Design and optimization of the XeCl excimer laser′s stimuli circuit*

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Abstract: The stimuli circuit of the XeCl excimer laser has a great effect on the output characters of the laser. In order to improve the output character of the laser,the Spark Gap Switch(SGS) was originally and satisfactorily used to control the instant high current trigger signal of the XeCl excimer laser which was made by ourselves.To begin with, the design of the structure of the XeCl excimer laser was discussed, and then the circuit parameter of the laser was determined. Secondly,to deal with the problems in the experiments,the current foldback, optical coupler insulation and electromagnetic shielding were used to optimize the circuit performance of laser. Finally, the measured data shows that the laser worked stably and the output characters reached the design values by the improved methods.Thus it would offer the reference of the improvement of the laser´s output characters.

Key words: XeCl excimer laser; Optimization; Spark gap switch; Rogowski coil

CLC Number: TN242 **Article ID**: A **Document Code**: 1007-2276(2005)05-0617-05

XeCl 准分子激光器激励电路设计与优化*

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摘要: XeCl 准分子激光器激励电路性能对激光器的输出特性有着很大的影响，为了提升激光器的输出特性,我实验室自制的 XeCl 准分子激光器创新性地采用了火花开关控制电路,对瞬时大电流进行控制,取得了满意的效果。从激光器电路部分的设计入手,研究了 XeCl 准分子激光器的电路结构,确定了激光器的电路参数。针对激光器在实验过程中出现的问题,采用了过流保护、光耦合器隔离、电磁屏蔽等措施,优化了激光器的性能。实测数据表明采用的设计及改进措施使激光器激励电路工作稳定,激光器输出达到设计要求。为提高 XeCl 准分子激光器的输出特性提供了参考。

关键词: XeCl 准分子激光器; 优化; 火花开关; Rogowski 线圈

0 Introduction

The excimer is a kind of unstable compound, which can be composed of the molecular in the excitation state and decomposed to the atom in the ground state. The emission transition occurs between

收稿日期: 2005-01-20; 修订日期: 2005-03-10

* 基金项目: 国家自然科学基金资助项目(50331040, 60171043); 陕西省自然科学基金资助项目(2001C21)

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the bound excitation state and the repellent ground state. The spectrum of excimer laser lies not only in the ultra-red but also in the vacuum ultraviolet, the excimer laser becomes an important illuminant in the actinochemistry and ultraviolet spectroscopy due to its high energy, power and repetition frequency. The discharge pumping XeCl excimer laser is a kind of ultraviolet laser with the 308 nm wavelength. Due to its short wavelength and high efficiency, it can be used in the production of the semiconductors and photoelectric detector, the laser lithography of giant magnetroresistance and the pulsed laser deposition,etc[1~3].

The XeCl excimer laser made by ourselves has the characteristics of high power and short wavelength, and the Spark Gap Switch (SGS)was used to control the instant high current trigger signal. But at the begining of the experiment, the off-standard stability and heavy electromagnetic interference made by the discharge became a difficult problem that troubled the normal working of the laser. Therefore the circuit was then optimized and after that the problems were solved.

1 The SGS control circuit of laser

The Fig.1 shows that the SGS control circuit of laser is made up of seven parts. In order to get a nanosecond discharge to control the SGS, to begin with, the digital pulse generator outputs a quadrate wave which can be modified at the frequency of 1~5 Hz. Secondly, due to its voltage is less than 1 V,the double amplifier is needed to translate it into a 400 V sharp pulse to drive the gas triode. And the gas triode-controlled by the front circuit generates a 16 kV 0.8 μs square wave, and then it is translated into the sharp

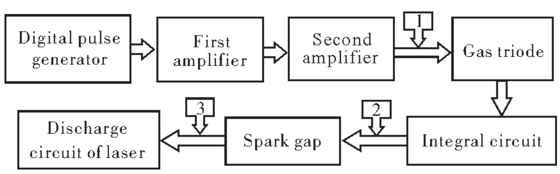

Fig.1 Block diagram of the XeCl excimer laser's stimuli circuit

pulse by the integral circuit to drive the SGS. At last, the 29.5 kV voltage is generated and then it stimulates the discharge circuit to excite the laser when the SGS works on.

The SGS is a kind of device which is used to generate the ultra-fast pulse by the spark discharge,and it doubles the energy to the plasma by the gas breakdown with the fast-rising high voltage pules during the avalanche preionization, and the structure is shown in Fig.2.G_0 and G_1 are conductive hemispheres,the S is trigger needle, and the nitrogen is filled in the gap. When the high positive voltage is added on the G_1, the G_0 and S is connected to the ground. During the trigger time,the negative pulse is added on the S to conduct the G_1 and S, and then the G_0 and S, finally the G_1 and G_0 ,to generate the nanosecond ultra-high current pules.

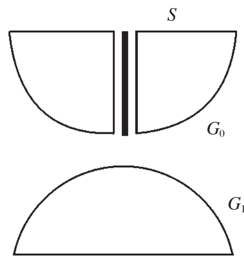

Fig.2 Structure diagram of spark gap switch

When the high voltage is added on the SGS,the electron is driven from the cathode to the anode by the electric field. Between the longitudinal electrodes,the electrons collide the atom of the gas in the SGS,and the ionization occurs.If the ionization coefficient of the electron is α,the cathode escape density is n_0, and the distance of the electrode is d, thus the number of the electron reached to the anode is:

$$n_e = n_0 e^{\alpha d}$$

the current density on the anode is:

$$J_e = \frac{J_0 e^{\alpha d}}{1-\gamma(e^{\alpha d}-1)}$$

If $1-\gamma\ (e^{\alpha d}-1)=0$,the discharge of the SGS is called self excited discharge, on the inflammation state, and the gas medium is punctured.At the same time,the SGS is on,and the capacitance C_s discharges through the main electrodes[4,5].The current is shown in Fig.3.

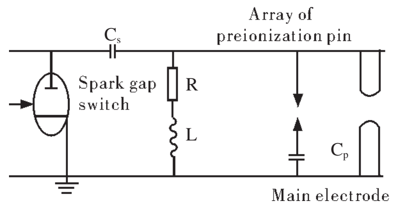

Fig.3 Electrode discharge circuit controlled by the SGS

After the discharge, the plasma in the SGS must be immediately black out, so the circulative nitrogen is added to effectuate the fast recovery. The process can be described by the equation below：

$$Q_F=\sqrt{\frac{pd^2}{a^2}\left(\frac{V_m}{R_m}\right)^2 1-e^{-\pi RZ_m}}$$

where Q_F is the function of current and time , p and d are the pressure and distance of the electrode, a is the collision ratio of gas molecular , V_m is the charge voltage of C_s , R_m and Z_m are the resistance and impedance of the circuit, and $Z_m=\sqrt{L_m/C_m}$, L_m and C_m are the induction and capacity of the SGS. The energy consu - ming in the gas is related with the parameter of SGS, if the breakdown voltage keeps unchangeableness.If the distance of electrode was decreased and gas pressure was increased,the energy consuming in the SGS would decrease to shorten the resumption time and the repeat frequency.

In order to get the nanosecond rising edge, the discharge gas pressure of the SGS must be increased to get the shorter discharge pulse. In the pressure of 0.1～0.5 MPa, the discharge time can be shortened from 20 ns to 6 ns. Keeping the SGS in the high pressure can get the nanosecond short pulse, and the following methods must be done. Firstly, the induction of the circuit must be reduced to the minimum.Secondly,the millisecond rising pulse must be generated by the RC charge -discharge circuit. Finally the millisecond pulse was passing through the SGS,Marx generator,and blumlein line,and sharpen into nanosecond pulse by the RC circuit.

2 Optimization of laser′s circuit

At the begining of the experiment, although the design parameter was conformed to the requirement val - ues,its stability was off -standard,and malfu nction often occurred.After several maintenance and replacements of damaged devices,the main problems were found in the defect design of circuit and heavy electromagnetic inter - ference.After that, the two problems were analy - zed and then the optimization program was carried out.

2.1 Optimization of unstable control circuit

The unstable problems lie in two facts, one is the devices of the digital pules generator and the other is the second amplifier were often damaged, thus the triode can be triggered. After the measurement and analysis, the reason was the huge countercurrent´s breakdown of the digital pules generator and the second amplifier which was made by the nonscheduled discharge of gas triode. The gas triode is a kind of electron tube, and the anode has a 16 kV voltage and 325 A current at working, if the gas triode was not triggered for one time, the electric charge on the anode would discharge,and this countercurrent would come back to the front circuits and course the failure of them. But the countercurrent of the gas triode can not be avoided,so the protection circuits must be added on the front current ,and its principle figure and actual circuit are shown in Fig.4.

To avoid the effect of the countercurrent to the digital pulse generator,the optically coupled isolator was added to translate the signal only from the digital circuit to the analog amplifier. Due to the magnification of the second amplifier can output a 400 V sharp pulses,and would be affected more by the counter - current,so the protection circuit was added between the second amplifier and the gas triode.Firstly the protection circuit samples the trigger signal and sends it to the operational amplifier. Then the operational amplifier calculates and regains the signal and compares it with the benchmark voltage in the voltage comparator.When the signal is normal working, or it is less than the benchmark voltage, thus there is no output, but if abnormal current occurs, it is greater than the benchmark, the voltage comparator would trigger the control current and the electrical relay. At last the current source of the second amplifier would be shut down, so the effect of the countercurrent of the gas triode can be avoided.

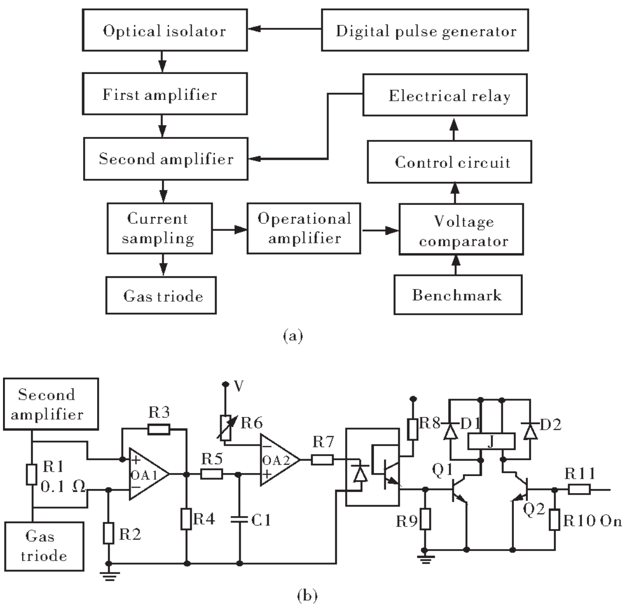

Fig.4 Block (a) and circuit (b) diagram of the protection circuit

Another unstable problem lies in that the capacitor C_s was often broken down,the nominal pressurization of C_s is 40 kV, and the voltage added on it is 35 kV. During the instant discharge, the voltage on the C_s is greater than 35 kV, if the insulation of the capacitor is not good enough to avoid the marginal discharge. Although the lasting time is short, the generated energy would damage the capacitor. Thus the assembly technology is improved to avoid the marginal discharge.In the experiment,firstly, the two ends of the capacitor were smoothed,and secondly all the metallic joints were well welded,and finally the C_s was encapsulated by the LSI insulation material.The operations can be held easily and has a good insulation,so the marginal discharge was avoid entirely.

2.2 Optimization of large electromagnetic interference during the discharge

When the main electrode of the laser discharges, the big current of high voltage circuit fluctuates instantly.The process would send out the energy by the electromagnetic wave,and it would greatly effect the control circuit of the laser and other electronic instrument in the laboratory.It was dislodged by the below methods:

(1) The separation of low voltage circuit and high voltage was taken, and they have their own separated earth electrode, to control the electromagnetic interference only in the high voltage circuit.

(2) In the high voltage circuit,each point of earth electrode was perfectly linked optimized to cut down the circuit effect to the minimum.

(3) The faraday cage was added on the circuit to shield the electromagnetic interference to the other electronic instrument.

By these methods above, the electromagnetic interference was deduced efficiently to base the condition of measurement next step.

3 Parameter measurement of laser's improved circuit

The parameter of circuit affects the output character directly, and it is also a verification to measure the parameter of the circuit, and it sets the basic future improvement of output characters.

3.1 Measurement of the gas triode's trigger signal

The gas triode is triggered by use of the digital pulse generator and amplifies in Fig.1. The curve in Fig.5 is the trigger signal of gas triode on the test point 1,the result can be seen that the 1 V square wave generated by the digital pulse generator was translated into 400 V sharp pulse by the two amplifies,and the pluse width is 0.5 ms.The output of pulse works stabilizely and the amplitude and pulse width are fit for the trigger requirement of gas triode.

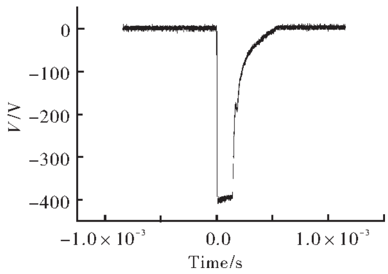

Fig.5 Trigger waveform of gas triode

3.2 Measurement of the discharge signal of SGS

In the experiment, the Rogowski coil was used to measure the large current pass through the SGS and main electrode of the laser.The wire was reeled on a non-ferromagnetic ring-shaped frame,and the primary busbar is on the center of coil, and is separated from the oil. If the self-induction is great,we can get that:

$$I(t)=\frac{Nu(t)}{R_0}$$

The type of the wire is GB−5023−85, and frame is made up of polyethylene.The number of turns are 50 and 30, the internal resistance R_0 are 0.2 Ω and 0.1 Ω.

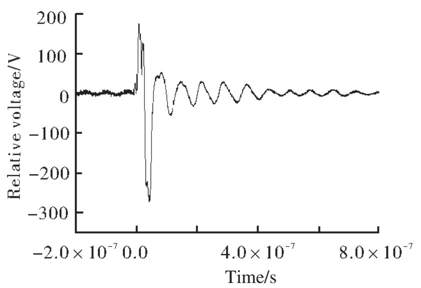

Fig.6 Trigger waveform of SGS

Fig.6 shows that the 16 kV,0.8 μs pulse output when the ZQM1−325/16 gas triode triggers the spark gap passing through the integral circuit. Due to the nitrogen pressure of 0.1~0.5 MPa nitrogen, the 6 ns rise-time was gotten, and the lasting time is 50 ns.The trigger signal of SGS requires a less than 10 ns rise-time , and can be blank out immediately,so the data measured is fit for the design requirement.

3.3 Measurement of discharge electrode

Fig.7 shows that the rise time of voltage of C_s discharged by 30 kV direct current is 14 ns.After the charging,the spark gap is triggered,and C_s charges the C_p The whole lasting time is 126 ns, and the voltage on the C_p reaches the maximum, then the main electrode discharges to get laser.

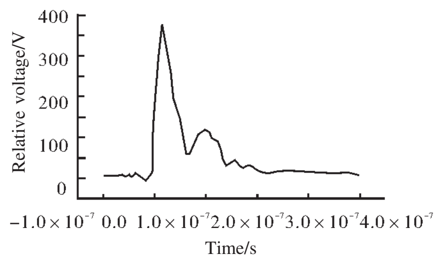

Fig.7 Charge and discharge waveform of C_s

The relation of energy and voltage on the C_s is shown in Fig.8. The energy is linearity without decrement, and can be increased with the increasing of voltage on the C_s. Therefore,the energy output can be hoisting in the range of 19 kV to 30 kV.

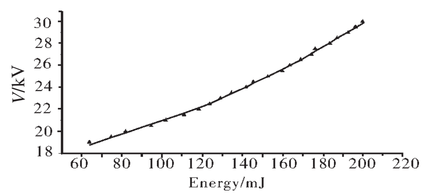

Fig.8 Relation of energy of laser and voltage on the C_s

The output energy translated from the energy storage capacity C_s to the discharge capacity C_d would be increased due to the increase of voltage on U_d. But the energy translation efficiency of C_s to C_d would be decreased by the gas alteration of breakdown phase angle following the increase of voltage. Thus the best breakdown point can′t be gotten.

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controlled by sing -chip microcomputer [J].Laser Journal (邹文栋,高益庆.单片机控制的半导体激光驱动电源.激光杂志), 2002,23(4):70–71.

[4] XU Xiu-fang,HU Xiao-dong.The power steadiness and control technology of semiconductor laser[J].Acta Photonica Sinica(徐秀芳,胡晓东.半导体激光器的功率稳恒控制技术.光子学报), 2001,30(6):761–764.

[5] GAO Dong-jie, TAN Jie,LIN Hong-quan.Applications advannced control technology[M].Beijing:National Defence Industry Publishing Company (高东杰,谭杰,林红权.应用先进控制技术.北京:国防工业出版社),2003.

[6] TAO Yong-hua.New Type PID Control and the Application[M]. Beijing:Mechanism Industry Publishing Company (陶永华.新型 PID 控制及其应用.北京:机械工业出版社),1998.

[7] LIN Ming,XUE Hong. Computer Control Technology and System [M]. Beijing: Light Industry Publishing Company(林敏,薛红.计算机控制技术与系统.北京:中国轻工业出版社),1999.

[8] XU Wen-hai,YANG Ming-wei,TANG Wen-yan. Development of multifunctional laser diode driver[J].Infrared and Laser Engineering (许文海,杨明伟,唐文彦.多功能半导体激光器驱动电源的研制.红外与激光工程),2004,33(5):465–468.

[9] LI Cheng-ren, SONG Chang-lie,LI Shu-feng,et al.Experimental investigation of the change of semiconductor laser output wavelength corresponding to operation current[J].Infrared and Laser Engineering(李成仁,宋昌烈,李淑凤,等.半导体激光器输出波长随工作电流的实验研究.红外与激光工程),2003,32(2):144–147.

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The stimuli function of laser had been done stably by the improved circuit,the parameter fits for the design, and the laser is dependable normal working.

4 Conclusion

In this paper the XeCl excimer laser discussed is a kind of frequency adjustable discharge gas laser.The pulse width is 18 ns, and the repeat frequency is 0.5~5 Hz. The innovative SGS was explained firstly,and the problems in the circuit was analyzed and solved. Finally, the trigger waveform of gas triode,and waveform of SGS and main electrode of laser was measured to set the basis of the further improvement of output character of the laser.

5 Acknowledgements

The authors gratefully acknowledge support of the Chinese Natural Science Fund (50331040, 60171034).

References:

[1] QIANG Xi-wen,ZHANG Jian-quan.Analytical investigation on mechanical effects of detector materials induced by laser beams. [J].Infrared and Laser Engineering(强希文,张健全.高功率脉冲激光产生的激波在靶材中的传播.红外与激光工程),1999,29 (6):47–51.

[2] CHEN Yu-qing,WANG Jing-huan. The Principle of Laser[M]. Hangzhou:Zhejiang University Press(陈钰清,王静环.激光原理.杭州:浙江大学出版社),1992.

[3] REN Ren,CHEN Chang-le,ZHU Shi-hua,et al.Dynamic model of a new XeCl laser with short duration time and UV grow discharge system design [J].Laser Technology(任韧,陈长乐,朱世华,等.短脉冲 XeCl 激光动力学模型及辉光抽运设计.激光技术), 2004,28(4):434–437.

[4] Roberts Thomaster L.Experiment studies of a CrF and ArF discharge laser[J].IEEE J,1978,QE–14(12):944–950.

[5] REN Ren,CHEN Chang-le, JIN Ke-xin,et al.Design of a new XeCl Mer laser pumped by pulse discharge for epositing film [J].ACTA Photonica Sinica(任韧,陈长乐,金克新,等.用于薄膜沉积的 XeCl 激基激光器研究.光子学报),2002,31(9):1097–1100.

[5] TENG Xue-shun,ZHANG Zhi-cheng.Study of RF CO_2 laser overheat protection circuit[J].Infrared and Laser Engineering(滕学顺,张治成. RF CO_2 激光器过热保护电路研究.红外与激光工程), 1995,24(3):45–50.

[6] CHEN Zhen-sheng.The technology and apply of a new sensor[J]. Building Electrical and Intelligent System(陈振生.新型传感器技术及应用.建筑电配),2003,12:10–18.