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Wideband Tuning of the Blue-Green XeF($C \rightarrow A$) Laser

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Abstract. Efficient wavelength tuning from 446 to 524 nm with a minimum spectral linewidth of 1 nm was demonstrated for an electron beam pumped XeF($C \rightarrow A$) laser. Energy densities of 0.1 J/l were obtained for an optimized Ar/Kr/Xe/F_2/NF_3 mixture.

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Broad wavelength tunability of a XeF($C \rightarrow A$) excimer laser centered in the blue-green at 485 nm has been reported previously [1–3]. This letter describes the tuning performance that has been obtained with an optimized multicomponent rare-gas halide mixture and a low-loss dispersive optical resonator design.

1. Experiment

The experimental apparatus used in this work has been described in [4]. A gas mixture comprised of 8 Torr NF_3, 2 Torr F_2, 10 Torr Xe, 300 Torr Kr, and 6.5 atm Ar was excited transversely by an intense electron beam (1 MeV, 250 A/cm^2, 10 ns FWHM). These conditions were found to result in efficient XeF($C \rightarrow A$) laser operation [5]. Details of the resonator modifications necessary for efficient tuning of the laser are depicted in Fig. 1. A Brewster-angled Littrow prism made of high-purity quartz serves as both the only viable intracell selective element and the flat end reflector with more than 99.9% reflectivity between 440 and 530 nm.

A large radius of curvature, concave mirror ($R = 6.7$ m) is used as output coupler. This reflector utilizes a broadband coating with 4% transmission centered at 485 nm. The reflector is protected by an Al_2O_3 overlay against fluorine damage. By placing an iris of adjustable diameter in front of the output coupler, laser oscillations can be restricted to a few transverse modes. The cavity can be conveniently aligned and calibrated in terms of wavelength using different lines from an argon ion laser.

2. Results and Discussion

The broad spectrum for an optimized Ar/Kr/Xe/F_2/NF_3 mixture shown in Fig. 2 indicates the potential wide-band tunability of the XeF ($C \rightarrow A$) laser transition. For the case of an untuned two-mirror resonator ($R_1 = \infty$, $R_2 = 6.7$ m, as depicted in Fig. 1a), the spectral bandwidth of the laser emission narrows from 80 nm for fluorescence to 30 nm. Figure 2 also shows for comparison the laser-output spectra obtained with NF_3 as the halogen donor and with an optimized multicomponent gas mixture specifically tailored to minimize medium transient absorption arising from various atomic and molecular processes discussed in detail in [4, 5]. This results in an earlier onset of laser oscillations and in an increase in wavelength-integrated output by more than two orders of magnitude. Furthermore, the structure in the laser spectrum mainly due to excited atomic species obtained with both F_2 and NF_3 as halogen donor is greatly reduced. With an extremely stable, optimized

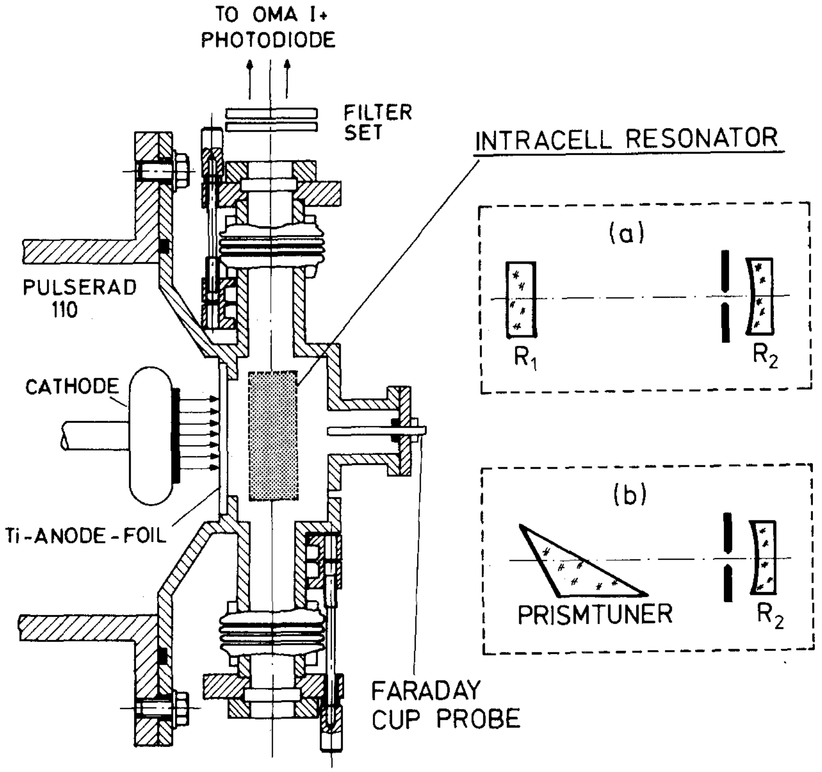

Fig. 1a and b. Schematic diagram of a transverse electron-beam pumped laser cell together with two different versions of optical resonators: (a) non-dispersive: $R_1 = \infty$, $R_2 = 6.7$ m, (b) dispersive by replacement of R_1 by a Brewster-angled prism-tuner

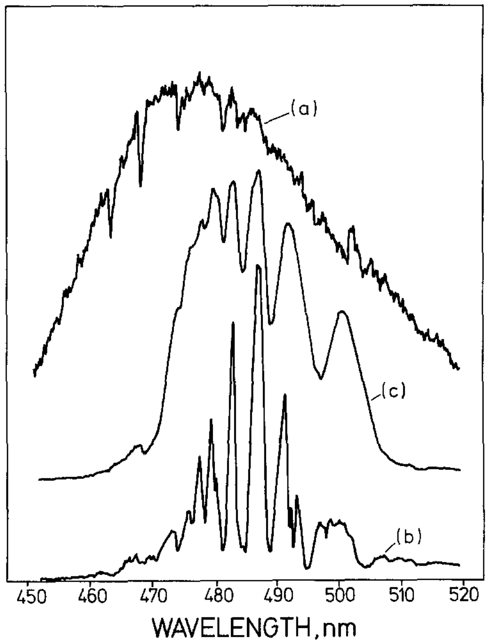

Fig. 2a–c. XeF($C \rightarrow A$) fluorescence (a) and laser spectra (b) with NF_3 as the halogen donor together with a laser output spectrum (c) of an optimized multicomponent rare-gas halide mixture, which was comprised of 6.5 atm Ar, 300 Torr Kr, 10 Torr Xe, 8 Torr NF_3, and 2 Torr F_2

cavity configuration ($R_1 = 0.5$ m, $R_2 = \infty$) and an Ar buffer gas pressure of 10 atm output energy densities as high as 3 J/l have been observed [5]. However, efficient broadband tunability required less tight internal cavity focusing conditions than needed for optimized energy extraction. Hence, the cavity geometry was appropriately modified, as shown in Fig. 1a, reducing the extraction efficiency by a factor 10 to 0.3 J/l. Replacement of the flat 100% reflector by the Brewster-angled quartz prism (Fig. 1b) further reduces the extraction efficiency to 0.1 J/l at the center wavelength (485 nm) of the XeF($C \rightarrow A$) laser. However, it increases the spectral brightness by nearly two orders of magnitude. A linewidth of 2 nm using an intracavity iris of 5 mm diameter was obtained throughout the entire tuning range (Fig. 3). The bandwidth can be further decreased to 1 nm at constant energy density by insertion of an iris of 2.2 mm diameter. The bandwidth of 1 nm was obtained from the spectrum shown in Fig. 3 after correction for the finite resolving power of the spectrometer-optical multichannel analyzer combination. The spectra obtained in the wings of the tuning range show excellent signal-to-noise ratios and are far above the amplified spontaneous emission (ASE) background. The tuning range from 447 to 524 nm was limited by an increase of the output coupler transmission to 10% at these wavelengths. Hence an overall tuning range of 90 nm from 440 to 530 nm should be feasible with optimized mirror coatings. In the spectral range from 460 to 520 nm the laser output energy followed the rather broad gain-profile (Fig. 2), with a decrease in output energy of 20%, as compared with the peak energy at 485 nm.

The narrow spectral linewidth of 1 nm in this experiment can be explained in terms of the dispersive properties of the low-loss prism tuner and gain nar-

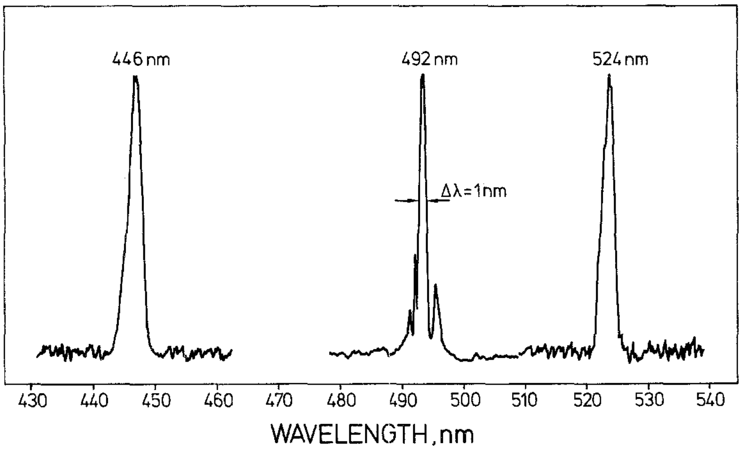

Fig. 3. Compilation of narrowband XeF$(C \rightarrow A)$ laser output spectra, obtained for different experimental conditions (for details see text)

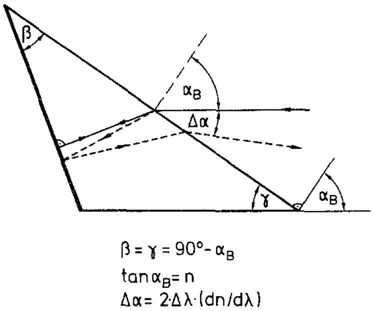

Fig. 4. Geometrical considerations of Brewster-angled quartz prism tuner used in the derivation of (1)

rowing [6]. Furthermore, channeling of most of the available energy in such a narrow line is a clear indication of complete homogeneous broadening of the XeF$(C \rightarrow A)$ transition in the presence of high argon buffer gas pressures. Fused quartz was chosen as the prism material instead of a more highly dispersive glass because of its resistance to optical damage by fluorine. The dependence of the passive bandwidth $\Delta\lambda_p$ on a small angle $\Delta\alpha$ can best be described by referring to Fig. 4:

$$\frac{\Delta\lambda_p}{\Delta\alpha} = \frac{2}{[dn/d\lambda]}. \tag{1}$$

With $[dn/d\lambda] = 6.012 \times 10^{-5}\,\mathrm{nm}^{-1}$ at $\lambda = 486.1$ nm, an angular dispersion of $\Delta\lambda_p/\Delta\alpha$ of 8.32 nm/mr is obtained. Since the ultimately observed divergence of a well-aligned resonator with an intracavity iris was ~ 1 mr, we attribute the low final active bandwidth $\Delta\lambda_a$ to a considerable amount of gain narrowing. Consideration of the processes within an active medium in terms of a regenerative amplifier of average gain g yields [6]:

$$\frac{\Delta\lambda_a}{\Delta\lambda_p} = \frac{1}{\sqrt{g \cdot L_{\mathrm{eff}}}}, \qquad L_{\mathrm{eff}} = c\tau_p. \tag{2}$$

For a typical pulse duration τ_p of 25 ns and $g \approx 2.5$ %/cm [4], $\sqrt{g \cdot L_{\mathrm{eff}}} \approx 18.75$. Hence, a reduction of the bandwidth by a factor of 4 is reasonable, resulting in the observed width $\Delta\lambda_a = 2$ nm.

3. Summary

Wide-band tunability of the XeF$(C \rightarrow A)$ excimer laser in the spectral range of 447 to 524 nm was demonstrated with a simple compact dispersive cavity in a transverse e-beam pump geometry. By using the recently developed multicomponent rare-gas halide mixture of Ar/Kr/Xe/F_2/NF_3 it was possible to obtain an output energy density of 100 mJ/l at the center of the tuning range at 485 nm and a spectral bandwidth as low as 1 nm. Even narrower spectral linewidths of less than 0.1 nm and larger output energies should be possible with dye-laser pulse injection and an unstable resonator configuration.

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