Designs of Q-switching Laser Power Supply with High Voltage Narrow Pulse

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Abstract: Based on the pulse generation principle of Q-switching and cavity-dumping technologies, this paper designs a power supply with high voltage and narrow pulse for switching avalanche transistor with rising edge of ns level. In the power supply, an avalanche transistor and VOMS transistor are matched to design a driving circuit, which outputs 4.6ns narrow pulse signal. The circuit replaces the traditional cable transmission signal drive mode, reduces the whole signal transmission distance, and improves the signal transmission stability. It makes the two ends of the laser Q-switched crystal KD*P be pushed off instantaneously, which shortened the output laser pulse width from 18ns to 5.6ns. The power supply with high voltage and narrow pulse can be well used in many laser fields including communication, medical treatment, ocean exploration, etc.

1. Introduction

High voltage pulse is widely used in laser pulse switch, laser radar and so on. There are two types of switch for high voltage pulse source: one is the electric vacuum device that uses electrons to operate in a vacuum; the other is solid-state device represented by avalanche transistor and VMOSE transistor with high voltage field effect. The electric vacuum device has the advantages of large volume, high power consumption, serious heat dissipation, power utilization inefficiency and weak structure; while the solid-state switch device is cheap, compact, long-lived with reliable performance. A single device can produce nanosecond and faster switching time and several hundred volts. After several devices are combined, it can produce high voltage of kilovolt level. At present, it has gradually replaced the use of other devices in pulse driving of the laser system [1]. Among all solid-state devices, avalanche triode is the most commonly used high-voltage fast pulse because of its low price, convenient use, fast switching speed and narrow output pulse front. In this paper, an avalanche triode and VMOS combination method is used to produce the high voltage 3KV electrical signal output with pulse front less than 7ns, and 5.6ns narrow pulse cavity empty laser output is obtained with the laser Q-switching system.

2. Essential Qualities of Avalanche Transistor

According to the working condition of the transistor, the output characteristic curve of the common emitter connection method can be divided into four regions: cut-off, amplification, saturation and breakdown regions. It is shown in Figure 1 below.

In case the emitter junction and collector junction are in reverse operation, the transistor is in the cut-off region.

In case the emitter junction and collector junction are in reverse operation, the transistor is in the forward direction, the transistor is in the amplification region.
In case the emitter junction and collector junction are in forward operation, the transistor is in the saturation region.

Figure 1. Common emitter output characteristic curve

In case the applied voltage is small without avalanche multiplication, in a common emitter circuit with open base, the circuit current relationship is as follows:

$$I_{CEO} = \frac{I_{CBO}}{(1-\alpha_0)}$$

(1)

If the applied voltage is high, avalanche multiplication effect will occur at the collector junction. At this time, the current amplification factor is $\alpha_0 M$, the current in the base region is $M I_{CBO}$, and the circuit current relationship becomes:

$$I_{CEO} = \frac{M I_{CBO}}{(1-\alpha_0 M)}$$

(2)

When $\alpha_0 M \rightarrow 1$, $I_{CEO} \rightarrow \infty$, the transistor breaks down, and when $\alpha_0 M=1$, the reverse voltage applied between C and E is $BV_{CEO}$.

The experimental results show that the relationship between the multiplication factor and applied reverse voltage is as follows:

$$M = \frac{1}{1-(V/V_B)^m}$$

(3)

Where $V_B$ is the avalanche breakdown voltage of collector junction, in the case of an open base, $V$ is approximately equal to $V_{CEO}$, and $m$ is a constant, which is related to the structure and material of the transistor.

The 2N551 used in this paper belongs to NPN type triode. When its collector was subject to reverse high voltage, a large electric field would be generated in the space charge area of the collector junction. As a result, the carriers passing through the collector junction accelerate and output high energy. The carriers collide with the lattice continuously, and then new carriers are generated. After the carriers are accelerated by the strong electric field, they continue to collide. This process is repeated continuously. The number of carriers flowing through the collector junction increases sharply, and the corresponding current will also increase rapidly, thus forming the transistor avalanche breakdown effect [3–4].
3. Design of High Voltage Narrow Pulse Q-Switching Power Supply

Figure 2. Circuit diagram of power supply with high voltage and narrow pulse

The high-voltage power supply was used in the electro-optic Q-switching structure of Buck cell. The VMOS avalanche transistor hybrid circuit provided $V_{\lambda/4}$ delay voltage for the Q-switching crystal. In order to achieve the best Q-switching state, we first measured the crystal voltage of the Q-switched crystal KD*P, and obtained the Q-switched voltage of 3KV. Referring to this voltage value, the VMOS avalanche transistor hybrid circuit was designed. This circuit is mainly composed of a VMOS with a driving voltage of 1KV and seven 2N5551 avalanche transistors with a working voltage of about 300V. The mixed circuit diagram of VMOS avalanche transistor is shown in Figure 2. The VMOS transistor added in the design has the characteristics of adjustable voltage and strong durability. Even when there is strong interference signal, it can also protect the circuit’s components from damage. The circuit is tested repeatedly. When the working voltage is stable, it can be used with the cavity dumping electro-optic Q-switching system.

High voltage narrow pulse cavity dumping power supply includes high voltage circuit, drive circuit and VMOS avalanche transistor hybrid circuit. The first pulse signal output by the driving circuit breaks down the first avalanche transistor, turns on the KD*P crystal, and the laser is in Q-switched state; when the dumping high voltage of the second avalanche string is withdrawn, the laser is in cavity dumping state and outputs narrow pulse laser. The system principle is shown in Figure 3 below.

Figure 3. Schematic diagram of Q-switched power supply system based on high voltage narrow pulse
4. Experimental Results

4.1 Experiment of Power Supply with High Voltage and Narrow Pulse

Two series of avalanche transistors were used in the high voltage and narrow pulse power supply designed in this paper. The matching mode of the two series avalanche transistors in avalanche process significantly influenced the laser Q-switching effect. The following two requirements should be satisfied: first, the avalanche voltage of two series of avalanche tubes should be identical; second, the laser setup time is consistent with the avalanche delay time, so that when the laser energy in the cavity reaches the maximum, all the laser is output.

By measuring the setup time of the traditional electro-optic Q-switched laser, we found when the avalanche delay time between two avalanche strings was adjusted to about 50ns, better instantaneous Q-switched laser output was ensured. Following multiple experiments, the avalanche waveform of avalanche string was obtained, as shown in Figure 4.

![Figure 4. Waveform of two avalanche strings at the same high voltage](image)

In Figure 4, the upper and lower curves correspond to the avalanche states of two avalanche strings at high voltage of 3KV. The falling edge indicates that the delay time of two avalanche processes was 48ns, consistent with the setup time of electro-optical Q-switched laser.

![Figure 5. Waveform of avalanche pulse front](image)

According to the waveform of avalanche pulse front shown in Figure 5, the output of avalanche string had only a narrow pulse front of 4.6ns, which precisely met the narrow pulse driving signal required by cavity dumping technology, and it is also the advantage of this power supply.
4.2 Experiment of Q-Switched Laser with Cavity Dumping

The instrument used in the experiment is a side pumped Nd. Its main parameters are shown in the table below:

| Parameter                  | Value       |
|----------------------------|-------------|
| Laser Crystal Size         | φ6mm×100mm  |
| Input Voltage              | 700V        |
| Repetition Rate            | 4.2Hz       |
| Output Mirror Transmittance| 12%         |

Figure 6. Waveform of cavity empty laser pulse

The high voltage narrow pulse power supply was used to replace the traditional Q-switched power supply for the laser. The avalanche string was added to both ends of Q-switched crystal, and 3KV high voltage was applied at both ends of the two avalanche strings, respectively. When the driving signal successively broke down the two avalanche strings, 5.6ns narrow pulse laser was output. As shown in Figure 6, the waveform was similar to that obtained by the conventional Q-switching technology, but the pulse width was much narrower. That is the experimental result of combining the cavity-dumping technology and the Q-switching laser power supply with the high-voltage and narrow pulse we designed.

5. Conclusion

A high voltage narrow pulse power supply was designed by using avalanche triode 2N5551 and VMOS in series. The power supply was used with Nd: YAG laser. The technology of decomposing Nd: YAG laser cavity-dumping Q-switching was used to achieve narrow laser pulse width output with pulse width of 5.6ns. The experimental results can be used in military radar, medical treatment, cosmetology and other fields. With a certain application value, the pulse source features simple hardware and stable performance.

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