A new electron-beam pumped XeF laser at 486 nm

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(Received 28 February 1979; accepted for publication 17 April 1979)

Laser emission has been observed from XeF on the $C(3/2) \rightarrow A(3/2)$ transition at 486 nm with a spectral bandwidth of 12 nm. A peak laser power of 5 kW was obtained from $Ar/Xe/NF_3$ mixtures in the ratio of 600:2:1 at total pressures of 350–800 kPa excited by 1-MeV 20-kA electron-beam pulses of 8-ns duration. Lasing can also occur on the usual $B(1/2) \rightarrow X(1/2)$ transition at 353 nm with an appropriate set of cavity reflectors under the same operating conditions.

PACS numbers: 42.55.Hq

Electron-beam- or discharge-pumped XeF excimer systems usually operate at 353 nm on the $B\,\frac{1}{2}$-$X\,\frac{1}{2}$ transition. Fluorescence measurements have shown the existence of a broad continuum band centered near 470 nm, which originates from the $C\frac{3}{2}$ state and terminates on the repulsive $A\frac{3}{2}$ state. Kligler *et al.* [1] and Brashears and Setser [2] have shown that the $C\frac{3}{2}$ state of XeF is the lowest ionic excited state. This state may have a considerably larger population than the $B\,\frac{1}{2}$ state at high buffer-gas pressures. In fact, Finn *et al.* [3] have just shown that the largest part of the C-state population is due to quenching from B to C at high pressures. However, secondary electrons arising from long e-beam pulses ($\sim 1\,\mu$s) can mix the two states [1] which then leads to lasing at 353 nm, because the transition probability for the $B \rightarrow X$ transition is about six times higher than for the $C \rightarrow A$ transition. [4,5] Subsequently, Hill *et al.* [6] have measured gain at 475.9 and 488 nm in $Ar/Xe/NF_3$ mixtures excited by short electron-beam pulses (2ns). Just recently, Bischel *et al.* [7] demonstrated laser action on the $C\frac{3}{2} \rightarrow A\frac{3}{2}$ transition around 483 nm by photolytic excitation of XeF_2 using Xe_2 excimer fluorescence at 172 nm.

In this paper we report laser emission on the $C\frac{3}{2} \rightarrow A\frac{3}{2}$ transition of XeF by direct electron-beam excitation of $Ar/Xe/NF_3$ mixtures. 1-MeV electron-beam pulses of 8-ns duration were generated by a Physics International Pulserad 110 electron-beam accelerator. The electrons passed through a 50-μm Ti anode foil into a stainless-steel cell transversely exciting an active column of 6-cm length. Time-resolved fluorescence and laser emission were observed with an ITT F4000 S-5 photodiode. Wavelength-selective measurements were made with a $\frac{1}{4}$-m Jarrel-Ash monochromator placed in front of the photodiode with a spectral resolution of 3 nm. By removing the exit slit of the monochromator, a 35-nm spectral range of the main portion of the 470-nm XeF band could be observed. Time-integrated spectra were obtained with a PAR OMA1 spectrometer-optical multichannel analyzer combination. A Faraday cup probe mounted inside the reaction cell monitored the current density of the electron beam. In this manner it was possible to observe the time history of the electron-beam excitation pulse and the subsequent temporal evolution of the fluorescence or laser pulses. The experimental apparatus is described in more detail in Ref. 8.

Fluorescence studies established the optimum conditions for emission via the $C\frac{3}{2} \rightarrow A\frac{3}{2}$ transition as compared to the $B\,\frac{1}{2} \rightarrow X\,\frac{1}{2}$ transition. The fluorescence band is centered at 476 nm and has a FWHM of 55 nm. Typical temporal characteristics of the electron-beam pulse and fluorescence intensity at 353 and 476 nm for a mixture of 16 Torr Xe, 8 Torr NF_3, and 600 kPa Ar are shown in Fig. 1(a). For xenon pressures between 4 and 30 Torr and NF_3 pressures of 4 –16 Torr the 476-nm/353-nm fluorescence intensity ratio increased with increasing Ar buffer-gas pressure. The total fluorescence output increased with Ar pressures up to 900 kPa, and then decreased, possibly due to higher absorption by the Ar excimers. Lower Xe and NF_3 pressures within the range mentioned above improved the 476-nm/353-nm fluorescence intensity ratio and lengthened the fluorescence pulses, but they considerably reduced the fluorescence peak power. The fluorescence pulse length was only determined by the Xe and NF_3 partial pressures, and not by the buffer-gas pressure. The 476-nm emission peak appeared several ns later than the 353-nm output. When neon was used as a buffer gas instead of argon, the 476-nm/353-nm fluorescence in-

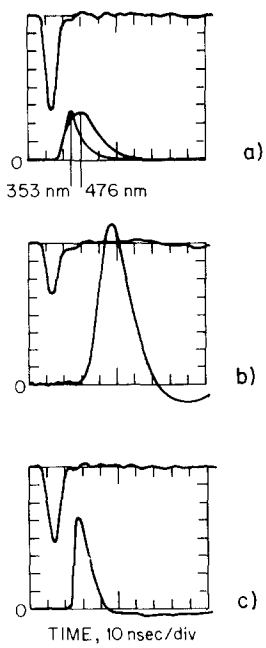

FIG. 1. Time history of e-beam pulse and (a) fluorescence at 353 and 476 nm, (b) lasing at 486 nm, and (c) lasing at 353 nm from a standard mixture of 16 Torr Xe, 8 Torr NF_3, and 600 kPa Ar; time scale : 10 ns/div.

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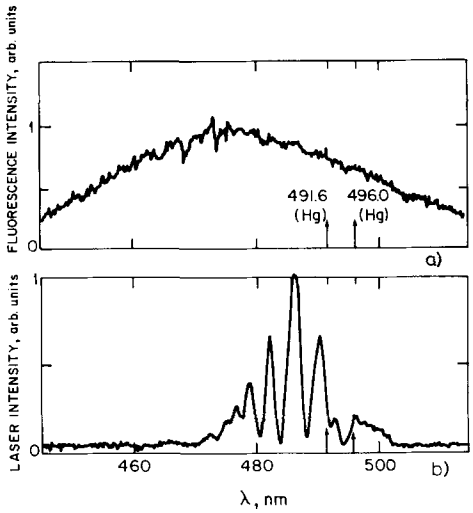

FIG. 2. Time-integrated spectra of (a) fluorescence and (b) laser emission from the $C\frac{3}{2} \rightarrow A\frac{3}{2}$ transition of XeF (16 Torr Xe, 8 Torr NF_3, and 600 kPa Ar.

tensity ratio always remained below 0.5, but the total output increased with pressure.

For the laser experiments, a prealigned intracell optical resonator, composed of two reflectors attached to a stainless-steel mount and a 6.7-cm-long spacer, was used. One mirror with a 0.5-m radius of curvature served as the end mirror ($R > 99\%$), while the other reflector was flat with different reflectivities. All mirrors were broadband coated for the range 460–510 nm. Laser emission occurred for mixtures of Xe partial pressure between 4 and 25 Torr, NF_3 pressure between 4 and 13 Torr, and Ar buffer-gas pressures of 350–800 kPa with a 98% reflectance output coupler. A mixture of 16 Torr Xe, 8 Torr NF_3, and 600 kPa Ar proved to be optimum with a peak output power of the order of 5 kW for a 98% reflectivity output coupler. The laser pulse occurs in the afterglow, as depicted in Fig. 1(b), which is in agreement with the results of the gain measurements reported in Ref. 6. Since secondary electrons mix the C and B states, [1] the time duration of the e-beam pulse has to be considerably shorter than the C-state lifetime. With the short pulses provided by our e-beam source there is a fairly long time period of afterglow without the presence of secondary electrons which allows a laser pulse to develop. For an output coupler with 90% reflectivity and an optimum gas mixture, the laser peak power was the same as for the 98% reflector, but the pulse duration decreased from 20 to 10 ns. Lasing just above threshold occurred when an 80% reflectance output coupler was used. A comparison of the output powers for these three different output couplers yielded a gain of approximately 25% per round trip for an optimum $Ar/Xe/NF_3$ mixture, which is slightly higher than the gain of 8% per pass reported in Ref. 6. For a resonator with 99 and 95% reflectivity mirrors for 353 nm, operating under the same conditions as described above, lasing can also occur at 353 nm. As shown in Fig. 1(c), such a pulse occurs earlier and is shorter than the blue-green laser pulse [Fig. 1(b)].

The time-integrated spectral characteristics of the XeF laser system are shown in Fig. 2. The fluorescence spectrum depicted in Fig. 2(a) is centered at 476 nm and is smooth, with no evidence of any significant absorption features. On the other hand, the laser spectrum shown in Fig. 2(b) has a regular spectral structure centered at 486 nm. The envelope of this laser emission spectrum has a FWHM of 12.5 nm. Laser experiments with different buffer gases were performed in order to determine whether the structure is due to buffer-gas absorption. With mixtures of 16 Torr Xe, 800 kPa Ne, or 200–400 kPa Kr, laser action occurred just above threshold. The fluorescence spectrum for both neon and krypton buffer gases were similar to that of argon. The laser spectrum showed the same spectral structure as for argon but with different different individual peak heights. The characteristic structure is probably due to emission from different vibrational levels of the $C\frac{3}{2}$ state to the $A\frac{3}{2}$ state. The spectral separation of the maxima is 4 nm, with corresponds to a vibrational level separation of 2.1×10^{-2} eV or 169 cm^{-1}.

In summary, we have shown that broadband XeF laser emission in the blue green can be achieved by direct electron excitation at buffer-gas pressures of around 600 kPa. Work is currently underway to explore the wavelength tunability of this laser by means of a suitable dispersive element, such as a prism or grating.

The authors would like to thank Dr. D.C. Lorents for his stimulating discussion at the outset of this work. We wish to acknowledge the Office of Naval Research, Robert A. Welch Foundation, and the National Science Foundation for their financial support.

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