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A nugget from FOCUS:

Title: Snapshots of Laser Wakefields Using Frequency Domain Holography

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Laser-generated plasma wakefields have become a standard method for producing high quality relativistic electron beams, with potential applications including injection sources for conventional accelerators, radiation oncology and nuclear activation. The beam quality from such laser wakefield accelerators (LWFAs) depends critically on details of the spatial structure of the plasma wave. For example, transverse emittance is sensitive to transverse density gradients and curvature in wake phase fronts, while energy spread is sensitive to non-linear wake features such as wave-breaking and “bubbles”. Direct visualization of such structures is critical for understanding and controlling LWFA output, and also for studying issues such as beam loading and pump depletion. Single-shot visualization has proven elusive, because of the stringent demands on temporal resolution and detection sensitivity. Wakes have been detected by time-consuming, multi-shot Frequency Domain Interferometry (FDI) [1]. However, multi-shot techniques are noisy, do not allow scanning and optimization of experimental parameters, and do not accurately measure wake structure when shot-to-shot variations are large (e.g. instability-driven wakefields).

Here we report the first *single-shot* measurements of wakefield structure, using an extension of FDI known as Frequency Domain Holography (FDH) [2]. Individual plasma waves, their evolution for 10-12 periods behind the pump, and fine details of their radial structure were clearly resolved for over 100 shots at pump powers of 10-30 TW in the near resonant wakefield regime. Wake structure is reconstructed from raw interferometric data within seconds, providing quasi-real-time feedback for experimental optimization.

Experiments were performed on the HERCULES laser system at the University of Michigan which delivered >1 J, 800 nm, 30 fs pulses focused at f/13 to a supersonic 2 mm He gas jet. Two second-harmonic probe pulses were generated, and recombined collinearly with the pump through a 1” thick dichroic high-reflector for 800nm that stretched the probe pulses to ~1 ps via linear dispersion, establishing the temporal window for FDH. The temporally advanced 2ω pulse arrived before the pump, and acted as a reference (or reader) pulse for FDH. The second 2ω pulse rode with the pump and the plasma disturbances (ionization front and wakefield), which impart a time/frequency-dependent phase shift to the probe pulse. This shift is recovered by interfering the probe and reference in a spectrometer. Imaging optics relay the interaction plane to the spectrometer slit with a 3-fold magnification, and provide a spatial resolution of several μm. Wakefields were holographically reconstructed for plasma densities in the range $1 < n_e < 6 \times 10^{18}$ cm^{-3}, driven by pump pulses of either 10 or 30 TW. Measured wake period scaled as expected with plasma density. At higher powers, horseshoe-shaped wave fronts were observed, consistent with simulations of strongly-driven high-amplitude wakes. FDH thus enables efficient single-shot characterization of wakefields in various density/intensity regimes.

[1] C. W. Siders et al., “Laser Wakefield Excitation and Measurement by Femtosecond Longitudinal Interferometry,” PRL **76**, 3570 (1996); J.-R. Marques et al., “Temporal and Spatial Measurements of the Electron Density Perturbation Produced…,” PRL, **76**, 3566 (1996)
[2] S. P. Le Blanc, E. W. Gaul, N. H. Matlis, A. Rundquist, and M. C. Downer, “Single-shot ultrafast phase measurement by frequency domain holography,” *Opt. Lett.* **25**, 764 (2000)