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Cubic Phase Control of Ultrashort Laser Pulses

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The temporal shape of an ultrashort laser pulse may change upon propagating through a linear dispersive medium having a phase shift $\varphi(\omega)$. The change can be characterized by the Taylor- coefficients of the phase shift which are calculated around the central frequency ω_0 of the pulse. Measurements and independent control of the group delay dispersion (*GDD*, $\varphi''(\omega_0)$) and the third order dispersion (*TOD*, $\varphi'''(\omega_0)$) are important in several research fields, particularly in the generation of ultrashort laser pulses by chirped pulse amplification (CPA) [1] and pulse shaping for molecular control [2].

The *GDD* and the *TOD* of an ideal pulse compressor are equal to the negative of the corresponding dispersion coefficients of the medium. However, in the case of prism-pair and grating-pair compressors, which are most often used in laser systems, the ratio of the *GDD* and the *TOD* of the compressor is different from the ratio of the coefficients of the medium to be compensated for. Therefore it is necessary to develop so-called cubic compressors that are able to control the *TOD* of the pulse, yet, do not affect the *GDD*.

In this paper a new cubic compressor setup is investigated theoretically and experimentally, which resembles the set-up proposed by White [3], however, we control the *GDD* and the *TOD* by the position of a birefringent, semi-cylinder crystal placed around the focal point of an achromatic lens. For the evaluation of the phase shift introduced by the proposed cubic compressor, a ray tracing program was written. The program allows optimizing the compressor parameters, such as the radius of the crystal, magnification of the lens etc. Calcite was applied because it is a strong birefringent material. Calculations showed that there is a trajectory, along which shifting the crystal the *TOD* can be tuned independently of the *GDD*. The value of the TOD changed in a relatively wide range between $-3.15 \cdot 10^5$ fs^3 and $-1.67 \cdot 10^5$ fs^3. Although the defocus also affects the angular dispersion of the pulse leaving the compressor, it does not exceed the 40 μrad/nm value.

For experimental verification, the cubic compressor was placed in one arm of a Michelson-type interferometer illuminated by a Ti:sapphire oscillator providing 20 fs (FWHM) pulses at a central wavelength of 800 nm. The compressor consisted of a calcite crystal with a radius of 15 mm and an achromatic lens with a magnification of 4 in accordance with the simulation results. The dispersion coefficients of the compressor were determined from the spectrally resolved interferograms (SRI) [4]. During the experiments, special attention was paid to minimizing the angular dispersion of the pulse leaving the compressor. The measured GDD and TOD were $3.8 \cdot 10^3$ fs^2 and $-2.6 \cdot 10^5$ fs^3, while the calculated values were $3.2 \cdot 10^3$ fs^2 and $-1.9 \cdot 10^5$ fs^3, respectively. Taking into consideration the paraxial approximation based simulation, the 25% average error of the dispersion values is acceptable. The simulation results can be used as rough estimation, and SRI can be applied for real-time fine tuning.

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