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Semiconductor Laser Drive Power Semiconductor Laser Temperature Control System Design

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Abstract

To solve the stability of the semiconductor laser's output wavelength and power, the paper designed a set of laser constant current drive power and temperature control systems. The paper uses a resonant negative feedback circuit to achieve constant current control of the laser drive current. It uses a hardware proportional-integral (PI) temperature control circuit combined with a constant current drive to control the semiconductor refrigerator's working current (TEC) to achieve precise control of the laser working temperature. The research found that the control accuracy of the designed temperature control system can reach ±0.05℃, and the set temperature is continuously adjustable, and the temperature can be monitored in real-time. Experimental results show that the design can ensure stable current output and temperature control and meet high-power lasers' requirements.

Keywords

Semiconductor Laser; Constant Current Drive Power; Temperature Control System.

1. Introduction

Semiconductor laser (LD) has the advantages of small size, lightweight, high conversion efficiency, long working life, etc., and has been widely used in industry, military, medical and other fields. LD is a kind of laser with a current injection as the excitation method. Its service life and operational characteristics depend primarily on the performance of the driving power used. It is necessary to design a driving power supply that meets LD's technical requirements, has stable performance, and works reliably. In recent years, many scientific research institutes have researched and developed a series of current LD sources to ensure LD's regular operation. As the prerequisite and basis for the realization of high-energy lasers, high-power semiconductor laser drive power technology has become a vital core technology of high-energy lasers. According to the different current output modes, the driving power supply has three output modes: continuous (CW), quasi-continuous (QCW), and pulse.

CW power supplies usually use negative feedback circuits to realize automatic current control (ACC), an automatic power control (APC), and automatic voltage control (AVC). QCW power supplies generally include negative feedback current stabilization, constant current charging, and energy storage capacitor units, which can output high-stability quasi-continuous current. The power supply of pulse output mode usually adopts an RC discharge circuit, which can output a high current pulse with a low duty cycle, but generally, there is no measure to stabilize current. The driving, as mentioned above, power output mode is too single and cannot meet the high-energy laser system requirements for multiple output modes [1]. In this paper, a high-power semiconductor laser control system that integrates two constant current drive and temperature control functions are designed and produced. The system has high driving stability and temperature control ability. Besides, the system adopts a modular design idea and has a certain universality. The design of the control system can be fine-tuned to adapt to other pumps with different output parameters.

2. System principle and characteristic analysis

2.1. System principle

Compared with the traditional direct absorption spectroscopy, the LD technology adds a high-frequency sine wave current signal to the laser sawtooth scanning drive current, which realizes the laser wavelength's high-frequency modulation and intensity. As the central controller of LD, the driving power system can not only generate superimposed driving signals of DC, sawtooth wave, and sine wave to tune the current and output wavelength of LD but also can precisely control the temperature of LD to make its lasing wavelength and gas absorption line Corresponding. After regulating the driving power system, the LD outputs a laser beam of the corresponding wavelength divided into two parts by L1 (BF2 beam splitter). Part of the light beam enters the reference channel, and the other part of the light beam enters the main channel and is reflected by the L2 (reflective objective lens) into the gas chamber. Due to the gas absorption characteristics, the beam output's intensity from the gas chamber changes, and the beam is detected by the detector together with the reference channel beam. The lock-in amplifier isolates the first and second harmonic components in the detector signal. The harmonic components are combined with the gas spectral absorption characteristics to obtain relevant information (such as concentration, pressure, etc.) of the gas to be measured [2]. As shown in the dashed box in Figure 1. The DC power supply is an adjustable regulated power supply; the control circuit controls the operating parameters of the entire power supply, including output mode selection, output current size, quasi-continuous current frequency, duty cycle, etc.; overcurrent protection circuit real-time monitoring of the drive power supply The size of the output current, when the laser is overcurrent, it outputs a signal to reduce the output current to the control circuit. After the control circuit responds to this signal, the control circuit controls the multi-output mode current stabilizer circuit to reduce the output current; the multi-output mode current stabilizer circuit uses energy compression technology. The negative feedback technology in series with the current realizes the output of high stability CW and QCW current.

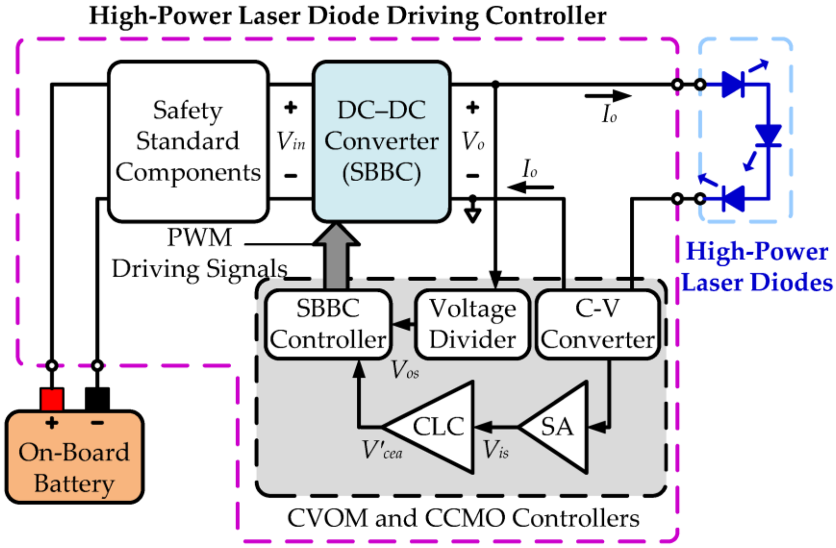

Fig. 1 Principle of high-power semiconductor laser drive power system

Energy compression technology means that the energy storage device accumulates energy steadily within a period and then releases the energy instantaneously and quickly through the load. A current pulse with a large peak current and a narrow pulse width can be obtained on the load. Figure 2 shows a circuit model commonly used in energy compression technology. MOSFET is used as the switch, and the parameters of charging voltage, discharging resistance, and trigger pulse width are appropriately selected, and the discharge circuit can generate approximately rectangular narrow high current pulses.

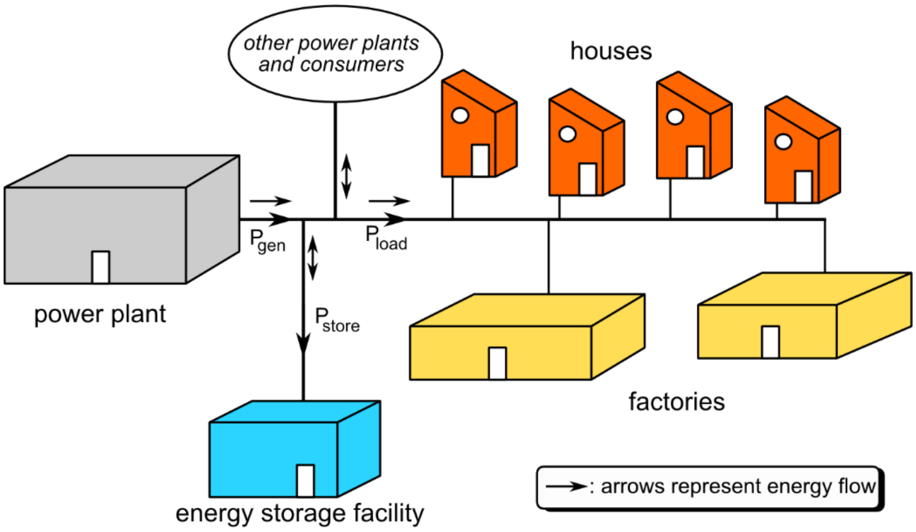

Fig. 2 Electric energy compression technology circuit model

2.2. LD output characteristic analysis

Figure 3 is a PIV characteristic curve of a typical high-power LD module, the relationship curves between LD output power and forward drive current. It can be seen from Figure 3 that when the driving current is lower than the threshold, the laser can only emit fluorescence, and when the driving current is greater than the threshold current of the laser, the laser can naturally emit laser light. Therefore, to make the LD emit laser light, it is necessary to supply the LD with a slightly larger threshold current. Moreover, the threshold current of LD is affected by temperature. The higher the temperature, the greater the corresponding threshold current [3]. At a specific temperature, when the driving current is higher than the threshold, the laser is output, and the optical output power increases rapidly with the increase of the driving current, and it rises approximately linearly.

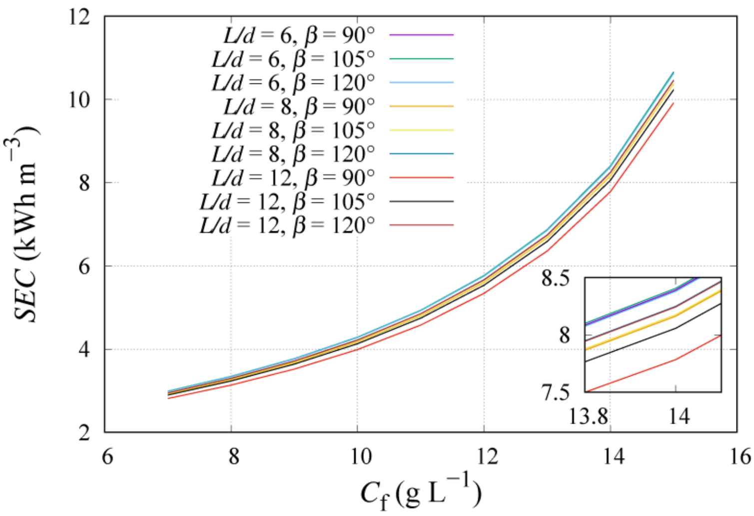

Fig.3 PIV characteristic curve of the LD module

3. Design of infrared laser power supply system

The structure of the infrared laser power supply system is shown in Figure 4, including three parts: (1) DCDC module; (2) constant current circuit; (3) power control unit. The DCDC module converts the input power into a voltage suitable for laser operation, reducing the voltage drop of the MOS tube in the constant current circuit; the constant current circuit uses current negative feedback to achieve precise control of the laser operating current. The power control unit is composed of an STM32F100C8T6 single-chip microcomputer and 485 communication circuit. It uses the Pelco_D protocol with the control host and realizes the laser switch control, brightness adjustment, and other functions according to the host's control command. The single-chip microcomputer collects the source voltage of the MOS tube of the constant current circuit through ADC1, the actual working current and the drain voltage of the MOS tube can be obtained through ADC2, and the working current setting of the current cross circuit is changed through the output of DAC2, thereby changing the laser light intensity [4]. Besides, to further optimize the steady-state operating efficiency, the microcontroller will also adjust the voltage output of the DCDC module through the DAC1, thereby reducing the power consumption of the MOSFET in the constant current circuit during steady-state operation and improving the overall operating efficiency.

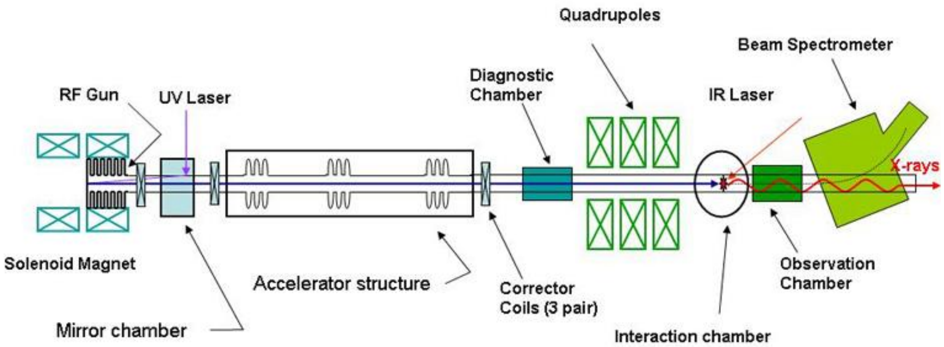

Fig. 4 System structure diagram

3.1. Rate equation

Lasers are light waves with a shorter wavelength than microwaves, and rate equations mostly describe the mathematical models of microwaves, so rate equations also express lasers. Considering the factors that cause changes in the number of carriers and photons, the rate equation of the semiconductor laser is

$$\frac{dN}{dt}=\frac{I_A}{a}-g(N)(1-\varepsilon S)S \tag{1}$$

$$\frac{dS}{dt}=\Gamma_g(N)(1-eS)S+\frac{\Gamma_g(N)}{\tau_n}-\frac{S}{\tau_p} \tag{2}$$

Where: N is the carrier density in the active region; I_A is the injection current; q are the electronic charges, V is the volume of the active region; g is the optical gain factor; ε is the gain compression factor; S is the active The photon density in the region; Γ is the light confinement factor; e is the gain compression constant; β is the spontaneous emission coefficient in the lasing mode; τ_n is the lifetime of the carrier; τ_p is the lifetime of the photon.

$$I_{spon}=\frac{aN}{\tau_n}=I_r\times\mathbf{exp}\frac{qV_j}{\eta KT} \tag{3}$$

$$I_{stim}=ag_0(N-N_0)(1-eS)S \tag{4}$$

Where: I_{spon} is defined as the spontaneous recombination current; I_{stim} is defined as the excitation-emission current; I_r is the saturation current of the heterojunction; V_j is the junction voltage of the heterojunction; η is the injection coefficient of the heterojunction; K is the Boltzmann Constant; g_0 is the optical gain constant; N_0 is the carrier density when g=0. From equation (4), we can get

$$N = I_{spon} \times \frac{\tau_n}{a} \tag{5}$$

3.2. Analog signal input

The design of the constant current drive system is shown in Figure 5. The analog signal input is used to set the working current of the constant current drive source. It can be provided by the D/A signal of the internal microprocessor of the system, or this interface can be left to the user, and an analog signal can be connected externally. The analog switch MAX4544 is used to select whether the analog signal input is provided by the internal microprocessor or by an external signal [5]. When the laser-on pin 1 of MAX4544 is low level, pin four and pin five are turned on, and the external signal is selected; when Laser-On is high level, pin six and pin five are turned on, and the internal microprocessor signal is selected.

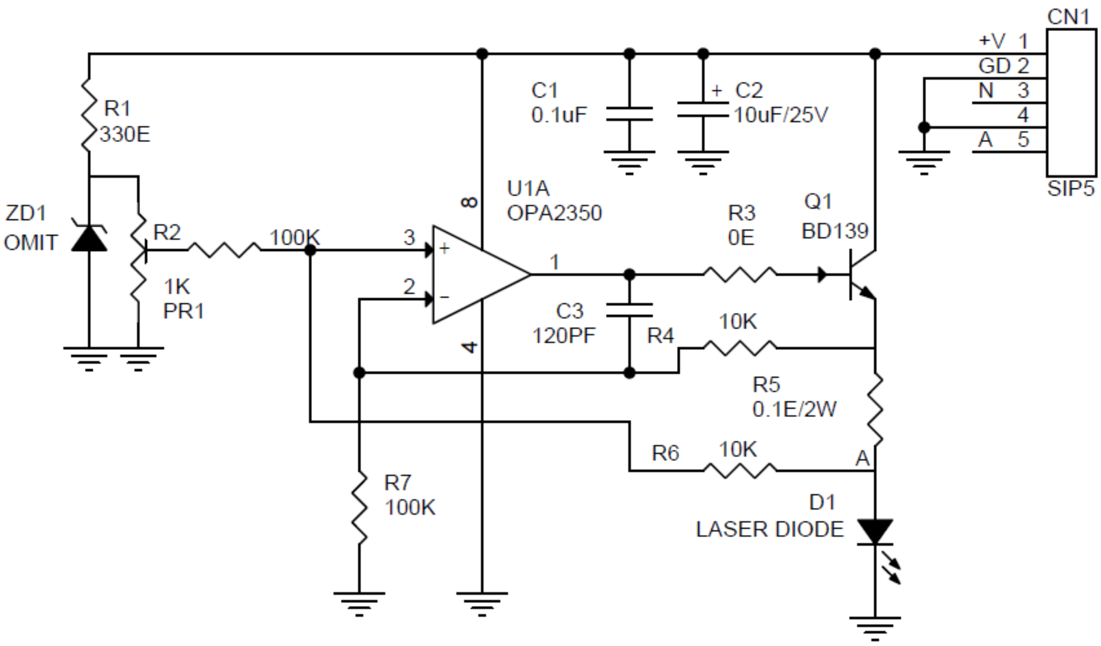

Fig. 5 Schematic diagram of the constant current drive system

3.3. Signal conditioning

To have a linear correspondence between the analog signal input and output drive current, a signal conditioning circuit is designed to adjust the linear multiple. The analog input signal is divided by R7 and R11, followed by AD822, and then through R8, R9 It divides the voltage with the sliding rheostat RP2 to generate the control signal Visit of the constant current unit.

3.4. Constant current unit

IRFP064 is used in this design, with a rated current of 110A and a thermal resistance of 40°C/W. Resistors R20-R23 are current-sense resistors, using low-temperature drift alloy resistors, with a resistance value of 10mΩ, 2510 package, and temperature drift 60ppm, which reduces the temperature rise and reduces the impact of resistance errors. U8-C, R31, R33, and R34 are 10.1 times feedback amplifier circuits. The output of U8-C is connected to the MCU ADC2 to realize the sampling of the MCU's working current. The output voltage of U8-C enters the error amplifier U8-D, U8- D, R24, and C28 form a proportional-integral circuit, whose reference signal comes from the single-chip DAC2 output. R19 and C27 form a phase compensation circuit, which introduces a zero point in the control loop to compensate for the zero points generated by the capacitance between the MOS tube's GS poles to prevent oscillations in current dynamic adjustment. This circuit realizes the control of the laser current by adjusting the gate voltage of Q3.

U8-B, C31, R32, Q6 constitute the laser overcurrent hardware protection function, and its protection threshold is 8.5A. When the working current is higher than this threshold, U8-B outputs a high level, Q6 turns on and quickly pulls down [6]. The gate voltage of Q3 turns off the MOSFET. If the MCU detects that the output of the operational amplifier U8-B is high, it indicates that an over-current fault has occurred, and the fault information will be reported to the PTZ host in time through the Pelco_D communication interface.

3.5. Principle and design of automatic temperature control

The thesis design uses a thermoelectric cooler (TEC) with a significant thermoelectric effect and high thermoelectric cooling power as the refrigeration element to realize the system's constant temperature control. The temperature sensor converts the measured temperature into a digital signal and sends it to ADuc842 for data processing. The LD operating temperature signal detected by the sensor is compared with the set temperature value. When the detection signal is less than the set temperature value, the single-chip microcomputer sends out heating temperature. When the detection signal is greater than the set temperature value, the single-chip microcomputer sends out a refrigeration temperature control signal. The control signal's size is controlled by software to realize the automatic temperature control (ATC) function. The temperature detection sensor adopts DS18B20, which is particularly suitable for forming a temperature measurement and control system with a micro-processing chip. This chip's temperature measurement range is -55℃-+125℃, and the resolution is 9-12 bits. Compared with the conventional thermistor, it can directly. The measured temperature can be read out, and a 9-12-digit value reading method can be realized through simple programming according to actual requirements [7]. The sensor transmits the temperature signal to ADuc842 for data processing and outputs through PWM pulse width modulation to control the thermoelectric cooler's drive current to achieve constant temperature control.

4. Power test results and analysis

Table 1 shows the measured output current data after 24 hours of continuous operation of the power supply. The calculated average value is 25.996A, and the expected value is 26.0A. Because of the high stability and low-temperature drift reference voltage reference, low-temperature coefficient current sensor, and current negative feedback network in the design, the drive power supply's output current has good stability.

Table 1 Power supply stability measurement data

Time/h	Current/A	Time/h	Current/A
1	26.0	13	26.0
2	26.0	14	26.0
3	26.0	15	26.0
4	26.0	16	26.0
5	26.0	17	26.0
6	26.0	18	26.0
7	26.0	19	26.0
8	26.0	20	26.0
9	26.0	21	26.0
10	26.0	22	26.0

11	26.0	23	26.0
12	26.0	24	26.0

This protection circuit has been used in practice. Due to the stable and reliable current limiting measures, the semiconductor laser's service life is guaranteed. Using the power device's turn-on, and the turn-off to absorb and isolate the surge impact forcibly, the surge impact in the pulse working state is also well suppressed. Figure 6 is the load's actual voltage waveform when the power supply is working in the pulse state.

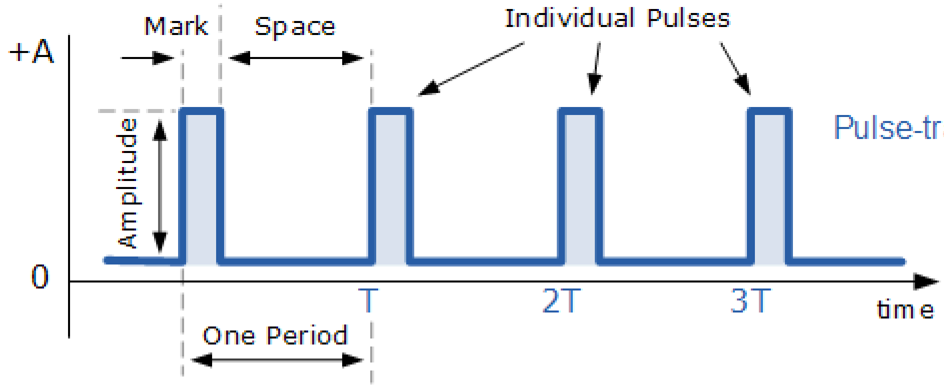

Fig. 6 Pulse current waveform

5. Conclusion

In this paper, a set of high-power laser pump source control system is designed and produced. The use of digital control mode makes the driving power supply highly intelligent and easy to operate; the use of two independent voltage-controlled constant current sources in parallel structure enhances the power output capacity and improves the power supply's reliability. It also has current limiting protection, current detection, and TTL. Various functions such as modulation, the output current can be continuously adjusted in the range of 0~12.5A, and the temperature control accuracy can reach ±0.05 ℃. The experimental results show that the system meets the design requirements and can meet the constant current drive and temperature control requirements of high-power semiconductor lasers, which has important practical significance.

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