ID: 874

Efficient fast isochoric heating process visualized with spatial-temporal-resolved x-ray imaging

Shinsuke Fujioka
sfujioka@ile.osaka-u.ac.jp
Institute of Laser Engineering, Osaka University

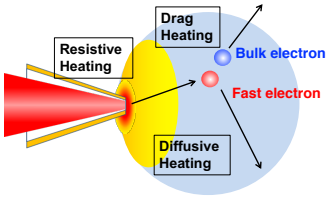
Summary

1. **The coordinated coupling of four plasma-devices have realized enhancement of heating efficiency of the fast-ignition laser-fusion scheme.**
   - **Guiding cone for efficient laser-to-electron conversion.**
   - **Laser-coil for guiding laser-generated electron beam to a fuel core.**
   - **Solid ball fuel for stable compression of a fuel.**
   - **Plasma mirror for reducing mean energy of laser-produced electron.**
2. **Drag heating efficiency was evaluated with electron-ion collision induced X-rays, namely *Kα*-X-ray yield and electron temperature of a heated plasma was evaluated from spectral shape of X-rays from highly-charged ions and Bremsstrahlung X-rays.**
3. **For further progress to the ignition condition, we are investigating extension of laser-driven magnetic field, self-generated magnetic field, dense fuel compression with tailored laser pulse.**

	Compression	Heating	Fuel	Others
Conventional Scheme indirect-drive central ignition	Indirect-drive Laser X-ray	Self-heating Hot spark Compressed fuel	Capsule Shell Gas	
Our scheme	Direct-drive Compression laser	external-heating Heating laser	Solid ball Ball	External B-field Field line
Challenges	• Hydro. instabilities • Hot elec. generation	• Relativistic laser-plasma interaction	• Large ablation pressure	• MHD effects • Kinetics

Three major mechanisms of isochoric heating with REB*

*REB: Relativistic Electron Beam



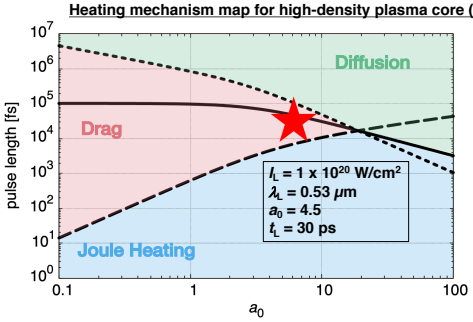
$$\frac{3}{2}n_e\frac{\partial T_e}{\partial t} = \underbrace{\frac{3}{2}\frac{n_h T_h}{\tau_e(T_h)}}_{\text{Drag Heating}} + \underbrace{\frac{\partial}{\partial x}(\kappa(T_e)\frac{\partial T_e}{\partial x})}_{\text{Diffusive Heating}} \leftarrow \underbrace{\frac{j_h^2}{\sigma(T_e)}}_{\text{Resistive Heating}}$$

Drag heating:
Energy transfer from relativistic electrons to bulk electrons via binary collisions.

Resistive heating:
Ohmic heating via a return current that is driven by the forward REB for sustaining the current neutrality.

Diffusive heating:
Heat transport from a heated plasma to a cold plasma via nonlocal-diffusive fashion.

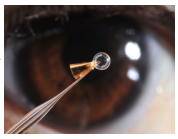
Heating mechanism map for high-density plasma core (300 g/cm³)



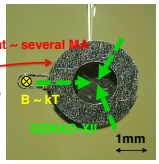
The drag heating efficiency is evaluated from Cu-*Kα* yield as a result of e-i collision. [C. Jarrot +, Nature Phys]

The diffusion and joule heating efficiencies are evaluated from resonance lines (Cu-Heα, Lyα) and Bremsstrahlung X-rays.

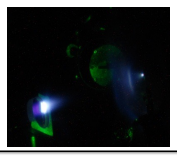
Guiding cone
for laser-absorption
R. Kodama+, Nature 2004.



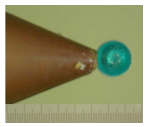
Capacitor-coil
for REB manipulation
S. Fujioka+, Sci. Rep. 2013.



Plasma mirror
for cooling REB
Y. Arikawa+, Appl. Opt. 2016.

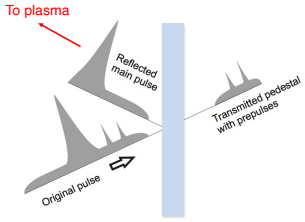


Solid ball
for stable fuel compression
S. Fujioka+, Phys. Rev. E, 2015.

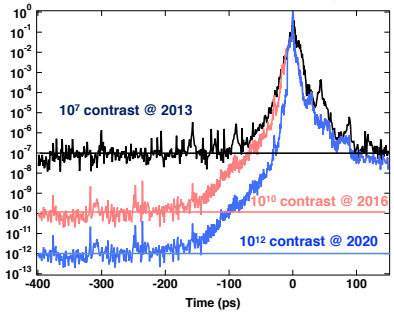


Realization of efficient plasma heating to Peta-Pascal level

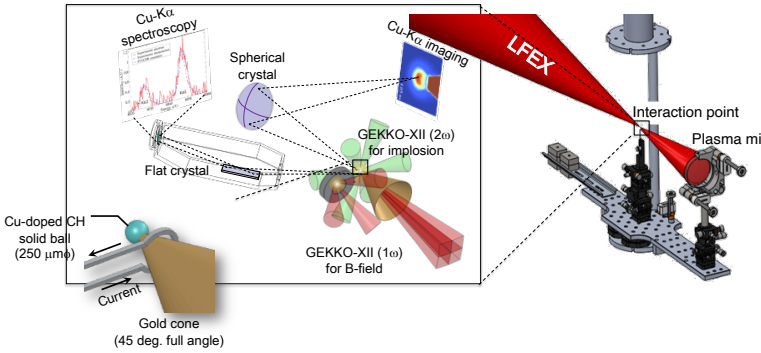
Plasma mirror
Only "clean" heating laser pulse is delivered to a plasma.



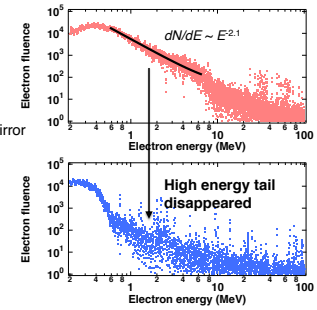
Pulse shape
Pulse contrast has been improved 5 orders of magnitude.



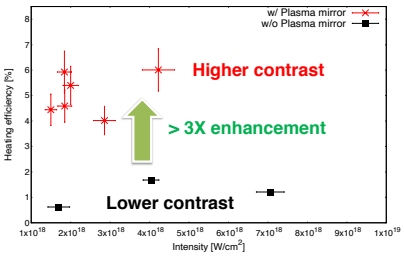
Experimental set-up



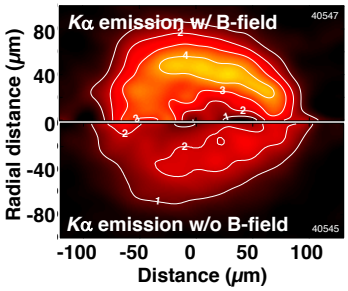
Electron energy distribution



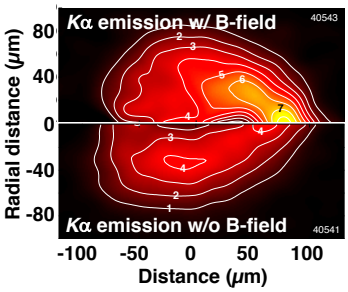
Drag heating efficiency

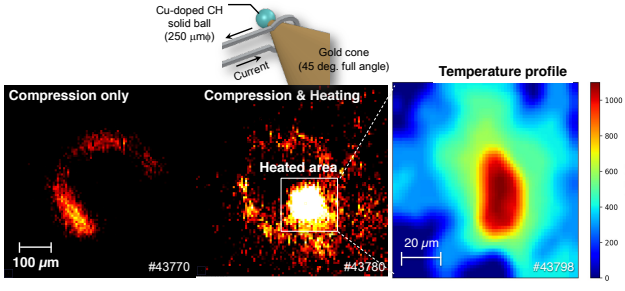


Heating before the max. compression



Heating at the max. compression





This work was supported by the Collaboration Research Program of the Institute of Laser Engi- neering at Osaka University and also the Collaboration Research Program between the National Institute for Fusion Science and the Institute of Laser Engineering at Osaka University (NIFS12KUGK057, NIFS15KUGK087, NIFS17KUGK111, and NIFS18- KUGK118), and by the Japanese Ministry of Education, Science, Sports, and Culture through Grants-in-Aid, KAKENHI (Grant No. 24684044, 25630419, 15K17798, 15K21767, 15KK0163, 16K13918, 16H02245, and 17K05728), Bilateral Program for Supporting International Joint Research by JSPS, and Grants-in-Aid for Fellows by Japan Society for the Promotion of Science (Grant No. 14J06592, 15J00850, 15J00902, 15J02622, 17J07212, 18J01627, 18J11119, and 18J11354).