Generation of 11-fs pulses from a Ti:sapphire laser without the use of prisms

Andreas Stingl, Christian Spielmann, and Ferenc Krausz

Abteilung Quantenelektronik und Lasertechnik, Technische Universität Wien, Gusshausstrasse 27-29, A-1040 Wien, Austria

Robert Szipöcs

Optical Coating Laboratory, Research Institute for Solid State Physics, P.O. Box 49, H-1525 Budapest, Hungary

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The generation of highly stable optical pulses as short as 11 fs from a Kerr-lens mode-locked Ti:sapphire laser containing no intracavity prisms is demonstrated. In the femtosecond oscillator design reported, novel dielectric mirrors provide broadband dispersion control for solitonlike pulse formation.

The past few years have brought significant advances in ultrashort-pulse laser physics. The recent appearance of novel ultrabroadband solid-state laser materials motivated the development of new ultrafast optical modulation techniques that are capable of shaping optical pulses down to a few femtoseconds in duration. The discovery of self-mode locking[1] and the exploitation of a solitonlike interplay between self-phase modulation and negative group-delay dispersion[2] (GDD) have been the major steps toward a powerful new femtosecond laser technology based on broadband solid-state gain materials.

Besides the gain medium and an optical intracavity aperture, standard femtosecond self-mode-locked oscillators contain a pair of Brewster-angled prisms for producing a net negative GDD in the resonator. Prism pairs[3] have been widely used for intracavity dispersion control in dye systems and adopted for the new generation of solid-state short-pulse lasers. While it has been imperative that a prism pair be used for femtosecond mode locking of solid-state lasers, the prism pair also appeared to set a limit to pulse shortening in sub-100-fs systems. Only the use of selected prism materials permitted the generation of sub-20-fs pulses in Ti:sapphire lasers.[4,5] Nevertheless, cubic dispersion still represents the major limitation, even in systems optimized for minimum prism-induced phase error. As a consequence, the spectra of the sub-20-fs pulses from prism-pair-controlled oscillators are inherently asymmetric and tend to exhibit a pronounced broad shoulder when the narrowest autocorrelation traces are measured. An additional problem in this time domain is the increased sensitivity of pulse width to cavity and prism alignment. Cavity mirror alignment changes the position of the resonator axis and thus the glass path through the prisms. Hence any small cavity realignment calls for a subsequent readjustment of the prism insertion(s) and orientations to restore the original pulse width.

In this Letter we report on a novel technology for cavity GDD control that is free from these drawbacks. We demonstrate what is to our knowledge the first GDD control over a bandwidth as broad as 80 THz in a femtosecond laser by using chirped dielectric mirrors as the source of broadband negative GDD. Our results suggest that engineering the phase-dispersion characteristics of cavity mirrors opens the way toward a new generation of mirror-dispersion-controlled (MDC) oscillators, which are more compact, reliable, and user friendly than any previous femtosecond laser and can produce pulses down to the 10-fs regime.

The idea of employing specifically designed dielectric mirrors for intracavity chirp compensation is not new. Gires–Tournois interferometers and double-stack mirrors were designed and tested in femtosecond laser cavities previously.[6,7] These devices provided a simple and powerful means of controlling the net intracavity dispersion; however, they proved unsuccessful in supporting pulses shorter than 50 fs. This is due to the rapid variation of GDD with wavelength (high-order dispersion), which relates to the physical origin of dispersions in these dielectric mirrors: the incident field energy is temporarily captured in Fabry–Perot-like resonant structures, and the frequency dependence of the group delay (and of the GDD) results from that of the energy storage time.[8]

Recently we reported a new physical concept that can be exploited for broadband and essentially high-order dispersion-free GDD control with multilayer dielectric mirrors.[9] Briefly, by modulating the multilayer period during the deposition a chirped quasi-quarter-wave dielectric coating is fabricated. The variation of the layer optical thickness gives rise to a field penetration depth that is dependent on the (carrier) frequency and thus on the group delay suffered by different frequency components on reflection on the mirror. By careful design a near-linear variation of the group delay with frequency can be realized over the entire high-reflectivity wavelength range. The bandwidth of chirped mirrors can potentially be even broader than that of standard single-stack quarter-wave mirrors.

Using this concept, we have produced a chirped

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