FY20 Rutherford Appleton Laboratory Report on Omega Laser Facility Experiments

Shock Augmented Ignition

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Shock ignition[1] is a laser-direct-drive approach to inertial confinement fusion that seeks to reduce the implosion velocity required for ignition by adding a strong shock toward the end of the implosion. The strong shock heats the hot-spot ions and further compresses the DT fuel. In the standard approach to shock ignition, the strong shock is launched by a spike in laser power, and therefore intensity, toward the end of the drive pulse. Research indicates that shock ignition may have various advantageous characteristics in comparison to central hot-spot ignition, in particular reduced implosion velocity and the potential to achieve high fusion energy gain. Questions do remain, however, regarding the requirement for high laser intensity. These high laser intsensities can cause significant laser backscatter (due to stimulated Raman and Brillouin scatter) and accelerate hot electrons toward the cold fuel (due to stimulated Raman scatter and/or two-plasmon decay).

In this work we have performed the initial experimental evaluation of a concept that seeks to retain the advantages of shock ignition without the requirement for high laser power and/or intensity. Shock-augmented ignition uses a dip in power prior to a rise in power (see Fig. 1). The dip in power reduces the ion sound speed in the ablation plasma, aiding shock generation, while the subsequent rise in power is, according to radiation-hydrodynamic simulations, able to launch a very strong shock as per the shock-ignition concept, but with a peak intensity of around 10^{15} W/cm^2—significantly lower than that required for shock ignition.

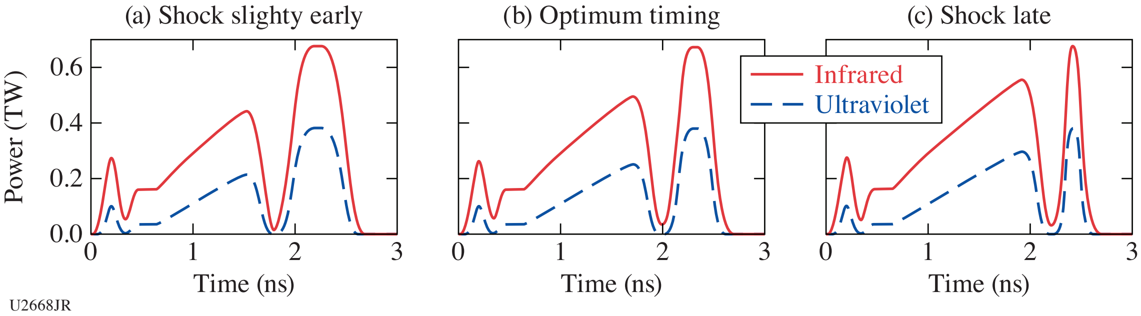

Figure 1
Three shock-augmented ignition pulse shapes used on this OMEGA-60 campaign. Each pulse shape has a slightly different timing of the dip and power spike combination in order to launch the shock at different times. The shock launching time was varied in order to find the optimum experimental shock-launch timing.

The OMEGA laser was used to perform spherical direct-drive implosions of 860-μm-outer-diam, 27-μm wall, deuterium-filled and D_2 + 0.25% Ar (by atomic number)-filled capsules. The argon dopant was used for spectroscopic purposes. Three direct-drive monochromatic imager[2] instruments were fielded along quasi-orthogonal lines of sight to measure time, space, and spectrally resolved images of the hot-spot x-ray emission. These will be used to reconstruct 3-D tomographic spatial distributions[3] of the hot-spot electron density and temperature. Two wedge-range filter[4] diagnostics were used to record down-scattered proton spectra in order to measure the shell areal density. A Sydor framing camera was also used to image the ablation front.[5]

The single-line-of-sight time resolved x-ray imager[6] and Kirkpatrick–Baez microscope (KBframed)[7] diagnostics were used to record time-resolved images of the hot-spot x-ray emission.

Figure 1 depicts three of the five pulse shapes employed to find the optimum experimental shock-launching time. Figure 2 depicts (a) the change in D–D neutron yield and (b) ion temperature as functions of the timing of the dip in laser power. An optimum timing of 1.8 ns was found; the yield was more than 2× greater than an equivalent shot with a later shock-launching time. Initial analysis indicates that the shocks propagate more slowly than predicted by radiation-hydrodynamic simulations. This is tentatively attributed to stimulated Brillouin scatter, which was measured at the ~10% level during the spike's rise in power. Post-shot simulations that accurately reproduce the trends and yields indicate that a shock pressure of ~0.6 GBar was attained prior to merging with the rebound shock at the shell's inner surface.

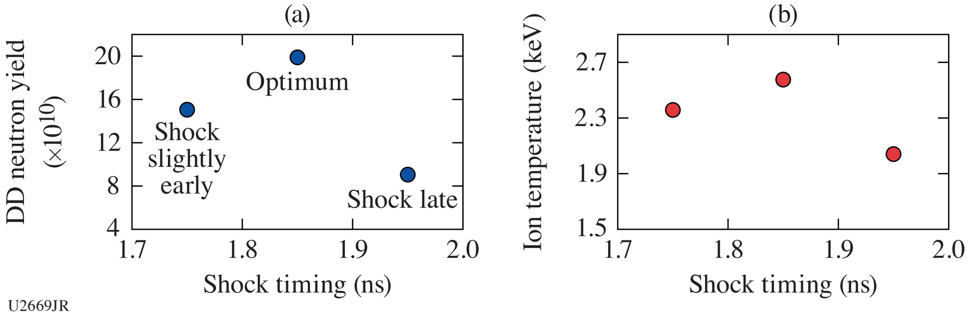

Figure 2
The variation in D–D neutron yield as a function of (a) shock launching time and (b) the associated variation in ion temperature.

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