Impact of Raman Scattering on Temporal Reflection from a Short Soliton

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An optical pulse can be reflected at a temporal boundary across which the refractive index changes with time.[1] The reflected pulse is frequency shifted by an amount set by the law of momentum conservation. While a temporal boundary where the refractive index changes everywhere at the same time is hard to create in practice, reflection can also happen at a moving boundary. Such a boundary can be created through the optical Kerr effect by injecting an intense pump pulse into a dispersive nonlinear medium. This configuration has been studied in optical fibers when a weak pulse collides with an optical soliton.[2–4]

When a femtosecond soliton is formed inside an optical fiber, intrapulse Raman scattering between its different spectral components leads to a continuous red shift that decelerates the soliton as it propagates. This work considers the situation where a weak pulse reflects from such a decelerating soliton. It is shown that the reflected pulse can be much shorter than the input pulse, involving a new type of temporal focusing. The effect is explained using space–time duality and derive an approximate transformation law for Gaussian-shape input pulses.

Using the generalized nonlinear Schrödinger equation, the temporal reflection of a probe pulse from a soliton (called the pump pulse) is numerically simulated. Results are shown in Fig. 1 for a realistic set of parameters for silica fibers. In the time domain,

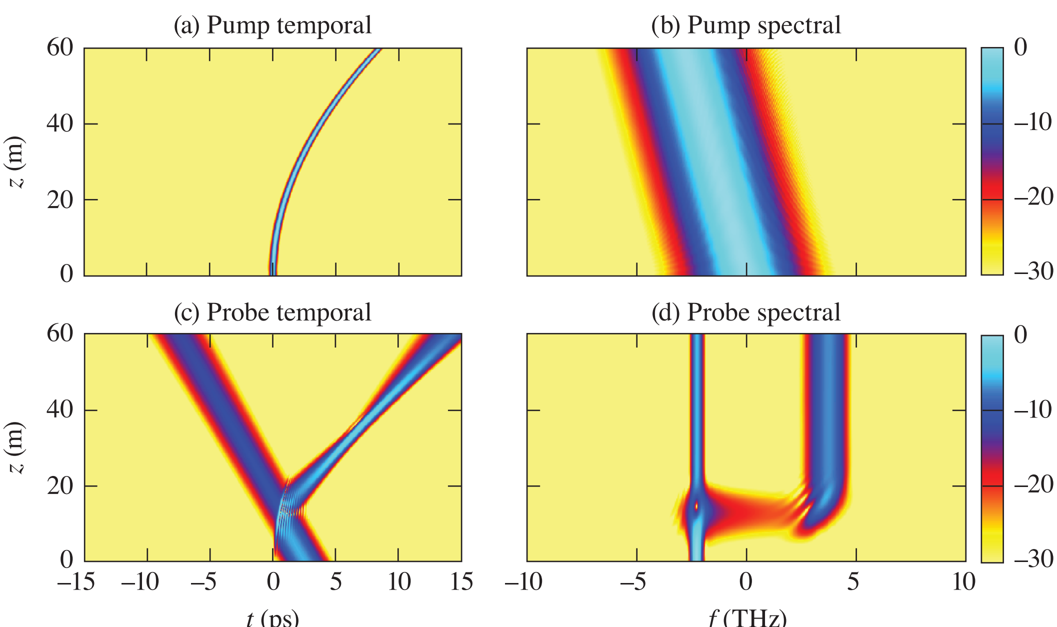

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Figure 1
Simulation of temporal reflection of a probe pulse on a pump soliton. The pump soliton continuously red shifts because of Raman scattering.

the trajectory of the soliton has a parabolic shape because of its Raman-induced deceleration. When the probe pulse hits the pump pulse, it splits into a reflected pulse and a transmitted pulse.

The reflected pulse undergoes a frequency shift and its spectrum becomes broader than the incident spectrum. The reflected pulse also becomes narrower before it broadens again. This is an example of temporal focusing induced by the decelerating soliton. This effect can be explained using the concept of space–time duality.[5] The decelerating soliton forms a temporal boundary with a parabolic trajectory. A probe pulse reflected from this boundary is analogous to an optical beam being reflected by a parabolic-shaped mirror. It has been found that temporal focusing is more significant for longer incident pulses.

An approximate analytic theory has been developed that describes how the spectrum of an incident Gaussian pulse is modified when the pulse is reflected by a decelerating soliton. Figure 2 compares the analytical prediction with the numerical results. Both the reflected pulse spectrum and the rms pulse width of the reflected pulse agree well with the numerical simulations. The analytical approximation can be used to understand the temporal focusing effect.

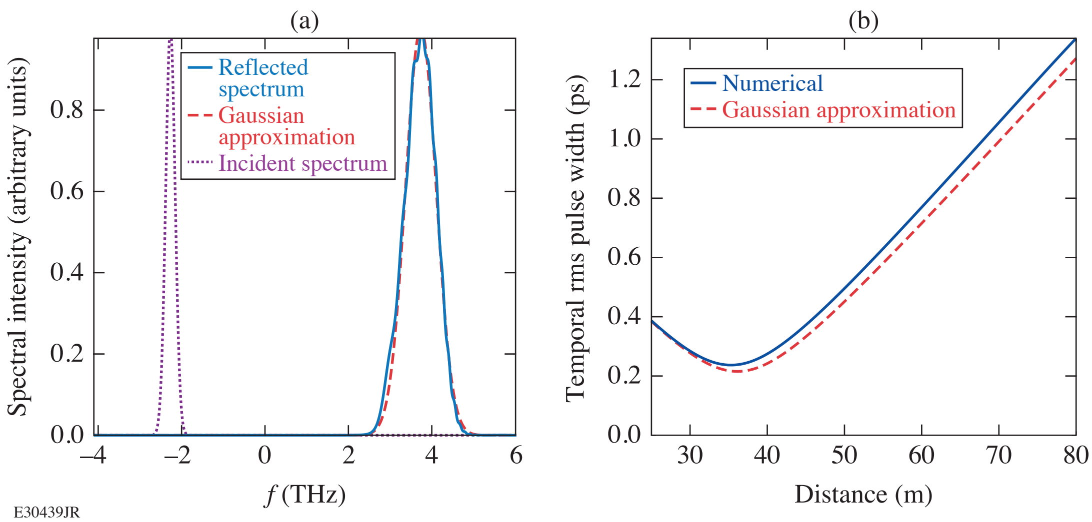

Figure 2
Comparison of analytical formula with numerical result. (a) Reflected pulse spectrum; (b) rms pulse width of a reflected pulse as it propagates.

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