



# Applications of High-Power Semiconductor Lasers in Marine Environmental Monitoring

Dongxin Xu<sup>1,2</sup>, Yana Zhu<sup>1,2</sup>, Guojun Liu<sup>1,2</sup>, Yi Qu<sup>1,2</sup>(✉), Zhibin Zhao<sup>1,2</sup>, Hao Chen<sup>1,2</sup>, Cheng Cheng<sup>1,2</sup>, and Zaijin Li<sup>1,2</sup>

<sup>1</sup> College of Physics and Electronic Engineering, Hainan Normal University, Haikou 571158, China

quyihainan@126.com

<sup>2</sup> Hainan Provincial Key Laboratory of Laser Technology and Optoelectronic Functional Materials, Innovation Center of Hainan Academician Team, Haikou 571158, China

**Abstract.** The protection and utilization of marine resources is an important development strategy in China. It is of great significance to the healthy development of marine environment to monitor the sea targets round the clock timely and effectively, to perform measurement of wind power and direction, Ranging at sea, extraction of wave-making resistance information, and water pollution detection, etc. High power semiconductor lasers have the advantages of compact, light weight, high efficiency, good tunability, etc., and have become the ideal light source for ocean environment monitoring photoelectric systems such as wind detection radar, through fog range finder, wave monitoring, heavy metal detection instruments, and satellite-borne ocean altimeter and underwater imaging system for marine pollution control. This paper focuses on high power semiconductor lasers' applications in the field of marine environmental monitoring. The development status and prospects of the respective semiconductor lasers used for these applications have also been summarized and analyzed.

**Keywords:** Semiconductor Lasers · Ranging · Detection · Marine Environmental monitoring

## 1 Introduction

Oceans are the cradle of human civilization and also the important carrier of human sustainable development, having great impacts on modern and future human life and survival. The effectiveness of the ocean's development, utilization, and protection determines the quality of human survival and development. With the continuous development and utilization of marine resources, the protection of the marine environment has also attracted worldwide attention. Marine environmental monitoring can normalize the supervision of the ocean and provide emergency response to disasters such as sudden marine red tides and marine pollution. It is utterly important to comprehensively, timely, and accurately collect and master the laws and trends of ocean movement, help people protect marine resources, make rational use of marine resources, and ensure the sustainable development of marine resources.

Laser technology has been dubbed the golden technology of the 21st century, of which the high-power semiconductor laser is the favorite, being small size, light weight, high efficiency, and easily tunable, which is an ideal light source for various marine environmental monitoring photoelectric systems. Semiconductor lasers have developed rapidly in many application fields since they were invented more than half a century ago. With the continuous emergence of various wavelengths and high-power semiconductor lasers, they have been applied in many fields, such as medicine, military, industrial processing, human life and work, and natural sciences. It has become the common consensus to actively develop and utilize rich and excellent marine resources, develop marine ecological environment monitoring, and improve the public's awareness of marine ecological security. High power semiconductor lasers have been widely used in the field of marine environmental monitoring.

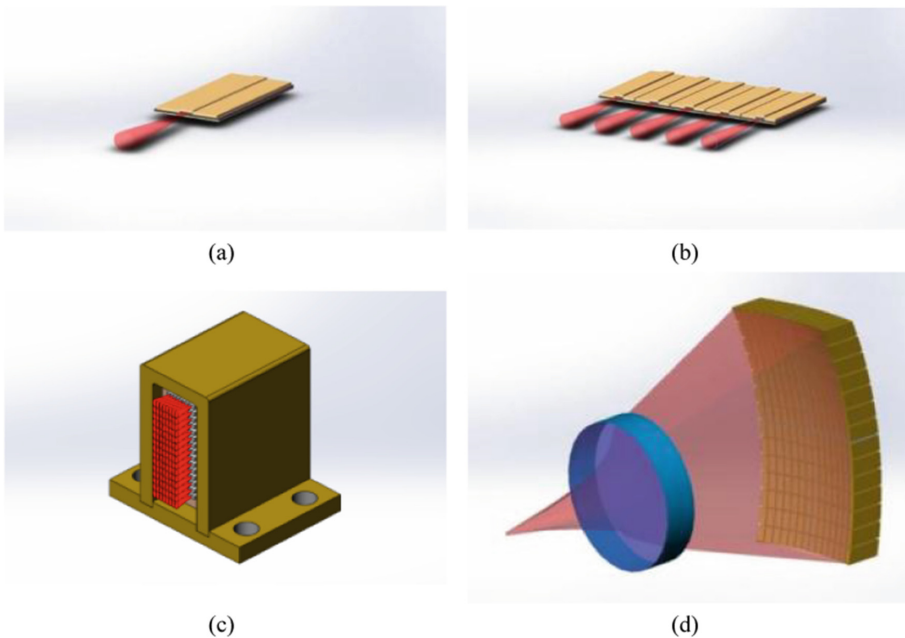
## 2 High Power Semiconductor Laser

Semiconductor laser, also known as laser diode, is a device that uses high crystal quality semiconductor materials as working media to generate laser through the process of stimulated radiation. Its working principle is to realize the non-equilibrium charge carrier population inversion either between the energy bands (conduction band and valence band) of the semiconductor material, or between the energy band of the semiconductor material and the impurity (acceptor or donor) energy level through a certain excitation mode. When a large number of electrons in the population inversion state are combined with holes, the stimulated emission dominates, which generates laser radiation. Semiconductor lasers are developing rapidly, with a wide wavelength range, simple packaging, compact, all-solid, reliable and easy to modulate. The application of semiconductor lasers has covered the whole field of optoelectronics and become the core technology of optoelectronics. Semiconductor lasers are widely used in ranging, radar, communication, simulation weapons, warning, guidance, fuze, aerospace, etc.

In 1962, the first generation of homojunction-injected semiconductor lasers in GaAs was born in the United States [1]. In the following year [2], a heterojunction semiconductor laser was successfully developed at the Joffe Institute of the Soviet Academy of Sciences. In 1967, IMB grew AlGaAs on GaAs using liquid phase epitaxy (LPE) technology. In 1970, the first AlGaAs/GaAs single heterojunction laser was successfully studied at Bell Laboratories in the United States. In the 1980s, the theory of energy band engineering has been proposed and great strikes have been made in new epitaxial technologies for the growth of crystal semiconductor materials such as molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD), liquid phase epitaxy (LPE) and chemical beam epitaxy (CBE), accompanied by breakthroughs in material passivation technology, heat deposition technology, and LD structure design, including single-mode lasers, distributed feedback lasers, laser arrays, and the simultaneous development of complementary technologies, all these contribute to the realization of high power output of semiconductor lasers.

So far, high power semiconductor laser single emitter CW power has exceeded 70 W, pulse output power has exceeded 100 W; LD bar CW power exceeds hundreds of watts, Quasi continuous wave (QCW) output exceeds kilowatts; The quasi-continuous output

power of the LD stack and the optical fiber combined laser already exceeds ten thousand watts. Multi-unit combination of the array laser light source through the LD stack enables power output above megawatt level and multiwavelength megawatt laser emission. The development of high power semiconductor lasers makes the downstream laser technology develop rapidly. In the field of downstream laser technology, semiconductor lasers are used for pumping doped crystals (diode-pumped solid-state lasers) or doped fibers (fiber lasers) with high conversion efficiency, long life, good stability and excellent beam quality. With thermal management, spectrum control, output beam control, and optical beam shaping element process improvement, high frequency or continuous megawatt high power semiconductor lasers have been developed. Commercial products will also be widely used in various fields (Fig. 1).

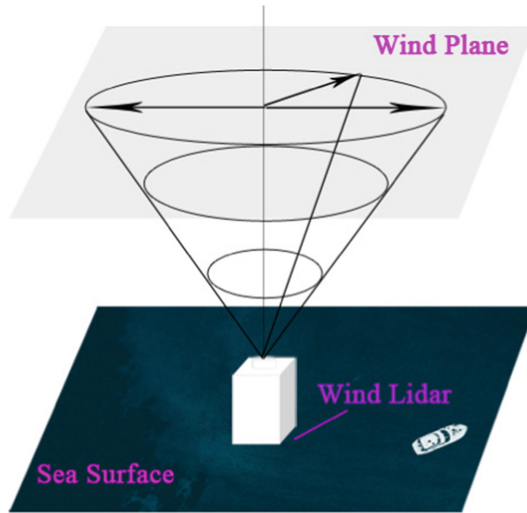


**Fig. 1.** Various forms of semiconductor lasers. **(a)** Hundred watt class single emitter LD. **(b)** Kilowatt level LD Bar. **(c)** Ten thousand watt level LD stack unit. **(d)** Megawatt level LD stack array.

### 3 High Power Semiconductor Lasers for Wind Measurement Radar

The wind measurement radar, or Anemometer radar, is a radar device used to measure the wind direction and wind speed in the air. Using the Doppler shift principle of laser, the wind speed and direction information is obtained by measuring the frequency change of

light wave reflection in the air when it meets the aerosol particles of wind motion and calculating the vector wind speed and direction data of the corresponding height. The wind measurement radar detection system mainly consists of the laser system, transmitting and receiving system, heterodyne detection system and digital signal processing system. Using semiconductor laser atmospheric acquisition sensor, combined with a variety of data processing and servo control system, remote sensing detection of atmospheric wind field at different heights can be achieved, fast and accurately and with high resolution, based on data from the measured space of three-dimensional atmospheric wind field information, these atmospheric wind field data can significantly improve the accuracy of numerical weather forecasting for military and civilian purposes (Fig. 2).



**Fig. 2.** Schematic Diagram of Semiconductor Laser Wind Measuring Radar.

Since the first coherent continuous wave wind laser radar (lidar) based on  $10.6\ \mu\text{m}$   $\text{CO}_2$  lasers was developed in 1970 [3], Doppler lidar technology has been developed soon afterwards. In 2000, Karlsson et al. [4] first released an all-fiber CW coherent wind lidar. In 2004, QinetiQ Company of the United Kingdom developed a commercial all fiber continuous wave coherent wind lidar, which can measure at 10 customized locations within the range of 10–200 m. It has played a significant role in wind energy fields such as wind resource assessment and wind farm planning. In 2014, the WindVISION wind measuring radar developed by Windar Photonics of Denmark measured the wind turbine wake, gust, turbulence and other data by transmitting four continuous wave laser beams focused at a point within 0–100 m and with a certain angle, providing data protection for the optimization of the wind power field systems.

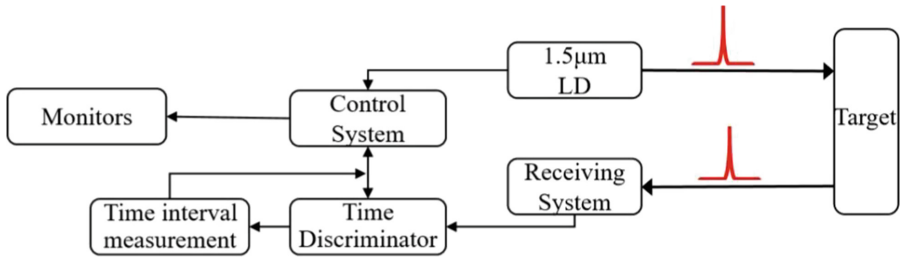
The introduction of high power semiconductor lasers has led to a renewed interest in the use of wind measurement radar once composed of solid state lasers. The development of high power semiconductor laser wind measurement radar has a positive impact on human life and ocean monitoring. The use of semiconductor light wind measurement

radar can avoid natural dangers, study the natural laws of the marine environment, and utilize marine resources, etc. High power semiconductor laser wind measurement radar can be used in clear sky, which can provide high precision and high resolution real-time atmospheric wind field information, and is the internationally recognized advanced technology for measuring wind field. The traditional microwave technology is applicable to a certain range of wavelengths, and the monitoring effect is better in cloudy and rainy conditions, and the detecting capability will be greatly hampered when encountering clear weather. Semiconductor lidar system can achieve high resolution wind speed measurement in small scale, combined with the scanning module, fixed elevation angle wind speed scanning measurement can be achieved, so that the wind speed scanning observation of near-surface wind field can also be achieved. High-power semiconductor laser-pumped solid-state lasers have replaced CO<sub>2</sub> lasers and flash lamp-pumped solid-state lasers, providing significant improvements in compactness, efficiency and lifetime. With the continuous improvement of laser power level, the distance of laser wind measurement radar system also comes farther and farther, and the expansion of output wavelength and detection capability, the wavelength of laser wind measurement radar is also developing in the direction of human eye safety. 1.55 μm wave band is located in the atmospheric absorption window, so this 1.55 μm laser band, with low absorption and less fiber loss in the atmosphere, has become the mainstream of laser wind measurement radar band, for example, with 500 μJ pulse energy, the action of the distance of 16 km can be reached.

High power semiconductor laser wind measurement radar is a new atmospheric remote sensing equipment, which can realize small scale, high precision and high resolution non-contact measurement and spatial scale wind velocity gradient measurement. Three-dimensional atmospheric wind field remote sensing observation can solve the problem of low level wind shear detection which seriously affects the ocean wind direction monitoring, maritime navigation safety and offshore areas. It can be widely used in meteorology, environmental protection, national defense, airport and other fields. It can be called the “downwind eye of the sea”.

#### **4 Application of High Power Semiconductor Lasers in Through-Fog Rangefinder**

Lasers have been used for laser ranging for many years, and laser rangefinders should be able to have fog-transparent ranging capabilities in harsh environments with low visibility such as at sea level. The advantages of laser ranging are high measurement accuracy, high resolution and anti-interference capability, and it is a ranging technology that uses laser as the information carrier to measure the distance to the target. It can be classified into pulsed laser ranging and phased laser ranging according to different laser signal processing methods. Due to the promising application of laser ranging and the development of semiconductor laser devices, pulsed laser ranging technology is developing in the direction of miniaturization, high accuracy, multifunctionality, solid-state components and human eye safety. The high power semiconductor laser as the light source of laser ranging technology is small in size, light in weight, simple in structure and high in efficiency, and is the preferred light source for fog penetrating rangefinders (Fig. 3).



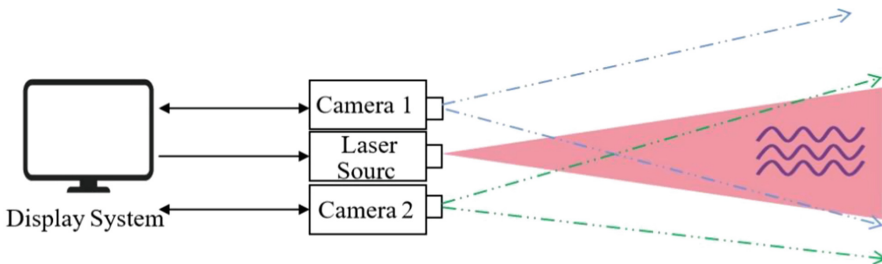
**Fig. 3.** Schematic diagram of 1.5  $\mu\text{m}$  LD ranging principle.

In 1960, the world's first ruby laser rangefinder at 694 nm was applied in the US military since its birth [5]. The early ruby solid laser rangefinder was large in size, low in efficiency and high in power consumption, and was soon replaced by the second generation 1064 nm near-infrared neodymium laser rangefinder [6]. Although the second generation laser rangefinder has greatly improved in volume, power consumption, efficiency and other performance, it does not meet the human eye safety standards. The rapid development of the third generation of laser rangefinders with eye safety and high integration has broken the limitations of the second generation of laser rangefinders, rapidly expanded the application scope of laser rangefinders, and more companies have also increased their efforts in the development of laser rangefinders. In the field of portable eye safe laser rangefinders, Tuyade and Danergy in the United States, Bosch and Olfa in Germany, Nikon in Japan, etc. have made great achievements. Leica and Bosch have obvious advantages in the direction of hand-held short-range laser ranging. Leica's S910 handheld laser rangefinder can directly measure the distance between two points, and can directly measure the area of irregular objects and any angle of space. In 2001, Swiss Research Institute used micro optics system to effectively shape the beam of high-power laser diode, and the overall beam efficiency increased by 28%. In 2011, Tuya developed the SP800 telescopic rangefinder using human eye safe semiconductor laser. The military 905 nm semiconductor laser range finder launched by Nukang Company in Canada has a measuring distance of 4 km and a ranging accuracy of  $\pm 1$  m. Its new product LP20K laser rangefinder uses semiconductor pumped 1570 nm solid-state laser, with a maximum operating distance of 20 km; The measuring distance of the range finder of the company can reach 1200 m, and the measuring distance of small targets can reach 450 m.

At present, 1530 nm Erbium glass laser which meets the safety standards of human eye is used in our country, and its measuring distance can be up to 6 km. Using a high power 1570 nm laser pumped by a semiconductor laser, the measuring range of large hulls, buildings or mountains over 20 km can be realized. 1.5  $\mu\text{m}$  laser has high transmittance, can achieve fog penetration, and good concealment, and can effectively reduce the interception or interference by the other side. Eye safe long-distance laser fog ranging system at 1.5  $\mu\text{m}$  can be called "sea perspective eye".

## 5 High Power Semiconductor Lasers for Ocean Wave Monitoring

Protection and utilization of Marine resources is an important development strategy in our country. As the main means of Marine traffic and transportation, the performance of ships plays a key role in the efficiency of Marine resources development and utilization. However, the wave-making resistance produced in the process of moving has an serious effect on the sailing speed and shipping efficiency of the ship. Therefore, in order to measure wave-making resistance timely and effectively, it is more urgent to observe and measure the waves. In addition, the development and utilization of ocean wave energy also requires real-time and accurate observation of waves (Fig. 4).



**Fig. 4.** Schematic diagram of semiconductor laser wave monitoring principle.

In the 1970s, laser technology was applied as a new light source and observation tool for wave monitoring. In 1973, Tober et al. [7] used a 632.8 nm He-Ne laser as a light source to calculate the slope of waves by observing the spatial position change of the beam after refraction of the underwater laser beam through the wave surface. In 2004, Wang Juncheng et al. carried out wave measurements with a solid-state laser. Using ship-based laser wave measurement instrument, there was no instrument with the same principle used at home as abroad at the time. What were used is a laser wave measurement device installed on the oil platform [8]. Computer vision-based motion target detection technology was applied to wave detection at an early stage, and the United States developed the EVS (Erdman Video System) system in 1998, which combined a video camera and a high-resolution camera to achieve coastal protection, beach management, and marine vessel monitoring. Australia's Coast Watch developed the Coastal COMS (Conditions Monitoring System) system in 2008 for coastal monitoring needs, mainly for beach visitor detection, shoreline extraction and offshore sports vessel monitoring. The Center for Shoreline Protection Technology at Atlanta University in the United States has developed a marine video monitoring system for marine traffic monitoring.

Since 2006, the National Marine Technology Center has conducted in-depth research on the nearshore monitoring technology, and made remarkable achievements in ship target detection and coastal monitoring. The application of moving target detection technology in the monitoring of sea moving target (wave) not only cuts short the development cycle of wave monitoring software, reduces the difficulty of software development, but also can be quickly applied to the real life, which is helpful for the subsequent analysis of the height of the wave climbing, event alarm and so on.

With the development of laser technology, small size, light weight, high efficiency and tunable semiconductor laser light source will be gradually extensively used in the field of wave monitoring. The ocean wave parameters measurements in the target sea area have been readily realized, based on high definition through-frog infrared night vision technology and binocular stereo vision technology, and combined with digital image processing technology, in which a high power semiconductor laser is used as the light source and a binocular stereo vision system as the acquisition platform. With two high-resolution cameras, the system can respond to the infrared band, complete the acquisition of all-weather wave video pictures. The wave height, period and direction information of the ocean waves in the target sea area can be calculated from the captured wave video. Wave eigenvalues are extracted by synchronous contrast processing of two-sided video images, and the inversion algorithm is used to complete the three-dimensional reconstruction of wave information. Wave video preprocessing is used to extract image frames and calculate the inter-frame difference from them to form a three-channel image containing static and dynamic wave height information. A model capable of detecting wave height is built, and a training dataset is constructed from the image set after video preprocessing. The network model is trained to detect different wave heights, and the training model is used to detect the instantaneous wave heights of nearshore waves with high accuracy. Using continuous wave high power fiber coupled semiconductor laser over 30 W as auxiliary illumination, day and night sea area monitoring of 3 km can be achieved. With the binocular wave measuring system, the wave elevation range is 0 ~ 20 m, with the measurement error of  $\pm 10\%$ , the accuracy of wave period measurement is 0.5 s, and the accuracy of wave direction measurement is  $\pm 10^\circ$ .

High power semiconductor laser night vision and ocean wave monitoring system can be used for inter-island lookout, waterway management, maritime management, marine dynamic monitoring, fishery law enforcement, aquaculture safety, hydrological monitoring, port and dock management, offshore mine, offshore power generation device perimeter prevention, etc. High-power semiconductor lasers are truly the “eye of the sea nighthawk”.

## **6 High Power Semiconductor Lasers for Marine Heavy Metal Detection**

With the accelerated global industrialization, the problem of heavy metal pollution in water bodies is becoming more and more serious, posing a great threat to human health and ecological environment. Therefore, there is an urgent need for a method that can perform rapid and sensitive detection of hazardous metal elements in aqueous solutions. At present, the commonly used analytical methods for elemental detection in aqueous solutions include inductively coupled plasma emission spectrometry, atomic absorption spectrometry, atomic fluorescence spectrometry and electrochemical analysis, etc. Although these methods are more sensitive, the detection process is time-consuming and requires complex pretreatment of the sample, which is difficult to meet the practical needs of rapid on-site detection. Laser-induced breakdown spectroscopy was first proposed by Brech and Cross et al. in 1962, and can be used for qualitative and quantitative determination of elemental components in solution samples.



Laser Induced Breakdown Spectroscopy (LIBS) is a new method in spectroscopic analysis applied to trace element analysis. The basic principle is that a laser excites the measured substance to a plasma state, and based on the position and intensity of the spectral lines of light emitted from the plasma, the analysis obtains valid information about the composition and concentration of the measured element. It has many advantages over atomic absorption spectroscopy, liquid chromatography and other detection methods, such as no pretreatment of samples, short analysis time, multi-element analysis, no additional contamination of samples, and no restriction of sample morphology, and therefore has a wide range of applications in solid, liquid and gas fields. This method not only has the advantages of fast detection and no or less sample pretreatment, but is also one of the few techniques that can perform real-time, in situ, non-contact detection, and is particularly suitable for monitoring toxic metal elements in industrial wastewater. Despite the obvious advantages of LIBS over other methods, the conventional single-pulse LIBS technique for trace metal element detection and analysis in water has some problems, such as low detection sensitivity and poor signal reproducibility. This can be partly attributed to the properties of water bodies, which are known to have a higher thermal conductivity and are difficult to be compressed compared to air. Therefore, underwater LIBS is a spectroscopic technique that uses short pulses of high energy laser light focused on the sample surface to excite the sample to the plasma state, generating atomic emission spectra and then analyzing the elemental content of the substance. This technique has the following advantages: easy to meet the requirements of online detection, easy and fast processing and analysis, and no need to add any processing and analysis reagents.

LIBS technology is widely used in the detection of various substances, and the exploration of marine detection is also being carried out. LIBS technology can not only detect various heavy elements in the ocean, but also determine the growth environment of marine organisms by detecting them, and determine the global climate change during their growth cycle by detecting shells. The full use of LIBS technology can obtain more information about the ocean and provide support for people to develop and protect marine resources. Research on the detection of metal pollution in the ocean has mainly focused on Cu, Pb, Zn, Fe, Mn, Cr, Hg and other elements. Although trace elements such as Mn, Cu and Zn in human body are essential for human life activities, but when the concentration of these heavy metal elements exceeds a certain range, it turns harmful to human body (Fig. 5).

Overseas, the LIBS technique has developed rapidly since 1962. In 1995, Dana et al. used LIBS to measure the salt concentration in seawater aerosol droplets, determined the plasma temperature, and made a standard curve of 589 nm for Na and 656.3 nm for Na as a standard for determining the Na concentration in seawater, and this method can determine the Na concentration in the range of 100 ppm to 10000 ppm. In 2011, Man et al. used the LIBS technique to determine the concentrations of four elements, K, Mg, Ca, and Al, to classify 11 sea salts by attribution, and compared the results obtained with the ICP-AES method to demonstrate the reliability of the LIBS method for sea salt classification, and to demonstrate that the production method of sea salt can be determined by the spectral intensity of Al. In 2017, Luan Kunxiang et al. of the First Institute of Oceanography, State Oceanic Administration of China, used an underwater

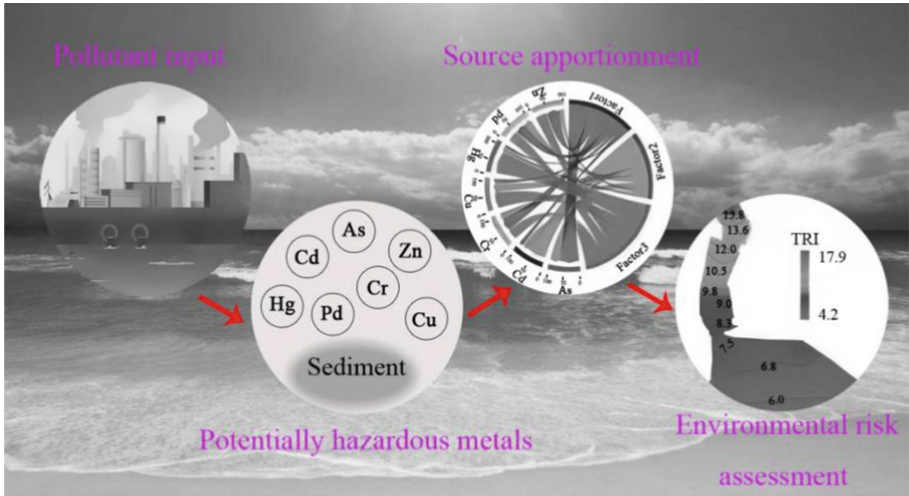


Fig. 5. Marine Heavy Metal Pollution Detection.

intelligent robot to sample our sea area and combined UV-Vis spectrophotometer with Kalman filter algorithm to achieve real-time monitoring of a variety of heavy metal elements to detect pollution in our sea area [9]. In 2004, A. De Giacomo et al. used a double-pulse laser to act inside seawater to detect the signal of metal elements in it. Wang Chuanhui and Cui Deifeng from Anhui Normal University and China Ocean University tried to analyze the metal elements in aqueous solutions of  $\text{AlCl}_3$  and  $\text{CuSO}_4$ , and the detection limit reached 23 ppm.

High-power semiconductor lasers can be used to create miniature heavy metal detectors that can perform real-time metal element analysis at sea. The method and system for measuring the content of heavy metals in water based on laser induced breakdown spectroscopy can be called “the golden eye of underwater knowledge”, which has the ability to comprehensively improve the environmental supervision of marine heavy metals.

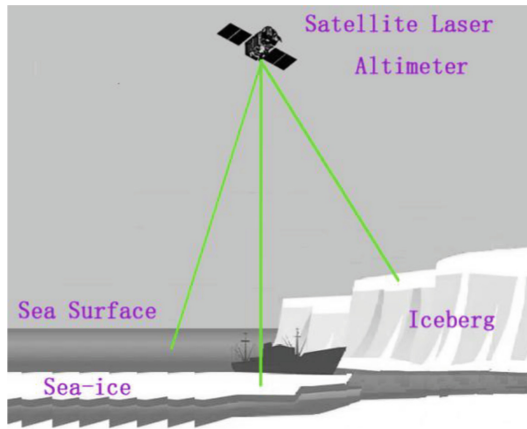
## 7 Applications of High Power Semiconductor Laser in Satellite Ocean Altimetry System

The impact of human activities on the atmospheric and oceanic systems has been increasing, and global temperature rise, sea level rise, and global climate extremes have become hot issues of global concern. The development of satellite-based lidar altimetry technology has provided a new data source for scientific exploration of polar regions, measurement of global land topography and sea surface height measurement, and a new perspective and means for ocean altimetry.

Compared with the traditional microwave altimetry, the high-powered semiconductor laser satellite altimetry system has the advantages of wide coverage, more concentrated pulse energy, high detection accuracy, and the ability to obtain three-dimensional information. The satellite-based laser altimetry system provides a new observation method

to obtain large spatial scale and high spatial and temporal resolution observation data, which greatly expands the depth and breadth of ocean research. The accuracy of decimeter level provides a new way and favorable conditions for the measurement of sea surface height, sea ice height and sea ice thickness in polar regions.

Satellite laser altimetry system and microwave altimetry system have the same basic principle and both are satellite-carried system. For microwave altimetry system, the sensor is microwave radar, its operating frequency band is microwave, while laser altimetry is an optical remote sensor, its operating frequency band is green and near infrared light, so the laser altimeter operating frequency is many times higher than that of the microwave altimeter. High frequency means that the laser pulse will not penetrate deeply into the surface of the ground and snow and ice surface, which not only can reduce the altimetry error, but also can be well applied in the polar region containing snow and ice. Satellite laser altimeter adopts active detection method, its basic working principle is to obtain the target information by accurately detecting the time experienced by the emitted laser pulse from the emission to the earth's surface and reflected back to the receiver, and the shape of the returned full waveform. Then, based on the precise orbit and attitude data, the precise elevation data and geographic location information of the laser foot point can be determined (Fig. 6).



**Fig. 6.** Schematic Diagram of Satellite Laser Altimeter.

The United States was the first country to use satellites for altimetry. On May 14, 1973, the National Aeronautics and Space Administration of the United States launched the first satellite Skylab with altimetry performance. Its orbit running height is 425 km, the orbit inclination is  $50^\circ$ , the altimetry accuracy is 85–100 cm, and its working life is only about three months. As the Skylab is the first satellite used for height measurement, it is the result of the principle experiment of satellite height measurement, marking the official launch of the height measurement satellite. On April 9, 1975, Ceos-3 was launched from a U.S. Air Force base with an orbital altitude of 840 km, an orbital inclination of  $115^\circ$ , a high accuracy of 25–50 cm, and an operational lifetime of 2–3 years

and a repeat cycle of 23 days. Compared with Skylab, Ceos-3 not only increases the working lifetime, its orbital height, orbital inclination and height measurement accuracy have also been optimized and improved. During the 3 years of normal operation of Ceos-3, measurements of parameters such as Earth's level, wind speed, waves, ice and ocean currents can be made, providing data-based support for oceanography and geodynamics. On June 28, 1978, the U.S. launched the ocean satellite Seasat, with an orbital altitude of 800 km, an orbital inclination of  $108^\circ$ , a high accuracy of 20–30 cm, a working life of 106 days, and a repeat cycle of 3 days (pre) and 17 days (post). Its purpose is to measure the level of the ocean, wind speed, waves and currents. The launch of the ocean satellite Seasat is a historic milestone in oceanography. On March 12, 1985, the United States Navy Base launched Geosat, a geodetic satellite that provides geodynamics with accurate data of the earth's gravity field covering the whole world, and can analyze the sea surface shape, sea ice, level and other parameters. Geosat has a track running height of 800km, a running track inclination of  $108^\circ$ , a height measuring accuracy of 10-20cm, a working life of 4 years, a repeat period of 17 days. The first European remote sensing satellite, ERS-1, was launched on July 17, 1997, with an orbital altitude of 785 km, an orbital inclination of  $98.5^\circ$ , a high accuracy of 10 cm, and an operational lifetime of 3 years. Its outstanding feature is that it can change its own orbital altitude and change its own operation period. This remote sensing satellite ERS-1 can detect sea surface topography, circulation, sea ice, and it can detect 90% of the world's oceans. On August 10, 1992, the National Aeronautics and Space Administration (NASA) and the French Space Agency (ASA) jointly launched the Topex/Poseidon ocean topography test satellite, which enables more accurate measurements of the ocean surface, currents and tides. The orbital altitude of this satellite is 1336 km, the orbital inclination angle is  $66^\circ$ , the measurement accuracy is 6cm, and the working life is 4 years [10, 11].

Compared with foreign countries, China's independent research and development of altimetry satellite started later [12]. On August 16, 2011, Taiyuan Satellite Launch Center carried the "Ocean II (HY-2A)" satellite on a Long March 4B launch vehicle and successfully launched it into space. HY-2A [13] is China's first independently developed altimetry satellite applied to the ocean power environment, which can detect sea surface height, waves, currents, sea surface temperature and other ocean information parameters. During 2018–2021, China successfully launched the ocean power satellite HY-2B/2C/2D, HY-2 series altimetry satellites. The measurement accuracy of the satellites is 5-8cm, the effective wave height measurement accuracy is 0.4 m, the sea surface wind speed measurement accuracy is 1.5 m/s, the wind direction accuracy is  $19.5^\circ$ , the sea surface temperature measurement accuracy is 1 K, and the wet tropospheric path delay error is  $<20$  mm. so far, 23 altimetry satellites have been launched worldwide.

The high power semiconductor pumped solid laser altimeter carried by the satellite can measure the elevation of the sea surface, sea ice and land surface, draw the sea and land topographic map, detect the slope, reflectivity and roughness of the ice surface and sea surface, and retrieve the vegetation canopy height and biomass. Satellite altimetry has played an important role in polar scientific research, providing more abundant observation data for polar ice and snow surface elevation, sea ice density, sea ice freeboard, height and other aspects of research. The satellite laser altimeter can be called the "eye of the sea".

## 8 High Power Semiconductor Lasers in Marine Underwater Imaging Systems

The development of marine resources puts higher requirements on underwater imaging technology. At present, there are two ways of underwater imaging, optical imaging and acoustic imaging. Acoustic imaging can transmit to a long distance but with limited resolution, mostly used for seafloor topographic survey. Sonar equipment has high resolution but expensive. Optical imaging form is intuitive, more convenient for human eye observation, with the advantages of fast transmission, high resolution, real-time, etc., is the most suitable imaging method for underwater environmental monitoring.

The irregularity of suspended particle motion in the ocean causes multiple reflections and severe backscattering of seawater for optical signals, which results the light wave transmission with certain amounts of loss and strong noise, and seriously affects the imaging distance and quality of underwater optical imaging systems [14]. In order to suppress the strong backscattering of the optical signal by seawater and obtain the ideal imaging quality, researchers at home and abroad mainly use underwater laser imaging techniques such as distance selective pass and simultaneous scan imaging. The simultaneous scanning technique can effectively reduce the overlapping area between the receiver field of view and the illuminated water body, so that the backward and forward scattered light entering the receiver can be reduced to the minimum, and effectively improve the imaging quality and extend the observation distance. Underwater laser imaging plays an important role in the observation and identification of marine targets, compared with the traditional means of sonar, laser imaging has significant advantages in terms of image visualization, resolution and visibility, affected by the backward scattering of laser signals by suspended particles in the water. In order to improve the signal-to-noise ratio and imaging clarity of underwater laser imaging equipment, it is needed to use the distance selection pass synchronization control technology: using pulsed laser and image intensifier CCD camera, to separate the scattered light and the reflected light of the target in the process of laser propagation, so that the radiation pulse reflected back by the observed target just reaches the camera and images are formed within the selective time of ICCD camera (Fig. 7).

The development of foreign underwater laser imaging technology is mainly focused on the improvement of the traditional camera lens, color balance filter, pressure hole, in addition, the introduction of high-resolution camera has also greatly improved the technology. At this stage, the quality of the photos taken underwater is often not high, so the impact caused by the physical properties of water has become the focus of research on underwater laser imaging. Research on underwater laser imaging systems in the United States began several decades ago and was not reported for reasons of confidentiality. At present, the more recognized underwater laser imaging system is a synchronous scanning underwater laser imaging system used by the U.S. Navy [15], which uses an argon ion laser as the laser source, and the field of view of this system can reach  $70^\circ$ , the imaging distance range is 2.5–45 m, and the resolution can reach 25 mm for imaging distance of 30 m. There are several models of foreign underwater Laser imaging system being introduced, mainly used in underwater video recording, target detection and other purposes. Such systems can also be deployed underneath ships and vessels to capture two-dimensional images of the underwater. When the ship is underway, the

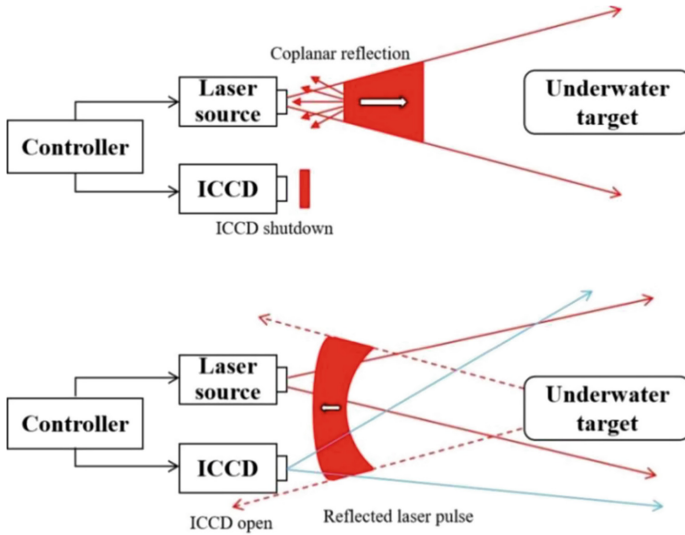


Fig. 7. Schematic diagram of underwater laser imaging principle.

two-dimensional image of the seabed will be formed by the system, the underwater laser imaging and detection distance can reach the attenuation length, the image clarity and resolution are very high. In addition, there are reports on the development of prism control laser technology system with fast rotation characteristics, which has been assembled in the military submarine.

The laser underwater imaging system can monitor submarine cables and underwater pipelines for easy detection and maintenance, and can search for submarine and mine and other underwater military targets. In the search and observation of moving targets at the same time can also achieve tracking, ranging and video recording. At present, underwater laser imaging technology has entered the practical stage, and has received the attention of the military departments of various countries.

The underwater imaging system uses a 532 nm green laser light source combined with polarization technology [16], which can be used to simulate imaging in the turbid marine environment. By combining the 532 nm laser active illumination with polarization technology, the acquired polarized image at a certain polarization angle is richer in image information and clearer in imaging quality compared to the conventional imaging raw image. This underwater imaging method can improve the resolution of the target through high contrast image information, and can provide new ideas for ocean underwater observation, worthy of being the “laser eye under the sea”.

## 9 Conclusions

In addition to ocean wind-detecting radar, through-frog rangefinder, ocean wave monitoring device, heavy metal detector, satellite range measurement system, and underwater imaging system, the high-power semiconductor laser is also the preferred light source for

underwater communication system, marine oil spill measurement fluorescence system, seabed mapping system, ocean chlorophyll concentration measurement system, marine airborne and shipborne monitoring multi-function radar system, etc. There is no doubt that high-power semiconductor lasers are the eyes of the ocean.

With the rapid development of computer science and technology, microelectronics integration technology, material chemistry science and technology, semiconductor packaging technology, precision processing, and manufacturing technology, intelligent big data fusion technology, and aerospace technology, high-power semiconductor lasers can not only be widely used in the field of marine monitoring, but will infiltrate into every corner of human activities. It is the “ideal light” and “wisdom eye” for us to look forward to and enjoy beautiful life, protect ecology, maintain peace, and explore the universe.

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