WIDEBAND TUNING EXPERIMENTS WITH AN INJECTION-CONTROLLED XEF (C→A) LASER

W.L. Wilson, C.B. Dane, S. Yamaguchi
Th. Hofmann, R. Sauerbrey and F.K. Tittel

Department of Electrical and Computer Engineering
Rice Quantum Institute
William Marsh Rice University
Houston, TX 77251-1892

Abstract

This paper reports on scaling experiments on an electron beam pumped XeF (C→ A) laser. Scaling from an active mode volume of 0.02 liters to 0.5 liters resulted in an increase in output energy from ~30 mJ to ~ 1J. Intrinsic efficiency was 1.5% with an output energy density of ~ 2 J/liter. Details of the tuning characteristics and spectral purity of the laser are reported.

Introduction

The XeF (C→ A) laser is an efficient, tunable source of radiation in the blue-green region of the spectrum (See **Figure 1**). Efficient operation of this laser system has been demonstrated over a wide range of electron beam excitation energy densities ranging from 250 kW/cm^3 to 12 MW/cm^3 [1-4]. When short pulse, high current density electron beam excitation is used, peak values of the small signal gain exceeds 3%/cm, which permits efficient operation under injection control. This leads to very narrow band, wavelength agile operation across the entire 450 nm to 530 nm band of operation for this device. Over the range from 470 nm to 510 nm, an output energy exceeding 1 J/ℓ has been achieved.

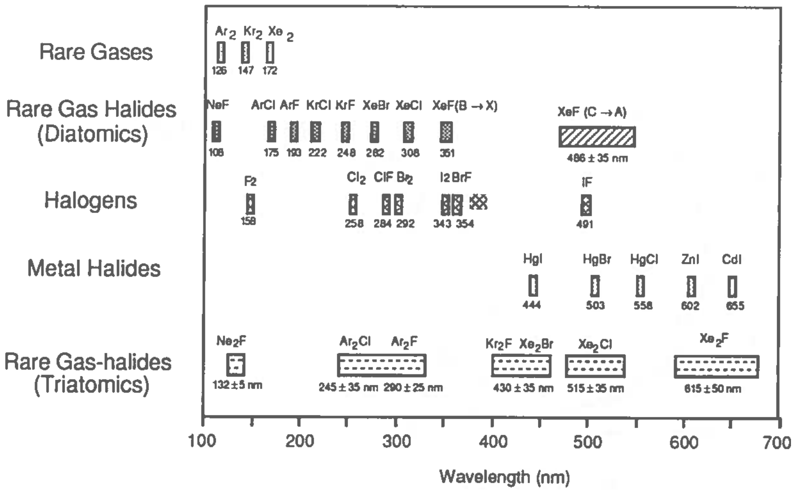

Figure 1. Spectral Characteristics of Excimer Transitions

Because the XeF (C→ A) laser operates in a gaseous medium, it is readily scalable to the high power and energies which would be required for remote sensing, materials processing, optical communications and the amplification of ultrashort pulses. This paper describes recent experiments on scaling of the XeF (C→ A) laser from a relatively small active volume of ~0.02 ℓ [5] to one of ~ 0.5 ℓ. A unique numerical model developed to aid in the design of the optical cavity for the scaled-up configuration is described, as well as re-optimization procedures for the five component gas mixture for operation under much longer gain lengths than were used in the small volume experiments.

Several different magnification values were used with the external cavity, as shown in **Figure 6**. The cell windows for the external configuration were AR-coated fused silica, tilted by 3° to prevent any unwanted cavity effects resulting from them.

In most of the experiments reported here, the injection source was a dye laser pumped with a 60 ns FWHM XeCl excimer laser, resulting in a 40 ns FWHM injection pulse. The linewidth of the output from the dye laser was ~ 0.005 nm, except when a special intercavity etalon was used, in which case the linewidth was reduced to < 0.001 nm. The relatively long injection pulse allowed complete filling of the unstable resonator cavity before the e-beam was fired, which resulted in quasi-CW injection. The injection intensity could be varied using neutral density filters. The maximum energy which could be delivered to the unstable resonator injection aperture was about 2 mJ (after taking into account losses due to turning mirrors, telescope and the delay line which is used to prevent damage to the dye laser resulting from energy reflected from the injection aperture).

A computer controlled diagnostic system was developed to extensively characterize the performance of the XeF (C→ A) laser on each shot. As shown in **Figure 7** the output beam from the laser is directed to several sensors. A pyroelectric energy meter was used as a primary measurement of the total output from the device. A vacuum photodiode (with < 1 ns resolution) was used to obtain the temporal profile of the output pulse, while an optical multichannel analyzer (OMA) monitored the spectral characteristics. The performance of the electron beam generator was monitored with current and voltage monitors, while a pressure transducer monitored the shot-to-shot energy deposition within the cell.

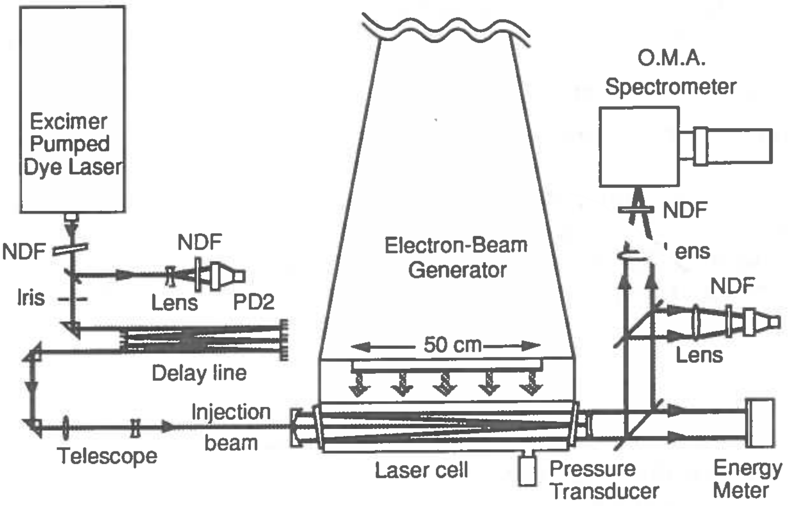

Figure 7. Diagram of the Experimental Layout

Experimental Results

As shown in Figure 3, the energy deposition within the laser cell varied significantly from front to back. Because of this, it was possible to measure the variation of XeF (C→ A) small signal gain as a function of energy deposition by changing the position of the gain probe beam as it passed through the cell.

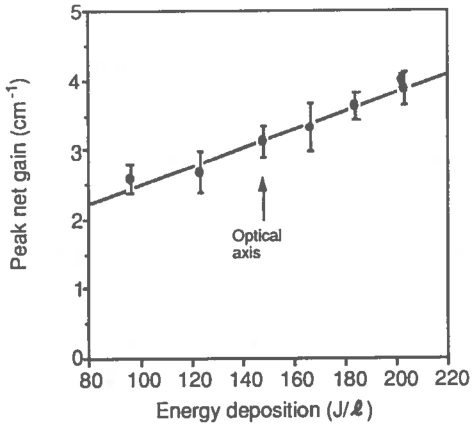

Figure 8. Gain as a Function of Energy Deposition

Figure 8 shows the results of this study. As can be seen, the gain increases almost linearly with deposition energy density up to 200 J/ℓ . Previous measurements on the small scale laser indicated the onset of gain saturation for a deposition energy density of about 80 J /ℓ with a peak in the intrinsic efficiency occuring at about 90 J /ℓ [5]. The interpretation of the earlier results however was complicated by very non-uniform electron beam pumping (no magnetic guide field was being used then) For the results obtained here, under much better controlled conditions, it appears that further increases in gain (and hence laser output energy) could be achieved with even greater pumping intensities.

Figure 9 shows the variation of the output energy from the XeF (C→ A) laser as a function of *average* energy deposited in the laser cell. The deposition energy was varied by adjusting the charging voltage of the Marx bank in the e-beam generator between 65 kV and 95 kV. Again, a nearly linear dependence is observed with no apparent indication of saturation up to the maximum average deposition of 125 J/ℓ. Using an internal resonator with a magnification of 1.7 and an optimized five-component gas mixture [9], and an injection intensity of about 3 MW/cm^2 (~ 2 mJ), laser output energies as high as 0.92 J have been achieved at 490 nm, near the peak of the XeF (C→ A) gain spectrum. This corresponds to an energy density of about 1.85 J/ℓ and an intrinsic efficiency of 1.5%.

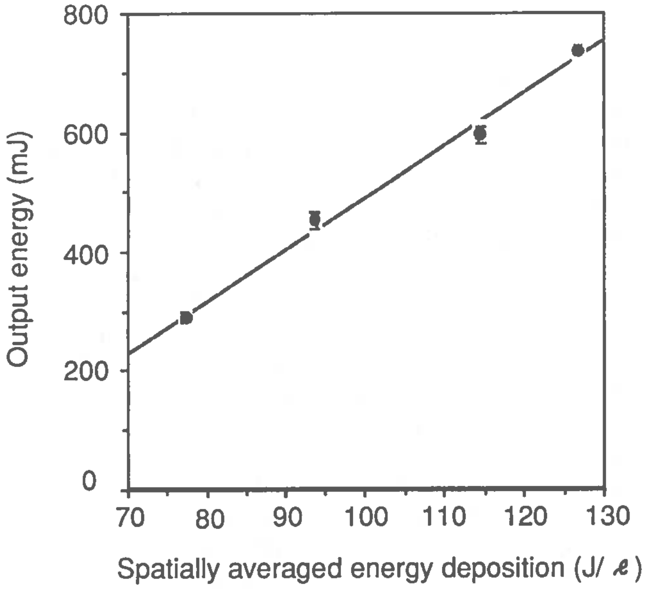

Figure 9. Output Energy as a Function of Spatially Averaged Energy Deposition

In order to investigate the spectral characteristics of the XeF (C→ A) laser, a set of wavelength tuning experiments was performed. An unstable resonator with a magnification of 1.34 was chosen in order to obtain good performance in the wings of the XeF (C→ A) laser spectrum. The somewhat reduced output coupling (as compared with the M=2 optics) significantly enhanced the performance of the laser in the low-gain wings, while not lowering the output in the central region too much. Three different sets of optics, with coating reflectivities optimized for specific regions of the spectrum were used for these measurements. Four different Coumarin dyes (460, 480, 503 and 521) were necessary in order to completely scan the tuning range of the XeF (C→ A) laser. The intensity injected into the unstable resonator cavity was adjusted to 2 MW/cm^2, corresponding to about 1.5 mJ injected energy, so that the performance at different wavelengths for the XeF (C→ A) laser could be compared at the same injection intensity.

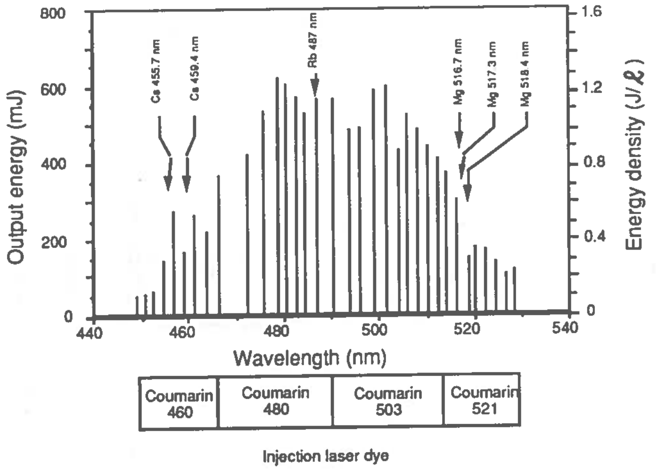

Figure 10. Spectral Characteristic of the Injection Controlled XeF (C→ A) Laser

Figure 10 shows the output energy of the XeF (C→ A) injection controlled laser as a function of wavelength from 450 to 530 nm, at wavelengths chosen not to coincide with known narrowband atomic absorptions. The injected signal had a linewidth of 0.005 nm and was held at a constant intensity of 2 MW/cm^2. Also shown in Figure 9 are some of the atomic resonance filter lines which might be employed for optical communications purposes in the blue-green region of the spectrum.

When the XeF (C→ A) laser is operated in a "free running" mode - that is with no injection and the signal allowed to build up from spontaneous emission, it is found that a number of narrow-band absorption lines appear in the spectrum, resulting from excited atomic absorbers created by the electron beam excitation. The effect of these absorbers can be significantly reduced by injection control of the XeF (C→ A) laser. Because the stimulated cross-section for the (C→ A) transition is relatively small, it is possible to build up sufficient intensity within the cavity to bleach or saturate these absorptions before the laser transition itself saturates. This effect is evident in **Figure 11,** which depicts the output energy as a function of injection intensity both on and off one of these narrow band absorptions. As can be seen, when the injection intensity is sufficiently large, the ratio between the output on an absorption and off is significantly reduced, showing saturation of the absorbing species.

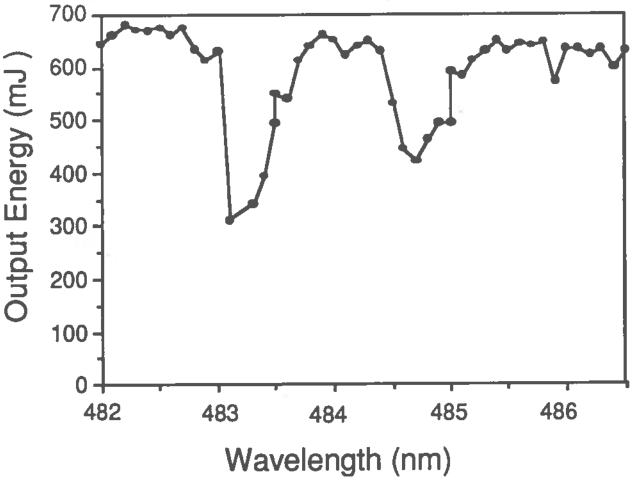

Figure 12. Detailed Wavelength Scan Using Agile Injection Source

In order to measure the spectral bandwidth of the injection controlled XeF (C→ A) laser, an intercavity etalon was installed in the dye laser which narrowed its output to ~0.001 nm FWHM. The output from the XeF (C→ A) laser was focused onto an opal glass diffuser with a 50 cm focal length plano-convex lens placed in front of an air-spaced plane-plane etalon with a finesse of 30 and a free spectral range of 9 GHz. The resulting circular interference pattern was then imaged onto a CCD array, and the variation in fringe intensity along one axis analyzed by computer software. **Figure 13** shows the analysis of both the injection signal itself, as well as the output from the XeF (C→ A) laser. As can be seen the spectral purity of the amplified signal very closely matches that of the input.

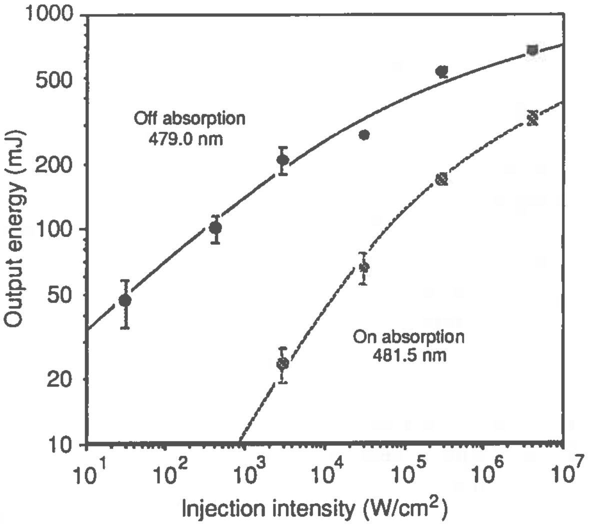

Figure 11. Output Energy as a function of Injection Intensity both On and Off a Narrow Band Absorption

To more fully take advantage of the ease of tuning via injection control, a novel wavelength agile injection source was developed by the United Technologies Research Center for use with this laser [10]. By selecting the desired wavelength of interest by computer control of a dye laser cavity and galvometric mirror wavelength adjustment, exact wavelength control (to ~0.01 nm) for a *random* sequence of wavelengths is possible. In order to demonstrate this, a spectral region from 482 to 486.5 nm was scanned using 0.1 nm steps. The results of this detailed investigation of the output spectral characteristics of the injection controlled XeF (C→ A) laser are shown in **Figure 12.**

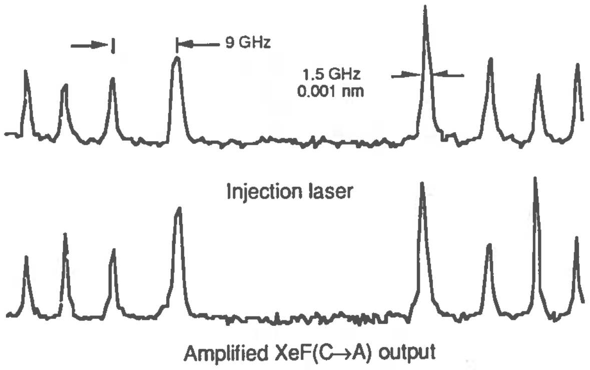

Figure 13. Comparison of the linewidth of the Injection Spectrum and that of the Amplified XeF (C→ A) Output

Conclusions

The XeF (C→ A) laser has been successfully scaled from a 0.02 liter to a 0.5 liter active volume. A peak output energy of 920 mJ, corresponding to an energy denisty of 1.85 J/ℓ at 1.5 % intrinsic efficiency has been observed near the gain maximum. The laser has been tuned, using injection control, over a bandwidth extending from 450 nm to 530 nm with several hundred mJ of output energy in a bandwidth of less than 0.001 nm. Using a unique wavelength agile injection source, rapid tuning, under automated control has been demonstrated. Careful measurements of both the small signal gain as well as output energy with e-beam deposition indicate that improved performance can be expected from more intense excitation of the laser active medium.

References

1. W.L. Nighan, R. Sauerbrey, Y. Zhu, F.K. Tittel and W.L. Wilson, IEEE J. Quantum Electronics, 23, 253 (1987)
2. G.J. Hirst, C.B. Dane, W.L. Wilson, R. Sauerbrey, F.K. Tittel and W.L. Nighan, Appl. Phys. Lett, 54, 1851 (1989)
3. P.J.M. Peters, H.M.J. Bastiaens, W.J. Witteman, R. Sauerbrey, C.B. Dane and F.K. Tittel, IEEE J. Quantum Electronics (submitted)
4. A. Mandl and L.H. Litzenberger, Appl. Phys. Lett., 53, 1690 (1989)
5. N. Hamada, R. Sauerbrey, W.L. Wilson, F.K. Tittel and W.L. Nighan, IEEE J. Quantum Electronics, 24, 1571 (1988).
6. S. Lloyd, Y.G. Chen, G. McAllister, M. Montgomery, T. Olson, J. Shannon, B. Dane, G. Hirst, R. Sauerbrey, F. Tittel and W. Wilson, in Proceedings of the Seventh IEEE Pulsed Power Conference, Monterey CA.
7. W.P. Bishop, K.C. Humphreys and P.T. Randike, Rev. Sci. Instrum., 44, 443, (1973)
8. C.B. Dane, Th. Hofmann, G.J. Hirst, S. Yamaguchi, R. Sauerbrey and F.K. Tittel (to be published in Appl. Phys. Lett.)
9. C.B. Dane, G.J. Hirst, Y. Yamaguchi, Th. Hofmann, W.L. Wilson,. Jr., R. Sauerbrey, F.K. Tittel, W.L. Nighan and M.C. Fowler IEEE J. Quantum Electronics (to be published)
10. R.A. Rubino, W.L.Nighan, W.H. Glenn, A.J. Cantor and M.J. Roman in Proceedings of the 1989 LEOS Annual Meeting, 160, Orlando, FL (1989).

A 20 J FLOW COMPATIBLE XECL LASER

Andrew J.W. Brown, Edward G. Sergoyan, Fred E. White,
Mike vonDadelszen, and Charles H. Fisher

Spectra Technology, Inc.
2755 Northup Way
Bellevue, Washington 98004

Abstract

We have fabricated and tested single shot the laser head and fast pulser for a high energy, flow compatible, x-ray preionized XeCl laser. The pulsed power used to drive the 12x9x120 cm discharge utilizes a high efficiency spiker sustainer circuit with a magnetic isolation switch. A single pulse output energy of 19 J at 2.2% efficiency and pulse length of 230 ns has been demonstrated, corresponding to an extracted energy density of 1.5 J/L.

INTRODUCTION

Following their conception there has been a continuing effort to improve the extracted energy and efficiency of excimer lasers. Of the various excimers, XeCl has demonstrated the best performance and has been the focus of extensive research. In particular preionized discharge excitation schemes have received much attention because of their simplicity and potential high efficiency. The aperture over which a uniform discharge can be generated has increased dramatically since the introduction of x-ray preionization, enabling large scale devices to be built. Preionized discharge XeCl lasers have achieved energies of 66 J per pulse at efficiencies approaching 1%[1] and typically operate at efficiencies of approximately 2% at substantially lower energy.

Novel discharge excitation schemes using spiker sustainer circuitry have improved the efficiency of these lasers to approximately 4% at the 3-4 J level.[2 3] In this technique a fast rising, high voltage pulse from the spiker circuit is used to break the gas down and the separate, low impedance, Pulse Forming Network (PFN) supplies the majority of the pump energy. This allows optimization of the PFN charge voltage to ideally twice the discharge self sustaining voltage for maximum efficiency. Isolation between the spiker and sustainer circuits can be achieved using a rail gap switch,[2] two gap laser head[4] or a saturable magnetic switch.[3,5] The simplicity and high reliability of the magnetic isolator made it the preferred choice for the system described here.

Recent development of these lasers has been directed towards achieving output power at the kilowatt level. At this high average power close attention must be given to the pulse power design to achieve efficient electrical pumping combined with long lifetime. Flow considerations are also important to ensure the hot gases are removed from the discharge region prior to the next pulse. This paper describes the proof-of-principal, single-shot experiments for a flow-compatible, XeCl laser head and pulser designed for 20 J per pulse at 50 Hz repetition rate.

Figure 1 shows a cross section of the flow compatible laser head and discharge region. The design of such a head must satisfy the conflicting requirements of minimizing flow disturbance while maintaining a low inductance geometry to achieve the required high pump power and fast electrical discharge characteristics. In addition, the large apertures required for high energy lasers lead to inductive laser head geometries to prevent tracking at the high voltages necessary for gas breakdown. The laser head was designed to satisfy these conflicting demands using modeling tools developed for excimer and other gas discharge lasers.