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Neutronic effects on ignition and burn dynamics in fast ignition laser fusion

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Introduction

In laser fusion, self-heating by fusion products drives ignition and burn. In DT fuel, self-heating of α-particles through Coulomb interactions with plasma particles is the dominant mechanism. Heating by uncharged neutrons is generally neglected as a secondary effect. Neutrons, however, can produce MeV-class recoil ions through nuclear elastic scattering (NES) with plasma ions, and the subsequent transport of these recoil ions contributes to plasma heating. This neutron-induced heating has been discussed in detail for both the central ignition [1] and volume ignition [2] schemes. In the fast ignition scheme, where fuel compression and ignition spot formation are separated, the role of neutron heating has not yet been thoroughly investigated. This study aims to clarify the effect of neutron heating on ignition and burn in fast ignition DT laser fusion based on numerical simulations.

Simulation modeling

We used the burn simulation code FIBMET [3], which is described in a two-dimensional axisymmetric Eulerian coordinate system. This code is a hybrid code based on a one-fluid, two-temperature radiation fluid model, coupled with a transport code for high-energy particles using a particle scheme. It solves the transport of DT reaction-produced α-particles, neutrons, and the recoil deuterons and tritons generated by NES with neutrons. For energetic charged particles, Coulomb interaction with plasma particles is considered, while for neutrons, NES is taken into account. The effects of plasma thermal and fluid motions are considered in the generation and interaction processes of energetic particles.

The simulation starts from the maximum compression state, where a uniformly compressed DT spherical plasma (density $\rho = 300$ g/cm³ and temperature $T = 0.16$ keV) is assumed. The hot spot formation process was assumed to be uniform heating of the plasma electrons in the cylindrical region at the core edge (radius $r = 20$ μm, depth $\rho L = 2$ g/cm² and heating power $P_h = 1.5$ PW). Simulations were performed for fuels with ρR values ranging from 0.5 to 4 g/cm² by varying the fuel radius R. To ensure sufficient external heating energy for ignition, the heating pulse duration was set to $\tau_h = 15$ ps. For the case of $\rho R = 4$ g/cm², additional calculations were also performed by varying the heating pulse length to investigate the neutron heating effect on reduction of the external heating energy required for ignition.

Results and discussion

Figure 1 shows the spatial profiles of density ρ, ion temperature T_i and DT fusion reaction rate R_{DT} at peak fusion power for the case without and with neutron heating. The hot spot is located at the left edge of the fuel core, and the burn wave propagates from there.

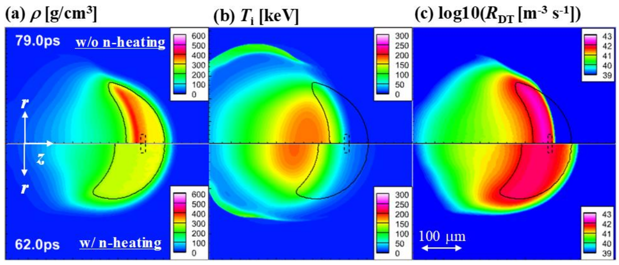

Fig.1 Spatial profile of (a) density ρ, (b) ion temperature T_i and (c) DT fusion reaction rate R_{DT} at the peak of fusion power. The upper and lower ones are for the case without and with neutron heating.

In the case without the neutron heating, the burn wave propagates accompanied by a compression wave. This propagation mode is similar to chemical detonation, but differs in that the burn wave is driven by non-local α-particle heating instead of a shock wave.

When the neutron heating is included, the propagation mode changes drastically. Because the neutrons broadly heat the unburned region, the burn wave propagates faster. In addition, the propagation mode changes from the α-particle driven mode to neutron-induced mode, and the compression wave disappears, and the burning region becomes broader. Thus the neutron heating significantly affects the ignition and burn dynamics.

At the conference, in addition to the neutron heating effect on the burn dynamics described above, I will report on the reduction of the external heating energy required for ignition and the dependence of neutron heating effect on fusion output with respect to the fuel size.

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References

[1] T. Johzaki et al., Laser Part. Beams **15**, 259 (1997).
[2] Y. Nakao et al., Fusion Eng. Des. **44**, 181 (1999).
[3] T. Johzaki et al., J. Phys. IV France, **133**, 3059 (1998).