100-Fold compression of picosecond pulses from a parametric light source in single-mode optical fibers at wavelengths 1.5–1.65 μm

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Compression to a pulse length $\tau = 275$ fs has been achieved by pumping a single-mode optical fiber, 250 m long, with the light from a parametric source with a pulse length $\tau = 30$ ps and a wavelength tunable over the interval $\lambda = 1.5$–1.65 μm.

Several methods using optical fibers have recently been proposed for forming ultrashort pulses with lengths in the picosecond and subpicosecond ranges: 1) the compression of an ultrashort pulse by diffraction gratings after a spectral broadening of the pulse by phase self-modulation in an optical fiber[1,2]; 2) the formation of picosecond pulses through the use of stimulated Raman scattering[3]; 3) the self-compression of an ultrashort pulse in an optical fiber by virtue of the joint effects of phase self-modulation and a negative group-velocity dispersion (for fused-quartz fibers, the condition $dv_{\rm gr}/d\lambda < 0$ corresponds to wavelengths $\lambda > 1.3$ μm; Ref. 4). Mollenauer *et al.*[5] have achieved a 27-fold compression of a pulse ($\tau = 7$ ps, $P_p \approx 200$ W) from a color-center laser ($\lambda = 1.55$ μm) in a fiber with a length $L = 100$ m.

The light source in the experiments we are reporting here is a synchronously generating parametric light source[6] which uses a $Ba_2NaNb_5O_{15}$ crystal and the second harmonic ($\lambda = 0.53$ μm) of a cw-pumped Nd:YAG laser in Q-switched operation with active mode locking. The parametric source emits a train of ultrashort pulses with a repetition frequency of 100 Hz, and a pulse length $\tau = 30$ ps with a repetition frequency of 250 MHz. It can be tuned continuously over the wavelength interval 0.76–1.77 μm by varying the temperature of the $Ba_2NaNb_5O_{15}$ crystal. The pulse length is determined from the autocorrelation function, which is in turn found by the method of noncollinear second-harmonic generation. Measurements with a monochromator (Fig. 1) revealed the spectral width of the parametric light source to be $\Delta\nu = 1.34$ cm^{-1}. Here we have a product $\tau \cdot \Delta\nu = 1.21$.

For the experiments we use a $SiO_2 + GeO_2/SiO_2$ optical fiber with a length $L = 250$ m, a loss of 2.5–1.7 dB/km in the interval $\lambda = 1.5$–1.65 μm, a difference $\Delta n = 4 \times 10^{-3}$ between the refractive indices of the core and the cladding, and a core diameter ~ 10 μm.

The light from the parametric source is coupled into the fiber by a lens with $f = 1$ cm. The energy characteristics are determined from the measured average power of the light beam. The spectra and autocorrelation functions of the light are measured with a strobe integrator, with an averaging over many pulses (Fig. 1).

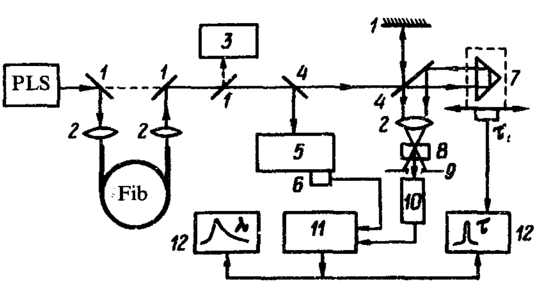

FIG. 1. The experimental arrangement. PLS—Parametric light source; 1—total-reflection mirrors; 2—lenses; 3—power meter; 4—beam splitters; 5—MDR-23 monochromator; 6—Ge photodiode; 7—prism with displacement pickup; 8—$LiIO_3$ crystal; 9—iris; 10—photomultiplier; 11—strobe integrator; 12—chart recorder.

When a pulse with $\lambda = 1.59$ μm and $P_p = 0.6$ kW (with a power density $I = P_p/A_{\rm eff} = 0.6\times10^9$ W/cm^2, where $A_{\rm eff}$ is the effective area of the mode) is coupled into the fiber, the light spectrum at the fiber exit broadens to $\Delta\nu = 55$ cm^{-1} (Fig. 2; stimulated Raman scattering does not occur). We wish to call attention to the asymmetry of the broadened spectrum. The autocorrelation function measured in this case is shown in Fig. 3b. The width of this function, 426 fs, corresponds to $\tau \approx 275$ fs for a pulse with a sech^2 envelope ($\tau\cdot\Delta\nu = 0.45$). By tuning the pump frequency over the interval 1.5–1.65 μm, we were able to tune the frequency of the compressed pulse; τ remained less than 500 fs.

A remarkable feature of the pulse compressed in the fiber is an amplitude stability very high in comparison with that of the pump pulse (Fig. 3). As can be seen from the autocorrelation function (Fig. 3b), the compressed pulse has a low-intensity pedestal, although this pedestal stretches out to $\tau_t = \pm 50$ ps. According to estimates based on the autocorrelation function, the energy in the compressed pulse is ~ 0.1 of the total energy; correspondingly, we have $P_p \approx 5$ kW and an energy 1.5 nJ. One possibility for suppressing the pedestal is to make use of the Kerr effect in a fiber,[5] specifically, the

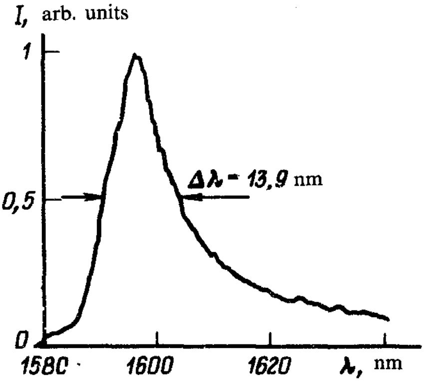

FIG. 2. Light spectrum at the exit from an optical fiber with a length $L = 250$ m at $P_p = 0.6$ kW.

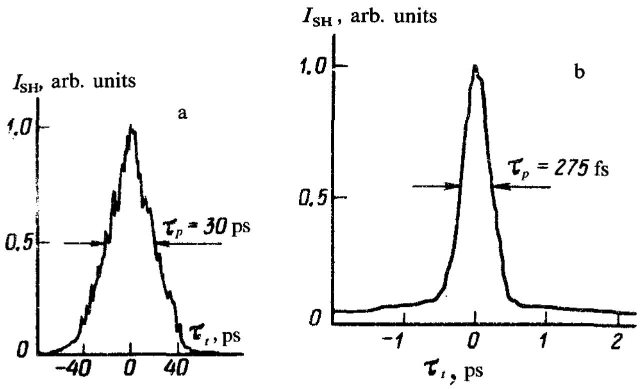

FIG. 3. Autocorrelation functions of the pulses at (a) the entrance to the fiber and (b) the exit from the fiber. The autocorrelation functions were measured at an identical integration time constant of the strobe integrator in these two cases.

fact that the polarization state of the light for an intense peak is generally different from the polarization state of the pedestal.

The requirements on the amplitude stability of the pulse to be compressed are considerably less severe in this pulse-compression method than in the method using diffraction gratings. The theoretical curves[5] of the degree of pulse self-compression $(dv_{gr}/d\lambda < 0)$ and of the distance over which the self-compression is maximized as functions of the order of the soliton (N) can be approximated at large N by $\sim 1/N$. In our case, according to the formulas in Ref. 7, a power $P_p = 0.6$ kW corresponds to a soliton order $N \sim 100$, and the period of the soliton is $z_0 \sim 20$ km. It may thus be suggested that at $N \gg 1$ the fluctuations in the parameters of the input pulse and thus the fluctuations in N should not cause any substantial fluctuations in the properties of the compressed pulse.

We note in conclusion that this method could apparently be used to achieve a degree of compression even greater than a factor of 110, by carefully determining the fiber length which corresponds to the degree of maximum self-compression at the given value of N. Even at this stage of the research, the ultrashort pulses produced in these experiments have a power high enough for use, for example, in nonlinear spectroscopy and for nonlinear frequency conversion (second and third harmonics, stimulated Raman scattering, etc.), so that the problem of suppressing the wide pedestal can be resolved.

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