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Intense Laser Generation from an Atomic-Fluorine Laser

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Abstract. An intensive generation of radiation from a discharge-pumped atomic-fluorine gas laser is reported. A peak power exceeding 330 kW and a total energy of more than 2 mJ is obtained for a number of lines in the red, using a NF_3: He (1 : 100) gas mixture at total pressure of 500 Torr. The circuitry optimization is described and the conditions for effective operation of the atomic-fluorine laser are discussed. The temporal and the spectral characteristics of the laser emission are also presented.

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In recent years interest in the atomic-fluorine laser has been constantly increasing. This is due to the specific excitation mechanism, which necessitates intense studies [1–4], as well as to the great number of red lines, spanning a range from 624 to 780 nm and offering a wide selection of wavelengths.

Several excitation mechanisms have been proposed, including predissociation of the excimer HeF* [1], direct excitation of the fluorine atom, following the dissociation of the fluorine donor or the recombination of He^+ and F^- ions [2], or the dissociative excitation by collision of an excited He* atom with the fluorine donor [3]. Recent studies [4] revealed strong correlation between the populations of He_2^+ ions and the intensity of the spontaneous emission of the quartet system of F*. A two-step excitation mechanism was proposed, comprising dissociation of the fluorine molecule by electron impact into F^- and F and a charge transfer from He_2^+ to F^- (ion-ion recombination), as follows:

$$F_2+e \rightarrow F^-+F, \tag{1}$$

$$He_2^+ + F^- \rightarrow F^*(3p)+2He. \tag{2}$$

The pressure-dependence of the spectral content is an interesting feature of the fluorine laser [3–6]. Loree and Sze [5] have concluded that the observed pressure dependence is due to the population transfer from doublet to quarted states, caused by the collision of an excited F* atom with another F atom [5].

More recently the gain and the saturation intensities of the atomic-fluorine laser have been measured [7]. Saturation intensities of 1.2 and 4.5 kW/cm^2 have been found for the transitions at 745 and 635 nm with corresponding small-signal gains of 0.44 and 0.31 cm^{-1} for the two transitions, respectively. The high gain and the low saturation intensities explaned the uncontrolled, superradiant nature of the output from the atomic-fluorine laser.

In most of the experiments (modified) commercial [5, 6, 8] or specifically designed for TEA operation CO_2 or excimer lasers have been used. They provide high pumping rates, needed for the operation of the F*-laser. Output energies of the order of 0.5–2 mJ [3, 6, 9] and peak powers of less than 200 kW have been reported.

In the present paper we report on a high-energy, high-power discharge-pumped atomic-fluorine laser, capable to deliver more than 2 mJ and peak power more than 330 kW in the red. The laser was designed to operate as a rare-gas halide excimer and multigas laser, and in one of the first experiments, performed with NF_3: He gas mixture, strong red emission was obtained. The subject of the present paper is the description of the laser itself, as well as the temporal and the spectral characteristics of the F*-laser emission.

1. The Laser Design

Most of the lasers, designed for TEA operation, necessitate preionization of the discharge volume in order to obtain an arc-free discharge at high pressures. From the existing variety of types of preionization and pulse-forming networks (PFN) we have choosen a combination which provides a simple and reliable operation of the laser.

The laser is schematically shown in Fig. 1. The laser chamber was made of a plexiglass tube. A properly rounded 45 cm long aluminum electrode served as anode. The cathode was made of stainless steel sheet with a matrix of holes providing 55% transperancy for the preionizing illumination. The effective cross-section of the discharge was 2.4 cm^2 with a distance of 3 cm between the anode and the cathode. The active discharge volume was approximately 100 cm^3. The preionization source consisted of 36 sparks, placed behind the cathode.

The pulse-forming network (PFN) was a 1.3 Ω water-dielectric line with total capacitance of 18 nF. A multichannel rail-gap was placed between the laser chamber and the water-dielectric line in order to provide fast risetime of the voltage across the electrodes. The rail-gap was made of an array of 40 brass pins and a brass rod, both incorporated in a plexiglass box. The N_2-pressure inside the rail-gap was varied between 1 and 2.5 atm.

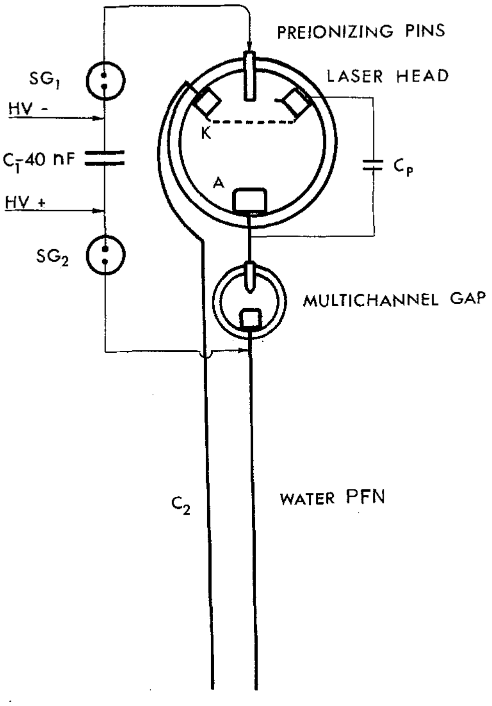

Fig. 1. Schematic diagram of the water-dielectric PFN, automatic preionization gas laser

The water-dielectric PFN was pulse-charged by means of a storage capacitor C_1 (40 nF, 100 kV, Maxwell Inc.) and two self-triggered spark gaps, SG_1 and SG_2. One of the spark gaps was connected to the water-dielectric capacitor C_2 and the other was connected to the preionizing pins by means of 36 wires, 500 nH each.

In this experiment especially, peaking capacitors C_p (K 15 – 4 type) were connected parallel to the laser electrodes. Their total capacitance was varied between 0 and 5 nF.

The laser cavity consisted of a quartz plate as an output window and an aluminum coated quartz plate as a total reflector.

2. Results and Discussions

The operation of the laser utilized automatic preionization, similar to that described in [8]. However, in our case, the auxiliary preionization discharges were not directed from the pins to the perforated cathode, but to an additional aluminum sheet. We found, that this was important to provide more uniform illumination of the active volume.

In order to obtain a fast risetime of the discharge voltage across the laser electrodes and low impedance PFN for effective energy deposition to the discharge volume, we used a combination of a multichannel railgap and a 1.3 Ω water-dielectric pulse-forming line. This combination proved to be a very effective one [10].

The storage capacitor C_1, charged up to 40–60 kV, after the breakdown of the spark gaps SG_1 and SG_2 charges up very rapidly the water-dielectric capacitor C_2. The latter is charged through the multiple preionizing discharges, providing in this way automatic preionization. The fast voltage risetime of 200 ns across the capacitor C_2 was sufficient to provide excellent multichannel operation of the rail gap with an average number of the channels of 20–30 per meter.

The active medium was a NF_3 : He gas mixture, excited by a fast pulsed discharge. Both gases were mixed in proportion 1 : 100 at a total pressure of 500 Torr. A number of experiments were performed in order to determine the influence of the different parts of the laser design on the F*-laser generation. When the multichannel rail gap was shunted and the water-dielectric PFN connected directly to the laser tube, a weak red line was generated. Significantly enhanced laser action was observed with the multichannel rail gap placed between the laser chamber and the water PFN, as shown in Fig. 1. We explain this with the increased overvoltage across the laser electrodes, rather than with the improved quality of the discharge.

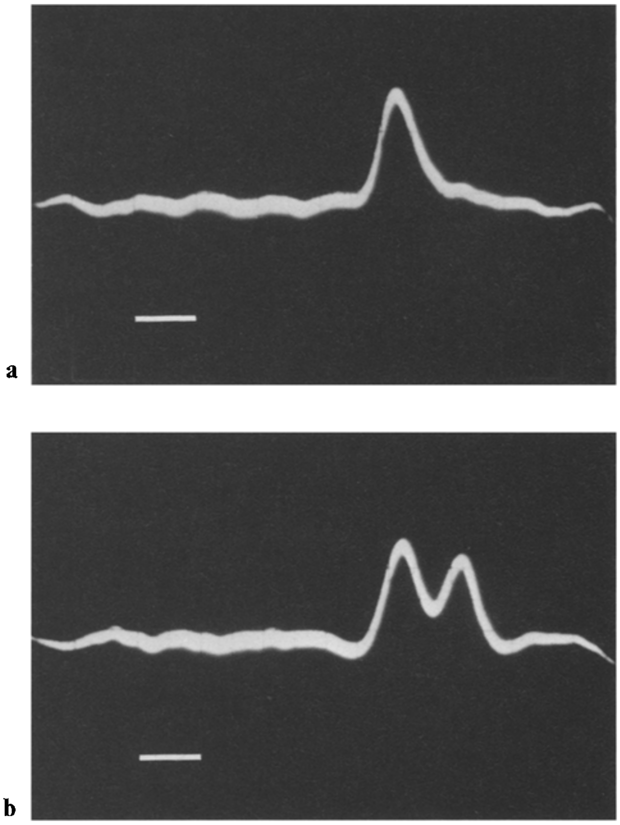

Fig. 2a and b. Oscilloscope traces of the F*-laser pulses. The time base is 10 ns/div: (a) for a NF_3:He gas mixture (1 : 100) at 500 Torr; (b) simultaneous red (the first pulse) and uv (337.1 nm, the second pulse) generation from a NF_3 : N_2 : He gas mixture (1 : 0.5 : 100) at 500 Torr

An intense laser action at a number of lines in the red was obtained when 4 to 5 capacitors 470 pF each were connected parallel to the laser electrodes, keeping the inductance as low as possible. Up to 2 mJ energy was measured by means of a Rj 7200 energy meter (Laser Precision Corp.) with Rj 765 Pyroelectric probe. We expect that the actual energy, delivered by this laser is more, because the cavity mirrors were damaged by the fluorine action.

The pulse width of the laser emission was measured using a coaxial photoelement FEK-15 (0.5 ns risetime) and a Tektronix 466 storage oscilloscope. Figure 2a shows the pulse form and reveals a 6 ns pulse duration (FWHM). In this way, the peak power exceeds 330 kW. To our knowledge, this is the highest peak power from an atomic-fluorine laser, reported to date.

The most probable mechanisms for F*(3*p*) population involve He* [3] or especially He_2^+ [4] formation as a necessary condition for the excitation of the atomic fluorine. In both cases the high energy for He atom excitation and ionization requires a high value of E/N. This is satisfied only at the initial short stage of the discharge, just before the voltage drop across the laser electrodes. Thus, energy deposition at high E/N is needed for an effective operation of the F*-laser. This imposes some limitations on the efficiency of the electric-discharge pumped atomic-fluorine laser. The peaking capacitor considerably improves the current pulse risetime, which together with the increased overvoltage (due to the multichannel rail gap) assures high energy deposition at the very beginning of the discharge. A value of 2 nF for C_p was found to be optimum. Indeed, higher capacitance would lead to a lower voltage risetime and lower overvoltage. Lower capacitance would provide smaller energy deposition at the initial stage of the discharge development.

An experimental verification of the above-mentioned considerations was made, when a small amount of N_2 (approximately 1–3 Torr) was added to the laser gas mixture. In this case simultaneous generation in the uv (337.1 nm, N_2-laser) and in the red (F*-laser) was obtained. The time behaviour of the two lasings was studied. It was found, that the F*-lasing always preceeds (approximately with 9 ns) the uv generation, as shown in Fig. 2b. This observation implies that the optimum value of E/N for the F*-laser is higher than this for the N_2 laser. In our view, the F*-lasing termination is caused by the E/N decrease, rather than by the discharge quality deterioration, because the uv generation starts when the red one is finished. Similar time dependence of simultaneous F*-laser and F*I-laser (457 nm) generation was reported in [11].

At 500 Torr total pressure we obtain simultaneous generation at both doublet and quartet systems. With a fresh gas mixture the intensity of the latter was orders of magnitude higher. The spectral content of the laser emission was analyzed by means of a DFS-8 grating spectrograph. We have observed the 623.9, 634.9 nm lines (quartet system) and the 712.8, 731.1, and 780 nm lines (doublet system), recorded on a NP 20 ORWO film. The behaviour of the intensities of the lines, orginated from the two systems was quite different in the course of the laser operation with a static gas mixture. While the intensity of the quartet system lines decreased with the total number of shots due to the fluorine donor exhaust, the intensity of the doublet system lines increased, in spite of the fluorine concentration reduction (Fig. 3). After 300 shots the intensities of the quartet and doublet system lines become comparable. Further fluorine donour exhaust caused a doublet system intensity decrease as well. This behaviour of the line intensities for the quartet and doublet systems with respect to the fluorine-atoms concentration is consistent with the assumption, made in [5], i.e. the collisions of an excited F* atom with another F atom lead to transfer of this atom from the doublet to the quartet state. It seems quite probable,

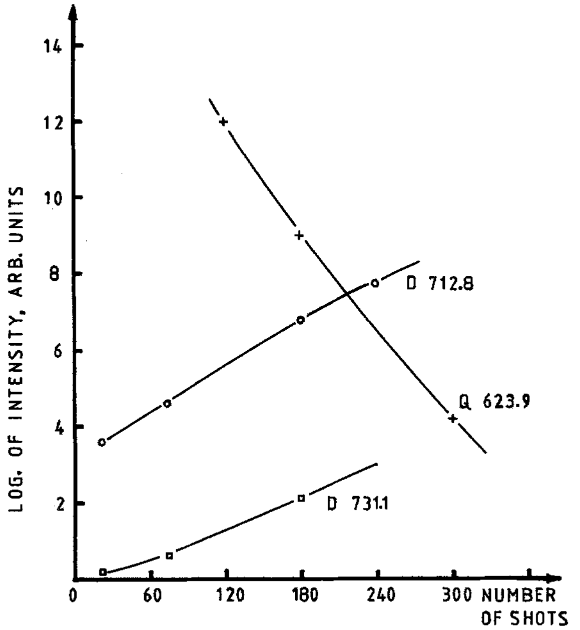

Fig. 3. Line intensity variation of two doublet system lines (*D*, ○, □) and one quartet system line *Q*, +) as a function of the number of shots for a static gas mixture. The fluirine donor concentration decreases with the number of shots. The most intense line at 634.9 nm is not shown (data taken from the microdensitograms)

that in our experimental conditions the doublet-states population is much higher than the expected one from the observed doublet-lines intensities and, because of the great concentration of F atoms at the beginning of the laser operation, high transfer rates from doublet to quartet states occur.

3. Conclusion

We have carried out experiments with a fast-discharge pumped laser, using NF_3 : He (1 : 100) gas mixture at a total pressure of 500 Torr. The laser was designed for multigas operation and featured an automatic preionization and water-dielectric pulse-forming network. High output energy, exceeding 2 mJ, and a peak power of 330 kW are obtained for five red lines of the F*-laser.

A number of experiments, including PFN optimization, simultaneous uv and red generation showed that for an effective operation of the atomic-fluorine laser, predominant energy deposition at high values of E/N is required.

The doublet and quartet system lines intensity dependence on the fluorine donor concentration indicated that at high concentrations collisional relaxation from doublet to quartet states may take place.

The output power, obtained from this laser are suitable for pumping infrared dye lasers.

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References

1. L.O. Hocker: J. Opt. Soc. Am. **68**, 262 (1978)
2. J.E. Lawler, J.W. Parker, L.W. Anderson, W.A. Fitzsimmons: IEEE J. QE-**15**, 609–613 (1979)
3. S. Sumida, M. Obara, T. Fujioka: J. Appl. Phys. **50**, 3884–3887 (1979)
4. C.B. Collins, F.W. Lee, S.M. Carroll: Appl. Phys. Lett. **37**, 857–859 (1980)
5. T.R. Loree, R.C. Sze: Opt. Commun. **21**, 255–257 (1977)
6. A. Rothem, S. Rosenwaks: Opt. Commun. **30**, 227–230 (1979)
7. R. Sadighi-Bonabi, F.W. Lee, C.B. Collins: J. Appl. Phys. **53**, 3418–3423 (1982)
8. T.J. McKee, J. Banic, A. Jares, B.P. Stoicheff: IEEE J. QE-**15**, 332–334 (1979)
9. I.J. Bigio, R.F. Begley: Appl. Phys. Lett. **28**, 263–264 (1976)
10. S. Watanabe, A.J. Alcock, K.E. Leopold, R.S. Taylor: Appl. Phys. Lett. **33**, 3–6 (1981)
11. M. L. Dlabal, S.B. Hutchinson, J.G. Eden, J.T. Verdeyen: Appl. Phys. Lett. **37**, 873–876 (1980)