Drivers for High Power Laser Diodes

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Abstract: During the last year the high power laser diodes jumped over the 1 kW level of CW power for a stack, and the commercial 1 cm bars reached 100 W output optical power at the standard wavelengths around 800 nm and 980 nm. The prices are reaching the industry acceptable levels. All Nd:YAG and fiber industrial lasers manufacturers have developed kW prototypes. Those achievements have set new requirements for the power supplies manufactuers–high and stable output current, and possibilities for fast control of the driving current, keeping safe the expensive laser diode. The fast switching frequencies also allow long range free space communications and optical range finding. The high frequencies allow the design of a 3D laser radar with high resolution and other military applications. The prospects for direct laser diode micro machining are also attractive.

Keywords: high power laser diodes; power supplies; drivers

1 Introduction

High power laser diodes (HPLD) usually have more than 10 W CW output optical power, or more than 20 W peak power for more than 1 s pulse duration. When we talk about HPLD, we shall not distinguish between single stripe emitters, or linear bars, or bar stacks. From this point, three main groups of HPLD according to their design and applications may be categorized. The first group includes continuous CW HPLD, consisting of one or several linear bars, fiber coupled in most cases, the second group includes the long pulse (more than 1 s and less than 1 ms pulse duration) QCW HPLDs. This HPLD group involves vertically or horizontally stacked linear bars, and the third group includes the diodes with short pulse duration, less than 1 s, and pulse repetition rates up to 100 kHz. An intermediate group includes the diodes that work at high repetition rates, more than 1 MHz and average power more than 20 W. For this purpose, mostly CW diodes are used with different power supplies. We shall try to define the requirements for the three main groups and at the end for the intermediate group.

2 General Requirements for the Power Supplies

The most important requirement when a HPLD is driven in the safety operation of the HPLD. The laser diodes are very sensitive devices, and even small disturbances may lead to their malfunction or drastically shortening their life time. The most important feature is that the laser diode is a current feed component. The output power depends linearly on the input current after a threshold is reached, and the voltage drop over the diode is nearly constant. In this case the dynamic impedance may be very low. For example, a standard 100 W linear bar with slope efficiency of 1 W/A: 1.89 V at 100 A minus 1.8 V at threshold of 10 A means 1 m. In all cases the power supply must satisfy the general requirements:

· slow initial start–up and shut down;
· spikes in the current must not exceed 5 % of the set current (CW or pulsed);
· appropriate grounding corresponding the grounded anode or cathode of the diode;
· not more than 0.1 V reverse voltage over the diode during operation;
· appropriate maximum current limit;
· special protection against sudden drop out in the input line–the power supply must not loose output control what ever happens;
· special protection against sparks and arcs in the connecting wires (more than 100 A with more than 100 V voltage drop are running);
· galvanically isolated control circuit.

3 Examples

1. The first group–CW HPLD. Most of the power supplies for driving laser diodes available on the market are designed following the traditional approach: low voltage power supply with current limiting circuit. The output of the power supply is a voltage one with current limitation. The feedback is taken as a voltage drop over a shunt component, and thus it became a regulated current source. In order to achieve low ripples and noise, a capacitor is used as an output filter component. This structure works well under CW operation, but it can not be switched faster than the recharging time of the output filter circuit, which is in order of several kHz. It may be increased by increasing the inverter frequency, but the feedback response is still too slow. The need for fast response comes from the protection requirements for arcs along the connection from the power supply to the laser diode. If an arc happens – the current source is out of regulation and the laser diode may be destroyed.

The possible solution is to design the power supply as true current source. Following the tradition for small space and high efficiency, a high frequency inverter transforms the input voltage (a 220 V AC mains or 24 V, 48 V input) in Fig.1. After that the transformer output current is rectified. If the inverter is designed in a way that the current through its primary coil is followed as a source for the feedback, then the transformer is designed as a current transformer, and the output current at the secondary coil follows the primary current with the ratio of the transformer. In this case the output voltage is not defined–it depends on the primary coil voltage, which is not regulated. The voltage drop over the laser diode depends on.

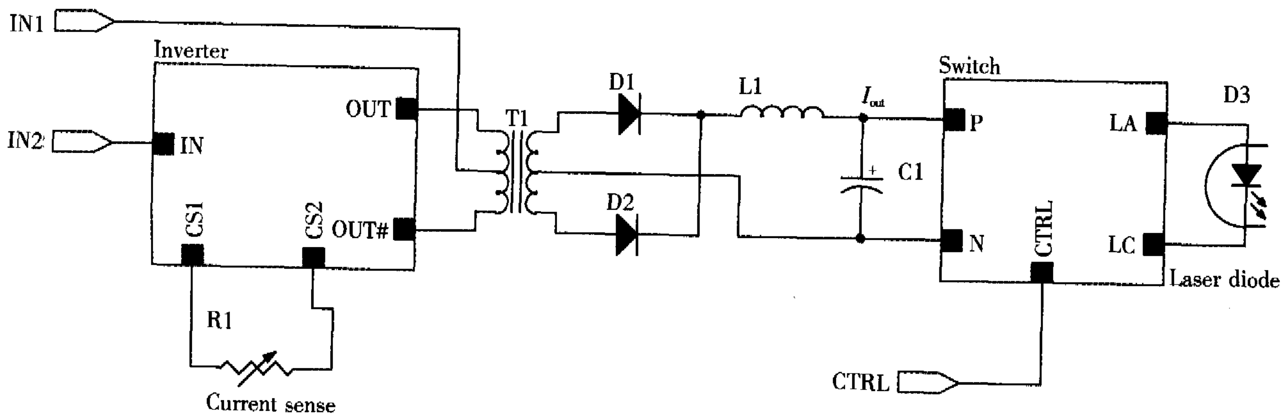

Fig.1 Current source with fast switch. max. peak currents are determined by the Max. DC current.

The efficiency calculated for the output/input power has sense only at the maximum output power. For example the current source may work when the output leads are shortened–output voltage is zero and output power also. From engineering point of view, the maximum output voltage without current must be at least 10 times higher than the voltage drop over the diode. In the other case the current source becomes a power source, and special feedback must be included in order to keep the regulation linear. Unfortunately, this is the common case, because, for example, if we have a 100 A linear diode bar with voltage drop (including connecting wires) of 3 V, we have to design a power supply with 3 kW capability.

The big difference between a true current source and a voltage source with current limitation is the output filter. In case when a voltage source is used, the output filter is a capacitive, while in the case when a current source is used, the filter is an inductive. This allows the inductance of the connecting wires between the power supply, and laser diode to be included in the total inductance of the output filter and a power supply for the third group HPLD to be implemented. The switch, located very close to the laser diode, is a combination of parallel and serial switching elements. The only inductance is the inductance of the solid leads of the laser diode itself, which may be assumed approximately several nH. The parallel and series switching elements are synchronized with appropriate delay between them. Thus, the current from the power supply is not interrupted, during switching on and off, and is regulated independently. Additionally, the voltage drop over the parallel switch may be chosen equal to the voltage drop over the laser diode. There are no spikes in current and reverse voltage over the diode during the transient times. The structure allows, according to the commercial component parameters, switching currents in the order of 200 A and higher, voltages over the laser diode stacks to 400 V, rise/fall times in the order of 5 ns and switching frequency for square wave pulses DC–30 MHz. The restrictions for higher frequencies come from the delay times of the switching elements, and the phase delay of the circuit.

An inexpensive version of the circuit (low cost and commercial switching elements) is tested with a 40 A fiber coupled laser bar. This diode is chosen because of the excellent non–inductive coupling, very good thermal coupling, easy to operation and enough space for the switch inside. The current source is LDCS–100 DC from "Y & S" company. This is a current source that delivers 100 A DC max., with 3 V maximum output voltage and galvanically isolated outputs. The noise and ripples are <0.5 % at maximum DC current. In Fig.2, the optical pulses at 40 A are shown. It is seen the rise/fall times for 200 ns pulse duration. For this switch version the rise/fall times are 18 ns / 25 ns. It is seen also that the spikes do not exceed 5 %.

The reverse pulse (interrupting the laser emission) with current–35 A is shown in Fig.3. For 200 ns the

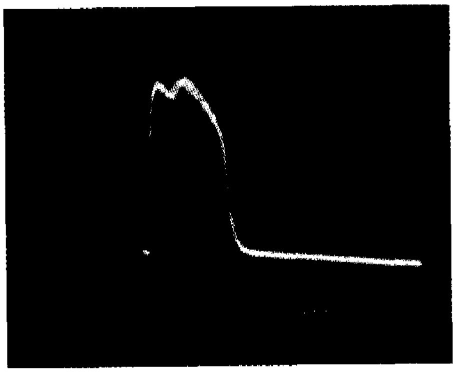

Fig.2 100 ns/division , 40 A peak current.

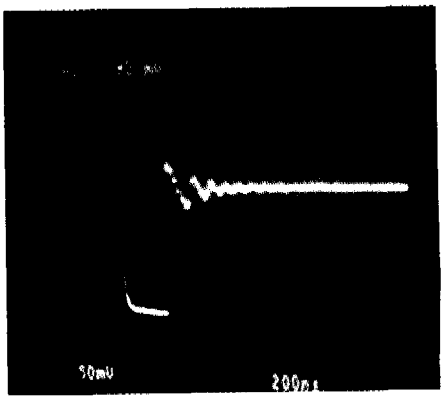

Fig.3 200 ns/division, 35 A interupted DC current.

laser diode is stopped. This version allows maximum 5 MHz switching frequency for square wave optical pulses at maximum currents 96 A. The laser diode was not driven with over currents, besides that this is possible for low duty cycles for the Coherent products. The switch is a DC one, i.e. when there is no driving input CMOS pulse, the laser diode runs at CW mode. This opens the possibility to leave the laser diode to run at 100 A DC, which is beyond the diode parameters, and we put a current limit of 40 A. The power supply has been tested with a different load at maximum output of the current source.

This example shows the possibility to drive high power (more than 100 W CW) laser diodes at high switching frequencies. This output power means hundreds km free space communication at 70 Mb/s, possibility for a 3D range finder with 15 km distance (without retro prism) and 1 cm distance accuracy.

2. The second group HPLD. This group HPLD attracts the attention of the industrial users, because those diodes give the possibilities to obtain high peak powers (in the order of kW). The average power may not exceed the CW power of the single linear bar (in practice it is less, because the cooling of the bars inside the vertical stack is poor). Normally the producers define a several times higher peak current than the CW one for pulse duration 200 s, and a duty factor of current pulses less than 20%. That means the power supply should be designed with a energy storage component (capacitor or inductor), and average power compared with the power which can be dissipated from the HPLD. Very promising when such a stack is driven with pulses duration less than 500 ns. In this case the peak current may exceed several times (even more than 10 times) the CW current. For short pulses the damage threshold of the diode facets is higher, and this major reason gives the possibility to obtain peak optical power in the order of 10 kW. This power is suitable for marking, annealing, vacuum deposition applications and etc. The power supply developed by us enables to obtain x 100 A peak currents for stacks with voltage drops 300 V and more (100 bars vertically arranged) and current rise / fall times less than 50 ns. The block diagram is shown in Fig. 4. It consists of ZCS charger of the filter capacitor, which controls the voltage, hence the diode current under CW mode. This structure is chosen, because it works as a current source, and is able to deliver high currents in compact and safety volume.

The main supply is placed in a separate case, which may be located away from the HPLD. Close to the diode and on the same heat sink is the switch. The switch consists of several modules connected in parallel. The number of the modules is chosen from the maximum current of to the HPLD, and the safety current of each of the switch MOS and IGBT transistors. The diagram of single switch is shown in Fig. 5. The transistor Q1 is turned on for an interval, needed for the current to charge the inductor and the connecting wires. Normally this time is in the order of several hundreds ns to several s. The voltage drop over Q1 is much less

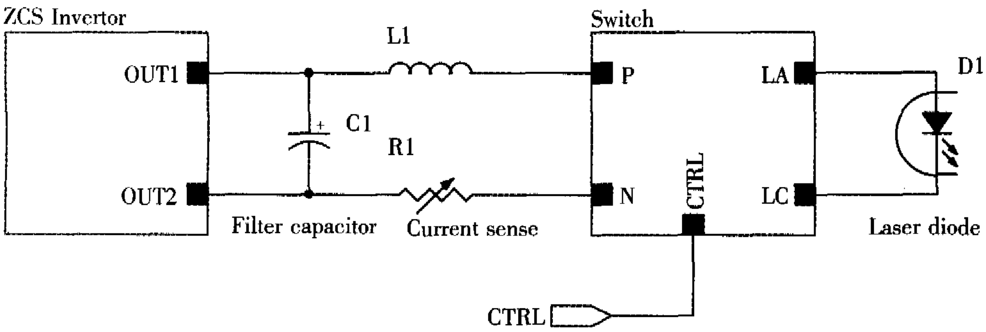

Fig. 4 Voltage source with fast switch. max. peak currents are determined by the max. voltage, resistor "current sense" and transistor "Qz".

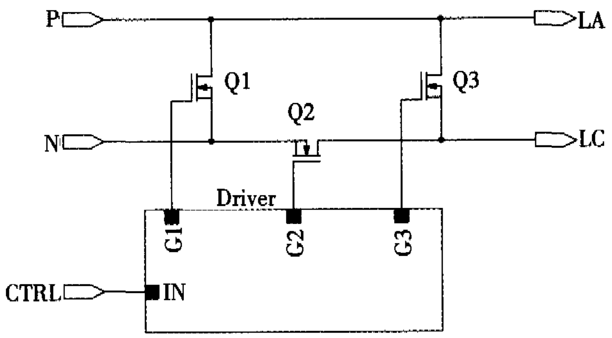

Fig.5 Diagram of the single switch.

Fig.6 20 ns/ small division, 400 A peak current.

than the voltage drop of the HPLD. For this interval the transistor Q1 is calculated according to this avalanche parameters (peak current and avalanche energy). During this time interval the switch Q2 is turned also on after a delay from the Q1 turn on of 20 ns. Rising of the current through the laser diode occurs when Q1 is turned off. The rise time of the optical pulse from the laser diode is determined from the turn off time of Q1, the inductance of the wires inside the diode and its capacitance. In Fig. 6 the 200 ns optical pulse waveform for 400 A (only 3 modules are connected) is shown. As it is seen the rise/fall times are below 10 ns and 20 ns. The current is flowing through a 40 A 10 vertically stacked bars HPLD . It is seen that the optical pulse do not have spikes more than +/–5 % from the maximum. The optical pulse energy is measured by a sensitive pyroelectric detector. The pulse peak power is calculated.

–E pulse/t pulse=0.44 mJ/220 ns=2 kW

The average power is approximately 20 W at repetition rate of 20 kHz.

4 Conclusion

The paper shows the possibilities of high power laser diodes to be driver with increased safety, thus increasing the diode lifetime.(No.1)