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Long-wavelength continuum generation about the second dispersion zero of a tapered fiber

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Abstract: We demonstrate continuum generation at wavelengths longer than the zero-dispersion wavelength of ordinary fiber for the first time using a narrow-diameter tapered fiber.

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Much attention has been paid to the spectral broadening of femtosecond pulses that occurs in microstructured and tapered fibers [1]-[3]. To date, experiments in this area have been performed at pump wavelengths around 800 nm; however, applications such as optical Doppler tomography (ODT) [4] and optical frequency metrology [5] motivate the development of broadband light sources at longer wavelengths. A requirement for the generation of broadband

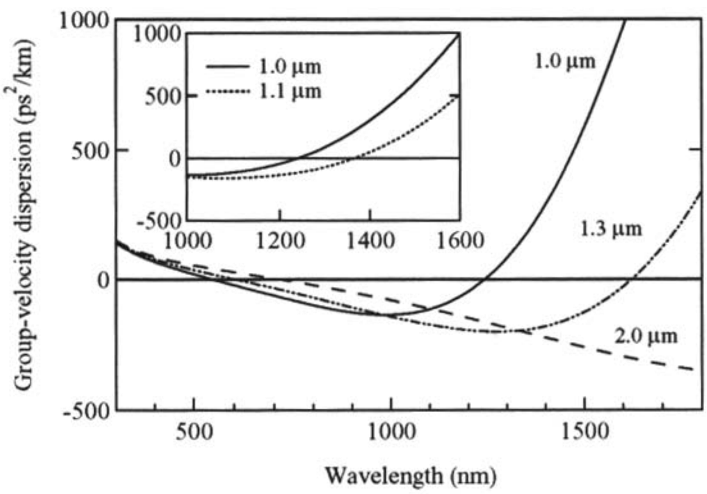

Fig. 1. Calculated group-velocity dispersion for (top to bottom) 1.0, 1.3, and 2.0 μm-diameter waist tapered fibers. The inset shows the GVD of the 1.0 and 1.1 μm waist tapers in proximity to their second ZDWs.

continua is small group-velocity dispersion (GVD) at the propagating wavelengths. In addition to reducing dispersive spreading of the input pulse, propagation near the zero-dispersion wavelength (ZDW) allows phase-matching and group-velocity matching of four-wave mixing (FWM) processes. It is known that higher-order dispersion produces a second ZDW at longer wavelengths in both microstructured and tapered fibers. In this work we show that this second ZDW can be exploited to generate continua centered on ~ 1300 nm.

Calculations indicate that tapered fibers with waist diameters between 1.0 and 1.1 μm should have the second ZDW at 1240 nm and 1370 nm, respectively (Figure 1). Therefore, a tapered fiber was prepared with a targeted diameter within this range [2]. The resulting structure consists of a 20-mm-long taper waist with a diameter of ~ 1 μm, connected to untapered fiber on each side by 35-mm-long transition regions. We numerically model the propagation of intense femtosecond pulses through the tapered fiber with an extended nonlinear Schrödinger equation including Kerr nonlinearity, self-frequency shift through Raman scattering, and up to fifth-order dispersion [6]. Propagation of 80-fs pulses centered near 1260 nm with varying energy content is considered in the simulations (Figure 2, top).

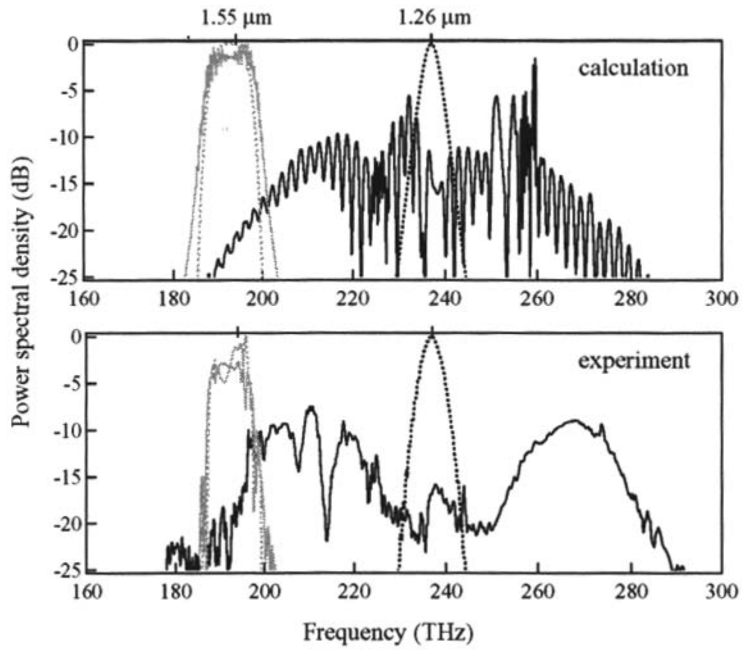

Fig. 2. Comparison of numerical simulations (top) and experimental results (bottom) for: 750-pJ, 80-fs pulses at 1.26 µm (black) and 350-pJ, 100-fs pulses at 1.55 µm (gray). The input spectra are shown as dotted lines.

A mode-locked Cr:forsterite laser provided 1.5-nJ, transform-limited, 80-fs pulses centered at 1.26 µm [7]. Approximately 50% of the available energy was coupled into the taper's input fiber, which was kept as short as possible to minimize the initial pulse broadening. The evolution of the continuum observed in the experiment with launched pulse energy varying between 7 pJ and 750 pJ is presented in Figure 3. As the pulse energy is increased, the spectrum splits and most of the energy is shifted to higher and lower frequencies, which leaves the center of the spectrum largely depleted (Figure 3, 375 pJ – 750 pJ). The observed features agree qualitatively and semi-quantitatively with the numerical simulations, and are consistent with nonlinear pulse propagation at the second ZDW. The experimental spectrum corresponding to 750 pJ pulse energy is plotted in Figure 2 (bottom) for comparison with the numerical results (Figure 2, top). The spectrum spans 700 nm at the points 20-dB from the peak of the continuum. As a control experiment, 100-fs pulses at 1550 nm from an Er-doped fiber laser were coupled into the same tapered fiber. We observed no significant spectral broadening of the pulses at the highest coupled pulse energy of about 350 pJ, in accordance with the numerical simulations (Figure 2).

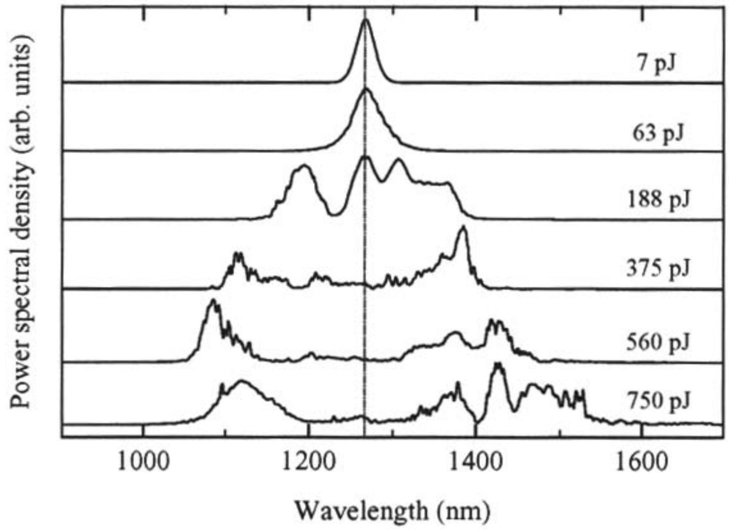

Fig. 3. Experimentally observed evolution of the continuum with pulse energy. The dotted line indicates the center of the input spectrum.

In conclusion, we have demonstrated that a tapered fiber is an effective medium for generating broadband light in the near-infrared by the use of its second ZDW. Unamplified femtosecond pulses from a Cr:forsterite laser were spectrally-broadened to cover 700 nm from 1000 to 1700 nm. By changing the diameter of the tapered fiber's waist, this method for continuum generation about the second ZDW should be easily adapted to other wavelengths. We expect continua generated this way to find application in high-resolution biological imaging systems as well as in frequency metrology for telecommunications.

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