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Comparative Study on Chinese and Global OLED Industry Based on Patent Data

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ABSTRACT Against the background of intelligent manufacturing, the development of chip technology has been widely discussed by scholars. The Chinese chip industry is constantly hit upon in the international background, and the reasons behind this exploration are particularly important for the future development of chip technology in the country. To solve this problem, the paper chooses to study the typical OLED technology in the chip industry. This paper uses 14979 patent data of OLED technology, from 1900 to 2017, as the research object. Data are taken from the global patent statistics database (PATSTAT). From the perspective of the annual application numbers and main research content, it is concluded that Chinese OLED technology has been a late starter, with companies mainly choosing the road of importing equipment. OLED technology lacks specific direction in view of the mastered technical patents, and the related technology is mostly in the peripheral activities. Therefore, OLED technology cannot enter the core area of this field. In this paper, the leading technology identification model, based on a PageRank algorithm, is used to identify the leading technology in the global and domestic OLED patents, and we compare the patents' holders. It is concluded that the Chinese OLED industry cannot occupy a favorable position on the international stage; some research institutes in China have R&D ability, but they lack production facilities. The development of industrialization restricts the sustainable development of related technologies. In view of the above results, this paper provides suggestions from the perspective of researchers, related enterprises, and government and patent protection agencies, in order to promote the development of the Chinese OLED industry and to play a referential role in the growth of China's chip industry.

INDEX TERMS Chip industry, OLED technology, comparative analysis, PageRank algorithm, dominant technology.

I. INTRODUCTION

In the ''Made in China 2025'' strategy, the Internet of things technology (which is called IoT in the following) plays an important role [1]. As the core component of the IoT, the chip is also the hub of the entire network information transmission and at the core position in all IoT applications [2]. However, today's high-end sensor devices across China often have a ''foreign core'', and the development of the Chinese IoT industry is caught up by tiny chips. On April 16, 2018, the Bureau of Industry and Security (BIS) made a decision to activate the refusal order of ZTE and Zhongxing KangXun company. This was done because ZTE did not promptly deduct bonuses and send a disciplinary letter to some employees involved in historical export control violations. ZTE also made a false statement in two letters submitted to the US government, on November 30, 2016 and July 20, 2017. Meanwhile, the US Commerce Department ordered the China Telecom equipment manufacturer to reject the export privileges of ZTE, and American companies are prohibited from exporting telecom parts and products to ZTE, for a period of seven years. A ban on sales in the United States has pushed ZTE to the line between life and death, and has also made the chip research and development shortage in Chinese industry once again become a hot topic in the field of technology. In the context of intelligent manufacturing, the development of chip technology will not only meet the urgent needs of China's powerful strategy, but will also provide China with unilateral control of the imported chips, so as to promote the action policy of Chinese intelligent manufacturing.

With scholars' unremitting efforts, research into the chip industry has made considerable progress. Generally speaking, scholars mainly start from two aspects of the theoretical

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research into the new energy industry. Some scholars have studied the development of the chip industry from the perspective of single technology. Sang summarized the development of the satellite navigation industry from two aspects (of China and other countries). He also analyzed the status of the Beidou navigation chip in the industrial chain, as well as the development status and the future development trend [3]. Wang expounds the new opportunities for the development of the 5G chip technology industry, and focuses on the changes in chips in terms of demand, technology, matching and competition patterns, based on the current status and development trends of the fifth generation of mobile communication (5G) in China [4]. Zhao uses the N index, the Simpson diversity index and the Shannon Wiener index to measure the technology fusion width and depth of the biochip industry. The study analyzes the mechanism of the new competitive synergy caused by the fusion of technology, in order to improve the performance of the strategic emerging industries based on the patent data [5]. Li uses the S growth curve model to study the technological development stage of the global biochip industry, based on 7894 patents from around the world. The results show that the development of biochip technology in China is still slow, with the main growth period from 2006-2022. In addition, there is a certain gap with other major technology owners [6]. As a typical technology in the chip industry, OLED technology is often regarded as the research subject of scholars. In the results of studies on OLED, no enterprise exists that could consummate the OLED industry chain in China. Also, the competitiveness of the upstream products in the OLED industry is weak [7]–[9]. Because of the low labor cost and backward technology in the Chinese market, most OLED manufacturers in China can only focus on the downstream product manufacturing links of labor-intensive industrial chains, such as display panels [10]. The R&D pertaining to raw materials for upstream equipment is almost zero and basically depends on imports from Japan and other countries. At the same time, China has no leading OLED technology enterprises (such as Samsung in South Korea and Toshiba in Japan), which results in limited brand influence [11]–[14].

In general, the research of the chip industry is focused upon the status or development of a certain technology, and the results of OLED technology are lacking in terms of adequate evidence. However, research into the contrast between the Chinese and global chip industries is not deep enough, and there is a lack of pertinent countermeasures. Based on the above analysis, in the era of an intelligent economy, the comparative research into the development of Chinese and other countries' chip industries is very important in terms of exploring the future technology development direction of the Chinese chip industry. In view of the similarity between the development of OLED technology and the chip industry, this paper tries to trace the development track of Chinese and global OLED technology from the three angles of the annual application numbers, main research content and leading technology identification. The aim is to explore the primary cause for the lagging development of Chinese OLED technology, so as to provide relevant policy guidance and reference for the development of the fast and independent development of OLED technology. The relevant results and countermeasure could also play a referential role in the growth of China's chip industry.

II. DATA SOURCES AND PREPROCESSING

An integrated circuit is a small component or electronic device. A large number of original parts are needed in the circuit. Each part (including diodes, resistors, inductors and capacitors) has its own function or functions [15]. The parts are connected together using certain techniques to make a small piece or a few small pieces of semiconductor wafers, and they become a small organization with a circuit function in a closed container. All of the components are structurally integrated, allowing electronic components to make a big step toward miniaturization, low power consumption and high reliability. An integrated circuit is represented by the letters "IC" in the circuit. The inventors of integrated circuits are Jack Kilby (silicon-based integrated circuits) and Robert Noyes (germanium-based integrated circuits). Most of the semiconductor industry today is based on silicon-based integrated circuits [16].

The development of semiconductor technology is divided into several stages. The first stage is the invention stage of the semiconductor industry. In 1947, Shockley, one of Bell Laboratories' employees in the US, made the first transistor with his two colleagues [17]. IBM released the first calculator with stored procedures in 1952, which eventually became the computers we use today. The second stage is the commercial phase of semiconductors. In 1960, Bell Laboratories invented epitaxy technology, which gave the semiconductor industry the ability to mass-produce. This technology allowed the industry to begin to grow rapidly. In a paper submitted to IEEE in 1975, Moore predicted that the number of transistors and resistors integrated on a semiconductor chip would double every two years, which is the most famous Moore's Law in the semiconductor industry [18]. The third stage is the quasi civil phase of semiconductors. In 1971, the world's first microprocessor 4004 (4 bit) was born in a company called Intel. In 1976, Steve Jobs founded Apple and designed the first civilian computer, which officially saw computers enter the civil era. The last stage is the continuous leap of semiconductor technology. In 1981, IBM launched its first model personal desktop calculator, called the PC. Some 30 years after the emergence of the PC, the entire semiconductor market has basically developed around those first PCs. The most important two semiconductor devices are the semiconductor memory and the microprocessor. Changes in the two semiconductor technologies (such as memory and microprocessors) have also caused the prosperity of the PC to soar [19]. Over the past decade, because of the rapid development of mobile phones and other intelligent terminal equipment, China is gradually becoming a big chip manufacturing and consuming country, with massive market demand.

With the advantages of low production costs, rich human resources, stable economic development and superior policy support, the capacity of the industry is gradually improving. With input from the government, competitive international companies have sprung up in various fields.

The study of OLED originated through an accidental discovery. In 1979, a Chinese scientist, Dr. C.W. Tang, found a luminescent organic battery in the laboratory, and OLED studies began [20]. Dr. Tang was also known as the father of OLED. In 1987, Kodak produced the first high-performance device using a sandwich structure. In 1997, OLED was first commercially produced for global use in car stereos by the Japanese Pioneer Co.. However, until 1999, the only market for OLED was a vehicle mounted display; this was extended to mobile phones, PDA (including electronic dictionaries, handheld computers and personal communications equipment, etc.), cameras, handheld games, testing instruments, etc. after 2000. In 2009, major manufacturers began to shift their focus to AMOLED, resulting in AMOLED value surpassing PMOLED for the first time [21]. In 2013, LGD and SMD launched a 55-inch OLED TV. In 2017, Apple launched its 10th anniversary commemorative mobile phone, the iPhone X, which uses an AMOLED screen. By the end of 2010, there were four 4.5 generation lines and four 5 generation lines in Mainland China. Statistics show that the development of AMOLED technology panel factories is currently mainly being led by Jingdongfang, Tianma Microelectronics, Vicino and Rainbow, etc. At present, small and medium-sized panel shipments in Mainland China are considered to be in line with those of South Korea and Taiwan, and China has now entered the fast lane of rapid development.

To sum up, although the development of OLED is occurring more than a few decades after the launch of chip technology, there is a similar development track between the two. The main technology originated in other countries. China, however, has gradually become a big manufacturing and consumer country, with huge market demand, and the country has produced a large number of manufacturers in recent years. Therefore, in order to conduct in-depth and multi-angle analysis, in China and abroad, the organic light emitting diode (OLED) technology is selected for this paper. An OLED is also known as an Organic Light-Emitting Diode [22]–[24]. Generally speaking, OLED displays use thin organic material coating and glass substrate. Organic materials will glow when current passes through them, so they have self-luminescent characteristics. Also, an OLED display screen has a large viewing angle, which can save energy to a certain extent [25]. Therefore, the OLED screen has many unparalleled advantages when compared to LCD, and it also has a pivotal position in the OLED manufacturing process.

The data used in this paper come from the Worldwide Patent Statistical Database (hereinafter referred to as PATSTAT), which is a snapshot database created by the European Patent Office. PATSTAT aims to provide researchers with a patent database that can be run on

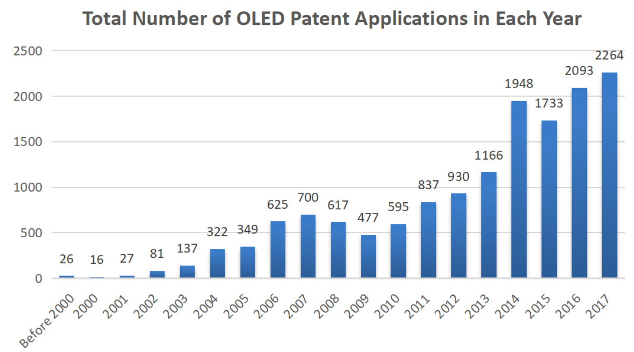

FIGURE 1. Total number of OLED patent applications in each year.

personal computers for statistical analysis purposes. Since being released to the public in 2007, PATSTAT has been widely used in the academic world, due to its characteristics in statistical analysis, uniform data compliance, and open data [26]. The paper uses the retrieval expression "TS(Title or Abstract) = ('Organic Light-Emitting Diode' or 'OLED' or 'OLED Technology'), TI(Title)=('organic light emitting display' or 'organic light emitting diode' or 'organic Electroluminescent')" and IP(International Patent Number) = (G09F∗ or G02F-001∗ or C23C-014∗ or C08G-061∗ or G01R-031∗ or G09G-005∗ or H01L-051∗ or H01L-033∗ or H01L-027∗ or C07C-211∗ or H01L-031∗ or C07F-015∗ or H05B-033∗ or G09G-003∗ or C09K-011∗), and the retrieval time is 19000101-20171231. Since the patent data of the PATSTAT web site shows information on up to 500 patents per page, and the total amount of patents needed for this article is more than 10000, we manually cut down and downloaded the relevant information to ensure the integrity of the patent data.

After de-reprocessing, we take 14979 patents as the research object and obtain the broken line graph of the total number of patent applications for OLED technology in each year, as shown in Fig. 1.

III. COMPARATIVE ANALYSIS OF PATENT TECHNOLOGY DEVELOPMENT TREND IN THE CHINESE AND GLOBAL OLED INDUSTRY

A. COMPARATIVE ANALYSIS OF ANNUAL TREND OF APPLICATION QUANTITY AND MAIN RESEARCH CONTENTS

The national code of Chinese patent literature is CN, so the paper selects patents beginning with the patent number CN and draws a comparison diagram of the number of patent applications in China and abroad, as shown in Figure 2

As shown in Figure 2, Chinese OLED technology started in 2001 and developed slowly over the next 10 years. This shows that, during the initial stage of OLED technology, China preferred the road of equipment importation; the country lacked specific direction in the process of technology development. Until 2014, OLED technology developed rapidly. According to the 2017 statistics, the total number of

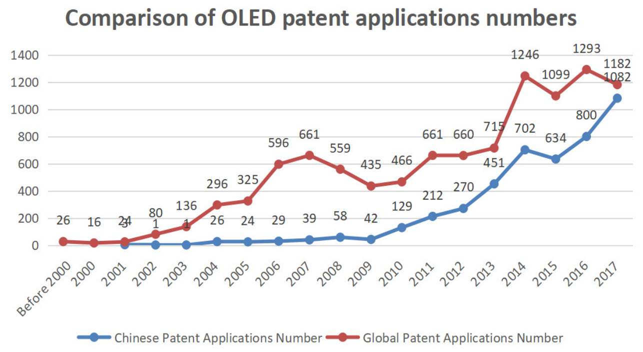

FIGURE 2. Comparison of OLED patent applications numbers.

patent applications from all countries was 1182, and the total number of patent applications from China was 1082. This shows that the importance of independent research and development has gradually been realized in related Chinese related, while both the government and China's visionary enterprises have increased their attention and investment, greatly promoting the industrialization process of OLED R&D in China.

In order to compare the main research content of Chinese and global OLED technology, the paper tries to extract the high frequency vocabulary found in 14979 patents, thus obtaining a relatively accurate key word frequency result through JAVA based on the calculation principle of TF–IDF. Note that TF–IDF is a numerical statistic that is intended to reflect how important a word is to a document in a collection or corpus [27]. It is often used as a weighting factor in information retrieval searches, text mining, and user modeling. It is also often used to construct a vector space model in information retrieval. TF - IDF evaluates the importance of a word in a document. The importance increases proportionally with the number of times that word appears in the document, compared to the inverse proportion of the same word in the whole collection of documents [28]. Roughly speaking, the TF–IDF measure associated with a term t takes:

•a higher value when the term t appears several times within a small number of documents;

•a lower value when the term t occurs fewer times in a document, or occurs in many documents;

•a lower value if the term t appears in almost all documents.

More formally, let $D = \{d_1, d_2, \ldots, d_n\}$ be a comprehensive collection of documents and t a term in the collection. The term frequency-inverse document measure is computed as follows:

$$tf - idf(t, d, D) = tf(t, d) * idf(t, D) \tag{1}$$

Specifically, $tf(t, d)$ represents the frequency of term t in document d, expressed by:

$$tf(t, d) = \frac{f(t, d)}{|d|} \tag{2}$$

where $f(t, d)$ is the number of times the term t appears in document d, and the denominator is the dimension of d, expressed as the cardinality of its own terms. The inverse document frequency $idf(t, D)$ is described as follows:

$$idf(t, D) = \log \frac{|D|}{|\{d \,|t \in d\}|} \tag{3}$$

where the denominator represents the number of documents in which the term t appears.

The result is shown in Table 1. The Chinese and global patent key words marked grey in the table are consistent, and the unmarked words are inconsistent. It can be seen that the top four categories of OLED patent technology in China and abroad are basically the same: 'Method', 'Device', 'Panel' and 'Manufacturing', which depends on the basic composition of OLED technology. In terms of words with which China is not consistent with other countries, there are two adjectives, including 'Active' and 'Same'. There are also two adjectives for global patents, namely 'Thin' and 'Transparent'. This shows that global researchers are pursuing more light and more transparency in OLED technology research and development, in order to achieve the best imaging effect. The two key words in China also indicate that the technicians prefer to follow and improve.

Among the different key words in China and other countries, China has three nouns, namely 'Structure', 'Preparation' and 'Screen'. There are five nouns in global OLED patents, namely 'Compound', 'Layer', 'Lighting', 'Transistor' and 'Color'. It can be seen that global researchers' study focus is clear and concrete. For example, the high frequency of 'Compounds' shows that applicants have paid great attention to the most important part of OLED technology, and the emergence of 'Transistors' embodies their grasp and continuous innovation of the core of OLED technology. However, the three key words in China are too general, and they lack pertinence, indicating that most of the research work is in the peripheral position and that a gap between the core technologies still exists.

Among the different high-frequency words, Chinese patents have three verbs, namely 'Touch', 'Control' and 'Drive'. There are two global patent verbs, 'Fabricating' and 'Comprising'. The appearance of 'Touch' and 'Drive' in Chinese patents' high frequency vocabulary shows that Chinese researchers have explored the breakthrough of OLED technology in the mobile phone industry. The emergence of global patents also shows the speed of the industrialization of OLED technology.

It is worth noting that the word "AMOLED" appears in the Chinese patent high frequency vocabulary, while AMOLED is an active matrix organic light emitting diode or active matrix organic light emitting diode, which is referred to as the next generation display technology. AMOLED technology has the advantages of wide color gamut, high contrast, ultra-thin design, outdoor readability and lower energy consumption. International manufacturers such as iPhone and Samsung have attached great importance to AMOLED-related technologies. The attention of Chinese researchers to this field shows that China has the ability to discover potential

TABLE 1. Chinese and global OLED technology patent word frequency list.

No.	Chinese patent		Global patent	
	Key words	Frequency	Key words	Frequency
1	Method	2065	Method	4257
2	Device	1994	Device	3370
3	Panel	742	Manufacturing	1769
4	Manufacturing	622	Apparatus	755
5	Structure	512	Panel	755
6	Preparation	437	Fabricating	725
7	Circuit	373	Driving	719
8	Pixel	353	Substrate	580
9	Substrate	348	Compound	459
10	Driving	334	Layer	440
11	Packaging	316	Comprising	435
12	Screen	288	Film	432
13	Active	263	Circuit	419
14	Same	260	Pixel	394
15	Matrix	242	Matrix	353
16	Material	201	Thin	264
17	Flexible	177	Lighting	259
18	AMOLED	148	Material	212
19	Film	142	Array	206
20	Array	136	Color	203
21	Touch	133	System	193
22	System	127	Flexible	187
23	Control	125	Transistor	177
24	Apparatus	121	Transparent	168
25	Drive	121	Packaging	167

core technologies, and the country has the relevant technical personnel. If these personnel can make a breakthrough in this field, China will enjoy a large proportion of the international OLED industry.

B. CONTRASTIVE ANALYSIS OF DOMESTIC AND GLOBAL LEADING TECHNOLOGY, BASED ON A RECOGNITION MODEL

Leading technology could represent the main direction of development in a certain period of time within a certain field, and this technology could cause major changes in the technological system. The effective identification of dominant technology can not only quickly determine the direction of development, but could also help China to make rapid decisions regarding technology selection, the scientific layout of related technology patents, correcting their own weaknesses and consolidating core competitiveness, all of which could provide a reference for technology research and a development strategy.

PageRank was first proposed by Sergrey Brin and Larry Page in a paper entitled ‘The Anatomy of a Large-Scale Hypertextual Web Search Engine’. This algorithm can evaluate web pages and assign each web page according to the sorting of the retrieved results. The basic idea behind

PageRank comes from the citation analysis of traditional bibliometrics [29]. Based on the idea of the PageRank algorithm, an enterprise patent reference network similar to a web link network was established by Pang and Liu [30].

In this paper, the number of link-in web pages corresponds to the number of cited patents, and the number of link-out web pages corresponds to the number of citing patents. The application of PageRank in the paper is more advantageous than the analysis of the web process. The reason is that patent references do not involve loops; mutual quotas between A and B will not appear. If patent A cited patent B, this shows that the publication time of patent A is later than that of patent B, and patent B will therefore not use patent A. Based on the advantages of this method in both theory and practice, the authors used a PageRank algorithm to construct the model.

The calculation of the PageRank algorithm can be briefly described as follows: if a small group is composed of four pages, namely A, B, C, and D, and if all the pages are linked to A, the PR (PageRank) of A is total value of B, C, and D, which is PR(A) = PR(B) + PR(C) + PR(D). If B can also link to C, and D has three pages linked to A but can't vote for a page two times, then B can only have half a ticket for each page. In the same way, D can only have three points, and one vote is cast to the PageRank value of A, so the PR value of A is $PR(A) = \frac{PR(B)}{2} + \frac{PR(C)}{1} + \frac{PR(D)}{3}$. Based on the PageRank value of link-out pages, $L(X)$ means the link-out pages' number of X, $PR(A) = \frac{PR(B)}{L(B)} + \frac{PR(C)}{L(C)} + \frac{PR(D)}{L(D)}$.

The authors called the plug-in unit of PageRank to get the "network rankings" window. In order to treat all the link-out pages fairly, the authors regulate that q = 0.85 (q is the damping factor which is the probability of a user going to a page and continuing to browse); 1-q = 0.15 is the probability that users will not go on to click to the new URL. The PageRank algorithm applies q = 0.85 to all pages to reflect the probability that a page can be put into a bookmark by people on the internet. The PageRank value of a page without links will be 0, so Google gives the initial PageRank value of each page based on the mathematical system, which is shown as (1).

$$PageRank(p_i) = \frac{1-q}{N} + q\sum_{p_j}\frac{PageRank(p_j)}{L(p_j)} \tag{4}$$

In the formula, $p_1, p_2, \ldots, p_i$ is the studied page. There is a link in the network that is from p_j to p_i page; $L(p_j)$ is the number of link-out pages from p_j, and N is the number of all pages. The PageRank value of all pages is a feature vector in a special matrix, which is shown as (2).

$$R = \begin{bmatrix} (1-q)/N \\ (1-q)/N \\ \vdots \\ (1-q)/N \end{bmatrix} + q \begin{bmatrix} l(p_1,p_1)l(p_1,p_2)\cdots l(p_1,p_N) \\ l(p_2,p_1)\ddots \\ \vdots \\ l(p_N,p_1) \end{bmatrix} \tag{5}$$

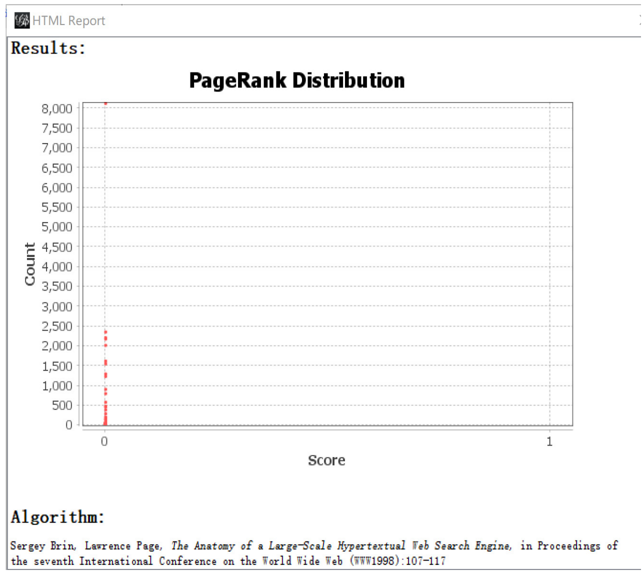

FIGURE 3. PageRank Distribution.

Therefore, the PageRank value of a page is calculated by the PageRank value of other pages, and the PageRank algorithm constantly repeats the PageRank value of each page. If each page is given a random PageRank value (not 0), then the PageRank values of these pages tend to be normal and stable after repeated calculations.

Figure 3 is the result of the distribution of the PageRank algorithm. Due to the large number of nodes, the PageRank score is close to 0. Based on the results of PageRank calculations, the 12 leading patents are obtained in Table 2.

Table 2 shows that there is no Chinese patent technology in the dominant global OLED technology patents. This indicates that Chinese OLED technology research and development started late, and OLED products are mainly imported. China has missed out on holding a dominant position in this field. It is noteworthy that the patentee of six technologies in Table 2 is the Kodak Corporation of the United States, accounting for 50% of the total. This is due to the fact that Kodak was the first company to develop OLED, which is arguably the ancestor of organic light-emitting small molecule materials. In recent years, most of the patents on this material are in the hands of the Kodak company. For example, the US44769292(A) granted on September 6, 1988, Alq3 was used as the main luminescent material of OLED for the first time. Because of its good thermal stability and film-forming property, Alq3 quickly became Kodak's core patent. Many luminescent materials, such as US5151629(A), US5141671(A) and US5294870(A), were developed around Alq3, which helped Kodak carry out further research and development on OLED technology. This R&D included the establishment of a certain advantage in the field of organic light-emitting materials, and this constantly improves the patent protection mechanism [31]. In addition, WO2006009024 (A1) owned by

TABLE 2. Global OLED technology patent PageRank algorithm recognition results.

No	Patent application number	Cited Frequency	Patent Holder	Holder's Country	Holder's Strength Ranking	PageRank Score
1	US4769292(A)	111	Kodak Company	U.S.A	5	0.00015
2	US5294870(A)	98	Kodak Company	U.S.A	5	0.000124
3	WO2006009024(A1)	64	Konica Minolta	Japan	3	0.000106
4	WO2005076669(A1)	62	Idemitsu Kosan	Japan	2	0.00011
5	US2006017375(A1)	58	Idemitsu Kosan	Japan	2	0.000182
6	US6534199(B1)	57	Idemitsu Kosan	Japan	2	0.0001
7	US5935721(A)	52	Kodak Company	U.S.A	5	0.000153
8	US5151629(A)	49	Kodak Company	U.S.A	5	0.00011
9	US2006105201(A1)	46	Samsung	Korea	1	0.000139
10	US2005175861(A1)	40	HC Starck	Germany	4	0.000112
11	US5141671(A)	37	Kodak Company	U.S.A	5	0.000097
12	US5908581(A)	36	Kodak Company	U.S.A	5	0.000096

Konica Minolta is designed to extend the lifetime of blue luminescent materials and set a world record for the luminescent rate of 139LM/W of OLED, which is proved that Konica Minolta has already taken a place in the aspects of lighting. The Japanese company Idemitsu Kosan is a pioneer in OLED technology, its patent WO2005076669 (A1) mainly studies the application of OLED materials in display devices. In 2009, it joined the LG industry to study TV panel. HC Starck's core patent –US2005175861(A1) is concerned with high-purity molybdenum sputtering target materials and has high technical content. The relevant industrial layout has been in more than 30 countries around the world, which resulted in greater economic benefits. According to the latest ranking of the world's top 500 companies by ⟪Fortune⟫, the paper ranks the position of enterprises in Table 2. We can conclude that, although Kodak's current situation is not very good, their present condition does not affect the dominant position of its patents in OLED technology.

At the same time, three patents owned by Idemitsu Kosan were identified as leading technology, accounting for 25% of the total. The reason is that, in 1993, Idemitsu Kosan began in-depth research and development of OLED technology in a wide range of fields. With the help of abundant funds and advanced science, they quickly occupied an important market position and become the world's leading supplier of small molecule organic light-emitting materials. The company mainly develops blue light-emitting materials, s uch as the patent US6534199(B1), granted in the United States in 2003. This patent uses anthracene compounds and DSA derivatives together as light-emitting materials. The product can increase the efficiency of light-emitting devices and decrease the drive voltage. Since the 1990s, Idemitsu Kosan has been devoted to the research and development of small molecule organic light-emitting materials. The company has acquired a large number of patents and established patent alliances with many enterprises through cross-licensing.

According to Table 3, eight global patents were obtained by Chinese dominant technology companies, based on the identification model, and only four Chinese local patents were obtained, accounting for 33% of the total. This further indicates that western developed countries, such as Britain and the US, have carried out patent distribution of OLED technology in China. This long-term layout has gradually developed into the largest holding of OLED technology in China. A number of patents are concentrated in the blank field of Chinese OLED technology patents, and this situation has caused some interference with China's autonomous development of OLED technology. The main reason for this is that the awareness of independent property rights in China is poor. Scientific researchers publish their achievements in various fields through various forms, which shows a lack of understanding of certain protection measures that should be taken for their own scientific research projects. These researchers do not realize that they are sharing their latest research results with the public. It could be said that they contribute their own work to the competitors' results and that they are unable to use legal weapons to protect their own technology.

TABLE 3. Chinese OLED technology patent PageRank algorithm recognition result.

No	Patent application number	Cited Frequency	Patent Holder	Holder's Country	Holder's Strength Ranking	PageRank Score
1	CN101006594(A)	53	Kodak Company	U.S.A	5	0.000102
2	CN1622727(A)	52	Samsung SDI Limited	Korea	1	0.000101
3	CN101996579(A)	52	South China University of Technology	China	9	0.000094
4	CN101447555(A)	48	Changchun Institute of Applied Chemistry, Chinese Academy of Sciences	China	7	0.000091
5	CN102064278(A)	45	LG Display Limited	Korea	3	0.000093
6	CN102742352(A)	33	Japan Light Industrial Corporation	Japan	6	0.000095
7	CN101978780(A)	30	Sumitomo Chemical Co., Ltd.	Japan	2	0.000091
8	CN105742509(A)	30	Visino Company	China	8	0.000092
9	CN102694128(A)	27	Toshiba	Japan	2	0.00009
10	CN102668695(A)	15	Sumitomo Chemical Co., Ltd.	Japan	4	0.000097
11	CN1785984 (A)	17	Visino Company	China	8	0.000092
12	CN102668695(A)	13	Sumitomo Chemical Co., Ltd.	Japan	4	0.00009

On the other hand, Table 3 shows that two of the patents in China are from research institutes. This indicates that the research level of Chinese universities and research institutes has greatly improved in terms of their ability to develop technology. In particular, CN101996579(A) discloses a pixel driving circuit of an active organic electroluminescent display and a driving method thereof, which could make the brightness of the OLED display screen is uniform and the high contrast is realized. CN101447555(A) provides a laminated organic electro-luminescent device of an organic semiconductor-based hetero-junction electric-charge generating layer, which is greatly reduced and the power of the device is greatly improved. However, the lack of follow-up steps of industrialization has resulted in the limited development of OLED technology. The other two dominant technologies (e.g., CN105742509(A) and CN1785984 (A)) are held by Visino. The main reason for this dominance is the joint R&D between Visino and Tsinghua University, which integrates large-scale production, marketing systems and independent industry development. Visino has made great achievements in the related research fields of organic light-emitting materials, which in turn has provided strong support for the development of scientific research in China. For example, BDPNTD is protected in patent CN1785984(A). Its electron transfer rate is much higher than that of conventional electron transfer material Alq3, which thus enhances the stability of OLED materials. Visino is a model of industry-university-research integration in the field of OLED in China. In 2008, the company built China's first large-scale OLED production facility, located in Kunshan, thus realizing the first large-scale production of OLED in Mainland China [32], [33]. Table 3 also lists the latest strength ranking of enterprises [34]. We can draw from the table that, although the Chinese institutions in the table are the best in the OLED field, they all rank behind foreign enterprises in terms of the strength ranking. This shows the gap between Chinese and foreign enterprises in terms of overall strength. It also helps to define and determine the goals and direction of the development of China's relevant institutions.

IV. CONCLUSIONS

This paper uses 14979 OLED technology patents, issued from 1900 to 2017, as listed in PATSTAT. From the perspective of the annual application quantity and main research content, the comparative analysis shows that Chinese OLED technology started relatively late and seemed to prefer going down the road of equipment import. Since 2014, relevant researchers have gradually realized the importance of independent research and development, so the OLED industry has developed rapidly. However, there is still a certain gap when compared with leading global enterprises. In the comparative analysis of the main research contents, we conclude that Chinese researchers have no specific direction with regard to technical patents. The related technologies are also mostly connected to peripheral activities, which means they are unable to enter the core areas of the field. Therefore, they are still in the exploratory stage on the road to independent research and development. The paper uses the dominant technology identification model, based on a PageRank algorithm, to identify the dominant technology in global and Chinese patents, and the patents of dominant technologies are compared. It is concluded that the Chinese OLED industry could not currently occupy a favorable position in the international arena, but some Chinese research institutes have R&D capabilities. They only lack industrialization development, which restricts the sustainable development of related technologies. The relevant results also could play a referential role in the growth of China's chip industry.

V. COUNTERMEASURES

In view of the above results, we provide some countermeasures and suggestions for the development of the Chinese OLED industry.

① From the perspective of researchers, they should improve the quality of patent writing while actively developing the research of new generation OLED technology. According to the comparative analysis of the main research contents between China and other countries, Chinese OLED technology enterprises have greatly strengthened their efforts in patent applications in recent years, and the contents of invention books are increasingly rich. However, compared with global enterprises, the content and writing quality of Chinese patent applications still need to be further improved. Relevant technical personnel could diversify their thinking on the basis of existing technology and develop new application areas in the OLED industry. With the rapid development of science and technology, smartphones are becoming more and more popular with consumers. The popularity and constant evolution of capabilities and features is causing an increasing speed of renewal. At the same time, consumers' demand for high resolution and large display screens is also on the rise. The power consumption is mainly from the screen, so updating the research and development related to smartphone screens is particularly important and has become a common concern in the field of mobile phone research and development. Therefore, research and development on electricity consumption could help China to take the leading position in the international market, restricting the role played by opponents.

② From the perspective of related enterprises, they should build interdisciplinary R&D teams and achieve technological breakthroughs through school-enterprise cooperation programs. As a new technology, OLED technology covers many disciplines, such as chemistry, materials, electronics, physics and so on. The field needs high-knowledge talents with people from multi-disciplines and different technical backgrounds to solve the comprehensive list of existing problems. Therefore, relevant enterprises should pay attention to solving the cross-disciplinary problems and recruit scientific research personnel from different fields of knowledge at the beginning of each project start-up. This would not just include people from the fields of chemistry and physics, but also material production and electronic products. The aim is to increase the construction of scientific research teams and build interdisciplinary and cross-disciplinary research and development teams. According to the research results of universities and scientific research institutes, they have higher technical levels and stronger R&D ability than many of China's competitors. Chinese enterprises should establish long-term cooperative relationships with leading universities, in order to realize the effective integration of resources through the form of school-enterprise alliances. This could effectively promote the technological research aimed at industrialization and accelerate the transformation and achievements of the industry.

③ From the perspective of the government, they should promote the industrialization of technology and strengthen the construction of industry-university research alliances. The analysis results show that Chinese universities and research institutes have the necessary R&D capability, but they lack follow-up industrialization. Therefore, the government should promote the role of enterprises as the main body and strengthen the construction of industry-university-research alliances. Firstly, they should speed up the cultivation of the technological innovation capability of leading enterprises. Large and medium-sized enterprises should be guided to increase their investment in science and technology. The second step is to establish an effective incentive mechanism within universities and scientific research institutes. At the same time, build an incubation center in universities and promote the incubation process of various technologies, in order to improve the research and development initiative of universities and research institutes. The third step is to support enterprises, universities and research institutes in efforts to jointly build R&D institutions and undertake science and technology projects together. The government should focus on supporting leading OLED technology industry-university-research cooperation projects and promote the combination of industry-university-research facilities through the establishment of major scientific and technological projects.

④ From the perspective of patent protection, Chinese researchers should heighten their awareness of patent protection, while avoiding intellectual property risks. Both research institutes and R&D researchers should strengthen the protection of their new independent growth achievements. For example, they should set up a special annotated property rights section within the institution and establish an intellectual property system to include patents and standards. In addition, technical personnel need to do a better job in terms of the necessary intellectual property investigation and analysis. This is especially true with the process of product development, production and sales. Better practices could effectively avoid intellectual property risks. Global enterprises attach great importance to the protection of intellectual property rights, but Chinese enterprises, for various reasons, do not pay enough attention to (or even ignore) the potential risks of property rights. Therefore, Chinese enterprises must take reasonable measures to avoid intellectual property risks in the process of technology development and in international market development. On the one hand, experts could be invited to fully research and analyze the existing patented technologies when developing or introducing new technologies, so as to avoid duplicate development and in order to draw lessons from them. On the other hand, Chinese researchers should constantly study the laws and regulations of intellectual property rights in various countries and increase the application of patents and PCT patents in developed countries, in order to accumulate patents quantitatively and qualitatively. This will allow Chinese researchers to use the intellectual property laws of various countries to protect themselves. Patent barriers should be established as soon as possible, which could promote the rapid development of the Chinese OLED industry.

According to the similarity of development between OLED technology and the chip industry, both globally and in China, the countermeasures put forward for Chinese enterprises to promote OLED technology are also applicable to related enterprises in the chip industry.

The limitations of this paper are as follows: 1) The determination of dominant technology only depends on patent data and has not been verified by professionals. 2) The technology referred to in this paper do not represent the whole chip industry. It do not be comprehensive enough to study the chip industry by looking at just one technology. 3) The appearance of the first Chinese firms that master the relevant leading technologies is not involved in this paper, which makes the gap between China and other countries vague. In future research, we will invite professionals in the relevant fields to evaluate the identified leading technologies and to define accurate leading technologies. At the same time, we will try to select another technology or two as the research sample, in order to acquire more comprehensive results and suggestions for the development of China's chip industry. In addition, we will collect the information on the first batch of Chinese companies that master relevant leading technologies to evaluate how far are the Chinese firms from the globle firms.

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