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Key technologies of pulsed non-chain DF lasers

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Abstract: Pulsed non-chain deuterium fluoride(DF) lasers based on the chemical reaction are proper sources of powerful coherent radiation in the 3.5–4.1 μm spectral regions and they have intrinsic ability to store high levels of energy. These advantages make DF laser attractive to researchers in the mid-infrared laser field. In order to effectively improve the output performance of non-chain DF lasers, the key technologies of DF lasers were researched in this paper. The key technologies including self-initiated volume discharge, mixture ratio and recirculating and cooling were introduced. Particular emphasis was put on self-initiated volume discharge. These technologies will provide theoretical guidances for the further research on DF lasers.

Key words: non-chain DF laser; self-initiated volume discharge; mixture gas ratio; recirculating and cooling

非链式脉冲DF激光器的关键技术

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摘要: 基于化学反应的非链式脉冲DF激光器是产生3.5~4.1 μm波段的有效相干辐射光源,具有存储能量水平高等优点。这些优点使得该激光器倍受中红外领域激光研究者的重视。为了更好地提高非链式脉冲DF激光器的输出性能,研制高能量水平的DF激光器,本文详细介绍了自引发大体积放电技术、混合气体配比技术、循环冷却技术等DF激光器关键技术,重点介绍了自引发大体积放电技术。这几种技术将为研制高性能DF激光器提供理论指导。

关 键 词: 非链式DF激光器;自引发体放电;混合气体配比;循环冷却技术

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1 Introduction

Deuterium fluoride(DF) lasers have been under development since about 1970. The spectral regions of DF laser are from 3.5 μm to 4.1 μm, which is a good atmospheric transmission window as well as the absorption band of air pollutants(hydrocarbons, sulfur dioxide, nitrogen oxides, *etc.*). Its intrinsic ability to store high levels of energy makes this type of laser attractive to the researcher for producing high power levels for an air and missile defense weapon system. Besides, it can be used in laser radar transmitters, infrared fiber-optic communications and atmospheric detecting.

Pulsed DF chemical lasers based on the electrical dissociation of SF_6 are very attractive because they used gases easy to handle, while they are not corrosive and unlike F_2 and F_2 mixtures there is no risk of premature ignition[1]. The chain DF laser is driven by burning the gas mixture in combustor, and is comprised of a combustor, a nozzle bank, optics, a diffuser and a ejector. The chain DF laser uses F_2 as the oxidizer so it has the explosion possibility when F_2 reacts with D_2 or deuterocarbons. Compared with the chain DF laser, there is no risk of corrosion and explosion, and the structure is compact and easy to handle. For all these advantages, the non-chain DF laser becomes an attractive research object. However, the DF laser is different from other gas lasers or chemical lasers for its distinctive discharge characteristics and working mechanism. Electric discharged non-chain DF laser usually uses mixtures of F atoms (contained in SF_6) and D atoms(from deuterocarbons) as active media. The discharge is used to cause chemical reactions in order to achieve population inversion and then generate laser. Relative to other gases that can form stable negative ions by attaching electrons, SF_6 is a strongly electronegative gas. Its strong electro negativity makes SF_6 molecule dissociation very hard, so it is important to choose a suitable type of discharge. The uniformity of discharge should be concerned for it is one of the key factors to decide whether we can obtain laser output.

Mixture ratio technology is also very important. D atoms are from deuterocarbons, such as D_2, C_6D_{12} and C_2D_6. For choosing different deuterium donors, the expense and laser output will be different.

The by-products and heat generated during the chemical reaction and discharge process would reduce the laser quality, such as output powers, energy and pulse widths, so the recirculating and cooling technology seems important also.

The following section describes the key technologies in more details.

2 Self-initiated volume discharge

The strong electron attachment of SF_6 makes the establishment and maintenance of electrical discharge difficult in SF_6 containing gas mixture[2]. Various types of discharges have been developed to overcome these drawbacks. Recently, it was shown that in strongly electronegative gas especially in sustaining a non-chain reaction DF lasers, the self-initiated volume discharge presents a decisive advantage over the conventional ones and moreover is very simple to use[3-5].

Strongly electronegative gases, such as SF_6 and F_2 are distinguished by (1) high values of their operating reduced electric fields E/N and (2) high magnitudes of electro negativity χ_α defined as the negative ion to electron concentration ratio[2]. These give rise to some special features of the discharge displays. To briefly summarize, they are as follows. First, SF_6 molecule dissociation by electron impact becomes important. Dissociative ionization and electron attachment processes characteristic of SF_6 can significantly contribute to the gas decomposition, specifically to F-atom production[6]. Second, high positive ion concentrations along with that the relation electro negativity equal to electron attachment rate η holds under the working conditions lead to the dissociative electron-ion recombination can strongly influence the SF_6 discharge plasma parameters both qualitatively and quantitatively. Third, it is found that SF_6 molecules decomposition, either through electron impact immediately or by the dissociative ionization and electron attachment greatly influence the discharge characteristics, specifically its voltage and current waveforms. Professor Apollonov presented this new discharge technology, self initiated volume discharge, directed to the special characteristics of SF_6 molecules, and the following factors should be considered in order to achieve self initiated volume discharge.

(1) a cathode should posses a small-scale (10 ~ 50 μm) surface roughness; (2) to match a circuit wave impedance to the discharge plasma resistance at a given interelectrode distance, a mixture pressure should be chosen in such a way that the discharge burning voltage determined by the conditions of the gap breakdown in SF_6 [7] should be two times less than the voltage fed to the gap; (3) increasing electric energy through increase in the generator's capacitance at a given maximum generator, voltage should be followed by growth of the discharge volume V as $V \colon C^{3/2}$, where C is the generators' capacitance [8,9]. On fulfillment of all these conditions, one should also try to maximally decrease the period of time during which the energy is deposited in the discharge plasma.

The electrode structures used by Apollonov in self-initiated volume discharge are shown in Figs. 1, 2, 3.

The interelectrode distance in Fig. 1 is 4 cm. As the electrodes there were a copper stripe of 0.5 mm thick and 16 cm long (cathode) stood edgewise and a disk anode with the diameter of 6 cm rounded off along its perimeter to a radius of 1 cm. The breakdown was force initiated at the gap edge by a

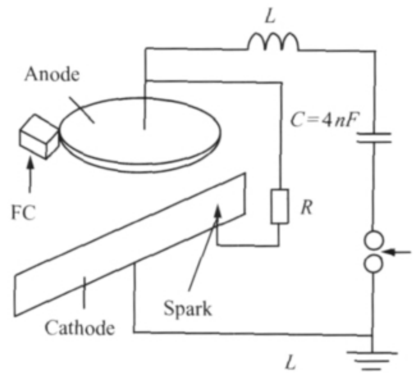

Fig. 1　Knife-edge gap geometry

low-current spark restricted by resistance R = 900 Ω.

The SIVD dynamics was also studied in the plane-plane gap geometry in experiments with a sectioned cathode diagrammatically depicted in Fig. 2. In this case, the interelectrode distance was the same as Fig. 1, however as a cathode there was a 2 mm flat disk rounded off along its perimeter to a radius of 1 cm. Isolated conductors of 1 mm in diameter were inserted into holes with the diameter of 2 mm drilled within the flat part of the cathode and spaced by a distance of 4 cm. The basic cathode and

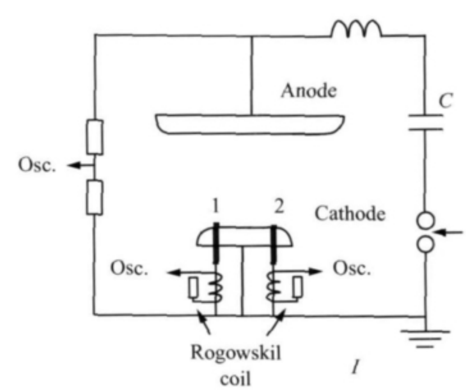

Fig. 2　Plane-plane gap geometry

these conductors were connected to a common bus. The current through each the conductor was recorded by Rogowskii coils. One of the conductors 1 extended 1 mm above the cathode surface which ensured a primary gap breakdown just at this point whilst comparison of oscillograms of currents through the initial

1 and control 2 conductors allowed the SIVD extension over the gap to be followed.

Fig. 3 shows a rod(cathode)-plane geometry and interelectrode distance $d = 4$ cm. The end of a 1.5 mm diameter rod dressed with polyethylene insulation was used as a cathode and the anode was a disk of diameter 10 cm[2].

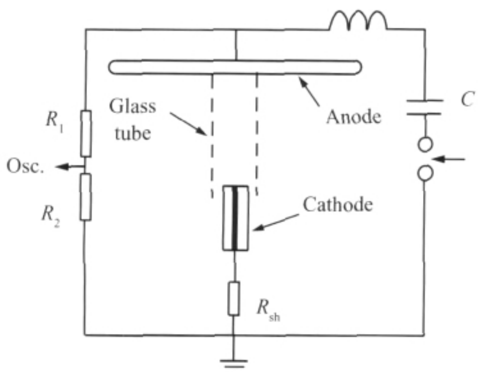

Fig. 3 Rod-plane geometry

They used this discharge technology to achieve more than 300 J laser energy output, and it is the highest energy output till now.

3 Mixture ratio technology

The active mediums are F and D atoms, and D atoms are from deuterocarbons, such as D_2, C_2D_6 and, C_6D_{12}, while F atoms are from molecules containing F atoms such as F_2 and SF_6. Note that choosing different donors of F atoms and D atoms will cause different output parameters of DF lasers, which concludes laser energy, electrical efficiency, output power and so on. At the same time, different donors of F and D atoms need different discharge conditions(like current, voltage, pressure, *etc*). So the expense will be different too. Therefore, it is important to choose suitable donors of F and D atoms. Simultaneously, after choosing the suitable donors, the ratio of the two molecules of mixtures is worth considering. Because the ratio of the mixture decide whether we can obtain laser outputs and if there has laser output, the ratio of the mixture affects the output laser quality. With the analyses above, we can conclude the following factors: (1) in order to choose the donors of F and D atoms, we should analyze the characteristics of the molecules; (2) before the experiment, it is important to read relative papers about DF lasers and then to do experiments according to the ratio of the mixture in the reference papers.

Now we compare the difference between F_2 and SF_6. Firstly, F_2 is the highest electro negativity molecule, so its ionization energy is higher than those of SF_6 molecules and the cost will be higher. Secondly, F_2 has high oxidbillity and toxicity, and can react with all the elements other than inert gas and nitrogen. But, SF_6 is one of the best materials to have good chemical stability and its inertia is similar to nitrogen and it is unit-poisonous. Thirdly, F_2 can cause chain reaction with deuterium compounds and have the risk of explosion, while SF_6 can make non chain reaction with deuterium compounds and be easy to control. HF and DF pulsed chemical lasers based on the electrical dissociation of SF_6 are very attractive because the gases they used are not corrosive, easy to handle and unlike $F_2 + H_2$ mixtures, and there is no risk of premature ignition.

The donor of F atoms is chosen, and then we need to consider the donor of D atoms. The experiments made by H. BRUNET in France showed that compared to the HF energy of 10 J obtained with C_2H_6 as hydrogen donor for the same experimental conditions the output energy previously achieved with D_2 was low, less than 3 J per pulse[10]. Two main reasons can explain this behavior. The first one is related to the kinetics of the pumping reaction and the other to the discharge stability. And the experiments showed that the electric discharge stability is increased by adding C_2H_6 to the SF_6 gas mixture. Unfortunately, it was not possible to employ C_2D_6 because of the excessive cost of this deuterium compounds. Therefore they made a search for a not too expensive deuterium hydrocarbon and they found that C_6D_{12} could be an interesting product. Then they first tested C_6H_{12} as a hydrogen donor instead of C_2H_6, and very good results were obtained on HF emission since the drop off in output energy was only about 5%. Consequently, C_6D_{12} was ordered and tested and the laser energy was higher than that achieved with D_2. Therefore considering all the factors we can conclude that C_6D_{12} is the best choice for donor of D atoms in the same experiment conditions.

4 Recirculating and cooling technology

The heat generated in the chemical reaction, the byproducts caused by the non chain reaction along with D_2, DF and other elements which could affect the output laser quality also should be considered. So it is very significant to have a gas recirculator loop to cool and process the gas mixture. In the following sections, we will discuss the different solutions direct to different problems.

Firstly, we choose the heat exchanger to cool the working gas. The heat exchanger is made of chillers; the water is constantly circulating in the chillers so as to bring the excess heat away. This system can make the temperature floating around in the 2 ℃.

Secondly, the cleaning of the discharge region of discharge products between pulses is especially important in DF chemical lasers because residual DF molecules would degrade laser outputs, so we choose axial-flow fan as a recirculating system. This axial flow fan has advantages as follows: high speed, small size and easy to integrate with the flow system. The recirculating system has two axial-flow fans, and the flow velocity of 80 m/s can realize 3 to 5 cleaning factors. H. BRUNET in France used two fans to realize a flow velocity of at least 4 m/s in the discharge region. This flow velocity is necessary to achieve an equivalent of even one full gas exchange between pulses at a repetition frequency of 100 Hz in his experiment.

Thirdly, the probable deleterious contaminants in the gas mixture like DF and S_nF_m-type species also would degrade laser outputs [3]. In order to solve this problem, we can use the chemical trap. The trap is a rectangular box placed inside the laser system. The molecular sieves are put in the rectangular box to remove deleterious contaminants. Direct to the characteristics of working medium, we choose 5 A and 13 X molecular sieves. Fig. 4 is the laser system used by H. BRUNET [11].

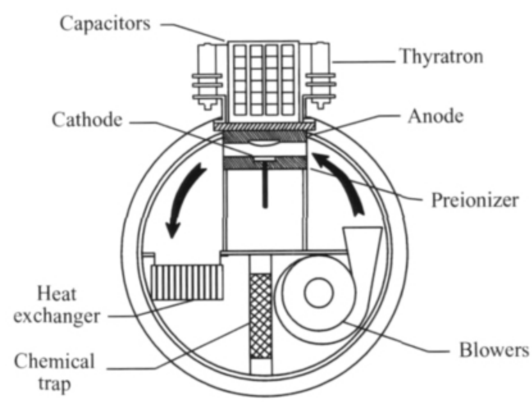

Fig. 4　Cross sectional drawing of laser system

5 Conclusions

Three key technologies about DF lasers have been discussed in this paper, which includes self-initiated volume discharge, mixture ratio, recirculating and cooling technologies. DF laser based on self-initiated volume discharge can obtain the highest output energy and power (the monopulse energy of DF laser is 330 J), so this discharge method is a effective way of chemical reaction sustain in working mixtures of non-chain DF laser. The structure of electrode is the decisive factor of self-initiated volume discharge. Mixture ratio technology, recirculating and cooling technology are important to develop all kinds of gas and chemical lasers.

Besides, there are other technologies that haven't been discussed in this paper, such as large volume uniformity discharge, efficiency improving technology, coating technology and so on. All the elements that may affect the laser output performance should be considered when a DF laser is developed.

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