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Using patent analyses to monitor the technological trends in an emerging field of technology: a case of carbon nanotube field emission display

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Abstract Carbon nanotube field emission display (CNT-FED) represents both emerging application of nanotechnology and revolutionary invention of display. Therefore, it is an important subject to monitor the states and trends of CNT-FED technology before the next stage of development. The present paper uses patent bibliometric analysis and patent network analysis to monitor the technological trends in the field of CNT-FED. These results firstly reveal the different aspects of patenting activities in the field of CNT-FED. Then, patent network analysis indicates the developing tendency of worldwide FED production based on the synthesis of CNT materials. Furthermore, key technologies of three clusters can be identified as the depositing CNT on substrate, coating phosphor on screen and assembling process for whole device. Finally, emitter material is taken for the key factor in R&D work to improve the efficacy in CNT-FED technology.

Keywords Patent bibliometric analysis · Patent network analysis · Carbon nanotube field emission display (CNT-FED)

Introduction

Patent documents contain much technological and commercial information, and they have important influence on technological innovation and development. Patent analysis transfers

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the data in the patent documents into systematic and valuable information. In general, patent bibliometric analysis is most commonly used to implement patent analysis (Narin 1994). The aim of this method is to find the status, relationship, technological and scientific foundation of patents. Furthermore, patent network analysis is an advanced technique of patent analysis proposed by Yoon and Park (2004). This method shows the overall relationship among all patents as a visual network. The overall structure and the influential patents can be comprehended in the network.

In flat panel displays, field emission display (FED) is one of the major subjects, and it is generated by impinging electrons from cathode onto phosphor coated screen (Talin et al. 2001). When a high electric field is applied on solid surface with a negative potential, electrons inside the solid are emitted into vacuum by the quantum mechanical tunneling effect, which is called field emission of electron (Saito and Uemura 2000). Recently, carbon nanotubes (CNTs) have been demonstrated the unique mechanical, electronic physical and chemical properties (Iijima 1991; Iijima and Ichihashi 1993). Due to these excellent properties, this remarkable material can be extended further to electron emission sources. Thus, this application is named for carbon nanotube field emission display (CNT-FED).

The strategic importance of patent analysis in high-technology management is even more highlighted. The information in patents can be used to realize the subject matter in technological field (Haupt et al. 2007; Corrocher et al. 2007). Nanotechnology is a key technology for the twenty-first century (Meyer and Persson 1998). It can be implemented in the fields of electronics, information technology, materials and medicines. Many studies have indicated the use of patent analysis to analyze the field of nanotechnology (Meyer 2000, 2001, 2006; Bonaccorsi and Thoma 2007; Hullmann 2007). Moreover, Gupta and Pangannaya (2000) used bibliometric analysis to analyze the patenting activity in the area of nanotubes, and Kuusi and Meyer (2007) used bibliographic coupling analysis to identify the leitbilder (guiding images) of nanotubes. These studies demonstrate that patent analysis can be used to explore the field of nanotechnology successfully.

A great deal of attention is being paid now to CNT-FED which represents a new generation of flat panel display (Nicolaescu et al. 2004). Even though CNT-FED has excellent advantages and unique potential, the current technology is not mature enough to resolve technical bottlenecks. It is necessary to monitor the current states and future trends of CNT-FED technology before next stage. Therefore, this study employs patent analyses to monitor the technological states and trends of CNT-FED. First, the patent bibliometric analysis is used to find the developmental path and current states of CNT-FED technology. Next, a network graph of CNT-FED patents is provided to find the overall relationship among all patents by using patent network analysis. And then, the cluster analysis is used to confirm the characteristics of clusters for all patents. Finally, the future directions and trends of CNT-FED technology can be presented based on the results of above analyses.

Methodologies

Selection of patent data

The data source of this study was from searching CNT-FED related codes in the titles and abstracts of patent documents. These documents were obtained from the U.S. Patent and Trademark Office (USPTO) database, and all the selected patents belong to granted patents. Then, the search result was further reviewed and eliminated the irrelevant ones by scientists who work for this field. The final 98 patents were collected from 1996 to 2007. Because the patent numbers were too long to be shown for patent analysis, the patents were sorted by issue date and labeled with serial numbers from 1 to 98. The oldest patent was labeled for number one.

Patent bibliometric analysis

Patent bibliometric analysis is utilizing bibliometrics to perform patent information analysis in order to evaluate technological activities (Narin 1994). In general, statistical analysis and citation analysis are the main methods for this analysis. Statistical analysis performs statistical calculations on the chosen set of bibliometric data to analyze the development and distribution of patented technology. Other patents and non-patent literatures cited in patent documents are main focal points of citation analysis. The highly cited patents reveal the important patents and establish the technological foundation of patents, and the non-patent literature can indicate the linkages between patented technology and basic science and ascertain the scientific foundation of relevant patents (Karki 1997). According to above mention, this study uses patent bibliometric analysis to realize the developmental path of CNT-FED technology and its current states.

Patent network analysis

Network analysis, by emphasizing the relationship connecting the social positions within a system, offers a powerful brush for painting a systematic picture of global social structures and their components (Knoke and Kuklinski 1982). Although network analysis was mainly developed for sociological studies, several studies used it in other research areas (Raan and Peters 1989; Courtial and Callon 1991; Raan and Tijssen 1993; Verspagen 2007). They adopted different methods, such as co-subfield, co-word and patent citation, to construct networks of particular field. Co-subfield method is useful to understand synthesis of knowledge from different subfields. The advantage of co-word method is that words are the foremost carrier of scientific concepts, and their use is unavoidable and they cover an unlimited intellectual domain (Raan and Tijssen 1993). Moreover, patent citation method is suited to tracing the historical development of main path in subject field. Also, Trajtenberg (1990) further suggested that patent citations represent indicators of the value of innovations.

Furthermore, Yoon and Park (2004) used the concept of network analysis in patent analysis and suggested patent network analysis. This method uses the frequency of keywords occurrence in patent documents as the input base to produce a visual patent network. Patent network analysis can visually display all the relationship among patents and assist the researcher in intuitively understanding the entire structure of patent database. This method is close to co-word method, but the major difference is that co-word method analyzes how many times that keywords occurs together (co-occurrence) with any other keyword in documents involved.

On the basis of above description, patent network analysis is carried on examining the overall relationship of CNT-FED patents and finding out the key patents. This study uses two mathematical tools to present the information from the patent network, namely graphs and quantitative techniques. Graphs can visually display the structure of a set of patents by generating patent network, and the quantitative techniques can clearly show the information on patent network.

For graphing the patent network, this study adopts the following steps proposed by Yoon and Park (2004):

Step 1: Technical experts select the relevant patent keywords based on the substance and characteristics of the patented technologies.
Step 2: Calculating the frequency of keywords occurrence in patent documents and integrate the data into keyword vectors. The keyword vectors from patent 1 to patent m are as follows:

$$\begin{array}{ll} \text{Patent 1}: & (k_{11}, k_{12}, k_{13}, \cdots, k_{1n}) \\ \text{Patent 2}: & (k_{21}, k_{22}, k_{23}, \cdots, k_{2n}) \\ \vdots & \vdots \\ \text{Patent } m: & (k_{m1}, k_{m2}, k_{m3}, \cdots, k_{mn}) \end{array} \tag{1}$$

For example, in the document of patent 1, the first keyword occur k_{11} times, the second keyword occur k_{12} times and so on as above.
Step 3: Utilizing Euclidian distance to calculate the distance between patents and to establish the relationship among patents. If keyword vectors of patent i and patent j are defined as (k_{i1}, k_{i2}, …, k_{in}) and (k_{j1}, k_{j2}, …, k_{jn}) respectively, the Euclidian distance value (E^d_{ij}) between two vectors is computed as follows:

$$E^d_{ij} = \sqrt{(k_{i1} - k_{j1})^2 + (k_{i2} - k_{j2})^2 + \cdots + (k_{in} - k_{jn})^2} \tag{2}$$

Step 4: Euclidian distance matrix (E^d matrix) is composed of all Euclidian distance values among all vectors. However, the E^dmatrix must be dichotomized in order to graph the patent network. It is necessary to transform the real values of E^d matrix into standardized values of E^s matrix from 0 to 1 for dichotomizing in next step.

$$E^s_{ij} = \frac{E^d_{ij}}{\text{Max}(E^d_{ij}, i = 1, \cdots, m; j = 1, \cdots, m)} \tag{3}$$

Step 5: The cell of the E^s matrix must be a binary transformation, comprising 0s and 1s if it is to exceed the cut-off value p:

$$I_{ij} = \begin{cases} 1, & \text{if } E^s_{ij} < p \\ 0, & \text{if } E^s_{ij} \geq p \end{cases} \tag{4}$$

The I matrix includes binary value where I_{ij} equals 1 if patent i is strongly connected with patent j. I_{ij} equals 0 if patent i is weakly connected with patent j or not at all connected. The determination of cut-off value is a task of trial-and-error. The researcher has to select a reasonable cut-off value so that the structure of network becomes clearly visible. Then, the I matrix can be employed to develop a patent network.

This study examines the relationship of patents using network analysis in overall network and cluster levels. In overall network level, this study uses whole patent network to examine overall relationship and to find key patents. In cluster level, this study clusters CNT-FED patents with similar technologies together to form a technology package. By examining the detailed relationship among patents in each cluster, the characteristics of clusters and important technologies are identified.

In quantitative techniques, several indexes can be employed to examine the structure of patent network in overall network and/or cluster levels. The first index that finds out the relatively important patents in overall network and cluster levels is technology centrality index (TCI):

$$TCI_i = \frac{C_i}{n-1} \tag{5}$$

$$C_i = \sum r, \quad r: \text{ ties of patent } i$$

where n denotes the number of patents. It measures the relative importance of a subject patent by calculating the density of its linkage with other patents (Yoon and Park 2004). That is, the higher the TCI, the greater the impact on other patents.

Furthermore, technology cycle time (TCT) index can be used to measure the trends of technological progress in overall network. Let T_i be the application date of patent i, and the formula for calculating TCT index of patent i is shown below:

$$TCT_i = \underset{j}{Median}\{|T_i - T_j|\} \tag{6}$$

where patent j and patent i are connected. It is defined as the median value of age gaps between subject patent and other connected patents (Yoon and Park 2004). Shorter TCT index reflects faster technology progress, and vice versa.

Finally, density index (DI) can be used to make a comparison among clusters and to realize the characteristic of connection in the network of each cluster:

$$DI = \frac{T_c}{n_c(n_c - 1)} \tag{7}$$

where T_c and n_c denote the number of ties and patents in the network of cluster respectively. The density index measures internal cohesion in the network of each cluster (Wasserman and Faust 1994). That is, the higher the density of cluster, the more connected technology package, and vice versa.

Results of patent bibliometric analysis

This study uses bibliometric techniques to analyze the status of technological development in the field of CNT-FED. The different aspects of patenting activities are compared, and the goal of this preliminary analysis is to understand the developmental path and current states of CNT-FED technology.

Growth in patents

Table 1 demonstrates the growth in the number of patents for the field of CNT-FED. Obviously, the number of patent application is rapidly increased after 2000. However, it is slowed down after 2004. Even though the published applications in 2005 and 2006 are included, the trend of patent growth just increases a little. The legal change for US patent system in the year of 2001 seems to have slight influence, but it doesn't change the whole trend of patent growth. The reason for the slow down may be that a lot of basic science

Table 1 Growth in patents

Application date		Issue date	
Year	Number of patents	Year	Number of patents
1994–1997	9	1996–1999	9
1998	6	2000	6
1999	9	2001	2
2000	15	2002	14
2001	16	2003	12
2002	19	2004	20
2003	15	2005	14
2004	8	2006	18
2005	1	2007	3
Total	98	Total	98

issues need to be understood and technological bottlenecks need to be overcome before the newly technological process is developed. Nowadays, the main bottlenecks of CNT-FED are due to the growth process of CNT and the design of electronic circuit for emitter.

Country comparison

Regarding the distribution of patenting activity in different countries, South Korea and USA, each owns 38 and 31 patents, are the most active in patents for the field of CNT-FED. Taiwan comes next and is followed by Japan. This means that the four major countries for CNT-FED development are South Korea, USA, Taiwan and Japan. In addition, it is noteworthy that China filed four patents and all were issued in 2006 and 2007. Although the number of patents filed is small, it still shows that China is starting to pay attention to this domain. This situation also indicates that their government attaches great importance to nano-materials, science and technology.

Assignee comparison

The types of assignees contain corporations, R&D institutes, consortiums of corporations and academia and consortiums of corporations and individuals in these patents. Because one of the reasons for seeking patent protection is to show an interest in the commercial exploitation of a new technology, most of the patent assignees are industrial enterprises (Schmoch 1997). The CNT-FED is no different. The corporations own 71 patents, 72% of the total patents are in this field.

This study goes further to analyze each assignee and attempts to find out which assignees are the most active in CNT-FED development. Among corporate assignees, Samsung from South Korea is the leading corporation with the highest number of patents in the field. This confirms the fact that South Korean corporations are the technological leaders in CNT-FED. Among all R&D institutes, Industrial Technology Research Institute (ITRI) from Taiwan is the most active in patents in this field. Furthermore, ITRI owned the majority of patents filed in Taiwan. It can be seen that the R&D of CNT-FED technology in Taiwan clusters on research institutes. There are five patents from consortiums of corporations and academia. Four of them were filed jointly by Hon Hai Precision Company in Taiwan and Tsinghua University in China. This shows that there is close cooperation between manufacturers in Taiwan and academic institutions in China. Lastly, only one patent, which was filed by Samsung and inventor Young-hee Lee, is from a consortium of corporation and individual.

Inventor comparison

This study analyzes the pattern of co-inventorship in the field of CNT-FED. For all 98 patents, only 15 patents are from single inventors, and all the remaining patents are from co-inventors. The highest number of inventors for one patent is seven. It is clear that research in CNT-FED development is most frequently done by R&D teams. Furthermore, the data of inventors could be used to evaluate the productivity of inventors. One inventor produced a maximum number of eight patents. However, 136 inventors produced only one patent each. The inventors owning only one patent make up 71.96% of all inventors. It means that few inventors owned more than one patent. The productivity of inventors is concentrated on a few inventors.

Highly cited journals

The literature cited in a patent may be used to quantify the dependence of a technology on basic science research (Narin and Olivastro 1988). In this study, the types and counts of journals for CNT-FED related patents were examined and shown in Table 2. According to the Vinkler (1994) definition, over 50% of the references in this work are covered by two journals (Applied Physics Letters and Science). Thus, they are strong contributor of basic scientific knowledge in the field of CNT-FED. Applied Physics Letters emphasize rapid dissemination of key data and new physical insights, and Science is the leading journal of original scientific research in the world and publishes research in various scientific areas. Both of them can be seen that most basic knowledge of CNT-FED comes from the latest scientific concepts. The remaining highly cited journals are mostly from fields of applied physics as well as fields of applied chemistry. So it is evident that the basic scientific knowledge of CNT-FED comes mainly from applied physics and applied chemistry.

Highly cited patents

Karki (1997) points out that the highly cited patents are patents more than average technological impact. There are five highly cited patents among all mutually cited patents in

Table 2 Highly cited journals

Name of the journal	Number of citations
Applied Physics Letters	47
Science	40
Journal of Applied Physics	18
Nature	9
Journal of Vacuum Science & Technology	7
Chemical Physics Letters	6
Others	46
Total number of journals (30)	173

the field of CNT-FED, including patent number 9, 6, 20, 17 and 15. These five patents provided important guidance in the early developmental phase of CNT-FED before 1999. These patents all deal with construction or composition for the electron emitter of FED and are considered the foundational patents for the technology. However, note that the serial numbers of patents are sorted by the issue date, and older patents have more chances of getting cited (Yoon and Park 2004). The highly cited patents represent only the important basic technology in the early period. Therefore, it is necessary to examine the overall relationship among all patents in order to grasp the technological trends in CNT-FED.

Results of patent network analysis

This study uses patent network analysis to further analyze the overall structures among patents in the field of CNT-FED. The steps of graph shown in the section of methodologies were adopted. A total of 13 keywords were selected in step 1, including “field emission display”, “carbon nanotube”, “cathode”, “anode”, “phosphor”, “emitter”, “glass”, “vacuum”, “channel”, “gate”, “operating voltage”, “thick film printing” and “chemical vapor deposition”, and the cut-off value $p = 0.27$ was chosen in step 5. The patent networks were drawn by using UCINET 6.0 (Borgatti et al. 1999). In the following section, we describe the structural features of patent networks in overall network and cluster levels.

Overall network level

Figure 1 shows the overall patent network in terms of connectivity. The network analysis divides all patents into two sets, an interconnected set and an isolated set. The interconnected set represents the overall patent network, including 91 patents and the relationship among these patents. It provides much information for in-depth analysis. There are seven patents in the isolated set. Among these patent documents, there are a few keywords which mostly showed up in the “background of invention” section of documents. Obviously, these patents do not focus on CNT-FED, so we exclude them from the patent network through patent network analysis. Finally, there are 91 patents and 902 ties in overall patent network, but this graph doesn’t show the relative importance of individual patents clearly. Therefore, the quantitative techniques of TCI and TCT index can be used here to analyze the overall patent network thoroughly.

From Table 3, the front six patents with higher TCI values are further classified according to their patent documents. The first, second and sixth of patents are related to the fabrication processes of FED device, and all of them employ the CNT as the emitting material. This result clearly indicates the CNT is an important material for the FED production. All the scientists may pay more attention in this subject to improve the present research for industries, academia and government R&D institutes. Nevertheless, there are two other important patents focused on the whole process of FED fabrication. The third and fifth of patents claim their major subject on field emission device, and more particularly to methods of forming a FED. Finally, the fourth of patents emphasizes the preparing and using of phosphor material as the anode in FED. The importance of this patent reveals that phosphor is one of the key materials in FED device, and the application of phosphor can be adjusted by different composition of activator and coactivators for various displays. Therefore, TCI analysis indicates the key factor of FED fabrication is not only the CNT material, but also the whole process and the phosphor material.

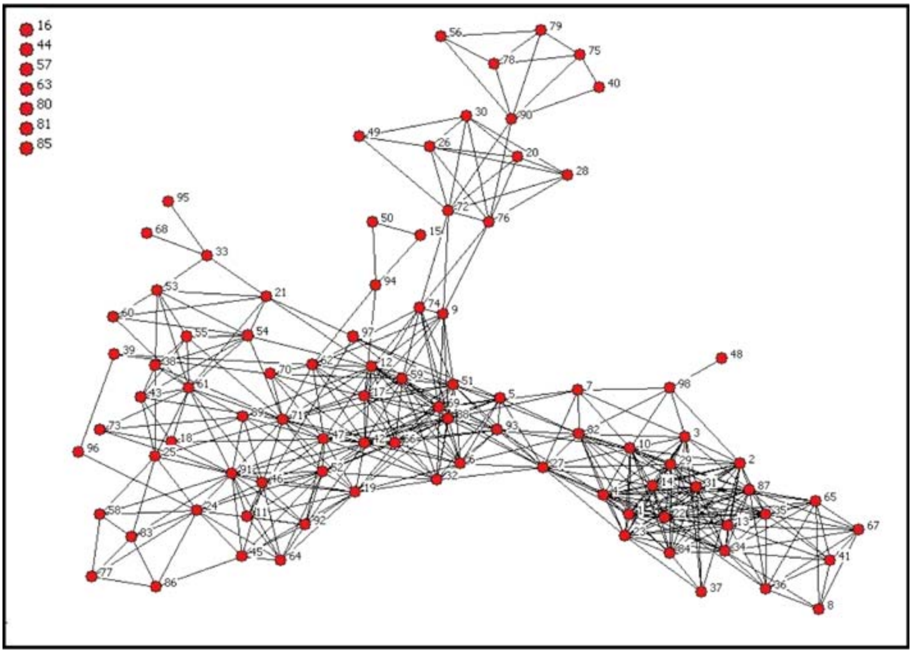


Fig. 1 Patent network in overall network level

Table 3 TCI values of the relatively important patents in overall network level

Patent number (real patent number)	TCI value
71 (U.S. Patent No. 6,911,767)	0.2062
42 (U.S. Patent No. 6,630,772)	0.2062
69 (U.S. Patent No. 6,891,319)	0.1959
87 (U.S. Patent No. 7,067,073)	0.1856
88 (U.S. Patent No. 7,070,472)	0.1856
91 (U.S. Patent No. 7,115,013)	0.1856

Regarding TCT index, we calculate the median of age gaps between each patent and other connected patents in overall patent network. The TCT varies from 0.73 to 6.10 years, which indicates the technological innovation rate is different in the field of CNT-FED. Table 4 shows the representative patents with shorter (less than one year) and longer (more than four years) values.

In general, the patents which have short cycle time are related to the fabrication of CNT-FED. The patents numbered 58, 71, 55 and 77 are related to methods for making or finding optimal conditions for CNT based cathodes. The scientists and researchers pay their attention to this matter for improving technology progress by lowering the threshold field of emission as well as increasing emission current. This also shows that a larger proportion of the CNT based research which is promoted in both academia and industrial is of immediate relevance for the inventive activity leading to FED fabrication. In addition, there are still two patents regarding FED production owning short cycle times (No. 90 and 74). This may indicate the FED related industries are quickly increased, and there are still many problems could be overcome or improve for present process.

Table 4 Short and long TCT index values of some patents

Short TCT group		Long TCT group	
Patent number (real number)	Index value	Patent number (real number)	Index value
58 (U.S. Patent No. 6,798,127)	0.73	98 (U.S. Patent No. 7,176,614)	6.10
90 (U.S. Patent No. 7,102,278)	0.76	5 (U.S. Patent No. 5,708,451)	5.63
71 (U.S. Patent No. 6,911,767)	0.85	84 (U.S. Patent No. 7,052,352)	4.73
55 (U.S. Patent No. 6,774,548)	0.85	82 (U.S. Patent No. 7,021,982)	4.72
77 (U.S. Patent No. 6,975,063)	0.87	7 (U.S. Patent No. 5,814,934)	4.34
74 (U.S. Patent No. 6,936,972)	0.99	8 (U.S. Patent No. 5,844,361)	4.29

Furthermore, the patents which have long cycle time are all related to the subject of phosphor. Owing to the same emission principle for CRT and FED, the phosphor materials and structures have been found for a long time. The current demand in phosphor is mainly promoted for the application at low voltage. Therefore, patents with higher TCT index have made their significant progress for improving the performance of low-voltage phosphors in reducing the power consumption for displays. However, the new fabrication process or anodic pattern is very difficult to establish. All researchers are moving their resources to create the cathodic materials, and the cycle time became longer and longer for the phosphor related patents. From the above result, TCT index can quickly point out that the popular key factor of CNT-FED fabrication is not only the fabrication CNT material, but also the whole process of device production.

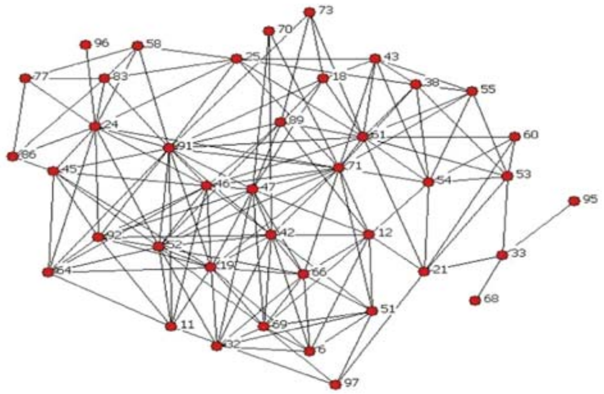
Cluster level

Cluster analysis is a statistical analysis technique to create categories that fit observations. This study adopts a two-stage clustering procedure, which combines hierarchical clustering with nonhierarchical clustering techniques, to identify several clusters in the patent network of CNT-FED (Sharma 1996). Through the procedure, three different clusters as well as patents within each cluster were determined. Figure 2 shows the relationship among patents in each cluster, and the detailed information about the three clusters is discussed as follows.

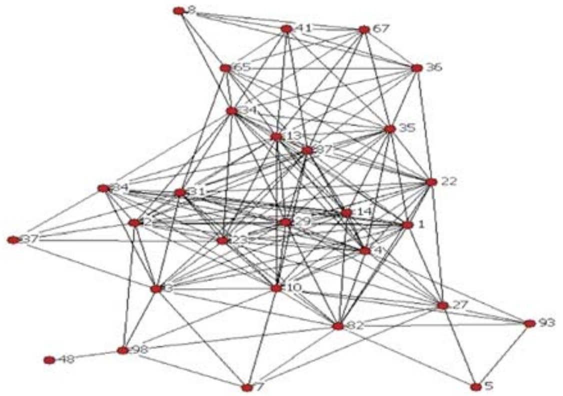
CNT emitter material technology cluster

This cluster is consisting of 40 patents. These patents all deal with the manufacturing techniques for CNT emitter materials. Compared with the other clusters, this cluster has a medium level of connection, and the density index value is 0.188. This result indicates that CNT based cathodic materials have a high variation in production of field emission devices, and there are still many unknown processes and applications which can be created in the future.

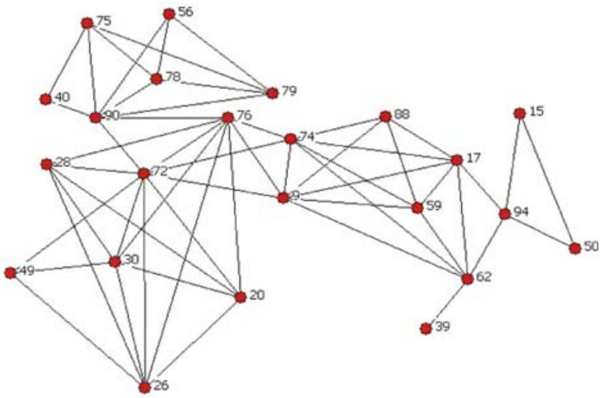
Table 5 shows that the TCI values of relatively important patents in this cluster. These seven patents are all in the central position of network. It reveals that the higher value can turn out to be the more influential patent in this cluster. The patent numbered 91 which relates to a method for making a FED device. The main object of this invention is to provide a concrete method for producing CNT-based FED, and the detail procedure is exhibited. The significance of this patent provides the advantages and novel features of



(1) CNT emitter material technology cluster



(2) Anode material technology cluster



(3) Whole process and other materials technology cluster

Fig. 2 Patent network in cluster level

Table 5 TCI values of the relatively important patents in the CNT emitter material technology cluster

Patent number (real patent number)	TCI value
91 (U.S. Patent No. 7,115,013)	0.4390
71 (U.S. Patent No. 6,911,767)	0.4146
52 (U.S. Patent No. 6,739,932)	0.3659
61 (U.S. Patent No. 6,812,480)	0.3415
19 (U.S. Patent No. 6,346,775)	0.3415
47 (U.S. Patent No. 6,699,642)	0.3415
42 (U.S. Patent No. 6,630,772)	0.3415

present invention for other CNT-FED based researches. As anticipated, patent number 52, 61, 19 and 42 describe the method for making a CNT-FED device. In addition, the other two patents, patent number 71 and 47, provide an improved field emission cathode that features treated CNTs as emitters by reducing work voltage and increasing emission sites.

Anode material technology cluster

This cluster contains 28 patents that deal with anode materials for CNT-FED. These patents possess close mutual linkages, and the density index value is 0.409. This phenomenon shows that anodic materials are relatively simple in production of field emission devices, and these patents mainly focus the anodic fabrication on novel phosphor and phosphor deposition.

Table 6 shows the TCI values of relatively important patents in this cluster. These patents are all highly related to phosphor material or process for manufacturing a phosphorescent screen in FED. The patent numbered 87 provides a low harmful ZnS-based phosphor and a process of preparing the ZnS-based phosphor. The main object of this invention is to improve color coordinates and luminance for use in low-voltage display devices, and it can provide the novel features for other patents on the fabrication processes. In addition, patent number 34 and 13 describe the method for making the improved phosphors which have a prolonged lifetime and efficient luminescence as the emitting layer. Moreover, the other four patents (No. 10, 31, 4 and 23) relate generally to methods for producing a phosphor layer for use in display screen or device.

Whole process and other materials technology cluster

This cluster owns 23 patents which are chiefly concerned with methods for fabricating FED or various materials, and the density index value is 0.157. Obviously, this connection is

Table 6 TCI values of the relatively important patents in the anode material technology cluster

Patent number (real patent number)	TCI value
87 (U.S. Patent No. 7,067,073)	0.6429
10 (U.S. Patent No. 6,015,587)	0.6071
31 (U.S. Patent No. 6,500,040)	0.6071
4 (U.S. Patent No. 5,697,824)	0.6071
34 (U.S. Patent No. 6,517,740)	0.6071
23 (U.S. Patent No. 6,409,564)	0.6071
13 (U.S. Patent No. 6,129,860)	0.6071

Table 7 TCI values of the relatively important patents in the whole process and other materials technology cluster

Patent number (real patent number)	TCI value
72 (U.S. Patent No. 6,922,014)	0.3462
76 (U.S. Patent No. 6,956,334)	0.3077
9 (U.S. Patent No. 5,973,444)	0.2692
74 (U.S. Patent No. 6,936,972)	0.2692
90 (U.S. Patent No. 7,102,278)	0.2692

weaker than the other two clusters. By considering the whole setting of cluster analysis, this cluster may reflect the various manufacturing method of FED, and FED related subjects are still looking forward to further improvement.

Table 7 shows the TCI values of relatively important patents. These patents contain important fundamental technologies for FED fabrication, and they are highly related to carbon-based material. The patent numbered 72 which relates to a FED with carbon-based emitters. The main object of this invention is to provide a FED that minimizes diffusion of electron beams generated by electron emitting sources. And a FED is provided that improves the structure of electron emission sources and the configuration for focusing electron beams generated by electron emission sources, to thereby improve an overall quality of FED. Furthermore, patent number 76, 9, 74 and 90 also describe the method for making FED that minimizes diffusion of electron beams generated by electron emitting sources while having the carbon-based material as emitters.

Conclusions

Regarding the whole analytical results of this study, first, the growth of invention, active countries, active assignees, co-inventorship, productivity of inventors, and scientific and technological foundation are illustrated. Especially, we observe that the development of CNT-FED is rapidly increased after 2000. Highly cited of patents and journals indicate the importance of synthesis, process and production of CNTs for FED application. Second, the network graph in overall network level can be obviously distinguished three portions of highly central patents. They consist of CNT emitter material, phosphor material and whole process of CNT-FED in patent network diagram. From the results of TCI and TCT measurements, the tendency of FED production focuses on the fabrication and construction of CNT materials, and this phenomenon indicates that CNT is expected for the ideal material as the emitter in FED fabrication. Third, the patents are further analyzed in cluster level. The key point, critical bottleneck and popular direction of each cluster can be rapidly compiled and analyzed by this method. The depositing CNT on substrate, coating phosphor on screen and assembling process for whole device play the important role for CNT-FED fabrication. Fourth, this study reveals the approaches for making a CNT-based FED by two categories; one is replacing field emitter with alternate material, and another is field emitter design without traditional technology. For this purpose, researchers have to investigate materials which possess either a lower electron work function or a larger intrinsic field enhancement.

In addition to the analytical findings, there are many interesting results with regard to methodologies in this study. First, patent bibliometric analysis assists the researchers in easily understanding the developmental states of subject technology through looking at different aspects of patenting activities. Second, patent network analysis can visually display all the relationship among patents. The visualization of network enables the researchers to intuitively comprehend the overview of a set of patents in the field of technology being studied. Third, both TCI and TCT measurements can clearly show the information in overall network level. TCI can be used to identify the influential patents, and the information from analyzing these is useful for revealing the critical technologies and the developmental trends. On the other hand, TCT index calculated from the degree of newness of patents can help the researchers to point out the changing trends of technological advancement. Finally, the cluster level analysis can effectively assist the researchers in understanding the characteristics of clusters and managing the technology packages. Undoubtedly, the fruitful methodologies that were applied in this study are helpful for the analyses of technological states and trends. The patents selected by these analyses express important insights in technology management. For the future research, combining patent bibliometric analysis with patent network analysis will offer a useful avenue to monitor the emerging technology.

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