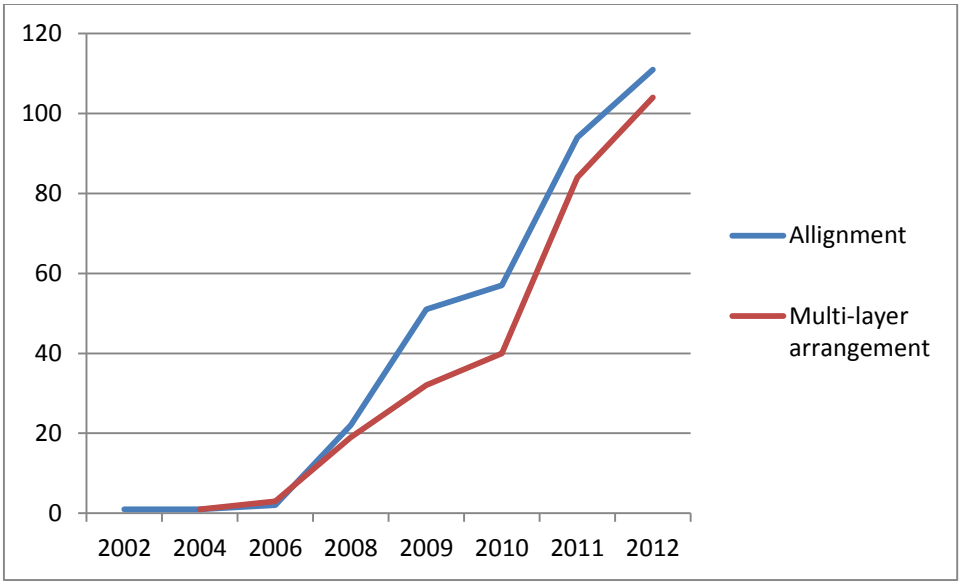


Figure 17: Evolution in properties of CNT film

In the recent years, a lot of stress has been laid upon the carbon nanotubes' layers arrangement and the arrangement of the multilayer structure. This is because the properties of film change with changes to the layer structure.

7. Conclusion

This article showcases carbon nanotube fibers in the form of buckypaper and its various applications, along with fabricating methods. Buckypaper provides multiple applications in various spheres of technology such as growing biological tissue, illuminating computer and television screens, and strengthening material for helmets and body armor.

The landscape analysis generates a clear view of the buckypaper technology thus, giving insight of different market key players. With regard to geographies and jurisdictions USA and China are showcased as the most dominant markets in this technology.

Interestingly, the technical analysis provides valuable knowledge about path of evolution of the technology. As per the study, fabrication methods are direct methods and solution based deposition methods. The study helps realize that a solution-based process has several advantages over alternatives. This is because it is a low temperature (<100 °C) process, compatible with plastic substrates; it does not need a high-vacuum system, which reduces costs significantly; and the deposition occurs at high speeds up to 200 ft./min using roll-to-roll techniques. The apparent advantages are recognized by industry as well, with a sharp rise in development of these methods since 2012. Similarly, the stats also reveal an upward trend with regard to

alignment and arrangement of the multilayer structure as the properties of the film changes with the layer structure.

More recent patents are related to solution based deposition methods and with regard to alignment and arrangement of the multilayer structure of the buckypaper films.

The analysis also brings to light the focus of the major key assignees under different technology heads related buckypaper. Around 80% patents of Hon Hai Precision Industry Co. Ltd. , Beijing Funate Co. Ltd. and Shih Hua Technologies are focused on alignment and arrangement of CNT films, whereas, more than three-fourths of the total patents of the patent portfolio of Nantero Inc. are focused on fabrication methods.

Among different criteria of analysis, the assignee-application stats analysis showed that Shih Hua Technologies has all buckypaper related patents describing flat panel display technology (touchscreen panel).

Through the analysis, one may infer that buckypaper technology has witnessed tremendous growth in recent years. Due to its immense potential with respect to applications, R&D will further increase, which will eventually result in the use of buckypaper in various spheres of technology.

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