

# High-Power Laser Technology and Industrial Development Research

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**Abstract:** High-power laser technology is widely used in manufacturing processing, medical diagnosis, and treatment, and is one of the important fields of strategic high-tech competition in China at the moment. In the context of industrial upgrading, high-power laser technology plays an important role in leading the development of the manufacturing industry and industrial intelligence. Based on this, this paper carries out research on high-power laser technology and industry, summarizes the basic principle and classification of high-power laser technology, analyzes the current status of high-power laser technology industry, points out the opportunities and challenges faced by the industry development, puts forward suggestions to promote the development of high-power laser technology industry, and to provide an effective reference for the application and development of high-power laser technology.

**Keywords:** High-power laser technology; Industrial development; Research

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## 1. Introduction

With the rapid development of science and technology, high-power laser technology is increasingly widely used in industry, medical treatment, scientific research, and other fields. As one of the cores of modern optoelectronic technology, the development level of high-power laser technology is directly related to the competitiveness of related industries<sup>[1]</sup>. Therefore, an in-depth study of high power laser technology and its industrial development is of great significance for promoting scientific and technological innovation and promoting industrial upgrading. This paper aims to comprehensively analyze the classification, industry status, challenges, and opportunities faced by high-power laser technology and put forward targeted development suggestions for relevant enterprises and policymakers to provide a reference<sup>[2]</sup>.

## 2. High-power laser technology related overview

High-power laser technology is the core component of modern optical and optoelectronic technology, and it plays

an important role in many fields such as scientific research, industry, medical treatment, and the military by using the coherence, directivity, and high intensity of the laser. With the progress of science and technology, high-power laser technology continues to break through, and its output power, wavelength stability, beam quality, and other performance indicators have been significantly improved, providing strong technical support for the development of related industries [3].

### 3. The category of high-power laser and its industry status

High-power lasers are mainly divided into gas lasers, semiconductor lasers, fiber lasers, and solid-state lasers according to their working principles and different media [4]. With the rapid development of science and technology, the high-power laser technology industry is experiencing unprecedented rapid development, attracting the attention of a large number of researchers, and promoting the transformation and upgrading of related industries.

#### 3.1. Semiconductor laser

A semiconductor laser, also known as “direct semiconductor laser,” is where a semiconductor material is the working medium of the laser, using the electronic transition process in the semiconductor to produce a laser, with small size, lightweight, high efficiency, easy to modulate, and other advantages. In high-power applications, semiconductor lasers usually achieve high-power output by series or parallel multiple laser diodes and directly achieve power amplification through efficient beam combining technology, thus used in industrial applications. The laser is driven by electric power. The use of semiconductor materials as the gain medium, through the electro-optical conversion mechanism to stimulate the generation of laser, and finally integrate multiple lasers into the fiber to output high-power laser.

Compared with other types of lasers, it has many advantages such as high electro-optic conversion efficiency (up to more than 50%), long service life (more than 100,000 hours), superior direct electrical modulation performance, easy integration, small size, and compact structure. In the industrial field, high-power (up to kilowatt level) semiconductor lasers are mainly used in precision machining scenarios such as quenching and cladding. The hundred-watt semiconductor laser is often used as a pump source for fiber lasers and solid-state lasers. At present, China has achieved large-scale mass production in red laser diode (LD), and the output power can reach tens of watts, keeping pace with the international level, but in the field of blue LD, it still faces certain challenges [5].

At present, the international leading Blu-ray LD mass production power has broken through 5 W, and more top products are approaching 10 W, but the key technologies and processes are still highly confidential. In recent years, China has strengthened scientific and technological research and development, scientific research institutions such as Xiamen University and San’an Optoelectronics (Xiamen), and others have made significant progress in this field, achieving a breakthrough in output power such as 8.04 W, but compared with the international top level there is still room for improvement.

#### 3.2. Fiber lasers

Fiber laser is where the fiber is the waveguide and gain medium of the laser, mainly by the gain medium, fiber grating, buncher, and other optical components, driven by the electrical control system, the use of doped ions in the fiber (such as ytterbium ions, erbium ions, etc.) under the action of the pump light energy level transition, resulting in laser. Ytterbium-doped ( $\text{Yb}^{3+}$ ) fiber is good at the output of lasers in the 1,064 nm band, while erbium-doped ( $\text{Er}^{3+}$ ) fiber is good in the 1,310 nm or 1,550 nm band.

Overall, the output of fiber lasers is mainly concentrated in the red band. Fiber lasers have the advantages of good beam quality, excellent heat dissipation performance, easy-to-achieve long-distance transmission, and amplification, and are widely used in the industrial field, among which continuous fiber lasers are mostly used in thick metal materials cutting, welding, and other macro processing fields. Pulsed fiber lasers are mostly used in solid state laser seed sources, which provides a solid foundation for the in-depth application of laser technology.

Currently, the technology has become the mainstay of China's Motor Control Center (MCC) laser. Relevant data show that in 2020, the proportion of fiber lasers in China's industrial laser market has reached 67%, and the total market sales have exceeded the 9.42 billion yuan mark. Shenzhen, Wuhan, and other places are the gathering of many fiber laser companies, forming an industrial agglomeration effect. In recent years, China has strengthened the research on the power of fiber lasers and obtained remarkable results, such as Wuhan Rayco and the University of South China jointly developed the first 100 kW fiber laser and its supporting equipment, and its output power has approached 120 kW level of IPG company in the United States, highlighting the strong strength of China's laser technology. However, China is still facing the bottleneck of core materials and devices in the field of high-power fiber lasers, such as special fiber, fiber grating, and other key components still need to rely on imports, to a certain extent, limiting the pace of development of high-power fiber lasers in China <sup>[6]</sup>.

### **3.3. Solid-state laser**

Solid-state laser is a kind of laser that can produce metal ions with excited radiation as the gain medium. It uses the electrons in the solid to make an energy level transition under the action of pumping light to produce a laser. Its structure is complex, including a pump source (commonly used semiconductor laser LD), seed source, amplification module (built-in gain medium), frequency conversion module (including nonlinear crystal), modulation module, and other key components. Compared with pulsed fiber lasers, it can realize ultra-fast pulse laser, and convert infrared light into green light, ultraviolet light, and deep ultraviolet light by frequency doubling crystals. The laser has the advantages of short wavelength, short pulse width (picosecond, nanosecond), and peak power, and is suitable for high-precision micro-machining fields, such as nanoparticle drilling and cutting of thin, brittle metals and non-metallic materials.

At the moment, most of the mainstream precision device board and pipeline-cutting equipment on the market use solid lasers, such as scientific research, medical processing, etc., especially in the medical field, it plays an important role in laser treatment, photodynamic therapy, and so on. However, China's development in the field of solid-state lasers started late, and there are fewer model enterprises. There is a significant gap between the domestic technical level and that of foreign countries. The high-end solid-state laser market is monopolized by foreign manufacturers, and the phenomenon of technical blockades and embargoes is serious, affecting the development of China's high-end manufacturing industry <sup>[7]</sup>.

In summary, all kinds of lasers in high-power applications have shown unique advantages and challenges. With the continuous development of science and technology, the high power laser technology industry is still facing many challenges and opportunities.

## **4. Industrial development opportunities and challenges**

### **4.1. Opportunities for industrial development**

At present, the high-power laser technology industry is facing good development opportunities. On the one hand, the high-power laser market has good prospects for development. With the progress of science and technology,

high-power lasers have shown a wide range of application prospects in many fields. For example, in the field of manufacturing, it is used in material processing, precision manufacturing, and intelligent manufacturing, which can effectively improve the production efficiency of enterprises. In the medical field, it has been applied to laser therapy, photodynamic therapy, and other aspects to promote the innovation of medical technology. With the support of emerging industries such as new energy, the application fields of high power lasers are constantly expanding, and the market potential is huge. On the other hand, the international industrial situation accelerates the process of localization of lasers <sup>[8]</sup>.

The change in the international industrial situation has provided a strong impetus for the localization process of high-power lasers, and domestic research institutions have strengthened the promotion of independent research, constantly breaking the international monopoly, promoting the localization of laser core materials and devices, and improving the core competitiveness of products. In addition, the support and guidance of national policies also provide a strong guarantee for the localization process of high-power lasers, and provide more development opportunities for domestic enterprises <sup>[9]</sup>.

## **4.2. Industrial development challenges**

Although China's high-power laser technology has made remarkable progress, it still faces several challenges. For example, the level of engineering technology requires further improvement, particularly in effectively controlling thermal effects and light damage during high-power output, as well as enhancing the stability and reliability of lasers. Additionally, optimizing the structure and design of lasers to reduce costs and improve production efficiency remains a priority. Since the development of engineering technology in China started relatively late, the adaptability of computer numerical control (CNC) systems and laser coordination during actual use also needs enhancement. These challenges require further research, development, and innovation to overcome <sup>[10]</sup>.

## **5. High-power laser technology industry development suggestions**

### **5.1. Strengthen research on key technologies and overcome difficulties in key materials and devices**

In the process of industrial development, it is essential to prioritize the research, development, and innovation of key technologies to overcome challenges related to critical materials and devices. The core of high-power laser technology lies in high-performance materials and devices, necessitating efforts to address the technical and process challenges of industrializing pump semiconductor lasers, as well as resolving bottlenecks in high-performance artificial crystals, fibers, and other key materials. Strengthening research on critical materials and devices for high-power lasers, combining independent innovation with international cooperation, is crucial to overcoming these challenges swiftly.

For example, organizing cross-disciplinary research teams involving scientific research institutions, relevant departments, and enterprises can help tackle the challenges of key technologies and materials for high-power laser devices. Additionally, promoting international scientific and technological cooperation, learning from advanced international experiences and achievements, and enhancing the global competitiveness of China's high-power laser technology are vital steps forward <sup>[11]</sup>.

The government and enterprises should increase the investment in the research and development of the key technologies of high-power laser, provide adequate financial support and policy guarantee, encourage scientific research institutions and enterprises to carry out long-term and stable cooperative research, achieve engineering

and industrialization, and ensure the independent production of key materials and devices.

## **5.2. Promote industry-university-research collaboration and promote the transformation of scientific and technological achievements**

To promote the transformation and application of scientific research results and help industrial upgrading, relevant departments should actively carry out industry-university-research collaboration, break down barriers between scientific research, education, and industry, promote close cooperation among scientific research institutions, higher education institutions and enterprises, build a resource sharing system, and promote the transformation and application of scientific research results. Focusing on the technical dilemma of a high-power laser, scientific research institutions and institutions of higher learning should strengthen the promotion of cooperative research and development, the use of advanced experimental equipment and rich scientific research personnel, and constantly promote technological innovation and breakthroughs. Enterprises should assist and participate, combined with market demand and practical application scenarios, and promote the transformation of scientific and technological achievements into products with market competitiveness <sup>[12]</sup>.

The government should take the lead in building an industry-university-research cooperation platform, promote information sharing and technical exchanges between multiple entities, encourage collaboration between various departments, support outstanding enterprises to achieve technological research through industry, open up the upstream and downstream industrial chain, and promote the process of localization of high-power lasers. Scientific research institutions and enterprises carry out project cooperation, jointly undertake the task of scientific research projects and transformation of results, promote the rapid transformation and industrialization of scientific research results, and bring economic and social benefits to enterprises <sup>[13]</sup>.

The government should introduce relevant policies to support and incentivize industry-university-research collaboration and the transformation of scientific and technological achievements, such as providing research funding subsidies, tax incentives, and intellectual property rights protection, to stimulate the enthusiasm and creativity of all parties. In the whole process of research and development, talent is the first element. All parties should participate in the cultivation of talents, cultivate high-quality talents with innovative ability and practical experience, and promote the updating of knowledge and the dissemination of technology through the flow of talents and academic exchanges, to promote industrial upgrading and economic development <sup>[14]</sup>.

## **5.3. Improve domestic production lines and expand domestic market layout**

At present, with the fierce competition in the global manufacturing industry, China has paid more attention to improving the technical level and market share of domestic equipment. High-performance and high-power laser and laser equipment is an important support of the advanced manufacturing industry, its localization process is of great significance for breaking foreign technology monopoly, reducing production costs, and improving industrial competitiveness. Therefore, the relevant departments should pay attention to improving the production line, expanding the domestic market layout, and accelerating the realization of high-performance high-power laser and laser equipment engineering.

Firstly, strengthen policy support. To achieve industrial goals, policy guidance and support are particularly critical. Government departments should introduce relevant policies to encourage laser processing manufacturers to give domestic lasers and equipment online verification opportunities, through the actual production and application to test its performance and stability, to promote the process of localization of laser equipment, for

domestic laser equipment to provide valuable practical experience and improvement direction. Policy support can stimulate the vitality of enterprise innovation, promote its continuous efforts in the field of technology research and development and product upgrading, and then make breakthroughs.

Secondly, we should strengthen the linkage between upstream and downstream research and development (R&D) enterprises. In the process of technology research and development, upstream and downstream enterprises should form a joint effort to build a good ecology of collaborative innovation. The actual needs of the downstream application field are an important guide for the research and development of lasers and equipment, and the adaptation of lasers and equipment to application scenarios should be improved under the guidance of actual application scenarios. Through the close cooperation of upstream and downstream enterprises, the research and development cycle of products can be shortened, and the transformation and application of technological achievements can be accelerated <sup>[15]</sup>. In this process, the relevant enterprises should strengthen the exchange and cooperation with international advanced technology, the introduction of absorption and innovation, and constantly improve the core competitiveness of domestic laser equipment.

Finally, strengthen the market promotion. In the promotion of technology, the relevant departments should increase the publicity of domestic laser equipment, and improve its visibility and influence in the industry. For example, hold product exhibitions, technical exchange meetings, and other activities, so that more users understand the advantages and characteristics of domestic laser equipment, to enhance their trust in domestic equipment and purchase intentions. Establish a perfect after-sales service system, to provide users with timely and professional technical support and maintenance services, to ensure the stable operation of equipment and the interests of users. In addition, with the development of emerging industries, as the application demand for high-power lasers in intelligent manufacturing, aerospace, new energy, and other fields continues to grow, relevant departments should pay attention to expanding the domestic market layout, applying high-power laser technology to more fields and scenarios, and helping the transformation and upgrading of related industries.

## 6. Conclusion

In summary, high-power laser technology is a key field of modern optoelectronics technology. Its development level is directly related to the competitiveness of related industries. Currently, the high-power laser technology industry has broad prospects for development. To promote its sustainable and healthy development, relevant departments and personnel need to strengthen research on key technologies and overcome difficulties in key materials and devices, promote industry-university-research collaboration to promote the transformation of scientific and technological achievements, and improve domestic production lines and expand domestic market layout, to constantly improve the layout of high-power industries.

## Disclosure statement

The author declares no conflict of interest.

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