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Frequency Resolved Optical Gating in the 1.55 μm-band via Cascaded $\chi^{(2)}$ Interactions

Jerry Prawiharjo, Katia Gallo, Neil G.R. Broderick, David J. Richardson
Optoelectronics Research Centre, University of Southampton, UK
jep@orc.soton.ac.uk

Abstract

We investigate cascaded $\chi^{(2)}$ ultrashort pulse interactions and propose their use for frequency-resolved optical gating at telecom wavelengths in a waveguide configuration. Better efficiency and time-resolution compared to single-step $\chi^{(2)}$ interactions can be achieved.

Introduction

Complete (intensity and phase) optical pulse characterisation techniques have become an essential aspect in telecommunications systems, especially as pulse durations become shorter. Telecom applications typically require time-resolutions and sensitivities particularly adapted to the ultrashort pulses with milliwatt peak powers. Frequency- resolved optical gating (FROG) [1] is well- established as an accurate and reliable technique for complete pulse characterisation. Long $\chi^{(2)}$-based devices (SFG or DFG XFROG [2]) in guided-wave configurations promise better overall sensitivity, but their time-resolutions are normally limited by the temporal walk-off.

We propose to use cascaded second-harmonic generation and difference frequency generation (SHG:DFG) interactions in a quasi-phase-matching (QPM) $LiNbO_3$ channel waveguide [3] for FROG applications. We show through theoretical and numerical analyses that this configuration offers higher efficiency with time-resolutions well beyond the limit normally imposed by the walk-off effect.

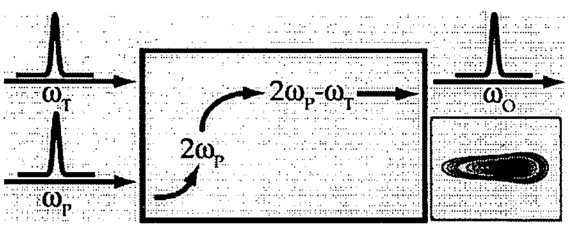

Fig. 1 An illustration of the quadratic cascading device for FROG technique

The proposed device (Fig. 1) has two inputs: a test (ω_T) and a pump (ω_P) pulse. The pump pulse is upconverted to its second-harmonic (SH, $\omega_{SH} = 2\omega_P$) which then mixes via DFG with the test pulse genrating a new output pulse at $\omega_{SH} = 2\omega_P - \omega_T$. The test, pump and output pulses are all in the 1.55 μm-band. By introducing a variable time-delay between the input pulses and recording the spectrum of the output pulse, a spectrogram can be obtained. The spectrogram can then be fed into a blind-deconvolution algorithm to retrieve the intensity and phase of the test pulse.

Ultrashort pulse cascaded SHG:DFG

We developed a theoretical analysis of the cascaded SHG:DFG interaction in the frequency domain following the formalism of Ref. [4]. We assumed undepleted pump and unamplified signal in this analysis. In addition, we performed extensive numerical simulations (based on the full set of coupled mode equations) for a more quantitative study of the device, going beyond the assumptions taken in the theoretical analysis.

We found that the distributed nature of the $\chi^{(2)}$ processes and the interplay between the temporal walk-offs, can enhance the performance of a SHG:DFG FROG device compared to its single-step counterparts. Owing to the small group-velocity mismatch (GVM) between the test and the output pulses, the cascaded interaction does not suffer from the spectral filter function which broadens the output pulse in SHG or SFG interactions. Hence, the time-resolution of the cascading scheme is hardly limited by the interaction length. This small GVM also guarantees a good overlap between SH of the pump and the test and the output pulses, such that the output pulse keeps growing. Therefore, in contrast to the CW case, whose efficiency can only be equal to or less than the efficiency of the single-step $\chi^{(2)}$ interactions, ultrashort pulse cascaded interactions can be more efficient than SFG or DFG interactions.

SHG:DFG blind-FROG

Conventional XFROG uses a fully-characterised pulse to gate the test pulse and applies a phase retrieval algorithm to obtain the intensity and phase of the test pulse. A similar approach might be applied to the cascaded FROG, but the gate

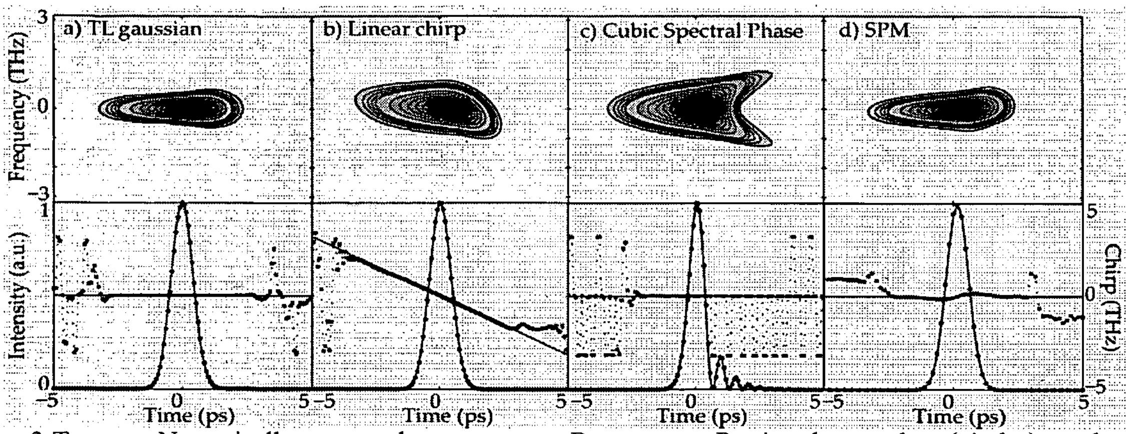

Fig. 2 Top row: Numerically generated spectrograms. Bottom row: Retrieved test pulses (circles) overlayed with the input simulation (solid lines). The test pulses are: a) a TL gaussian, b) a linearly chirped gaussian, c) a gaussian with spectral cubic phase, and d) a gaussian with self-phase modulation (SPM)

pulse (an "effective" SH pulse) is actually difficult to determine. The problem can be circumvented by using a blind-deconvolution algorithm [5] to retrieve both test and gate pulses without *a priori* knowledge of neither the pump and of the QPM transfer function.

We evaluated the performance of the SHG:DFG blind-FROG scheme by numerically simulating the device. Figure 2 shows the numerically generated spectrograms and various retrieved test pulses. The length of the device was 5 walk-off lengths. The peak power of the test pulses was 1 mW, whereas the peak power of the pump pulse was 50 mW. Despite the length exceeding the walk-off length, the retrieval quality is excellent.

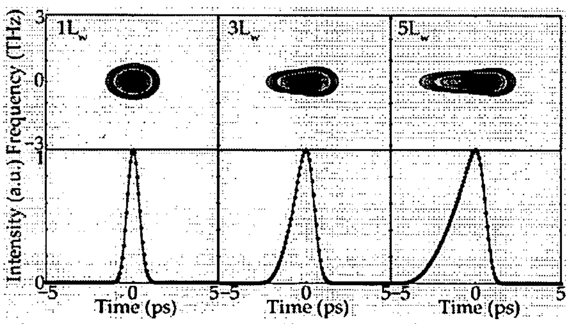

Fig. 3 Top row: Numerically generated spectrograms of TL gaussian and test pulses for one, three and five walk-off lengths interactions. Bottom row: Retrieved gate pulses (circles) and their theoretical predictions (solid lines).

Figure 3 shows the numerical spectrograms for three different propagation lengths and the retrieved gate pulses (circles). On the same plot, the predictions of our theoretical analysis are shown as solid lines.

A retrieval quality assessment based on Wigner's representation [6] was applied to the numerical experiments and confirmed the versatility and robustness of the proposed configuration. For instance, excellent retrieval qualities were verified for highly chirped 1 ps pulses in a 10 walk-off lengths-long device, for input pump peak powers varying as much as 3 orders of magnitude (50 mW to 50W). High quality retrievals can even be expected for pulses as short as 0.5 ps,,in a 5 walk-off length device.

Conclusion

In conclusion, we have analysed theoretically and numerically cascaded SHG:DFG for FROG applications. The proposed SHG:DFG blind-FROG configuration was found to exhibit better time resolution and efficiency compared to single-step $\chi^{(2)}$ interactions. It is particularly suited for the characterisation of weak ultrashort pulses in the 1.55 μm-band using long QPM waveguide devices.

References

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