Progresses of Impact Ignition

*M. Murakami, H. Nagatomo, T. Johzaki, K. Shigemori, Y. Hironaka, T. Watari, Y. Arinaga, T. Norimatsu, H. Shiraga, H. Azechi
Institute of Laser Engineering, Osaka University,
2-6 Yamada-oka, Suita, Osaka 565-0871, Japan

M. Karasik, J. Weaver, Y. Aglitskiy, A. Velikovich, S. Zalesak, J. Bates, A. Schmitt, J. Sethian, S. Obenschain
Naval Research Laboratory, Washington DC 20375, USA

*e-mail:murakami-m@ile.osaka-u.ac.jp

In impact ignition scheme [1], a portion of the fuel (the impactor) is accelerated to a super-high velocity (Fig.1), compressed by convergence, and collided with a precompressed main fuel. This collision generates shock waves in both the impactor and the main fuel. Since the density of the impactor is generally much lower than that of the main fuel, the pressure balance ensures that the shock-heated temperature of the impactor is significantly higher than that of the main fuel. Hence, the impactor can reach ignition temperature and thus become an igniter.

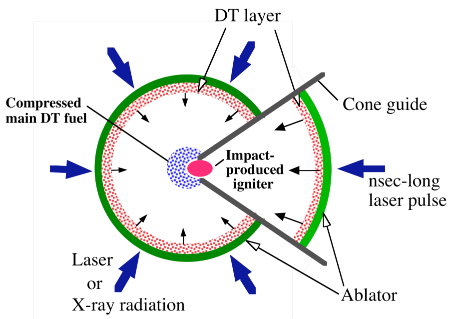

Fig.1 Impact Ignition Target

Here we report major new results on recent impact ignition research: (1) A maximum velocity ~ 1000 km/s has been achieved under the operation of NIKE KrF laser at Naval Research Laboratory (laser wavelength = 0.25μm) in the use of a planar target made of plastic and (2) We have performed two-dimensional simulation for burn and ignition to show the feasibility of the impact ignition.

1. Achievement of a super-high velocity ~ 1000 km/s

Impact ignition, as well as the other designs such as hot-electron-driven fast ignition [2] and shock ignition, reduces driver energy requirement by heating a portion of DT fuel in terms of an additional heating mechanism. The significant advantage for these approach is to separate the compression from the heating. This report describes experiments that, for the first time, reach target velocities in the range of 700 – 1000 km/s. The highly accelerated planar foils of deuterated polystyrene, some with bromine doping, are made to collide with a witness foil to produce extreme shock pressures and result in heating of matter to thermonuclear temperatures. Target acceleration and collision are diagnosed using large field of view monochromatic x-ray imaging with backlighting as well as bremsstrahlung self-emission. The impact conditions are diagnosed using DD fusion neutron yield, with over 106 neutrons produced during the collision. Time-of-flight neutron detectors are used to measure the ion temperature upon impact, which reaches 2 – 3 keV. The experiments are performed on the Nike facility, reconfigured specifically for high intensity operation. The short wavelength and high illumination uniformity of Nike KrF laser uniquely enable access to this new parameter regime. Intensities of (0.4 − 1.2) x 10^{15} W/cm^2 and pulse durations of 0.4 − 2 ns were utilized. Modeling of the target acceleration, collision, and neutron production is preformed using the two-dimensional radiation hydrodynamics code with a non-LTE radiation model. Moreover, detailed analytical model addresses the feasibility of even higher velocities. (see Figs.2-4)

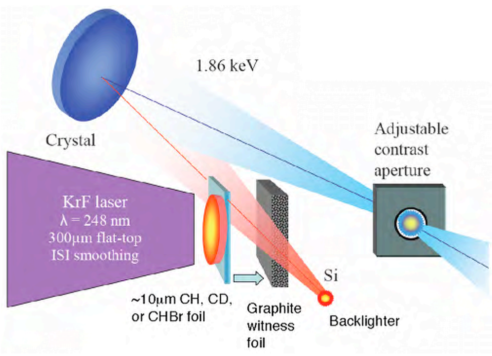

Fig.2 Experimental set up

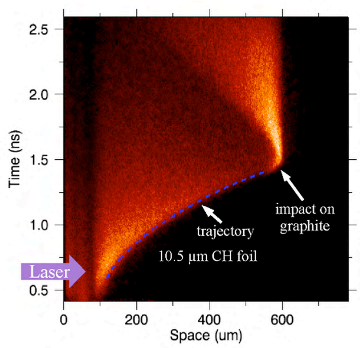

Fig.3 X-ray image

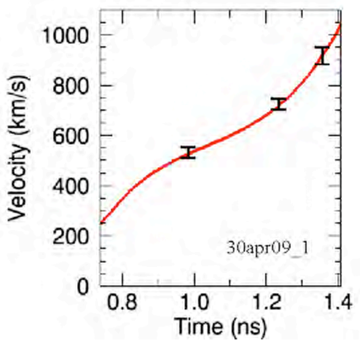

Fig.4 Sim. vs. Exp. on target velocity

2. Two-dimensional simulation for ignition and burn

Our hydrodynamic simulation shown in Fig. 5 demonstrates [3] that ignition occurs when an impactor with a velocity of 1750 km/s and a density of 50 g/cm^3 collides with the main fuel with a density of 400 g/cm^3. Here, the implosion and acceleration processes are neglected. The impactor in a bullet-shape initially has spatial extensions of 60 and 70 μm in the perpendicular and the parallel directions with respect to the collision axis, respectively. The main fuel has a concave shape to tamp the impactor, as is observed in an implosion with a cone. The impactor energy is only about $E_i \sim 10$ kJ, whereas the main fuel has a much higher energy than this. However, if the energy of the main fuel is reduced so that it is one to two times the impactor energy, i.e., $E_m \sim 10\text{-}20$ kJ, and if a typical coupling efficiency of $\eta_c \sim 10$ % from the laser to the internal energy of the fuel assembly is assumed, we estimate that the laser energy for ignition will be $E_L = (E_i+E_m)/\eta_c \sim 200\text{-}300$ kJ. This energy is much lower than that required for central hot spot ignition and is comparable to that required for conventional fast ignition. The primary challenges are thus to generate such high velocities while maintaining target integrity and to achieve such high impactor densities. Throughout this study, unless stated otherwise, we define the time origin as the time of maximum compression of the main fuel.

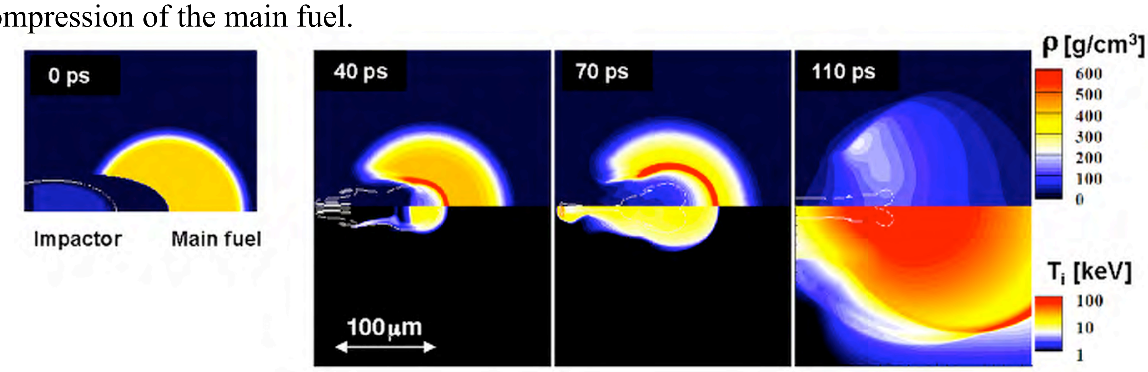

Fig. 5 Snapshots of density and temperature distributions obtained from the two-dimensional simulation. At t = 110 ps, ignition and burn can be observed with temperatures > 30 keV.

As a conclusion, by increasing the impactor velocity from 700 km/s to over 1500 km/s, and the energy efficiency from 2% to 10%, we estimate the laser energy necessary to create a hot spot to ignite DT fusion fuel to be 200–300 kJ, which is much lower than that required for central ignition. Scaling up of the present experiments will demonstrate that full-scale impact ignition could be attained within a practical range.

References

[1] Murakami, M. and Nagatomo, H., Nucl. Inst. & Meth. Phys. Res. A**544** (2005) 67.
[2] Azechi. H., *et al.*, Nucl. Fusion **49** (2009) 104024.
[3] Azechi, H., *et al.*, Phys. Rev. Lett. **102** (2009)235002.