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Picosecond pulses produced by mode locking a Nd:glass laser with Kodak dye #26

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Kodak dye #26 was used to generate picosecond laser pulses by mode locking a Nd:glass laser. The intensity profiles and characteristics of the pulses were compared with those of pulses emitted using dyes #5 and #9860.

For the past 15 years, neodymium–glass lasers mode locked by Kodak dye #9860 have been used extensively in the investigation of picosecond phenomena[1,2] because the optical pulses emitted from this type of laser are of high peak power (1 GW) and short duration (7 psec). These key characteristics have allowed for a deeper understanding of many nonlinear optical effects and kinetics processes in materials.[1,2] In order to achieve a better temporal resolution for kinetic measurements one needs reliably to generate shorter pulses from mode-locked lasers. To accomplish this task, a photostable ultrafast infrared saturable absorber is required to mode lock glass and YAG lasers. The main obstacle in the use of most infrared dyes is the poor photochemical stability resulting from their chemical structure. In 1977, Reynolds and Drexhage[3] reported on synthesizing a series of dyes from the heptamethine cyanine family, which absorbs in the infrared and was much more stable than the Kodak #9860 dye. Kopainsky *et al.*[4] reported measuring the absorption recovery times at 1060 nm for saturable absorbers #5, #15, #18, and #9860. The recovery times measured were 2.7, 4.1, 4.0, and 6.5 psec, respectively. Most recently Kopainsky *et al.*[5] extended this research to synthesize more photostable IR dyes. In particular, it was found that dye #26 dissolved in 1,2-dichloroethane is 10^4 times more stable than #9860 and has a 22-psec recovery time. Alfano *et al.*[6] reported passive mode locking and ultrashort pulse generation of 4 psec with dye #5 in a multitransverse-mode glass laser. Kolmeder and Zinth[7] found that owing to higher saturation flux and TEM_{00} cavity design they could not obtain passive mode locking with dye #5 when it was substituted into a contact dye cell. However, using a folded-cavity design, they were able to obtain good mode locking. Most recently, Goldberg and Schoen[8] reported on the generation of a 6-psec pulse in a hybrid approach using both active acousto-optic modulation and passive mode locking using #5 dye.

In this paper, we report a picosecond pulse generation by passively mode locking a glass laser with dyes #26, #5, and #9860. The characteristics of the laser pulses were measured and compared using a 2-psec streak camera system.

The laser consisted of a 1-m-long cavity with a 60% dielectric output reflector and a 99.8% dielectric rear reflector, a K-1 Korad power supply, a K-1 Korad laser head with a 17.8 cm × 1.27 cm Brewster-angle-cut phosphate rod, and an optical dye cell. The threshold voltages for lasing for dyes #26, #9860, and #5 were approximately 2.8, 2.9, and 3.3 kV, respectively. In order to select a single pulse from the train, a Lasermetrics electronic single-pulse selector (8601) and a KDP Pockell cell were used. Typically, the pulse was selected within the first half of the pulse train. The dyes #26, #9860, and #5 were obtained from samples from Kodak and dissolved in 1,2-dichloroethane solvent. The transmission was set at 70% at 1060 nm in a 1-cm cell. The transmission stability of the dye #26 solution (without flowing) did not change by more than 1% after two weeks. The time development of the laser pulse train was measured using a fast Hamamatsu (R1328U) phototube coupled to a Tektronix (7904) oscilloscope. The pulse trains from the three dyes were reproducible from shot to shot. The profile and the duration of a laser pulse at 530 nm were measured and analyzed directly using a 2-psec streak-camera system: a Hamamatsu (C1370-01)

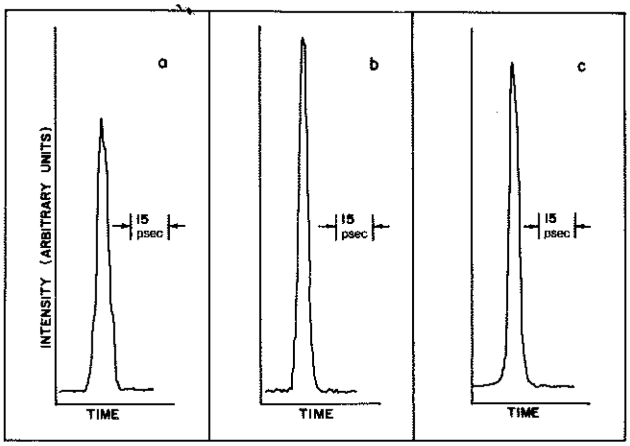

Fig. 1. Intensity profile of a laser pulse versus time as measured by a streak camera system for dyes: a, #26; b, #5; c, #9860.

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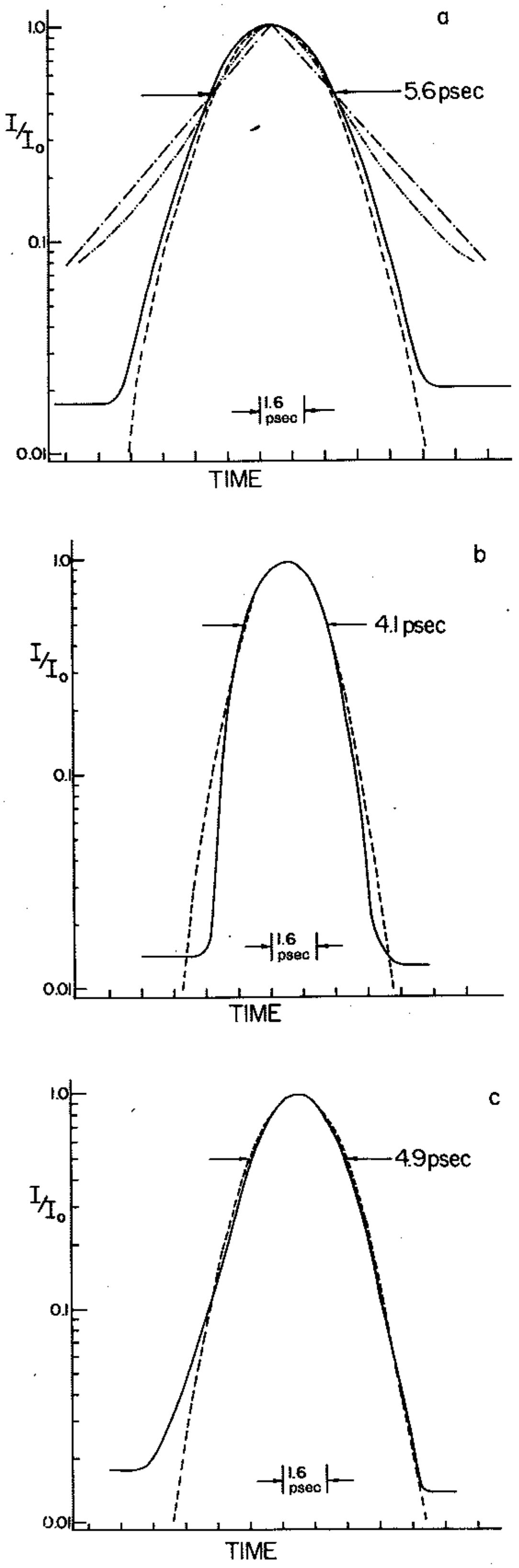

Fig. 2. The envelope shape of a typical laser pulse is fitted to different shapes: a, experimental (—), Gaussian (- - -), Lorenzian (-·-), and exponential (· · ·) fits for dye #26. The FWHM of the Gaussian envelope is 5.6 psec. The laser pulses displayed in b and c are the experimental (—) and Gaussian fit (- - -) curves for dyes #5 and #9860, respectively. The FWHM of the Gaussian envelope is 4.1 and 4.9 psec, respectively.

Table 1. Laser Pulse Durations and the Absorption Recovery Time for Dyes #26, #5, and #9860

Dye Number	Laser Pulse Duration (Experimental) FWHM (psec)	Pulse Duration Value (Deconvoluted) FWHM (psec)	Absorption Recovery Time at 1.06 μm (psec)[a]
26	5.9 ± 0.9	5.5	22 ± 1.5
5	4.3 ± 0.5	3.8	2.7 ± 0.1
9860	5.5 ± 1	5.1	7 ± 1

[a] Ref. 4.

temporal disperser coupled to a readout consisting of a SIT video camera (C1000-18) and a temporal analyzer (C1440-03) minicomputer system. The digitized data were displayed on a video monitor and output onto a chart recorder. The recorded time profiles of a typical single pulse for dyes #26, #5, and #9860 are shown in Figs. 1a, 1b, and 1c, respectively.

Three different models were used to fit the intensity laser profile in time. As shown in Fig. 2a, for the dye #26 a Gaussian pulse shape describes the intensity-profile pulse better than either Lorenztian or exponential profiles. Similarly, the intensity profiles of laser pulses produced using dyes #5 and #9860, shown in Figs. 2b and 2c, respectively, can also be fitted to a Gaussian function. The average pulse duration for the three dyes measured for more than 10 laser shots each are 5.9 ± 0.9 psec for dye #26, 4.3 ± 0.5 psec for dye #5, and 5.5 ± 1 psec for dye #9860. The deconvoluted pulse durations obtained for each dye are estimated from the relation for Gaussian pulses: $\tau_p = (\tau^2{}_m - \tau^2{}_R)^{1/2}$, where τ_p is the deconvoluted FWHM pulse duration value, τ_m is the measured FWHM pulse duration value, and τ_R is the streak-camera time-resolution factor. The pulse characteristics, including the absorption recovery time,[4] are summarized for each dye in Table 1. Occasionally, when dye #26 was used, one out of fifteen laser shots showed a complex pulse structure within the pulse envelope shape. The duration of these types of pulses is measured to be about double the typical pulse duration.

In conclusion, dye #26 has been shown to be a reliable mode locker for a Nd:glass laser. Mode locking with dye #5 has been reconfirmed.[6] Gaussian shapes were shown to describe the intensity profiles of the pulses generated using dyes #26, #5, and #9860 in mode-locked glass lasers. Dye #26 is more photostable than dyes #5 and #9860 for mode locking a Nd:phosphate glass laser and produces light pulses with a duration of less than 6 psec. In addition, the extended stability of dye #26 makes it an ideal alternative to the most commonly used dyes, #9860 and #9740, for mode locking glass lasers and most importantly for mode locking the high-repetition-rate Nd:YAG lasers. What is interesting is that the pulse produced with dye #26 is much faster than the absorption recovery time.

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