Wavelength-agile operation of an injection-controlled XeF(C→A) laser system

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(Received 17 August 1990; accepted for publication 6 November 1990)

The performance of a pulsed laser system consisting of an electron beam pumped XeF($C\rightarrow A$) amplifier injection-controlled by a wavelength-agile dye laser is reported. Random sequence tuning over a 27 nm spectral region, centered at 478.5 nm, was demonstrated at a 1 Hz pulse repetition frequency. Laser output energies of 0.8 J with pulse durations of 10 ns were measured.

Since its first demonstration more than a decade ago, the electron beam pumped XeF($C\rightarrow A$) excimer laser has been developed into an efficient, scalable gas laser system.[1-5] It is continuously tunable between 450 and 530 nm,[6] covering the entire blue-green region of the spectrum. Output energy densities exceeding 1.0 J/ℓ have been obtained for wavelengths between 470 and 510 nm. Maximum specific laser energies of 2 J/ℓ were observed and scaling studies indicate potential for even higher output energies.[1-3,7]

A five-component gas mixture, tailored through kinetic modeling,[8] along with injection control by a pulsed dye laser, enables the XeF($C\rightarrow A$) laser to achieve a high intrinsic efficiency of 1.3%.[2] Optimization of the unstable resonator design, guided by numerical modeling,[9] contributed to the high-energy extraction efficiency. Beam quality of better than three times the diffraction limit was demonstrated. Narrow linewidth output of 0.001 nm was achieved,[6] limited only by the bandwidth of the injection laser. Recently, a transverse flow system was developed, permitting pulse repetition frequencies of up to 1 Hz for more than 20 shots with no decrease in output energy.[7]

For remote sensing, spectroscopic, and other applications it is desirable to combine the characteristic features of the XeF($C\rightarrow A$) laser, that have so far only been demonstrated separately, into one integrated laser system. In this letter we report for the first time repetitive pulsed operation of a XeF($C\rightarrow A$) laser amplifier, controlled by a wavelength-agile dye laser.[10] Laser operation with high pulse energies (~1 J) at 1 Hz pulse repetition frequency (PRF), and random sequence pulse-to-pulse wavelength tunability over a wide bandwidth is described.

Figure 1 shows a schematic of the integrated wavelength-agile, high-energy laser system. A comprehensive computer-based data acqusition system[2] was used to monitor the performance of the dye laser and excimer amplifier for each individual shot. The temporal profiles of the injected and amplified beams were recorded by calibrated photodiodes. The pulse energy and the spectral profile of the output beam were measured by a pyroelectric energy meter and an optical multichannel analyzer (OMA) photospectrometer, respectively. The electron beam generator was characterized by monitoring the electron energy, the beam current, the voltage on the final output switch, and the pressure jump inside the gas cell due to the energy deposition.

The XeF($C\rightarrow A$) excimer gas mixture was transversely excited by a short (10 ns full width at half maximum), high-energy (650 keV) electron beam with a peak current density of 200 A/cm^2. An energy density of ~120 J/ℓ was deposited into the gas resulting in a pumping rate of ~12 MW/cm^3. The electron beam generator could be operated at a PRF of up to 1 Hz. The optimized gas mixture consisted of 12 Torr NF$_3$, 1 Torr F$_2$, 15 Torr Xe, and 750 Torr Kr, completed with Ar to a total pressure of 6.5 bar. The spatially averaged peak gain was measured to be ~0.03 cm^{-1}. A detailed description of the excimer system can be found in Ref. 2.

The dye laser injection beam was sent through a delay line which on a nanosecond time scale optically isolated the injection laser from the XeF($C\rightarrow A$) laser amplifier. After collimation by a telescope of magnification $M=5$, the dye laser beam was injected into the amplifier resonator. The delay time between triggering the dye laser and firing the electron beam was carefully adjusted to yield maximum laser output energy.

A positive branch confocal unstable resonator geometry was used for the amplifier cavity. The dye laser pulse was injected through a hole centered in the concave end mirror. The magnification of the resonator was $M=1.33$, corresponding to 23 single passes of the injected pulse through the gain medium. Mirrors with highly reflective coatings for the wavelength region from 465 to 505 nm covered the entire tuning range of the injection laser. The active gain region was 50 cm long and 3.5 cm in diameter, limited by the aperture of the resonator.

A transverse flow system allowed repetitive operation of the excimer amplifier without energy degradation due to thermally induced turbulence in the gas cell. Interferomertric measurements have shown complete recovery of the laser gas within 40 ms after electron beam excitation.[7]

The dye laser was especially designed for use as an injection source for the XeF($C\rightarrow A$) amplifier.[10] The main criterion for the injection laser was to provide precise and

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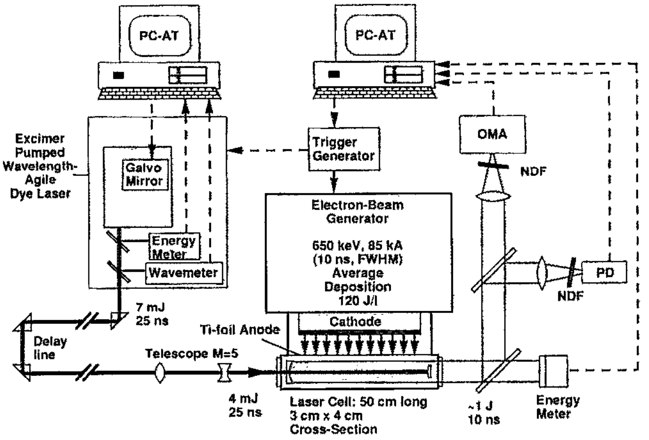

FIG. 1. Schematic diagram of the experimental arrangement. NDF: neutral density filters, PD: vacuum photodiodes,OMA: optical multichannel analyzer.

rapid wavelength tunability on a pulse-to-pulse basis for any preselected random list of wavelengths over the entire gain band of the dye laser. The wavelength-agile dye laser was designed for high PRF operation (> 50 Hz) for the purpose of demonstrating compatibility with the future development of electron beam technology and XeF($C \rightarrow A$) discharge pumped lasers.

A commercial excimer pumped dye laser incorporating a modified oscillator section was used to achieve the required performance characteristics. The Hansch oscillator of the commercial unit was replaced by one based on a grazing incidence grating as the primary wavelength dispersive element. Wavelength agility was achieved by using a beam reducing telescope between the grating and a galvonometer driven mirror. In this way, a large portion of the grating could be illuminated for excellent wavelength discrimination while at the same time the tuning mirror can be made quite small permitting high-speed tuning.

An equally important detail of the injection laser system is the integration of on-line wavelength and energy diagnostics. A Fizeau wavemeter permitted absolute wavelength calibration of the galvonometer driven tuning mirror as well as monitoring of the wavelength on a pulse-to-pulse basis. The output energy of every pulse of the injection source was measured by a pyroelectric energy meter. The entire dye laser system was operated and monitored with a PC-AT microcomputer.

The dye laser was tunable at a PRF of up to 50 Hz with a wavelength accuracy of 0.01 nm. The tuning range, using Courmarin 480 laser dye, was 27 nm centered at 478.5 nm. The maximum output energy, when pumped by a 65 ns, 150 mJ XeCl excimer pulse was 7 mJ with a pulse length of 25 ns and a linewidth of 0.015 nm.

The experiments reported in this letter were designed to demonstrate the performance of the wavelength-agile injection-controlled XeF($C \rightarrow A$) laser. In a first experiment the excimer laser system was tuned at a PRF of 1 Hz over 27 nm, which corresponds to the entire bandwidth of the Courmarin 480 dye. The wavelength of the injection laser was changed for each shot in a preprogrammed random sequence. Figure 2(a) shows the output energy trace measured by a pyroelectric energy meter together with arbitrarily selected wavelengths for each shot. The measured energies are minimum values due to a limited number of sampling points of the recording digital oscilloscope. Figure 2(b) depicts the corresponding spectrum recorded by the OMA system. Pulse energies of several hundred millijoules were obtained over the entire tuning range. The measured wavelength of the amplified pulse corresponds to that of the selected dye wavelength to within the OMA resolution of 0.1 nm.

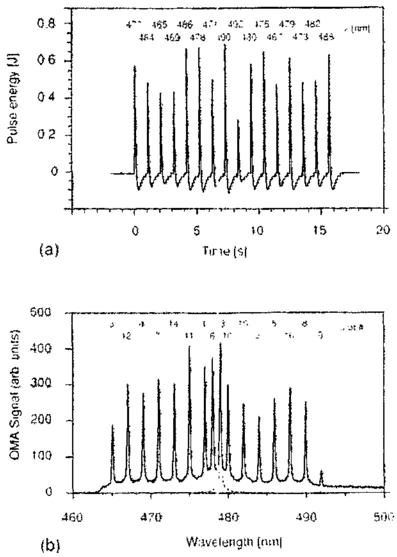

FIG. 2. Temporal and spectral dependence of the XeF($C \rightarrow A$) laser output of a random wavelength sequence at a 1 Hz pulse repetition frequency. (a) Pulse energy vs time measured with a pyroelectric energy meter. The wavelength of each shot is indicated. (b) Spectrum of the same shot sequence shown in (a) recorded by an OMA. The numbers at the top of the figure represent the order in which the shots were made.The elevated base line is due to a summation of instrumentally induced pedestals of the single shot recordings.

In another experiment, four atomic rubidium transition wavelengths were selected in two consecutive runs at 1 Hz PRF. Special interest in rubidium wavelengths arises from the potential use of the XeF($C \rightarrow A$) laser as an illuminator for remote sensing which would require an atomic resonance filtered (ARF) detection system.[11] Output energies of approximately 0.7 J were obtained for the wavelengths 489.7, 489.2, and 487.4 nm (Fig. 3). The reduced output energy at 492.0 nm results from the smaller injection energy of the dye laser at this wavelength and is not a limitation of the XeF($C \rightarrow A$) amplifier. In both runs the desired wavelengths were obtained.

Wavelength-agile tuning of the XeF($C \rightarrow A$) amplifier at 1 Hz was demonstrated with excellent wavelength accuracy. The entire bandwidth of the dye laser of 27 nm could be accessed with wavelength agility, and output energies of >0.8 J with a 10 ns pulse duration were obtained. To our knowledge this is the only laser system to date that is capable of producing pulse energies in the 1 J range in the blue-green spectral region, while being randomly tunable

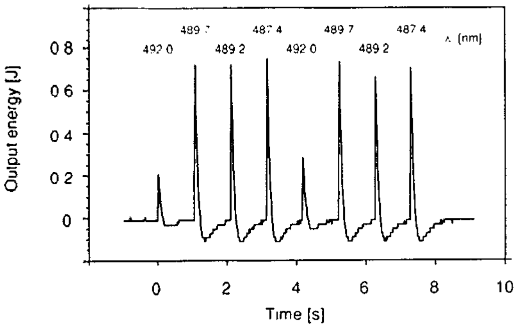

FIG. 3. Temporal scan of laser output energy of four rubidium transitions at 1 Hz measured with a pyroelectric energy meter. The wavelength of each shot is indicated.

at 1 Hz over a broad bandwidth. With the availability of an even more broadband injection source the entire tuning range of the XeF($C \rightarrow A$) excimer of ~80 nm, demonstrated in single shot operation, should be accessible to wavelength-agile tuning.

The authors wish to thank J. Hooten and M. Roman for their valuable technical assistance. This work was supported by the Office of Naval Research and the Welch Foundation.

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