Accurate Retrieval of Satellite Pulses of Single Isolated Attosecond Pulses

Michael Chini, He Wang, Sabih D. Khan, Shouyuan Chen, and Zenghu Chang[1]

J. R. Macdonald Laboratory, Kansas State University, Manhattan, KS, 66506-2604, USA

Synopsis: When isolated attosecond pulses are reconstructed from an ideal streaked spectrogram, the relative intensity of accompanying satellite pulses can be identified from interference. However, the interference pattern can be distorted by variation of the streaking laser intensity in the focal volume or by the use of large delay steps in acquiring the spectrogram. We investigate these effects on the reconstruction of satellite pulses with full- and half-cycle separations and find that satellite pulses with full-cycle separation are largely unaffected by these issues.

Single isolated attosecond pulses with duration less than 300 as have been generated by several gating schemes [1, 2, 3]. However, pre- and post-pulses always accompany the main pulse, separated by a half or full cycle of the driving laser field. Accurate characterization of the relative intensity of satellite pulses is crucial for improving the pulse quality for experimental applications. Typically, attosecond pulses are measured using the near infrared (NIR) assisted streaking method. The resulting spectrogram can be analyzed using frequency-resolved optical gating (FROG) to retrieve the pulse, a technique known as CRAB (complete reconstruction of attosecond bursts) [4].

Ideally, the presence of satellite pulses can be determined from interference in the XUV spectrum. However, the NIR streaking field may influence the interference, and the trace may be distorted by experimental issues such as spatial variation of the streaking intensity within the XUV focus and limited delay resolution in the spectrogram.

In the following simulations, the streaking NIR pulse was assumed to be 9 fs in duration with a peak intensity of 10^{12} W/cm^2. The XUV spectrum was assumed to support a transform-limited pulse 90 as in duration, with satellite pulses separated by a half or full cycle of the streaking field. The pulse contrast I_s/I_m was set to be 10^{-1} or 10^{-2}, as indicated, where I_m and I_s are the peak intensities of the main and satellite pulses, respectively. A linear chirp of 5000 as^2 was added to the XUV spectrum.

To study the effect of intensity variation in the focal volume, averaged CRAB traces were created and used for retrieval. The results are shown in Figure 1(a), where w_{XUV} and w_{IR} are the $1/e^2$ radii of the XUV and NIR focal spots. As the spot size ratio is increased, the satellite pulses with full-cycle separation can be retrieved accurately, whereas those with half-cycle separation are severely underestimated. This can be explained by differences in the streaking in the two cases [5].

Similar retrieval error can be seen when the delay step size is large. The results are shown in Figure 1(b). The contrast is underestimated for satellite pulses with half-cycle separations for delay steps greater than ~100 as, whereas it is retrieved well for full-cycle separation.

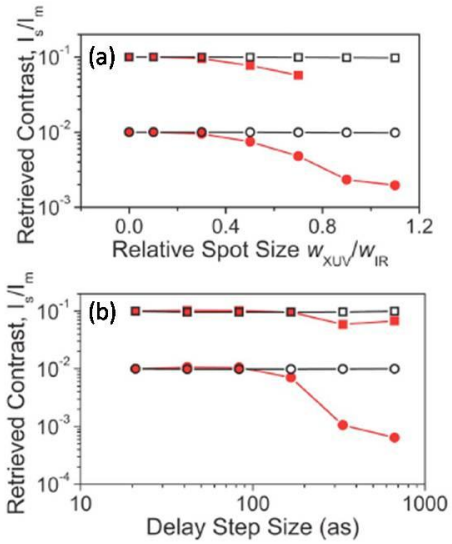

Fig. 1. Retrieved contrast as a function of (a) the spot size ratio and (b) the delay step size for full- (black open shapes) and half-cycle separation (red filled shapes).

In conclusion, we find that the retrieval of satellite pulses with full-cycle separation, as in the case of double optical gating, is largely unaffected by streaking laser intensity variation and large delay step sizes, whereas those with half-cycle separation can be severely underestimated.

This material was supported by the U.S. Army Research Office under grant number W911NF-07-1-0475 and by the Chemical Sciences, Geosciences, and Biosciences Division, U.S. Department of Energy.

References

[1] E. Goulielmakis *et al*., Science **320**, 1614 (2008).
[2] G. Sansone *et al.*, Science **314**, 443 (2006).
[3] Z. Chang, International Symposium in Ultrafast Laser Science 7, Kyoto, 24-28 November 2008.
[4] Y. Mairesse and F. Quéré, Phys. Rev. A **71**, 011401 (2005).
[5] M. Chini *et al*., Appl. Phys. Lett. **94**, 161112 (2009).

[1] E-mail: chang@phys.ksu.edu