

Gas-discharge XeF* ($B \rightarrow X$) laser with high specific output energy

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Abstract. The discharge characteristics of the XeF* ($B \rightarrow X$) laser are investigated. The NF₃ and Xe partial pressure of the laser gas mixture and the total gas pressure have been varied. A highest specific output energy of 4.7 J/l with an efficiency of 0.5% was obtained from a X-ray preionized Ne/Xe/NF₃ gas mixture at 6 bar with single-pulse excitation through a multichannel spark gap.

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The technology of electrical discharge lasers has been improved greatly in the last decade. High repetition-rate excimer lasers operating with average powers of 100–300 Watt are commercially available now. Most of the scientific research on discharge-excited excimer lasers has been concentrated on the XeCl* laser, from small systems working at high gas pressures [1, 2] to very large systems producing output powers in the kW range [3]. Far less results have been published on excimers with F₂/NF₃ halogen-donor-based gas mixtures as KrF* or ArF*, although these lasers have at least the same or even better output characteristics as the XeCl* laser [4]. This is probably caused by the fact that it is more difficult to make a homogeneous discharge in such gas mixtures compared to HCl-doped gas mixtures. Especially the discharge stability is a real problem due to the stronger electron affinity of the F₂/NF₃ halogen donor in these gas mixtures [5].

Results on the XeF* ($B \rightarrow X$) discharge laser are even more scarce although e-beam pumping of this laser transition has been studied very extensively [6, 7]. The fact that in the past these type of F₂/NF₃-doped laser-gas mixtures have not been investigated extensively in gas-discharge devices certainly has to do with the enhanced probability for discharge instabilities. In the last decade,

however, the techniques to excite laser-gas mixtures by an electrical discharge have been improved considerably. The use of X-ray preionization and pre-pulse-main-pulse excitation makes it easier to handle these strong electronegative gas mixtures. Kumagai and Obara [8] investigated the role of the buffer gases He/Ne and of the F₂/NF₃-halogen donor in laser-gas mixtures for the discharge-pumped XeF* ($B \rightarrow X$) laser at low gas pressures. In their experiments they used a more or less conventional electrical excitation circuit with a spark-gap switch and UV preionization. They obtained an output-pulse length of about 20 ns and a maximum specific output energy of 1.2 J/l.

In this paper, we report on a high-pressure XeF* ($B \rightarrow X$) discharge laser preionized with X-rays and with the electrical circuit connected to the laser head by means of a low-inductance multichannel spark gap. With this device it was possible to produce laser output-pulse lengths of 85 ns (FWHM) at a total pressure of 6 bar. Under optimised conditions a highest output energy of 350 mJ (4.7 J/l) was measured.

1 Experimental setup

The experimental setup is described in detail elsewhere [9, 10]. A cross-sectional view of the system is shown in Fig. 1. The transfer capacitor C_t , which is an array of small (TDK, 2.7 nF, 30 kV) capacitors, is charged by a low-inductance storage capacitor C_s (Maxwell, 80 nF, 50 kV). In order to improve the voltage rise time on the anode, the transfer capacitor C_t is connected to the anode by a low-inductance multichannel spark gap (Fig. 1). The Multi-Channel Spark Gap (MCSG) is not externally triggered, its voltage-breakdown value is controlled by the gas pressure inside the gap. The MCSG consists of a brass rod and knife mounted in a perspex housing. The gas pressure, the gas usually is nitrogen, can be varied from 1 to 2.5 bar absolute and the electrode distance between 5 and 20 mm. The peaking capacitor C_p consists of 8 capacitors (TDK, 0.7 nF, 40 kV each) in parallel.

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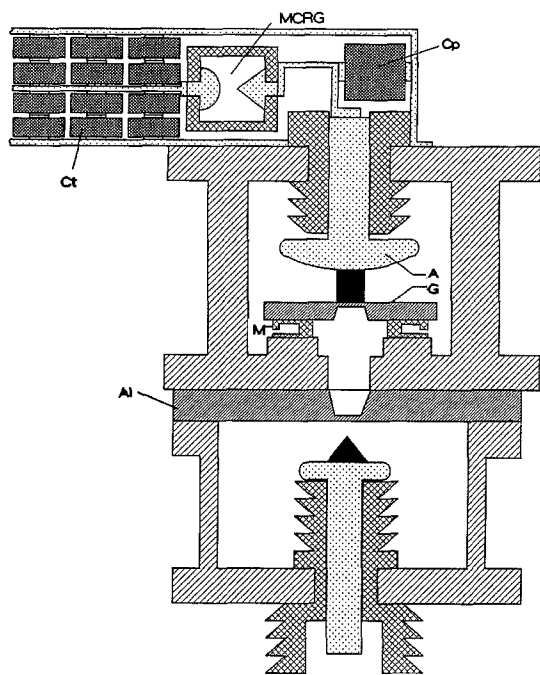


Fig. 1. Cross-sectional view of the X-ray source, laser chamber, multichannel rail gap (MCRG), transfer capacitor C_t and the peaking capacitor C_p . (A: anode; G: grounded electrode with X-ray window; M: monitor for the discharge current)

The laser chamber is designed to work at high pressures (up to 10 bar).

The optical resonator configuration consists of two dielectric mirrors. The total reflector ($R = 99.99\%$) is concave with a radius of curvature of 5 m while the outcoupling mirror is flat and has a transmission of 50%. The distance between the mirrors is 130 cm. The length of the discharge channel is 60 cm, the height between the electrodes 1 cm and the discharge width approximately 1.25 cm.

The discharge current was accurately measured by a built-in inductive pick-up loop (Fig. 1:M). The optical output energy was detected by a Gen-Tec ED 500 pyroelectric device and the temporal behaviour of the output pulse was recorded by means of a photodiode (EG&G, FND 100Q) in reverse bias (90 V).

2 Experimental results

All measurements have been performed with gas mixtures containing Xe, NF_3 and Ne as the buffer gas. Unless otherwise stated, the load voltage of C_s was always 40 kV. First, we investigated the dependence of the output energy on the NF_3 and Xe partial pressure. The output energy as a function of the partial pressure of NF_3 and Xe is shown in Fig. 2 for a total laser-gas pressure of 6 bar. We see from this figure that the NF_3 concentration is a rather sensitive parameter and that the optimum pressure is about 1–1.5 mbar NF_3 . At a fixed NF_3 concentration, the output increases with increasing Xe partial pressure until saturation occurs. If the partial pres-

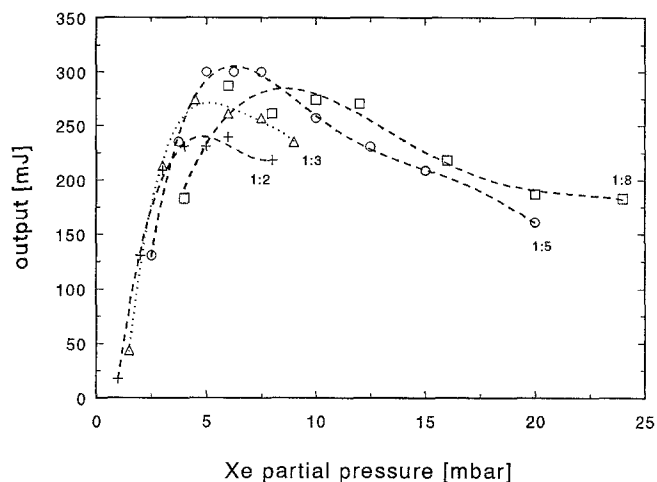


Fig. 2. The output energy as a function of the Xe partial pressure. The NF_3 partial pressure is given as a parameter, the total pressure is 6 bar (neon)

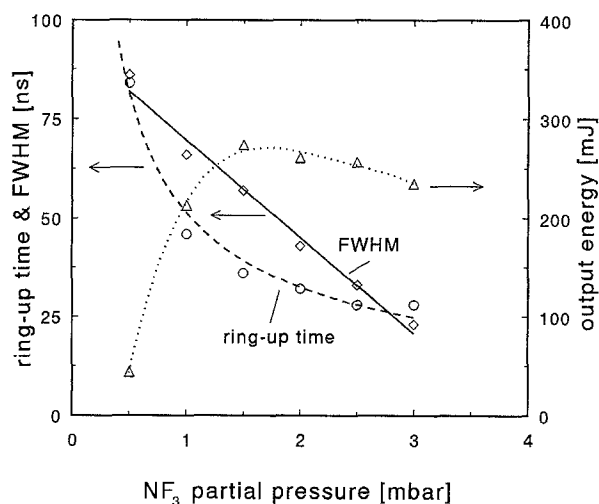


Fig. 3. Output energy, ring-up time and optical pulse width (FWHM) as a function of the NF_3 partial pressure. The NF_3 :Xe ratio is 1:3 and the total pressure 6 bar (neon)

sure of NF_3 is too large only a decrease in output energy is found for increasing partial pressures of Xe.

Due to the strong attachment of NF_3 , it is expected that a change in the concentration of NF_3 has a large influence on both the optical pulse width and the ring-up time of the laser output pulse. (The ring-up time is defined as the time difference between the onset of the main current through the laser-gas mixture and the onset of the optical laser-output pulse.) These effects are shown together with the output energy in Fig. 3 for a gas mixture with a NF_3 :Xe ratio of 1:3 and a total pressure of 6 bar. We see that if the partial pressure of NF_3 is too low, the ring-up time is very long and the output energy is low. If the NF_3 concentration is high enough to produce sufficient F^- ions or F^* atoms for the production channel ending in XeF^* , the output energy increases and the ring-up time decreases. This means that the gain is increasing with increasing NF_3 partial pressure due to

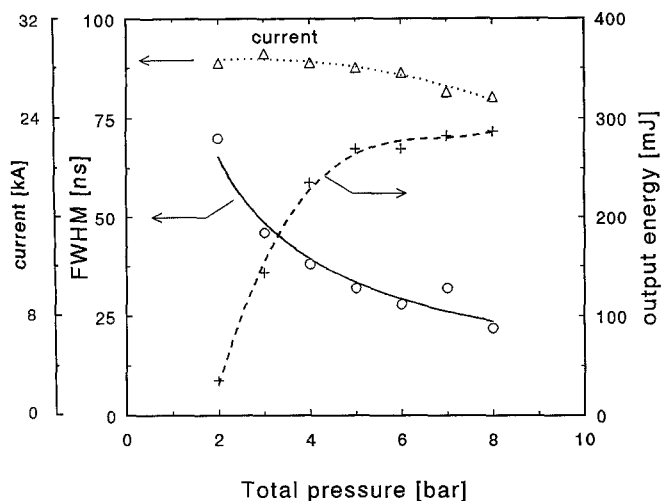


Fig. 4. Laser output energy, peak discharge current and optical pulse width (FWHM) vs the total pressure. The buffer gas is neon, the $\text{NF}_3:\text{Xe}:\text{Ne}$ ratio is 1:2:3000

the above-mentioned effect of the increasing XeF^* density. For NF_3 pressures above 1.5 mbar, the output energy decreases. It means that this is about the optimum NF_3 density. Increasing this density further on the one hand produces more XeF^* molecules in the stable part of the discharge, but, on the other, it attaches more electrons from the discharge leading to a faster destabilization of the discharge, as can be seen from the shorter optical pulse widths.

In Fig. 4, the output is shown as a function of the total pressure at a fixed laser-gas mixture ($\text{NF}_3:\text{Xe}:\text{Ne} = 1:2:3000$). No laser output was found at 1 bar. From 2 bar to about 4 bar the output increases almost linear with the pressure, while at higher pressures the output seems to saturate. In this figure we also show the peak discharge current. During the experiments, the charging voltage is kept constant at 40 kV. As the steady state voltage of the gas discharge linearly increases with pressure and the peak current is almost constant, the power deposition also increases almost linearly with the pressure. In order to obtain a higher output energy, the discharge current should be enhanced. This can be done by increasing the load voltage of C_s , because the peak current depends on the difference between the load voltage and the steady-state discharge voltage.

The influence of the delay time between the onset of the X-ray preionization pulse and the discharge current on the output energy was also investigated and the results are presented in Fig. 5. From this figure it is clear again that the attachment rate plays an important role in these gas mixtures. If the NF_3 concentration is too high, the electrons created in the preionization pulse will be removed from the discharge volume almost instantaneously by attachment and the allowed delay time will be short. On the other hand, if the NF_3 concentration is low enough, the effective lifetime of the electrons produced by the preionization source is larger and, consequently, the delay time can be much longer.

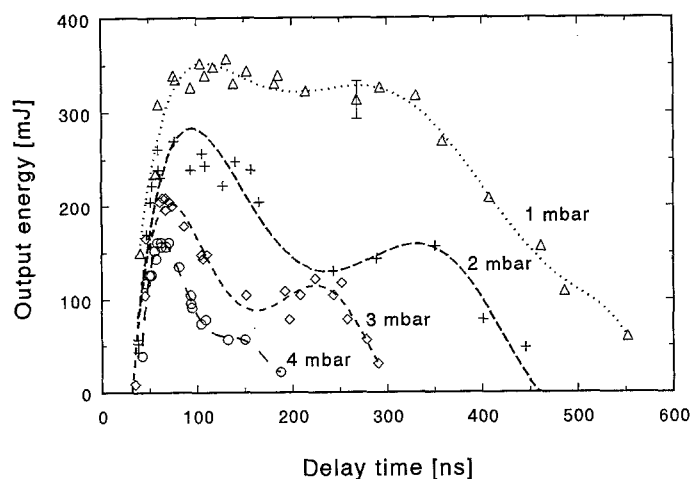


Fig. 5. Output energy as a function of the delay time between the X-ray preionization and main discharge for various pressures of NF_3 . The $\text{NF}_3:\text{Xe}$ ratio is 1:5 and the total pressure 6 bar (neon)

3 Conclusion

In conclusion, in this paper it is shown that with a relatively simple excitation method a high specific energy of 4.7 J/l can be achieved from a gas-discharge XeF^* ($B \rightarrow X$) laser. The use of a simple excitation circuit with a low-inductance multi-channel spark gap, however, has also some disadvantages. The MCSG introduces a small but additional self-inductance in the discharge circuit. More serious is the dissipation of energy in this gap which reduces the overall efficiency considerably. If the system should be run at high repetition rates for a longer period of time, also the lifetime of the brass electrodes of the gap will be a serious problem. For XeCl gas-discharge lasers more reliable excitation techniques have been developed [11]. It is expected that, for example, a pre-pulse-main-pulse excitation technique combined with a magnetic switch will yield even much better results.

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