Development of a dual beam facility for multiple wavelength, short pulse optical probing of experiments in Target Area 2

D. R. Symes, E. J. Divall, P. S. Foster, M. J. V. Streeter, D. Neely and J. L. Collier
Central Laser Facility, STFC, Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Didcot, OX11 0QX, UK

J. S. Robinson and J. W. G. Tisch
Blackett Laboratory, Imperial College London, London SW7 2BW, UK

Main contact email address **d.r.symes@rl.ac.uk**

Introduction

This year has seen the beginning of a project to provide scientists using Astra TA2 with two probe sources essential for understanding its ultra-high intensity plasma physics experiments. The concept is illustrated in Figure 1. First, a 10fs ultra short pulse will be created enabling scientists to probe inside the main laser pulse (40fs) itself and understand the various mechanisms at work. Second, a wavelength tuneable probe pulse will be built to produce high resolution images of the plasma structure at wavelengths where the cameras are not blinded by harmonic self emission from the plasma itself. The energy in each of the probe beams will need to exceed ~1mJ in order to overcome the large amounts of light emitted by the hot plasma. These two beams will be available simultaneously and with independent delays with respect to the main pulse. The permanent availability of the probe beams will greatly improve the current experimental situation in which probe beams are created on an ad hoc basis by harmonic conversion of a portion of the main beam. They will be used on a wide variety of experiments such as electron acceleration [1], photon acceleration [2] and self-focussing [3] and shock wave studies [4, 5].

Pump laser for the probe beams

A diagram of the proposed dual probe scheme is shown in Figure 2. The pump light for the two probe systems is provided by diverting ~20mJ out of the main beam after the second Astra amplifier. This is compressed using the grating compressor, previously employed for TA1 experiments, which is currently located in LA1. The pump beam for the tuneable system described below has specific bandwidth and pulse duration requirements which need to be met through spectral tailoring, which we can perform within the grating compressor.

Ten-femtosecond system

The ultra-short (<10fs) probe pulses will be generated through the hollow fibre compression technique. We are purchasing a system from the Imperial College Attosecond group based on the same design as the one currently operational in TA1, which has been described in detail in a previous report [6]. In brief, the 800nm pump pulse is spectrally broadened by self-phase modulation as it propagates through a hollow-core waveguide filled with noble gas. The pulse emerging from the fibre is then compressed using a sequence of reflections from commercial chirped mirrors. The fibre is differentially pumped so that the pulse encounters a rising density profile thus avoiding the problem of gas breakdown at the entrance. This design is superior to the alternative static fill fibre [7] and increases the energy of operation. The system will be built and tested using a sub-mJ kHz laser system at Imperial College before being transported to TA2. Since we will require higher output energies than previously used in TA1, the installation period will include testing of the system at higher pump energies. It should be possible to achieve the >1mJ probe pulses needed since it has already been demonstrated that similar systems can produce energies > 5mJ [7].

Tuneable system

Pulses at visible wavelengths will be generated using a commercial “TOPAS-White” optical parametric amplification system purchased from Light Conversion Ltd. [8]. This system requires ~1mJ of the 800nm light as a pump. The spectral bandwidth from Astra will need to be limited to about 10nm, lengthening the pulse to ~100fs, in order to optimise the non-linear processes which take place inside the commercial unit. A small portion of the pump is used to generate a white-light continuum in a sapphire

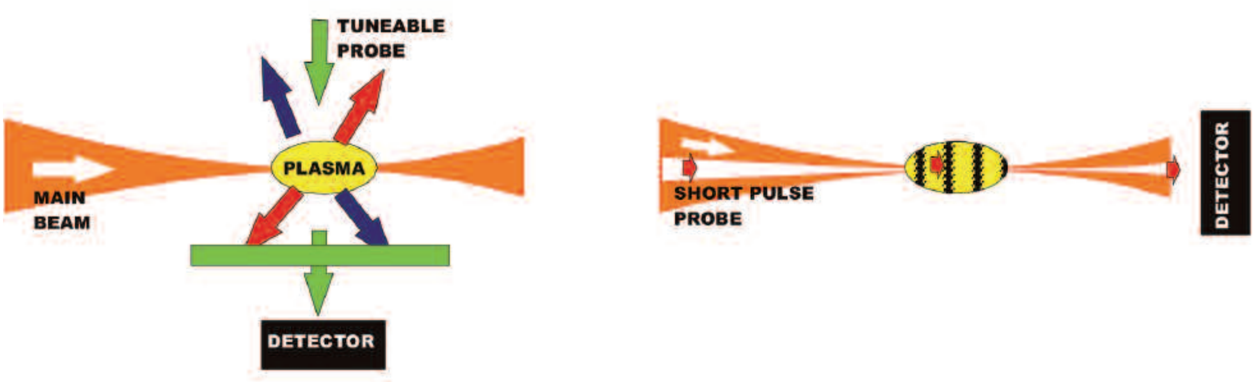

Figure 1. The concept of the dual beam project.

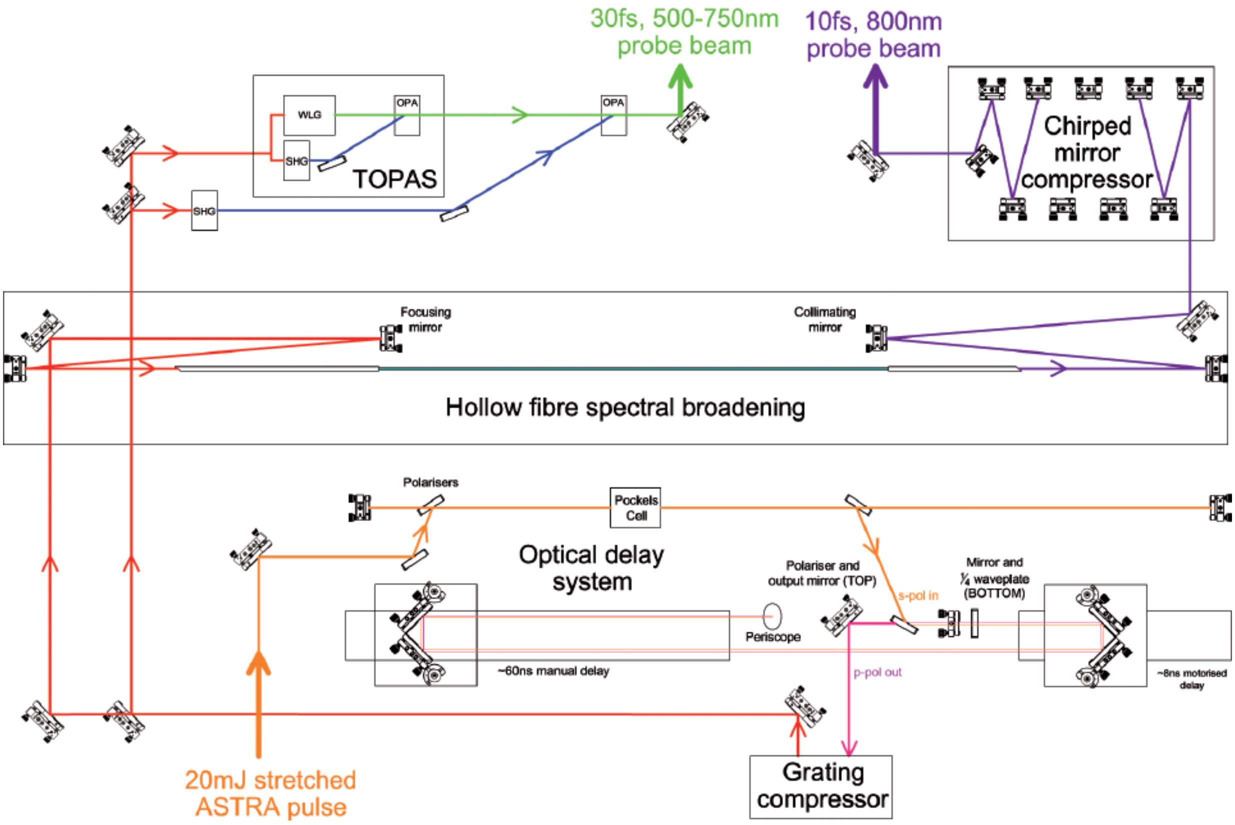

Figure 2. Proposed layout for the dual probe beam setup in TA2.

plate to act as a seed pulse. The rest is frequency doubled to pump a two stage non-collinear optical parametric amplifier. The output pulse has a tuneable wavelength from 500-750nm with energy up to 80μJ in a pulse duration <30fs. For experiments driven with the full energy of Astra in TA2 (~1J), the light emitted from the hot plasma, even away from the harmonic frequencies, will be comparable to this brightness of probe light. Therefore we will need to build an additional amplifier stage using the TOPAS-White output as a seed and taking extra pump energy to generate more second harmonic to pump the external stage. This stage should increase the energy up to 1mJ, while maintaining the sub-30fs pulse duration.

Probe delay lines

For some of the experiments performed in TA2, it is necessary to delay the probe pulses substantially compared to the main driving pulse. For example, experiments studying shock waves launched in gases[3,4] require measurements of the evolution of these structures on timescales of 10's nanoseconds. The ability to delay the probes independently will provide a very versatile system. This could be utilised to study phenomena on a short timescale (< nanosecond) such as heat transport and laser beam self-focusing[3] on the same shot as the associated long timescale (> nanosecond) behaviour such as shock wave formation[4,5].

Optical delays can be achieved by sending the pulse multiple times along the optical table. We have designed and built a system offline in which the pulse transits the table eight times. This will generate a delay of 80ns when installed on the 3 metre optical table in TA2. The layout is shown in Figure 2. The s-polarised pulse is injected by reflection from a polariser. Two pairs of mirrors in a rooftop arrangement bring the pulse to a periscope. Another two pairs of rooftop mirrors at the lower height return the pulse to a zero degree mirror which retro-reflects the pulse back to the polariser. A quarter-waveplate rotates the polarisation so that the beam is now transmitted. The mirror sets on one end of the delay system are placed on a motorised translation stage allowing users to set the delay by computer up to ~8ns. Further delays are achieved by moving the opposite set of mirrors along a manual slide. Reflective systems for delays longer than ~100ns become unwieldy so we propose to use a pulse trapping cavity using a Pockels cell. This would allow the pulse to be delayed by fixed intervals of ~20ns, with the intermediate times available by using the optical delay.

Practical issues arising from such long beam paths are beam quality and beam pointing. We will delay the pulse before compression to avoid the non-linear effects of self-focussing and self-phase modulation associated with short pulses. Deterioration of the stretched beam can be reduced using image relaying or spatial filtering. In addition, the compressor will be moved into TA2 to minimise the path length of the laser once it has been compressed to ~40fs. Changing the position of the delay stage invariably gives rise to a slight misalignment of the output beam which is easily rectified with manual adjustment. However, to simplify the operation of the probe beams for facility users it may become necessary to automate this alignment using a system such as the one recently installed on Astra itself[9].

Measurement of pulse duration

When we generate short pulses in the visible region we will need to install a new diagnostic for measuring the pulse duration. The existing apparatus in both TA1 and TA2 consists of reflective autocorrelators and commercial GRENOUILLE devices designed to measure pulse durations at a wavelength of 800nm. An autocorrelator to measure pulses in the visible is available commercially [10] but does not operate on a single shot, rather building up the trace over many shots. These units are more suited to kHz lasers and are difficult to use at 10Hz.

We have therefore designed a system using frequency resolved optical gating (FROG) which will measure pulse durations down to 10fs across the wavelength range of the TOPAS-White output (500-750nm). This can be achieved by using a BBO crystal (cut at 45.5°) to generate second harmonic because this material can be phase-matched over a very broad bandwidth [10]. A second BBO crystal (cut at 29.2°) can be exchanged to operate the FROG at 800nm. The autocorrelation section of the FROG will be built using vacuum compatible components and be housed inside the compressor vacuum chamber in TA2. This is desirable for measuring the ultra-short (<10fs) pulses from the hollow fibre because it avoids the need to send the beam through an output window which affects the properties of the pulse. This arrangement will allow us to diagnose the pulse duration of both probe pulses, as well as the main Astra pulse, whenever necessary. The FROG will be built by the Attosecond Group at Imperial College.

Conclusions

The installation of two short pulse probe beams will provide an important diagnostic tool for high power laser experiments conducted in TA2. The ability to have independently delayed multiple wavelength probes will constitute a unique facility. By probing with the sub-10fs pulses generated using the hollow fibre technique, plasma dynamics on a timescale faster than the driving pulse itself can be investigated. The system will also act as a test-bed for the design of probe beams for experiments using higher driving energies following the Gemini upgrade.

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