HIGHLIGHTS
LAMBDA PHYSIK

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500 W XeCl – "Magic" Mark Nearly Attained

A team headed by Peter Oesterlin recently approached this goal (see Fig. 1) in an experimental set-up at Lambda Physik. The multi-hundred Watt project was supported by the German Ministry for Research and Technology. The laser is seen in Fig. 2. The laser channel and the beam output (4 cm x 5 cm) are at the small flange near the experimentalist's head. The tank is in fact a compact wind tunnel driven by two radial fans. 4 thyratrons mounted above the tank are connected in parallel to provide energy switching. Preionization is performed by UV sparks mounted behind a mesh electrode.

The set-up is an experimental one. It will also be used in the future for applied research within the Eureka EU 205 project, the European program for the investigation of multi-kilowatt excimer lasers.

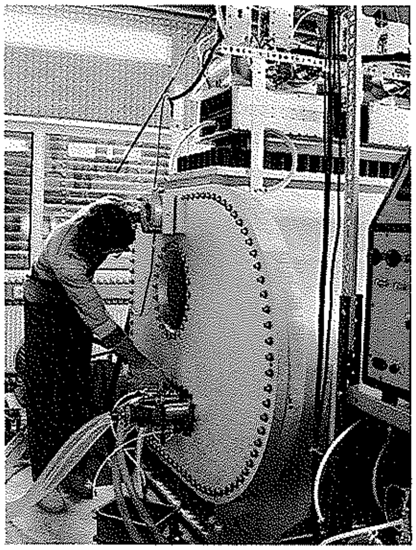

Fig. 2 Set-up of the 500 W laser

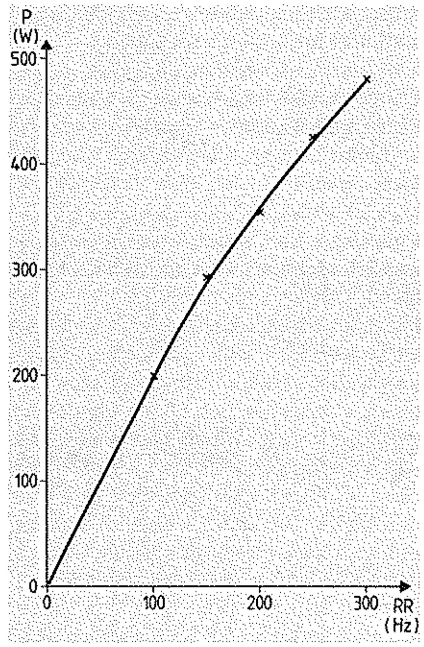

Fig. 1 Power versus repetition rate of the 500 W XeCl excimer laser

Polarized Excimer Laser Light

Frequency-narrowed excimer lasers (as EMG 150/160) emit polarized light. The broadband excimer lasers emit unpolarized light in their bandwidths given by the active excimer molecules (natural bandwidth).

Sometimes there are requests to have polarized light even for emission in natural bandwidth. Such applications are:

* Experiments which need a definite photon angular momentum as in nonlinear optics, frequency conversion and stimulated scattering. Introducing an additional quarter-wave plate leads to circular polarization.

* Molecular beam experiments or experiments in low-pressure gas cells needing aligned or oriented molecular excitation, e.g. by absorbing excimer laser photons at spectral positions of incidental coincidence.

* Low beam losses if only a small portion of the beam has to be coupled out by a tilted quartz plate for beam monitoring. The beam can be passed loss-free via Brewster cells.

The intracavity polarizing optics, shown in Fig. 1, has now been introduced for LPX lasers. Since it has been realized by polarization-dependent dielectric coating, it was tested firstly for one emission band, 308 nm; however, it is possible to reach similar results using coatings for 351 and 248 nm. For 193 nm, suitable coatings are not yet available.

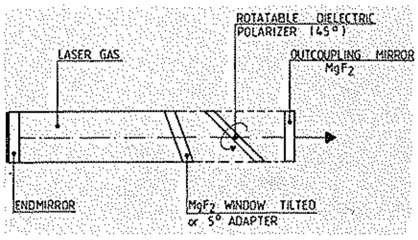

Fig. 1 Intracavity polarizing optics

The polarizer, which works for the 45° mounting, can be rotated around the laser beam axis to allow polarization plane rotation without beam displacement.

The degree of polarization was measured to be >100 for 130 mJ. There is no dramatic loss in total beam energy by inserting the polarizer: in the cavity configuration of Fig. 1 pulse energy rose to 140 mJ taking out the polarizer. Mounting the outcoupling mirror directly on the discharge unit (standard), energy rose to 160 mJ.

The polarizing optics will be available in summer 1988.

New Results from the Lambda Physik Application Lab:

Excimer Laser Beam Coupling into Quartz Fibers

Laser beam-optical fiber coupling is performed in many laboratories. Especially excimer laser-fiber coupling contains pitfalls for the experimentalist. The consequence usually is a reduction in the pulse energy which can be reliably transmitted. In this article we communicate two aspects which may help to improve the performance of a laser beam-fiber interface.

Filling the fiber phase volume completely

The internal beam divergence of a standard excimer laser such as the LPX 120i is about 5 mrad (FWHM) horizontally and 1 mrad vertically. These values are far from the diffraction limit. However, even this is not sufficient for beam-fiber coupling.

The maximum amount of energy which can be reliably transmitted is limited by damage mechanisms. The most important is volume damage, which occurs when the local intensity in the fiber becomes too high, as a result of internal focusing.

Coupling a laser beam of low divergence into a fiber favours local intensity enhancement. This is immediately realized when one takes into account the fact that fibers are waveguides with well-defined wave propagation modes. The fibers used for power tranmission are of the multimode type, and accept a wide cone of radiation which corresponds, in the interior of the fiber, to higher order transverse propagation modes. Therefore, in order to transmit as much pulse energy as possible without the risk of damage, it is necessary to fill all propagation modes of the fiber. This can be achieved by filling the acceptance cone of the fiber at each point on the input face.

Liouville's theorem, which is valid for any beam guiding and beam shaping, states that the phase volume is preserved. In broad terms, this means that imaging to smaller dimensions leads to higher divergence and vice versa. Hence, suitable beam divergence on the fiber face (and corresponding filling of transverse modes in the fiber) can be achieved by imaging an aperture filled by the laser radiation onto the fiber's face at a reduced scale.

As a demonstration, an experiment was set up using a short (8 mm) quartz fiber with 600 μm core diameter, a variable aperture illuminated by the laser beam (308 nm), and a demagnification optics which used a field lens to avoid overfilling of the acceptance cone near the edge of the fiber face. In the tests, the aperture was imaged at the reduction ratios of 3.5, 8, and 11 onto the full entrance face of the fiber which meant that the aperture had to be adjusted in diameter according to the reduction of the imaging ratio. The beam illuminating the aperture was appropriately attenuated to keep the laser pulse energy transmitted through the aperture constant.

Fig. 1 a to 1 c show photographs of the laser beam shape obtained behind the fiber for the different imaging conditions.

For the demagnification ratios of 3.5, 8, and 11, a clear change from a locally inhomogeneous and filamentary pattern towards a more homogeneous one is observed. Consequently, the beam energy is better distributed in the waveguiding volume of the fiber. This result is independent of the applied excimer laser wavelength.

In a separate set-up, the fiber length was increased. It was found that longer fibers favour homogenization so that no significant differences were measured for different demagnification ratios. These observations are consistent with the experience that fibers usually break within the first few centimeters when energy is too high. Clearly, using a fiber of typical laboratory length and trying different imaging conditions, no significant differences would be observable in the beam shape at the output. Thus, when trying to find the optimum energy transport by a given fiber, a suitable procedure is to begin with short pieces according to Fig. 1 a-c.

Longer pulses are easier to transmit

Excimer lasers with longer pulse duration have been developed (e.g. LPX 605i: > 50 ns (FWHM), LPX 610i: 250 ns (FWHM), the successor to the EMG 602 described on p. 4 of *Highlights 10*). We report on tests at 308 nm which were designed to determine the reliable transmission of pulses through a polymer-cladded quartz fiber of 600 μm core diameter.

Measurements were made to determine how much energy can reliably transmitted in relation to pulse length. Fig. 2 shows a logarithmic plot of that quantity. A straight line fitted to the data by eye has a slope of 1/2, indicating that the pulse energy transmittable increases with the square root of the pulse length.

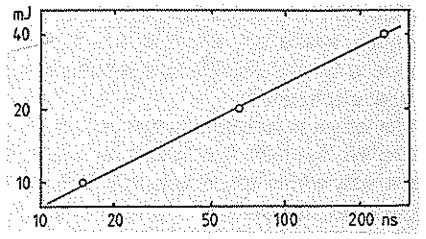

Fig 2 Reliably transmittable pulse energy at 308 nm for three different pulse durations

This result is consistent with that previously reported by Taylor et al. (R.S. Taylor, K.E. Leopold, S. Mihailov, R.K. Brimacombe, Opt. Commun. **63** (1987) p. 26) who also gave an explanation (CLEO 88) which, however, is still under discussion.

More details of these experiments will be published in the August issue of *Laser und Optoelektronik* (U. Sowada, H. J. Kahlert, D. Basting, in German).

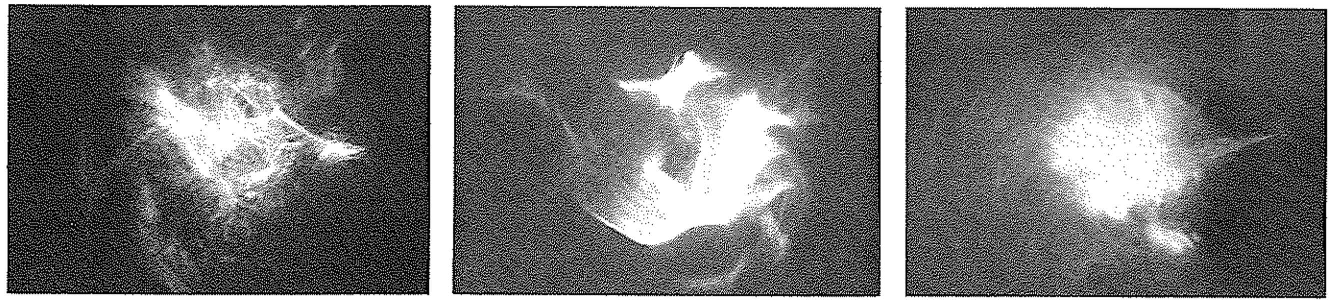

Fig. 1 Output of a short (8 mm) quartz fiber (∅ 600 μm) filled with excimer laser radiation at three different divergences: (a) low, (b) medium, (c) high divergence

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Spectral Purity of a FL 3002 Dye Laser Measured with a High-Resolution Monochromator

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Introduction

The pulsed tunable dye laser has proven to be a versatile tool for the spectroscopist. In general, pulsed dye lasers do not emit exclusively at the selected frequency but show a spectrally broad background of spontaneous emission which is amplified by the high gain medium (ASE). Two kinds of ASE can be distinguished in an excimer laser-pumped dye laser: a first part is released immediately after excitation, a second part coincides with the build-up of optical feedback in the oscillator cavity. Although, due to high gain, most of the laser energy is concentrated in a narrow laser line, a low-power ASE background is always present.

The first part of the ASE can be easily suppressed in a dye laser, which consists of an oscillator and subsequent amplifiers, by an appropriate time delay in the optical excitation of the different stages. In order to suppress the second part, Lambda Physik introduced earlier the "Lambdapure" scheme for the FL 2001/FL 2002 dye lasers, in which the grating is used as an additional filter for the oscillator output.

Recently, Nogar and Keller [1] measured the resonant ionization mass spectrum (RIMS) of lutetium atoms using an excimer-pumped dye laser (Lambda Physik, FL 2002). The authors attributed the intense satellite lines (which appeared at 3 cm^{-1} intervals and covered a range of 15 cm^{-1} from the central peak) to weak sidebands in the output of the dye laser. The spectrum of the dye laser output was consistent with RIMS spectra showing sidebands with an intensity $< 0{,}5$ % of the central laser peak. In a technical note, Klauminzer [2] discussed the current Lambda Physik oscillator design and claimed that this design can produce a considerable ASE background in the central part of the tuning curve. Since in our experiments the spectral purity of the dye laser is of great importance, we decided to carry out more detailed studies on ASE background using the latest dye laser model from Lambda Physik, an FL 3002 in standard configuration.

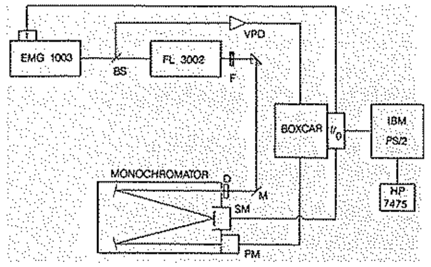

Fig. 1 Set-up for measurements of the dye laser line profile by the high-resolution spectrometer. T: external trigger of excimer laser, VPD vacuum photodiode (Hamamatsu), F: neutral density filter, D: diffuser, BS: beam splitter, M: mirror, SM: stepper motor, PM: photomultiplier

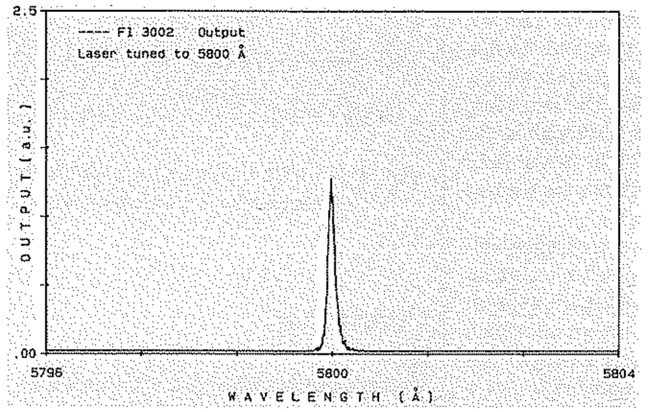

Fig. 2a FL 3002 dye laser line profile. The entire spectrum was recorded using aT=0.005 neutral density filter

Experimental Methods

The experimental set-up used in these studies is shown in Fig. 1. The FL 3002, operating with an oscillator, pre- and main amplifier was pumped by the excimer laser (EMG 1003i, Lambda Physik). A high-resolution grating monochromator (1,5 m spectrometer Jobin Yvon, model THR) was used to analyse the dye laser output spectrum. The spectral resolution of this monochromator was about 0.01 Å at a slit width of 5 μm. The dye pulses were attenuated by neutral density filters and diffused by scattering. The output of the monochromator was recorded with a photomultiplier (1P28A, RCA). The photomultiplier signals were measured with the boxcar (Stanford Research System, Model SR 250) operating in the last-sample mode.

An IBM PS/2 computer was connected via an I/O interface with the boxcar, the excimer laser and the stepper motor of the monochromator. The computer was used to control the entire experiment and to process the data from the boxcar. The stepper motor and the excimer laser were simultaneously triggered. At a fixed position of the monochromator the desired number of pulses was recorded by the boxcar and averaged by the computer. The spectra presented in the next section were obtained by averaging 10 pulses and tuning the monochromator with a stepwidth of 0.08 Å. The width of the sample gate was set to 300 ns, and the laser pulse rate to 16 Hz. Rhodamine 6G in methanol was used in both the oscillator/preamplifier and amplifier dye cuvettes. All measurements were carried out at excimer laser pump energy of 100 mJ, which produced a dye laser pulse energy of about 15 mJ.

Result and Discussion

Fig. 2a shows the dye laser output recorded after an adjustment of the FL 3002 at the maximum of the dye tuning curve (λ = 580 nm), following a standard procedure. The laser beam was very strongly attenuated by the neutral density filters to avoid saturating the photomultiplier as the monochromator was scanned across the laser peak. In this recording, no satellite lines or structures at the wings of the laser line were observed. The situation was quite different when the detection sensitivity was increased as shown in Fig. 2b. The left and right parts of the laser line were amplified by a factor of 200. This was accomplished by removing a T = 0.005 neutral density filter. At this intensity, conspicuous structures appeared at the wings of the laser line spectrum. The dotted line in Fig. 2b is a Lorentzian curve with the same halfwidth and peak height as the observed laser line. On the left side of the spectrum, the laser intensities show mostly higher values than the calculated Lorentzian curve. The wavelength period of the observed oscillations was, however, not the same as that reported by Nogar et al.[1]. The maximum height of the structures observed in the wings was less than 0.25 % of the laser peak height. This explains why the structures do not appear in Fig.2a.

In experiments where spectra of highly different peak heights have to be recorded, care has to be taken to avoid spurious lines. Hence, we decided to put more effort into the adjustment of the laser. The dye laser profile (λ = 580 nm) recorded after a very precise adjustment of the FL 3002, especially of the main amplifier stage is shown in Fig. 3. The spectral purity of the dye laser was significantly improved; both left and right wings of the laser line exhibited no structures. The Lorentzian curve was plotted with the measured linewidth of 0.07 Å ($\approx$ 0.2 cm^{-1}). The experimental values of the laser intensity at the wings of the laser line are well below the calculated Lorentzian curve. Both curves merge 4 Å away from the laser line. We calculated that 99 % of the dye laser energy is concentrated in a range of 5 Å $\cdot$ $\Delta\lambda$ (5 times the linewidth) resulting in 0.35 Å at λ = 5800 Å.

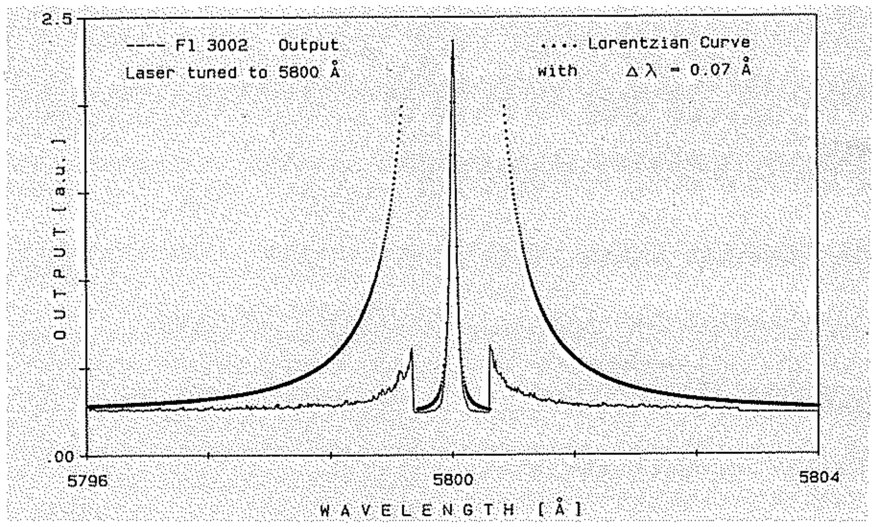

Fig. 3 FL 3002 dye laser line profile. The data was recorded as in Fig. 2b. A spectrum of this quality can only be achieved by a very careful adjustment of the FL 3002

Conclusion

We have demonstrated that in the center of the dye gain curve (see Fig. 3) there is no evidence of any ASE "hump" background when the system is very well adjusted. Even after coarse adjustment of the laser a "hump" ASE was not observed (see Fig. 2b). However, the laser output spectrum in this case revealed some similarities to the spectrum observed by Nogar et al. [1]. In Ref. [2] it was speculated that insertion of a highly reflective mirror near the dye cell causes a background hump. Our experiments have shown that this conclusion is not correct, but results from an oversimplified model. After optical feedback begins, the ASE and laser emission cannot be evaluated separately.

In conclusion, a very careful and precise adjustment of the FL 3002 is recommended when an extremely high spectral purity is required.

References

[1] N.S. Nogar and R.A. Keller, Analytical Chemistry 1985, **57,** 2992

[2] G.K. Klauminzer, "Aspects of pulsed dye laser design" in Technical Note No. 8 (1987) edited by Questek Inc., Billerica, MA, USA

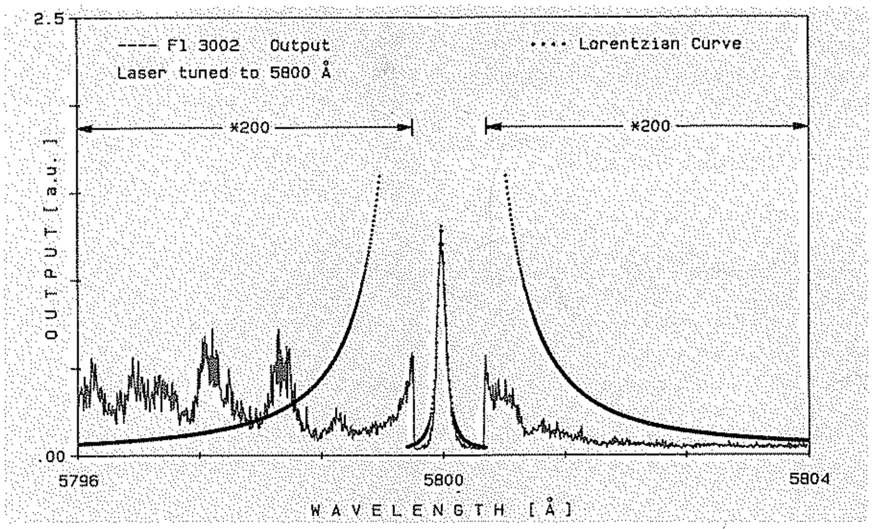

Fig. 2b FL 3002 dye laser spectrum, recorded without T=0.005 neutral density filter, except around the laser peak. The dotted line is a Lorentzian curve plotted using the measured laser linewidth

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