A Novel Source of Injection Electrons for a Capillary Waveguide Accelerator

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Wakefield Acceleration Basics
When a high-intensity (HI) laser pulse passes through a low-density plasma, electrons are displaced by the laser's ponderomotive force, while leaving the massive plasma ions. Thus the Coulombic force acts as a restoring force on the electrons. Therefore, a spatially periodic electric potential is setup and trails the laser pulse, much like a wake field is setup behind a moving ship. For very high-intensity lasers, these potential waves can be very steep, allowing for acceleration of injected charged particles or creation of an electron beam via self-injection.

Capillary Waveguide Basics
Capillaries with ID ~200-500 micron can be used to extend the length over which a laser remains focused. This is known as “guiding”. Guiding is useful because the high intensities required for wakefield acceleration mechanisms are generally only achievable by tightly focusing a short pulse (HI) laser. Standard focusing optics only focus over a short range. A capillary waveguide guides light much the same way a gradient-index optical fiber guides light. The key to both is creating a refractive index profile which is greatest on axis and decreases toward the walls parabolically. Light is then continually guided toward the center.

Capillary waveguides are useful because:

- Increase focused length
- Increased e- acceleration length
- May be tapered or stepped
- Increased dephasing length
- Density may be low
- Maximize dephasing and dephasing length

Capillary waveguides may allow the acceleration of laser-produced electron beams to higher energy - perhaps to several GeV in just a few centimeters. If the gain length is limited by dephasing then (Mor 2006) the energy gain is:

\[ E_{\text{gain}} = \frac{m_e^2 c^2}{8 \pi^2 n_e L_\text{cap}} \left( \frac{\sigma_{\text{beam}}}{\sigma_{\text{cap}}} \right)^2 \]

where \( n_e \) is the capillary density. In a typical plasma with \( n_e \approx 10^{19} \text{cm}^{-3} \), the gain is greater than \( 10^7 \)

Guiding Through the Capillary
In our capillary waveguide the refractive index profile for guiding is created by ablating material from the walls with a second laser pulse (the “ignitor”) and forcing a large current through the capillary. The plasma density profile will be parabolic, as shown at right, over a certain time window. During this window, the HI pulse can be guided and create a wakefield.

We have demonstrated guiding for HI pulses with power between 1-10 terawatts.

Shot at full regen Shot at 3.4 TW

Ablated Plasma Interferometry
A Michelson interferometer was used to observe the plasma plume created at the ablation surface.

Shot after without discharge Shot after without discharge

The ablated plasma is reproducible throughout at least 10s of shot at the same spot on the ablation target.

Analyzing the Electron Spectrum
The energy spectrum of the electron beam was analyzed based on deflection by passing through a transverse B field. The spectrum was analyzed at two different energy scales in two separate experimental runs. By adjusting the density through which the HI pulse travels, we were able to create electron beams with a variety of energy spectrum shapes. The density was controlled by adjusting the energy of the ablator pulse, the delay between ablation pulse and HI pulse, and the ablation target position.

Summary
- Guiding has been achieved up to 10 TW using a 3cm capillary waveguide.
- Electron beams have been created by sending a HI pulse through an ablated plasma plume.
- The plasma density seen by the HI pulse determines the characteristics of the beam and can be controlled with timing and target position.
- Injection will be attempted next.

Discussion and Future Work
Injection of the electron beam into an accelerating capillary has not yet been achieved. Guiding and production of injection electrons have been demonstrated separately. Before attempting injection, further work is being conducted to optimize guiding using different capillary materials and diameters.

It is uncertain whether a broadband or quasi-simonoenergetic target will be better for diagnostic injection. Based on the extent and density of the ablated plasma, we can determine a desired separation for the ablation and capillary. The target and capillary positions will be controlled independently in situ for injection experiments.

The ablated plasma and electron spectra were analyzed for four different ablation surface materials: polystyrene, Teflon, glassy carbon, and beryllium. A reliable electron beam was produced most easily using Teflon. Carbon and polystyrene were somewhat less reliable and beryllium had a very limited spatial and temporal window for producing electrons.