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Femtosecond Pulses Generated from a Synchronously Pumped Chromium-Doped Forsterite Laser

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Summary

Kerr lens mode-locking (KLM) has become a standard method to produce femtosecond pulses from tunable solid state lasers.¹ High power inside the laser resonator propagating through the laser medium with nonlinear index of refraction, coupled with the stability conditions of the laser modes in the resonator result in a passive amplitude modulation which explains the mechanism for pulse shortening. Pulses of 17 fs FWHM were generated using KLM from Ti:Sapphire laser.² Pulses of 50 fs³ and pulses of 150 fs⁴ were also generated from Cr³⁺:LiSrSiF₆ using KLM in combination with a saturable absorber in the cavity and active mode locking, respectively. Recently, chromium doped forsterite was shown to exhibit similar pulse behavior.⁵ Transform limited 60 fs pulses were generated from an actively mode locked forsterite laser using intracavity chirp compensation. The pulses were generated even when the active modulator was turned off, suggesting that KLM technique was operative in the generation of femtosecond pulses from Cr: forsterite laser.

In this presentation, we report on the first successful attempt to generate femtosecond pulses from a synchronously pumped chromium-doped forsterite laser with intracavity dispersion compensation. Stable, transform limited pulses with duration of 105 fs were routinely generated, tunable between 1240 to 1270 nm.

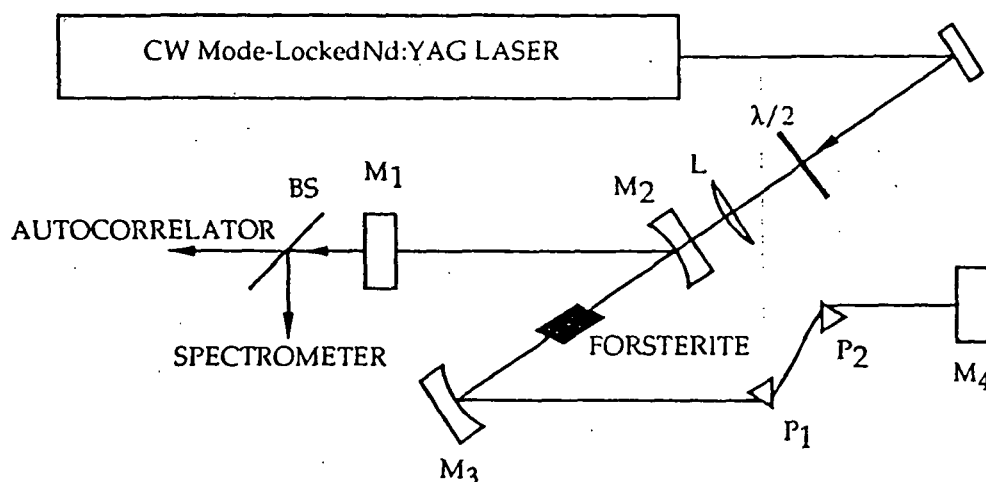


Fig. 1. Schematic diagram of the synchronously pumped mode-locked operation of the Cr:forsterite laser: $\lambda/2$, half-wave plate for 1064 nm; L, focusing lens; M₁, output mirror, M₂, M₃, 10-cm-radius folding mirrors; M₄, back mirror; BS, beam splitter; P₁ and P₂, Schott SF14 glass prisms.

The experimental arrangement is shown in Fig. 1. The Brewster-angle-cut forsterite crystal was placed in a four-mirror, Z-fold astigmatically compensated cavity. The combination of mirrors used was: a flat back mirror, two 10-cm-radius folding mirrors, and a flat output coupler. The transmission of the output coupler was 1% at the lasing wavelength, while the folding mirrors and the back mirror had reflectivity $R=99.9\%$ for the 1200-1300 nm range. The length of the sample was 1.2 cm with absorption coefficient at the pump wavelength of 1064 nm of $\alpha=1.1 \text{ cm}^{-1}$. The laser crystal was mounted in a copper block and was cooled by a single-stage thermoelectric cooler. The Cr:forsterite crystal was pumped by an actively mode-locked Nd:YAG laser (82 MHz). The pump beam was focused by a 7.5-cm lens through the 10-cm-radius folding mirror into the crystal. The 1064-nm pump power incident on the forsterite crystal was 5.3 W, of which 3.9 W was absorbed by the crystal. The output of the forsterite laser was monitored with a fast germanium detector and an oscilloscope. The pulsewidth was measured with a noncollinear background free real-time intensity autocorrelator. A collinear interferometric autocorrelator was also used to determine the chirp characteristics of the output pulses. The bandwidth of the mode-locked forsterite laser was measured using a PbS detector coupled to a 50-cm Jarrel Ash monochromator, equipped with variable aperture slits.

Mode locking was observed when the length of the cavity was matched to the length of the mode locked Nd:YAG laser. Once mode-locking was achieved two regimes were observed. In the first we observe long duration pulses (200-300 ps FWHM). By further alignment of the cavity and slightly changing the position of the laser crystal and the distance between mirrors M2 and M3 the pulsewidth was reduced down to 105 fs with a spectral width of the order of 20 nm. The output power of the forsterite laser when femtosecond pulses were generated was 45 mW. An intensity autocorrelation trace and the corresponding spectrum of a typical pulse are shown in Fig. 2 (a) and (b). The pulsewidth shown is 105 fs and the bandwidth is 16 nm. The pulsewidth-bandwidth product $\Delta\tau_p\Delta\nu = 0.32$, indicating transform-limited pulses for a sech^2 pulse. Fig. 3 shows a picture of the interferometric autocorrelation trace of the output pulses. Since there is good visibility of the fringes at the wings of the pulse it is evident from this picture that the pair of prisms compensated for the nonlinear chirp introduced by the forsterite crystal.⁶

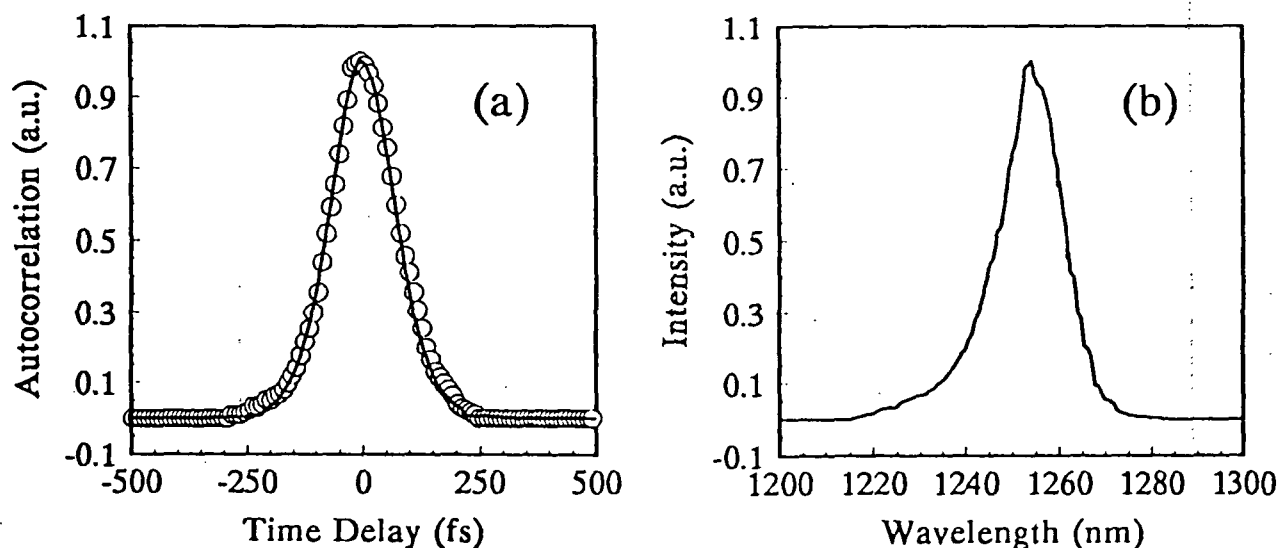


Fig. 2. An autocorrelation trace (a) and spectrum (b) of 105-fs pulses obtained from a Z cavity with glass prisms for chirp compensation. Circles represent experimental data and the solid line is the best fit. sech^2 pulse shape was assumed for fitting. The pulsewidth-bandwidth product $\Delta\tau_p\Delta\nu = 0.32$.

The pair of prisms used in the cavity was made of SF14 Schott optical glass. The optical characteristics of this type of glass for 1250 nm are $n = 1.729$, $dn/d\lambda = -0.02017$, $d^2n/d\lambda^2 = 0.02262$, and $d^3n/d\lambda^3 = -0.0999$.⁷ The optimum distance between the two prisms when stable 105-fs pulses were obtained, was determined to be 35 cm. Carrying out the calculation for the phase derivatives with respect to frequency we get $\partial^2\phi/\partial\omega^2 = -3273 \text{ fsec}^2$ and $\partial^3\phi/\partial\omega^3 = -2170 \text{ fsec}^3$.^{8,9} This indicates that SF14 is not the most appropriate glass for pulse shortening in this wavelength region since it introduces a large cubic phase term. This suggests that by using material which will introduce less cubic phase, shorter pulses will be generated as is the case with Ti:Sapphire. Different types of glass prisms will be discussed which minimize the effect of the cubic phase term.

The passively mode-locked forsterite laser was tuned using an aperture between prism P_2 and mirror M_4 . We were able to continuously tune the laser between 1240 and 1270 nm. The duration of pulses did not vary much throughout the whole tuning range.

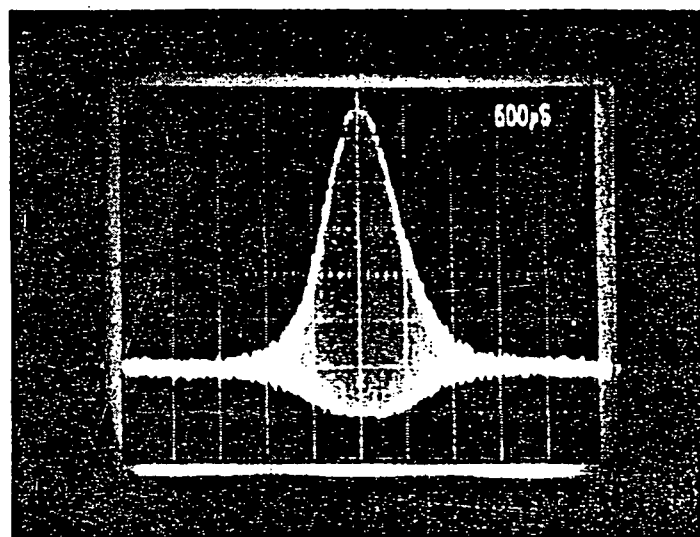


Fig. 4. Interferometric autocorrelation of the output pulses of the forsterite laser

In conclusion, transform-limited femtosecond pulses were generated from a synchronously pumped chromium-doped forsterite laser. Stable 105 femtosecond pulses in TEM_{00} mode were obtained. The tuning range was of the order of 30 nm, limited only by the coating of the mirrors used and the available pump power.

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