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TITLE TRANSFORM-LIMITED-BANDWIDTH INJECTION LOCKING OF AN XeF LASER

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TRANSFORM-LIMITED-BANDWIDTH INJECTION LOCKING OF AN XeF LASER

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ABSTRACT

A pulsed Ar-ion laser, operating on the 3511 Å line of the doubly ionized species, has been used to injection lock an unstable resonator XeF laser. A single longitudinal mode of the Ar-ion laser was selected with a Fabry-Perot étalon, and the resulting XeF bandwidth was measured to be ∿ 50 MHz which is the Fourier-transform limit corresponding to the XeF laser pulse duration of ∿ 20 ns. Since the XeF B → X emission originates from more than one upper vibrational level, for this pulse duration it was determined that ∿ 60% of the total output was available to be locked to the reference oscillator line. The 2 MW output beam was also found to be near (< 1.5 x) diffraction limited.

INTRODUCTION

The channeling of the energy of high-power excimer lasers into very narrow spectral bandwidths in low divergence beams is a prerequisite for many potential applications of these lasers. High spectral brightness is required for spectroscopic applications and optical harmonic generation,[1,2] and the long coherence length associated with a narrow bandwidth is required for nonlinear phase conjugation, backward stimulated Brillouin and Raman scattering[3] among other applications. Ultranarrow bandwidth is virtually essential for most nonlinear vuv generation schemes.

It is by now well recognized that the simplest way to control the spectral bandwidth and beam divergence of high-gain excimer lasers is by the combined implementation of an unstable resonator and injection locking. This conclusion is not new, nor is it without precedent. Injection locking has long been recognized as a way to lock the frequency of a high-gain broadband oscillator to the frequency of a low-power narrow-bandwidth reference oscillator.[4] This technique has been applied successfully to unstable resonators for CO_2 lasers[5] as well as for dye lasers.[6] It has also been used previously to narrow the bandwidth and reduce the divergence of high-gain unstable-resonator excimer lasers.[7,8]

The technique is attractive because near-diffraction-limited output and ultranarrow linewidth can be achieved with no loss of laser efficiency. Moreover the attractiveness of the technique is enhanced by the fact that very little reference oscillator power is required to achieve those parameters. The contribution of our work has been to determine (and obtain) the theoretical minimum required injected power for reliable locking,[9] and to achieve transform-limited bandwidth in an injection-locked excimer system[10] (also with ultralow reference oscillator power).

In this paper we review the simple technique employed for achieving transform-limited bandwidth in an XeF laser.

EXPERIMENTAL PROCEDURE

The experimental setup used for injection locking the XeF laser is schematically depicted in Fig. 1. As a reference oscillator we used a small pulsed Ar III-ion laser followed by a Fabry-Perot étalon, which passed a single longitudinal mode of the laser. The Ar-ion laser is inexpensive and simple to construct, and its design closely follows that of Ref. 11. It emits a polarized 10-W, 0.5 -μs-duration pulse whose divergence is near the diffraction limit. Because of the selectively reflective optics, most (∼ 80%) of the output energy was at the 3511-Å transition of the doubly ionized Argon atom.. It was composed of several longtitudinal modes within the inhomogeneous Doppler linewidth (∼ 1 GHz).

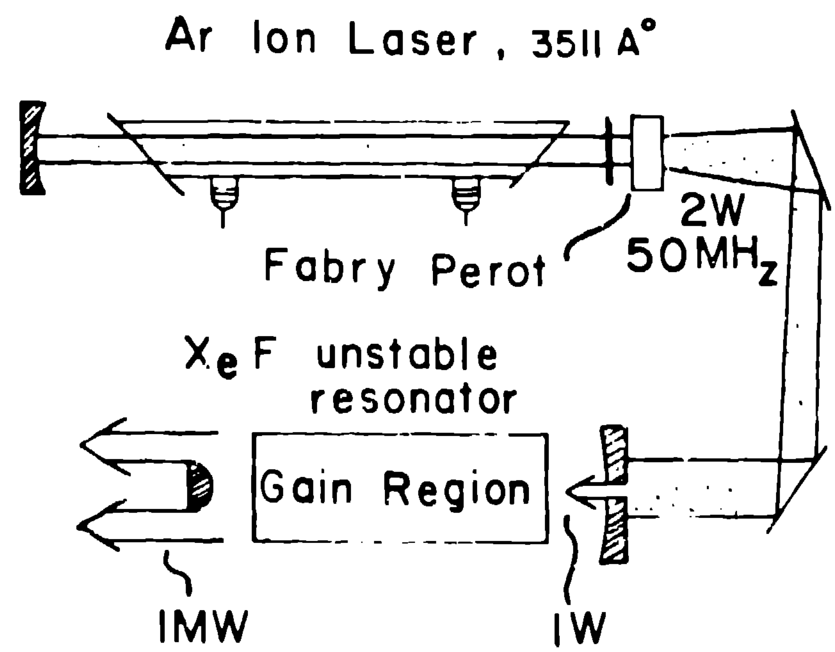

Fig. 1

The single longitudinal mode transmitted by the étalon (~ 2 W) had a bandwidth of < 50 MHz. About 50% (1 W) of the Ar-ion beam was injected through a 1-mm hole in the rear mirror of the positive-branch confocal unstable-resonator cavity of an XeF laser. The unstable resonator is ~ 100-cm long (variable ± 5 cm), and the magnification is 3. The discharge dimensions are 2 cm x 2 cm x 60 cm, and the device is similar to the one in Ref. 9. The free-running XeF laser's total output energy was ~ 40 mJ, and the beam was unpolarized. The timing of the XeF (25-ns pulse duration) and the Ar-ion laser are easily adjusted for injection locking since the Ar-ion laser-pulse duration is as long as 0.5 μs. The single-pass gain of the XeF amplifier at 3511 Å was measured to be ≥ 10.

RESULTS

In contrast to the KrF, XeCl, and ArF lasers, there are inherent limitations to the injection locking of a XeF laser on the B → X transition. The XeF emission is composed of many distinct lines with several different upper vibrational levels,[11-13] and there is no necessarily fast energy transfer among these upper levels. Consequently, only part of the total energy is available to be pulled into a specific locked line. The effect is similar to that of an inhomogeneously broadened laser when one attempts to force it to run on a single longitudinal mode.

Since our 1-m spectrometer's resolution was ~ 0.1 Å (~ 50 GHz), the spectrometer was not useful for measuring the locking efficiency into a 50-MHz bandwidth. Thus we determined the energy transfer by measuring the amount of XeF output energy pulled by the injection process into the polarization state of the Ar III laser. This measurement was accomplished by a deceptively simple yet accurate technique. First the laser energy was measured in both locked and unlocked (i.e. with the reference oscillator blocked) conditions. Then the measurements were repeated with a linear polarizer placed in front of the detector and oriented so as to block the polarization state of the reference oscillator. Some simple algebraic manipulation of the four numbers yields a locking fraction of ~ 60%. (This can be compared with ~ 100% for KrF or ArF.) The fraction locked can be expected to improve with higher temperature, higher pressure, and longer pulse duration.

The beam divergence (for the locked fraction) was found to be very near (< 1.5 x) the diffraction limit when compared with the theoretical optimum for an Airy disc of the same aperture. When unlocked, the divergence was 5 - 10 times greater.

In Fig. 2 we present a high resolution Fabry-Perot interferogram of the locked XeF output, demonstrating the 50-MHz bandwidth.

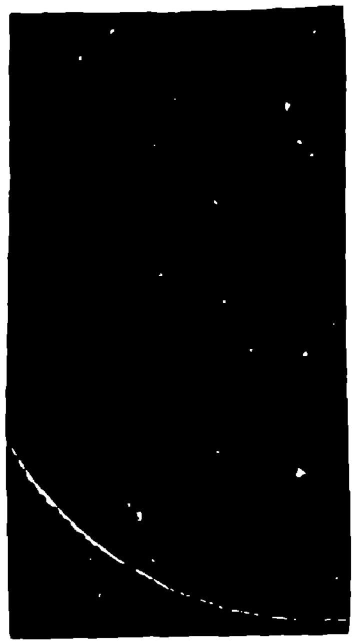

Fig. 2

CONCLUSIONS

We have demonstrated the channeling of ~ 60% of the output energy of an unstable-resonator XeF laser into a 50 MHz Fourier-transform-limited bandwidth at 3511 Å. This has been achieved by injection locking the XeF laser with ~ 1 W of power from a Fabry-Perot-filtered Ar-ion laser. If one wants to remove most of the remaining 40% broadband XeF output, it is possible to do so in a simple manner by extracavity filtration with an étalon after the unstable resonator or by spatial filtering since the unlocked portion has much larger divergence. Finally, we have been able to observe backward-stimulated Brillouin and Raman scattering from several liquids by use of the injection-locked XeF laser. These stimulated processes were observed only when the laser was locked, thus providing an additional indication of the reduction of the XeF laser bandwidth.[14,15]

These injection locking techniques demonstrate that ultahigh spectral brightness and excellent beam quality are available from excimer lasers with relatively uncomplicated and moderate-cost systems. This should enable a much larger number of researchers to probe nonlinear optics in the uv and vuv.

REFERENCES

1. R. T. Hawkins et al., Appl. Phys. Lett. 36, 391 (1980), H. Egger et al., Opt. Lett. 5, 282, (1980).
2. J. Reintjes, Appl. Opt, 19, 3889 (1980).
3. I. J. Bigio et al., CLEO '81 postdeadline paper THS3, IEEE J. Quantum Electron. QE-17, No. 12-II, 220 (1981).
4. R. Adler, Proc. IRE 34, 351 (1946).
5. C. J. Buczek, R. J. Frieberg, and M. L. Skolnik, Proc. IEEE 61, 1411 (1973), C. Cason et al., J. Appl. Phys. 48, 2531 (1977)
6. Irving J. Bigio, in High-Power Lasers and Applications, K. L. Kompa and H. Walther, eds. (Springer-Verlag, Berlin 1978), p. 116.
7. J. Goldhar and J. R. Murray, Opt. Lett. 1, 199 (1977); J. Goldhar et al., IEEE J. Quantum Electron. QE-16, 235 (1980).
8. T. J. Pacala and C. P. Christensen, Appl. Phys. Lett, 36, 336 (1981).
9. Irving J. Bigio and M. Slatkine, Opt. Lett. 6, 336 (1981).
10. Irving J. Bigio and M. Slatkine, Opt. Lett. 7, 19 (1982).
11. J. C. Hsia et al., Appl. Phys. Lett. 34, 208 (1979); M. Rokni et al., Appl. Phys. Lett. 36, 243 (1980).
12. J. Tellinghuisen et al., J. Chem. Phys. 64, 4796 (1976).
13. J. Tellinghuisen et al., J. Chem. Phys. 68, 5177 (1978).
14. I. J. Bigio, B. J. Feldman, R. A. Fisher, and M. Slatkine, CLEO '81 postdeadline paper FK3, IEEE J. Quantum Electron. QE-17, No. 12-II, 228 (1981).
15. Michael Slatkine, Irving J. Bigio, B. J. Feldman, and R. A. Fisher, Opt. Lett. 7, 108 (1982).