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Pulse compression of nanojoule pulses in the visible using microstructure optical fiber and dispersion compensation

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ABSTRACT Experimental results on the pulse compression of 1-nJ, 150-fs pulses from a tunable, 76-MHz Ti:sapphire laser oscillator operating at around 750 nm are reported. The length of the pulses can be compressed to nearly one tenth by applying a high-delta, single-mode microstructured optical fiber exhibiting zero group-delay dispersion at 767 nm, and by a prism-pair/chirped-mirror compressor. The experimental results are verified by theoretical investigations modeling the pulse propagation taking into account non-linear self-phase modulation and fiber dispersion.

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1 Introduction

Recent years have brought revolutionary progress in the generation and application of femtosecond laser pulses. One of the main directions of development is generating shorter and shorter laser pulses for laser spectroscopic investigations in the sub-10-fs time domain. With the invention of Ti:sapphire laser active media [1], Kerr-lens mode-locking [2] and chirped-mirror technology [3], it has become an everyday routine to generate sub-10-fs pulses: nowadays, such oscillators are available from several vendors, but their average output power and tunability are poor compared to commercial "100-fs" laser oscillators. From the practical point of view, it might be an important question whether it is possible to upgrade an existing 80–150-fs laser oscillator to a 10–30-fs one, since the price of such a short-pulse laser oscillator is still not negligible. There is an interest in pulse shortening possibilities in other technical fields as well [4]: laser oscillators used for optical communications exhibiting ultrahigh (~ 10 GHz) repetition rate cannot surpass the picosecond limit, although the broad spectrum is required for wavelength-multiplexing data transmission. Recently, pulse compression in the solitary-pulse-compression regime down to 54 fs was reported in dispersion-flattened optical fibers in the near-IR regime [4].

The first generation of commercial 100-fs Ti:sapphire pulse laser oscillators incorporates relatively long laser active media (the path length is typically between 20 and 25 mm) with low doping concentrations, which are required for the broad tunability of these lasers: the lower the doping concentration (and the absorption at the pump wavelength) the higher the figure of merit (FOM) of the crystal. The dispersion of these relatively long crystals is typically compensated by a prism pair compressor (e.g. by an SF10 prism pair) exhibiting strong higher-order dispersion, limiting the minimum pulse duration of the laser at around 60 fs. By replacing the highly dispersive prism pair with lower dispersion prisms and increasing the prism separation, the pulse duration can be reduced to approximately 30 fs, although this modification changes the laser geometry considerably, requiring basic modifications to the laser mechanics. Another problem is the bandwidth of the one-element (1T) birefringent filter (BRF) used for the tuning of these lasers, which limits the laser bandwidth to 5–8 nm. Accordingly, the BRF must be replaced by a new BRF element supporting higher bandwidths.

In time-resolved spectroscopic studies, it would be desirable to work with femtosecond-pulse laser oscillators exhibiting broad tunability and a highly variable pulse duration (and spectral width) that do not require the changing of the cavity optics and mechanics. One possible, but rather expensive, solution is applying a kHz repetition rate, non-collinearly-phase-matched optical parametric amplifier pumped by the second-harmonic beam of a Ti:sapphire amplifier system [5]. In the case of more cost-effective fs-pulse laser oscillators, the first step to developing such a versatile system was the development of ultrabroadband chirped mirrors [6] for broadly tunable femtosecond-pulse Ti:sapphire laser oscillators, which exhibit high reflectivity and smooth group-delay versus wavelength functions over the bandwidth of 680 to 1060 nm [6]. (These mirrors are often referred to as "XBand optics" or "XWave optics".) The pulse duration of Ti:sapphire oscillators incorporating XBand/XWave optics can still be varied in the 80 to 150-fs regime by adjusting intracavity dispersion. Further pulse shortening could be achieved by extracavity pulse compression [7], although the pulse energy (usually 1–10 nJ) and the corresponding light intensity of present day 100-fs laser oscillators are too low for efficient self-phase modulation in single mode, step-index fused silica optical fibers. The main problem is the rapid temporal broadening of the pulse due to chromatic dispersion, which reduces the peak power and thus the self-phase mod-

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