Magnetized fast laser isochoric (MFI) heating for efficient creation of high-energy-density states

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Summary

- Kilo-tesla magnetic field has been generated by using laser-driven capacitor-coil target for magnetized fast isochoric heating (MFI).
- Externally applied magnetic field can penetrate through 7-µm-thick gold cone wall due to decrease of electrical conductivity induced by inductive current.
- ~8% of laser-to-core coupling was obtained by using the MFI scheme even with a small pre-compressed core ($\rho R = 0.1 \text{ g/cm}^2$). 15% is achievable with a 0.3 g/cm$^2$ core.
Guiding of REB by the external B-field

Large divergence of laser-driven electron beam reduces energy coupling efficiency from the heating laser to the fuel core.

The external magnetic field is applied to the “insulator” fuel before the compression beam irradiation.

(1) B-field generation and diffusion

(2) Fuel compression under strong B-field

(3) Laser plasma interactions and REB transport in B-field

(4) Thermal electron and α-particle confinement by B-field

Magnetized Fast Ignition Experiment
Integrated experiments of MFI scheme

Magnetic field diffusion time in the Au cone depends on electron conductivity and geometry of the cone.


Calculated 2D magnetic field profile (430 kA)

\[ t_{\text{diff}} = \frac{1}{2} \mu_0 \sigma r L \]

- **Diffusion time scale**: 860 ps
- **Electrical conductivity**: \(2 \times 10^6 \text{ S/m (0.1 eV-gold)}^*\)
- **Cylinder radius**: 50 \(\mu\)m
- **Diffusion spatial scale**: 7 \(\mu\)m cone wall

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Magnetized Fast Ignition Experiment
Integrated experiments of MFI scheme

Magnetic field can penetrate through the 7 µm-thick Au cone wall because the Au cone is heated by inductive current.

Temperature dependence of electrical conductivity


2D magnetic field diffusion dynamics
Integrated experiments of MFI scheme

Cu-doped solid ball were used in integrated experiment for visualization of energy-deposition and measurement of temperature.

Experimental set-up

- Cu-Kα spectroscopy
- Spherical crystal
- Cu-Kα imaging
- Flat crystal
- GEKKO-XII (2ω) for implosion
- Cu-doped CH solid ball (250 µmφ)
- Gold cone (45 deg. full angle)
- GEKKO-XII (1ω) for B-field

Graph:
- Peak normalized laser intensity vs. time [ns]
- Peak normalized magnetic field strength

(a) B-field generation laser pulse
(b) Compression laser pulse

S. Sakata et al., submitted.
Integrated experiments of MFI scheme
Temporal change of core compressed under external magnetic field was measured with a flash x-ray backlighting technique.

Backlight experiment layout

- Capacitor coil
- Spherically Bent crystal
- GEKKO-XII for implosion
- Gold hollow-cone
- GEKKO-XII for B-field generation
- Cu plate
- Image plate
- Cu-Kα backlight image on imaging plate
- (1) GEKKO-XII for B-field generation
- (2) GEKKO-XII for implosion
- (3) LFEX for X-ray generation

Cu-Kα backlight image on imaging plate

2D density profile

- Radial distance (µm)
- Distance (µm)
- $t = 0.38$ ns
- $t = 0.72$ ns
- $t = 0.92$ ns
Integrated experiments of MFI scheme
REB energy deposition in the shocked region and the far edge of the core was clearly enhanced in the magnetized core.
Integrated experiments of MFI scheme

REB energy deposition in the shocked region and the far edge of the core was clearly enhanced in the magnetized core.

Heating before the max. compression

Heating at the max. compression
Integrated experiments of MFI scheme

Efficient laser-to-core coupling (~8%) was achieved even with a relatively small $\rho R$ core (~0.1 g/cm$^2$) by application of external $B$-field.

**Cu-K$\alpha$ spectra**

- Heating with B-field
- Heating without B-field
- Compression only

**Dependence of laser-to-core coupling**

- Laser energy [J]
- Laser intensity [W/cm$^2$]

- Solid marks $t = 0.61 – 0.72$ ns
- Open marks $t = 0.37 – 0.42$ ns

Magnetized Fast Ignition Experiment
**Heated region imaging of magnetized fast ignition scheme**

Fresnel Phase Zone Plate (FPZP) was used to image both Ti-$K_\alpha$ and Ti-$He_\alpha$ emissions from cold and heated regions.

**X-ray imaging with FPZP**

\[ f = \frac{a^2}{\lambda} \]

\[ f = 136 \text{ mm} @ \text{Ti } He_\alpha \text{ line} \]

\[ f = 130 \text{ mm} @ \text{Ti } K_\alpha \text{ line} \]

Ti contained solid ball target

**Visualization of heated region**

Magnetized Fast Ignition Experiment
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