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Transient Characteristics of a Nonlinear GaAs Photoconductive Semiconductor Switch*

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Abstract: The transient resistance, voltage, and power of a nonlinear GaAs photoconductive semiconductor switch (PCSS) are presented by the finite difference formula to deal with the experiment data, based on the conversation of energy in the switch circuit. This method resolves the problem of directly measuring the transient characteristics of PCSS in nonlinear mode. The curve of transient voltage shows that the average electric field of PCSS in the lock-on period is always higher than the Gunn threshold, and increases monotonically. By comparing the transient power curves of the PCSS and the electrical source, it is demonstrated directly that the power shortage leads to the PCSS from the lock-on state into the self-turnoff state, so a controllable turnoff of the PCSS in lock-on by changing the distribution of the circuit power is predicted.

Key words: photoconductive semiconductor switch; lock-on effect; nonlinear mode; controllable turnoff

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1 Introduction

The photoconductive semiconductor switch triggered by laser pulse has attracted great attention in the field of pulsed power technology. There are two working modes for PCSSs: linear and nonlinear. The nonlinear mode (also known as the lock-on mode or the high-gain mode) has demonstrated many amazing experimental phenomena[1,2] and is observed in Ⅲ-Ⅴ PCSSs. In some applications, such as the firing set, the nonlinear mode is better than the linear because the triggered laser power of the former is far less than that of the latter and the rise-time of the former is faster. Although the nonlinear mode of PCSS was discovered more than 20 years ago[1], the study of the physical mechanism of the lock-on effect is still unsatisfying to resolve the operating instability[2]. Thus, the nonlinear PCSS has not come into practical application. The transient characteristics of PCSS are important in studying the physical mechanism and optimizing the structure, but the transient electric field on PCSS is quit difficult to measure directly by electro-optic sampling based on the Pockels effect.[3,4] The transient resistance and power of PCSS have not be reported, so the multifarious models explaining lock-on and high-gain are based upon data from estimates or purely theoretical calculations[5~7]. In this paper, the transient resistance, voltage, and power of a nonlinear GaAs PCSS are presented by the finite difference formula to deal with the experiment data, using the formula based on the conversation of energy in the switch circuit.

2 Experiment

As shown in Fig. 1, the GaAs PCSS consists of three parts: the undoped semi-insulating GaAs : EL_2 chip, two electrodes with Au/Ge/Ni Ohmic contacts, and 50Ω microstrips connected outside with coaxial connectors. The parameters of this GaAs: EL_2 chip are: the thickness is 0.6mm, the dark resistivity (ρ) $\geqslant 5\times10^7\Omega\cdot$cm, and the electron mobility >5500cm^2/(V·s). The gap (l) between the electrodes is 3.5mm. Because of a special insulation protection[8] on the surface, the dark insulation intensity of the

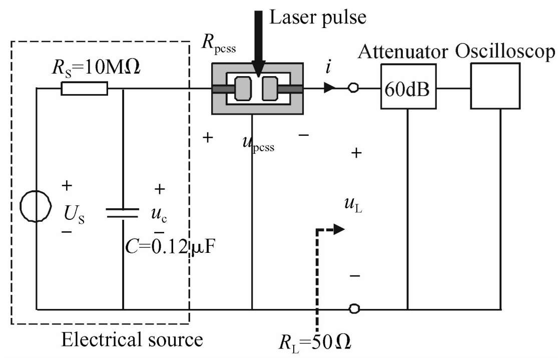

Fig.1 Circuit model of experiment

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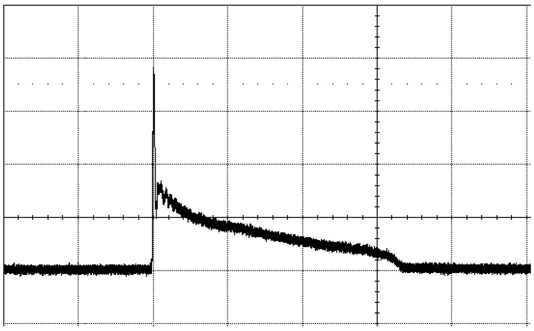

Fig.2 Waveform of nonlinear mode (x: 500ns/div, y: 500mV/div)

surface is more than 35kV/cm.

The circuit for the experiment is shown in Fig. 1. The transmission lines are impedance matched with the lecroy-8600A oscilloscope (as 50Ω load) and the 60dB coaxial attenuator (0～18GHz bandwidth). The PCSS is triggered by a laser pulse (1064nm, 3.5ns and 1.8mJ) from a Nd:YAG laser when $U_S = 2200$V. As shown in Fig. 2, three periods are observed in the 1650ns: trigger-on state (40ns), lock-on state (1560ns), and self-turnoff state (50ns).

3 Calculation and discussion

The capacitance of PCSS is less than 1pF, so we regard the PCSS as a time-varying resistance (R_{pcss}). Since $R_S C = 1\text{s} \gg 1650\text{ns}$, the charging process from U_S to C is ignored. The energy dissipation on the transmission line is ignored because the impedance of the transmission line is matched with the load and the length of the transmission line is very short. Moreover, it is known by fast Fourier transformation that the frequency spectrum of the signal is mainly under 10MHz, so the reflection and radiation of electromagnetic wave in the PCSS is ignored. Therefore, the formulas for energy transformation based on the conversation of energy are:

$$\Delta W_c = \frac{u_L^2(n)}{R_L^2} \times [R_{pcss}(n) + R_L] \times \Delta t \tag{1}$$

$$u_c(n+1) = \sqrt{\frac{2 \times [W_c(n) - \Delta W_c]}{C}} \tag{2}$$

$$R_{pcss}(n+1) = \frac{u_c(n+1)}{u_L(n+1)/R_L} - R_L \tag{3}$$

$$u_{pcss}(n) = R_{pcss}(n) \times \frac{u_L(n)}{R_L} \tag{4}$$

$$p_{pcss}(n) = u_{pcss}(n) \times \frac{u_L(n)}{R_L} \tag{5}$$

The initial condition is:

$$W_c(0) = \frac{1}{2} C U_S^2,\quad R_{pcss}(0) = \rho \frac{l}{s} \tag{6}$$

where W_c is the energy of the capacitor, p_{pcss} is the power of the PCSS, and s is the flow area of the PCSS. The discrete-time data of u_L is given by the oscilloscope. These formulas are independent of the structure (lateral or vertical), the material (GaAs : Cr, GaAs : Cu, InP, etc), and the laser pulse. These formulas are unfit for the linear mode because the reflection and radiation of the electromagnetic wave in the PCSS is ignored. These formulas are also unsuitable for other circuit structures, such as the Blumlein structure.

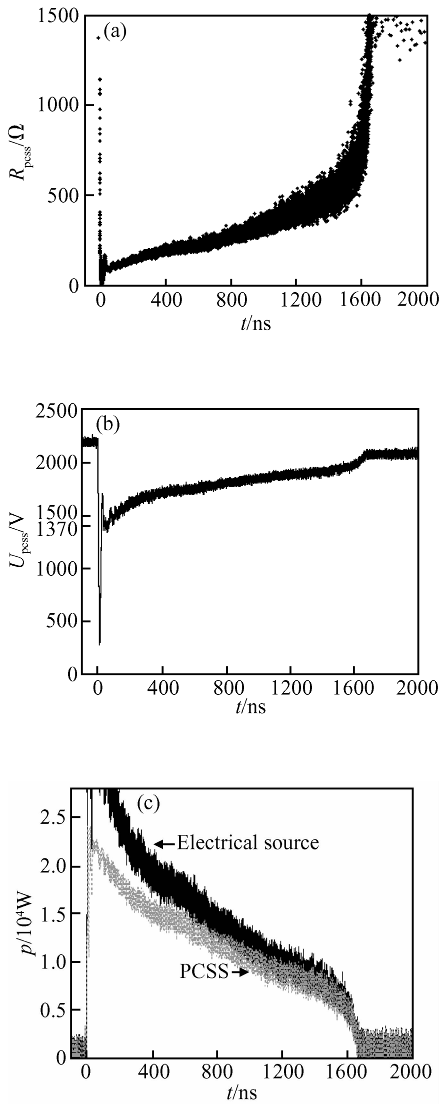

Fig.3 Transient characteristics of nonlinear GaAs PCSS (Step is 5×10^{-11}s) (a) Transient resistance; (b) Transient voltage; (c) Transient power

The calculation results are shown in Fig. 3. As shown in Fig. 3(a), R_{pcss} always fluctuates in a range of 300Ω, implying the randomicity of carrier motion. As shown in Fig. 3(b), at the beginning of lock-on, the voltage is at its minimum (1370V), but the average electric field (1370V/3.5mm = 3914V/cm) is enough to bring on the Gunn effect is around 3400V/cm[8]. Therefore, there must be Gunn domains which result in the charge avalanche multiplication process[2,9,10]. As shown in Fig. 3(c), at 1600ns, the PCSS starts into the period of self-turnoff as soon as the output power of the capacitance is not sufficient to keep the PCSS in lock-on, although the voltage on the PCSS reaches the maximum at that moment.

4 Conclusion

We repeat a series of experiments for the nonlinear mode with different parameters, and these transient characteristics are similar to above. The curve of the transient voltage shows that the average electric field of PCSS in the lock-on period is always higher than the Gunn threshold, and increases monotonically. By comparing the transient power curves of the PCSS and the electrical source of the circuit, it is demonstrated directly that the power shortage leads to the PCSS from the lock-on state into the self-turnoff state, so a controllable turnoff of the PCSS in lock-on by changing the distribution of the circuit power is predicted.

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非线性 GaAs 光电导开关的瞬态特性分析*

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摘要: 基于能量守恒原理推导出非线性 GaAs 光电导开关电路的差分公式,代入实验数据计算出开关的瞬态电压、电阻、功率.该方法解决了长期以来非线性 GaAs 光电导开关的瞬态特性难于测量的问题.通过 GaAs 光电导开关的瞬态电压曲线知,在锁定期间开关平均电场强度总是大于耿氏阈值,并随时间单调递增.通过对比开关与其电路电源的瞬态功率曲线,证明了电源功率不足是导致 GaAs 光电导开关从锁定状态进入自关断状态的根本原因,因此提出了在锁定期间通过改变电路的功率分布使开关可控关断的思想.

关键词: 光电导开关; 锁定效应; 非线性模式; 可控关断

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