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Demonstration of direct fast heating of counter-imploded core plasma by LFEX laser

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A world-class ultraintense laser LFEX at ILE, Osaka University directly heated a CD shell target, imploded by GEKKO XII(GXII) laser. Illuminating LFEX energy of 246 J increased the core internal energy by 23 ± 3 J, leading to the conclusion that the heating efficiency is 9 ± 0.8 %. The results encourage the fast ignition scheme fusion as a hopeful candidate of the fusion machine.

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For the fast ignition fusion[ref1], the direct illumination of an ultraintense laser onto the core is the simplest technical and economical way. To demonstrate the feasibility of direct core heating, we have performed experiments with difficult illumination configurations, such that (a) LFEX is coaxial to the GXII bundled beams axis (Fig. 1(a)), and (b) LFEX is transverse to the axis (Fig.1(b)). (a) mode will be the simplest scheme, but the cutoff point is far from the core and much plasma clouds may block the hot electron and ion transports[ref2]. (b) mode may not be so simple to operate the power plant, but the cutoff point is close to the core and there are less cloud plasmas, which block the transport[ref3]. However, because the transverse mode results are not yet confirmed, we concentrate to the axial (a) mode. Counter illuminating 6 beams from the GXII has imploded a CD shell target. Ratio of shell radius μ to focal distance μ is -3. LFEX laser is directly focused to the core center.
The intensity on target is 1.05μ W/cm500μ. We have estimated the LFEX fast heating efficiency from the following procedures.

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Without LFEX illumination, Fig. 2(a) shows a DD reacted proton energy peak (3.02 MeV) shift down to 750 keV (red arrow in Fig.2 (a)) due to the core plasma, yields an areal density of 0.016 g/cm7μ along the transverse direction. Peak shift to 1500 keV (green arrow in Fig. 2 (a)) yields 0.011 g/cm$R$ to the axial direction[ref4]. Considering an ellipsoidal core figure, these results lead us to the core density d/R g/cm$0.5 \sim 1 \times 10^{19}$ and volume ^{2} cm$\times$.

An x-ray streak camera, in Fig. 2 (b), shows both the core emissions due to the implosion +200 ps after the GXII peak and the LFEX heating +600 ps after. The intensity of core emission here is same as that without LFEX, but once LFEX is just on the compression, as in Fig. 2 (c), the core emission becomes $\longrightarrow$20 times stronger than the emissions without LFEX. The stagnation period ^{3}, within which the maximum compression continues, $\longrightarrow$ ps. We assume that the neutron generation period is also close to μ.

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± 100 neutron yields(Ny) without LFEX illumination in Fig.3 (a) gives us the ion temperature ^{2} to be 700 eV, if we assume ^{2}. While, with LFEX at +200 ps, Ny of Fig.3 (b), $\rho = 2.8 \pm 0.3$ gives ^{3}1.0 keV. The ion temperature increment $V = 3.2 \times 10^{-7}$ is 0.3 ^{3} 0.4 $\sim$, or τ300 eV.Supposing ≤ 50 in equilibrium, then τ eV with LFEX. The intensity of x-ray emission of the core (Fig.3(d)) is 4 times larger than the Fig.3 (c), leading to the electron temperature increment $N_y = 3.5 \times 10^6/4\pi$ is ($9.8 \times 10^6/4\pi$-1)3.5×10^6, if the core is yet in equilibrium. The increment of core energy is given by T_i, where $Ny = n_i^2/4 < \sigma v >_{Ti} V\tau$ and 9.8×10^6 are the electron and ion contributions, respectively. Assuming the core plasma is fully ionized, then $T_i \sim$, where ΔT_i is total charges of a CD ion and also using $\sim$, we could estimate $T_i \sim T_i \sim T_e$ J. Since the LFEX energy is 246 J, we expect the heating efficiency to be $\Delta T_e \sim \Delta T_i \sim 300$ % for the axial mode. Without LFEX, the implosion efficiency, defined as a core internal energy divided by an implosion laser energy (now GXII), is ΔT_e %. With LFEX, we can estimate that the total implosion efficiency is improved to 85 J/1946 J = 4.4 %.

We will discuss the transverse mode later on.

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