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„A Study on the Development of China's Laser & Optoelectronic Technology and Industry"

with city cases of Wuhan, Shanghai and Changchun

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List of Abbreviations

717	CSIC The 717th Research Institute
Alcatel	Alcatel Shanghai Bell
BIOET	Beijing Institute of Opto-Electronic Technology,
BJUT	Institute of Laser Engineering of Beijing University of Technology
BUT	Beijing University of Technology
CETDZ	Changchun Economic & Technological Development Zone
CETC	China Electronics Technology Group Corporation
Chutian	Chutian Laser Group,
CIOM	Changchun Institute of Optics, Fine Mechanics and Physics, CAS
Compound Crystal	Beijing Compound Crystal Technology (substitute of Institute of Semiconductor, CAS
Corning	Corning Shanghai Fiber Optics Co., Ltd.
Daheng	Daheng Laser Co. Ltd.,
FiberHome	FiberHome Technologies Group,
GILA	Guangzhou Institute of Laser Application
GISM	Guangzhou Institute of Semiconductors Materials
Gongyan	Wuhan Gongyan laser,
Huagong	Huagong Tech Co., Ltd,
HUST	Huazhong University of Science and Technology
Infovision	Infovision Optoelectronics (KunShan) Co., Ltd
IOE of SCNU	College of **I**nformation and **O**pto**e**lectronics (**IOE**) of **S**outh **C**hina **N**ormal **U**niversity
ISC	Institute of Semiconductors of CAS
KLFOSTIP	Key Lab. of Fiber Optic Sensing Technology and Information Processing
KLOP	Key Lab. of Optical Physics in CAS
NCLT	National Center of Laser Technology
NCRIEO	North China Research Institute of Electro-optics
NVD	Next-generation Versatile Disc,
OEMT	State Key Laboratory of Optoelectronic Materials and Technologies of SYU
Philips	Joint venture of Blue-ray disc with Philips.
SAST	Shanghai Academy of Science and Technology
SILT	Shanghai Institute of Laser Technology,
SIOM	Shanghai Institute of Optics & Fine Mechanics of CAS
SITP	Shanghai Institute of Technical Physics of CAS
SLG	Shanghai Laser Group
SOCC	Shanghai Optical Communications Co. Ltd.
SYU	SUN Yat- Sen University
SZU	Shenzhen University
Unity	Unity Laser Co. Ltd.
WIPM	Wuhan Institute of Physics and Mathematics
WJI	Wuhan jh-laser research institute
Worldbest	Shanghai Worldbest Fiber
WRI	Wuhan Research Institute of Posts & Telecommunications
WTD	Wuhan Telecommunication Devices Co.,Ltd., Co. Ltd.
WXZTE	Wuxi Zhongxing Optoelectronics Technology Co.,Ltd.
XIOM	Xi'an Institute of Optics & Precision Mechanics of CAS
XOAI	Xi'an Optics Application Institute
YOFC	Yangtze Optical Fiber and Cable Company
YOFC shanghai	Yangtze optical fiber and cable (shanghai) company ltd.

Preface

China aims at becoming a technologically advanced industrialized country – instead of only a low-cost producer. The country has indeed made progress in establishing a relevant science base and in creating incentives towards technological upgrading. However, building a truly innovative economy takes time.

Optical Technology (OT) seems a promising field for fast technological catch-up: The manufacturing of OT products is often a labor-intensive process, and China is still a country of cheap and skilled labor. Thus, the technological progress in China's OT industry can tell us much about the country's economic future.

This report gives an overview of the state of OT in China. It puts emphasis on the relevant science base, key players, leading economic regions, and cooperation in innovation. Furthermore, it includes information that is available in Chinese only.

The report is a first step in research cooperation between Economic Geographers at Justus Liebig University, Giessen, and Economic Geographers at the East China Normal University, Shanghai, with a focus on China's OT. It will be of interest for any researcher working on technological catch-up, and Optical Technology.

Gießen, August 4, 2008

Prof. Dr. Ingo Liefner

Introduction

The booming trend in laser and the optoelectronic industry and the fast adoption of optoelectronic technology when traditional industries decide to upgrade have attracted attention and fascination in the world of research. Due to its strategic situation in the twenty-first century, laser and optoelectronic industry has already been the subject of research for geographers and economists (Hassink & Wood, 1998; National Research Council 1998; Hendry et al. 1999, 2000, 2003; Grupp H. 2000; Mathieu et al. 2004; Frietscha R. & Grupp H.2006; Buenstorf, G., 2007), as well as the research institute and the industry itself (NRC, 1998; Photonics 21, 2006). The countries and companies which have great control over this field of technology are to be regarded as the new models of the coming era. As a competitor, and with a huge market in laser application and optoelectronic industry, companies in China are an engaging research objective. This paper attempts to give a brief overview of China's laser and optoelectronic technology and industry and then analyze its development trajectory and offer some policy implications under the theoretical framework of network and cluster analysis.

China, which is lagging behind in the information technology era, is catching up with other countries in the optoelectronic technology and industries. While China's first laser was developed in the Changchun Institute of Optics, Fine Mechanics and Physics (CIOM), Jilin Province, in 1961(Deng Ximing, 1991), one year later than the world's first laser – developed in U.S., China's development in the industrialization of optoelectronic technology lagged more than one year behind in certain domains of those companies in the U.S., Japan, Germany, UK and France. This, however, did not stop the determination of China to catch up with the world. Besides, China's huge market potential and relative low labor cost attract a lot of FDI (Foreign Direct Investment) in this industry.

As early as when the Open Door Policy was enacted in China, and especially after the year 1990, the construction of the so called "optical valley" showcased China's ambition of upgrading and commercializing this technology throughout major technological and economically advanced cities like Wuhan, Shanghai and Changchun, as well as Beijing, Guangzhou and Shijiazhuang.

A brief empirical study on the optical and optoelectronic technology as well as the industry will be presented. The rest of the paper is organized as follows: The first section attempts to sharply define the heterogeneous and multidisciplinary optical technology industry. The second part summarizes the main development of the laser and optoelectronic industry in the world. Thirdly, an overview and an analysis over the features of regional laser and optoelectronic technology in China are carried out, and key players in China's optoelectronic technology and industry are identified. Fourth, a cluster and network study of the laser and optoelectronic industry in China is given. Finally, the summary of major findings, as well as policy implications is tendered.

1. Laser & optoelectronic technology, an Introduction

1.1 The definition

Nowadays, the whole world is whirling in so-called information technology era. And at the dawn of twenty-first century, we are introduced into an era of lights, an epoch rich with optical-related technology (Wang Da-heng, 2004). The terms optics, optoelectronics, photonics, optical electronic, and laser has ever been popular around the academic world and the high-tech industry, though in terms of its industrialized history it is still quite young. It is to be one of the leading technologies that have a promising future in the twenty-first century, as well as providing the modern economy its great influence and benefits.

Optics is a branch of physics that describes the behavior and properties of light and the interaction of light with matter. Traditionally, optics mainly focuses the study of visible light.

The academic basis of modern information technology experienced two periods: electronics and optoelectronics. As electronic technology matured, optoelectronic technology became its successor. Photonics, the study of photons (the carrier of information and energy), generates two general branches (Poldervaart, 1970)[1]: information photonics and energy photonics. Their independent development as well as the combination and fusion of the two streams of research led to many inventions and new technologies. Although optoelectronics will become the center in information and communication technology, electronic technology will still play an important role in future information-related technology and products (Gan Fu-xi,2001; Han Jian-zhong,2005; Ji Guo-ping, 2005). Naturally, people from different perspectives have similar definitions and names for sub-categories of laser and optoelectronic technology. Here we will define some of the terms we will use in this paper. First, optoelectronics, refers to “a branch of electronics that deals with electronic devices for emitting, modulating, transmitting, and sensing light” (Merriam-Webster Online). The Advisory Council On Science and Technology, UK (ACOST) also defined optoelectronics as “the integration of optical and electronic techniques in the acquisition, processing, communication, storage, and display of information” (ACOST, 1988)[2]. There are broad and narrow definitions of this term. The broad definition of “optoelectronics” includes the applied field of information technology and energy carriers. The narrow one just refers to the field applied in information technology. The definition here in this paper is a narrow one. Second, besides the narrow definition of “optoelectronics”, there is another word, laser. The words “laser” and “energy optoelectronic” have similar meanings and often refer to same field for research and business, as the production of laser, laser processing, laser medical instruments and other laser instruments. Here the paper adopts the term, “laser”.

Here, optoelectronics mainly includes the joint knowledge of electron-optics and photonics. Electron-optics deals with the focusing and deflection of electrons using magnetic and/or electrostatic fields and is a branch of physics. The electron-optics and photonics together cover many aspects of the field of optics, a branch of physics which is highly related to the generation and transmission of lights. Based on this, optoelectronics formulates the underpinnings of almost all fields in the Information

[1]From Liu Song-hao,1998, the world of Optoelectronic: from Electronics to Photonics, Hubei Education Press (in Chinese)P.48

[2] Adapted from Hendry C.; Brown J.; Defillippi R., Hassink, R.,1999, Industry clusters as commercial, knowledge and institutional networks: Optoelectronics in Six Regions in the UK, USA and Germany. In Anna Grandori, Inter-firm Networks: Organization and Industrial Competitiveness 151-184

Industry. It also includes the collection (imaging) of information, transmitting and displaying of information, storage and processing[3].

Laser technology is crucial to significant scientific experiments, national defense, and the upgrading of traditional technology and hi-technology. The laser technology industry has created some new sectors in the economy, such as laser AV (Audio & Video), laser communication, laser holographic imaging, laser bar-code, and laser military industry, though it is not an industry with large output in and of itself (ZhangYu-chuan, 1996; OITDA 2006; PIDA 2006; COEMA 2006). The development of laser technology has 3 major sub-divisions. First, Solid-State Lasers compose the mainstream, with Laser Diode and Diode Pumped Solid-state Lasers holding key roles in laser processing apparatuses. Second, laser technology is optimizing its input-output rate and technological applications. Third, laser technology is blending with many emerging subjects so as to offer more service to daily life: laser clinics, laser cosmetology, laser printers, laser scanners, laser discs, fiber-optic communication and inspection lasers, etc. (Sun Hua, 2002). The manufacture of semiconductors is the the incubator of the next-generation of lasers. Ultraviolet lasers have been applied to high-density-contact drilling in the electronic parts business. This field arouses the most interest in Stacked IC-drilling and vertical interconnected laser slicing. The processing of semiconductor devices or components are booming today.

1.2 Trends in the technology and related markets

1.2.1 The technology

Generally speaking, laser and optoelectronic technology mainly include four parts or sections: 1) optic emission and control (laser); 2) optical transmission and light wave direction; 3) optical detection and display; and 4) applications in mutual-functioning lights and other materials. Among them, the laser is by far the most important and the fundamental part of the opto-technological market (Liu Song-hao, 2004).

Ever since the first Ruby Laser was developed by Maiman in 1960, Solid-State Lasers occupied the main part of laser technology and its market. In 1980s', the appearance of semiconductor laser and the affiliated all-solid-state laser gradually became the most promising laser field, featured by small volume, low weight, high stability and longevity (Chen Yi-hong, et. al 2002). Beside the all-solid-state, ultra-fast, ultra-short, ultra-intense, and widely tunable lasers are included within the mainstream of laser technology.

Information Optoelectronic technology is the study of optoelectronic devices, integrated photonic components, fiber-optical communication, optical displays, optical storage (recording), and fiber-optical sensors (see attached Note 1) (Zhou Bing-kun, 2001; Gan Fu-xi, 1996, 2002; Liu Song-hao,

[3] There are some other definitions of photonics or optoelectronics:
"the acquisition, processing, communication, storage, and display of information"(Canadian Advisory Council on Science and Technology)
"The technology of generating and harnessing light and other radiant energy whose quantum unit is the photon."(Photonics Directory)
"Field of science and engineering encompassing the physical phenomena and technologies associated with the generation, transmission, manipulation, detection, and utilization of light."(U.S. National Research Council, 1998)

2004; Li Qiang, 2007) . Among them, the invention and progress of optoelectronic materials and devices used in the aforesaid 4 sections, and in opto-communications are crucial technologies and have great edge over other developments.

1.2.2 The market

Due to the blurring boundaries between different applications, the market division of laser and optoelectronic industry is also mixed (Liu Song-hao 2001; Ji Guo-ping 2005; Berg A. 2006). Based on the work of the authors just cited, the paper adopts a market division as follows,

- **Optical parts and devices** become small-sized, high-stability, multi-function, modular, and integrated**.**
- **Optical Information**
  - Optical Displays show trends in true color, High-Resolution, High-Definition, Large Screen Displays, and Flat Panel Displays.
  - Optical input/output has a direction in multi-function, high-speed, and low cost.
  - Optical Storage adopts next-generation new technology and new material, hence leading to high density and high-speed storage products.
- **Optical Communication** will have a new fashion in hyper-volume, high speed, and completely optical networks, with hyper volume, intelligent DWDM in the main stream.
- **Lasers** and their applications are following a new trend in all-solid-state, super-microwave, micro-process and high-stability, and blending with other subjects makes it enjoy even more applications in industrial processing, national defense, environment protection, agricultural production, academic research, aeronautics, astronautics, and medical treatment.

And thus we see a general picture of our targeted research fields. While there are notable trends in some remarkable sub-sectors (Berg A. 2006; Cao Jian-lin et. al, 2001; Ji Guo-ping, 2005), the "optical applications are everywhere [...] and the role of optics as an enabler" (NRC 1998), so we will only focus on certain areas where China mainly developed, which follow:

1) The market in high velocity, broad-band **Optical Communication** Networks. The fiber-optic as applied in main-stem network and Metropolitan Area Network is to be promoted by FTTH (Fiber to the Home). Related markets like system technology, opto-devices, CMOS chips and broad band technology will be also booming accordingly.

2) The **LED** with small volume, high reliability and longevity, including LED lights and OLED, etc.

3) **Consumption Optical Products** (corresponding to optical information in the last paragraph), includes VCD, DVD, DC, TV, Palm-Computer, Intelligent Mobile phone, Mobile AV(Audio & Video), Photograph, Projection and Imaging, OA (laser print, FAX, photocopy), Information Display (CR/TFT-LCD/STN-LC/POP/FED/LED/LCOS).

Brief summary: Fast development and variance in network communication markets changed the structure and weight of optoelectronic technologies and their industry in the late 1990s and early 2000s (Berg A. 2006). It formed a market-driven power highlighted by the solutions and products offered in LED, network communication, and consumption optical products like LCD and optical storage devices. Although the optical application and related markets in health care and bioscience, national defense, and education are also important, they will not be the main focus of this paper.

1.3 Classification of laser and optoelectronic industries

There are various, but similar ways to classify in the laser and optoelectronic industries. One classification, though rough, is based on applications or the market, and is divided into information optoelectronics, energy optoelectronics and entertainment optoelectronics (Mei Song & Hou Hanping2000); another is in accordance with the OIDA statistics and estimation of products, and is divided into 6 categories: optoelectronic materials and cells, optoelectronic displays, optical input/output, optical storage, optical communication, and lasers and other applications. Ji Guo-ping (2001) divided the optoelectronic industry into 5 groups: optoelectronic materials and components, traditional optics (including devices), optical information, optical communication, and lasers and applications. And the optoelectronic market mainly centers in display, storage, communication, and imaging. Liu Song-hao (2000), Liu Tie-gen, et. al (2004) gave a classification (Tab.1), which is similar but more in-detail than that by OIDA[4].

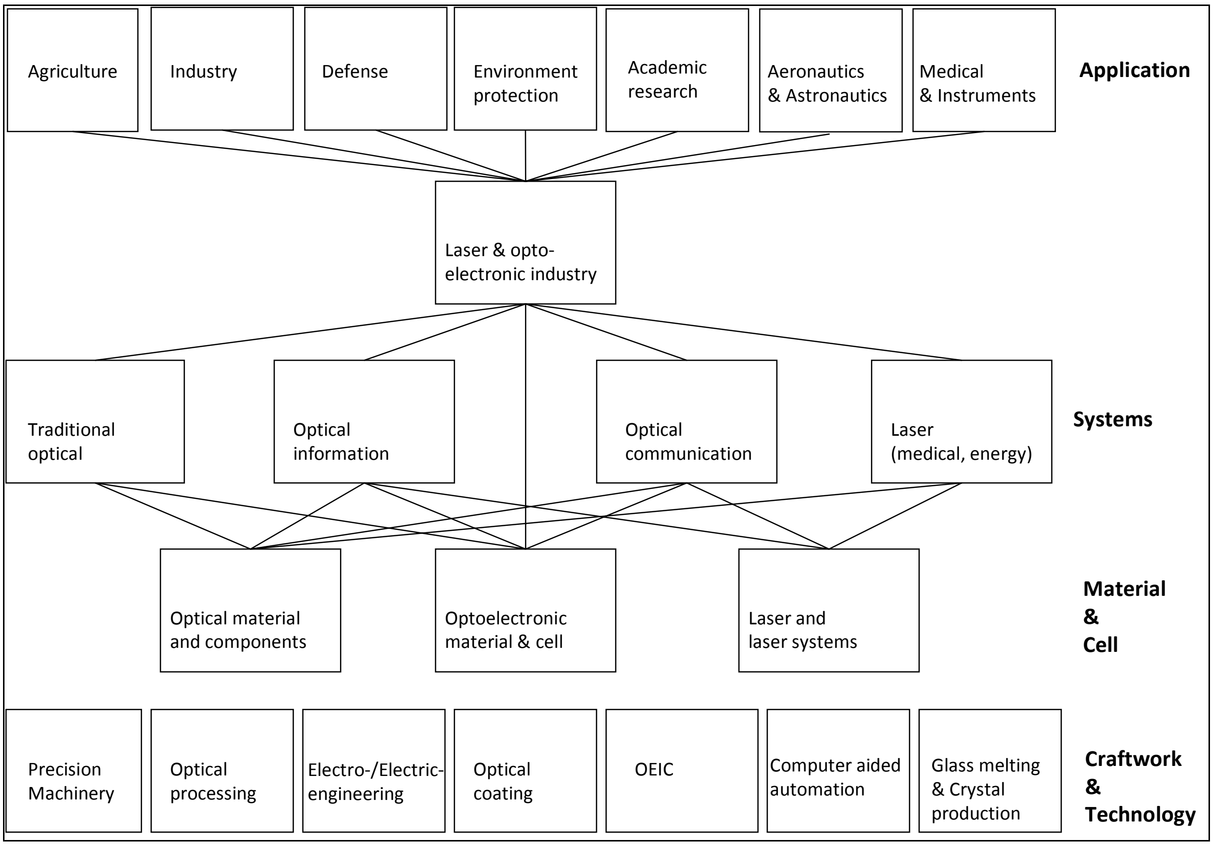
Liu Song-hao (2000, 2001), member of CAS (China Academy of Science), gives a brief layout of the laser & optoelectronic industry as well as its applications. It also shares similar ideas with USF (1999) and Ji Guo-ping's (2001) general classification. In this paper, we attempt to adopt basically the classification of Liu Song-hao (2000, 2001) (Fig.1) for his understand and viewpoints over the whole industry. The similar classification from USF (1999) also supports this point.

By now we have a brief image of optics and its modern descendent, optoelectronics. The basic components of lights application include: light (laser), material, and device. In modern applications, we create lasers to replace sunlight; and modern materials to replace the mirror (in enriching light), and in even more and more occasions we need a device to integrate the related functions and to make it more reliable.

A more thorough classification can be found in the following Table 1.

[4] See also in Ji Guo-ping (2001), OIDA(Optoelectronics Industry Development Association, USA) has a classification of Optoelectronics as: optical communication, optical information equipment, non-military optical facilities used in transport equipment, optical facilities used in industry and medical treatment, and military optical facilities used in transport equipment.

Fig. 1: Contour of laser & optoelectronic industry



Source: based on Liu Song-hao (2001), USF (1999)

Tab. 1: The classification of optoelectronic industry

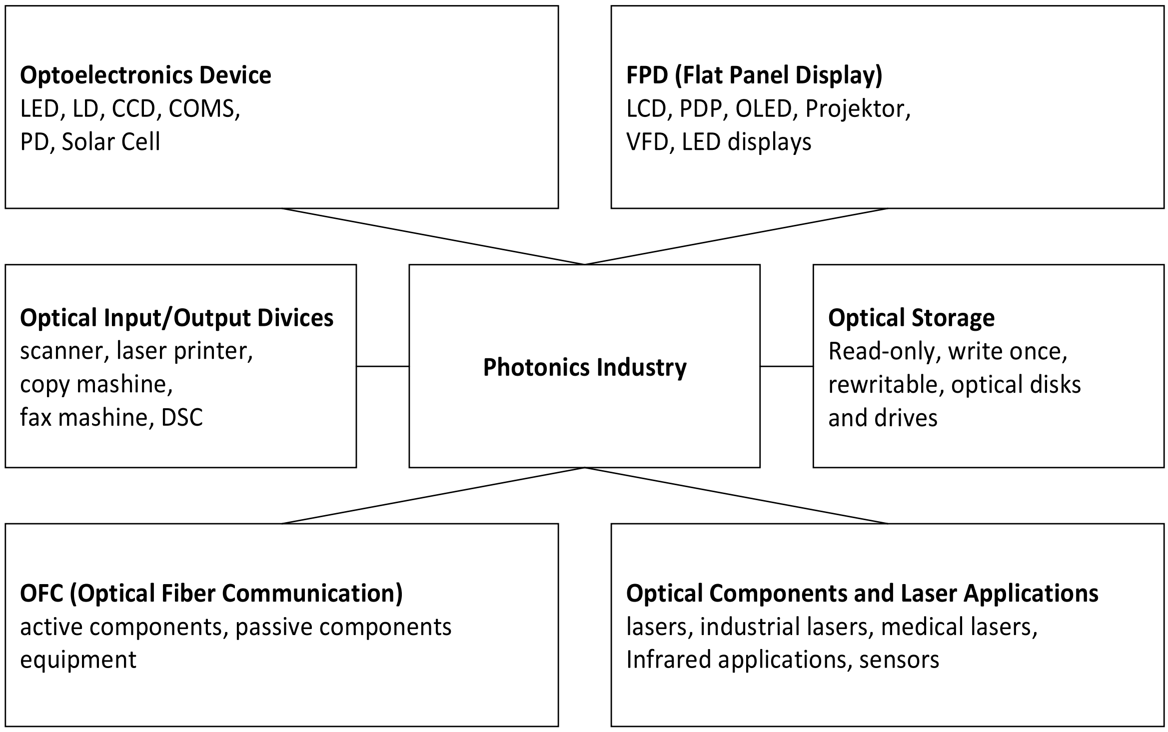
branch	product group	main products
optoelectronic material, components and devices	1) Flat display devices	1) LCD parts, 2) Light Emitting Diode Display Parts, 3) OLED, 4) FED(field emission display)
	2) Optoelectronic devices	1) LED, 2) optoelectronic detective components, 3) solar battery
	3) optoelectronic material	1) Special Optical Glass, 2) Special Optical Plastic, 3) Special Optical Crystal, 4) Special Optical Material, 5) semiconductor optoelectronic material, Epitaxy Material

branch	product group	main products	
Optical information (Storage)	1) Optical input/output device	1) scanner, 2) Table reader, 3) word identification, 4) Barcode scanner, 5) Digital Camera, 6) laser printer, 7) laser Xerox, 8) optical FAX	
	2) Optical storage	1) device	(1) Disk Reader (2) Optical-card reader
		2) optical recording media	CD/VCD/LD/CD ROM/MO/DVD/CD-R/others.
Optical communication	1) system and device	1) Fiber-optic transmitting device, 2) Fiber-optic regional network device, 3) inspection and monitoring device, 4) Fiber-optic construction device, 5) Terminal Unit, 6) CATV	
	2) cell and components	1) Single & Multi Mode Fiber 2) Fiber connector	
		3) Optical Active Devices	(1) optic-amplifier, (2) Laser to Fiber Coupler, (3) Laser to Detector Coupler, (4) Laser to package device, (5) detector to package device, (6) Optical pump device
		4) Optical Passive Devices	(1) optical coupler, (2) Optical Switch (3) Optical attenuator (4) Optical isolator (5) optical splitter (6) avelength division multiplex (WDM)
Laser and its application (energy & medical)	1) manufacture of laser	1) semiconductor laser, 2) solid-state laser, 3) gas laser, 4) dye laser, 5) excimer laser	
	2) laser application	1) in industrial processing, 2) in medical and surgery, 3) in military, 4) in academic research, 5) other application	
	3) optical sensor	1) optoelectronic sensor, 2) Acoustic-optic sensor, 3) Fiber-optic sensor, 4) others	
Optical equipment	1) telescope, 2) microscope, 3) camera, 4) lens, reflector 5) sensor		

Sources: Liu Song-hao (2000), Liu Tie-gen, et. al.(2004)

The above complicated classification may be turned into a relatively simple but industry-oriented one that is provided by PIDA (2006), only after you have a better understanding of the perspective of each position (Fig.2).

Fig. 2: Brief Map of Laser & Optoelectronic industry



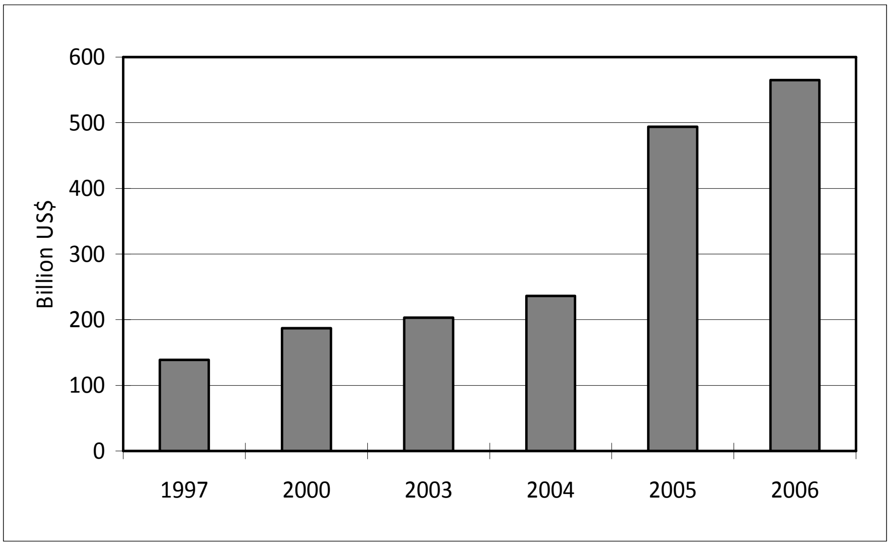
Source: PIDA 2006

2. A Glance over Laser & optoelectronic industry around the world

Worldwide optoelectronics markets' expansion has been "strong and steady" (OIDA, 2007) from 1997 to 2006 (Fig.3).

"Optoelectronics is still a vibrant, emerging technology with a bright future" (Berg, A. 2006). A similar evaluation can be found in Photonics 21 (2006): "the future prospects are also promising; as a result, the total photonics world market is expected to at least triple within the next 10 years." On the global level, a large volume of production in the optoelectronic industry is located in low cost countries, especially Asia, while the high, value-added sector, integrated devices and systems seem to still be located in advanced industrial nations, like the U.S., Japan and Western Europe. Another structural property of the industry is the common existence of "global niche players" (AIM 2007), and the small optoelectronic companies are even competitive around the globe because they are so few. Hence, the result is that there are rarely whole supply chains located in one specific region. This is especially true in the sector of telecommunication applications.

Fig. 3: The growth of worldwide optoelectronics market (1997-2006)



Source: (Berg, A.2006, OIDA, 2007)

(Note: the sharp increase from the figure of 2004 to that of 2005 and 2006 does not mean that the industry has an explosive growth over the year, but from the different statistical scale. In the figure of 2005 and 2006, the total value of optoelectronics-enabled products and systems are calculated.)

2.1 An Overview of the laser and optoelectronic cluster around the world

Because the laser and optoelectronic industry is fast-growing and science-based, they still enjoy the development of agglomeration and clustering, making several "sticky places in slippery spaces (Markusen 1999)". According to SPIE, an International Society for Optical Scientists and Engineering, there are a number of optoelectronic or photonics clusters that can be identified (Fig. 4). They refer to, under the definition of SPIE, "concentrations of optics-related firms and universities that maintain strong research and workforce ties, create quality jobs, share common economic needs, and work with government and stakeholders to strengthen the industry" (SPIE 2008). It is a relatively comprehensive map of optoelectronics/photonics clusters, although there exist some double-counting, like OptecNet and Photonic Net in Hannover. OptecNet, which headquartered in Hannover, refers to the association of the German regional Competence Networks for Optical Technologies, with Photonic

Net is a member of it. At the same time, some emerging clusters, like Changchun and Shanghai in China, and Hamamatsu in Japan are omitted.

Due to its combination of international reach and regional concentration, the advance of optoelectronic technology and industry are internationally linked with a small number of specialized technology and products providers and mass production bases.

In recent years some optoelectronic/photonics clusters in developed countries have begun to form inter-cluster alliances. Examples can be found in "Tri-cluster Berlin-Tucson-Ottawa Alliance," ICOIA (now IOA) on global bases, and INNOVA initiative European Network of Optical Clusters (ENOC), which is based on the existing links between partners from France, Greece, Italy, Spain, and the UK. The purposes of such coalitions or alliances are to "ease market access and increase exchange and communication among cluster members" (AIM 2007). Besides, the Optranet (http://www.optra.net), which is an IST (European Information Society Technologies) sponsored education-oriented collaboration between countries (namely Germany, UK, Sweden, Poland and France), started in 2003 and aimed at "highlighting and promoting the European training offer in Optics and Photonics".

Under the driving of the consumer and entertainment market, the laser and optoelectronic technology is likely to maintain its growing trend, although the growth rate of different segments within this industry may vary in the case of different optical associations. (OIDA 2006; OITDA 2006)

2.2 Technological and Industrial Advantages of Photonics / Optoelectronics in different countries

The technologies, as well as industries of laser and optoelectronics, are under fast development, and so the classification of each subsection changes radically also. Some fields within the industry witness an rising trend (like the LCD display), while others suffer a decline (like PDP display), and even some products (e.g. VCD) will drop out of the market in near future due to technological upgrading. Another characteristic of the industry is its blurring boundaries which make it difficult to give statistical figures, showing different results in some papers (Berg, A 2006; PIDA 2006). Based on the importance in world market share and its trend since 1996 (Liu Song-hao 2004; Berg, A 2006; PIDA 2006), the FPD (Flat Panel Displays) are on the top list of market share, which accounts for about 1/3 of annual market sales after 2004. Right behind the FPD market are optical input/output and optical storage, which both belong to optical information, and then the market of optical communication, optoelectronic devices and components, laser etc. follows.

For the production of FPD, the current technological and production priority is LCD related products, mainly located in East Asia. The value for displays (mainly LCD) in the financial year of 2006 reached USD 32.7 billion in Japan, 46.2% in terms of its market share that year (OITDA 2006), and equal to about 38% of FPD output of 2006. The FDP output of Taiwan and Korea reached USD 28.4 billion and USD 7 billion, respectively. TFT-LCD technology is by now the mainstream in FDP and major technological patents are in the name of companies in Japan, Korea and Taiwan.

In the market of optical input/output and optical storage, the two fields both enjoy a value of around 44 billion USD in 2006. Digital Cameras, photo copiers, fax machines, and laser printers are the spread of Japan's brands. Nikon, Canon, and Sony take most of the market share, followed by Samsung from Korea and Kodak from US. In optical storage, the competition focuses on brands in optic drives, like CD/VCD/DVD players and CD/DVD-R/ROM drives, while the manufacture of the drives are mainly agglomerated in China. However, the development and production of optical discs are in the era of upgrading, with blue ray disc from Sony directed group and NVD from China competing for the market of next generation of optic discs.

In the market of optical communication, the optical fiber plays crucial role. Some companies like Corning from the U.S., Alcatel from France and FiberHome, YOFC from China act as not only optical fiber and cable providers, but also packaged solution providers.

In the optoelectronic devices field, the LED and solar cell (or Photovoltaic) are two of the largest markets. Most LED high value-added sectors and patents are controlled by companies from Japan, U.S. and Germany, while the companies of Taiwan and China are in the role of late comers, and try to share more market in not only low-end package but also high-end Extension and Chip development, as well as its application in automobile and common lighting.

In terms of lasers and their applications, Germany and the U.S. are in the leading positions. In order to hold the technological advantage, the governments of the U.S., Japan, the UK, and Germany have launched some scientific plans or strategies, as well as the establishment of national laser centers. Famous companies include Coherent and Lumenis of the US, Trumpf and Rofin in Germany, and Mitsubishi and Panasonic in Japan. All these companies offer various lasers and laser systems, especially applied to material processing (e.g. in macro processing of cutting, welding, marking, etc. and in micro processing of semiconductors, printed circuit boards, electronic components) and the medical field (cosmetics, optometry, etc.). In 2006, the world laser market reached 5.45 billion Euros (Optech-consulting, 2007).

In order to keep the technological leadership in a scientifically motivated industry, government or non-government organizations in the U.S., Japan and the European Union have attempted to establish various projects or programs to enhance the scientific and technological cooperation among scientific institutions, universities, and industries. Examples can be found in Photonics 21, the European Framework Programme, German's BMBF programme in Europe, and the Defense Advanced Research Projects Agency (DARPA) in U.S. (OpTech-Net 2006; OIDA 2006).

Compared with the U.S.'s attention on optoelectronic application in defense, Europe (especially Germany) is better at macro laser processing, while Japan sits at the top by itself in many fields with its large market share, such as FPD, LED, optical information, etc.

Tab. 2: Optics and Photonics Clusters around the world

Europe	Bayern Photonics e.V.	Muenchen, Germany
	Brittany Optics Coast	Brest, France
	Hanse Photonik	Hamburg, Germany
	Midlands Photonics Cluster	Birmingham,United Kingdom
	Optics Valley France	Palaiseau - Paris, France
	Optec-Berlin-Brandenburg e.V.	Berlin-Brandenburg, Germany
	Optence e.V.	Darmstadt, Germany
	OpTech-Net e.V.; Duisburg	Duisburg, Germany
	OpTech-Net Deutschland e.V.	Hannover, Germany
	OptoNet e.V.; Jena	Jena, Germany
	Photonic Net	Hannover, Germany
	Photonics BW	Oberkochen, Germany
	PhotonAIX e.V.	Aachen, Germany
	Scottish Optoelectronics Association	Livingston, United Kingdom
	South East Photonics Network	Banbury, Oxon, United Kingdom
	The Welsh Opto-electronics Forum	St. Asaph, United Kingdom
United States	Arizona Optics Industry Association	Tucson, Arizona
	Carolinas MicroOptics Triangle	Western N. Carolina and upstate S. Carolina
	Colorado Photonics Industry Association	Longmont, Colorado
	Florida Photonics Cluster	Orlando, Florida
	New Mexico Optics Industry Association	Albuquerque, New Mexico
	Photonics Industry Association of New York	Rome, New York
	Rochester Regional Photonics Cluster, Inc.	Rochester, New York
Canada	British Columbia Photonics Industry Association	Vancouver
	Montreal Photonic Network	Montréal
	Ontario Photonics Industry Cluster	Ontario
	Ottawa Photonics Cluster	Ottawa
	Quebec Optics and Photonics Association	Quebec
Asia Pacific	Korean Association for Photonics Industry Development	Gwangju-Jeonnam, Korea
	New Zealand Cluster	Wellington City, New Zealand
	Optics Valley of China	Wuhan, China
	Singapore Photonics & Optics	Singapore, Singapore
	Victorian Photonics Network (VPN)	Melbourne, Australia

Source: SPIE-the International Society for Optical Engineering (2008) (www.photonicsclusters.com)

3. The story of China, a promising Laser & optoelectronic industry

What embarrassed China are the strange situations in this field: while many scholars affiliated to China’s key universities or academic institutions are buried in articles or other academic publications, the business owners of related industry in China have to buy crucial technologies and equipments from overseas producers. The gap between academic research and industrial application shows briefly the disadvantage of China’s laser and optoelectronic technology and industry, although there do exist some technologies in fiber optics that are good examples of university-industry and research institute-industry knowledge transfer in China.

Currently, China’s research in laser processing, fiber-optics, and optoelectronic devices has put China in the leading group of the world with some competitive technologies like Strained Quantum Well Laser materials, devices, optic-electronic IC (OEIC), and photon IC (PIC), but in general, the researchers are still on the level of followers, especially in medical lasers, LED, and R&D. Producing technology and supporting materials, parts, and accessories that are necessary for the optoelectronic industry is still being developed (Li Hai-hua, et. al 2002, Liu Song-hao, 2004). Some cities, especially those with great academic achievements and potentials, are trying to establish a local competitive edge under the benefit of spin-off enterprises and academic-industry cooperation. Wuhan, Shanghai, Changchun and Beijing are among the strong, along with Guangzhou, Tianjin and Xi’an.

3.1 The market of laser and optoelectronic industry in China

The laser and optoelectronic industry, by now, is not an independent industry under China’s statistical system, although the term “laser and optoelectronic industry” is being used more often than ever. As Kodama (1995) wrote:

> *“...in the case of opto-electronics the point at which technologies come together is often at the level of basic science, and involves disciplines such as traditional optics, solid-state physics, materials science and information technology, with the consequence that the industry is heavily reliant on scientific research and the ability to envisage the commercial potential of a discovery, when used in conjunction with other results”.*

Thus, there is a character of “technology fusion” (Hendry, C. et. al, 1999) in the optoelectronic industry, so because each section of the laser and optoelectronic industry do not by any means stand independently from one another the gross income of the industry can not be found in official statistical yearbooks. Main figures about the achievements of the industry in China are from the industrial association or based on local industrial parks.

Over the past 30 years, China's reform and Open Door Policy have promoted China's laser and optoelectronic research to join the application market. Due to the high preliminary input, the development of the laser and optoelectronic industry needs a great deal of government support. In many national strategic scientific plans, laser and optoelectronic technologies are given a lot of importance. Laser technology and optoelectronic technology (including laser technology used in information industry) are among the seven big plans of “863.” In 1995, Inertial Confinement Fusion was added to the list. Optoelectronic technology as an item on national defense has also been set up as a cross-departmental project. In the national “Six-Five” and “Seven-Five” plan, laser and optoelectronic technologies are listed as important items. Beside this, the State Fund for Natural Sciences sponsored a number of research projects in laser and optoelectronic technologies from 1986 to 1998.

By now, the China Optics and Optoelectronics Manufactures Association (COEMA)[5] is an organization that can release crucial figures in terms of output and sales volume of sub-sections. Due to more "fusion" with other fields, statistics on optical information and optical communication come from COEMA reports. Wang Lin (2006), head secretary of COEMA, introduced the development of sub-sectors which have close connections with COEMA, including 1) optoelectronic displays (LCD+LED), 2) optoelectronic parts and devices, 3) lasers and their applications, and 4) traditional optical cold processing (Tab.3)[6]. In 2005, the total sales volume of China's laser and optoelectronic industry reached about RMB 44.24 billion. In addition, in 2006, the market of information industry related material (optoelectronic material) reached over RMB 77.6 billion. Moreover, optoelectronic communication is a crucial part in the optoelectronic industry, and the total sales volume of fiber optic, as reported by COEMA, reached 24 million km in year 2006. Among the industry, optoelectronic parts and devices, crystal-related products, and lasers are the major contributors to the industry since 2003 (Wang Xi-jun, et. al 2006).

Tab. 3: Distribution of optoelectronic market in China (2005)

	LCD*	LED Display*	optoelectronic parts and device*	Laser**	Total
sales volume (in billions of Y RMB)	21.89	3.34	15	4.01	44.24
Market Share (%)	49.5	7.5	40	9.0	100

Source: *Wang Lin(2006), ** COEMA statistics www.coema.org.cn/sum

Note: The figure in this table only include the members of COEMA, while the output of many non-member Joint-ventures or foreign owned companies, which are also very crucial, are excluded.

With new introductions of funds and technology from Taiwan, clusters of liquid crystal-related products were formulated in Shenzhen, Xia'men, Shanghai, Suzhou and Nanjing. Due to an advantage in the manufacture of the LCD and LED Display, the production cooperation and technological transfer of LCD manufacture is also growing very fast across the Taiwan Strait. In the year 2005, the output of the optoelectronic industry of Taiwan amounted to USD 31 billion (Wang Kai-yi, 2007), accounting for 16% of that of the world. According to The Photonics Industry and Technology Development Association of Taipei (PITDA), the main optoelectronic products categorized in Taiwan's optoelectronic industry are centered in LCDs, LED Displays, optical I/O, optical-recording devices and optoelectronic components, Fiber Optic, laser, lens, etc.

[5]For detail introduction to COEMA, see attached Notes 2

[6]There are only some figures on production capacities of traditional optical cold processing in Wang Lin (2006).

3.2 Key players in China

3.2.1 The companies and enterprises: based on sub sections in laser and optoelectronic industry

The laser and optoelectronic technologies concern many related fields, even including those that go far beyond the concept of the laser and optoelectronic industry. This character of technological penetration makes it necessary to pay attention to the closely-related sub-sectors, which suggest more information on the map of this technology and industry. The following introduction of the subsections covers mainly, but not every part of, China's laser and optoelectronic industry.

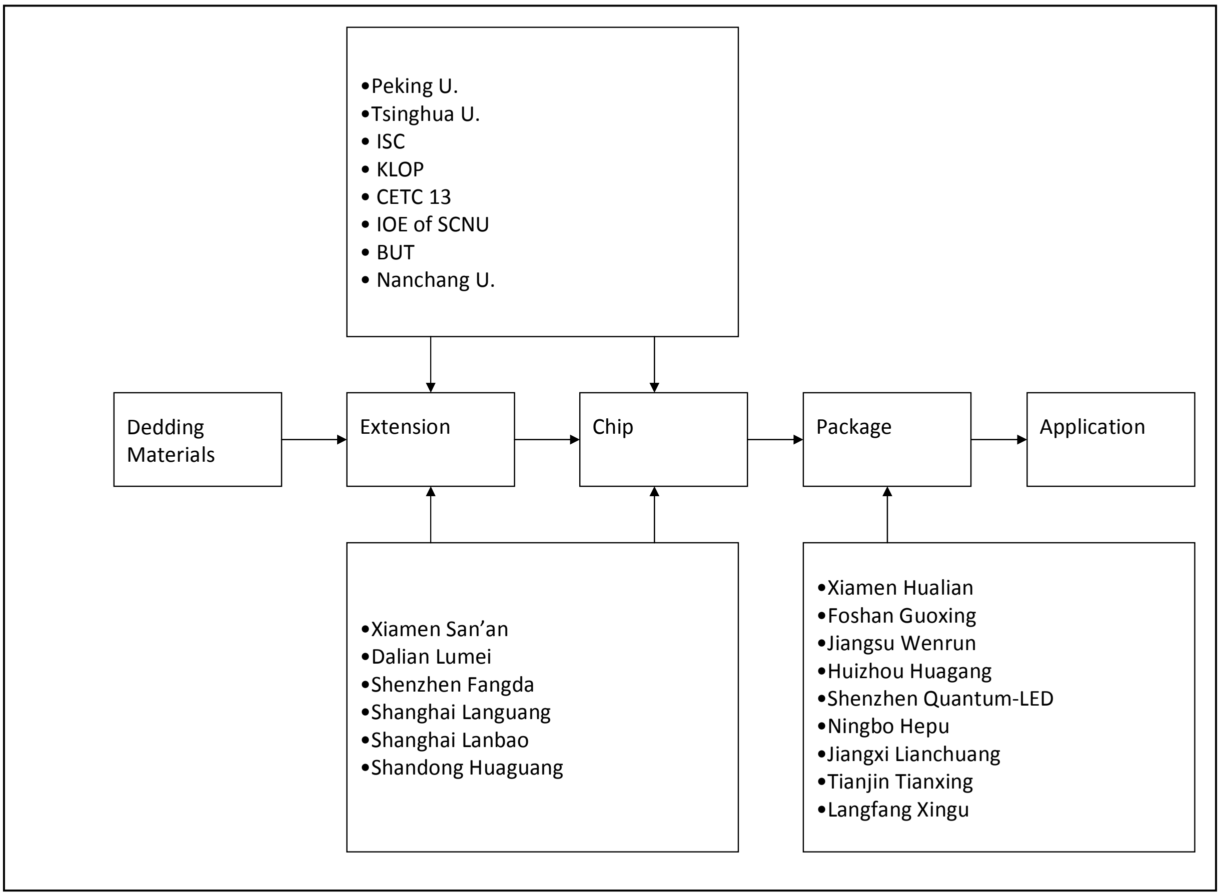
- **Solar Photovoltaic (PV) Industry**

The development of the Solar Photovoltaic (PV) Industry in China can be traced back to early 1980s, when some semiconductor device manufacturers began to produce monocrystalline silicon solar batteries (Zhao Yu-wen, 2004). The PV Industry continued to grow steadily until a sharp increase in output in 2003, when Wuxi Suntech Power Co. was established. In 2005, China produced 145.7MWP solar batteries, and 56.3% of the output was from Suntech Power (Zhao Yu-wen, et. al 2007). Also, the polycrystalline silicon, which is the raw material of the solar battery, reached an output of 130 tons in 2005 (Zhao Dai-qing, et al. 2007), far behind the annual demand of 1,516 tons the same year in producing solar batteries. In terms of China's PV market, the installed solar power capacity only reached 70 MWP, lagging far behind the industry's producing capability. Most of China's PV productivity was digested by countries like the US, Japan and Germany, where there are many government-promoted solar energy strategies or plans to be carried out. In 2005, the solar power capacity in the U.S. reached 1508 MWP, over 20 times that in China (Wei Jian-ming, 2006). The major products from China's PV industry are batteries and devices, and fewer PV power systems, showing that China's PV enterprises are still more than producers of appropriate power systems (Luo Ting-lin, 2006).

- **LED lights material and cells (parts and devices)**

China's LED industry is mainly located mainly in Guangdong, Yangtze River Delta, Jiangxi, Fujian, Beijing and Dalian. In terms of the LED lights field, the key enterprises (as well as R&D institutions, which are crucial to the LED development) can be found in the following Fig. 4, which is based on value chains.

Fig. 4: **Major Enterprises and developers of China's LED Lights**



Source: Ling L. (2004), Wang Lin (2006), Chen Yang (2007)

Except for its application, the manufacture of LED lights can be divided by industrial chain into 4 parts: Dedding materials, extension, chip manufacture, and packaging. Extension and chip manufacture accounts for most of the added value, and most patents as well as profits are in the name of some multinational companies, like Nichia, Toyoda Gosei, Lumileds, Cree Lighting, Osram, etc.

The development of LED lights has experienced fast growth ever since the 1960s when the first red LED was invented. In the 1990s, two crucial inventions from HP (LumiLeds Lighting) and Nichia, High-Brightness red-yellow LED and blue-green LED, brought a breakthrough in business of full-color LED and white LED (Ling L., 2004). Due to its great market potential in large screen display and decoration, auto and traffic lights, and other instrument panels, the high-brightness patents holders gradually transferred the low-end package of LED to China. Thus, half of the package plants are in the Pearl River Delta (Peng Wan-hua, 2005). In 2005, the output of LED (optoelectronic parts and devices) reached RMB 15 billion (Wang Lin, 2006). By the end of 2004, there were about 3,500 LED firms in China, with more than 500,000 employees (COEMA 2008). In Nanchang, capital of Jiangxi province and Shanghai, a relatively complete chain of value in this field has been established.

- **Optoelectronic information (mainly LCD display)**

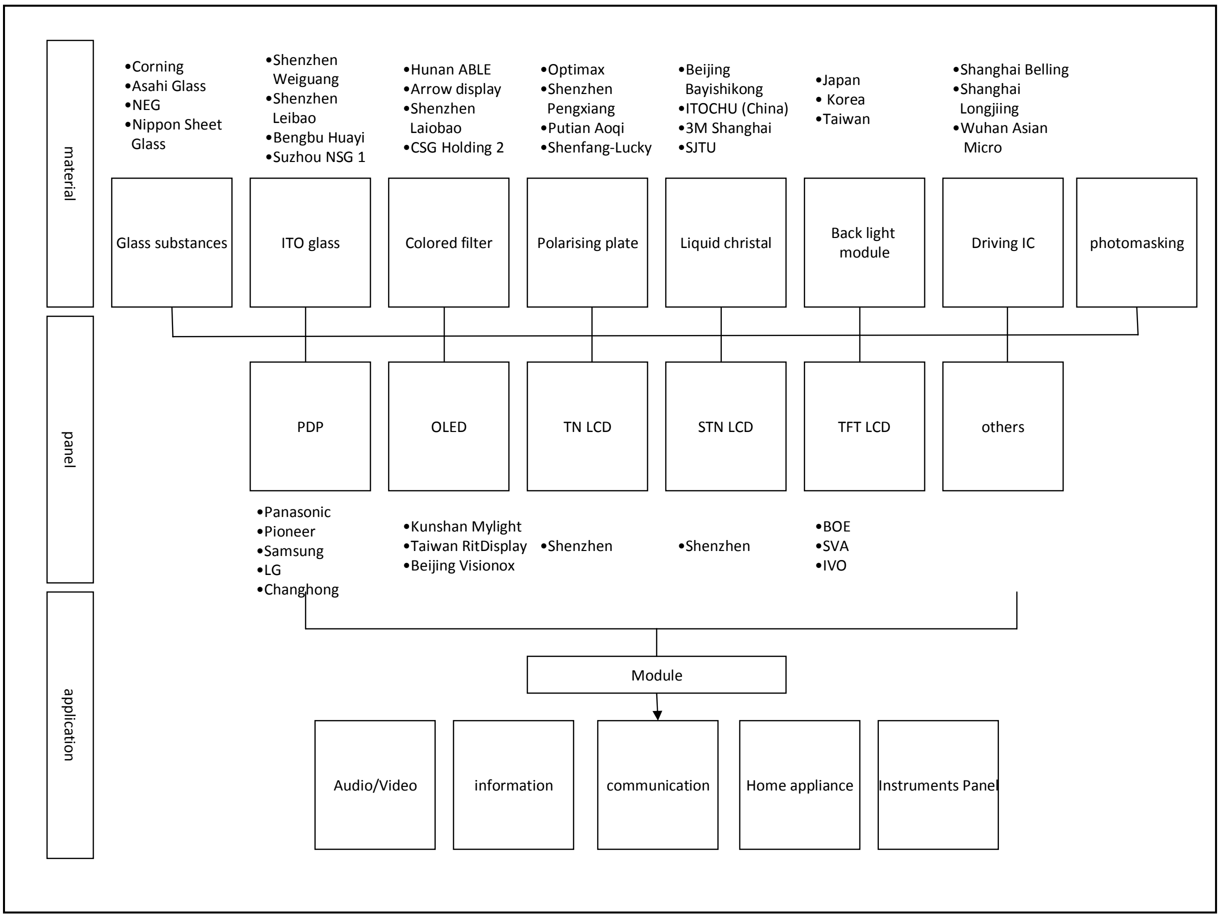
The optoelectronic information industry is by far the field with the largest market potential. Optoelectronic information includes 3 sections: optical displays, optical input/output, and optical storage.

In the field of optical displays, large technological and capital inputs are necessary, while the companies from Japan, Taiwan and US control most patents and the related market in the upper stream, material production. The liquid crystal, colored filter, ITO glass, and polarizing plate are mainly dependent on imports, with few companies like Shenzhen Laibao, Arrow Display, and CSG holdings providing the aforesaid materials used in TN/STN LCD. China`s major investment is on the middle stream, the panel production. Among them, the TFT-LCD manufactures, BOE, SVA and IVO are the 3 largest production plants, and their technological suppliers are from Korea, Japan and the U.S., respectively. Compared with those in Japan, Korea and the U.S., the 3 plants are far smaller in scale. In addition, there are many TN/STN LCD manufactures and companies located in Shenzhen. PDP panel suppliers are also mainly from Japan and Korea, with Changhong trying to find a market niche after a buy-outs by Korean companies. Generally speaking, the Japanese and Korean investors have tried to settle down locally by technological transferring, establishing joint ventures, or forming wholly owned companies. Local technological advantages are seldom found and many local invested companies are also based on technology introduced by Japan, Korea and Taiwan. As a new comer in flat panel display, OLED grows fast in the application in some short-time displays, like those on PDAs, DCs and DVs. China lags less behind in the technology of OLEDs than that of LCDs (Shao Zuo-ye, et. al, 2005) (Fig.5).

The field of optical input/output, scanners, readers, Digital Cameras, printers, Xerox and FAX machines is mainly controlled by companies from Japan and Korea. Cannon, Sony, Panasonic, Samsung, Kodak, Epson, and HP have established their plants in China and took most of the market to China.

The optical storage sector includes disc readers (players) and discs. Many disc and DVD player production lines are established the in Pearl River Delta, Yangtze River Delta and Bohai Bay Area. Due patents within this sector are mainly being controlled by multinationals like SONY, Phillips, etc., the DVD player manufactures in China have to pay high cost on the usage. A large percentage of profit goes to foreign competitors and thus make China put more effort on the competition for the next Generation of DVD. By now, China’s independently developed NVD (Net Video Disc) is trying to find its position in the standard competition with Toshiba’s HD-DVD and Sony’s Blue-ray DVD. The NVD was developed in the Shanghai National Disc Engineering Center, Xinhui, and Wuhan Donghu Disc.

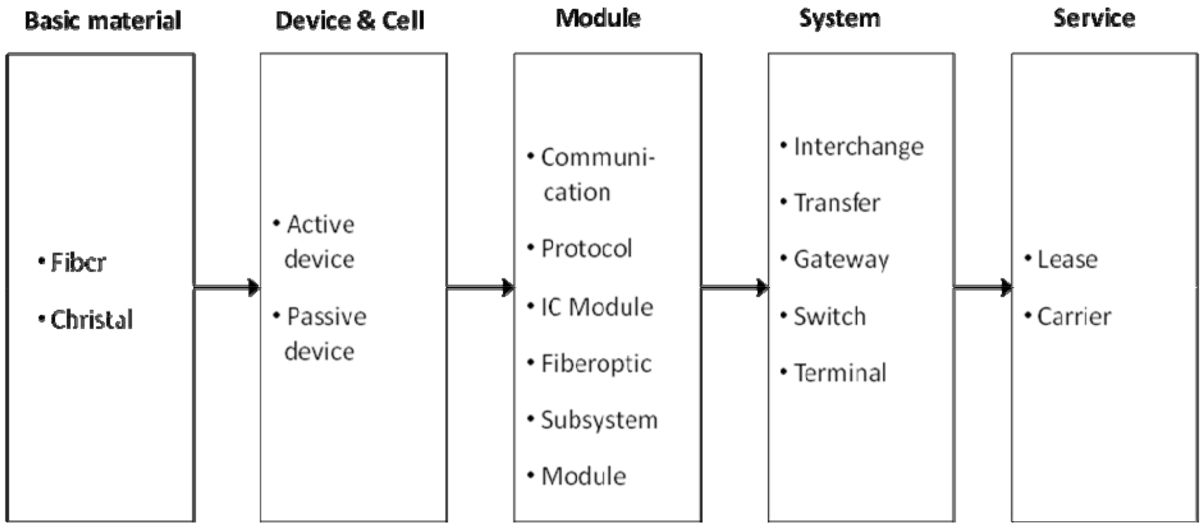
Fig. 5: Major Enterprises on China's FDP Market



- **Optoelectronic communication**

Optoelectronic communication suffered a temporary slowdown in 2002, when a series of financial difficulties were started by the bankruptcy of Worldcom Communication Co., which was blamed on the overheating of the communication industry. The industry has witnessed a recovery since 2005 and the multinationals and their domestic rivals in China continue to invest heavily on the market with its fast growth rate. In terms of value chains, the optoelectronic communication field can be divided as shown in Fig.3. Here, the paper only focuses on the production sectors, which include the production of devices, fiber optics, transfer systems and switch systems. Major fiber optics, cables, and solution suppliers include YOFC and Fiberhome, located in Wuhan, Zhongtian; Hengtong; Futong Tongguang Yongding in Jiangsu Province, with Huawei, Zhongxing, Datang in Shenzhen; and Shanghai Bell Alcatel as the major system and solution providers. Smaller device providers scatter around the major players in the Yangtze River Delta, the Pearl River Delta and the Bohai Bay Area. Key active devices and passive devices applied in the whole network are still technologically backward in China, despite their scattered breakthroughs in technology, when compared with world leading companies like Lucent-Alcatel etc.

Fig. 6: Value Chain of Optoelectronic Communication Industry



Source: based on introduction of PIDA, COEMA

- **Laser**

In the field of lasers and their applications, the most developed ones in China are the laser processing apparatus and optoelectronic communication. Other applications, including that in medical instruments grow fairly slow and only produce some low technological apparatuses, like laser cosmetology (Zhang Yu-chuan, 2000; COEMA,2007;). However, laser holography grows fast due to its application in tobacco and medicine packaging.

In terms of the output of the laser processing sector (Tab. 4), it is still a smaller one when compared with other optoelectronic industries. In 2002, the total sales volume of the world laser processing market was USD 2.99 billion, while the output of China reached RMB 10.335 billion, equal to about 1/26 of the world market share (Chen Miao-hai, 2004). The figure reached RMB 1.5 billion in 2004, RMB 1.8 billion in 2005, and RMB 2.5 billion in 2006, respectively (COEMA, 2006).

Tab. 4: Classification of laser processing apparatus and its application

Classification	Application	Laser device
Laser marker	Printing, Packing, Scale	YAG, CO2, Diode
Laser drilling	Aeronautic & Astronautic, auto manufacture, Chemical, semiconductor IC, diamond bearing, Multilayer printed circuit board	YAG,CO2, excimer, Isotope, diode
Laser welder	Auto body sheet metal, auto parts, lithium battery, heart pacemaker, sealed relay, other clean welding parts	YAG,CO2, Diode-pump laser
Laser cutter	Manufacture of auto, computer and electric machine cover, cut and slice of metal and non-metal parts, Process of tube, deformation components and Screen Plate	YAG ,CO2
Heat treatment	Heat treatment of Auto Hydro-cylinder Bush, Crankshaft, piston ring, steer-ing, gear wheel, heat treatment of parts in aeronautic and astronautic, machine tool, machinery parts	YAG ,CO2
Polishing & Rapid Prototyping	Model industry	YAG ,CO2
Laser coating	Aeronautic and astronautic, model and electric machinery	YAG ,CO2
Laser cleaning	Surface Cleaning of electrical parts, Chips and metals, Porcelains	YAG ,CO2

Source: Chen Miao-hai(2004); report on Hans-laser Co. Ltd. by United securities, Sep.15, 2005

There are about 100 laser apparatus suppliers scattered around China, with Wuhan Chutian, Wuhan Huagong, and Shenzhen Han's as the 3 leading ones (Chen Miao-hai 2004). In 2006, the sales volume of laser processing apparatus record RMB 2.5 billion, an increase of nearly 30% compared with that of RMB 1.8 billion in 2005 (Tab. 5).

Tab. 5: Market of Laser Processing Apparatus in China (2006) (million RMB)

	Laser cutter	Laser marker	Laser graver	Laser welder	Polish /Coating / clean	others	Total
Sales volume	761.1	609.93	594.94	254.87	167.41	109.94	2498.7
Market share	30.46%	24.41%	23.81%	10.2%	6.7%	4.4%	100%

Source: COEMA (2007)

- **Traditional Optics and optical materials**

Due to information unavailability and industrial minor position in the whole industry in China, this section goes beyond the paper`s research.

3.2.2 The Research Institutes and Universities

The laser and optoelectronic industry relies heavily on technological advancement as well as the human resources that are available locally and nationwide. The academic and technology advantage in a local area largely decides the future orientation or path of the industry there. By now, the academically powerful cities with great achievements or great potential in the laser and optoelectronic technology and industry are Wuhan, Shanghai, Changchun, Beijing and Xi'an (Tab. 6).

Tab. 6: Regional Major Academic and R& D establishments of laser and optoelectronics in China

Fields / Cities	Optoelectronic Communication	Optoelectronic Information (Storage, Imaging)	Laser
Wuhan	WRI		HUST, WJI, Gongyan, 717
Shanghai	CETC 23, SJTU, SEU (Nanjing)	SITP	SIOM,SILT
Changchun	Jilin University	CIOM, Jilin University	CIOM,
Beijing	Beijing U. Tsinghua U.	ISC, Nankai U.(Solar Battery)	CETC11, BIOET, KLOP, NCRIEO,BUT(NCLT), Tsinghua U., Beijing U.
Xi'an	XOAI	XIOM	
Shijiazhuang	CETC13		
Guangzhou/Shenzhen	OEMT of SYU	GISM	IOE of SCNU, GILA, SZU

Source: Cao Jian-lin, et. al 2001; Chen Miao-hai (2004); Sun Wen (2004); Official website of related institutions

Within the research establishments, State Key Laboratories (SKL) can be taken as an index to track the basic academic potential in a related technological field. SKL was established in different parts of the nation as early as the 1980s, with the purpose of enhancing the capabilities of national basic scientific research. Furthermore, SKLs are part of China's National Innovation System. The SKL around the whole nation are affiliated with the faculty of a university or a branch of CAS (Tab. 7).

Tab. 7: Distribution of SKLs for laser and optoelectronic technologies in China

	Optoelectronic devices and materials	Optoelectronic Information	Optoelectronic Communication	Laser
Beijing	1) Superlattices and Microsturctures 2) Surface Physics 3) Superconductivity 4) Magnetism 5) Artificial Microstructures and Mesoscopic Physics	Software Development Environment	1) Networking and Switching 2) Microwave and Digital Communication	
Shanghai	Infrared Physics		1) Sensor Technology 2) Optical Communication	1) Optical and Magnetic Resonance Spectroscopy 2) High Intensity Optics
Wuhan		Software Engineering		1) Spectroscopy, Atomic and Molecular Physics 2) Laser Technology
Changchun	Integrated Optoelectronics	Applied Optics		
Chengdu	Electronic Thin Films and Integrated Devices			Microfabrication
Xi'an		Transient Optics and Photonics		
Guangzhou	Optoelectronic Materials and Technology			
Hangzhou	Silicon Materials	Modern Photonics Apparatus		
Jinan	Crystal Materials			
Nanjing	Solid State Microstructures			
Taiyuan	Quantum Optics Device			
Tianjin		Precision Test		

Source: www. chinalab.gov.cn

According to Chinalab, which belongs to basic research department of China's Ministry of Science and Technology, there were 220 SKLs around the whole nation by the end of 2007. The SKL system is a measure of major China's basic research capacity. Altogether, there are 27 SKLs that are laser and optoelectronic, or photonic related, accounting for 12.2%. And most of the 27 SKLs are located in the eastern part of China. Most of the labs center on the basic science and a few of them act as technological providers, i.e. CIOM, HUST and SIOM, to their affiliated spin-off companies and enterprises. Such institutes and universities have powerful technological influence over the laser and optoelectronic industries in China. For instance, almost all laser optoelectronic companies in Changchun are spin-off enterprises of CIOM or technologically supported by CIOM.

The arrangement of such research institutes and universities is partly because of the central government's planning, like Changchun, and partly because of a city's strategic position in China, like Shanghai or Beijing. Directed by the preferential regional and technological policies, the geographical distribution of these research powers is featured by polarization and mainly located in municipalities and provincial capitals. Due to their openness, all laboratories have various kinds of technological coordination and academic communication with academicians from technologically advanced universities and institutes. Although Beijing has the largest number of SKLs, it still lags far behind Wuhan in the development of laser and optoelectronic industry. However, in some sectors that have a technological disadvantage but great market potential industry, like LCDs and LEDs, the research powers act as technological challengers to those multinational companies.

Apart from research establishments financed by the central government, there are also some research institutes in technological agglomerated cities like Wuhan and Shanghai financed by local government.

3.3 Regional industrial Advantage

According to China's state "863" technological plan, laser and optoelectronic industrial bases are now established in Wuhan, Changchun, Shanghai, Beijing, Shenzhen and Shijiazhuang. All but Shenzhen are municipalities or provincial capitals with China's key universities and research institutes. Hence, the development of the laser and optoelectronic industry in different cities showed various paths. For cities like Wuhan, Shanghai, and Beijing, the local development of the laser and optoelectronic industry are both the result of academic advantage and the inflow of domestic and foreign capital. However, only a few research establishments like WRI and HUST in Wuhan act as a strong technological provider, while others put more effort on scientific research. Hence, China's quick development of mass scale industries like LCD, LED, and crucial optoelectronic devices are the result of foreign capital's market exploitation. That's the reason that many such plants in industrialized regions of China's Yangtze River Delta, Pearl River Delta and Bohai Bay Area, are at the low ends of value chain. For cities like Shijiazhuang and Changchun, the industries are based on local technological edge or resources advantages, and the capital inputs are mainly domestically oriented.

Tab. 8: Regional Comparison of China's Laser and Optoelectronic Industrial Base

	Technological advantage	Representative Enterprises	Industrial Base
Wuhan	Optoelectronic Communication *	FiberHome, YOFC, WTD, KLFOSTIP	China optical valley
	laser Process	Huagong, Chutian, Unity, 717	
Shanghai	Optoelectronic Display & LED	SVA-NEC, Tianma Shanghai, Infovision; Languang, Lanbao	Pudong,Minhang, Kunshan
	Optoelectronic Communication	Yangtze Shanghai ,Corning, Worldbest, Alcatel, WXZTE	Songjiang, Cao he jing, Chongming, Jinqiao
	Optic device, Laser	NVD, Philips, Daheng, SILT, SLG	Jia ding /Song jiang
Beijing	Optoelectronic Display	BOE	Yi zhuang Indus. Park
	Opo-Comm. Components	Compound Crystal	Tong Zhou
	Laser(Power & Medical)	Daheng Information Technology	Zhong guan cun
Changchun	Optoelectronic Display	Northern Caijing (LCD)	CETDZ
	Power Laser	CNI LASER, UP Optotech, Chuangchun Guanghua Microelectroincs	
Shenzhen	Fiber Optical, Comm.& Storage Device	Huawei, ZTE, Great wall, Huaqiang, Shenzhen SDG, Photon, Kaifa	Hi-tech park
	Optoelectronic Display	TIANMA, KONKA, SKYWORTH	
	Laser	HAN'S	
Guangzhou	Optical, Optoelectronic material and device, opto-information, opto-communication, laser	Small firms	Economic & Technology Development Zone, Hi-tech Zone, Tianhe, Panyu
Shijiazhuang	LED Solar Battery Monocrystalline Silicon	CETC 13, Hebei Jinglong	Luquan Devlopment Zone, Ningjin County

Source: National Optical-information Center http://gd.whlib.ac.cn/, Li Hai-hua, et.al.(2002), Zhang Zhi-he, et.al (2001, 2002), Liu Song-hao (2004), Zhou Zhong-lin (2005) Note: * Including optic fiber preparation stick, optic fiber, optic cable and supporting components, optical communication components.

Within the city-based optoelectronic industries, Wuhan and Shanghai developed comparatively fast in terms of products output. While Shanghai and its nearest neighbor, Kunshan, mostly depend on huge capital input, the development of Wuhan laser and optoelectronic industry mostly benefits from local technological spin-offs. Changchun, Beijing also has great potential due to its technological advantages. Even technological cooperation can be witnessed between ISC in Beijing and Jilin University in Changchun. A brief introduction of optoelectronic industrial bases in Wuhan, Shanghai and Changchun, follows. The three regions all have distinct characteristics and could show a limited but representative picture of the development and trajectory of China's laser and optoelectronic industry.

3.3.1 Wuhan

Among the laser and optoelectronic industrial bases in China, Wuhan·China Optical Valley, which is mainly located in Wuhan East Lake High-tech Development Zone (WEHDZ), is by far the best developed in this industry. Due to its early start, technology advantage, talents agglomeration, and better infrastructure ever since the 1990s, Wuhan became China's leading region for Fiber optics and cable, both R&D and manufacture. And the leader in fiber optics is Wuhan Research Institute of Posts and Telecommunications (WRI), which now is FiberHome4 Technologies Group. Especially by telecommunication standards, namely X.85, X.86 and X.87, issued by WRI in 2001, 2002 and 2003, approved by International Telecommunications Association, WRI became one member in the world telecommunication club (Sun Shu-sheng, 2001; Yan Yan et al., 2002). Along with FiberHome, Yangtze Optical Fiber and Cable Company (YOFC5) are the other giants in Wuhan's fiber and cable production. YOFC dedicated much to the research and development of optical fiber and cable products.

HuaZhong University of Science and Technology (HUST), is pioneering in the field of laser technology. HUST began to do research in gas lasers, solid lasers, and their respective applications as early as 1971. The State Key Laboratory for Laser Technology (SKLLT) was finished in 1989 and based in HUST. The key research directions of NKLT are high power lasers and interaction between lasers and materials. This advantage has made HUST the leader in laser technology and laser application in China ever since (Zhu Xiao, et al.2007, Yan Yan et al., 2002).

By the end of 2005, Wuhan National Laboratory for Optoelectronics[7] (WNLO) was founded in Wuhan and sponsored by the China's Ministry of Science and Technology. WNLO aims at constructing a large-scale scientific research platform with the joint technological edge from HUST, WRI, WIPM (Wuhan Institute of Physics and Mathematics, CAS), and the 717th Institute.

Besides a National Software Engineering key lab based in Wuhan University, a Plastic Forming Simulation key lab based in HUST, a National telemetric mapping key lab, a National GPS engineering research center, and a national multimedia software engineering research center based in Wuhan University, a national Numerical Control System Engineering Center, and a national CAD supporting software engineering center in HUST formulate the technological power locally and nationwide. Supporting organizations and institutes, such as China Geology University, Wuhan University of Technology, the 709th Institute, the 105th Institute, the National Earthquake Research Institute, and the Hubei Chemical Research Institute all established their developing centers for optics, telemetric, optical material, or applied software engineering center (Yan Yan et al., 2002) (Tab.9).

By the end of 2006, the Wuhan·China Optical Valley (mainly in WEHDZ) was the home for 11647 registered enterprises and had an employment of 145,000 people. In 2006, the general income, including technology transfer, industry output and trade volume, reached 100 billion Yuan (about 10 billion Euros), an increase of 17.93% compared with that of 2005. Among it, 77 billion Yuan came from large scale enterprises, with an annual increase of 36.1%. The industrial added value reached 32 billion Yuan, an annual increase of 36.5%, and 28.5 billion Yuan were contributed from large scale enterprises (Tab. 10).

[7]The construction of National Laboratory plan was launched in 2003 and is based on the technology edge of several existed State Key Laboratories.

In accordance with the 11th five-year economic and social development plan of WEHDZ, the high-tech zone projects a total output volume of RMB 150 billion, and within it, optoelectronic communication projects RMB 12 billion; LED: 5 billion, opto-displays: 10 billion, NVD related: 10 billion, and power lasers: 6 billion. It might also be possible to win support from the Hubei Provincial Government as the development of optoelectronic communication, fiber and cable, and laser equipment are on the top supporting list of Hubei High-tech 11th five-year plan.

Tab. 9: Representative Entities of technological and Industrial Advantages in Wuhan

Technological Dimension	Technological advantage	Industrial advantage
Optical information	HUST	Wuhan Gaoke (NVD), East lake Storage, Eastlake Disc
Optical communication	WRI ,WHU, WUST, 709th, 105th	FiberHome, Wuhan NEC, YOFC
Laser	HUST,717th, WIPM	Huagong, Chutian, Unity,
Traditional Optical		

Source: Personal Compile based on information from Yan Yan, et.al. (2002), Official website of related entities, Official website of Wuhan Optical Valley: www.wehdz.gov.cn

Tab. 10: General Income and Number of Opto-enterprises in Wuhan „China Optical Valley"

		2000 *	2001 *	2002 *	2003	2004	2005	2006
General Income (Billion Yuan)		11.34	15.93	12.62		21.358	26.588	35.094
Number of Enterprises		175	412	503				
	Under-scale**	21	76	117				
	Above-scale	154	336	386				

Source: Statistical Information of Eastlake High-tech Development Zone (www.wehdz.gov.cn)

(* Liu Li-ming, et.al.,2003;
** According to the Statistical Standard of China, industrial firms with annual sales volume lower than RMB ¥ 2 million are termed as under-scale, and reaching or higher than RMB ¥ 2 million termed above-scale.)

3.3.2 Shanghai

Shanghai, the largest city in China, with its neighboring cities, enjoys higher prestige in terms of the investment input than other regions in China. Compared with the densely agglomerated optoelectronic research power in Wuhan and Beijing (as in Tab. 6), Shanghai also enjoys a powerful position in terms of basic optic research and some applied research. By far, the Shanghai Institute of Optics and Fine Mechanics of CAS (SIOM) and Shanghai Jiaotong University (SJTU) are the most active academic institutions in laser and optoelectronic technology in Shanghai, not only in academic research but also in industrialized application (Tab. 10).

SIOM puts its research efforts in High Intensity Optics, although it is also good at Quantum Optics and Information Optics. In the field of application, High Power Lasers, High Density Optical Storage, Laser Applications and Laser and Optoelectronic Materials are major concerns. SIOM has several spin-off enterprises, like Daheng Optics, Huazhong Leo laser and Xinhui Disc, showing its technological application achievements. SJTU is located in southern part of Shanghai and has an academic advantage in optical communication. The SKL on Fiber Optic Communication Networks and Advanced Optical Communication Systems is a key part of SJTU winning such fame. Also, an SKL of Optical and Magnetic Resonance Spectroscopy affiliated to ECNU (East China Normal University) launched some basic study in an optical-related field.

Apart from the key academic establishments in laser and optoelectronics, Shanghai makes a great contribution to China's development in (Light-emitting Diode)LED, (Flat Panel Display)FPD and (Optics Fiber Cable and Optoelectronics device)OFCOD. These 3 fields each need a large capital to support their operation and will witness fast growth in the 21st Century (Han Jian-zhong, 2005;Tang Guo-qing, 2006).

Tab. 11: Representative Entities of technological and Industrial Advantages in Shanghai

Technological Dimension	Technological advantage	Industrial advantage
Optical information(LED/FDP)		Blue light, Tianma, SVA-NEC, Xinhui Disc
Optical communication(OFCOD)	SJTU, Lucent, SAST, CETC 23	GE, Lucent, CSFOC(Corning), Photonic Bridges (China), OPTIWORK, SOCC, Jabil Circuit
Laser	SIOM,SITP, SILT	Daheng, Shanghai Laser Group, Unity-prima
Traditional Optical		Phoenix optics

Source: Liu Songhao (2004); Caohejing Today (2007); Zhangjiang Optical industry report (2007); CHEN Yang (2007)

Unlike the agglomeration of firms in optical valley of Wuhan, Shanghai has several state-level development zones which are scattered around the corners of the international metropolis. Following (in Tab. 12) is the spacial distribution of the laser and optoelectronic industry in different development zones around the city.

Tab. 12: Areas and Zones of Optoelectronic Industry in Shanghai

Region	Advantage in Industry	Research Institution	Representative enterprises
Zhangjiang	LED, FPD, Optical Storage, optical communication, Photo-voltaic Solar		Blue Light, Yuti, xinying; Arrow Display, Tianma; USI; (SH) S-TEK; Xinhui Disc
Caohejing	Optic Fiber & Cable, Optical Active Devices	SJTU, SAST, Lucent, SILT	GE, Lucent, Tyco, Jabil Circuit, Andrew, CSFOC(Corning), Photonic Bridges (China), OPTIWORK, SOCC, DT mobile, Shanghai Laser Group
Songjiang	Optoelectronic parts and device, display, communication		TSMC, Foxconn, YOF(Shanghai), Shanghai Rainbow (LED, CAS Physics), SME, Seefull Electronic, DIODES Shanghai
Jiading	Opto-system Integration, opto-network and device, display and information material	SIOM,SITP,SIC(Pilot test base),SIKM(Pilot test base)	Daheng, Hengyi, Hengjin, Leo laser, Xinhui Disc (Zhangjiang), Shanghai Power Equipment for Laser
Minhang	FDP, laser		SVA, Unity-prima laser

Source: Personal Compilation from Official websites of related industrial parks and research institutions, field study of Zhangjiang High-tech Park

In 2006, the gross annual income of Optoelectronics in Zhangjiang High-tech Park (Zhangjiang) reached 3.22 billion RMB, far behind that of IC manufacture and the bio-pharmaceutical sector, the two pillar industries in Zhangjiang. However, the annual gross income per capita and per company is higher that these other two, reaching 839 thousand RMB and 179 million RMB, respectively. By the end of 2006, there were 46 optoelectronic companies operating in Zhangjiang and employed 3,840 staff. The major fields of Zhangjiang optoelectronics are LEDs and LCDs, which need large capital input. The Caohejing hi-tech park mainly focuses on the development of optoelectronic communication, and is home to many FDI from multinational companies. The Songjiang Industrial Park attracted an inflow of capital from Taiwan, i.e. TSMC and Foxconn, and mainly works in foundries. Also the Songjiang is home for some industrial bases of research institute as well, like rainbow. Jiading is the base of SIOM and its major spin-off companies located in the industrial park of Jiading. SVA, a large provider of FDP in China, is attempting to build a value chain within their company and has headquartered itself in Minhang, in the Southern part of Shanghai.

3.3.3 Changchun

Changchun, capital city of Jilin province, is the original place for China's laser and optoelectronic technology. According to Wang Xi-jun (2006), there are about 280 laser and optoelectronic companies operated in the Changchun Economic and Technological Development Zone (CETDZ) and the Changchun High-technology Industry Development Area (CHIDA), respectively. Located in opposite corner of Changchun, CETDZ (east) and CHIDA (southwest) have become the two carriers of so-called Changchun·China optical-valley (Cao Jian-lin,2001). In 2001, the optoelectronic industry park of CETDZ was named the optoelectronic industrialization base by the Ministry of Science and Technology, and thus opened the veil of Changchun·China optical-valley. CETDZ agglomerates mainly the enterprises related to Changchun Institute of Optics, Fine Mechanics of CAS (CIOM), while CHIDA is home to enterprises with relation to Jilin Unviersity and Changchun University of Science and Technology (CUST).

Among the 280 companies (Qian Long-sheng, 2003), only 16 are FDI (Foreign Direct Investment) companies, established since 2004. The rest are all domestic owned companies, and most of them have an annual sale of not more than RMB 10 million (Wang Xi-jun, 2006).

CIOM is the first institute of CAS (China Academy of Sciences) in the field of laser and optoelectronics. Its academic history can be traced back to 1952, when China's State Council and CAS decide to establish an academic establishment in the field of laser and optoelectronics. In 1958, Changchun College of Optics, Fine Mechanics, now CUST, was established with the academic help of CIOM to cultivate students in laser and optoelectronics. In 1961, CIOM developed the first ruby laser in China. In the year that followed, CIMO establish a branch in Xi'an, Shaanxi Province, and is called the Xi'an Institute of Optics, Precision Mechanics and Physics of CAS (XIOM). In 1964, another branch was established in Shanghai, SIOM. In 1999, CIOM combined with another institute of CAS, the Changchun Institute of Physics, and received the new name of the Changchun Institute of Optics, Fine Mechanics and Physics, still short as SIOM. The work of CIOM is divided into 3 parts, namely, basic academics, basic application, and engineering. In basic academics, CIOM is in the leading position of excitation physics, which is based on a state key lab in CIOM. In basic application, luminescence, shortwave optics and space optics are the major concerns. In engineering, the work is mainly focused on the development of optical inspection, detectors and mechanical integration of related devices and apparatuses (Deng Xi-ming, 1991, Jilin chorography (online), 2007).

Ever since the first spin-off company (Changchun Daheng, which was established in 1989), CIOM contributed much to the industrialization of its academic edge, i.e. North Caijing Crystal in LCD module and Changchun Cedar in LED module (Zhu Ye-jing 2002). By now, there is a Changchun Optoelectronic Industry Park, CAS, located in the CETDZ.

Jilin University (JLU) is another academic power in Changchun, and its research advantage is mainly in semiconductor materials, devices and their integrations applied in communication and displays. With its are its spin-off companies, as well as those spin-offs from CUST, mainly located in CHIDA.

Tab. 13: Representative Entities of technological and Industrial Advantages in Changchun

Technological Dimension	Technological advantage	Industrial advantage
Optical information	CIOM	Northen Caijing Crystal, Changchun Cedar, Changchun First Optics(encoders)
Optical communication	JLU	
Laser	CIOM	CNI LASER
Traditional Optical		

Source: Official website of CIOM and JLU

Tab. 14: Brief Contour of Changchun Optoelectronic Enterprises

	Optoelectronic Display	Optoelectronic Material & Device	Opto-device, apparatus & Equipment
CETDZ	**Northen Caijing Crystal,** Jilin Huaruan, Jilin Zijing, ChangChun Lancer Photo-Electron (all CIOM spin-offs)	Lancer Photo-Electron, Jilin Guangxin (JLU), Changchun Huabo Opto(CIOM), Changchun XinXin Photoelectricity (Lens, prism & Coating) Changchun HUAXIN, **Changchun Cedar (**LED leader) (CIOM) **CNI LASER** (CIOM)	Changchun Liancheng Instrument (LCD Test) (CIOM) CIOM digital display (sensor) Up-optotech (CIOM) CIOM Medical Instrument Changchun Guanghua Micro-electronics Equipment (CIOM, Laser) Changchun Fangyuan Opto-Electronic Technology (high-precision optical components, lenses, optical fingerprint scanner) (CIOM)
CHIDA	Jilin CHANGHONG	Changchun Changxing(software), Jilin Dongya Nightview Binocular, Changchun Dongguang Capacitor, Changchun Jinglong (Auto Audio), Changchun First Optics (encoders) (Yuheng & Shidai), Jilin Changtong Opto-communication(Cable Optic)	Jilin Etena opto-apparatus, Changchun Sanfeng Sensor Technology (JLU, encoder) Hongda Fingerprint, JIDA Wuhua (CO2 laser)(JLU)

Source: Personal Compilation based on information from COIIA (Changchun Optoelectronic and Information Industry Association), CETDZ, CHIDA

Changchun plans 3 pillar products: 1) optoelectronic parts, cells and devices 2) laser processing equipment, and 3) illumination and information display. Such a plan originated from the technology edge in display technology and devices, optical material and opto-scientific apparatuses, hence the potential of establishing optoelectronic industrial agglomeration (Changchun Municipal Government, 2006).

4. Clustering and network of laser and optoelectronic technologies & industries

The hi-tech clusters (Powell et al. 2002) seem to profit significantly from spatial proximity, allowing for more interpersonal and inter-organizational interaction, even across different social spheres such as business, science and government. The laser and optoelectronic industry is in large part characterized by small and medium-sized enterprises (SMEs), co-operation between large and small companies, as well as between firms and research organizations (AIM, 2007). The fusing of many technologies makes the innovation of the laser and optoelectronic industry an interdisciplinary one. The entire supply chains do not always rely on local resources, and some fields, like telecommunication, have worldwide strategic applications, although fields like defense and scientific instruments are domestically oriented.

Generally speaking, the development of clusters is based on different roots and regional settings, although the chase for profit can be the ultimate reason for the spatial agglomeration. It can first be traced from the advancement, differentiation, and specialization of the technology (bringing the potential research cooperation) to the perceived need (customer relations, labor market etc.), aligning the two groups to work closely together with other competent actors. Second, local and national government make initiatives to promote regional clustering activities.

The latecomer firms (LCF), as described by Mathews (2002), especially those in the laser and optoelectronic industry in China, are trying to make themselves players in the industry. However, are they really attempting to set up linkages "with advanced firms in various kinds of contracting or licensing arrangement", and leverage "resources (knowledge, technology, market access channels) from such linkages"? Do they use the process of "learning" to "enhance their capabilities and technological competences"?

The current situation for China's laser and optoelectronic firms partly complies with the conditions set by Mathews (2002): late entrance to an industry by historical necessity, resource-poor, catch-up strategy, and competition position. It is especially true in sub sectors like FPD, LED lighting and laser processing, and laser medical equipment. The purpose of this section is to check whether the linkage, leverage, and learning procedures work or not, or work in some other way of implementation.

Under the framework of Mathews' "linking + leveraging + learning", this section of the paper attempts to make a primary investigation of the competitiveness and network development in China's laser and optoelectronic industry. Matuschewski A. (2006) also presents a three-level theoretical concept on clusters, including functional entities, social and cognitive entities and spatial entities. We also recognize here that the literature in the past, present, and future can only partially point out the whole picture of cluster formation and development. What we can do now is try to make the theoretical framework closer to the real trajectory of the industrial clustering phenomena.

Starting from the outset, the following studies center on the establishment and extent of local, national and international linkages of optoelectronic, academic, and industrial entities in Wuhan, Shanghai, and Changchun, respectively.

4.1 Academic linkages

As one of the knowledge intensive industries in the current economy, the laser and optoelectronic industry is for certain a center of different kinds of knowledge, explicit and tacit, which extend from patents and publications to processing experiences and technological know-how. Different workshops, colloquia, associations, exhibitions, research projects, strategies, etc., may act as way of promoting the diffusion of such knowledge and the establishment of related channels, networks or linkages.

Based on an ISR (Industry Science Relations) (here referred to as "knowledge diffusion channels") described by Brennenraedts R. et al. (2006) (See Tab. 15), there are several choices for the diffusion of knowledge between the scientific and industrial field.

Tab. 15: Different categories and forms of ISR

1) Publications	Scientific publications Co-publications Consulting of publications
2) Participation in conference professional networks & boards	Participation in conferences Participation in fairs Exchange in professional organizations Participation in boards of knowledge institutions Participation in governmental organizations
3) Mobility of people	Graduates, Trainees Mobility from public knowledge institutes to industry Mobility from industry to public knowledge institutes Double appointments Temporarily exchange of personnel
4) Other informal contacts/ networks	Networks based on friendship Alumni societies Other boards
5) Cooperation in R&D	Joint R&D projects Presentation of research Supervision of a trainee or Ph.D. student Financing of Ph.D. research Sponsoring of research
6) Sharing of facilities	Shared laboratories Common use of machines Common location or building (Science parks) Purchase of prototypes
7) Cooperation in education	Contract education or training Retraining of employees Working students Influencing curriculum of university programs Providing scholarships Sponsoring of education
8) Contract research and advisement	Contract-based research Contract-based consultancy
9) IPR	Patent texts Co-patenting Licenses of university-held patents Copyright and other forms of intellectual property
10) Spin-offs and entrepreneurship	Spin-offs Start ups Incubators at universities Stimulating entrepreneurship

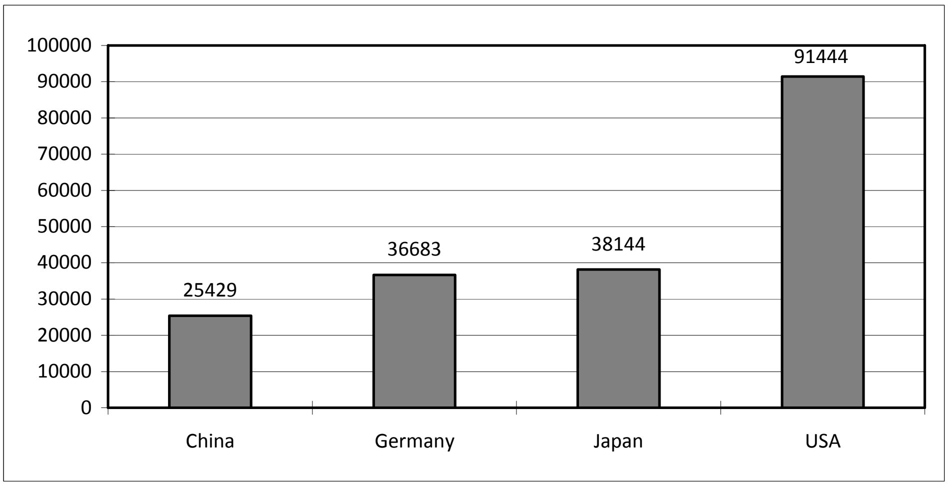
Source: Brennenraedts R. et. al (2006)

It is true that the channels described in Table 15 may act as comprehensive and potential ways of knowledge transfer or diffusion. However, all but the publications may be used as indicators of knowledge diffusion and network building, especially for the primary literature study without support from field interviews.

Here, the author attempts to use the Thomson's "ISI web of knowledge" to briefly describe the academic cooperation between or among authors from within and outside of China.

Adopting the advanced search function of ISI, with the 2-character tags, Boolean operators, parentheses, namely, TS=(opto* OR photonic* OR laser*) AND CU=China, Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI., the query reaches a result of 25,429 records. However, the citation report gives a higher number when the countries limit was changed to the USA, Japan and Germany. In the figure, we can only find the disparities in the number of citations, where it is not possible to count on the impact factor of each citation. However, it gives an idea of the primary active situation of academic research in these developed countries.

Fig. 7: Citation of ISI records in optical field



Source: ISI web of knowledge

In terms of China's co-authorship with foreign counterparts, the USA ranks the first with a record of 1410, Japan and Germany are second, with records of 903 and 549, respectively. However, in papers authored in the USA, the co-authors are mainly from Germany (4.3010 %), Japan (2.6628 %), France (2.2167 %), England (2.1849 %), and Canada (2.0504 %); followed by Russia (1.6950 %) and China (1.5419 %). In papers authored by Japan, the co-authors are mainly from the USA (6.3837 %), China (2.3673 %) and Germany (2.1969 %). In Germany, the USA (10.7216 %), Russia (5.3158 %) France (4.4189 %), and England (3.5957 %) are on the top of the list, while China (1.4966 %) ranks 10th, after Switzerland, Japan, Italy and Netherlands.

Looking at the numbers, which are derived from the Boolean operators, a co-author's paper in China, Japan, Germany, or the USA, is always written by scholars from two countries. Seemingly very few or none are results of cooperation among scholars from three or more countries. From the record, we only find that academic cooperation between advanced countries in America, West Europe and Japan are still taking crucial importance, while China is acting positively to be a player in this field (see Table 16).

Tab. 16: Leading Co-authored article countries with China

USA	Japan	Germany
1410	903	549
5.5449 %	3.5511 %	2.1590 %

Source: by the author, data from ISI web of knowledge

Analyzing the results by adding new tags to rank the record by cities, the author finds that cities in China enjoy different research capacities as well as potentials within this science-based industry. The figures in the following Table 17 just refer to the frequencies of citation, while some overlap exists due to co-authorship.

Tab. 17: Academic active cities in photonics in China

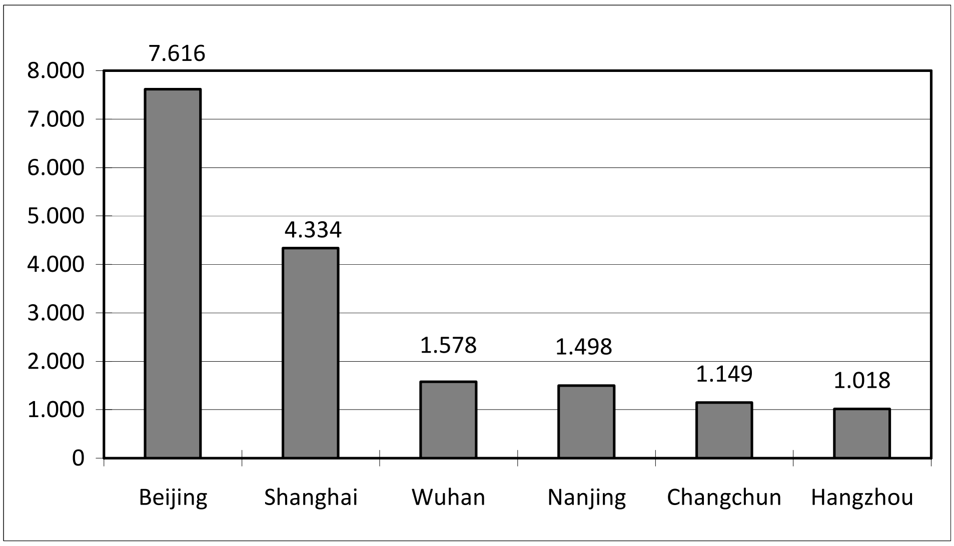
TS=(opto* OR photonic* OR laser*) AND CI=					
Beijing	**Shanghai**	**Wuhan**	**Nanjing**	**Changchun**	**Hangzhou**
7,616	4,334	1,578	1,498	1,149	1,018

Source: by the author, data from ISI web of knowledge

In the academic cooperation within these cities, the USA almost takes every top of the list, with only Nanjing cooperating more with authors from Singapore. More than 1/4 of the records go to Chinese Academy of Science (CAS), followed by Tsinghua Univ. (5.0140 %), Fudan Univ. (4.0072 %), Nanjing Univ. (3.9286 %), Shandong Univ. (3.9089 %), Univ. of Science and Technology China (3.7674 %), Zhejiang Univ. (3.6061 %), HUST (3.1539 %), and Peking Univ. (3.0241 %).

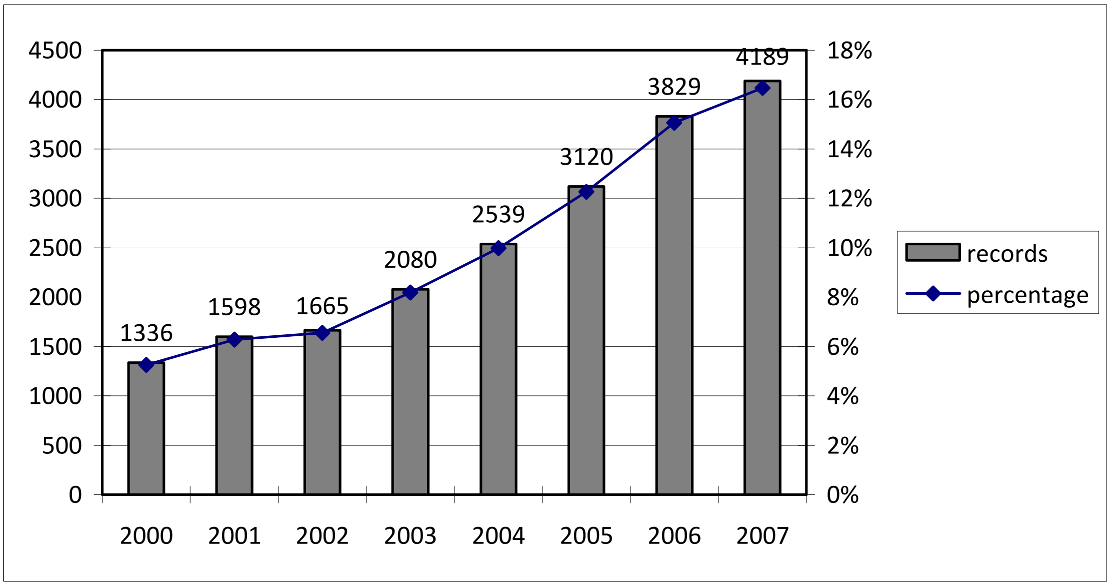
For the 25,429 records, the increasing trend in the records year by year witness an improvement of academic achievement in China's research in the optoelectronics field. The total number of papers from 1991-1999 only accounted for 15.0811 % of the total records, while in the year 2008 up to April 27, the papers account for 4.8645 % of the total number of papers.

Fig. 8: **ISI citations of optoelectronics in major cities in china**



Source: by the author, data from ISI web of knowledge

Fig. 9: **The rise of ISI citations of China in optical and optoelectronics research**



Source: by the author, data from ISI web of knowledge

Such an increase in academic citation can only be regarded as more achievement in fundamental research, although it does not always mean that the academic achievement can directly support China's related industry development. China's academic research witnessed a growth when compared with the relatively stable academic outcome of that of the USA, Japan, and Germany. Considering the academic prestige and the high impact factor for some U.S. based journals, the scholars from North America, Western Europe, and Japan still position themselves in the main stream of such journals, while academicians from China, Korea, and Taiwan are still in some stage of emergence or growth.

4.2 Industrial linkages and leverages in Wuhan, Shanghai and Changchun

4.2.1 Industrial linkages of the three cities

Considering the characteristic of optoelectronic industry, the concentration of laser and optoelectronic companies was carried out not only on a global scale, but also on a national and sub-national scale. In such terms, we can regard most companies as knots of different value chains on varied scales.

Motivated by its cutting edge in basic research and technology development, Wuhan gradually became the Optical Valley of China, with the support of local government, provincial government, as well as the central government. The laser and optoelectronic firms in Wuhan, geographically densely resided in WEHDZ is nicknamed Optical Valley of China. The four main segments of optoelectronic industry refer to lasers (especially in processing), opto-communication (especially in Fiber optics and package solutions), and optical discs (mainly referring to NVD), software, etc.

The three leading laser enterprises in Wuhan are Huagong, Chutian, and Unity. Huagong laser (HG Laser) is the flagship company among public listed companies. Huagong Tech Co. Ltd. (Huagong Keji), a spin-off company of HUST mainly transformed from the former "National Laser Processing Engineering Center"(traced back to 1972), and is still technologically support by the academic achievement of SKL Laser Technology. According to its self-introduction, "HG Laser purchase ACS company in Australia and established Wuhan HG-Farley Laser lab cutting systems; Cooperate with Tohi company from Germany, set up export laser welding diamond blade manufacture base in Wuhan; Cooperate with Fuji Electric and Miyachi (from Japan to) manufacture highly quality diode pumped laser marker etc." (HG Laser, 2006). The major market of HG Laser is in China, with its products and applied package solutions, and is facing competition from within the nation and around the world. Chutian Laser was established in 1985 by an academician who worked in an institute in Wuhan. Chutian Laser claims the largest number of patents among its other domestic competitors. Most of its technologies are self developed and applied in aerospace, aeronautic, material processing, and medical instruments. Unity Laser group was started in 1994 by an academician who has been a longtime staff member of SKL Laser Technology in HUST. Its major product is a high-power CO2 laser, applied in metal refinery and auto manufacture. A new affiliated company was established in 2007 by a joint effort from Huagong Laser and Unity Laser (Optics Valley Laser), aiming at providing laser cutter equipment.

In the optical communication field, the major players concentrate in fiberoptic products and solutions, and the representative firms are FiberHome, Wuhan NEC and YOFC. FiberHome, as the successor of WRI, has witnessed the development of China's fiberoptical industry for the past 30 years and tried to position itself as leader in providing solutions in optical communication, and is technologically self-satisfied. YOFC, started in 1988 by Wuhan Yangtze Communications Industry Group Co. Ltd. (YCIG), has topped the charts in sales volume in the fiberoptic and cable market of China ever since 1992. YOFC is also a joint venture with Daraka Communications from the Netherlands. Wuhan NEC is also a joint-venture of YCIG and NEC, which focus on the production of optic transmitting devices.

However, the optical storage (disc), namely NVD, has mainly developed under the technological power from SIOM, Tsinghua University and WNLO, as well as being financially supported by Wuhan Hi-Tech Holding Group Co. Ltd.

The most competitive photonic sector of Shanghai in China's market is FPD, which is pioneered by SVA-NEC, although LEDs and fiberoptics are also crucial development sectors. With the technological support of NEC in Japan, SVA was equipped with a 5th generation TFT-LCD production line, and shared with market and technological diffusion from the other FPD plant, IVO, in Kunshan, which is about 70 km away from Shanghai and also jointly financially and technologically supported by firms from Japan and Taiwan.

Due to technological upgrades, the TFT-LCD production line in Changchun Northern Caijing Co. was forced out of the market of large screen displays and returned to the market niche of small screen displays. Changchun Cedar, a spin-off of CIOM, however, as a large-screen LED display provider, advanced itself in this field in China and the world. Generally, the optoelectronic industry development in Changchun mainly depends on the technological edge from CIOM and few direct ventures with firms from other countries.

4.2.2 Industrial leverages

According to Mathews (2002), the latecomer firms lack resources and have some strategic intent to catch up with rivals, as well as having competitive advantages like low cost. When we turn the focus to China's laser and optoelectronic industry in 21st Century, the research of Chinese firms in this industry should be divided by sub-sectors due to their different situations.

In the field of FPD, the three 5th generation panel production lines of TFT-LCD, which are located in Shanghai (SVA), Kunshan (IVO) and Beijing (BOE), comprise the flagships in the middle stream China's FPD industry. Strategic alliances were established in 2006 between SVA and IVO to make SVA focus on large screen displays and IVO focus on notebook displays. Similar alliances can be witnessed between BOE, Shenzhen Municipal Government, and four domestic Color TV manufactures, KONKA, TCL, SKYWORTH, and CHANGHONG. Major technologically intensive parts in the upper stream of LCDs have been localized by investment from technology holders from Japan, the USA, Korea, and Taiwan. Large numbers of downstream module manufactures are scattered around the Yantze River Delta and the Pearl River Delta, especially in cities like Shanghai, Nanjing, Suzhou, Wuxi, Shenzhen, and Dongguan. Such locations can be attributed to the agglomeration of computer firms and television manufactures. China's huge markets, as well as production capacities in notebook computers, desktop displays, and other digital products pull such investment. Due to the relatively even distribution of manufacture costs in the process of LCD production (Zheng Sheng-de 2005), LCD panel producers find it difficult to make a profit from low human resource costs.

In the field of LEDs, the huge market potential and application in architecture decoration, traffic lights, display, backlights and auto lights attract the confidence of investment companies. International giants and patents holders like Nichia, ToyotaGosei, Sony, Sanyo, Cree, Lumileds, Osram, and Philips continue to promote the application of LEDs into high-lighting, expecting a revolution in common lighting. Similar situations also appeared in Taiwan, where agglomerations of competitive firms have established close business relations with mainland China. Most firms in China still survive on the low end of packaging because of the low cost in human resources, although there are firms in each sector of LED manufacture in China. However, research institutions and universities are trying their best to develop key instruments, like MOVCD, in order to break the monopoly of this field.

Generally speaking, the situation of LCD and LED firms in China comply more with latecomers described by Mathews (2002), and the two sectors both have great market potential. More technological blocks might be witnessed from leading firms in the USA, Japan and Germany, and a small amount of patents authorized can be the source of technological diffusion, due to their strategic arrangements.

In the case of China's optical communications, which are not far from world leadership, sections can be subdivided into research sectors like fiberoptics, cable, and devices. The fiberoptic, cable, and solutions providers are relatively better off than device providers in terms of technological advantage. Key technologies in active devices (like amplifiers) and passive devices (like connectors) are still mainly in the control of advanced companies in the west, though some breakthroughs can still be seen in China. In lasers and their applications, the market can be divided into several parts as in the following table:

Tab. 18: Leading laser companies in China

laser processing	Laser communication	Laser measuring	Laser medical	Laser material & parts
1) Chutian, 2) Han's, 3) Huagong, 4) Optics Valley, 5) Dongguan Mingyue, 6) Shenyang Dalu Laser, 7) Shanghai Unity-prima	1) WTD, 2) ACCELINK, 3) HG Zhengyuan, 4) Shenzhen Neo-Photonics, 5) Shenzhen Fiber-xon	1) Jiangsu Shu-guang, 2) Changzhou Lai-sai, 3) Hubei Huazhong Science & Tech-nology, 4) Xiwu Laser	1) Chutian, 2) Huagong	1) Fujian Casix

Source: COEMA Laser Branch (2007)

Laser processing developed faster than that of measuring and medical instruments, and is especially concentrated in Wuhan, with HUST as their technological source. However, there are still technological gaps, especially in the high-power macro laser cutter, between China's firms and world leaders like Coherent, Trumpf and Rofin, Yamazaki Mazak, TANAKA, AMADA, Bystronic, etc.

4.3 The learning potential and process

Concerning the general following position for China's laser and optoelectronic firms, universities, and research institutions, as well as the catch up strategies launched by central and local government, the innovation oriented national development plan will be confirmed by various learning and cooperation with foreign counterparts. In this sense, the National Learning Systems (NLS) (Viotti 2001) and National Systems of Economic Learning (NSEL)(Mathews 2001) are crucial for a late industrialized economy (e.g. China), and in its emerging industries (e.g. photonics or optoelectronics). Liefner (2007) referenced this idea and applied it in China's Yangtze River Delta, arguing for "regions that are already strong at knowledge absorption, learning and URI (universities and public research institutes)-based research" to promote the planning and policy that are helpful for the construction of knowledge and technology diffusion network.

Recent works by Asheim and Chenen (2006) further the idea that "which types of regional innovation system represent effective innovation support for what kinds of industry in different regions analyses must be contextualized by reference to the actual knowledge base of various industries as well as to the regional and national institutional framework, which strongly shape the innovation processes of firms." Hence, the industrial context and institutional framework of a host country are of importance.

Compared with the two groups of ideas, NLS (or NSEL) and contextualized NIS, Mathews (2001) underlined the successful firms as "instigators" of innovation process, but not recipients of technology diffusion or transfer. He also emphasized the importance of local "institutional structure," which shares similar ideas with that of Asheim and Chenen (2006).

Based on the aforesaid idea, this section assumes that the learning process of the laser and optoelectronic industries in China also depend on the type of knowledge within the industry, as well as the market structure, financial system, education system, labor market, and role of government that formulates the social institutions.

4.3.1 Learning ability

The research of Viotti (2001) distinguishes different learning abilities, with absorption as the common characteristic in a passive or active way. Mathews (2001) regarded the NSEL as a framework or institution for knowledge diffusion in the successful examples of Asian latecomer firms in IT, computer, or semiconductor fields. The advantage of NSEL comes from firms' clustering and related institutional supports, such as established large firms, public laboratories, or institutions.

This paper argues that, however, learning ability may be regarded as the primary stage of innovation capability, and the firms, universities and research institutes in industrializing countries may take advantage of various kinds of contacts, including scientific cooperation, symposium, FDI, and contract manufacture with technology holders to improve their competitiveness in the future.

In each sub-sector of China's laser and optoelectronic industry, the situation of learning is different for reasons of various technological and market positions. Generally speaking, the sector of FPD and LED lighting are in the period of learning by technological absorption and contract manufacturing. Only LED displays can be in a competitive situation with its major technology based on in-house R&D (Changchun Cedar). Due to enormous market potential in FPD (especially in LCD) and LED application, technological diffusion may also be difficult for technology holders. On a certain scale, few knowledge transfers can be seen on an engineering-based level, and only basic academic research-based cooperation and co-author publication are more available. In the solar photovoltaic sector, Wuxi Suntech is a good example of technology absorption introduced by overseas Chinese brain backflow. Whereas most other firms within this sector still attempt to be the basic material or cell providers, which lay emphasis on low labor cost and natural resource orientation. In the optical communication sector, the market drive and technological innovators in Wuhan (e.g. FiberHome and YOFC) make domestic companies accumulate profits for R&D not only in fibers but also in devices. In the field of optical discs, the NVD is totally self developed and intends to be a new industrial standard, so as to compete with the powerful standard-blue ray disc launched by MNCs including Sony and Phillips. In the laser sector, companies in laser processing are also mainly technologically supported by domestic capacities. However, technological gaps exist in advanced macro laser processing, medical lasers, and laser measuring. Basic research and cooperative R&D could be possible in WNLO and other research institutes with their foreign counterparts. In the traditional optic sector, China has become the manufacturing field of world class advanced lens makers. Contract manufacture of final products makes China's firms in the primary stage of learning.

4.3.2 Learning procedure

There are various ways of learning. The powerful government role in the institutional framework act as national or regional planners or strategy establishers that actively influence the procedure and priority in different sub-sectors. Shenzhen Municipal Government, as an example, is actively promoting the investment in LCD production line, and with it, part of the city's technological upgrade strategy. Similar academic or industrial promoting, planning, or institutions can also be the story in Europe, the USA, and Japan.

International products expositions, along with symposiums and technological communication will also be a method to promote learning and potential technological cooperation. The Shanghai-München laser expo and annual conference of IOA are superior ways of approaching the technological edge.

Industrial associations and academic societies are crucial, not only in information exchange, but also in creating cooperative ventures.

5. Major Findings and Discussion

This paper is primary research on the development of China's laser and optoelectronic industry, mainly based on material from articles, website information, and other paper-based information. No interview carried out makes this paper subject to information comprehensiveness and profoundness. However, it is a brief overview of the shape of China's laser and optoelectronic industry, as well as a start for further study on such an interesting direction of research.

The major findings of this paper are as follows:

1. The laser and optoelectronic industry is in a more fluctuating situation than any technology and industry ever in the development of hi-tech industry, even in so-called knowledge economy. Such fluctuation makes it difficult for people to accurately define the industry and predict its development. Hence, annual figures provided by different industrial associations may be varied. Even within one association itself, the statistics may also be subject to change over time.
2. Different scientific tradition and development strategies make the three leading countries (the USA, Japan, and Germany) in this industry enjoy various technological advantages. The USA is powerful in basic academic research, optical communication, and medical laser instruments; Japan is leader in FPD, LED, and optical input and output instruments. Germany is good at laser application and LED lighting. Emerging powerful countries and territories are Korea and Taiwan, with LCD and LED as their priority.
3. Laser and optoelectronic industry in China enjoys a comprehensive yet unbalanced history of development, only attributed to different technological advantages and market differentiations.
4. Four major regions witnessed the growth of the optoelectronic technology and industry. Beside the three economically developed regions, i.e. the Yangtze River Delta, the Pearl River Delta and the Bohai-bay Area, Wuhan and its surrounding cities have become the center of the laser and optoelectronic industry.
5. Beijing, Shanghai, Wuhan, Nanjing, and Changchun are academic centers in laser and optoelectronic technology in China. Wuhan tops the other cities in academic-engineering transfer, with a strong research capacity agglomerated in it.
6. Different technological situations and market potentials make China not always the recipient of imported technologies. Powerful MNCs establish loose or intensive technological relations with China, based on their global technological strategy and market exploitation plans. Thus, it is more than complicated in different sub-sectors to develop in either an independent or with a foreign-partnership.

Notes

1. **Namely, it has 5 major research directions or trends:**
    1) High-speed large volume fiber-optical communication and broad-band fiber-optical, including DWDM (Dense Wavelength Division Multiplexing), Ultra-Speed Optical Time Division Multiplexing, optical exchange, broad-band optical network, IP over WDM(Wavelength Division Multiplex), intelligent optical network, Optical Code Multiplexing and connection, Fiber To The Home (FTTH) and Radio-over-Fiber(ROF), development of fiber optic amplifier, and Fiber Grating.
    2) Integrated optoelectronics and photonics devices, including new semiconductor laser, high speed optical modulator, optical switch, micro-opto-electro-mechanical system (MOEMS), Audio-optical device, optical crystal material and devices, etc.
    3) New type display material and device, including new Field Emission Display, Wide Band Gap luminescence devices, Electro-chromic Film, and nano-film.
    4) Film, vacuum technology, Secondary Ions Mass Spectrum, and ultrasonic material testing.
    5) Application of fiberoptic sensors, including testing of electric current, voltage, and temperature; and liquid, intelligent structure, and material study.

2. **China Optics and Optoelectronics Manufactures Association (COEMA) was established in early 1987 and approved** by State Council, the social organization voluntarily sponsored by enterprises, institutions engaging in optics and optoelectronic science researching, manufacturing, teaching, and studying through out of the country. A civil organization approved by Civil Administration of China. COEMA plays an advisor and assistant role for government administrating optics and optoelectronic industries. COEMA is administrated and guided in business by the Ministry of Information Industry (MII), and supervised and administrated by the Ministry of Civil Administration.

    There are 712 members resisted in COEMA, divided into seven branches in accordance with specialty fields: laser, infrared technology, optical elements, optical instruments, optoelectronic device, optoelectronic diode display screen, liquid crystal, and laser holography branches. Its membership institutions include not only high-tech enterprises such as BOE Technology Group Co., Ltd. , SVA Electron Co., Ltd. , Shenzhen Tianma Microelectronics Co., Ltd., Shanghai Nicera Sensor Co., Ltd. , China Daheng Laser Engineering Co. Ltd., but also national important science research institutes, such as North China Research Institute of Electro-Optics, No.33 Institute, Beijing Tsinghua National Liquid Crystal Technology Engineering Research Center, No. 8358 Institute of China Aviation Industry General Corporation, Fujian Institute of Research on The Structure of Matter, CAS etc.

    China Optical Society (COS) was established in December, 1979, authorized by China Association of Science and Technology. It has 17 branch committees and 7 working committees. Ever since 1987, COS has become a member of International committee of Optical (ICO). Long-term cooperation was established between COS and International Society for Optical Engineering (SPIE). There are 8 academic periodicals under the guidance of COS, namely, "Acta Optica Sinica," "Chinese Journal of Lasers," "Journal of Infrared and Millimeter Waves," "Acta Photonica Sinica," "Spectroscopy and Spectral Analysis," "Chinese Journal of Laser Medicine and Surgery," "Information of OME," and "Chinese optics letters." Apart from many academic conferences every year, COS holds an optoelectronic expo in Shenzhen every September.

3. **FiberHome Technologies Group** is the most outstanding product and solution provider in China in the field of information and communications. The first optical fiber in China was pulled out in FiberHome Technologies. Established in 1974, Wuhan Research Institute of Post and Telecommunications (WRI) is the predecessor of FiberHome Technologies Group. WRI has been the National Research Center for Fiber-Optic Communication Technology and Engineering, and it has three strategic fields: optical communication systems, optical fibers and cables, and photoelectronic devices. Approved by the state, it is the National Research Center for Fiber-Optic Communication Technologies and Engineering, the National Research Center for Optoelectronic Technologies (Wuhan Branch) and the National Industrialization Base for High and New Technology R/D Planning Results.

   Through development for nearly 30 years, the Group has evolved a development pattern of three industries: fiberoptic communication, future public network represented by IP, and wireless communication. At present, with a total staff of over 4000, it incorporates several subsidiaries of different forms--listed, controlled, fully-owned, and joint venture. Its total capital has reached RMB 5.8 billion. (Source: http://www.fiberhomegroup.com/)

4. **Yangtze Optical Fiber and Cable Company Ltd. (YOFC)** was established in May, 1988. It's being operated by China Telecommunications Corporation, Wuhan Yangtze Communications Industry Group Co., Ltd. and Draka Comteq of the Netherlands. It is the only specialized company in China which masters preforms making, fiber drawing, and cabling techniques for mass production.

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