PUSHING THE LIMITS of Femtosecond Technology: Chirped Dielectric Mirrors

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Snapshot: The authors explain the theory behind ultrashort pulses and offer a new method — chirped dielectric mirrors — for achieving sub-10 fsec pulses.

One of the major trends in laser physics today is the research and development of femtosecond laser sources. The motivation for generating short electromagnetic waveforms comes from many areas of science and technology. Ultrashort optical pulses are capable of taking "snapshots" of the state of matter and hence following the evolution of ultrafast processes at the microscopic level. Probing charge-carrier dynamics in semiconductors, the formation and breaking of chemical bonds, or time-resolved studies of photoisomerisation in biology are just a few examples of a number of intriguing applications. The generation of pulses shorter than previously possible would benefit many application fields and calls for a precise dispersion control over increasingly broad bandwidths in femtosecond laser oscillators as well as in subsequent optical systems. With the advent of chirped multilayer dielectric mirrors, feedback and phase dispersion control over unprecedented bandwidths have become feasible, thus opening the way for further advances in femtosecond technology.

Optical pulse propagation in dispersive media

Short electromagnetic waveforms (henceforth pulses) can be thought of as a superposition of long, quasi-monochromatic wavepackets of different carrier frequencies. For a particular spectral intensity distribution, minimum pulse duration is achieved when the centers of the wavepackets coincide in space. Under these conditions the pulse is referred to as Fourier-limited or transform-limited because the shortest pulse attainable with the spectral intensity distribution given has been realized.

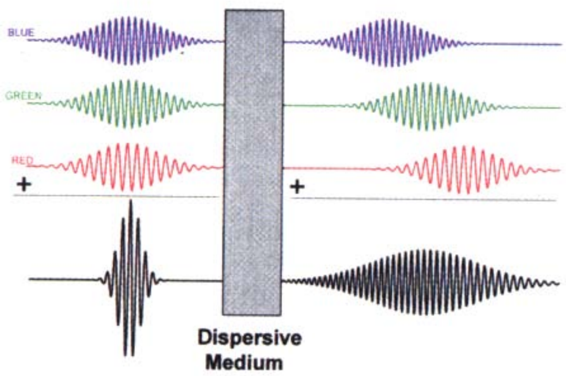

Figure 1. Optical pulse propagation through a dispersive medium: a frequency-dependent group delay leads to a pulse broadening and to a carrier frequency sweep.

If such a transform-limited pulse is sent through a dispersive medium, in which wavepackets of different carrier frequency propagate at different velocities, the pulse envelope will be broadened and carried by a time-varying instantaneous frequency at the output, as illustrated in Figure 1. Dispersion can be quantified by expanding the phase retardation $\phi(\omega)$ of a dispersive system about the center of the pulse spectrum ω_0 in the form

$$\phi(\omega) = \phi_0 + \phi'(\omega-\omega_0) + \tfrac{1}{2}\phi''(\omega-\omega_0)^2 + \tfrac{1}{6}\phi'''(\omega-\omega_0)^3 + \ldots \quad (1)$$

where $\phi_0 = \phi(\omega_0)$, and the derivatives ϕ', ϕ'', etc. are also evaluated at ω_0. The first derivative ϕ' is called group delay because it gives the time taken by the center of the pulse to reach the output of the wave-propagating medium. The higher-order terms in the expansion describe a frequency dependence of the group delay,