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Sun Yat-sen University College Student Innovation Training Project

application

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| Item Number | 2 | | |
| project name | Re-pump lasers for magneto-optical trap systems | | |
| Project manager | Zhong Nanxing | contact number | 13600227825 |
| College | School of Physics and Astronomy | | |
| student ID | 22344188 | professional class | Physics Grade 22 Class 3 |
| mentor | Thibault Thomas Vogt | | |
| Email | ttvogt@mail.sysu.edu.cn | | |
| Date of Application | December 14, 2023 | | |

Sun Yat-sen University Academic Affairs Department

#### 1. Basic situation

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| project name | Re-pump lasers for magneto-optical trap systems | | | | | | | | | | | | |
| Discipline | First-level subject category: Physics Second-level subject category: Atomic and Molecular Physics | | | | | | | | | | | | |
| project source | □ A. Students choose topics independently, which comes from their long-term accumulation and interest in the topic.  ☑ B. Topic selection from teachers’ scientific research projects  □ C. Students are responsible for selecting topics for projects entrusted by society and enterprises. | | | | | | | | | | | | |
| Application Amount | 22300.00 yuan | | Project deadline | One year | | Project level to be applied for | | | | National level | | | | | |
| principal | Zhong Nanxing | | gender | male | | nationality | | Han nationality | | Date of birth | | November 2003 | | | |
| student ID | 22344188 | | contact number | Mobile: 13600227825 | | | | | | | | | | |
| mentor | Thibault Thomas Vogt | | contact number | Mobile: 13322866303 | | | | | | | | | | |
| Project Description | | This experiment will design and manufacture a digitally standardized grating external cavity semiconductor laser serving the magneto-optical trap system. Realize digital control and countable action services for the basic laser components of the optical platform, becoming a universal terminal for larger experimental computing platforms. | | | | | | | | | | | |
| The person in charge’s previous participation in scientific research | | none | | | | | | | | | | | |
| Instructing teachers to undertake scientific research projects | | The magneto-optical trap system serves to capture a single cesium atom and provides a basic experimental platform for the tutor's bit gate construction of Rydberg ion detection and neutral atom calculations. | | | | | | | | | | | |
| Instructor’s support for this project | | Teachers will provide important experimental equipment such as original models and optical isolators, as well as a dedicated optical experimental platform for system construction. | | | | | | | | | | | |
| Main members of the project team | Name | student ID | | | college | | professional class | | contact number | | Project division of labor | | |
| Li Hongyi | 21305340 | | | School of Physics and Astronomy | | Physics Level 21 Class 2 | | 15875570365 | | Design and manufacturing of PCB boards and casings for laser information terminals. | | |
| Xing Yanbin | 21305438 | | | School of Physics and Astronomy | | Physics Grade 21 Class 1 | | 18210421592 | | Responsible for optical theory analysis and optical path design. | | |
| Liu Jiyang | 21305088 | | | School of Physics and Astronomy | | Physics Grade 21 Class 3 | | 13240133630 | | Design of laser information terminal control and communication system. | | |
| Wang Jian | 20344055 | | | School of Physics and Astronomy | | Class 3, Grade 22, Physics | | 19898070670 | | Assembly of lasers and design and manufacture of passive units of laser information terminals. | | |
| Zhong Nanxing | 22344188 | | | School of Physics and Astronomy | | Class 3, Grade 22, Physics | | 13600227825 | | Assembly of lasers and design and manufacturing of passive units of laser information terminals as well as overall procurement and reimbursement. | | |
| mentor | Name | Job number | | | College/Unit | | job title | | contact number | | e-mail | | |
| Thibault Thomas Vogt | 190327 | | | School of Physics and Astronomy | | Associate Professor | | 13322866303 | | ttvogt@mail.sysu.edu.cn | | |
| **1. Research purpose**  Magneto-optical trap technology is the basis for realizing atomic cooling and trapping. It is also the most common method to achieve atomic cooling so far. The laser system is its specific implementation method. The magneto-optical trap laser system we are building includes an 853nm high-power frequency-stabilized pump laser system, a 1064nm laser system that is being built for dipole force trapping of single atoms, and a 510nm laser system that has been frequency-stabilized using electromagnetic-induced transparent spectrum. . This project will build a re-pump laser and stabilize and control its frequency. It will also be an important part of the magneto-optical trap laser system.  As for the laser itself, we will mainly independently develop and implement a digitally standardized laser terminal that serves the magneto-optical trap system, which will be used to drive and monitor the laser. A large number of expensive non-domestic dispersed low-digital, non-standardized implementations The unit and sensing unit are unified and integrated into a master control information terminal. It is expected to realize monitoring data in lasers in a high-speed and high-density environment.Real-time export and real-time execution of control data.  **2. Research content**  The specific implementation of external cavity semiconductor lasers generally includes:  (1) The TEC board is used to control the temperature of the laser diode (LD/Laser Diode) within the working range near 22 degrees Celsius through a thermal conductive structure such as a heat sink layer. (Input: Generally plus or minus 10V, within 10W)  (2) Use piezoelectric ceramics (PZT) to adjust the position of the collimating lens and the angle of the grating in the model to form a littrow optical cavity. The external cavity is used for self-injection locking to compress the linewidth of the emitted light to the order of 10 kHz. (Input: generally within 100V, close to 0W)  (3) The laser diode itself needs to be powered as a current source component. (Input: generally 0.1A, within 0.1W)  (4) The thermistor is placed next to the LD to detect the temperature. (Output: detecting about 0-200KΩ)  (5) Other external sensing elements (such as using a Febry-Parot interferometer to check whether the single-mode properties of the laser beam are good) (all output)  In view of the above scenario combined with general optical experiments, we need to build aThe laser information terminal monitors and controls the above objects.  In terms of information flow, we decouple high and low speed (Analog + Data) dual channels, build two sets of high and low speed ADC conversion systems for monitoring data output, and a high-speed DAC system plus an RS485 execution system for control data execution.  The total data flow is expected to reach 10Mps, mainly contributed by multiple lines responsible for high-speed dynamic control (more than 30Kps each).  wps  Overall flow chart  **3. Research status and development trends at home and abroad**  External cavity semiconductor lasers have been widely used. Whether in gravitational wave detection projects or optical quantum computing platforms, these lasers are favored for their simple structure and excellent performance and are considered classics. However, laser monitoring and control systems are still mostly composed of decentralized and isolated terminals.  These terminals have different brands and models. In addition to being expensive, they also have different usage methods. It often takes a lot of effort for research institute personnel to learn to use these devices. The human-computer interaction is very bad. The better ones are like the Rigol oscilloscope that provides laser absorption spectrum. Although the SCPI communication is extremely slow and the VISA port operation is limited, it can at least perform external numerical control and data export and manual knob adjustment; the worse ones are like a certain service The temperature-controlled LCD module of the laser actually requires researchers to use a multimeter to monitor the internal PID data flow.  These devices that serve the laser body form dispersed units, which are isolated from each other, powered by each, and exported (if digitalized). After a failure, they must seek maintenance support from their respective manufacturers, making it difficult to guarantee and troubleshoot by themselves. The overall stability is actually It is not high, the assembly is even more complicated, and the packaging degree is often too high or too low. Eventually, the experimental platform often becomes a mess of standards made by IWC, filled with various instructions, calibration tables, and Datasets.  In short, this project expects that the digital laser we designed can effectively alleviate the above problems and make up for the lagging behind of the optical platform in this regard.  **4. Innovation points and project features**  **Innovation:**  (1) The input and output system will be integrated at the hardware layer to achieve multi-functional integration, replacing a large number of scattered modules, and is cost-effective.  (2) In order to achieve high-speed response, passive modules will be used as much as possible and computing modules will be reduced to serve as universal terminals.  (3) The high-voltage bipolar low-energy supply module (1mV noise under micro-current) and the low-voltage bipolar high-energy supply module (depending on heat generation, try to reduce it to 100mV) while sharing module resources as much as possible (such as overall bus noise reduction) The overall realization of three high-precision, low-noise, special-function modules (internal) and current source system (optical system micro-current 1mA noise).  **Program features:**  The external cavity semiconductor laser itself has low cost, high performance-to-price ratio, and its structure and principle are relatively simple. Many research groups at home and abroad choose to make their own lasers for experiments instead of purchasing them from companies.The cost of a laser is much higher than the cost of making a laser from raw materials (nearly ten times the price).  **5. Technical route, problems to be solved and expected results**  **Technical route:**  In terms of optical principles, we plan to adopt the design of Littrow configuration grating external cavity semiconductor laser. On this basis, we will use CAD to independently design and assemble each part to build a tunable external cavity semiconductor laser system. In order to conduct accurate wavelength analysis of the output laser, we use a spectrometer and measure the wavelength with a wavelength meter. In addition, we will use Fabry-Perot etalon to detect line width to ensure that the laser output meets the expected accuracy requirements. Through the combination of these means, we can achieve high-precision measurement and control of the wavelength of the laser.  In terms of circuit technology, we plan: (1) After the output data undergoes different measurements (resistance measurement, voltage measurement, current measurement), the high-speed output sensing data is quickly transmitted to the outside after the high-speed ADC module, and the low-speed data uses the low-speed ADC module. (2) The high-speed input control data is uniformly used in Analog after the DAC, so that it passes through passive units one by one and is finally modulated to the output in the specified form to achieve low latency. The low-speed control data is directly applied to the industrial controlled module under the RS485 signal to achieve low-speed output such as emergency stop or calculation of fixed parameter adjustment or sensing signal amplitude modulation.  This dual-line solution divides tasks in the frequency domain to achieve resource conservation while maintaining high performance, and effectively improves cost performance.  **Problem to be solved:**  (1) The integration workload is large: after analyzing the principles of a large number of modules, the circuits are organized and miniaturized. The board will be quite complex and requires repeated simulation and testing.  (2) Noise is difficult to eliminate: In addition to general pink noise, thermal noise will be the main noise, which places high requirements on the cooling system and faces challenges in hardware structure design. The cold noise voltage regulator is relatively expensive. It requires the design of an integrated voltage regulator master control and the use of a large number of controllable boost and buck modules, which requires a high level of professionalism in circuit design.  **Expected results:**  In order to achieve more functions and control, we control the laser through a highly integrated information terminal:  Real-time temperature control: We designed a cost-effective experimental digital control system from another experimental group, which can monitor and adjust the temperature of the system in real time to ensure stable working conditions and achieve precise wavelength control.  Blank grating angle control: The laser we built will allow the experimental digital control system to accurately control the angle of the blazed grating to adjust the optical path and interference conditions, thereby achieving precise control of the output laser wavelength.  Current size control: By adjusting the current size injected into the laser, the wavelength and output power of the output laser can be accurately controlled.  Through these extended control methods, we can achieve a higher level of precise control, so that the wavelength of the output laser can be adjusted in real time as needed. This will enable us to better adapt to different application needs, provide a more flexible and customizable experimental and research platform, and change the difficult and chaotic situation of building laser arrays in laboratories.  **6.Project research progress arrangement**  January to March 2024: Literature study (such as in-depth consolidation of optical and atomic physics knowledge required for this project) to supplement electronic technology knowledge, and learn to use Git as a working information terminal.  Early March to the end of March 2024: Design and manufacturing of lasers.  Early April to the end of July 2024: Laser information terminal module manufacturing  Early August to the end of October 2024: Integrated design and testing of laser information terminal.  Early November to the end of November 2024: Overall laser packaging.  Early December to mid-December 2024: Prepare for completion.  **7. Already have a foundation**  **(1) Research accumulation and achievements related to this project**  It should be emphasized that the Rydberg Laboratory has conducted research and collected important knowledge and background applications related to laser cooling and cesium atom capture. Therefore, we are fully prepared in terms of theoretical knowledge and necessary equipment to ensure the overall success of the project.  We have prepared a wavelength meter for detecting arbitrary Rydberg state wavelengths.  We have obtained a master laser that provides frequency stability.  We already have a cesium atomic gas chamber and a suitable photodetector.  We have implemented the PZT control module.  We have implemented the TEC control module.  We have implemented the temperature reading module.  **(2) Conditions that are already in place, conditions that are still lacking and solutions**  The project team has certain research experience: three of the team members have studied electronic technology courses, have experience in designing circuits and successfully packaging systems, and have preliminary studied basic circuit knowledge such as noise reduction mechanisms and signal conversion; one team member has participated in laser Manufacturing; one team member is determined to delve into the optical platform.  As the project progresses, we may face many technical problems. If necessary, we may need to seek technical support and seek specific guidance from our instructors. | | | | | | | | | | | | |

#### 3. Budget

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| **Expenditure account** | **Budget funds (yuan)** | **The main purpose** | **Funding plan released in stages (yuan)** | |
| **first half stage** | **second half stage** |
| Total budget funds | 22300.00 |  | 11150.00 | 11150.00 |
| 1. Business expenses | 4300.00 | Expert consultation, cloud services, computational analysis and testing, conference travel, literature search and paper publication. | 2150.00 | 2150.00 |
| (1) Expert consultation fees | 1500.00 | Seek technical consultation for a fee when necessary | 750.00 | 750.00 |
| (2) Meeting and travel expenses | 600.00 | Weekly group meeting of five people | 300.00 | 300.00 |
| (3) Literature search fee | 1200.00 | To obtain reference design drawings, purchase membership in relevant web development forums | 600.00 | 600.00 |
| (4) Paper publication fee/patent application fee | 1000.00 | Patent application may be considered | 500.00 | 500.00 |
| 2. Instrument and equipment purchase fees | 3000.00 | Supplementary test oscilloscope | 1500.00 | 1500.00 |
| 3. Experimental device trial production fee | 7600.00 | Experimental device processing and packaging | 3800.00 | 3800.00 |
| (1) Overall standardized manufacturing of lasers | 3000.00 | Direct actuator purchase and frame manufacturing (the frame has been determined, so I won’t go into details here) | 1500.00 | 1500.00 |
| (2) Laser information terminal PCB board manufacturing | 800.00 | About 100 yuan per board (sight distance and number of layers are specified) | 400.00 | 400.00 |
| (3) Laser information terminal PCB board patch welding | 1000.00 | After integration, it will be difficult to solder by oneself using micro-components. | 500.00 | 500.00 |
| (4) Laser information terminal power supply system manufacturing | 500.00 | The main power supply is subdivided into low-noise signals | 250.00 | 250.00 |
| (5) Laser information terminal cooling system manufacturing | 300.00 | Fan/thermal paste/heat sink | 150.00 | 150.00 |
| (6) Laser information terminal shell manufacturing | 2000.00 | Multi-channel large-volume housing, planned transparent and removable acrylic panels | 1000.00 | 1000.00 |
| 4. Material fee | 7400.00 | Purchase of major component modules | 3700.00 | 3700.00 |
| (1) Purchase of high-precision controllable boost chip | 1000.00 | Tens of dollars per chip, a large number of channels | 500.00 | 500.00 |
| (2) Purchase of operational amplifier chips required for high-precision controllable current sources | 1200.00 | One operational amplifier module costs more than a hundred, and requires a large amount of calculation and control. | 600.00 | 600.00 |
| (3) Purchase of high-precision power amplifier chips | 1000.00 | A 30W output module costs a hundred and a half, and a large amount of output requires | 500.00 | 500.00 |
| (4) Purchase of high-speed 16-bit ADC module | 1500.00 | Nearly two hundred single channels | 750.00 | 750.00 |
| (5) Purchase of high-speed 16-bit DAC module | 1500.00 | Same as ADC | 750.00 | 750.00 |
| (6) Purchase of low-speed ADC chips | 1000.00 | Low speed is cheaper, but it is also indispensable to realize automatic measurement and other mechanisms, and the quantity is large. | 500.00 | 500.00 |
| (7) Purchase of RS485 high-speed communication port chip | 200.00 | Multi-channel forwarding, more than ten per channel | 100.00 | 100.00 |

#### 4. Opinions of instructors

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| **tutor:\*\*\***  **Yearmoonday** |

#### 5. Recommendations from departments

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| **Seal:**  **Yearmoonday** |