

Study on the circuit producing high-speed pulse with high peak current

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To achieve high peak current with narrow pulse width, the circuit model is analyzed based on a fast and high-power metallic oxide semiconductor field effect transistor (MOSFET) as the high speed switch of the resistor-capacitor (RC) charge and discharge circuits. It is easy to obtain a narrow high-current pulse by adopting the narrow triggering pulse to control the on-off state of the MOSFET switch, and using the driving pulse to modulate the exponential decay pulse in the RC discharge loop. The procedure for the high speed MOSFET switch is then discussed. To make the speed of the MOSFET switch as quick as possible, the push-pull driving circuit for the grid of the MOSFET is brought forward and the circuit for producing the narrow trigger pulse is designed. The experimental result shows that the full width at half maximum (FWHM) of the trigger pulse is about 500 ps when the narrow trigger pulse is connected with the discharge return circuit. Measured results demonstrate that the RC discharge loop produces a narrow high-current pulse, with a peak current of up to 92.5 A and FWHM of 6.2 ns. After adjusting relevant parameters, the peak current could reach up to 115.9 A. However, the corresponding pulse width is broadened. Finally, influencing factors on the narrow pulse width for the discharge loop are briefly analyzed.

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In engineering, narrow high-current pulses have important values. For example, in a semiconductor pulsed laser ranging system, the laser must be a high peak power pulse to achieve high precision and wide-range measurement. Given that the output laser pulse is directly controlled by the excitation pulse, and the value of the driving current pulse determines the peak power of the laser pulse, the incentive system must produce a narrow current pulse.

Energy compression technology can be adopted in order to obtain a narrow high-current pulse. In this technology, energy is accumulated stably by storage devices and then released quickly by the load resistance, making it easy to obtain a narrow high-current pulse. In the discharge circuit, the storage device can be both a capacitor and an inductor.

The switch plays an important role in energy compression technology. The non-linear switch device can be a thyristor, an avalanche transistor, *etc.* However, the peak value of the current pulse generated using such a switch is not high enough. With the development of high-speed, high-power metallic oxide semiconductor field effect transistor (MOSFET) technology, using the MOSFET as a switch to produce a pulse with high speed and high current has become a good choice^[1-4]. Therefore, the driving unit used for generating narrow high-current pulse is designed based on MOSFET as a high-speed switch.

Restor-capacitor (RC) circuit discharge is the most common energy compression technology being used today. The simplified equivalent circuit of the RC charge-discharge circuit using MOSFET as a switch is shown in Fig. 1. The narrow driving pulse for the gate of

the MOSFET controls the on-off states of the MOSFET switch. These on-off states demonstrate the charge-discharge states of the RC circuit, respectively. Using the driving pulse to modulate the exponential decay pulse in the RC discharge loop, and choosing the proper parameter values of the charging voltage and the discharge resistance, it can be easy to obtain a narrow rectangle high-current pulse.

Assuming the initial charge voltage is V_0 , we ignore the role of the distribution inductance in the circuit. Then, when the charging voltage value of the capacitor C reaches V_0 , we turn the switch on. Combined with the initial conditions, the circuit equation is:

$$I = \frac{V_0}{R} e^{-\frac{t}{RC}}. \quad (1)$$

According to the equation, the current flowing through the load resistance is shown as the decay exponential, and the decay process is related to the time constant RC . The peak current is decided by the value of the initial voltage V_0 and load resistance R . If the value of RC is great enough, in a very short time after the initial moment,

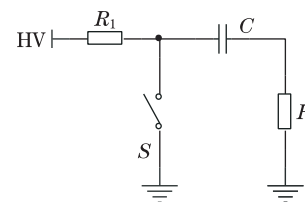


Fig. 1. The equivalent circuit of the RC charge-discharge loop.

the current function is essentially a constant. Therefore, when the time is far less than the time constant (RC), we can obtain a narrow rectangle pulse in the discharge circuit easily when we turn off the switch. Regarding MOSFET switching, rising and falling time alternates, thus, the electrical pulse becomes trapezoidal with certain rising and falling edges. In the actual discharge circuit, there must be distribution inductance consisting of wiring and switch turn-on inductances leading to increased front and back edges along the pulse. These result in curvature in the before and after points along the trapezoidal pulse, making the electrical pulse similar to the trapezoidal pulse. If the value of the distributed inductance is large enough and the width of the pulse is narrow enough, the degree of departure from trapezoidal pulse becomes significant, thus allowing the pulse to be approximated sinusoidal.

The MOSFET is a unipolar voltage controlling device with majority carriers conducted. Figure 2 is the equivalent mode of the MOSFET switch as a high-speed switch^[5]. To better understand its basic process, the storage inductances in the model are temporarily ignored.

N-channel-enhanced MOSFET works as a high-speed switch. When the gate is charged with a certain driving voltage, the turn-on and -off courses of the N-channel-enhanced MOSFET are divided into four intervals^[5,6]. The MOSFET starts when the driving signal is at a high level. In the first step, the value of the input capacitance C_{gs} of the device is charged from 0 to V_{TH} . During this interval, the MOSFET switch is not on, so the period is called turn-on delay interval. In this stage, both the drain current I_d and the drain voltage of the device remain non-charged. Once the gate is charged to the threshold level, it enters the second step. In the second interval, the gate voltage rises from V_{TH} to the miller plateau level- $V_{gs-miller}$. The MOSFET is ready to carry current, and the output current- I_d is proportional to V_{gs} . As C_{gs} is gradually charged, N_{gs} and I_d increase during this interval. In the third stage, the gate-source voltage- V_{gs} maintains the constant miller voltage. The drain-source voltage- V_{ds} quickly declines, whereas I_d remains constant. In the last step of the turn-on stage, the gate-source voltage increases from $V_{gs-miller}$ to driving signal voltage- V_{dir} . In this stage, since the turn-on resistance of the MOSFET slightly decreases, V_{ds} becomes very weak and I_d remains constant. When the driving signal reaches a low level, the MOSFET turns off. The shutdown process is similar to the turn-on process, although this one occurs in reverse.

The characteristics of the MOSFET switch essentially

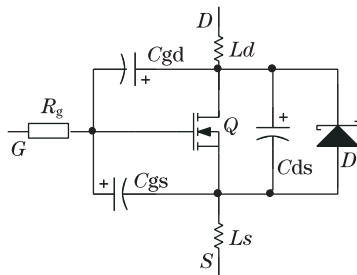


Fig. 2. The equivalent model of MOSFET as a fast switch.

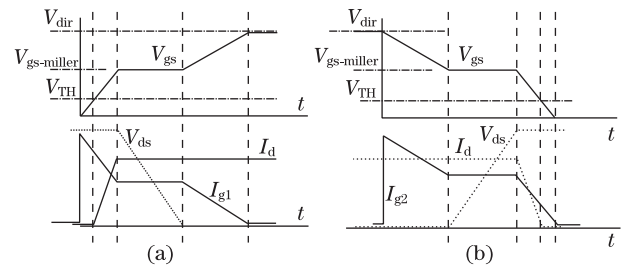


Fig. 3. MOSFET (a) turn-on and (b) turn-off time intervals.

boil down to the changed relationship among V_{ds} , I_d , and V_{gs} (Fig. 3). The parameters I_{g1} and I_{g2} represent the gate charge current and discharge current, respectively. With the existence of C_{gs} and C_{ds} , the static gate driving current almost equals to zero. However, during the dynamic process of the on or off state, the driving circuit needs to provide a push-pull current that is high enough.

According to the above analysis on the process of the MOSFET switch, in the RC discharge loop, where MOSFET is used as a high speed switch to obtain a narrow high-current pulse, the driving circuit should meet the following requirements: (1) the rising and falling edges of the trigger pulse should be fast enough, and the trigger pulse should be narrow enough; (2) when the MOSFET works as a non-linear switch on the turn-on or turn-off state, a low resistance for the gate charge and discharge circuits is necessary; (3) the driving circuit should provide a high enough push-pull current during the turn-on and turn-off dynamic processes.

To meet requirements (2) and (3), we adopted the push-pull driving method for the MOSFET (Fig. 4). Here, we chose the MOSFET characterized by low resistance, very small capacitance, and short response time for M1 and M2. When M1 turns on and M2 turns off, the output voltage of the driving circuit is at a high level. At this moment, the gate capacitor of the non-linear switch M3 is fast charged by the power through M1, and M3 turns on soon after. When M1 turns off and M2 turns on, the output voltage of the driving circuit is at a low level. At this time, the gate capacitor of the non-linear switch M3 is discharged quickly through M2, and M3 turns off soon after. The turn-on or turn-off time depends on the charge and discharge time of the gate capacitor. Using this push-pull driving mode speeds up the on and off speed of the non-linear switch M3. To obtain a narrow high current pulse, M3 should also choose the MOSFET with low resistance, very small capacitance, and short response time.

To meet the special requirement of the trigger electrical

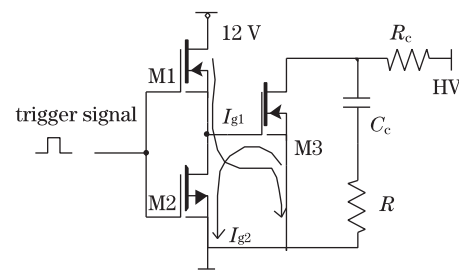


Fig. 4. Push-pull driving circuit drawing.

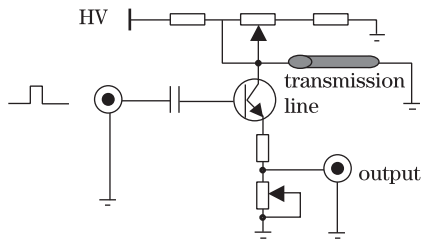


Fig. 5. Pulse reshaping circuit.

pulse for the push-pull driving circuit, we use the 555 oscillator and the pulse shaping circuit to produce the narrow high-speed trigger pulse^[7,8]. The 555 oscillator circuit is used to generate the square wave signal whose frequency and duty cycle can be adjusted. The pulse shaping circuit shown in Fig. 5 is used to make the square wave signal narrow.

In the pulse shaping circuit, we adopted the avalanche effect of the transistor and pulse forming line technology. The transistor with low avalanche breakdown voltage often has faster rising time of avalanche, but shows lower amplitude of the output pulse. The full width at half maximum (FWHM) of the square wave generated by the pulse forming line is given by^[8]:

$$\Delta t = \frac{2L}{v}. \tag{2}$$

The parameter L is the length of the pulse forming line, and v ($v = 0.19$ m/ns) is the speed of the electromagnetic field transmitting in the pulse forming line. Measurement result of the high-speed trigger pulse is shown in Fig. 6, which shows that the width of the trigger pulse can reach up to 500 ps at the very least.

When the narrow trigger pulse is connected with the discharge return circuit, we can obtain the voltage waveform of the load resistance of 0.5Ω (Fig. 7(a)).

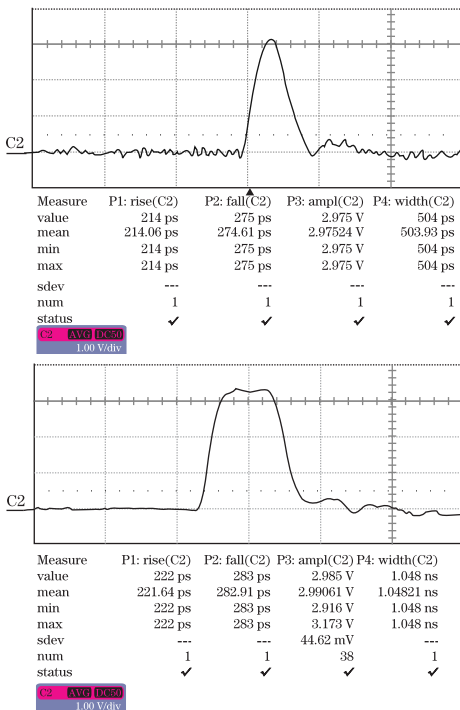


Fig. 6. Narrow trigger pulses.

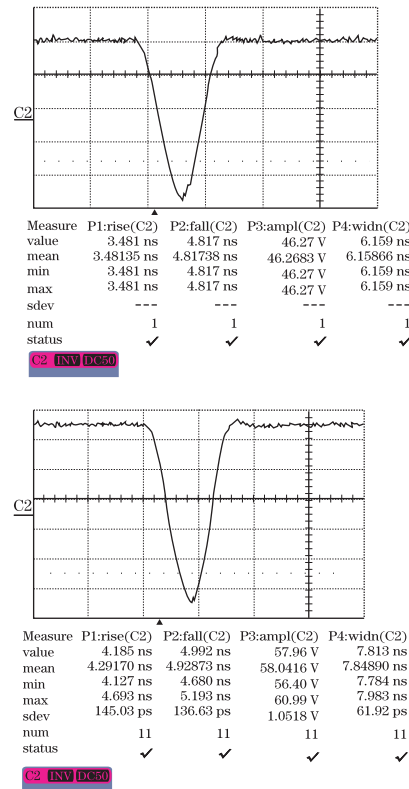


Fig. 7. (a) The voltage waveform of 0.5Ω resistance and (b) the voltage waveform after adjusting parameters.

Measurement results in Fig. 7(a) demonstrate that the RC discharge loop produces a narrow-high current pulse, with a peak current of up to 92.5 A, and a FWHM of about 6.2 ns. After adjusting relevant parameters, the measurement results are shown in Fig. 7(b). The peak current can reach up to 115.9 A, however, the corresponding pulse width is broadened.

Let LD replace resistance R , as shown in Fig. 8(a). The type of LD is LDMP-0905-0070-93. Using PIN diode

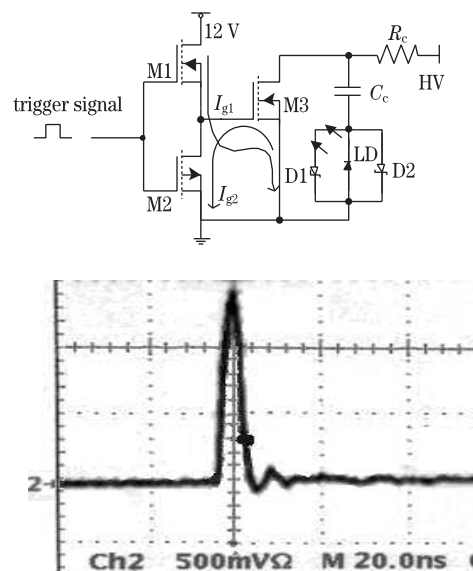


Fig. 8. (a) Schematic diagram of the laser emitting and (b) voltage waveform of the photoelectric conversion.

S5971 with the peak wavelength at 900 nm as the photoelectric detector, we can achieve the voltage waveform of the photoelectric conversion (Fig. 8(b)).

From the experimental results, the width of the pulse generated by the discharge loop is wider than the trigger pulse. This is because the width of the pulse produced by the discharge loop is determined by the width of the trigger pulse, the parameters of the MOSFET switch, the output resistance R_{dr} , the capacitance C_{dr} , the inductance L_c of the driving circuit, the connecting resistance R_c , the capacitance C_c , and the inductance L_c between the driving circuit and the discharge circuit. Therefore, the components on the circuit board should be coupled tightly so that the impact of the distributed parameters on the pulse width in the discharge circuit can be reduced as weakly as possible.

In conclusion, we have applied the transistor avalanche effect and pulse forming line technology to produce narrow trigger pulse signal. Combined with the push-pull driving mode of MOSFET to control the on-off state of high-speed MOSFET switching, the narrow high-current pulse in the RC loop has been obtained. Experiment results show that the peak current of the narrow pulse can be over 100 A, and the pulse width can be limited to several nanoseconds. The narrow high-current pulse can be used as the driving pulse for narrow high-power laser

pulses.

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