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Optimisation of the pulse duration of a discharge-pumped XeF($B \rightarrow X$) excimer laser

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Abstract. In an x-ray preionised XeF($B \rightarrow X$) discharge-excited laser driven by a magnetic-spiker sustainer circuit with a magnetic pulse compressor the influence of the various parameters on the optical pulse duration was experimentally investigated. Laser pulses at $\lambda = 351$ nm with a duration of 212 ns (FWHM) have been achieved in a NF_3/Xe/Ne mixture by using very low (0.25 mbar) NF_3 partial pressures in a total gas pressure of 2.5 bar and with a high-reflecting output coupling mirror.

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In recent years long optical pulse discharge excited excimer lasers became of practical and scientific interest. The low peak power associated with long-pulse operation permits greater laser energy transfer through fused silica fibers, making these lasers attractive sources for medical applications. In addition, the increased number of cavity round-trips times provided by long-pulse operation permits the control of the laser divergence, line width, polarisation, and level of amplified spontaneous emission. There are a number of factors such as the electrical circuit, halogen concentration, total pressure, output coupling mirror transmission and electrical energy deposition which influence the rare-gas halide laser-pulse duration. Recently, the use of magnetic-spiker sustainer excitation circuits for XeCl rare-gas halide lasers has resulted in a higher efficiency, longer optical pulse durations and higher beam quality compared to conventional electrical discharge excitation circuits [1–3].

The magnetic-spiker sustainer technology also has been used to achieve long optical pulse KrF (170 ns) [1] and KrCl (185 ns) [4] laser operation. Spiker-sustainer circuits [5] comprise of two electrical circuits. A high-impedance, high-voltage spiker circuit and a low impedance sustainer circuit which deposits the main part of the stored energy into the discharge. The spiker circuit provides a fast rising voltage pulse to increase the electron density from its preionisation value to its quasi steady-state value. Once the discharge has been ignited the sustainer circuit can deposit the energy efficiently into the discharge under impedance-matched conditions. In magnetic-spiker circuits [6, 7] a saturable inductor provides the electrical insolation between the spiker circuit and the sustainer circuit. In this paper we report on the achievement of long-pulse laser emission from an x-ray preionised XeF($B \rightarrow X$) discharge excited laser ($\lambda = 351$ nm) driven by a magnetic-spiker sustainer circuit with a magnetic pulse compressor. The influence of the various parameters on the optical pulse duration was experimentally investigated. Results are presented on the operation of a long-pulse-duration gas discharge XeF($B \rightarrow X$) laser using the resonant overshoot mode. The longest measured optical pulse duration (FWHM) was 212 ns.

Experimental setup

The laser chamber used in the experiments is a high-pressure stainless-steel vessel. A 60 cm long high-voltage electrode of Ni coated aluminum is mounted above a ground electrode made out of a stainless-steel plate. The gap between the electrodes is 2.5 cm. The active volume is 60 cm (L) × 1 cm (W) × 2.5 cm (H). The discharge volume is preionized by a cold-cathode x-ray source. The cathode (made of carbon felt) is separated 2 cm from a Ta-foil anode operating in the transmission mode. The Ta-foil is mounted on a thin aluminum plate which separates the high-pressure laser chamber from the evacuated x-ray source.

The optical resonator consists of a flat dielectric output mirror with either 10%, 30% or 50% transmission and a concave ($R = 5$ m) dielectric total reflector. The distance between the mirrors or the cavity length is 130 cm. The temporal behaviour of the optical pulse is detected by a silicon photo diode (EG & G FND 100 Q). The dis-

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charge current, the voltage at the peaking capacitor, the voltage at the x-ray source and the optical pulse are monitored simultaneously on a digital oscilloscope (Tektronix TDS 640). The laser output energy is recorded using a pyro-electric energy detector (Gentec ED 500).

The pulse forming network of the sustainer circuit consists of a double-plate transmission line connected to the laser head. Each side of this double-plate transmission line contains 10 individual lines in parallel, each with 5 TDK capacitors of 2.7 nF, resulting in a total capacitance of 270 nF. The spiker circuit is insulated from the low-impedance PFN by a saturable inductor. This inductor is made from 8 blocks CMD 5005 ferrite of $2.5 \times 2.4 \times 40\ cm^3$ (Ceramic Magnetics) arranged in a rectangular configuration with a 4 mm central slit for the high-voltage conductor of the PFN. A one-stage magnetic pulse compression network is inserted into the spiker circuit in order to reduce the spiker rise time. The magnetic pulse compressor includes a coaxial saturable inductor employing 4 rings of CMD 5005 high frequency ferrite. The peaking capacitor consits of 8 TDK capacitors (0.70 nF each) in parallel resulting in a total capacitance of 5.6 nF.

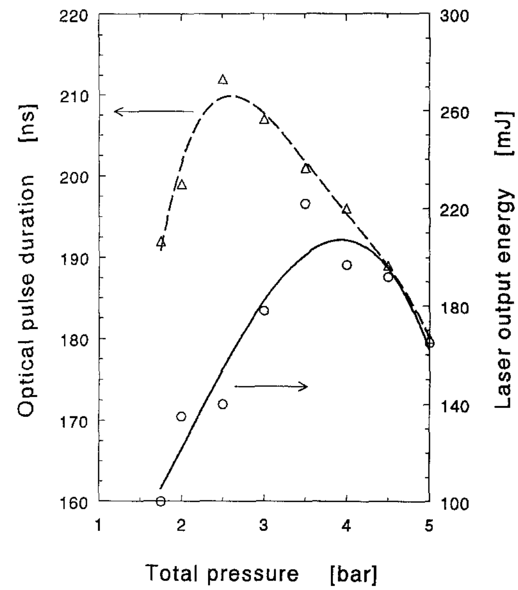

Fig. 2. Optical pulse duration and laser output energy as a function of the total pressure (same conditions as under Fig. 1 with 0.25 mbar NF_3)

Experimental results and discussion

In order to achieve long-pulse operation it is necessary to produce a very stable glow discharge. The growth of discharge instabilities can lead to the premature termination of lasing. During all our measurements we only used NF_3 as fluorine donor. The main reason for this is that compared to NF_3 molecular F_2 has a rather large absorption cross-section at the lasing wavelength of 351 nm. Moreover, it appeared during preliminary measurements that by adding F_2 to the laser-gas mixture the discharge became unstable more quickly compared to NF_3 based gas mixtures while the laser output energy did not change significantly.

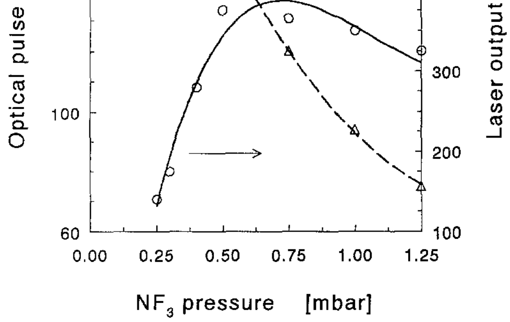

Fig. 1. Optical pulse duration and laser output energy as a function of the partial pressure of NF_3 and Xe. The NF_3:Xe ratio is 1:5. ($p = 2.5$ bar, $C_{PFN} = 270$ nF, $V_{PFN} = 13.65$ kV, $V_{sp} = 30$ kV, $T_{mirror} = 10\%$)

First, we verified the important role of the gas composition on the duration of the optical pulse. Figure 1 shows the optical pulse duration (FWHM) and laser output energy as a function of the partial pressure of NF_3 (and Xe) in a Ne-based gas mixture with a total pressure of $p = 2.5$ bar. With the variation of the NF_3 concentration from 0.25 mbar to 1.25 mbar the optical pulse duration decreases monotonically from $\tau = 212$ ns to $\tau = 78$ ns. In Fig. 2 the optical pulse duration and laser output energy are plotted as a function of the total pressure for 0.25 mbar NF_3 and 1.25 mbar Xe. From this figure it can be seen that the optical pulse duration increased with the total gas pressure, reaching a value of 212 ns at $p = 2.5$ bar and then decreased gradually to $\tau = 180$ ns at $p = 5$ bar. From the figures we found that the laser pulse duration is a sensitive function of the NF_3 concentration. Even a small reduction in the NF_3 partial pressure can lead to a noticeable improvement of the optical pulse duration. So for long-pulse lasing of the XeF($B \rightarrow X$) laser gas mixtures lean in NF_3 are necessary. However, for NF_3-lean gas mixtures the laser output energy is low due to insufficient laser gain. In this case increasing of the total pressure (neon) will not be beneficial for long-pulse generation but will improve the laser efficiency. Of course, the pressure dependence of the net small signal gain is a trade-off among the enhanced rate of the kinetic reactions and the reduced discharge current.

Secondly, the effect of the energy deposited into the laser gas mixture on the optical pulse duration was examined. Figure 3 presents the optical pulse duration as a function of the PFN charging voltage for different partial pressures of NF_3 and Xe. The figure shows that the

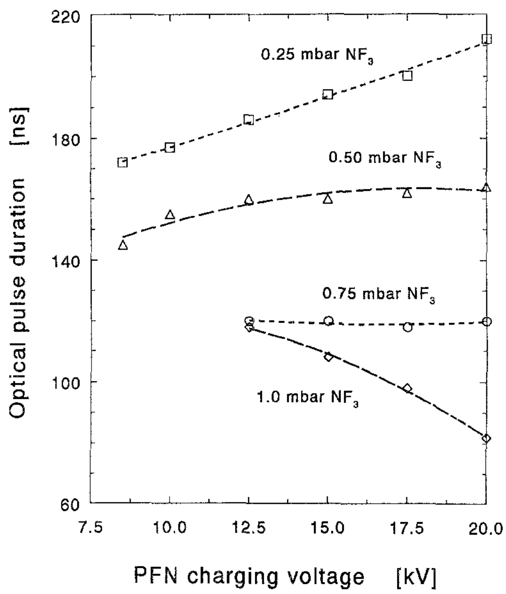

Fig. 3. Optical pulse duration as a function of the PFN charging voltage for different partial pressures of NF_3 and Xe (same conditions as under Fig. 1)

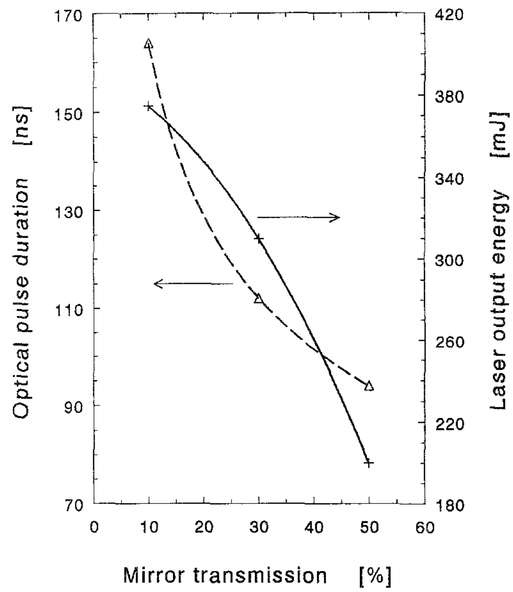

Fig. 4. Laser output energy and optical pulse duration as a function of the output coupling (same conditions as under Fig. 1 with 0.50 mbar NF_3)

optical pulse duration increased linearly with the PFN charging voltage for very low NF_3 concentration (0.25 mbar). For 2.5 mbar and 0.75 mbar NF_3 the optical pulse durations were almost constant, more or less independent of the energy input. With higher NF_3 concentrations the optical pulse duration decreased almost linearly with the increasing electrical energy deposition. With a high NF_3 content and a high PFN charging voltage the decrease of the optical pulse duration always correlates with a discharge instability. Variation of the spiker charging voltage did not change the optical pulse duration significantly while the output energy increased almost linearly with the spiker voltage. This is due to an enhanced energy deposition during the first part of the discharge.

The optical pulse duration and laser output energy as a function of the output mirror transmission (T_{mirror}) is shown in Fig. 4 for a laser gas mixture containing 0.5 mbar NF_3, 2.5 mbar Xe and $p = 2.5$ bar. It appears from Fig. 4 that the laser pulse duration is strongly dependent on the output mirror transmission under the same excitation conditions. Therefore, a low output mirror transmission will be required to achieve a long pulse laser emission from a XeF($B \rightarrow X$) laser. In Fig. 5 the optical pulse duration and the laser output energy are plotted as a function of the delay time between the X-ray preionisation pulse and the beginning of the gas breakdown. The figure shows that the maximum laser pulse duration was obtained when the delay time was between 146 and 192 ns. The optimum delay time is a function of E/N. It decreases when E/N increases. If the preionisation is applied too late the electron density is too low to achieve a fast breakdown of the gas and a uniform discharge. For longer delay times the electron density increases before application of the spiker due to acceleration of electrons by the voltage between the electrodes

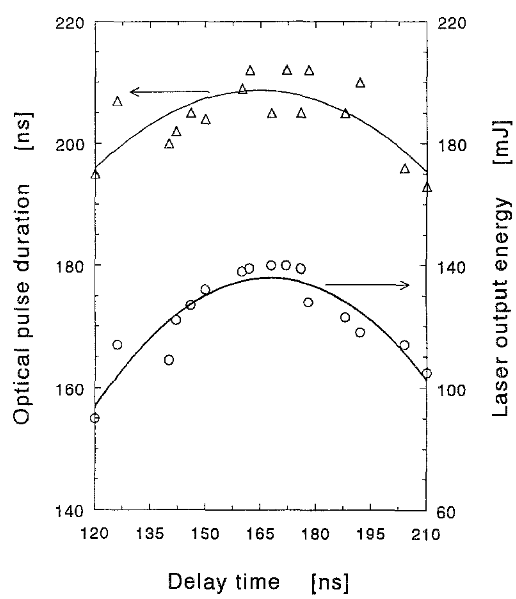

Fig. 5. Optical pulse duration and laser output energy as a function of the delay time between the onset of the preionisation and the beginning of the gas breakdown (same conditions as under Fig. 1 with 0.25 mbar NF_3)

which is already present at that time. The increased electron density leads to a decrease in the breakdown time. For a delay time greater than 192 ns, the laser pulse duration decreased as a result of delayed gas breakdown at a lower voltage which degraded the discharge quality. The shot to shot reproducibility of both the optical pulse length and the output energy was always within 5% as can be seen in Fig. 5.

In conclusion, an experimental investigation of the effect of the various parameters on the optical pulse duration of a $XeF(B \rightarrow X)$ discharge excimer laser has been carried out. Laser pulses with a duration of 212 ns (FWHM) have been measured in a NF_3/Xe/Ne gas mixture with very low NF_3 (0.25 mbar) and Xe (1.25 mbar) partial pressures at a high total pressure ($p_{Ne} = 2.5$ bar), by using a magnetic-spiker sustainer circuit with a magnetic pulse compressor, an output coupling mirror with a low transmission ($T_{mirror} = 10\%$) and with a high electrical energy deposition ($C_{PFN} = 270$ nF, $V_{PFN} = 13.65$ kV).

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