Noise discrimination in the propagation of a quasisoliton pulse in a single-mode optical fiber

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An experimental study has been made of the dynamics of pulse propagation in a quasisoliton regime. The noise component of the pulses weakens during the propagation.

One method for generating ultrashort light pulses, with lengths in the femtosecond range, is to make use of cascaded stimulated Raman scattering in a single-mode optical fiber while simultaneously making use of the effects of a modulational instability in the region of negative chromatic dispersion.[1] Several experimental studies have been carried out[2,3] to implement this method. We do not, however, have an exhaustive, detailed theory for the process since it has not yet been resolved whether the pulses which are formed are indeed solitons or instead are stationary because energy is pumped out of the shorter-wavelength region by stimulated Raman scattering. In Ref. 4, all of the light leaving the optical fiber in which the short pulse was formed was coupled into a second fiber of the same type. Since a pump was also coupled into the second fiber, and the entrance loss prevented observation of a steady-state propagation, that experiment did not answer the question.

On the other hand, there have been few experiments on the dynamics of soliton-plus-noise perturbations. Gouveia-Neto *et al.*[4] described a propagation regime of ultrashort pulses with noise in the presence of a pump. A contraction of the pulses and a reduction of the pedestal on the autocorrelation function were explained in terms of a stimulated-Raman amplification in the pump field. It was shown in Ref. 5, however, that a soliton in a fiber can scatter noise even in the absence of a pump.

Our purpose in the present study was to learn about the dynamics of the propagation of a quasisoliton with noise in the absence of a pump, i.e., in a conservative system.

The experimental apparatus which we used was similar to that described in Ref. 2. The second fiber was a single-mode fiber with a core area of about 50 μm^2 and a zero chromatic dispersion at the wavelength $\lambda_0 \approx 1.6\ \mu\text{m}$.

The spectrum of the light in the second fiber (Fig. 1) remained constant as the length of this fiber was varied. Autocorrelation functions were measured by a background-free method; from these functions we calculated the pulse length under the assumption that the pulses have a sech^2 shape. The pulse length at the exit from the first fiber at the wavelength $\lambda = 1.68\ \mu\text{m}$, for example, was $\tau = 78$ fs at a contrast $K \approx 3.5$.

Figure 2 shows the behavior of the pulse length and the contrast of the autocorrelation function with distance. After passing through two lenses and a prism, the pulse

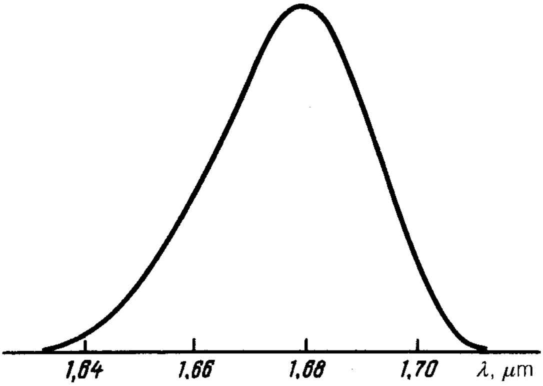

FIG. 1. Spectrum of the light in the second fiber.

becomes deformed and broadens to about $\tau \approx 200$ fs at the beginning of the second fiber. (Note that there was no broadening as the light was coupled into the second fiber in the experiments of Ref. 4—apparently because there was no prism.) Later on, as can be seen from these results, the pulse contracts by about 30%, and the contrast increases from $K \approx 3$ to about 6.

Let us look at some numerical estimates. The calculated power of the initial 220-fs pulse is about $P_1 \approx 216$ W. In the region $\lambda = 1.68$ μm the chromatic dispersion is $D = 4.3$ ps/(nm·km), the dispersion length is about $L_d \approx 2.43$ m, and the power of a soliton pulse 220 fs long is $P_0 \approx 148$ W ($N = \sqrt{P_1/P_0} = 1.21$). A numerical calculation of the change in the pulse length was carried out on the basis of a nonlinear Schrödinger equation (the solid line in Fig. 2); its results agree quantitatively well with the

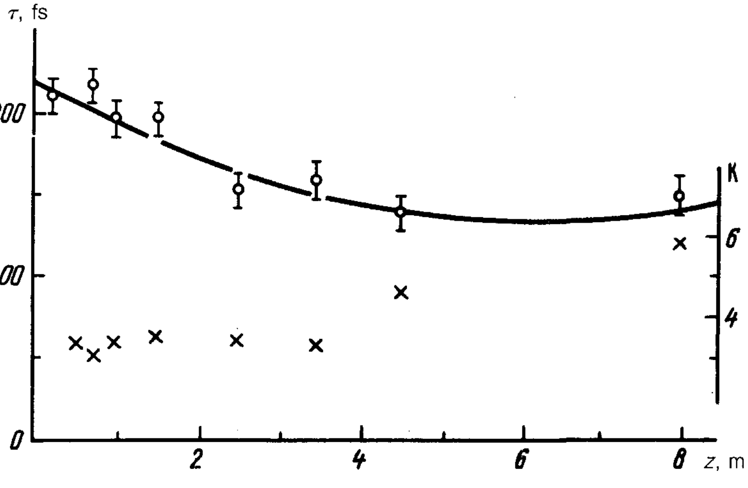

FIG. 2. Circles—Experimental pulse lengths; solid line—calculated pulse lengths; crosses—contrast of the autocorrelation function for various lengths of the second fiber.

experimental data. According to the calculations, the minimum pulse length is 61% of the original length ever a distance of about $z \approx 2.5L_d$; thereafter, it increases slightly.

The evolution of the light pulse length in the second fiber is thus described well by the nonlinear Schrödinger equation, and we can assume that this pulse has soliton properties. In contrast with Ref. 4, where Gouveia-Neto *et al.* explained the contraction of the pulse and the decrease in the pedestal on the basis of an amplification caused by the pump, the system in the present experiments is conservative, and a slight compression of the pulse may result from soliton effects alone.

The decrease in the pedestal, on the other hand, is apparently a consequence of a "purification" of noise from the quasisoliton pulse[5] through a dispersive "scattering" of the noise components, which have a spectral composition different from that of the soliton components.

In summary, these results are evidence in favor of the interpretation that soliton pulses form during the combined effects of stimulated Raman scattering and a modulational instability and that these soliton pulses may shed their noisy component through dispersive effects. Unfortunately, we were not able to observe the subsequent evolution of the pulse because of the limited length of the second fiber.

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