

**COMPRESSION OF AMPLIFIED CHIRPED OPTICAL PULSES** <sup>☆</sup>

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We have demonstrated the amplification and subsequent recompression of optical chirped pulses. A system which produces 1.06  $\mu\text{m}$  laser pulses with pulse widths of 2 ps and energies at the millijoule level is presented.

The onset of self-focusing of intense light pulses limits the amplification of ultra-short laser pulses. A similar problem arises in radar because of the need for short, yet energetic pulses, without having circuits capable of handling the required peak powers. The solution for radar transmission is to stretch the pulse by passing it through a positively dispersive delay line before amplifying and transmitting the pulse. The echo is compressed to its original pulse shape by a negatively dispersive delay line [1].

We wish to report here a system which transposes the technique employed in radar to the optical regime, and that in principle should be capable of producing short ( $\lesssim 1$  ps) pulses with energies at the Joule level. A long pulse is deliberately produced by stretching a short, low-energy pulse in a single mode optical fiber. The pulse is linearly chirped in the fiber by the combination of group velocity dispersion and self-phase modulation [2]. The stretched pulse is amplified and then compressed by a double grating compressor [3]. Amplifying the stretched pulse rather than the compressed pulse allows for higher energies to be achieved before self-focusing occurs. The amplification does not appear to affect the chirp linearity and so the pulses can be fully compressed [4]. A potential benefit of amplifying a chirped pulse in an inhomogeneous medium is gain sweeping. In this case, the amplified

pulse would be free from gain saturation effects, because the frequency varies along the pulsewidth and each frequency component sees gain independently.

A schematic diagram of the amplifier and compression system is shown in fig. 1. A CW mode-locked, Nd : YAG laser (Spectra-Physics Series 3000) is used to produce 150 ps pulses at an 82 MHz repetition rate. Five watts of average power are coupled into 1.4 km of single-mode non-polarization-preserving optical fiber. The fiber (Corning Experimental SMF/DS<sup>TM</sup>) has a core diameter of 9  $\mu\text{m}$ . The average power at the output of the fiber is 2.3 W. The pulses have a rectangular pulshape with a pulse width of approximately 300 ps, as can be seen from the autocorrelation trace in fig. 2. The bandwidth of the pulses is 50  $\text{\AA}$ . The stretched pulses are injected into a pulsed, Nd : glass, regenerative amplifier, by reflection from an AR coated window. An AR coated window is used to protect the fiber end from being damaged by the retroreflected, amplified pulses. The glass (Kigre Q-246) is a high gain silicate glass, with a 350  $\text{\AA}$  bandwidth. The gain of the Nd : glass amplifier peaks at 1.062  $\mu\text{m}$ . A quarter-wave plate frustrates lasing and rejects the injected pulses after two round trips. A pulse is trapped in the cavity, by applying a quarter-wave voltage to the Pockels cell, which then compensates for the quarter-wave plate. The Pockels cell is triggered at the peak of the fluorescence. After approximately 100 round trips (1  $\mu\text{s}$ ), the Pockels cell is triggered again with a voltage sufficient for half-wave rotation, in order to reject the pulse from the cavity.

<sup>☆</sup> This is a corrected version of the paper published in Optics Comm. 55 (1985) 447, where inadvertently a wrong figure was printed as fig. 1.

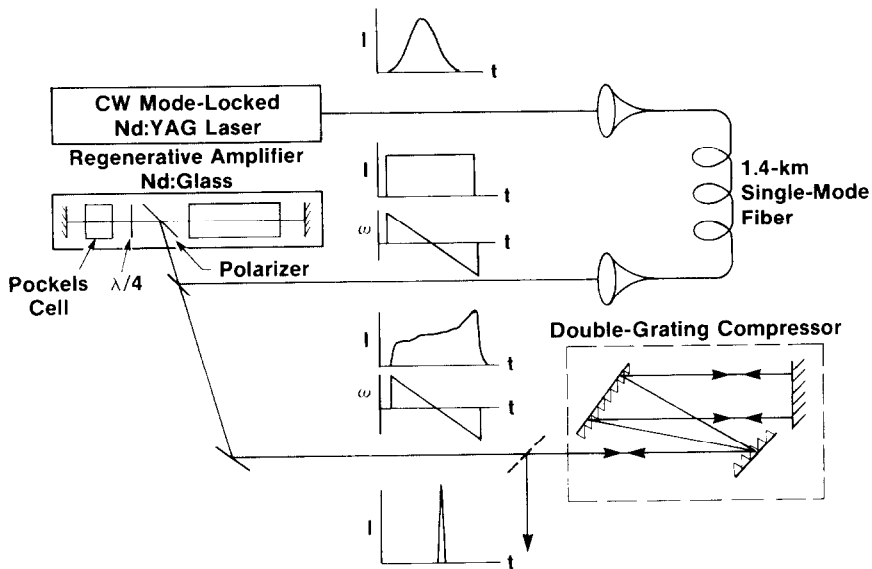


Fig. 1. Amplifier and compression system configuration.

The energy of the amplified pulse is  $\sim 2$  mJ. The amplified pulse is transmitted through the AR coated window to a double pass of a double grating compressor. The gratings have 1700  $\ell$ /mm groove spacing and are used in near Littrow condition. The grating spacing was optimized for maximum compression of the pulses directly from the fiber. The gratings were set at  $65^\circ$  angle of incidence and separated by 25 cm.

A double pass of the grating system was used to retain a circular beam profile [5]. The energy efficiency of the grating compressor is 50%. A pulsewidth of 1.5 ps was achieved as can be seen from the autocorrelation trace in fig. 3.

In previous compression experiments of  $1.06 \mu\text{m}$  pulses, shorter fiber lengths were used because maximum power output was desired [6]. In this case, the pulses are amplified in a regenerative amplifier and therefore the losses in the fiber are immaterial. The

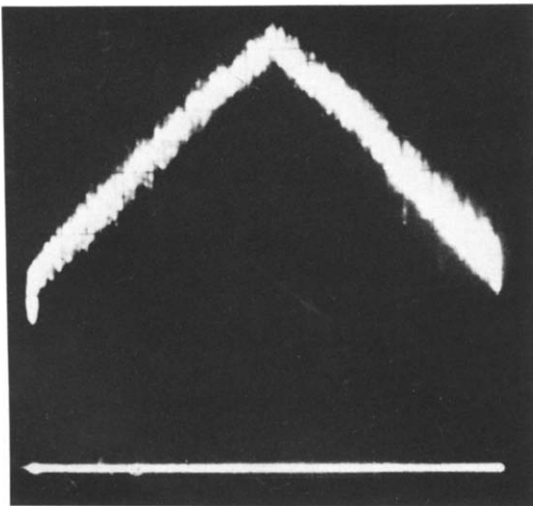


Fig. 2. Autocorrelation of stretched pulse at output of fiber. The pulse is rectangular in shape with a 300 ps pulsewidth.

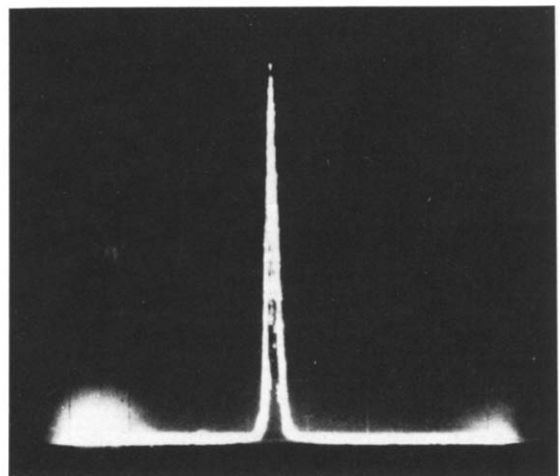


Fig. 3. Autocorrelation of 1.5 ps compressed pulse.

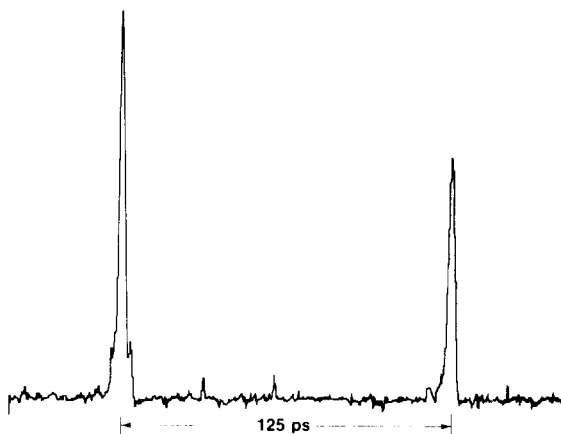


Fig. 4. Streak camera trace of amplified and compressed pulse with a reflection from an etalon. Separation between pulses is 125 ps. Pulsewidth is limited by the streak camera response at 2 ps.

long fiber lengths required to linearize the chirp can then be used and the pulses can be compressed without wings.

Regardless of pulse distortion due to spectral and gain saturation of the amplifier, the pulse was compressed after amplification, indicating that the pulse remains linearly chirped. The pulsewidth of the amplified compressed pulses was measured using a streak camera. Fig. 4 shows a streak camera trace of a pulse and a reflection from an etalon. The spacing between the two pulses is 125 ps. The FWHM of the pulse is 2 ps which is limited by the streak camera response.

In the future, we will be improving the mode-locking of the laser, such that the initial pulsewidth is less than 100 ps. A pulsewidth of 0.5 ps could then be achieved after compression. Also, we are planning to add successive amplifiers in order to have pulse energies of a few hundred millijoules. Conceivably, this technique could be used to generate subpicosecond pulses, with energies at the Joule level.

We will be studying the amplification of these chirped pulses to determine the effects of spectral and gain saturation, on the chirp linearity. In particular, we will be looking for the effects of gain sweeping.

It is important to note that this technique can be

used to amplify any short pulse, for instance that from a short pulse dye laser. The short pulse can be stretched by the GVD of a single-mode fiber. The pulse can then be amplified and recompressed to its original pulsewidth, in a completely analogous manner to the radar transmission.

In conclusion, we have shown that by first stretching a chirped optical pulse and then amplifying before compressing, high peak power pulses can be achieved. To date, we have produced 2 ps pulses with an energy of 1 mJ.

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