Spectral evolution of femtosecond pulses in nonlinear waveguides: measuring continuum generation and group velocity with NSOM

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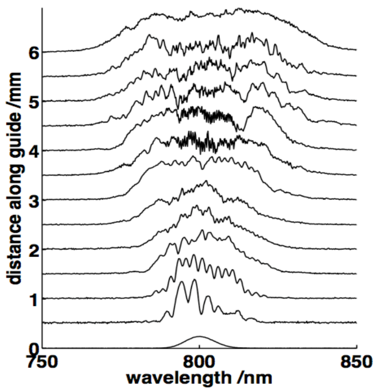
We describe spectral measurements using NSOM of the nonlinear propagation of femtosecond pulses in waveguides. Nonlinearity produces self phase modulation, which broadens the spectrum of the propagating light as it travels along the guide. This process is the basis for supercontinuum sources that span octaves in frequency, which are important for metrology[1] and carrier-envelope phase measurement[2]. Our experiments uniquely measure the spectral evolution of this continuum as the light propagates along the waveguide by sampling the evanescent field with an uncoated NSOM tip, allowing measurement of the spectrum as it develops over long (mm) length scales, and also allowing the study of the sub-micron evolution of the spectra both along and across the guide. The evolution in one example is shown in figure 1(a). We will compare the measured continuum generation with our nonlinear propagation modeling, and discuss how the observed spectra differ from predictions of simple models.



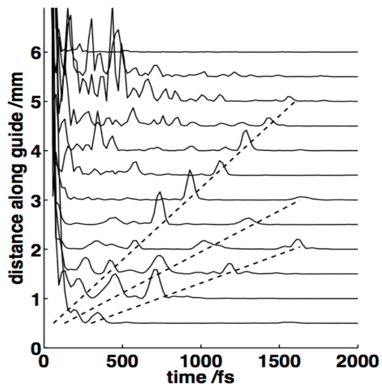


Fig. 1: (a) Evolution of continuum spectrum along 6mm length of guide. (b) Fourier transform of spectral intensity, illustrating different propagation constants.

The broad spectrum of the femtosecond pulse also allows measurement of multimode propagation constants in these guides. Spectral interference between pulses that separate in time as they propagate causes spectral modulation – this can be seen as oscillations in the lower traces of fig 1(a). A Fourier transform of this modulation gives the time separation of the pulses directly, shown in fig 1(b), where several modes propagating with different group velocities show increasing time separations down the guide, allowing direct measurement of the group velocity differences between modes. Modeling of the waveguides will be presented for comparison with the data.

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[1] R. Holzwarth, T. Udem, T. W. Hansch et al., Physical Review Letters **85,** 2264 (2000).
[2] D. J. Jones, S. A. Diddams, J. K. Ranka et al., Science **288,** 635 (2000).