Phase-amplitude retrieval

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process is repeated up to five times to correct from the slightly nonlinear response of the DM. Once the right correction is applied one can turn off the closed loop or let it run to correct for slow drift of the system.

The remaining uncorrected spectral phase is due to the actuator size on the mirror, it is periodical and clearly visible on the corrected measurement shown on Fig. 2.

With more actuators on the mirror one can perform pulse shaping in a CPA laser system, like sharp edge pulses useful for high field science experiments.

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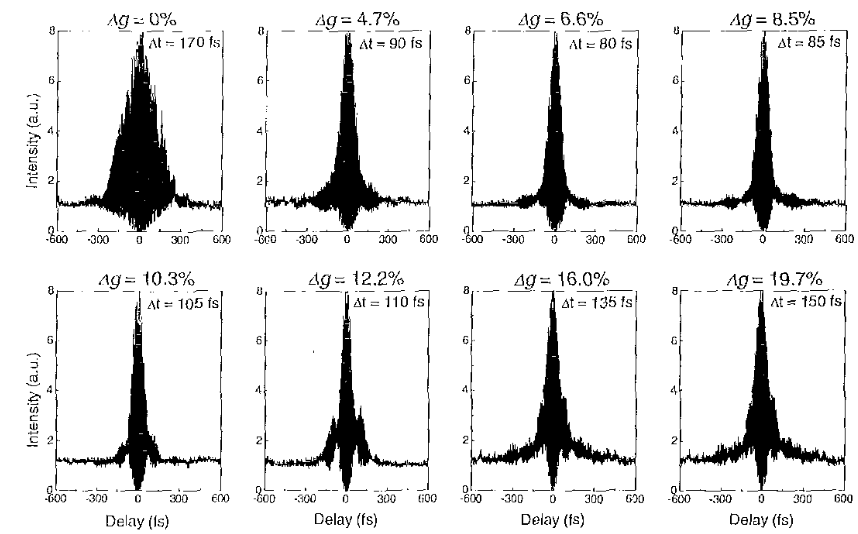

CThM38 Fig. 2. Interferometric autocorrelations obtained for different positive crystal chirps.

CThM38

Frequency doubling and compression of chirped femtosecond pulses using aperiodically poled lithium niobate

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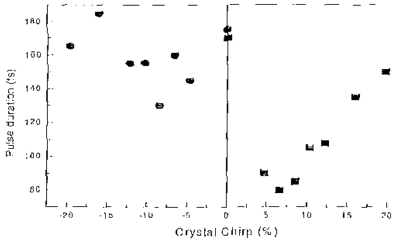
The technique of periodic poling has made possible the design of nonlinear crystals with novel phase-matching characteristics based on quasi-phase-matching (QPM). This technique has permitted frequency doubling of a wide range of wavelengths at high conversion efficiencies within the picosecond and femtosecond regimes. When chirped pump pulses are used it is possible to reduce the pulse duration of the second-harmonic pulses using discrete compression schemes such as those based on prisms-pairs or diffractive elements. Self-compression of the second-harmonic pulses is made possible by designing crystals with gratings, which are not periodic along the propagation direction. In particular, by fabricating frequency-doubling crystals with a linearly varying grating period one can define the position in the crystal at which any given frequency is converted to its second harmonic.[1] When a broad-bandwidth chirped pulse is used as the input to such a crystal, the variation of its frequency with time can be arranged so that the converted frequency components all leave the crystal simultaneously, in the form of a transform-limited pulse. This technique was first demonstrated in aperiodically poled lithium niobate (AP-LN) to recompress artificially stretched pulses from an erbium-doped fiber laser,[1] and a theoretical study of the compression process for quadratic phase chirped pulses has been proposed.[2] More recently chirped femtosecond pulses from a synchronously pumped optical parametric oscillator (OPO), were frequency doubled and compressed using a aperiodically poled crystal of $KTiOPO_4$ (AP-KTP) and nearly-transfrom-limited pulses were obtained.[3] In this work we present the results of frequency doubling and compressing pulses directly obtained from an OPO using crystal of AP-LN with eight different linearly chirped grating periods. In each chirped grating, the initial (or input) period (Λ_i) and final (or output) period (Λ_f) are different while the average (or central) grating period $[\Lambda_{av} = (\Lambda_i + \Lambda_f)/2]$ is left constant. To effectively compress the chirped pulses delivered by the PPLN-based OPO, the crystal was oriented for positive crystal chirp $\Lambda_i > \Lambda_f$ (longest period facing the input pulses). Figure 1 shows the effect of the crystal grating chirp (Δg) on the pulse duration of the frequency doubled pulses.



CThM38 Fig. 1. Effect of the crystal chirp, $\Delta g = (\Lambda_i - \Lambda_f)/\Lambda_{av}$, on pulse duration.

For input pulses of constant positive chirp ($\Delta\nu\Delta t = 1.95$) with durations of 250 fs (FWHM) and centered at a wavelength of 1.24 μm, we determined that a crystal with a chirp of $\Delta g = 0.066$ provided optimum compression of the frequency doubled pulses. The shortest frequency doubled pulses were nearly-transform-limited with durations of 80 fs and duration bandwidth products of $\Delta\nu\Delta t = 0.43$. Figure 2 shows the interferometric autocorrelations of the frequency doubled pulses for different experimental values of Δg.

With the crystal oriented with shorter periods at the input face, compression of the fundamental pulses did not occur and the interferometric autocorrelations showed more phase structure as Δg increased. We have compared our experimental results with the predictions of a complete numerical model, which uses the amplitude and phase profile of the input pulses determined by frequency resolved optical gating. Results of the model will be presented, which show close agreement with the experimental data. The widespread and availability of PPLN combined with its large nonlinearity allows the extension of this technique to other picosecond and femtosecond of laser sources for practical generatrion of chirp-free visible pulses using extracavity or intracavity configuration.

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CThM39

Phase-amplitude retrieval: SHG FROG vs. SPIDER

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Frequency resolved optical gating (FROG)[1] and spectral phase interferometry for direct electric-field reconstruction (SPIDER)[2] are nowadays leading techniques that provide access to phase-amplitude pulse retrieval. Each of these techniques has a number of outstanding features that establish the method applicability under certain experimental conditions. For instance, FROG is perfectly suited for pulse characterization precisely at the position of the sample in most spectroscopic applications because it utilizes similar excite-probe geometry. On the other hand, SPIDER has the advantage of real-time pulse measurement at high repetition rates. While in an ideal case both methods allow the precise amplitude-phase reconstruction of an ultrashort pulse, in practice specific experimental conditions such as phase-matching, detector noise etc. affect the reconstruction quality. For instance, experimental comparison of the techniques in the case characterization of a single pulse has shown some discrepancies in the retrieved parameters.[3]

In this contribution we present a comparative study of SPIDER and second-harmonic generation (SHG) FROG techniques. Two main sources of errors are analyzed: the limited phase-matching bandwidth of the nonlinear medium and the detector noise. We show that under similar experimental conditions SPIDER performs somewhat better than SHG FROG.

For the assessment of the phase-amplitude reconstruction quality we use a recently introduced Wigner trace error[4]

$$\varepsilon = \sqrt{\sum_{i,j}^{N} \left[W^0_{i,j}(t_i, \omega_j) - \alpha W_{i,j}(t_i, \omega_j)\right]^2} \Bigg/ \sqrt{\sum_{i,j}^{N} \left[W^0_{i,j}(t_i, \omega_j)\right]^2} \qquad (1)$$

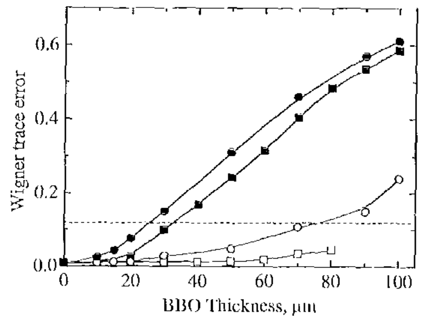
that is based on the comparison of Wigner representations of ideal and reconstructed pulses

$$W(t,\omega) = \int E^*\left(\omega + \frac{\omega'}{2}\right) E\left(\omega - \frac{\omega'}{2}\right) \times \exp(-i\omega' t)\, d\omega'. \qquad (2)$$

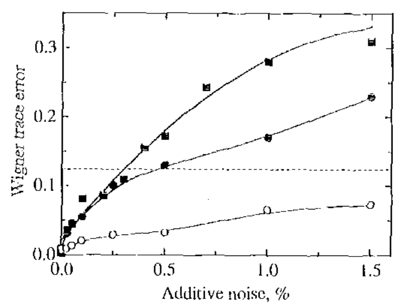
As the test case, we used a pulse with a Gaussian spectrum centered around 800 nm and corresponding to a 10-fs spectral limited pulse, and with the third-order spectral phase that lengthens the pulse to ~20 fs.

The influence of the crystal thickness on the pulse reconstruction quality is illustrated in Fig. 1. The finite crystal thickness leads to the effect of spectral filtration due to limited phase-matching bandwidth. Based on the obtained results we conclude that SHG FROG and SPIDER have a similar sensitivity to the thickness of the crystal. The pulse reconstruction quality can be substantially improved if the spectral correction[5] is applied to the experimental data (open symbols in Fig. 1). Note that such a correction is more efficient for SPIDER because in this technique the pulse spectrum is measured independently and therefore is not affected by nonlinear conversion.

The impact of the detector noise to the phase-amplitude reconstruction quality is illustrated in Fig. 2. We have considered two different regimes of measurements: single-shot and multishot. In the single-shot mode we introduce the equal amplitudes of the additive noise in both SHG FROG trace and SPIDER interferogram. For low noise levels, both methods were found to have quite similar sensitivity to the noise (solid symbols), but for



CThM39 Fig. 1. The reconstruction quality of SPIDER (squares) and SHG FROG (circles) as a function of the thickness of the nonlinear crystal (BBO crystal cut for type I phase-matching). Solid and open symbols correspond to the calculation without and with spectral correction, respectively. Dashed line depicts the level of the acceptable error.



CThM39 Fig. 2. The dependence of the reconstruction quality of SPIDER (circles) and FROG (squares) on the fraction of the additive noise. The results obtained for the single-shot regime are depicted by solid symbols. Open symbols correspond to the multishot regime. Dashed line depicts the level of acceptable errors.

higher levels of the noise FROG technique yields worse results, which is caused by the features of the inversion algorithm. In the multishot regime we have taken into account the fact that during the measurement of a single $n \times n$ FROG trace one can collect n SPIDER interferograms obtaining in this manner lower by a factor of $\sqrt{n}$ noise level. Under these conditions, SPIDER obviously has an advantage and shows much better results than FROG (Fig. 2, open circles).

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CThM40

Variable angle terahertz impulse ranging on cylinders

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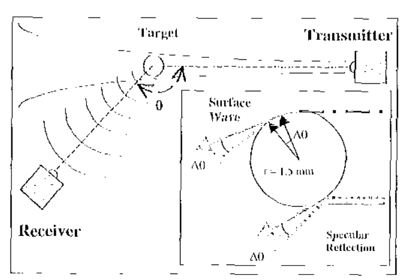
Optoelectronically generated freely propagating terahertz (THz) impulse ranging experiments have been demonstrated.[1–3] The subpicosecond resolution permits temporal isolation of scattering mechanisms.[3]

Limitations of previously demonstrated systems are the fixed bistatic angle between the transmitter and receiver and wide aperture associated with the collection optics of the receiver reducing resolution. The configuration reported here overcomes these limitations by introducing a freely positionable receiver allowing a wide range of detection angles (21° to 180°) and by using a small aperture receiver allowing the use of plane wave approximations. Both capabilities are important for investigating complex near-resonant targets.

This impulse ranging system, shown schematically in Fig. 1, is a modification of the THz beam system used for THz time-domain spectroscopy.[4] The angle Θ between the transmitter and the receiver can be continuously adjusted.

Previous measurements separated out scattering mechanisms of which one is the surface or creeping wave. For near grazing incidence some of the incident radiation appears to couple to the surface and travel around the outside of the target (see inset of Fig. 1). For small Θ, the observed surface wave can take a path through the dielectric at the critical angle



CThM40 Fig. 1. Conceptual layout of variable angle THz impulse ranging configuration. Θ is continuously variable from 21° to 180°. The inset shows specular reflection and surface wave. ΔΘ is the change in angle which corresponds to the change in path along the surface of the cylinder, ΔΘr.