Generation of subpicosecond pulses from a continuous-wave mode-locked Nd:YAG laser using a two-stage optical compression technique

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By using a two-stage optical-fiber grating pair pulse-compression technique, 1.06-μm pulses as short as 0.7 psec have been obtained from an actively mode-locked cw Nd:YAG laser. This represents an overall pulse-compression ratio of 113.

The optical pulse compression of ultrashort laser pulses by exploiting the combined effects of self-phase modulation and group-velocity dispersion in single-mode optical fibers followed by a dispersive delay line comprising a grating pair has been demonstrated to be a convenient method for compressing femtosecond and picosecond laser pulses. Relatively long (30–100-psec) pulses from a cw mode-locked Nd:YAG laser have also been shortened or this scheme, and experimental results have been in relatively close agreement with theoretical predictions.

Recently we carried out an experimental study of the relevant parameters for an optical pulse compressor used with a cw mode-locked Nd:YAG laser in which the input power, fiber length, input pulse width, and grating separation were investigated. In that case, for an input pulse width of 100 psec, a 47X compression was achieved with 10X enhancement in the peak power. In this Letter we report on the measurement of an overall compression factor of 113X for Nd:YAG laser pulses propagated through a two-stage optical compressor. The 85-psec pulses from the cw mode-locked Nd:YAG laser were reduced to 0.75 psec (assuming Gaussian pulse shapes), which represents the first reported demonstration of a subpicosecond generation from this type of laser using an extracavity technique. A two-stage pulse compression was reported previously in conjunction with a picosecond dye-laser system, and an overall 65X compression was measured.

A schematic of our compression arrangement is shown in Fig. 1. An actively mode-locked cw Nd:YAG laser (modified Quantronix Model 116; performance characteristics described in Ref. 10) was used as the source of pulses of 85-psec duration. In the first stage of the compressor we used 125 m of fiber, which was monomode and nonpolarization-preserving with a 7-μm core diameter and 1-dB/km loss at 1.06 μm. The input pulse width was monitored by directing part of the laser output through the beam splitter BS, and calibration delay-line arrangement onto a Photochron II Synchroscan streak camera (Si photocathode). The remainder of the beam was focused into the fiber by using a 20X microscope objective and recollimated at the output with a 10X microscope objective. We previously reported a broadening of 1.5 times for an input pulse with a width of 85 psec and a peak power of 80 W propagating through 125 m of this type of fiber. At the optimum peak power (80 W) the spectral bandwidth of the pulse leaving the fiber was measured to be ~1 nm (Fig. 2), which is representative of the pulses at this first stage of the compression. The input pulse width as recorded by the streak camera and indicated in Fig. 2(a) represents a typical value of 85 psec. After traversing the 125 m of fiber the input pulses had broadened to 127 psec, as shown in Fig. 2(b). The input pulse is also shown in the streak-camera trace of Fig. 2(b) for comparison purposes. At the optimum peak power for pulse compression (the region where the output pulse showed the rectangular pulse shape) the associated spectrum [see Fig. 2(c)] had a width of 1.06 nm. For

Fig. 1.  Experimental arrangement.

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lengths of fiber (viz., 25 and 125 m) fail to generate an adequate bandwidth for subpicosecond-pulse generation. With a 400-m fiber and input average powers of 40 and 70 mW, spectral broadening to 2.0 and 2.5 nm, respectively, was obtained. After propagating through this fiber, the pulse was broadened from 2.8 to about 32 psec [see Fig. 3(a)], and the bandwidth increased from 1 to 2.5 nm [Fig. 3(b)] at the input peak power of 200 W.

Fig. 2. Pulse parameters at first-stage compressor. (a) Input pulse widths recorded by streak camera. (b) Output (left) and input (right) pulse shape with 125-m fiber. (c) Output spectrum from the 125-m fiber. (d) Autocorrelation of 2.8-psec 1.06-μm compressed pulse after first stage of compression.

Fig. 3. (a) Autocorrelation of 32-psec pulse at output of 400-m fiber in second stage. (b) Spectrum corresponding to pulse in (a).

Fig. 4. (a) Autocorrelation of optimized, compressed 0.75-psec pulse following two stages of compression. (b) Autocorrelation of pulse after two stages of compression with second grating pair separation increased by 3 cm beyond optimum.

these data the optical delay line consisted of a pair of 1800-line/mm holographic gratings with a 90% diffraction efficiency at 75° angle of incidence.

A double-pass scheme for the gratings was used, which resulted in extremely good beam quality and enabled the physical separation of the gratings to be minimized. An overall path length through the gratings pair of 1 m was used. Mirror M1 was used to retroreflect the beam through the gratings slightly below the level of the input beam and out of the system through mirror M2. A typical compressed pulse recorded after the first stage is shown in Fig. 2(d), where a non-background-free autocorrelation in a 5-mm-thick KDP crystal was used. Assuming Gaussian pulse shapes throughout, a deconvolved pulse width of 2.8 psec was inferred, and the output peak power was 1 kW. The compressed pulse was then passed through a second-stage compressor, which incorporated a 400-m length of similar monomode fiber and gratings. Shorter
A single-pass arrangement was used, and as a result the output beam shape was elliptical (with a ratio of 3:1). It was found that the grating separation was much more critical on the output pulse width in this stage than it had been in the first, and with the input parameters described above an experimental grating separation of 17 cm was found to be optimum.

The pulses were measured using a standard autocorrelation technique (non-background-free) with a 1-mm-thick KDP crystal (giving an estimated time resolution of 180 fsec), and Fig. 4(a) shows a fairly representative autocorrelation trace of the doubly compressed pulses. The deconvolved pulse width is 0.75 psec, which is quite close to the transform limit sustained by a 2.5-nm bandwidth at 1.06 ktm. An average output power of 30 mW was obtained, which corresponds to 400-W peak power. The two small peaks, one on either side of the main pulse, in the autocorrelation [Fig. 4(a)] are real and are predicted for the compression process.12

The main features of our measurements agreed quite well with the numerical calculations of Grischkowsky and Balant.12 However, in practice the grating separation in the second stage differed markedly from that suggested by theory,8 presumably because our experimental conditions are well beyond the boundary conditions set by the theoretical considerations. Small deviations from the optimum grating separation in the second stage resulted in a pulse profile having accentuated shoulders or dominant substructure, and an example of this can be seen in Fig. 4(b). Variations of 1 cm from the 17-cm separation used seemed to be the tolerance limit in obtaining pulses similar to those shown in Fig. 4(a). This is consistent with the recent results of Halbout and Grischkowsky, which have shown that in the compression of femtosecond pulses a variation in the grating separations of 1 mm can be critical to the degree of compression obtained.13

In conclusion, we have demonstrated the generation of subpicosecond pulses by compressing the 85-psec output pulses from a cw mode-locked Nd:YAG laser by a factor of 113 times in a two-stage fiber grating pair delay line. Peak powers of 400 W and transform-limited pulse widths of 0.75 psec were obtained. By using a longer length of fiber or a higher peak power in the second-stage compressor, a broader bandwidth should be generated, which would then support even shorter pulses. Alternatively, the application of this technique to a Q-switched mode-locked Nd:YAG laser would provide a subpicosecond source with peak powers in the megawatt region. We have already demonstrated that 3-psec, 1.5-MW pulses can be produced at a 500-Hz Q-switch rate by using a single-stage compressor.14 It is our intention to use these compressed pulses in the study of transient nonlinear effects in optical fibers in the subpicosecond regime.

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