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Strategic Research on China's Laser Technology and Its Application by 2035

Research Group of *Strategic Research on China's Laser Technology and Its Application by 2035*

Abstract: To promote the development of laser technology and its application, the Chinese Academy of Engineering launched a major consulting project "Strategic Research on China's Laser Technology and Its Application by 2035" in 2018. This study briefly analyzes laser technology and its instrumental role in scientific research and industrial application, and summarizes the present situation of its research and applications in frontier lasers, manufacturing, information and communication, medical treatment, etc., in China. Several problems that restrict the rapid development of lasers are presented; the development goals of China's laser technology, and the plan of its application by 2035 are outlined. To achieve these goals, China should enhance the overall planning at the top level, and strengthen basic research to achieve breakthroughs in fundamental problems, common technology foundations, basic materials and devices. It should also establish research and development of special projects concerning laser application to create multiple new laser industry chains, and innovate its industry coordination mechanism to improve the innovation ecology of the laser industry. Moreover, China should strengthen the basic education concerning laser technology, and promote the cultivation of talent in disciplines associated with lasers and optics.

Keywords: laser technology; laser manufacturing; laser communication; laser diagnosis and treatment

1 Introduction

The laser is one of the most important inventions of the 20th century, as significant as atomic energy, semiconductors, and computers. Being intensely bright, highly directional, monochromatic, and coherent, it is dubbed "the sharpest knife", "the most accurate ruler", and "the brightest light". Laser technology has developed and fused with related technologies, giving birth to cross-discipline technologies such as laser manufacturing, laser communication, laser inspection, laser medical treatment and so on, offering a great set of new tools for humankind to understand and change the world. It has conceived and borne a variety of laser industries and equipment; changed and reconstructed many fields, such as high-end manufacturing, information and communication, medical diagnosis and treatment, national defense, and security [1–3]. As new laser devices and applications emerge, the effect of laser technology will be increasingly prominent, and will play an important role in shaping an innovative country, and increasing the competitiveness in the international industry.

Considering the importance of developing laser technology and promoting its application, the Chinese Academy of Engineering launched the significant consulting research project, "Strategic Research on China's Laser Technology and Its Application by 2035". The Research group delved into the laser industry and investigated the current state of laser technology. They found a disparity between China's laser technology and the international standards. The group outlined the need for industrial application of laser technology surrounding three major fields (manufacturing and processing, information and communication, medical treatment), and proposed development goals, key research points, and policy needs. This article is a comprehensive report of the project.

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2 The effect and position of laser technology and its application

2.1 Being important for studying fundamental physics and developing frontier technology in multiple fields

Research on frontier laser technology to achieve better features across the frequency (ultra-short wave, ultra-long wave, tunability, mono-frequency, broad spectrum and so on), time (ultra-fast, ultra-intense peak value and so on), and energy domains (high brightness, large power, high energy and so on) has always been a significant component of the world's scientific research.

High performance lasers can create some extreme conditions, which deems them important instruments for studying fundamental physics. For example, some ultra-fast and ultra-intense lasers have a power density and an electromagnetic field that can only be found in the core of a star or the edge of a black hole. This could be used to simulate extreme conditions created by great cosmic events in the laboratory – supernovae and black hole mergers, to name a few. This provides the necessary experimental tools to study concepts like the multiverse, super string/membrane theories, and other theories in fundamental physics.

The features or parameters of frequency, time, and energy domains created by high performance lasers make them necessary tools in the study of new materials, energy, biology and other scientific frontiers. For example, using a hard X-ray free electron laser as the next generation probing light makes it possible to observe evolution images at molecular, atomic, micro, and nano scales. This allows researchers to manipulate the state of molecules, atoms, electrons, and even atomic nuclei. This makes lasers the necessary tool for nuclear physics, atomic physics, molecular physics, cellular and molecular chemistry, and biological research.

Laser related research has been awarded the Nobel Prize many times in the past six decades, which shows the prominent contribution made by laser technology in advancing scientific research and boosting the progress of technology.

2.2 Being indispensable in shaping modern manufacturing, information, medicine, national defense, and other industries

Laser manufacturing is the main application of the laser industry. It comprises cutting, welding, surface engineering, additive manufacturing (3D-printing), repairing, remanufacturing, micro-nano manufacturing, and so on, taking up 30% of the product value of the laser application industry. With outstanding merits such as easy operation, no contact, high flexibility, high efficiency, high quality, conservation of energy and the environment, laser manufacturing is the mainstream method of cutting, welding, surface treatment, high performance complex component manufacturing, and precision manufacturing. It's dubbed "the universal processing tool," "the common processing method for manufacturing systems in the future." It leads to the development of the advanced manufacturing industry, causing profound impact on the progress of the intelligence industry.

Laser technology is the foundation on which the modern information industry is built. Without optical fiber communication, there wouldn't be high-speed Internet. Wireless optical communication is the only viable way for high-speed long-distance transfer of vast amount of information, and the main method for the exchange and transfer of vast amounts of data in and among supercomputers, large computing centers, 5G mobile communication bases, and data centers. Optical storage is the main storage method for big data. High resolution laser display technology will bring about a revolution in the history of human sight. Besides, laser technology lays the foundation for high precision measuring and sensing, automatic driving, and quantum communication.

Laser technology has been indispensable for medical treatment and diagnosis. Optical coherence tomography, photoacoustic imaging, multi-photon microscopy, and Raman mapping are important diagnostic techniques in modern medicine. Intense laser therapy, photodynamic therapy, and low-level laser therapy have already been used extensively for the treatment of more than 300 kinds of diseases across ophthalmology, surgery, gynecology, otorhinolaryngology, dermatology and so on. While minimally invasive or non-invasive, they lead the change in the field of medicine.

In the field of defense, lasers have been applied in ranging, imaging, pointing, guiding, communication, counter measures, and so on. They have improved the performance of weapon systems, such as increasing hit rate and reliability, changing the landscape of modern warfare. High energy laser (HEL) weapons, which use laser to destroy targets directly, have been approaching maturation in the recent years, and will go through the R&D stages and enter service in the near future. Due to the rapid deployment of small UAVs, low altitude laser defense systems have developed quickly as an indispensable security measure at important sites and for important events in peace time.

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2.3 Boosting the upgrade of the economy and the industry

The extensive application and continuous expansion of laser technology shows that it is a core technology which boosts the development, transformation, and upgrade of the economy and the industry.

First, the laser is an important instrument, whose application can accelerate the landscape change of related industries. Its application and expansion in manufacturing, information, communication, and medicine are evidence of the same.

Second, laser technology is quite permeable. The economy supported by laser products has a much larger scale than the products themselves. A research report from 2010 published by the Office of Science and Technology Policy of the United States indicated that the total value of the telecommunication, e-commerce, and information technology industries amounted to 4 trillion USD; the value of the laser industry (semiconductor and fiber laser) was a mere 3.2 billion USD. However, the importance of laser products is much greater than the values of the products [4].

Third, laser technology has great capacity to incubate new applications, creating new industries by fusing with other technologies, which shows its remarkable industry-guiding characteristics. For example, from the last 30 years, the performance of semi-conductor lasers has been improving. This has prompted optical switching technology to mature, and the capacity of optical fiber networks to reach transfer speeds of 1 trillion byte/s, which is the cornerstone of 4G and 5G communication technologies. Furthermore, the maturation of laser display technology will give birth to a trillion-dollar industry.

3 Analysis of the present situation of laser technology and its application in China

3.1 Research on laser technology is mainly done among institutes and universities, with little left in enterprises

Institutes and universities constitute the main scientific and technological centers for research on laser systems in China, such as the Chinese Academy of Sciences, defense industry corporations, China Academy of Engineering Physics, Tsinghua University, and National University of Defense Technology. According to “Annual Report on Chinese Laser Industry 2019”, among the 30 national research platforms (including 1 national experimental center, 14 state key laboratories, 5 national engineering research centers, and 10 national technological research centers), only the National Engineering Research Center of Precision Processing, and the National Engineering and Technological Research Center of Semi-conductor Pumped Laser are founded by enterprises, the rest are distributed amongst universities and institutes.

Universities and institutes took up a major part of the national research programs, and only a little was left for enterprises. In 2017, among the 415 laser related programs funded by the National Natural Science Foundation, with a total value up to 0.3 billion yuan, 4 institutes (including the Institute of Semiconductors, CAS), and 6 universities (including Xi’an Jiaotong University) constituted the top 10 entities being funded, taking up 44% of the total amount. In the same year, 26 significant scientific research instrument development programs in the electro-optical field were funded by the National Natural Science Foundation, with a total value of 0.18 billion yuan, which were distributed between 14 universities and 8 institutes [2].

In contrast, enterprises in China possess little capacity to do laser research and have less chances of being funded by national programs of science and technology. On one hand, it indicates that their research capability and base are weaker, unable to compete with universities and institutes. On the other hand, it indicates that the laser programs are more fundamental than industry-oriented; with relatively high risk and little correlation to industries, enterprises aren’t interested.

3.2 China’s laser research covers a large area, following behind in a major part, shoulder in shoulder in some part, leading in a few points.

In the frontier research areas, novel semiconductor lasers, ultra-fast ultra-intense lasers, deep/very deep ultraviolet lasers, high energy solid-state lasers, and free electron lasers are the main research objects. They have the following features: first, they have better performance in the essential laser features (frequency domain: ultra-short wave, ultra-long wave, tunability, single frequency, broad spectrum and so on; time domain: ultra-fast ultra-high peak values; energy domain: high brightness, large power, high energy and so on). Second, they have significant demand toward applications, and there is a discrepancy between that demand and the current performance. Third, they predict the laser technology development trends (containing discovery and invention of

new materials, structures, principles, and mechanisms) [4]. The development of frontier laser technology involves taking the high ground of scientific and technological strategy, a focal point toward which countries in the world compete. As of now, China's national plan of science and engineering has a layout and support for those objects. However, there is a certain disparity between China's current research on frontier laser technologies and the world's advanced level.

In the last decade, laser manufacture has developed in the advanced manufacturing field at a rapid rate, but most of the employed techniques are based on international standards. Micro-nano manufacture, macro manufacture, and additive manufacture of metal, non-metal, and biological materials have attained some distinctive features, and some techniques are on par with international standards. However, compared to the developed countries, many of them still lack original ideas that could lead to revolutionary or mutational progress in the economy and the society. High quality and high stability lasers, laser processing heads, and outside light path systems are still imported, with systems lacking intelligent integration. Some core techniques such as control software and special optical fibers, haven't achieved any breakthrough, which hinders the growth of the laser industry.

In the field of information, synchronous with the development of mobile and data communication in China, the research and the industrial development of optical fiber communication are at the international forefront. In the sector of wireless space laser communication, China successfully conducted the in-orbit test of "Satellite–Earth high-speed coherent laser communication payload" via the quantum satellite "Mozi" between December 2016 to January 2017. Laser displays have acquired a solid foundation and the whole technology chain from core optical materials and chips, semiconductors and solid lasers, to whole-machine integration has been established, generally on par with the international standards. The projective laser display technique has achieved breakthrough, and the related industry has surpassed the global norms, accelerating development conditions.

In the field of medicine, basic research and innovation of laser therapy have increased rapidly in the recent years. In 2019, among the 82 significant research instrument development programs funded by the National Natural Science Foundation, 16 were related to lasers in medicine, with the amount of 118.5787 million yuan taking up 20.44% of the total value. The base and clinical application of photo-dynamic treatment, weak laser treatment and other laser treatment techniques are already remarkable with respect to global standards. But the laser treatment industry mainly consists of small-medium private enterprises, where laser devices are typically imported, and motivated less by real clinical needs. Most of the laser treatment equipment are imported. Particularly, the core techniques and high-end equipment such as ultrafast laser devices used for precision treatment are monopolized by foreign countries. Moreover, compared to other countries, the requirements of registration, examination, and verification of laser treatment devices are too strict, the period too long, which hinders the development of new products. From 2016 to 2018, only 18 domestically developed laser treatment devices were market-approved in China, while there were 100 in America.

In the field of defense, with decades of efforts, China's laser weapon technology is among the world's best. In the security sector, especially for anti-terrorist operations and low altitude defense against small multi-rotor UAVs, the China Jiuyuan Hi-tech Equipment Corporation developed the "Silent Hunter" laser defense system in 2014.

3.3 China's laser application industry has developed rapidly, but with only a few original and high-end products

China's laser application industry has been developing rapidly. Large scale laser enterprises are all over the mainland. According to the "Annual Report on Chinese Laser Industry 2019", there are 37 laser industry parks distributed among 26 cities in China. From 2011 to 2018, the sales revenue of laser equipment increased more than five times. A pack of laser enterprises with an international level of competence, such as Han's Laser Technology Industry Group Co., Ltd., and HGTECH Co., Ltd., emerged in this period.

Through efforts across many years, China's laser enterprises have secured their footing in the low-medium end laser industry, but still lag behind the world's leading companies in the high-end industry and core components, by a significant margin. Many laser products are modelled based on foreign products; original products are only a few.

In the future, China's laser industry will develop rapidly. First, with the technological upgrade of traditional industries, adjustment of industry structure, conservation of energy and environment, and the development of individual need, China's laser manufacturing equipment will witness broader prospects of development. Second, information applications, such as fiber laser communication, laser display, laser storage and so on, will boast a vast development space; laser radar, laser wireless communication and so on, will pick up pace based on the

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development of the auto-drive. Third, the laser treatment equipment industry is in its infancy, and will eventually incorporate wearable equipment in future – playing a bigger part in the daily monitoring and prevention of chronic diseases.

3.4 Problems restricting the development of China's laser application industry

(1) Lack of institutional top-level layout and long-term planning. Laser technology and its applications involve many fields. Without regular planning at the national level, and without the institutional arrangement of evaluating development, the coordinated development would be slowed down to a certain degree.

(2) The fundamental research that supports the development of the laser industry (new principles, new mechanisms, and new processes supporting the research and development of new products) is not sufficient, which leads to the scarcity of original ideas in the laser industry. Mainstream research institutes have the human resource and the equipment, but don't understand the real demand from the market. Enterprises are unwilling to invest due to the high risks involved. Hence, fundamental research proceeds slowly, with little satisfactory results, and unlikely to incubate original industries.

(3) The supply of the key common techniques is insufficient. The research, development, and innovation systems of key common techniques have not yet been established. The organizing mechanism is incomplete, the supporting policies inconsistent, and the funds insufficient. The mechanism of sharing and promoting achievements needs to be improved urgently.

(4) The coordinated innovations of industries, universities, institutes and users have not been sufficient. The majority of research on laser technology in China is carried out in universities and institutes, with low correlation to enterprises. The research achievements do not support or transform the industry enough.

(5) Industry development policy needs to be improved, especially in medical field. China's regulation of medical equipment registration and certification requires considerable capital; the time taken through early R&D, inspection and clinical approval, discourages the promotion and application of innovative medical laser equipment, and doesn't fit with the expectation of the development in laser technology.

(6) The cultivation of talent is insufficient. Laser application is an inter-disciplinary field. However, in the current educational system, curricula in mechanical manufacturing, information, medicine, and other related majors often lack contents of laser technology, which hinders the development of novel laser techniques and products in the respective industries, and prevents laser equipment and products from playing a bigger role.

4 Contemplation of the development goal of China's laser technology and its application by 2035

4.1 Guiding thought

Guided by Xi Jinping's view of socialism with Chinese characteristics for a new era, to serve the "two one hundred years" goal and expand the capacity of supporting national security with laser technology and industry, top level planning should be enhanced. The administrative system should be reformed to boost innovations in laser technology and development of high quality industries. Core techniques should be self-reliant. Emerging laser application industries should be nurtured. The development of laser technology and its application industries should be quickened.

4.2 General objectives

By 2035, the general level and research capacity of China's laser technology and application should be remarkably elevated. Frontier technology, applicative technology, and industrialization should be balanced. Technologies in significant fields should be of a high international grade, and the laser industry should be on par with developed countries, to support sustainable development and create larger economic and social profits.

(1) Breakthroughs should be achieved in frontier laser techniques such as ultrahigh brightness, ultra-short pulse, single frequency, and ultra-stable lasers, to support the research of fundamental physics.

(2) A batch of significant laser devices (such as ultra-short ultra-intense, XFEL, and THz-FEL devices) should be built, to support fundamental research efforts in materials science, biology, energy and so on.

(3) Self-reliant breakthroughs should be made in key bottle-neck products (such as laser semiconductor chips and so on) to achieve self-sufficiency in core industries and to safeguard the security of the economy.

(4) Development of novel laser devices (including semiconductor lasers) must be promoted, fundamental

research should be expanded in its scope – including principles and processes in new laser applications, thereby creating new industries. This bolsters emerging industries (such as 5G, big data, cloud computing, quantum technology, and auto-drive) and leads to development.

(5) The technological standards and scale of laser industries in intelligent manufacture and information should rise to the world-class standards, and effectively support the transformation and upgrade of manufacturing industries.

(6) Serve the "healthy China" strategy, keep extending applications in medical treatment, and increase the capacity of medical equipment to meet the demand of the high-end market.

(7) Actively develop defense and security applications to meet the country's need.

4.3 Objectives in fields

By 2035, the general level of laser technology (such as semiconductor laser, high energy solid-state laser, ultrafast ultra-intense laser, deep/very deep ultraviolet laser, and free electron laser) should accomplish a series of breakthroughs across core techniques, and a batch of significant laser research devices should be built, to realize the transition of laser technology.

In the field of intelligent manufacturing, by 2035, a batch of original outcomes should be obtained. Key techniques of manufacturing core laser components should be developed to realize self-reliance of the industry chain of laser manufacture. Intelligent, extreme, advanced high-performance technology and equipment should be developed to realize self-reliance of the industry chains of laser manufacture for high-end equipment such as aviation engines. Industry application should be done on a large scale, and the economic scale of the laser manufacture-related industry should rise to a trillion yuan. The laser manufacturing and remanufacturing industry should meet the global standards.

In the field of information, China's laser information technology and associated industries should hold the world's leading position by 2035. Secure laser information technology systems should be established; core laser techniques in the field of information should be developed and controlled. Key techniques and processes should be mastered. New business ecologies and modes should emerge with the coordinated development of the industry and innovation chains. An innovative cooperation system should be formed. The collective developmental layout of the laser innovation economy should be formed; the development capacity and competiveness of the industry cluster of laser technology should among the world's best.

By 2035, in the field of medicine, the goal of development is to establish an evaluation standard for laser treatment systems, to improve medical treatment laser and even the whole ecology of laser industry. As for significant medical application, the core components and the key techniques of the lasers should be mastered and industrialized to form the whole industry chain and achieve international competiveness.

5 Measures to boost the development of China's laser technology and its applications

(1) Strengthen top-level planning and guide the rapid development of China's laser technology and application. First, the "medium-long term plan of China's laser technology and its application" should be made, oriented towards the national development goal of 2035. Second, relying on the Chinese Academy of Sciences and the Chinese Academy of Engineering, the development of laser technology and its applications should be evaluated every 5 years. The evaluation should propose the key areas of development and guiding goals, providing counsel to the nation.

(2) Strengthen fundamental research, concentrate and make breakthroughs on significant problems, core elementary materials, and devices concerning industrial development; strive to develop self-reliant industrial common technology to lay a solid foundation for sustainable development. For example, focus on core materials and devices such as high performance laser chips, semiconductor lasers with new operating mechanisms, high performance special laser fibers, laser crystals; and metal materials for additive laser manufacturing and remanufacturing, tackle key problems in resources, key equipment, design, processing, testing, and large scale production with organized and concerted efforts.

(3) Propose several special R&D programs on applications of lasers, increase policy support for industries, build multiple laser industry chains. For instance, in the manufacturing field, bolster research and testing of applications related to manufacture and remanufacture of high-end equipment (such as aerospace and mechanical manufacturing). In the field of information, research on fundamental scientific problems and developing core techniques for space laser broadband transmission and networking would be crucial. Plan the future layout of

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industries and accelerate the development of laser display technology. In the field of medicine, support research and development for high clinical performance femto-second lasers and equipment. Put low risk, mature clinical laser devices on the List of Medical Devices Exempted from Clinical Tests, and advance the laser medical treatment register system.

(4) Innovate an industry coordination mechanism and improve the innovation ecology of the laser industry. For example, relying on key clinical hospitals, amass the technological power of universities, institutes, and enterprises, and establish a national engineering research center for clinical transformation through lasers. The innovations of enterprises should be maximized, and industrial associations should be encouraged, to promote industrial plans, propose common technical problems, improve research and development, and formulate industrial standards and regulations.

(5) Enhance the education on the basics of lasers and cultivate talent for laser and optical applications. Set up laser medicine as a second-class discipline under clinical medicine, to meet the need of the accelerating laser applications. Enhance the education on the basics of lasers in majors like materials and manufacturing, to garner talent for the development of laser applications.

6 Conclusion

The year of 2020 marks the sixtieth anniversary of the invention of the laser. In the past six decades, laser technology and its application have significantly changed the world. The nineteenth congress of CPC has set the strategic goal of realizing socialism, modernization, and becoming a leading innovative country. This has brought unprecedented scope for development of laser technology and its applications, also demanding a higher standard. We must fully recognize the effect and potential of laser technology and its applications, to identify the difficulties and challenges hindering the development, and insist on self-reliant open innovation. Guided by the goals of application and industry, we shall bolster laser technique development and improve the innovation ecology of the laser industry.

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