Ultra-Wideband Electromagnetic Radiation from GaAs Photoconductive Switches *

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Abstract : The experiment results of ultrawide band electromagnetic radiation with DC biased GaAs photoconductive semiconductor switch combining double ridge horn antenna triggered by high repeat frequency femto-second laser pulse are reported. The GaAs switches are insulated by solid multi-layer transparent dielectrics and the distance of two electrodes is 3mm. The electrode material of the switch is ohmic contact through alloy technics with definite proportion of Au/ Ge/ Ni. This switch and double ridge horn antenna are integrated and the receive antenna is connected with the test instrument. From receiving antenna ,ultra fast electrical pulse of 200ps rise time and 500ps pulse width is obtained ,the repetition rate of the pulse is about 82MHz and the frequency spectrum is in the range of 4. 7MHz～14GHz. The radiation characteristic of the ultrafast electrical pulse is analyzed.

Key words : GaAs photoconductive switch ; ultra-wideband microwave ; femto-second laser pulse
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1 Introduction

The photoconductive semiconductor switches(PCSS) as a new kind of ultrafast microwave generator have drawn more and more attention in recent years. The switches offer unique properties such as GHz repetition rate , jitter free , small parasitic inductance and capacitance , optical insulated triggering ,wide dynamic range being suitable for various transmission lines ,etc. Besides , PCSS can operate at high voltage and high current , which is the most promising in the high power ultrashort electromagnetic pulse generation ,ultrawide band electromagnetic radiation generation , and electromagnetic weapons. The microwave source with PCSS is wideband. The rise time of electromagnetic pulse is in subnonasecond or picosecond level , and the relative wide of band exceeds 25 % , whose frequency band is ranged from tens of MHz to several GHz and even to tens of GHz[1～5]. In this paper ,the experiment results of ultra-wideband electromagnetic radiation by PCSS and double ridge horn antenna are reported. In the experiment ,we tested the radiated waveform and frequency spectrum and got the electromagnetic radiation with the rise time of 200ps ,the pulse width of 500ps ,the pulse repetition frequency of 82MHz , and the pulse frequency band wide of more than 14GHz. At the same time , we analysed the mechanism and characteristic of the radiation with PCSS.

2 Experiment

The semiconductor material used for photoconductive switch was a semi-insulating GaAs with a thickness of

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0.6mm. The resistivity in total darkness was $>5\times10^7\Omega\cdot$cm, and the mobility was $>5500cm^2/(V\cdot s)$. The sample size was 9.0mm ×6.0mm, and the distance between two electrodes was 3mm. Two parallel alloy electrodes of Au/Ge/Ni were deposited on the semi-insulating GaAs wafer, following which a 900nm Si_3N_4 layer and a new type of solid-state insulation protection material called organopolysiloxane gel was coated[6]. The GaAs switch chip is mounted on the suited planar transmission line that is connected to the outside by two coaxial connectors. The characteristic impedance of coaxial transmission line is 50Ω, and the bandwidth is 100ps.

A Ti-sapphire laser system produces 100 fs-pulse duration, 82MHz repetition rate, and 0.83～0.90W average power at 800nm wavelength. The optical pulse train is lightly focused to a 1.5mm-diameter spot and is incident upon the center of 3mm-gap GaAs photoconductive switch. The switch and double ridge horn antenna are integrated and the receive antenna is connected with the oscillograph and frequency analytical instrument through coaxial transmission line as shown in Fig. 1. The oscillograph is Lecory-8500A wavemaster series with the bandwidth of 0～6GHz. The spectrum analyzer is HP 85292L, and its scan frequency is 9kHz and the band width is between 9kHz～22GHz. The antenna used is double ridges horn antenna with bandwidth in the range of 1MHz～18GHz.

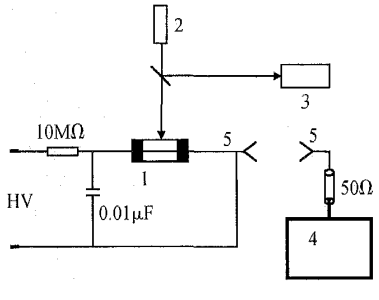

Fig. 1 Experimental setup of radiation of GaAs PCSS
1: PCSS; 2: laser; 3: energy radiometer; 4: oscilloscope/spectrum analyzer; 5: antenna.

A good temporal characteristic was observed when the switch was under the biased DC voltage of 800V and triggered with the fs laser pulses. A clear corresponding output electric pulse string was captured, as shown in Fig. 2. Being limited by the coaxial transmission line, the width of electric pulse is in subnonasecond level. From the sampling single pulse produced by PCSS biased at 5000V, we can see that the rise time is less than 200ps and the width of the pulse is about 500ps.

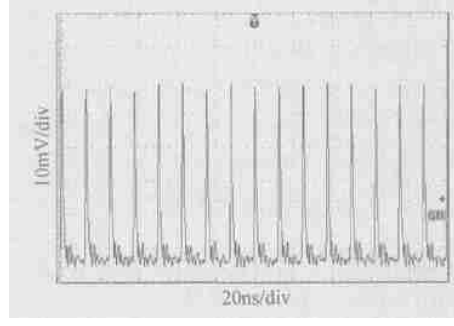

Fig. 2 Electric pulse string triggered by femtosecond laser pulse

The PCSS was triggered at different bias voltage between 0～10000V. The output electrical pulse from switch was radiated and received by wideband antenna in the scope of lab. At terminal the signal was inputted into oscillograph or spectrum analyzer. The electromagnetic wave string with repetition rate of 82MHz outputted from antenna with PCSS biased at 5000V has been collected by oscillograph as shown in Fig. 3.

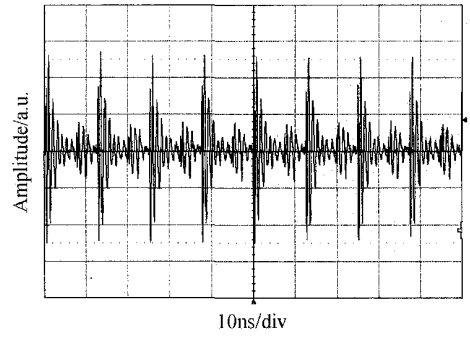

Fig. 3 Eelectromagnetic wave string with repetition rate of 82MHz outputted from antenna with PCSS biased at 5000V

From the spectrum analyzer fitted at the terminal, the

frequency spectrum of electromagnetic radiation was obtained shown in Fig. 4. The frequency spectrum begins from 4.7MHz and ends beyond 14GHz.

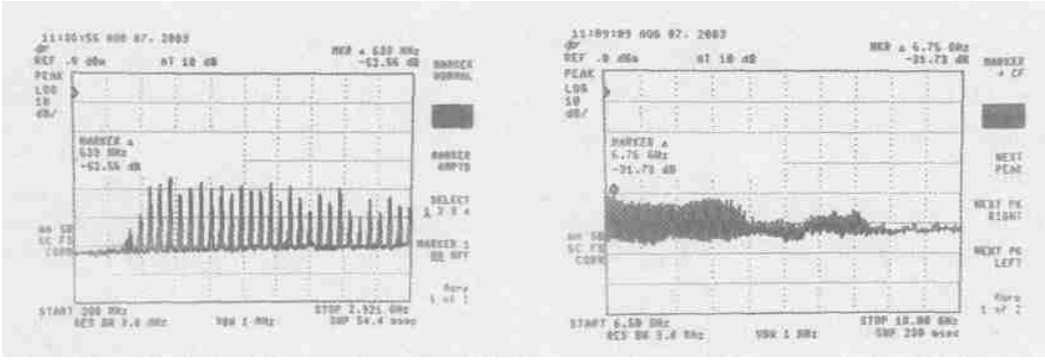

Fig. 4 Picture obtained by spectrum analyzer It shows the frequency spectrum of electromagnetic pulse outputted by receiving antenna.

3 Discussion

When the biased GaAs PCSS was triggered by fs laser pulses, the rise time and width of electric pulse depend on rise time and width of the triggering laser pulse, and the fall time of electric pulse is mainly effected by the lifetime of the carriers recombination of semiconductor. So, the waveform of electric pulse is determined by three factors: the waveform of laser pulse, the lifetime of carriers, and the charge dissipation coefficient[7~10].

For the semi-insulation GaAs material, the conductance can be expressed as

$$G(t) = q\mu N(t)(1 - R)/L^2 \qquad (1)$$

The output voltage on load Z_0 can be denoted as

$$V_{out} = V_{in} Z_0/[1/G(t) + Z_0] \qquad (2)$$

where q is the electric quantity, μ is the mobility, $N(t)$ is the number of carriers, R is the reflectivity of the light, L is the length of electrode gap, V_{in} is the bias voltage. From Eqs. (1) and (2), it is noted if the fabrication of the switches is certain, the change of output voltage is mainly limited by production rate of photogenerated carriers.

After the laser pulse was terminated, the recombination of electron-hole makes the density of carriers declined. If the lifetime of carriers is τ_r, the number of carriers reduced can be described as: $N(t) = N_0\exp(-t/\tau_r)$, so the photoconduction $G(t) \propto \exp(-t/\tau_r)$. From Eq. (2), the conclusion can be drawn that the fall time of PCSS outputting electric pulse is determined by the lifetime of the photogenerated carriers.

The rise time and fall time have a very important influence on the distributing of frequency. Supposing the trigger pulse is δ pulse, neglecting the influence of dark conductance, and considering the effect of carriers recombination, conductance can be denoted as:

$$G(t) = \begin{cases} 0, & t < 0 \\ g_0\exp(-t/\tau_r), & t \geq 0 \end{cases} \qquad (3)$$

where g_0 is the peak conductance, C_g is the gap capacitance of switches. The outputting voltage of PCSS is determined by[11]

$$V_{out} = \frac{V_{in} Z_0 G_0}{1 + Z_0 G_0}\left\{1 + \frac{1}{Z_0 g_0 C_g}\int_{-\infty} dt' g(t') \times \exp[-\gamma(t - t')]\right\} \qquad (4)$$

where $\gamma = (1 + Z_0 G_0)/Z_0 G_0$. Putting Eq. (3) into Eq. (4), we get the expression of outputting voltage

$$V_{out} = \frac{V_{in} g_0}{C_g}\left|\frac{\exp(-t/\tau_r) - \exp(-t/\tau_c)}{1/\tau_c - 1/\tau_r}\right| \qquad (5)$$

where τ_c is the rise time of electric pulse. The Fourier

transform method (FTE) was applied to Eq. (5) ,and then we get the function of the frequency distribution of the output electrical pulse as

$$|V(\omega)| = \frac{V_{in} g_0 Z_0}{\sqrt{2\pi}} \times \frac{\tau_r}{[(1 - \tau_r \tau_c \omega^2)^2 + \omega^2 (\tau_r + \tau_c)^2]^{1/2}} \qquad (6)$$

From Eq. (6) ,if both Z_0 and g_0 are unchanged ,the frequency distribution of the output electrical pulse is only influenced by the rise time of electric pulse (τ_c) and the lifetime of carriers (τ_r). If τ_r is stable and τ_c is more smaller ,the electric pulse will include more components of high frequency ,in other words ,the frequency bandwidth will be wider.

4 Conclusion

In summary ,the experiments of ultrawide band electromagnetic radiation with a lateral semi-insulating GaAs photoconductive semiconductor switch combining double ridge horn antenna triggered by high repeat frequency femto-second laser pulse were reported. The switches were insulated by solid multi-layer transparent dielectrics. The electric pulse string with 200ps rise time ,500ps pulse width ,and 82MHz repeat frequency from the 3mm-gap GaAs switches were observed. Being limited by the coaxes transmission line ,the width of electric pulse is in sub-nonasecond level. Integrating the PCSS to the double ridges horn antenna with coaxial cable ,the ultrawide-band electromagnetic wave can be radiated by PCSS microwave source. In our test the frequency spectrum of electromagnetic wave begins from 4.7MHz and ends beyond 14GHz. The mechanism and characteristic of the radiation with PCSS were analyzed. When the rise time of the electric pulse was more smaller ,the electric pulse would include more components of high frequency ,in other words ,the frequency bandwidth would become wider.

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基于 GaAs 光电导开关的超宽带微波源 *

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摘要：报道了用飞秒激光脉冲触发 GaAs 光电导开关产生超短电磁脉冲辐射超宽带电磁波的实验结果，分析了超短电脉冲串经宽带天线的辐射特性. 在接收端获得了上升时间 200ps、脉冲宽度 500ps、重复频率 82MHz 的超短电脉冲串和经宽带天线辐射的超宽带电磁波波形，其电磁波频谱覆盖 4. 7MHz～14GHz.

关键词：GaAs 光电导开关；超宽带微波；飞秒激光脉冲

PACC：0660J；5270G；4280W

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