High Efficiency Ultrashort Pulse Measurement with Aperiodically Poled Lithium Niobate (A-PPLN) Waveguides

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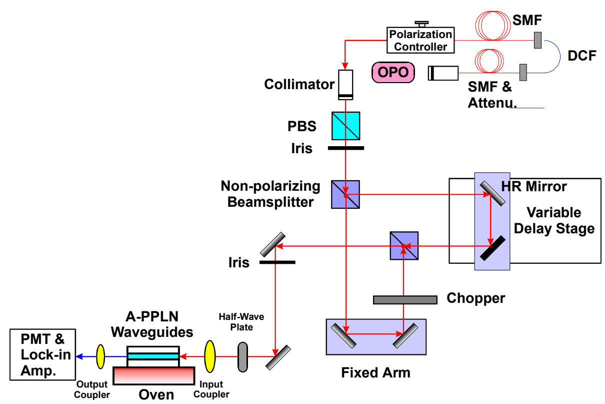
Typical autocorrelation techniques using second harmonic generation (SHG) in bulk crystals permit measurements of ultrashort pulses with energies down to a few picojoules (pJ). The sensitivity of these bulk crystal-based techniques is limited in part by the Gaussian beam diffraction, which prevents the coexistence of a small beam cross section area (A) and a long effective SHG interaction length (L), while the SHG efficiency is proportional to L^2/A. When very short pulses are involved, L is further limited in order to avoid measurement distortion linked to the group velocity mismatch (GVM) effect [1]. In lithium niobate, for example, the crystal length must not exceed 1 mm when measuring 300 femtosecond (fs) pulses. In this paper we report autocorrelation measurements using quasi-phase-matched (QPM) lithium niobate waveguides, which permit much higher SHG efficiency by confining the optical beam within a small area for a long distance [2]. By longitudinally chirping the poling period of the waveguides (aperiodically poled lithium niobate, or A-PPLN) [3], we overcome the GVM problem by broadening the SHG bandwidth to be compatible with that of input pulses. This leads to a substantial increase in sensitivity, which may be particularly useful for measurements of ultrafast lightwave communication signals.

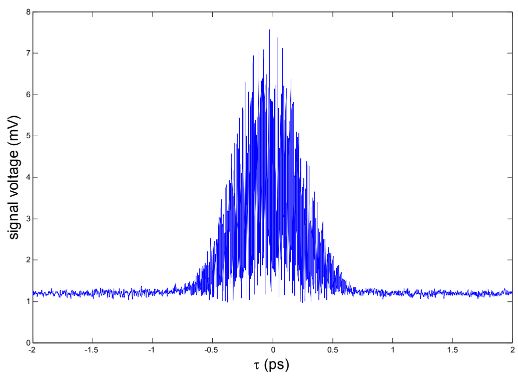
Our experimental setup is shown in Fig.1. An optical parametric oscillator (OPO) pumped by a mode-locked Ti:Sapphire laser generates pulses with ~200 fs duration, ~80 MHz repetition rate, 1538 nm central wavelength, and ~18 nm spectral width. The pulses are relayed to the measurement setup via a ~5.25 m fiber link that is partially dispersion compensated and passed through a variable attenuator. A 6.6cm-long lithium niobate chip with both unchirped (PPLN) and linearly chirped (A-PPLN) waveguides is used for SHG in a collinear-type autocorrelator. The output second harmonic signal is detected by a photomultiplier tube (PMT) along with a lock-in amplifier.



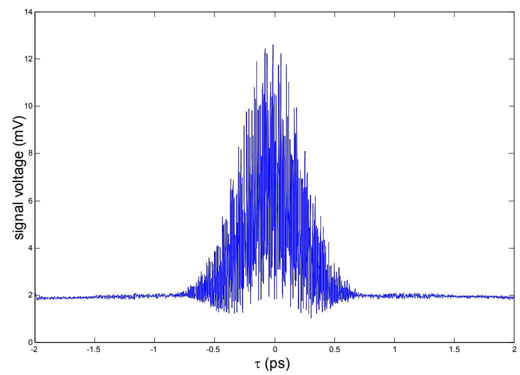
(Fig.1) Experimental setup

The unchirped PPLN waveguide has a room temperature phase matching spectrum centered at 1538.6 nm and a bandwidth of 0.22 nm, which is much less than that of the input pulses to be measured. In contrast, characterization of the chirped A-PPLN waveguide by a tunable CW laser shows phase matching for input wavelengths from 1529 nm to 1548 nm, which should be sufficient for an accurate measurement. The key point is that measurement accuracy requires sufficient SHG bandwidth [4]. With chirped A-PPLN, this criterion can be achieved even when the GVM exceeds the pulse duration.

Fig. 2 shows an interferometric autocorrelation by using a chirped A-PPLN waveguide. The coupled power values are 20 nW and 26 nW for the fixed and variable arm, respectively. Considering the 20% coupling efficiency as well as inevitable chopper loss and splitting loss in an autocorrelator, the input power amounts to 0.66 μW (8.3 fJ per pulse), while the background signal-to-noise ratio (SNR, defined by the ratio of the mean and standard deviation of the background signal in the trace) is 26.8. Note we simply chop input pulses from the fixed arm; the fringes around trace center won't drop to zero as in typical interferometric results. By applying an ideal low-pass filter to remove the interferometric terms, we get a typical intensity autocorrelation trace with a 3:1 peak-to-background ratio. The intensity full width at half maximum (FWHM) is estimated as 457 fs, if we assume Gaussian pulses. This broadening compared to the duration from the OPO is due to chirp in the fiber link. Fig. 3 shows the result using an unchirped PPLN waveguide. The coupled power values are 40 nW and 55 nW (input power is 1.35 μW, or 16.9 fJ per pulse); the background SNR increases to 38.3, and the estimated intensity FWHM is 386 fs, somewhat lower than the previous value. The discrepancy can be attributed to the significant difference of the SHG bandwidths of the two waveguides. As the input pulse is chirped, the narrow SHG bandwidth of the unchirped PPLN waveguide may greatly distort the shape and width of the autocorrelation trace [1].



(Fig. 2) Interferometric autocorrelation by a chirped A-PPLN waveguide.



(Fig. 3) Interferometric autocorrelation by an unchirped PPLN waveguide.

The SHG efficiency can be evaluated in terms of the coupled fundamental power values and the background second harmonic power in the interferometric trace. The SHG efficiencies are 72.1 %/pJ and 83.0 %/pJ for the A-PPLN and PPLN waveguides, respectively. Chirping the poling period to broaden the SHG bandwidth has little effect on the SHG efficiency until the SHG bandwidth begins to significantly exceed the fundamental pulse spectrum.

We conclude that A-PPLN waveguide-based autocorrelation lowers the required input power very substantially in comparison with the bulk counterpart, and alleviates the GVM restriction without sacrificing much SHG efficiency. This promising technique can be extended to more sophisticated measurements such as frequency resolved optical gating (FROG).

References

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