Design and Implementation of a Capacitive Energy Storage Pulse Drive Source

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Abstract. According to the requirement of driving power supply for pulsed semiconductor laser, a method of constant current output is proposed by combining large energy storage capacitance with MOS transistor working in linear region to solve the problem of generating high amplitude, short pulse width and high stability current pulse on low impedance load. The front stage uses the buck circuit to charge the energy storage capacitor, and through the hysteresis control of the buck circuit, the voltage of the energy storage capacitor is controlled. In the latter stage, the MOS transistor working in the linear region is used to realize the pulse output, and the PI module is used to adjust the output current to ensure the constant output current. Through PSPICE simulation, the key factors affecting the output pulse amplitude, pulse width and rise time are analyzed and verified by experiments. Using 155V DC power supply, the experimental results show that the capacitor energy storage pulse driver circuit can achieve a pulse constant current output with amplitude of 30A, pulse width of 300μs and rise time of less than 10μs on a 5 Ω low impedance load.

1. Introduction
Semiconductor laser, also known as laser diode, is an electro-optic converter which uses semiconductor material as working material to produce laser. Its working principle is to make a large number of electrons and holes in the state of inversion of particle number between the energy bands of semiconductors through a certain way of excitation, so as to produce stimulated emission [1]. It has many advantages, such as wide wavelength range, small size, light weight, high reliability, long life, easy modulation and so on. It plays an important role in production, life and military application, such as laser drilling and cutting, optical fiber communication, laser micro processing, semiconductor laser ranging, semiconductor laser radar, semiconductor laser guidance and so on [2]. The driving power supply of semiconductor laser is the core component of laser system. Its performance directly affects the laser quality, the stability of optical power and the service life of semiconductor laser. In recent years, with the wide application of semiconductor lasers in large-scale industrial and even military fields, semiconductor lasers are developing towards the direction of high-power and high-power density [3]. Therefore, new challenges are put forward to the driving source. This paper mainly studies the design method of pulse constant current source used to drive semiconductor laser, designs reasonable pulse generation circuit, and carries on the experiment verification, unifies the experimental result to carry on the improvement to the circuit, causes its output pulse current amplitude, the pulse width, the rise time...
and the overshoot oscillation amplitude and so on index to meet the technical target request, finally realizes the large current amplitude, the small pulse width The goal of degree.

In this paper, a circuit design scheme is proposed in which the energy storage capacitor stores all the energy required for high-power pulse discharge, which is regulated by a linear regulator and finally achieves a stable pulse constant current output. Compared with the switching power supply, it can avoid higher output ripple and improve the voltage regulation rate. At the same time, the linear regulator is used to adjust the output current to improve the output accuracy, and the efficiency of the power supply system will not be significantly reduced.

2. Design of pulse constant current source system
The overall scheme of the capacitor energy storage pulse driver circuit system is shown in Figure 1.

![Figure 1. System Structure Diagram](image_url)

As can be seen from the system structure diagram, the main body of the driving source system designed in this paper can be divided into two levels. The front stage is an energy supply module composed of buck circuit, energy storage capacitor and its control circuit, which provides all the energy required for the output of pulse current. The latter stage is a linear adjustment module composed of MOS transistors and their control circuits working in the linear region. The energy provided by the former stage is pulse shaped, and the final output current pulse waveform meets the requirements. The working process of the system is as follows: first, the front stage charging unit charges the energy storage capacitor voltage from zero to the set voltage, and the front charging unit stops working, and the set voltage is greater than the threshold voltage of the semiconductor laser load; then, the back stage linear regulation power transistor starts to work, shaping the output current waveform. Then, in the pulse discharge gap, the front stage charging unit continues to work. After charging the voltage of the energy storage capacitor to the set voltage, the front stage charging unit stops working to supplement the energy lost by the pulse discharge of the energy storage capacitor.

The power switch device of Buck circuit works in the switch state, so the efficiency can reach more than 90%. At the same time, because the switch tube has low power consumption and low heating, the volume of heat dissipation device will be greatly reduced, thus the temperature rise inside the circuit components will be lower, which will improve the stability and reliability of the whole switch circuit [4]. The control tube of linear current control method works in the linear region, although it will make the efficiency lower, but the linear control will not cause additional interference, which means that it has low electromagnetic interference and very low ripple coefficient [5]. Therefore, we can use the MOSFET working in the linear region to dynamically and accurately adjust the output of the front Buck circuit and the energy storage capacitor to achieve high-quality pulse constant current Output. When the post stage MOSFET is in the on state, it is equivalent to a variable resistor whose resistance is controlled by voltage. The equivalent circuit diagram is shown in Fig. 2.
Figure 2. Equivalent circuit diagram

The working principle of the circuit is that during the turn-on period of the MOS transistor, the resistance value is controlled by the voltage. The front stage supplies power to the laser load through this module, and the energy storage capacitor provides energy for the discharge pulse. At the same time, it also provides a stable DS terminal voltage for the regulator tube to make it work stably in the linear region. After the end of the discharge pulse, if the voltage $V_C$ of the energy storage capacitor is lower than the lower hysteresis voltage $U_L$, the PWM module starts to work, and the driving signal is high level. At this time, the switch $Q$ is on, and the current flowing through the inductance $L$ increases to charge the energy storage capacitor. When the voltage of the energy storage capacitor is charged to the set voltage, the front charging unit stops working to supplement the energy lost by the pulse discharge of the energy storage capacitor.

3. Circuit design

3.1. Design of linear adjustment module

In this paper, we use the MOS transistor working in the linear region to replace the variable resistor $R_{in}$. MOSFET has the characteristics of good linearity, fast switching speed and low driving power. The equivalent resistance value is shown in Formula 1. The resistance value is affected by the bias voltage $V_{GS}$ and the threshold voltage $V_{th}$. The working area of MOS transistor is shown in Fig. 3. The drain current $I_D$ is determined by the gate source voltage $V_{GS}$. Therefore, the drain current $I_D$ can be controlled by controlling the $V_{GS}$ to realize the fast response and dynamic tracking of load changes, and the constant current output can be achieved through negative feedback regulation.

$$R_{eq} = \frac{1}{\mu C_{ox} (W/L)(V_{GS} - V_{TH})}$$  \hspace{1cm} (1)

In the control part of the circuit, PI regulator is used to generate dynamic bias grid voltage to change the size of $V_{GS}$ by monitoring the sampling signal. The gate voltage also considers the effect of body effect on the threshold voltage, so as to ensure the accuracy of the equivalent resistance. As shown in Figure 4, the whole module is composed of MOS transistor, feedback network, error amplifier and PI regulator. The output is compared with the reference voltage through the feedback network. The error amplifier adjusts the drain current of the power transistor by amplifying the difference, so as to realize the stability of the system output current.
3.2. Design of energy supply module

The schematic diagram of the front stage buck charging unit is shown in Figure 5. When the voltage of the energy storage capacitor is lower than the set constant voltage due to discharge, the buck circuit works to charge the energy storage capacitor. In order to achieve the purpose of rapid adjustment, the hysteresis comparator with the fastest response speed is used. At the same time, because it does not need feedback loop compensation, the structure is simple and easy to design. Its working principle is: when the capacitor voltage $V_C$ drops to low hysteresis level, the output of hysteresis controller is high level, the buck circuit starts to work to charge the energy storage capacitor, when the capacitor voltage is charged to high level, the MOS transistor of buck circuit is turned off.

Hysteresis control has the advantages of simple design, easy implementation, good stability and transient performance. Compared with other control, the biggest advantage of hysteresis control is its response speed. Unlike other control, hysteresis control does not need slow feedback loop. Its transient response time is only related to the delay of hysteresis comparator and driving circuit, so hysteresis control is the fastest control mode in theory, and its loop characteristics are shown in Fig. 6.

![Figure 3. Adjust pipe work area](image)

![Figure 4. Linear regulation module](image)
In this circuit, the energy storage capacitor provides all the energy required for the subsequent stage pulse discharge. Because the output current is fixed during the pulse duration, the voltage of the energy storage capacitor decreases linearly. If the voltage on the storage capacitor changes too much after each pulse discharge, the MOSFET will suffer excessive power loss and easily exceed the safe working area. Therefore, the voltage variation of the energy storage capacitor is set as 5V during each pulse discharge.

\[ I = C \frac{du}{dt} \]  \hspace{1cm} (2)

When the current amplitude \( I = 30A \), the pulse width \( \Delta t = 300us \) and the allowable fluctuation range of capacitor voltage \( \Delta V = 5V \) are brought into equation 2, the capacitance value of energy storage capacitor is 1.8mF. Considering the deviation of the actual capacitance and the allowance, the capacity of the energy storage capacitor is determined as \( C = 2.2mF \) with 20% margin.

4. Simulation analysis

Based on the principle analysis, PSPICE is used to build the simulation model. The simulation circuit is shown in Fig. 7.
Figure 7. Simulation circuit

The simulation waveform is shown in Figure 8. From top to bottom is the voltage of energy storage capacitor, the control signal of front and rear stage MOS transistor, and the output pulse current. It can be seen from the simulation waveform that when the discharge signal arrives, the energy storage capacitor provides all the energy needed for the current output. Only when the capacitor no longer discharges to the later stage, the front stage will turn on and start charging the energy storage capacitor. The front and rear stages work independently and do not interfere with each other, which is consistent with the theoretical analysis.

Figure 8. Simulation waveform
5. **Experimental verification and analysis**

The experimental results show that the waveform in Figure 9 is pulse output signal and control signal $V_{gs2}$ at both ends of linear MOS transistor GS. Among them, blue is pulse output signal; purple is control signal $V_{gs2}$.

![Figure 9. Discharge pulse signal](image)

![Figure 10. Output waveform](image)

When the discharge pulse signal arrives, the driving signal $V_{gs2}$ of the back stage MOS transistor $Q2$ becomes high level, and the energy storage capacitor $C$ discharges to the load through the MOS tube $Q2$. The output current waveform is shown in Figure 10, in which the green waveform is the output voltage $V_{out}$ on the load, the blue waveform is the output current pulse $I_{out}$, and the purple waveform is the voltage $V_{DS}$ at both ends of the MOS transistor DS.
From the experimental waveform, we can see that only when \( Q_2 \) of the back stage MOS transistor is turned on, \( Q_2 \) is on and works in the variable resistance area. The energy storage capacitor \( C \) discharges the load through \( Q_2 \) and provides all the energy needed for pulse output. Then, the linear modulation module is controlled by PI regulator, and the constant current output is finally realized by changing the equivalent resistance of the linear MOS transistor. The constant current pulse waveform with 30A amplitude, 300us pulse width and 11.28us rise time can be output on the load. The system has good dynamic performance and steady-state performance. The current pulse rises rapidly and overshoot is small, and drops rapidly without reverse current. After the MOS transistor of the back stage is turned off, the front stage starts to work, and the energy storage capacitor is turned off after the upper limit of hysteresis loop, waiting for the next discharge signal. The experimental results are consistent with the theoretical analysis.

6. Conclusion
According to the characteristics of buck circuit, energy storage capacitor and MOS transistor linear working area, a high-power pulse driving power supply based on capacitor energy storage is designed. The output pulse current can be adjusted dynamically by MOS transistor working in linear region, so as to realize the purpose of constant pulse current output. Through the analysis of the principle and structure of the system, the experimental platform is built for verification. The stable output current pulse with amplitude of 30A, pulse width of 300us, rising edge of 11.28us and repetition frequency of 50Hz is realized on the 5Ω diode load. The experimental waveform is analyzed, which has certain reference significance for the design of related circuits in the future.

Reference
[1] Dong Renjun. Research on high power pumped diode laser pulse power supply [D]. Yanshan University, 2017
[2] Xiao Xingzi. Analysis and design of high power semiconductor laser power supply unit [D]. Huazhong University of science and technology, 2019
[3] Yu Wangzhu. Development of driving power supply for semiconductor laser[D]. Harbin Institute of Technology,2010.
[4] Wang Qing. Research on the theory and technology of pulse constant current source for semiconductor laser[D]. Jilin University,2011.
[5] Xue Huiyun. Research and design of high stability two-way constant current source for semiconductor laser[D]. Tianjin University,2014.