Simultaneous UV/Visible Laser Oscillation on the $B \rightarrow X$ and $C \rightarrow A$ XeF Excimer Transitions

ROLAND SAUERBREY, YUNPING ZHU, FRANK K. TITTEL, WILLIAM L. WILSON, JR., N. NISHIDA, F. EMMERT, AND WILLIAM L. NIGHAN

Abstract—Simultaneous laser oscillation from the 351 nm XeF($B \rightarrow X$) transition and the broad-band XeF($C \rightarrow A$) transition centered near 475 nm has been demonstrated using intense, short-pulse electron-beam excitation of high-pressure gas mixtures. Analysis of the causes of transient absorption suggests that it may be possible to obtain efficient UV/visible laser oscillation from each of the XeF excimer transitions excited in the same medium.

Introduction

XENON fluoride is the only diatomic rare gas-halide molecule exhibiting two lasing transitions. Laser oscillation occurs on the $B(\frac{1}{2})$-$X(\frac{1}{2})$ transition in the near ultraviolet at 351 nm, and on the broad-band tunable $C(\frac{3}{2})$-$A(\frac{3}{2})$ transition in the visible centered near 475 nm. Electrically excited lasers operating on the $B \rightarrow X$ transition have been under investigation for several years, and are capable of very efficient (~2-5 percent) generation of high-power UV radiation [1]. Recently, efficient (>1 percent) operation of the XeF($C \rightarrow A$) laser with an energy output in excess of 3 J/l was also demonstrated [2], [3]. For a variety of applications such as frequency mixing or multistep photoexitation, it might be of interest to have an efficient laser source that is capable of emitting intense UV *and* tunable visible radiation simultaneously. In this letter, the feasibility of simultaneous operation of the XeF($B \rightarrow X$) and ($C \rightarrow A$) laser transitions in the same apparatus is reported for the first time.

Experimental Apparatus and Procedure

A gas mixture comprised of 8 torr F_2, 8 torr NF_3, 16 torr Xe, and 6.5 atm Ar was excited by an intense electron beam (1 MeV, 250 A · cm^{-2}, 10 ns FWHM), conditions previously found to be compatible with efficient XeF ($C \rightarrow A$) laser operation [2]. In order to investigate the possibility of simultaneous laser oscillation on both XeF excimer transitions, a dual-wavelength resonator was constructed using broad-band mirrors that were available in our laboratory. The basic design of this resonator is shown in Fig. 1. A curved mirror with more than 99 percent reflectivity between 350 and 490 nm was used as the full reflector. Two flat output couplers were mounted as shown. The broad-band $C \rightarrow A$ output coupler had a reflectivity of 98 percent at a wavelength of 510 ± 30 nm and a transmissivity of 90 percent for 351 nm radiation, while the $B \rightarrow X$ output mirror had a reflectivity of 83 percent for the UV radiation and 60 percent transmissivity in the visible region. Between these two mirrors, a viton O-ring was inserted and, by means of a set of three adjustment screws, the $C \rightarrow A$ mirror was aligned so as to be parallel to the $B \rightarrow X$ mirror. Alignment was performed before the mirrors were installed in the reaction cell. Both mirror holders could then be aligned externally as described in [2]. The dual-wavelength resonator so constructed had relatively small intracavity losses for the $C \rightarrow A$ transition, while those for the $B \rightarrow X$ transition were quite high. However, the gain of the narrow-band UV bound-bound transition is considerably larger than that of the $C \rightarrow A$ transition, since the $B \rightarrow X$ stimulated emission cross section is about 30 times larger than that of the $C \rightarrow A$ transition.

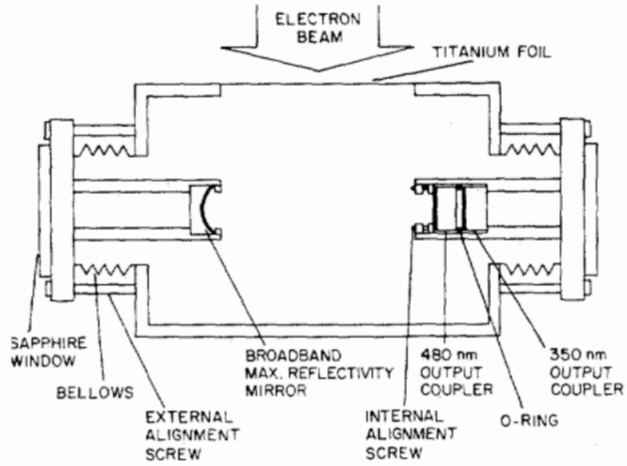

Fig. 1. Dual wavelength resonator configuration for the simultaneous operation of the XeF($B \rightarrow X$) and XeF($C \rightarrow A$) lasers.

Results and Analysis

Although the gas mixture was far from optimum for $B \rightarrow X$ laser oscillation [1], and the $C \rightarrow A$ resonator was not optimized, laser oscillation on both transitions was routinely observed. Presented in Figs. 2 and 3 are the temporal and spectral characteristics of the UV and blue/green XeF $B \rightarrow X$ and $C \rightarrow A$ laser pulses obtained using the dual, coincident UV/visible cavity configuration illustrated in Fig. 1. As described

Manuscript received November 7, 1984; revised January 11, 1985. This work was supported in part by the Office of Naval Research, the National Science Foundation, and the Robert A. Welch Foundation. The work of R. Sauerbrey was supported by the Deutsche Forschungsgemeinschaft.

R. Sauerbrey, Y. Zhu, F. K. Tittel, W. L. Wilson, Jr., and N. Nishida are with the Department of Electrical and Computer Engineering, Rice University, Houston, TX 77251.

F. Emmert is with the Physikalisches Institut der Universitat Wurzburg, D-8700, Wurzburg, West Germany.

W. L. Nighan is with United Technologies Research Center, East Hartford, CT 06108.

0018-9197/85/0500-0418$01.00

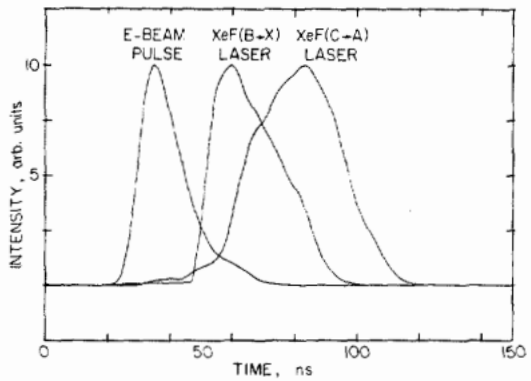

Fig. 2. Temporal evolution of the *e*-beam pulse and the XeF($B \rightarrow X$) and XeF($C \rightarrow A$) laser pulses for a mixture comprised of 6.5 atm Ar, 16 torr Xe, 8 torr F_2, and 8 torr NF_3.

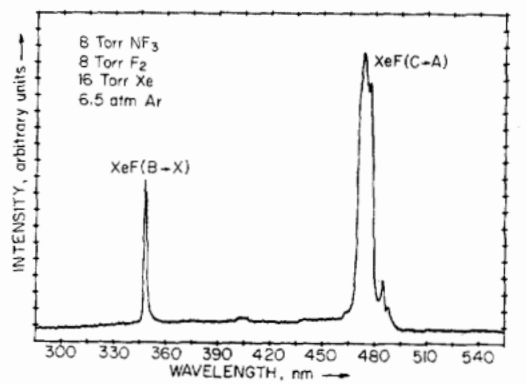

Fig. 3. Time integrated spectrum of the XeF $B \rightarrow X$ laser at 351 nm and $C \rightarrow A$ laser centered near 475 nm.

previously [2], the *e*-beam pulse results in the production of broad-band absorbing species, and therefore, the laser pulses appear in the afterglow regime (Fig. 2). The net effect of transient absorption is most severe for the $C \rightarrow A$ transition due to the fact that its cross section for stimulated emission is relatively small ($\sim 10^{-17}$ cm^2) [4]. Thus, the onset of the $C \rightarrow A$ laser pulse is delayed for a longer time than that of the $B \rightarrow X$ pulse.

The laser spectrum (Fig. 3) shows both the narrow $B \rightarrow X$ emission at 351 nm and the broad-band $C \rightarrow A$ emission centered near 475 nm. The laser wavelength and spectral width for the $C \rightarrow A$ transition are mainly determined by the specific properties of the end reflector and output coupler. For the present nonoptimized dual-wavelength resonator, the laser pulse energy levels were relatively low; ~0.01 J/l was obtained from the $C \rightarrow A$ transition and ~0.05 J/l for the $B \rightarrow X$ transition. However, for these specific conditions, $C \rightarrow A$ laser pulse energy in excess of 1.0 J/l has been routinely obtained using an optimized resonator [3].

Presented in Fig. 4 is the temporal evolution of the various contributions to the gain and absorption at 351 and 475 nm, computed for the conditions of Figs. 2 and 3 following the procedures described in detail in [2]. The *net* gain shown for the blue-green $C \rightarrow A$ transition is in very good agreement with experimental observations [2], [3]. We have not measured the gain/absorption in the UV region. However, the results

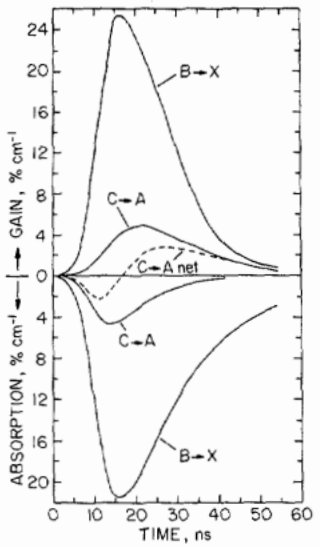

Fig. 4. Contributions to the XeF($B \rightarrow X$) and XeF($C \rightarrow A$) gain and absorption at 351 and 475 nm, respectively, computed for the conditions of Figs. 2 and 3 following the procedures described in [2].

of Fig. 4 show that the computed *net* gain for the UV $B \rightarrow X$ transition (~4 percent cm^{-1} maximum at ~15-20 ns) is the difference between two much larger gain-absorption values. For these specific mixture conditions, which have been optimized for blue-green $C \rightarrow A$ laser oscillation, the calculations show that absorption in the UV is dominated (>75 percent) by Ar_2F photodissociation [5]. Krypton has been found to be an effective quenching species for Ar_2F [6]. Moreover, subsequent to the completion of this work, it was found that the addition of Kr at partial pressures in the 0.5-1.0 atm range results in an increased rate of XeF(B, C) formation and in a decrease in absorption in the visible region, the combined effect of which is a significant increase in *net* gain for the $C \rightarrow A$ transition [3]. For these reasons, mixtures containing Kr might exhibit higher levels of net gain for *both* the $B \rightarrow X$ and $C \rightarrow A$ transitions than those indicated in Fig. 4. This suggests that significantly higher $B \rightarrow X/C \rightarrow A$ dual laser output may be possible.

Summary

We have demonstrated that an *e*-beam excited medium that has been optimized for efficient blue/green XeF($C \rightarrow A$) laser oscillation also exhibits strong net gain for the UV $B \rightarrow X$ transition, and that simultaneous laser oscillation on both transitions is possible. Further, our results show that the presence of a strong $B \rightarrow X$ flux has relatively little effect on $C \rightarrow A$ gain. These findings suggest that with an optimum resonator design and/or with additional mixture refinement, efficient ($\gtrsim$1 percent) UV/visible laser oscillation from *each* of the XeF excimer transitions excited in the same medium may be possible.

References

[1] J. C. Hsia, J. A. Mangano, J. H. Jacob, and M. Rokni, "Improvement in XeF laser efficiency at elevated temperatures," *Appl. Phys. Lett.*, vol. 34, pp. 208-210, 1979.

[2] Y. Nachshon, F. K. Tittel, W. L. Wilson, Jr., and W. L. Nighan,

"Efficient XeF($C \rightarrow A$) laser oscillation using electron beam excitation," *J. Appl. Phys.*, vol. 56, pp. 36–48, 1984.

[3] W. L. Nighan, F. K. Tittel, W. L. Wilson, Jr., N. Nishida, Y. Zhu, and R. Sauerbrey, "Synthesis of rare gas-halide mixtures resulting in efficient XeF($C \rightarrow A$) laser oscillation," *Appl. Phys. Lett.*, vol. 45 pp. 947–949, 1984.

[4] W. K. Bischel, D. J. Eckstrom, H. C. Walters, Jr., and R. A. Tilton, "Photolytically pumped XeF($C \rightarrow A$) laser studies," *J. Appl. Phys.*, vol. 52, pp. 4429–4434, 1981.

[5] W. R. Wadt and P. J. Hay, "Electronic states of Ar_2F and Kr_2F," *J. Chem. Phys.*, vol. 68, pp. 3850–3863, 1978. In the present work, the Ar_2F photoabsorption cross section at 351 nm was taken as 1.7×10^{-17} cm^2, a value typical of Ar_2^+. See H. H. Michels, R. H. Hobbs, and L. A. Wright, *J. Chem. Phys.*, vol. 71, p. 5053, 1978.

[6] R. Sauerbrey, F. K. Tittel, W. L. Wilson, Jr., and Y. Zhu, "The displacement reactions of the triatomic rare gas-halide excimers," *J. Chem. Phys.*, to be published.