Femtosecond-scale synchronisation of ultra-intense focused laser beams

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Introduction

Synchronising lasers to within 10's of fs is a particularly difficult task as mechanical and electrical systems cannot respond accurately on this timescale. Here we report on an experimental technique that ensures femtosecond-scale synchronisation of the foci of two ultra-intense laser pulses. The technique relies on spectrally-resolved optical interferometry and it is virtually applicable to any focusing geometry and relative intensity of laser pulses.

Motivation

For a meaningful experimental implementation of multiple beam experiments, it is indeed necessary that the high intensity foci of the lasers be spatially overlapped and temporally synchronised with a micron and femtosecond scale precision respectively. While spatial overlap is relatively easy to achieve, femtosecond scale synchronisation is a less trivial task, since it lays orders of magnitude below the typical resolution of electronic devices (which respond on the ns and 100's of ps scale).

By exploiting the relatively broad frequency envelope of a femtosecond laser pulse, detailed information about the phase front of a collimated laser beam can be obtained using a spectrally resolved interferometric technique [1,2]. Here we show that a suitable variant of this technique can be applied to the fine synchronisation of the foci of two ultra-intense laser pulses. The versatility of the proposed technique allows it to be operated in virtually any focusing geometry and relative intensity of the two laser beams. Experimental data collected using the two beam laser system Astra Gemini, gives clear evidence of the temporal synchronisation, with fs precision, of two counter-propagating high-intensity lasers.

Experimental Setup

Figure 1 gives the basic arrangement used to achieve multi beam synchronisation in a recent experimental campaign where two counter-propagating beams were used. Here, the two pulses are incident on a small pellicle which is placed at the point of beam overlap. This allows one beam to be partially transmitted while partially reflecting the other. A polariser is used to alter the relative intensities of the beams until they are roughly equal in intensity, and simultaneously allows the beams to interfere with one another. Using the first order reflection from a diffraction grating, the beams are dispersed into their composite frequencies in one axis only. A cylindrical lens is used to minimize the effects of spatial dispersion in this axis only. Naturally, the pellicle provides a small path difference (d) in the beams which produces a fixed number of spatial fringes on the CCD given by $n=2d/\lambda$ (here lambda represents the central laser wavelength). This means that there is a set of fixed spatial fringes in one axis of the plane of CCD.

As the delay between the two beams is altered, each spectral component, decouples with its neighbor at a slightly different rate. This means that in this axis, the fringes can vary. The overall effect is the observation of fringes which both rotate and compress as the delay between the pulses changes.

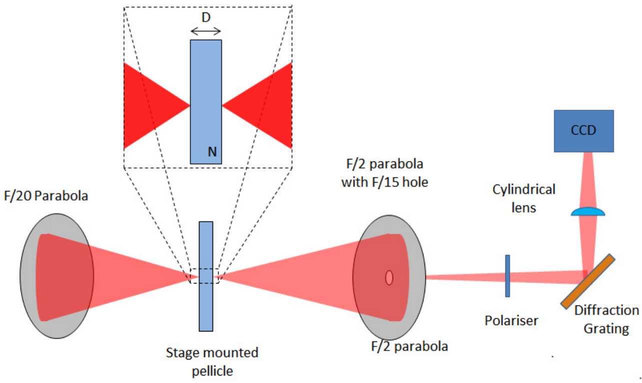

Figure 1. Two counter-propagating laser pulses are incident on the pellicle. A polariser is used to alter the relative intensities of the beams and allow the beams to interfere with one another as well as simultaneously providing a means for making the intensities of the pulses comparable. The diffraction grating spreads the beams in terms of frequency while the lens compresses this spread while due to the subtle path differences between the pulses, a unique interference pattern will be formed for each time delay. A CCD can be used to give real time information about the process.

Results

As the timing changes, the fringes begin to rotate towards a horizontal state. The separation between the fringes increases. This is within the expectations and shown in Fig. 2. The central image shows the CCD closest to synchronisation. As the images progress, the behaviour of the fringes is mirrored to the corresponding time steps. Hence, synchronisation can be achieved within ±50 fs. This value is only limited by the size of the steps that one takes on the delay stage and thus has further scope for improvement.

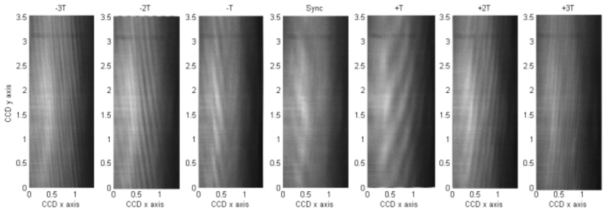

Figure 2. Results of the synchronisation process as seen on the CCD camera. The 7 images begin from left at a time delay of -300 fs progressing to +300 fs, in time steps of 100fs. It can be seen that the fringes begin almost vertically and rotate towards the horizontal plane. The separation between the fringes also changes. The central image shows the CCD closest to synchronisation. As the images progress, the behaviour of the fringes is mirrored to the corresponding time steps.

Conclusion

A method for synchronising ultra-short, ultra-intense laser beams in a real-time and precise way has been successfully demonstrated. It has been shown that the degree of synchronisation achievable, is only limited by the step size available on the delay stage and hence, one can easily achieve fs scale synchronisation. This technique should prove highly beneficial for multi beam experiment routinely carried out at the Astra Gemini laser.

Acknowledgements

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References

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