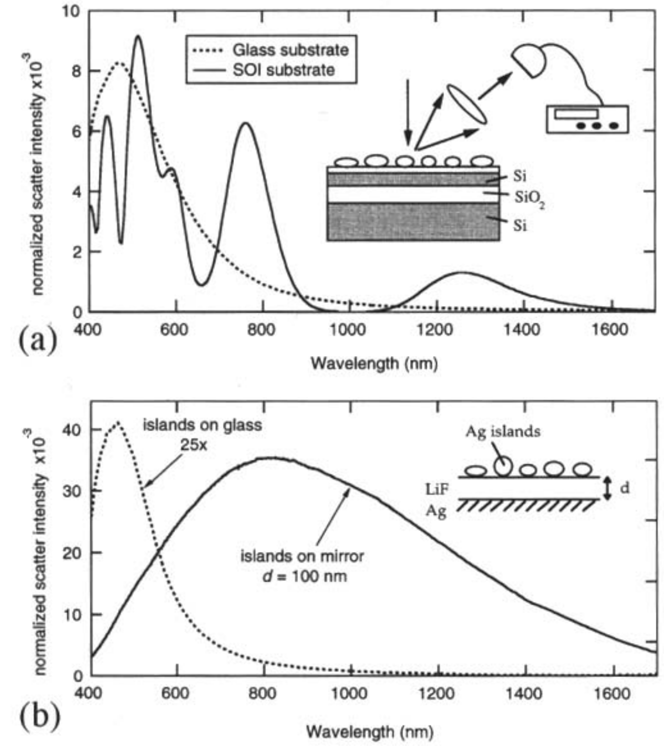

Stuart Figure 1. (a) The measured intensity of scattered light (normalized to the incident intensity) for a Ag-island film formed on LiF-coated glass (dotted line) and SOI (solid line). LiF thickness is 30 nm. The experimental geometry is shown in the inset. (b) Identical measurement for a Ag-island film formed on a LiF-coated silver mirror. The islands-on-glass curve is expanded by 25x. The single broad peak in the islands-on-mirror curve is due to the single-mode supported by the silver surface (the surface plasmon).

This novel energy-transfer process represents a new dimension to the dipole-surface problem with several potential applications (enhanced photodetection being one example). Plasma resonances supported by metal nanoparticles are known to produce important optical effects (such as SERS), due to strongly-enhanced local electromagnetic fields. The peaks seen in the figure are likely associated with enhanced local fields occurring at the new resonances of the composite particle-waveguide system. These structures may be capable of enhancing multifrequency nonlinear effects (such as second-harmonic generation) to a degree exceeding previous observations by several orders of magnitude.

Acknowledgments

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PROPAGATION

Unraveling the Mysteries of Intense Femtosecond Pulse Propagation

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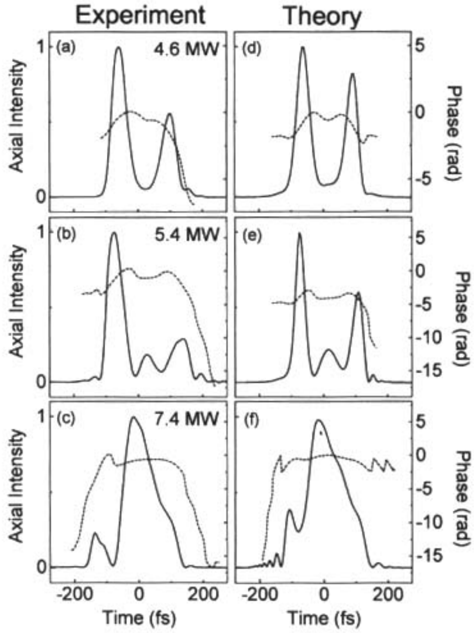
Propagation of electromagnetic pulses is of fundamental importance in pure and applied science, and the recent development of sources of intense femtosecond laser pulses has added many interesting twists to this long-standing problem. The broad spectral bandwidths, high peak powers, and 4-D nature of femtosecond fields give rise to complicated linear and nonlinear dynamics that have posed significant challenges to researchers. A few years ago, it was observed that in contrast to a continuous beam of light, a femtosecond pulse having the same peak power does not collapse to a singularity under the influence of self-focusing in a nonlinear medium.[1, 2] Instead, the original pulse splits temporally into two pulses of lower power.[2] However, the details of this splitting process remained unclear, and furthermore, it was unknown whether the newly split pulses would in turn undergo a secondary splitting.

In the past year, we have applied the new technique of frequency-resolved optical gating (FROG) to this problem.[3, 4] The FROG measurement gives detailed data on both the amplitude and the phase of the pulse, as opposed to the indirect techniques of auto- and cross-correlations. As such, FROG presents a unique opportunity of directly "seeing" the shape of a pulse on a femtosecond time scale and enables more quantitative comparison of theory and experiment. Based on our new experimental results, we offer a detailed scenario of the spatio-temporal evolution of femtosecond pulses in nonlinear media with normal group velocity dispersion. We find that the sequence of events at progressively higher powers can be characterized by a single splitting, then multiple splittings, and finally a coalescence of the pulses. This is shown in Figure 1, where both FROG measurements (left column) and numerical simulations (right column) are presented for three different peak powers. The measurements of the



Diddams Figure 1. (a–c) Measured intensity (black solid line) and phase (dashed line) of an intense femtosecond pulse after passing through 3 cm of fused silica. The input peak powers for fields of plots (a–c) are 4.6, 5.4, and 7.4 MW. Plots (d–f) show the corresponding numerical calculations.

on-axis portion of the beam were made with the FROG technique after an 85-fs near-Gaussian pulse (with varying peak power) had traversed 3 cm of fused silica. The corresponding numerical simulations involve the solution of a modified 4-D nonlinear Schrödinger equation that accounts for linear and nonlinear shock effects, a Raman nonlinearity, and higher-order dispersion.[5]

As seen in Figure 1a, at the lowest power the input pulse has split into two sub-pulses, with the leading pulse being larger. The asymmetry of the splitting is primarily the result of the linear and nonlinear shock terms, and the predominant negative curvature of the phase (dashed line) indicates that the spectrum of the leading pulse is red-shifted with respect to the trailing pulse. At higher powers (Figs. 1b and 1c), we see further splitting to three pulses and then a coalescence of the multiple peaks toward a broader single pulse. All measurements are in good agreement with the theoretical predictions shown in Figures 1d–f. A more complete understanding of femtosecond propagation dynamics, as demonstrated by this work, should prove valuable to emerging applications that use femtosecond pulses in areas as diverse as optical communications, biological imaging, plasma physics, nonlinear frequency conversion, and remote sensing.

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Long Distance Propagation in Air Due to Dynamic Spatial Replenishment

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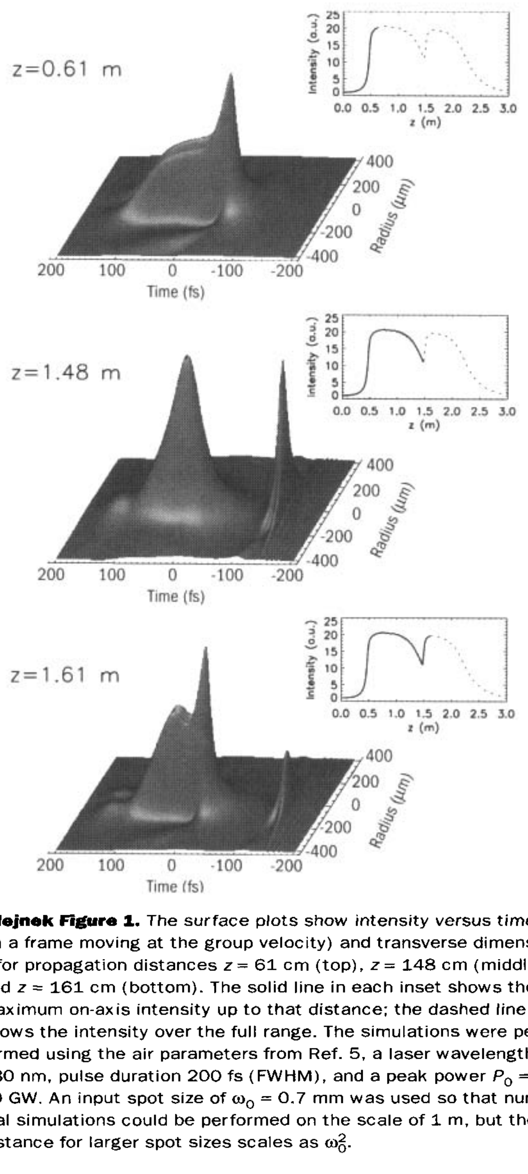
Recently, there has been considerable excitement regarding experimental demonstrations of propagation of femtosecond pulses over 10^2–10^4 m in air[1–4] due to its potential applications, *e.g.*, lightning channeling[2] and LIDAR.[3] To determine the utility of this phenomenon for these and other applications the underlying physics needs clarifying. The critical power for self-focusing in air is $P_{cr} = 1.7$ GW. Catastrophic collapse is avoided by a combination of multi-photon ionization (MPI), and absorption and defocusing by the electron-plasma generated by MPI. Our question is: How do these mechanisms conspire to produce long distance propagation?

To address this issue we have performed numerical simulations using a comprehensive air propagation model.[5] Typical results for a 780-nm pulse of duration 200 fs (FWHM) and peak power $P_0 = 10$ GW are shown in Figure 1. The surface plots show intensity versus time (in a frame moving at the group velocity) and transverse dimension x for various propagation distances z. The insets show the maximum on-axis intensity. The top plot for $z = 61$ cm is close to the paraxial collapse distance, but MPI and plasma defocusing arrest the collapse yielding a stabilized pulse. This creates the impression that long distance propagation is due to the stabilization of collapse by MPI and plasma defocusing.[1] However, upon further propagation this pulse decays due to absorption, but the fascinating result is that a new pulse grows from the trailing edge pulse: This phenomenon is shown in the middle plot for $z = 148$ cm where the leading edge pulse is decaying as the trailing edge pulse is growing. The formation of the trailing pulse is due to the re-self-focusing of the power that was displaced into spatial rings by the plasma-defocusing imposed on the trailing edge of the incident pulse by the collapsing front edge. In the bottom plot for $z = 161$ cm the trailing edge pulse has now replaced the leading one.



Mlejnek Figure 1. The surface plots show intensity versus time (in a frame moving at the group velocity) and transverse dimension x for propagation distances $z = 61$ cm (top), $z = 148$ cm (middle), and $z = 161$ cm (bottom). The solid line in each inset shows the maximum on-axis intensity up to that distance; the dashed line shows the intensity over the full range. The simulations were performed using the air parameters from Ref. 5, a laser wavelength of 780 nm, pulse duration 200 fs (FWHM), and a peak power $P_0 =$ 10 GW. An input spot size of $\omega_0 = 0.7$ mm was used so that numerical simulations could be performed on the scale of 1 m, but the distance for larger spot sizes scales as ω_0^2.

This process that we term dynamic spatial replenishment, in which the initial pulse forms, is absorbed, and is