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GENERATION OF STABLE P.S. PULSES
AT HIGH REPETITION RATE FOR
ULTRAFAST DIAGNOSTIC EXPERIMENTS

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Final Report

**"Generation of Stable Ps, mJ Pulses at High Repetition
Rate for Ultrafast Diagnostic Experiments": ***

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I. INTRODUCTION

Nd:Glass amplifiers have very good energy storage capabilities (5 J/cm^2), but, the energy extraction is extremely inefficient for short-pulse amplification. At relatively high peak intensities of $\sim 10 \text{ GW/cm}^2$, nonlinear phase shifts occur, leading to beam wavefront distortion which can result in filamentation and irreversible damage. In order that the peak intensity in the amplifier remain below this damage level, a picosecond pulse can be amplified only to an energy density of $\sim 10 \text{ mJ/cm}^2$, two orders of magnitude less than the stored energy level of 5 J/cm^2 . We have developed an amplification system, which uses an optical pulse compression technique to circumvent this peak power limitation.¹ This technique is analogous to a method developed over forty years ago for the amplification of radar pulses.² Briefly: a long optical pulse is deliberately produced by stretching a short, low-energy pulse, amplified and then compressed. The frequency chirp and the temporal broadening are produced by propagating a high-intensity pulse along a single-mode fiber. At the beginning of the fiber, the pulse undergoes self-phase modulation which produces a frequency chirp. The chirp is then linearized by the group-velocity dispersion of the fiber. This long, frequency-chirped, pulse is amplified, and then compressed to a pulsewidth approximately equal to $1/\Delta f$, where Δf is the chirped bandwidth. With this system, short pulses can reach the high saturation energy levels, with moderately low peak power levels being maintained in the amplifying medium.

II. EXPERIMENTAL SYSTEM AND RESULTS

We have demonstrated the principle of using a compression technique to produce amplified, short pulses (~ 1 ps) at the 100 mJ energy level. A schematic of the system is shown in Fig. 1. We use a cw mode-locked, Nd:YAG laser to produce 100-ps optical pulses. About one watt of average power from this laser is focussed into a 2.4 km length of single-mode, nonpolarization preserving fiber. At the output of the fiber the average power is 300 mw. The loss in power is almost entirely due to coupling losses. The fiber has a 4 μm core diameter. The laser power level in the fiber is determined by the onset of Raman generation. We run at the threshold level for Raman generation because this gives the best energy stability of the compressed pulses. Figure 2 shows streak camera traces of the infrared pulses at the input and output of the fiber. Due to the combined effects of self-phase modulation and group velocity dispersion, the pulses at the output of the fiber are 330 ps in duration and have a chirped bandwidth of 3.5 nm.³ [Originally, we used a 1.4 km length of fiber which had a 9 μm core diameter. With this fiber we had 800 mw of average power at the output and the pulses were stretched to 200 ps, as can be seen in Fig. 3. The pulses were frequency-doubled to be detected more efficiently by the streak camera. The frequency bandwidth was again about 3.5 nm. We switched to a longer fiber because the increased GVD should yield longer pulses with a more linear frequency chirp and therefore cleaner compressed pulses. However, we did not see a significant improvement.] For both fibers, we achieved 1.5 ps compressed pulsewidth with very little wings in the pulses. Figure 4 shows an autocorrelation of the cw compressed pulses. The stretched pulses are amplified in a series of two silicate glass (Kigre Q-246) regenerative amplifiers. The silicate glass has a bandwidth of 20 nm and peaks at 1.062 μm . The fiber is isolated from the regenerative amplifier by a Pockels cell switch-out, which operates at a 5-Hz

repetition rate. The switched-out pulses are then injected into the first regenerative amplifier by a second Pockels cell. The laser resonator is comprised of a 5 m radius 100% reflector and a flat 90% reflector. The cavity length is approximately 1.5 m. Originally, a $\lambda/4$ plate was placed in the cavity to frustrate lasing but it acted as a Fabry Perot etalon. We have eliminated this problem by removing the $\lambda/4$ plate and aligning the Pockels cell to have a static $\lambda/4$ birefringence. After 100 round trips, the pulse energy saturates at a level of 2 mJ and the pulse is cavity dumped by the second Pockels cell. The beam is up-collimated by a factor of 3 in order to fill the 9 mm rod of the second regenerative amplifier. The second amplifier cavity consists of two flat mirrors separated by 2 m. A vacuum spatial filter is placed inside the cavity to maintain a good spatial profile. Again, a Pockels cell is used to isolate the two amplifiers and a fourth Pockels cell is used to inject the pulses into the second amplifier. We use a $\lambda/4$ plate in the cavity to frustrate lasing. At present our water cooling flow rate is inadequate and we have to run at a pulse rate of 3 pulses per minute to avoid thermal focussing of the beam. The pulses remain in the second regenerative amplifier for 10 round trips and are then cavity dumped at an energy of 100 mJ. The amplified pulses are then compressed by a double grating compressor.⁴ The gratings have a 1700 μ /mm groove spacing and are used in a near Littrow configuration for maximum efficiency. The gratings are gold coated and are about 90% energy efficient. The gratings are spaced approximately 100 cm apart. The grating compressor is used in a double pass configuration to have a circular beam profile.⁵ The damage threshold of the gratings is presently being tested at our damage test facility here at LLE. Figure 5 shows a streak camera trace with a frequency-doubled pulse which was amplified in the first amplifier to 2 mJ and then compressed. The pulse is shown with a reflection from an etalon for calibration purposes. The measured pulsewidth is limited by the streak camera

response of 2 ps. Figure 6 shows a compressed pulse which was amplified to the 40 mJ level. Again, the measured pulsewidth was the camera limited value of 2 ps. Only 10 mJ of energy was actually incident on the gratings to avoid damage.

III FUTURE WORK

We are already working on the next laser source generation based on Nd:YLF and phosphate glass instead of Nd:YAG and silicate glass.

We are shifting to phosphate glass because it has better thermal characteristics, allowing us to work at higher repetition rates. Nd:YLF was the media selected for the oscillator because its lasing wavelength (1.054 μm) matches closely with the one of phosphate glass.

We have assembled a cw-pumped Nd:YLF oscillator. Nd:YLF has a larger bandwidth than Nd:YAG and, therefore, we can generate shorter pulses than we have in the past. Our oscillator delivers pulses as short as 37 ps. A static Faraday rotator has been built to decouple the oscillator from the fiber -- isolation greater than 30 dB has been achieved.

We are now building a regenerative Nd-phosphate glass amplifier with a 1 mJ expected output. This pulse will subsequently be amplified in the OMEGA driver line to the 1 Joule level. A small fraction of this pulse will then be compressed (we will be limited by the size of our gratings).

IV. SUMMARY

Using pulse stretching and chirping techniques, we have been able to amplify 100 ps, 10 nJ pulses emitted by a mode-locked, Nd:YAG oscillator to the 100 mJ level. These pulses were subsequently compressed to about 1.5 ps.

We are presently upgrading our system, switching to Nd:YLF and Nd:phosphate glass instead of Nd:YAG and Nd:silicate glass. These improvements will allow us to generate shorter pulses (subpicosecond) and to work at higher repetition rate (≥ 1 Hz).

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FIGURE CAPTIONS

- Fig. 1 (a) Block diagram of amplification and compression system. (b) Amplifier system configuration.
- Fig. 2 (a) Streak camera traces of IR pulses at 2.4 km fiber input. (b) Output of the fiber.
- Fig. 3 (a) Streak camera trace of frequency-doubled pulses at 1.4 km fiber input. (b) Output of the fiber.
- Fig. 4 Autocorrelation of cw-compressed pulses. Assuming Gaussian pulse shape, the pulsewidth equals 1.5 ps.
- Fig. 5 Streak camera trace of amplified and compressed pulse with a reflection from an etalon. The pulses were frequency doubled in order to be detected by cathode. Pulsewidth is limited by the streak camera response of 2 ps.
- Fig. 6 Streak camera trace of pulse amplified to 40 mJ and compressed to streak camera limit of 2 ps.

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