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GENERATION OF FEMTOSECOND LIGHT PULSES IN THE NEAR INFRARED AROUND $\lambda = 850$ nm

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Femtosecond light pulses tunable between 840 nm and 880 nm are generated in a synchronously pumped ring dye laser. The laser emits nearly bandwidth-limited pulses ($\Delta\nu \, t_p = 0.45$) with pulse durations down to 65 fs. At a pumping power of 450 mW of a mode-locked Ar-ion laser ($\lambda = 514$ nm) the infrared femtosecond dye laser has an output of up to 15 mW.

The generation of light pulses around 100 fs was made possible by the introduction of the colliding pulse mode-locking technique [1]. The specially designed laser produced femtosecond light pulses in the spectral range around 620 nm. The advanced understanding of the pulse shaping process and the introduction of an intracavity compensation of dispersion allowed the stable generation pulses between 27 fs and 100 fs [2–5]. While the standard CPM laser operates with cw pumping by an argon ion laser, attempts have been made to synchronously pump CPM lasers. Recently we were able to show that – by using a specially designed pumping scheme – stable CPM laser action is possible with synchronous pumping [6]. This laser system was further advanced now generating 60 fs pulses at 625 nm [7]. The major draw-back of CPM dye lasers is the very narrow wavelength range. Up to now the emission of femtosecond lasers is restricted to wavelengths between 600 nm and 635 nm. Femtosecond light pulses at other wavelengths have been produced with complex and expensive systems after amplification of the red femtosecond pulses and subsequent continuum generation [8,9].

In this letter we report on the first operation of a femtosecond laser in a new wavelength range. The wavelength of the femtosecond pulses is located in the near infrared; the tunability extends from 840 to 880 nm. Stable pulse trains with pulse durations as short as 65 fs were achieved.

The construction of the infrared femtosecond laser is similar to a standard CPM laser [1,3]. The laser resonator consists of a ring cavity formed by dielectrically coated mirrors (peak reflectivity around 850 nm). The amplifying jet (dye Styryl 9, 1 g/ℓ dissolved in a mixture of propylene carbonate and ethylene glycol, 1 : 4, pumped through a nozzle of thickness 0.3 mm) is in the focal region of a pair of curved mirrors ($R = 100$ mm). The absorber jet (dye IR 140, dissolved in benzylalcohol, $c = 0.1$ g/ℓ for a thickness of the nozzle of 0.3 mm) is in the focus of a second pair of mirrors ($R = 50$ mm). The dispersion of the laser cavity could be adjusted by four brewster prisms [3]. The output mirror ($R = 90\%$) is mounted on a high-precision translation stage. The cavity length of the dye laser is adjusted carefully in order to match the round-trip time of the dye laser to that of the pumping laser. The pumping Ar-ion laser is operated at a repetition rate of 73.3 MHz and at a pumping power of 450 mW at $\lambda = 514$ nm. The final alignment of the dye laser requires a careful adjustment of both the cavity length (within 100 nm) and the dispersion of the prism system. At the optimum alignment the ring laser operates with stable amplitudes (±5%) at an output power of 15 mW. Of special interest is the observation that the emission is unidirectional with only one pulse in the cavity, i.e. the laser does not operate in the colliding-pulse modelocking regime. As a consequence, there is no need of either a special pumping scheme as used in ref. [6] or a careful adjustment of the amplifier-to-absorber distances or a very

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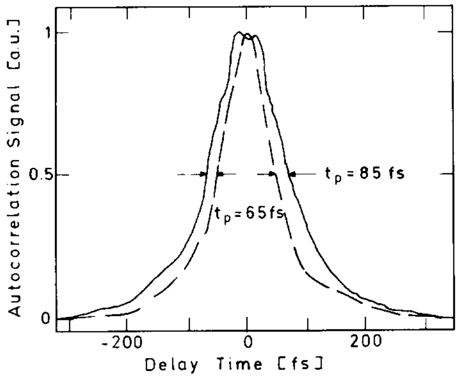

Fig. 1. Autocorrelation traces of the pulses from the IR ring dye laser operating under two different conditions. From the width of the autocorrelation traces one deduces pulse durations t_p of 85 fs and 65 fs, respectively.

thin absorber jet [1]. The autocorrelation traces are measured with the help of a KDP crystal (length 1 mm) [10].

Two autocorrelation traces of the light pulses are shown in fig. 1. In these experiments two slightly different adjustments of the cavity dispersion were used. The autocorrelation traces have widths of 135 fs (solid curve) and 100 fs (broken curve), respectively. There is no indication of a coherence spike. Assuming a sech^2-shaped pulse the widths of the autocorrelation traces correspond to pulse durations of 85 fs and 65 fs, respectively. The spectrum of the pulses with t_p = 85 fs is presented in fig. 2. The spectrum is lightly asymmetric with a faster decay on the long-wavelength side. The spectral width is $\Delta\lambda$ = 12.5 nm. From these measurements we determine the bandwidth product to be $\Delta\nu \times t_p = 0.45$. This number is close to the value of 0.32, which is expected for bandwidth-limited pulses of sech^2-shape. Adjusting the dispersion in the resonator we were also able to change the emission wavelength of the laser. The laser could be tuned from λ = 840 nm to λ = 880 nm holding the pulse duration below 100 fs. There was no need to adjust the concentrations of the absorber or amplifier dye solutions.

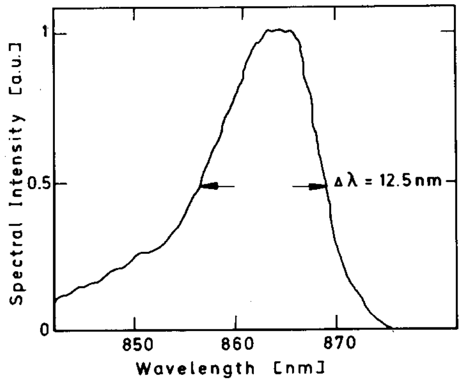

Fig. 2. Emission spectrum of the pulses with duration of 85 fs. From the spectral width and pulse duration one deduces the bandwidth product to be $\Delta\nu \times t_p = 0.45$.

The following comments concerning the stable operation of the described laser at short pulse durations are of importance.

(i) It was pointed out in ref. [11] that the quality of the mode-locking of a cw mode-locked dye laser strongly depends on the quantity S, which is made up of the cross sections of the amplifying and absorbing dyes and the light intensities in the amplifying and absorbing media: $S = (\sigma_{abs} I_{abs})/(\sigma_{amp} I_{amp})$. For fixed cross sections this ratio is enhanced in the standard CPM laser by the colliding of the light pulses in the absorber, increasing the effective intensity I_{abs}. In the present system the cross section of the infrared absorting dye, σ_{abs}, is very large. The resulting favorably large value of S does not require the operation of the dye laser in the colliding pulse mode.

(ii) The unidirectional operation of the presented ring laser is caused by the rather high transmission of the output coupler mirror of R = 90%, inducing different losses for pulses travelling clockwise or counterclockwise through the ring laser. There are well defined conditions for the remaining pulses entering the absorber and the gain medium. During each round trip the pulse enters the two jets only once, finding the absorber dye completely in the ground state and the amplifying dye at maximum inversion. This situation favors the unidirectional ring laser over a standard linear configuration.

(iii) Synchronously pumping of the infrared dye laser by a mode-locked pumping source is necessary, since a ground-state recovery time of the gain medium is rather short, $\tau \approx 600$ ps [11], and the absorption recovery time of the absorber is of the same order of magnitude.

This paper demonstrates femtosecond laser action with a new amplifier–absorber combination, which is different from the standard dyes Rhodamin 6G and DODCI. It seems promising to search for other dye combinations extending femtosecond lasers to other frequency regions.

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