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Short uv Laser Pulse Generation by Quenching of Resonator Transients

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Abstract. Short (<0.5 ns) ultraviolet laser pulse generation by quenching of resonator transients is described. An output energy of 100–150 nJ at $\lambda = 340$ nm is obtained using a pump energy of only 5–7 mJ at 308 nm. This pulse was amplified up to 100 µJ by a two stage amplifier.

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Short laser pulses in the ultraviolet (uv) are of importance as a pump source for ultrashort ps laser pulse generation and as an excitation source for photochemistry and bio-molecular spectroscopy. Short-pulse generation by excimer lasers has been reported by amplification, mode-locking and electro-optic pulse slicing techniques in several publications [1, 2]. These techniques required either another ps laser source or fairly complex set-ups for synchronization of lasers and electro-optic devices.

In this letter, we report a simple and surprisingly effective method to generate short (<0.5 ns) uv ($\lambda = 340$ nm) laser pulses using only $5 \sim 7$ mJ of pump energy from an excimer laser with a pulse duration of 20 ns as a pump source. This significant pulse shortening was achieved by quenching of resonator transients. In a previous paper we described a similar idea and gave the theoretical analysis and experimental study of the generation of 100 ps pulses using rhodamine 6G as an active medium [3].

Here two laser resonators coupled by the active medium are employed. One resonator is short and low-Q, the other long and high-Q. When all parameters are chosen correctly, the short resonator will emit the first spike of the ensuing relaxation oscillation only, while the rest is quenched because of the depletion of the inversion by the high intracavity photon flux in the long resonator.

1. Experiment

The experimental arrangement is shown in Fig. 1. The oscillator dye cell is a $1 \times 1\,\mathrm{mm}^2$ square-cell with an outer size of $2.5 \times 2.5\,\mathrm{mm}^2$. M_2 and M_3 are two high-reflectivity ($R \geqq 0.95$) dielectric mirrors with high reflectivity at the pumping and lasing wavelengths, attached to two adjacent side walls of the dye cell. The 4% reflectivity of M_1 is provided by the Fresnel reflection of the uncoated cell wall. The fourth side wall is antireflection coated (AR) at the pumping and lasing wavelengths. M_4 is a high-R dielectric mirror at a distance L from M_3. L was varied between 7.5–27.5 mm. The short, low-Q cavity is formed by M_1, M_2 and the long, high-Q cavity by M_3 and M_4. The dye cell is pumped diagonally through the uncoated and AR-coated cell walls by a fraction of the XeCl excimer laser beam at 308 nm with $5 \sim 7$ mJ pump energy. The peak pump power density was varied between 5 and 15 MW/cm² by changing the focussing conditions. The dye solution was *p*-terphenyl in dioxane at concentrations ranging from $c = 1.2 \times 10^{-4}$ M to $c = 2 \times 10^{-2}$ M. At the lower concentrations, which resulted in relatively uniform pumping over the dye cell cross-section (optical density $D \approx 1$), gain was too low for laser action in the short resonator. At the highest concentrations, no quenching action could be observed. The optimum concentration was found to be

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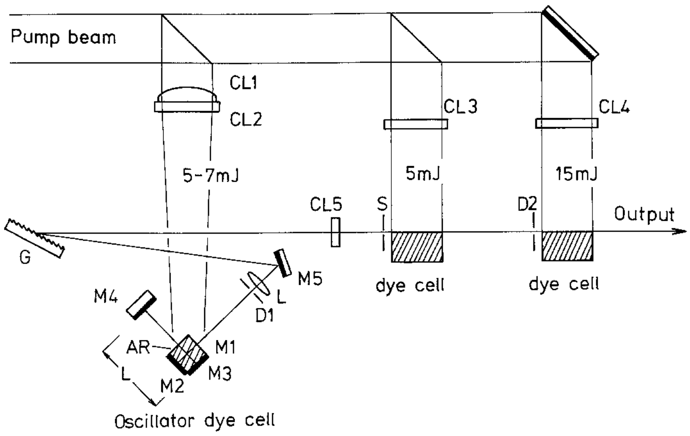

Fig. 1. Experimental configuration (M_1 uncoated dye cell wall; M_2, M_3, and M_4 high reflectivity ($R \geqq 0.95$) dielectric mirrors; M_5: reflecting mirror; L: quartz lens $f = 100$ mm; G: grating 2442 lines/mm; CL_1 to CL_5: cylindrical lenses; D_1, D_2: apertures; S: slit)

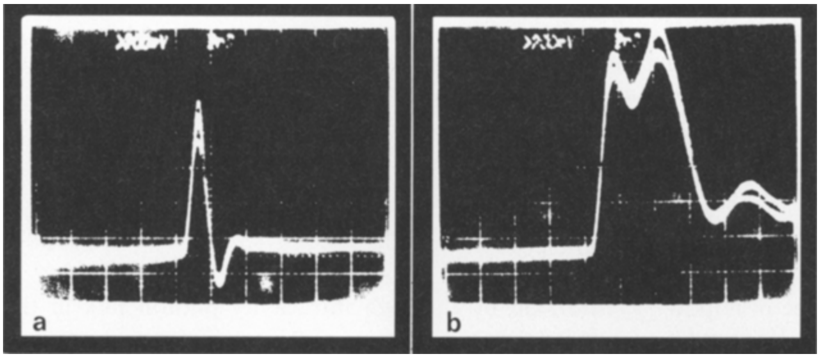

Fig. 2. (a) Short laser pulse produced by quenching of resonator transients; (b) without quenching. – These oscillograms were taken with a Tektronix 7104 1 GHz scope

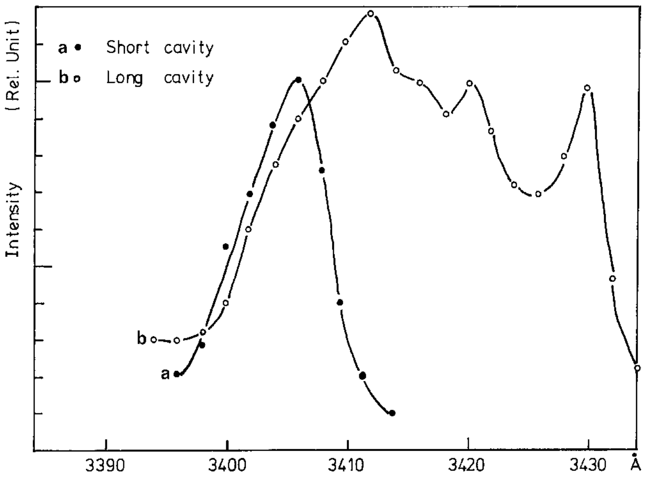

Fig. 3. Spectrum of the short laser pulse *a* and the output of the long cavity *b*

4.5×10^{-3} M ($D \approx 3$). The pulse duration was measured by a 1 GHz Tektronix 7104 oscilloscope, and found to be less than 0.5 ns. The output pulse shapes with and without quenching are shown in Fig. 2.

The spectrum of the laser output and the radiation in the long resonator are shown in Fig. 3. It can be seen that the lasing wavelength is near the peak of the fluorescence spectrum ($\lambda = 340$ nm). The bandwidth of the short pulse is about 10 Å, and that of the radiation in the long cavity is 40 Å. The output energy of the short pulse was about 100–150 nJ, which was measured by a calibrated biplanar photodiode (TVHR 113) and a set of attenuators.

The output beam (Fig. 1) was sent through a grating spectral selector and a two-stage transversally pumped amplifier. The output energy after the last stage was measured to be 100 µJ with ~2 Å bandwidth. We used this pulse to pump a distributed feedback dye laser oscillator.

2. Discussion and Conclusion

In our coupled two-resonator system the homogeneous excitation of the active medium is an important point for efficient quenching. For the diagonal pumping geometry of Fig. 1 the spacial dependence of the gain is determined by the absorption coefficient ε and the concentration c of the dye at the pumping wavelength. The distribution of the pump energy E absorbed in a unit volume along one side of the dye cell is plotted in Fig. 4 where the saturation of absorption is not taken into consideration. The parameter $A = \varepsilon \cdot c \cdot d$ (d: internal cell length) is varied from 1 to 3. It can be seen that when the absorption of the dye

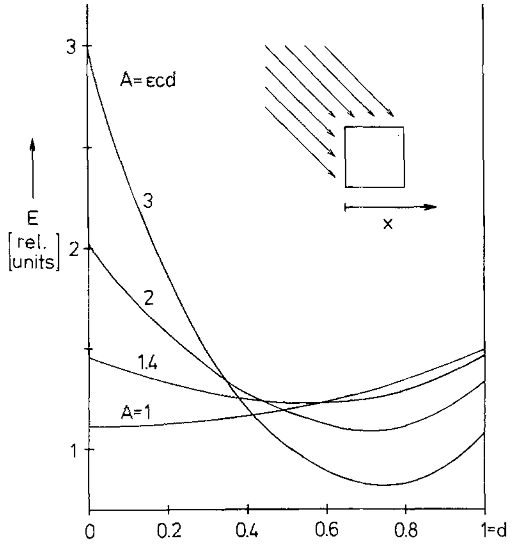

Fig. 4. Distribution of the pump energy E absorbed in a unit volume along one side of the dye cell. The absorption parameter A is varied from 1 to 3

solution is adjusted so that $A = 1.4$, the inversion in the dye cell is the most homogeneous. The values of A from 1 to 1.5 represent a good condition for quenched operation. In our system, the concentration of *p*-terphenyl was 4.5×10^{-3} M – corresponding to $A = 3$ – which was required to ensure the necessary small signal gain. It can be seen from Fig. 4 that in this case the excited-state population shows a strong spacial dependence. Only a small volume near the two front surfaces of the dye cell is excited, where two laser channels appear, which have the smaller coupling to each other the smaller the common part of them. In this case a small misalignment or damage of mirrors M_3 or M_4 is enough to destroy the adjusted quenching condition. For improvement, we suggest the use of a dielectric mirror for M_1 which has a 10–15% reflectivity at the lasing wavelength and is highly transparent at the pumping wavelength. This change would increase the dye laser gain in the short resonator so we can decrease the necessary dye concentration in order to improve the desired quenching behavior. Another way to improve the uniformity of the excited-state population is the partial saturation of the absorption by high pump light intensities, which, however, increases the risk of mirror damage. Similar results were obtained with several other uv laser dyes (QUI, DMQ, Coumarin 1).

In conclusion, ultraviolet short laser pulses could be produced by quenching of resonator transients. The attractiveness of this method is its simplicity and that it can be pumped by about 10% of an excimer laser beam.

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