Research on electrical pulse of 20-kV/30-Hz GaAs photoconductive switches

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Photoconductive semiconductor switches (PCSSs) are widely used in high power ultra-wideband source applications and precise synchronization control due to their high power low-jitter high-repetition-frequency. In this letter, a 14-mm gap semi-insulating GaAs PCSS biased under 20 kV is triggered by a 1064-nm laser with a repetition frequency of 30 Hz. Although the trigger condition is greater than the threshold of the lock-on effect, the high gain mode is not observed. The results indicate that the high gain mode of the PCSS is quenched by decreasing the remnant voltage of pulsed energy storage capacitor.

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Photoconductive semiconductor switches (PCSSs) have been widely used in applications of high power ultra-wideband source. Many switches can be closed at the same time to obtain a required power with "rep-rated" conditions[1]. The PCSS has two operating modes, namely, linear mode and nonlinear mode (i.e., lock-on mode or high gain mode)[2,3]. The linear mode has properties of high repetition frequency and long lifetime for its speedy opening and closing; in addition, its output pulse can be controlled primitively. However, the linear mode does not undergo a carrier multiplication process and requires a high power pulsed laser trigger. High gain mode has been achieved from the PCSS made from GaAs and other direct band gap material[4,5]. Comparatively, when the PCSS is operated in the nonlinear mode, the required energy of triggering laser pulse is lower. Megawatt orders of magnitude pulse power and the subpicosecond rising time of output pulse can be obtained when triggered by the laser pulse of nJ magnitude[4]. However, numerous experimental results have shown that the lock-on mode not only limits the maximum repetition frequency of switches but also reduces the lifetime of the switches[6−8].

In this letter, a PCSS with a gap of 14 mm is fabricated. The PCSS under bias voltages of 6−20 kV are triggered by a laser pulse with optical energy, which is about 10 mJ at the wavelength of 1064 nm. By decreasing the remnant voltage of pulsed energy storage capacitor in the circuit, the high gain mode of the PCSS is successfully quenched.

Liquid-encapsulated Czochralski (LEC)-grown non-doping semi-insulating (SI) GaAs with EL2 single crystal is used as the switch material. The material has the following properties: thickness of 0.6 mm and direction of (100)±0.5°; resistivity that is larger than 5×10^7 Ω·cm; electron mobility that is larger than 5500 $cm^2/(V\cdot s)$; and dislocation density of below 5×10^4 cm^{-2}. The structure of the PCSS is shown in Fig. 1. The electrode gap of PCSS is 14 mm. The size of the electrode is 6 ×4 (mm), and the fillet radius of the electrodes is 1.1 mm. Electrodes are deposited in 500-nm-deep slots that are etched by reactive ion etching.

When the capacitance (C) is fixed, the decrease of capacitor's voltage Δu_c becomes proportional to the discharged charge amount ΔQ_c given as

$$\Delta u_c = \frac{\Delta Q_c}{C}. \quad (1)$$

It can be concluded that the voltage of the capacitor descends quickly when C is small and the on state current of PCSS is large. Compared with the initial voltage of the capacitor, the residual voltage can be called the remnant voltage. When it is not strong enough to supply the electric field required by the high gain mode of PCSS, that is, the electric field across the switch decreases below the Gunn domain sustaining electric field caused by the insufficiency of discharge energy from the circuit, the Gunn domains become quenched in the bulk of PCSS away from the electrodes, resulting in the generation of the quenched-domain mode[9,10]. Switches then exit the high gain mode, and the high gain mode of nonlinear PCSS can be quenched by precisely adjusting the remnant voltage of the capacitor.

GaAs EL2 PCSS was triggered by the SGR-S/100Q neodymium-doped yttrium aluminum garnet nanosecond laser pulse. The laser operated at a wavelength of 1064 nm with a full-width at half-maximum (FWHM) of 8 ns. The laser pulse energy ranged from μJ to mJ. TDS-5104 (Tektronix, USA) storage oscilloscope was used to measure the output signal. A 60-dB coaxial attenuator with a bandwidth of DC-12.4 GHz (Shanghai Yamei Microwave Instrument Factory, China) was used between the PCSS and the oscilloscope. The capacitance of the pulsed energy storage capacitor was 3.2 nF in the circuit. The basic testing circuit is shown in Fig. 2, and the results are shown in Table 1.

The output electrical pulses at the bias voltages of 6, 15, 16, and 20 kV are shown in Figs. 3(a)−(d), respectively. When the bias voltage is 15 kV, the output pulse has oscillation in the trailing end (Fig. 3(b)). The

Table 1. Experimental Results of GaAs PCSS at Different Trigger Energies and Bias Voltage Levels

Bias Voltage (kV)	Laser Pulse Energy (mJ)	Frequency (Hz)	Output Electrical Pulse			Figure 3
			Rising Time (ns)	Descending Time(ns)	FWHM (ns)	
6	7	1	25	30	42	(a)
15	10	1	17	19	17	(b)
16	10	1	11	18	15	(c)
20	5	1	8	10	13	(d)

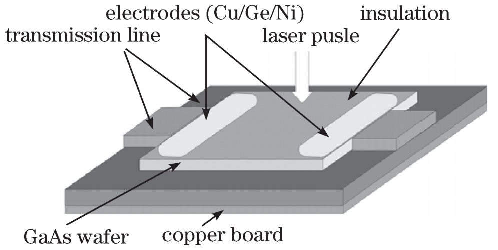

Fig. 1. Chip structure of PCSS.

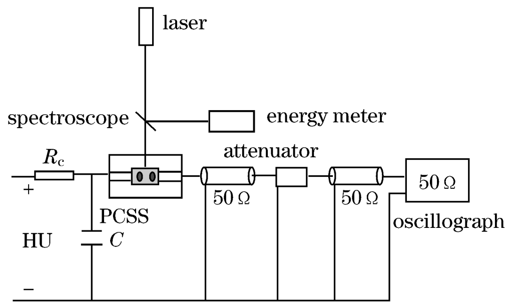

Fig. 2. Experimental circuit diagram. HU: DC high voltage power supply.

FWHM values at 16 and 20 kV are narrower than that at 6 kV, which are shown in Figs. 3(c) and (d).

If the pulsed energy storage capacitance can provide enough energy to the PCSS, it can work at a high gain mode when the laser energy and bias electrical field are higher than their thresholds[3]. Figure 4 indicates the typical non-linear output electrical pulse of the PCSS at the bias electrical field of 6.8 kV/cm and laser energy of about 10 mJ.

When bias voltage is below 8 kV, the switch works under the linear work mode because the bias electric field is less than the threshold required by the high gain mode of GaAs PCSS. When bias voltage is above 10 kV, bias electric field becomes much larger than the threshold. As a result, the switch works under the high gain mode at the beginning of light trigger, and the rising edge of output electrical pulse is faster than the linear mode. Given that the small reservoir capacitance is chosen, capacitor voltage descends quickly with the discharge of capacitor, causing the high gain mode of PCSS quench in few nanoseconds. The results of the experiment on the quench mode with high gain prove that the method of controlling the remnant voltage of reservoir capacitance is effective.

From the experiment, we also know that the rising edge of output electrical pulse is steeper and the peak voltage is higher when trigger laser energy is enhaned. Both the rising time and descending time decrease with the increase of bias voltage. This indicates that the FWHM becomes narrow because the velocity of the carrier is enhanced with the increase of voltage.

The stability of PCSS was tested by triggering number of times at the repetition frequencies of 10 and 30 Hz. These are shown in Figs. 5(a) and (b). The results indicate the high gain PCSS can be quenched and stable electrical pulse can be obtained by decreasing the remnant voltage of the pulsed energy storage capacitor.

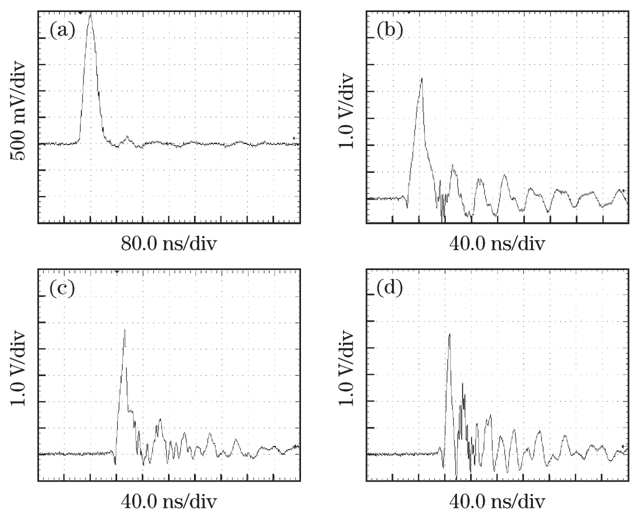

Fig. 3. Output electrical pulses when bias voltages are (a) 6, (b) 15, (c) 16, and (d) 20 kV.

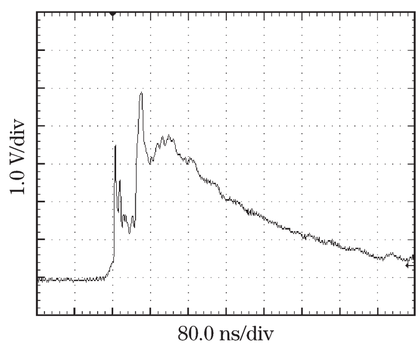

Fig. 4. Non-linear output electrical pulse at a bias field of 6.8 kV/cm.

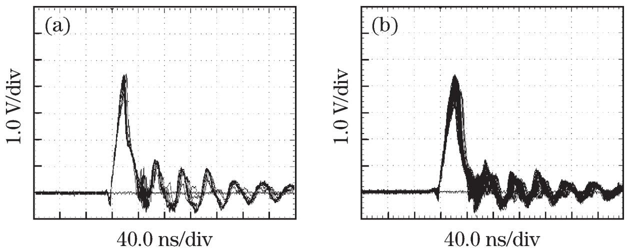

Fig. 5. Overlap wave shapes when repetition frequencies are (a) 10 and (b)30 Hz.

In conclusion, a 20-kV/30-Hz SI-GaAs PCSS with the gap of 14 mm and an optimized structure is fabricated. The PCSS is triggered by a laser pulse with the time duration of 8 ns. The high gain operation mode of PCSS has been quenched and the stable output electrical pulse obtained using a 3.2-nF pulsed energy storage capacitor to decrease its remnant voltage. At the linear mode, the rising time and FWHM obtained are 25 and 42 ns, respectively, at the bias voltage of 6 kV and trigger laser energy of 7 mJ. However, at the high gain quenching mode, the rising time and FWHM decreased to less than 20 ns.

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