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3.C High-Repetition-Rate Amplification of Subpicosecond Pulses

In the past, amplification of ultrashort optical pulses has been achieved through the use of high-energy nanosecond pump pulses generated by Nd:YAG,[1] nitrogen,[2] excimer,[3,4] and cavity-dumped argon-ion lasers.[5] In high-gain systems, the effective storage time due to fluorescence, molecular reorientation, and amplified spontaneous emission (ASE), does not exceed a few hundred picoseconds even for dye molecules with long fluorescence lifetimes. Therefore, in order to maximize the energy transfer between the pump and the dye laser pulses, it is important that the population inversion be established in a time significantly shorter than the effective storage time. In addition, the synchronization between the pump and dye laser pulses must be in the order of a fraction of the pump pulse width to take advantage of the peak gain.

A method of obtaining this synchronization is to drive the mode-lockers of two lasers with the same RF source. One laser is then used to synchronously pump a dye laser while the other is used to pump the amplifier. The dye laser produces pulses in the order of 100 fs at a repetition rate of 100 MHz.

The synchronous amplifier system was developed in order to provide a repetition rate high enough for signal averaging or lock-in techniques with an output energy sufficient to observe nonlinear processes. The system layout is as shown in Fig. 23. Subpicosecond pulses from the synchronously-pumped dye laser are amplified in a single-pass two-stage configuration. The amplifier is pumped by an actively Q-switched and mode-locked CW Nd:YAG oscillator (Quantronix 114-R-O/QS ML) which is frequency-doubled in a temperature-tuned CD*A crystal. This oscillator can be triggered at rates up to 500 Hz while establishing a stable CW mode-locked oscillation (prelase) prior to Q-switching. This prelase ensures an output pulse stable both in amplitude and pulse-width.

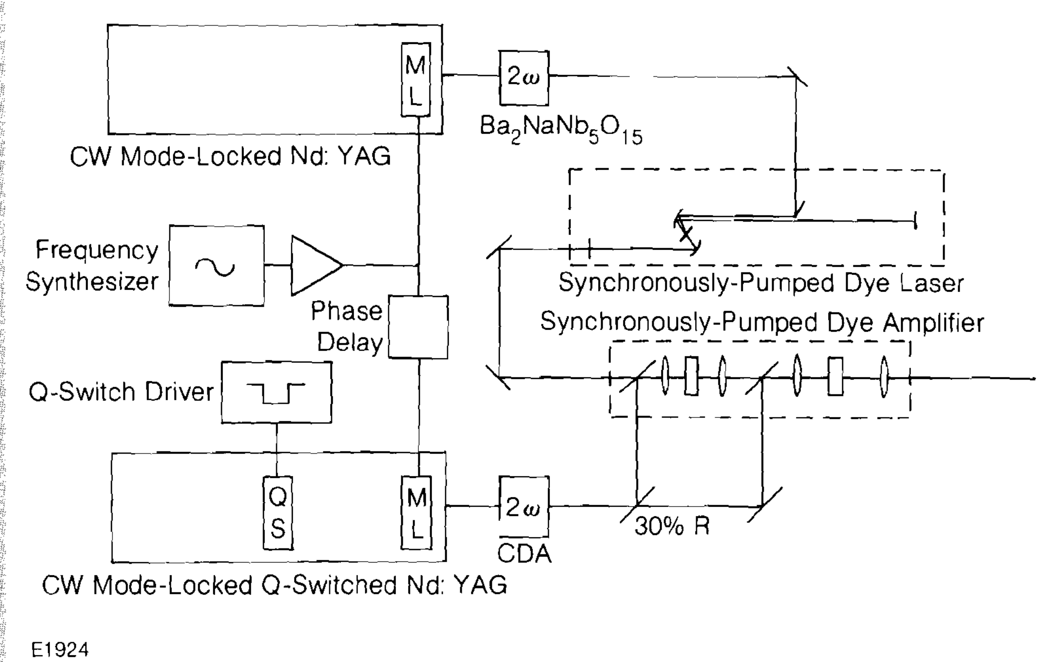

Fig. 23
Synchronized amplifier for femtosecond pulses using RF-coupled lasers.

To measure the timing accuracy (jitter) between the two pump lasers, the autocorrelation of each was taken. A Gaussian pulse shape was assumed to determine their respective pulse widths. The cross-correlation was then measured between the two lasers. The jitter was calculated, assuming a Gaussian distribution using,

$$\tau_{cc}^2 = \tau_1{}^2 + \tau_2{}^2 + \tau_j{}^2 \tag{5}$$

where τ_{cc}, τ_1, τ_2, and τ_j are the full-width half-maximum widths of the cross-correlation, first laser, second laser, and the timing fluctuation respectively. In this manner the jitter is measured to be a maximum of 40 ps. There is a large uncertainty in this value due to the inherent difficulty in using the cross-correlation for jitter measurement; however, this value is viewed as an upper limit in light of previous work on mode-locked oscillator synchronization.[17] The autocorrelations of each pump laser and the cross-correlation between the two are as shown in Fig. 24 (this figure is included to illustrate the relative clarity of the data, not the relative widths, since the horizontal scales are not equal).

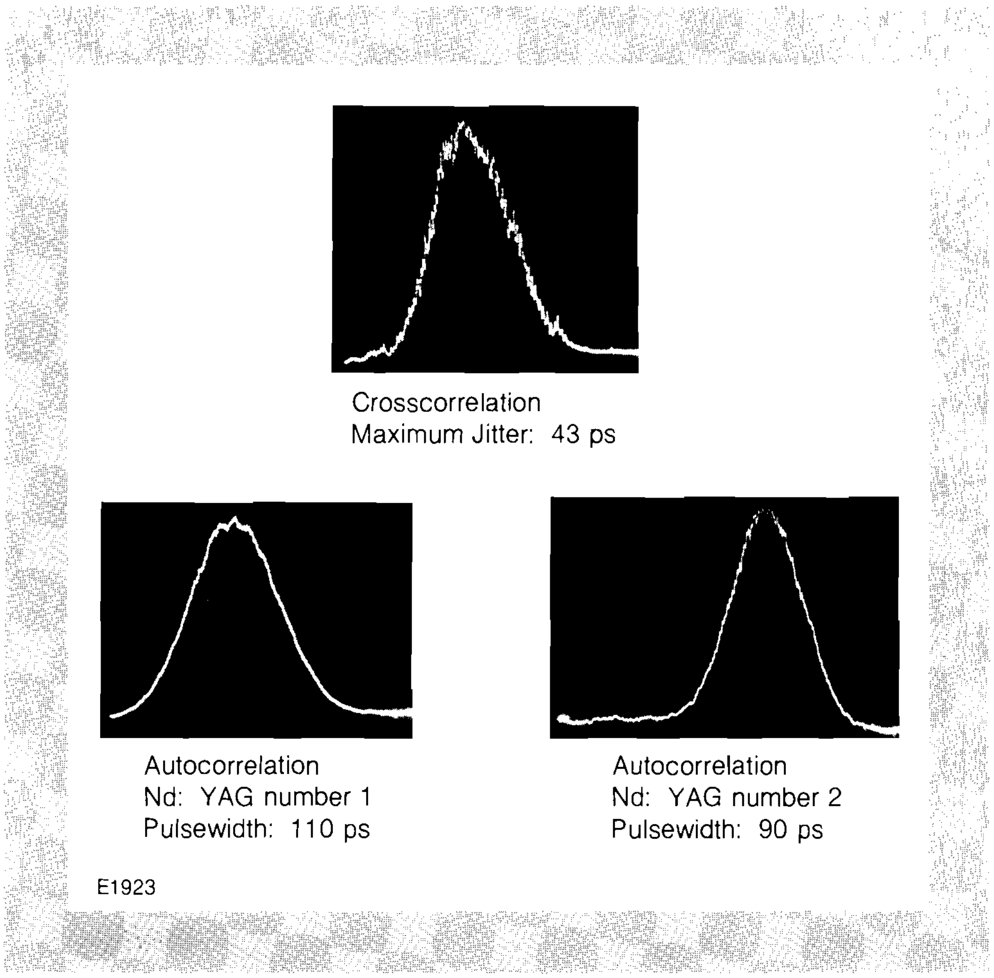

Fig. 24
Correlation measurement of the oscillator and amplifier pump laser to determine the relative timing.

The dye amplifiers were built using Kiton Red in water as the dye medium with 1 cm path lengths. The energy in the pump pulse is 25 μJ at 0.532 μm. Thirty percent of this energy is deposited in the first stage. Two amplifier stages are used in order to avoid the problem of heating during the train of pump pulses which would otherwise result in thermal blooming of the dye. This thermal problem is the limiting factor in the amplification. Output pulse energies of 350 nJ are obtained at 605 nm.

The thermal problem can be reduced by using a single pulse rather than the full train. Pulse selection has been accomplished either by a Pockels cell switchout external to the cavity or by cavity-dumping the pump laser. Single-pulse energies at 1.06 μm of 300 μJ have been obtained using a Pockels cell cavity dumper. The insertion loss of the dielectric polarizer and Pockels cell requires the prelase gain to be very close to threshold, significantly increasing the fluctuations in output energy.

The amplifier pump laser has a pulse amplitude peak stability of $\pm$ 1 % in a 25-pulse train. This stability is due to the better than 1 % regulation on the lamp current and the fact that a CW mode-locked prelase is established prior to Q-switching. By gating the Q-switch on a zero crossing of the carrier frequency (derived from the same synthesizer as the mode-locker RF), absolute timing between the Q-switch trigger and the peak pulse is established allowing accurate triggering of a switchout. Amplitude fluctuation of the switched-out pulse is ± 1.5%.

To determine if the 40 ps jitter was small enough to do synchronous pumping, the gain depletion in the amplifier, shown in Fig. 25, was plotted by measuring the gain as a function of dye-laser-pulse delay. This delay was varied by changing the RF phase to the amplifier pump laser mode-locker, eliminating the need for an optical delay line. The measurement confirms that the synchronization is sufficient to amplify the pulse under peak gain conditions.

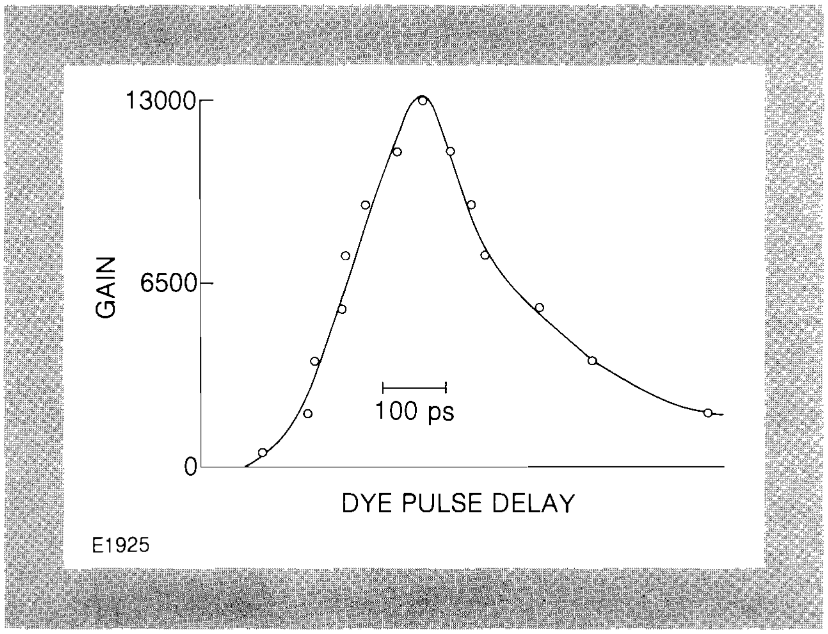

Fig. 25
Kiton Red amplifier (Fig. 23) gain versus time using the mode-locker RF phase to adjust the time delay.

The method of RF synchronization of two lasers can be generally applied to a wide range of systems, including the colliding-pulse mode-locked (CPM) laser,[8] provided that the mode-locker RF for the amplifier pump laser is derived from the CPM laser output and the cavity lengths of the two lasers are matched.

Synchronous pumping and amplification offer advantages as methods of femtosecond pulse generation and amplification. The benefits are particularly notable with regards to amplifying efficiency, decreased ASE, and the reduction of temporally-induced amplitude fluctuations. In addition, the synchronization between the amplifier pump pulse and the femtosecond pulse enables us to use the high-energy 1.06 μm pulse to drive detection electronics, such as jitter-free streak cameras,[9] or as an intense pump pulse for use in experiments.

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