Toward laser fusion

David Kehne

Focal zooming, a pulse-shaping concept in which the focal properties of a laser pulse change with time, improves the viability of fusion energy as a power source.

The ever-increasing need for energy in the world demands the development of new energy sources. Nuclear fusion, the process that powers the sun, has the potential to provide an effectively inexhaustible source of energy. The challenge is to create here on Earth the conditions that exist in the sun’s core. Several methods of harnessing fusion power have been put forth, with the primary ones confining a plasma magnetically or inertially. Direct-drive laser fusion is an example of the latter, where a spherical pellet consisting of hydrogen isotopes (deuterium and tritium) is irradiated uniformly from all directions by numerous laser beams. The resulting implosion causes the fuel to compress to extreme densities and temperatures, allowing fusion ignition to occur. Performing this at a sufficient repetition rate releases energy that can be used to generate electrical power. However, as the target implodes, less and less of the laser beam will interact with the target, and this reduces the efficiency of the process. Ideally, the laser spot size would decrease in unison with the pellet, a property known as ‘focal zooming.’ Simulations indicate that focal zooming can reduce the energy required for a direct drive fusion implosion by 30%.

Several zooming schemes have been proposed for solid-state lasers. In each case, the laser spot size is determined by placing an optical element known as a phase plate in the beam line immediately before it enters the target chamber. To make changes to the zooming conditions, new phase plates have to be manufactured and installed for each beam, which is costly in both expense and time. At the Naval Research Laboratory, we have proposed, and recently implemented on the Nike KrF gas laser, a method for achieving focal zooming in a flexible and inexpensive manner.

The Nike UV laser uses induced spatial incoherence (ISI) to produce laser beams of high uniformity, a characteristic critical to the success of direct drive inertial fusion. Here, an aperture that is illuminated early in the low energy pulse forming region of the laser is imaged through a series of large amplifiers and onto the target. Simply stated, the diameter of this single aperture determines the spot size, at the target, of all the beams. Changing the spot size requires only the trivial installation of a new aperture. Such an ISI system provides an excellent platform to implement focal zooming.

Installing focal zooming in the optical layout of our facility proved quite straightforward. The Nike laser delivers 56 UV beams into a final target chamber. All of these beams are created from a single source. On-target pulse shape, spot size, and time of arrival are imprinted on this single-source beam. The beam is then split and amplified numerous times to create a train of

Figure 1. A time-integrated focal plane equivalent image of the 4ns pulse taken in the low-energy end of the laser is shown. At this location, the beam diameter of the first 2.4ns is 9mm (red) and the diameter of the final 2ns is 2mm (yellow).
laser pulses that pass through a single final amplifier. We configure subsequent optical chains so that the fully amplified pulses arrive at the target simultaneously.

Recently, we succeeded in imprinting the zooming property onto the source beam and hence onto all on-target beams. In the non-zoom configuration of the Nike laser, a 20ns polarized source beam is sent through a ‘Pockels cell.’ A high-voltage (HV) pulse (typically 4ns) applied to the cell’s crystal causes the polarization to rotate 90° for the duration of the signal. The timing of the HV pulse defines the pulse width and the time of arrival of the beams, e.g., delaying the signal by 2ns delays the arrival on target by 2ns. After the Pockels cell, the beam is brought to a focus, overfilling a round aperture. This object aperture is image-relayed to the target. After pulse shaping, the 4ns pulse is split, amplified, and propagated to the target located roughly 350m away.

To achieve focal zooming, we create two beams, imprint a different pulse shape on each, and then combine them. An optical splitter creates the two beams. One follows the standard optical line, while the other passes through its own set of pulse-shaping optics. Using another optical splitter, the two beams are then recombined, effectively constructing a pulse consisting of two parts, each with independently adjustable on-target focal size, pulse width, and time of arrival. In initial tests, we created a 4ns pulse in which the on-target focus was 1.3mm for the first 2.4ns and 0.28mm for the final 2ns with 0.4ns of temporal overlap. A time-integrated focal plane image is shown in Figure 1. A streak camera was used to observe the time evolution of a narrow slice of the light emerging from the rear surface of the target, effectively tracking the beam diameter as it changes in time. Figure 2 shows this image, where the vertical axis is the diameter and the horizontal axis is time.

In summary, to make the generation of electrical power via laser fusion a reality, it is essential to maximize the efficiency of the laser energy target coupling. We have successfully implemented and demonstrated an inexpensive and flexible method of focal zooming that allows the laser spot size to stepwise track the size of an imploding pellet. In the future, we plan to use this system to construct more advanced pulse shapes required by experiments and diagnostics, and improve the tuning of the zoomed beam properties.

Author Information
David Kehne
Naval Research Laboratory
Washington, DC

The author received his PhD in electrical engineering from the University of Maryland in 1992. Specializing in electron guns and accelerators, he worked at the Thomas Jefferson National Accelerator Facility and FM Technologies until 2001, when he became manager of the Nike KrF laser located at the Naval Research Laboratory.

References