An optically multiplexed single-shot time-resolved probe of laser–plasma dynamics

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The complex dynamics of intense laser-plasma interactions evolve rapidly on timescales less than the laser pulse duration (femto- to pico-seconds) and are highly sensitive to initial plasma conditions and shot-to shot variations in the laser pulse parameters. Although some of these dynamics can be explored using numerical simulations, due to limitations in the physical processes that are included in codes and the use of idealised input parameters, measurements in the laboratory, in principle, give the most comprehensive insights. There presently exists a growing need for the development of experimental techniques which enable detailed and controlled investigation with high spatial and temporal resolution in order to investigate complex evolving laser–plasma dynamics such as self-focusing or the propagation of higher-order modes (such as Laguerre-Gaussian beams) in plasma. Progress in this area will open up a new dimension of experimental measurement and provide additional capability to quantify key factors that effect the control of laser-driven particle sources.

We will introduce a new approach to temporally resolve key ultrafast micron-scale processes via the use of a polarisation and wavelength multiplexed optical probe. We demonstrate that this technique enables highly precise time-resolved, two-dimensional spatial imaging of intense laser pulse propagation dynamics, plasma formation and laser beam filamentation within a single pulse over four distinct time frames. The design, development and optimisation of the optical probe system is presented, as are representative experimental results from the first implementation of the multi-channel probe with a high-power laser pulse interaction with both a helium gas jet target and also solid density targets using a picosecond driver. We will also consider how this technique can be extended to femtosecond-scale systems and compact beamline designs. This diagnostic approach has the potential to support improved control over laser-driven particle sources via a greater understanding the plasma dynamics during a single shot. This is an important aspect for the realisation of applications of laser-driven particle sources.

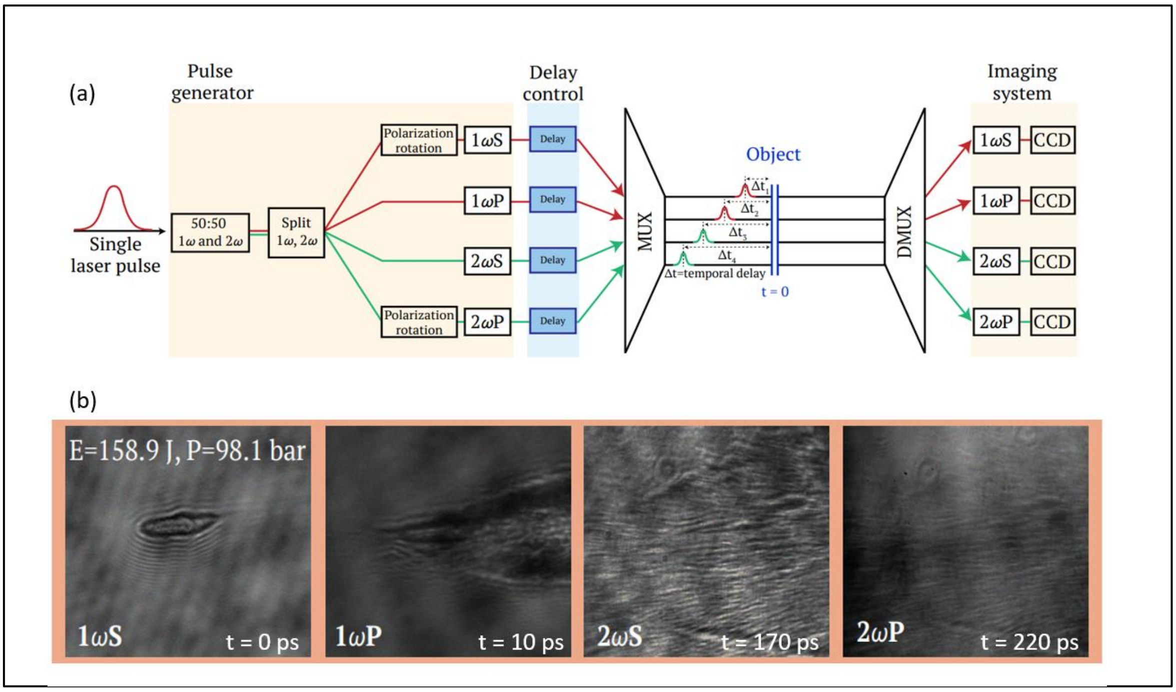

Figure 1: (a) Flow diagram of the multiplexed optical probe concept where a single pulse is divided into four pulses which are encoded by wavelength and polarisation. These pulses are then spatially multiplexed to probe the same point in the interaction across four different time-frames. The pulses are then separated and measured independently. (b) Representative experimental data showing laser pulse propagation in a helium gas-jet during a single interaction.

[1] Z.E. Davidson *et al.* Optics Express 27 (4), 4417-4423 (2019)