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The Tunable, Narrow-Bandwidth Excimer Laser, the New Workhorse for Photochemistry in the UV and VUV

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Excimer lasers are powerful sources of radiation in the UV, providing several laser lines between 157 and 353 nm. The excimer laser transition is bound-free, and thus the emitted wavelengths are broad-band (up to 200 cm^{-1}). In addition the high gain (0.15 cm^{-1}) of the laser gas causes a rather large divergence (>1 mrad) in conventional excimer lasers.

A new excimer laser concept is described which improves the spectral brightness in terms of watt/(rad × bandwidth) by three orders of magnitude. This allows, through non-linear processes such as Raman shifting the fundamental output and four-wave-mixing in gases, the generation of new laser lines in the UV and VUV.

Excimer lasers produce usually—due to their high gain—laser radiation with rather poor quality compared to normal laser standards. The most successful attempts to improve the beam divergence imply unstable resonators. Unfortunately, the bandwidth can only be controlled in stable resonator configurations with rather small mode volumes. The combination of both techniques is injection locking, where the radiation from the stable resonator acts as the seed signal for the unstable resonator. This technique has been used for moderate energy levels.[1,2,3] The purpose of this contribution is to demonstrate the feasibility of the regenerative amplifier scheme for which the requirements of the oscillator beam quality are less stringent. By proper timing of the oscillator and the regenerative amplifier high brightness radiation in the 1 Joule energy range is readily obtained.

The total system is depicted in Figure 1. The oscillator runs in a configuration with two flat mirrors. The outcoupler has a reflectivity of 30% to assure a reasonable resonator quality. An aperature with 1 mm diameter serves as the mode discriminator. The bandwidth is controlled by means of 3 disperging prisms and three prisms for enlarging the beam diameter for increasing the resolving power. The theoretical bandwidth for one path transmission is thus $0.8\,\mathrm{cm}^{-1}$. Tuning is accomplished by tilting the end mirror. For additional narrowing an etalon can be installed between the aperture and the outcoupler. The device delivers 500 μJ in the broadband version and 200 μJ in $0.5\,\mathrm{cm}^{-1}$, the tuning range is 3 Å (decrease to 50% of the central peak energy). The regenerative amplifier is equipped with a Cassegrain optic ($M = 10$), where the back mirror has a 1 mm diameter hole in its center. In the free running mode (without the injected signal) the amplifier emits 1 joule (KrF) within 1.0 mrad.

A major task is the exact timing of the two lasers. Due to the high gain and low storage time (<2 ns) the amplifier has to be filled with photons from the oscillator during the total pumping time. Therefore the oscillator pulse must be timed to ensure complete filling of the amplifier before the onset of the pump pulse. This sets a minimum time length of 20 ns. In addition taking into account some jitter between the two lasers a practical minimum duration of 25 ns for the oscillator is given. The exact timing is accomplished by a special switching technology which uses only one thyratron for both discharge circuits. The time delay can be adjusted by using the proper inductance

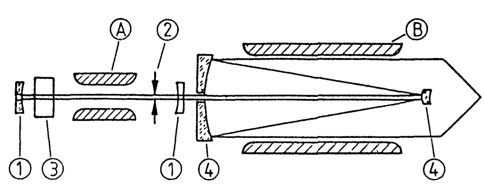

FIGURE 1 Setup of the oscillator amplifier device. (a) The oscillator beam is controlled by the stable cavity (1), the mode aperture (2) and the tuning device (3) which consists of a series of prisms. (b) The amplifier is equipped with a Cassegrain optic which enlarges the incoming beam 10 fold (4).

for the two circuits. An additional time delay can be incorporated by using different gas pressures in the oscillator and the amplifier.

The power required for driving the amplifier can be estimated from the fact that the stimulated processes have to beat the spontaneous losses:

$$\sigma \cdot c \cdot \Delta N \cdot \phi \geqslant \Delta N/\tau$$

with σ = cross section for stimulated emission, ΔN = inversion density and ϕ = photondensity. This yields an input power of:

$$P \approx 4 \cdot 10^5 \text{ watt cm}^{-2}$$

Injection through a hole of 1 mm diameter reduces the power for this part of the amplifier to $P \approx 3 \cdot 10^3$ watt totally. These considerations hold especially for the regenerative amplifier limit. For exact injection locking where the seed signal has already the proper linewidth of a mode of the amplifier this value can be considerably lower. In the described regime of operation a narrow bandwidth of the oscillator is not required.

For testing the efficiency of the device the radiation was investigated with respect to the divergence, bandwidth and polarization properties. Running the amplifier alone gave a quite different result than with the oscillator in operation. The divergence was reduced from 1.0 mrad to 0.2 mrad if the oscillator power exceeds 10^3 watts, which is in good agreement with the calculation given above. More dramatic is the result on the bandwidth shown in Figure 2. The bandwidth of the

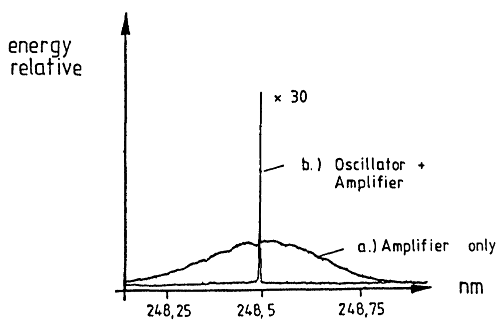

FIGURE 2 Example for the spectral narrowing of the KrF-laser radiation: (a) spectrum of the free running amplifier equipped with the unstable resonator configuration shown in Figure 1; (b) spectrum of the oscillator–amplifier device running in the regenerative amplifier mode.

free running amplifier amounts to ~3 A, while it is reduced to 0.03 Å in the oscillator-amplifier device. The tuning range is almost 3 Å taking a 50% "locking"-efficiency as the reference value.

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