FIREX Project of Osaka University
Present and Future

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Collaborators of the FIREX-I project


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Back ground and outline of this talk

• Fast Ignition Research was selected as one of the 4 main fusion projects of Japan in 2003.

• FIREX (Fast Ignition Realization Experiment) project has started as a collaboration program among Osaka Univ., NIFS, and other universities.

1) Introduction
2) Present status of FIREX project
3) Recent topics
4) Future plan
FIREX project toward Fast Ignition

- **GEK**
- **GEKKOMII**
- **NIF USA**
- **OMEGA, '96 (LLE, USA)**
- **GE**
- **'85-86**
- **'88-89**
- **Fast Ignition**
- **2001, ILE**

**Graph Details:**
- **X-axis:** Plasma Temperature (°K)
- **Y-axis:** Fusion Parameter (sec/m³)
- **Legend:**
  - Q=100
  - Q=1

**Projects and Dates:**
- **FIREX-I**
- **FIREX-II**
- **NIF** USA
- **GEK**
- **GEKKOMII**

**Institutions:**
- **LLNL, USA**
- **Lincoln Lab, USA**
- **ILE, USA**

**Additional Information:**
- **Fast Ignition**
- **Q=100**
- **Q=1**
600g/cc implosion and high efficiency heating of imploded target to 1keV

Si activation data

Azechi, Laser & Particle Beams 1990

Kodama, Nature 2002

Neutron Yield

Heating Laser Power (kJ)

Coupling 30%

Coupling 15%

Azechi, Laser & Particle Beams 1990

Kodama, Nature 2002
Heating Laser Specification for FIREX-I

Wavelength: 1053 nm (Nd: glass laser)
Pulse energy: 10 kJ
Pulse width: 1-20 ps (FWHM)
10 ps (typical)
Pulse shape: trapezoid with <2 ps rise time
Focal spot: 20-30 μm (≥50 % encircled energy)

Option: 10 kJ/1 ps, 5 kJ/0.5 ps (for high-field science)

(Ion driven fast ignition)
Present status of heating laser construction

06.5.19 3.6 kJ/1 beam (narrow band)
(Full beam equivalent = 14.4 kJ)
06.7 2 kJ/1 beam (broad band)

32.5 cm
FIREX-I Project Milestone

F. Year | Laser construction | plasma exp. & target fabrication

- 2003  | FIREX-I laser construction started |
- 2005  | Completion of amplifier  |
- 2006.5| 14.4kJ output energy |
- 2006.11 | Compressor beam alignment |

1) Cryogenic foam shell cone target fabrication and implosion test

2) Completion of FI3 and cone target design

- 2007.7 | 1 beam experiment | $D_2$ exp. ~2kJ input |
- 2008.3 | 4 beam experiment | $D_2$ exp. ~10kJ input |
- 2009  | $D_2$ 5keV heating |
- 2010  | DT experiment aiming at $Q=0.1$ |
Coherent combining of multi-short pulse laser beams has been tested.

**FIG. 6.** Compressor arrangement using two tiled gratings.

**FIG. 7.** (a): Prototype mechanics of tiled grating assembly holding a 200mm x 400mm grating and a small reference grating. (b): Stability test of phase locking of two gratings.
For FIREX-I

Cryogenic Target
- Diameter : 500 $\mu$m
- Fuel layer : $\sim$20 $\mu$m
- Fill tube: $\sim$10 $\mu$m$^\phi$
- DT fuel: $\sim$20 $\mu$m
- Foam density: $\sim$10 mg/cc

Present achievement;
Fill tube diameter: 30 $\mu$m$^\phi$
Foam density: 100 mg/cc, working gas: D$_2$

IAEA-FEC(2006), A.Iwamoto
Radiation loss by carbon contamination; 
Upper limit of foam density is 0.02 g/cm$^3$
Shell targets are made of Oil/Water/Oil emulsion.

Density matching of O/W/O emulsion is essential for target uniformity.

However, polymerization requires high temperature that degrades the density matching.

We have found a catalyst that accelerates polymerization at room temperature.

In-situ test of liquid D2 target

Transfer tubes

Deuterium gas line

Target exchange area

Foam supplied by GA

Filling tube
Preheat level is tolerable and not anomalous.

\[ \lambda = 527 \text{ nm}, \quad I = 1.1 \times 10^{14} \text{ W/cm}^2 \]

Tolerable preheat level = Fermi energy 5 eV.
Hydrodynamics of a foam cryogenic layer was tested by experiments and no anomalous preheating.
FI$^3$ Project
Fast Ignition Integrated Interconnecting code

Density

ALE radiation-hydro code

Laser plasma interaction

Fokker-Planck equation (hot electron transport)

$10^4 n_{cr}$

$2000 n_{cr}$

$\sim n_{cr}$

Cone-guided target

PW Laser

Laser for implosion

radius
Bremsstrahlung Emission Profile of 2-D Fluid Simulation agree with experimental result (2D-SIXS).

Simulation (PINOCO) \( n_e^2 x T^{1/2} \)

Experiment (temporal x-ray image at GXII, 2D-SIXS, Lee, et al)

Resolution time ~ 24[ps]
Space ~ 20[\mu m]

Temporal interval ~ 24[ps]
FIREX-I target design

Cone tip can survive till the maximum compression time.

Gold cone

Density contour

Temperature contour

2.29ns

2.30ns

2.40ns

2.41ns

100µm

20µm

2.29ns

2.30ns
High energy electrons are confined at cone tip

\[ \text{(energy density)} / N_c \text{mc}^2 \]

After laser pulse

\[ \text{(Quasi static field energy density)} / [(E_L^2 + B_L^2) / 2] \]

After laser pulse

Temporal evolution of electron energy stored in cone

25% is stored for a long time
Fast ignition experiments (Nature, 2002, ILE and UK) are reproduced with \( \sim 1 \mu \text{m} \) scale length (Fokker Planck simulation combined with Hydro and PIC code). Note that delayed heating is found very important.
Advanced cone-target design for FIREX-I

- Reducing the radiation loss by coating plastic on cone surface
- Tip of cone is close to core plasmas
- Inside of cone is coated by a foam layer
We started the study for introducing ion driven fast ignition in FIREX-1

- Energy injection and momentum injection
- 1 Tbar pressure could be produced by relatively low velocity and high density ion beam injection.
A New Fast Ignition Scheme: “Impact Fusion”

Target is composed of two components:
1. A spherical pellet
2. Impactor: A spherical foil with cone guide

Requirements for impact ignition
- Main fuel: compression to 1000 times solid density
- Impactor: acceleration to $>1000$ km/s and compressed to $>10$g/cc


IAEA-FEC 2006, IF/1-1; H. Azechi et al.
in collaboration with NRL
Experimental results

Neutron yield is enhanced by the impact of hemispherical CD.

Schematic of the impact heating experiment

**Main**: 2ω, $E = 3$ kJ
- CD shell: 7 µm
- Diameter = 500 µm

**Impactor**: 2ω, $I < 200$ TW/cm²
- Hemispherical CD: 10 µm
- Diameter = 500 µm

Neutron yield with impact is about a hundred times as large as that without impact.
Summary

• Fast ignition research in FIREX-I has been progressing.
• Construction of peta watt laser for FIREX-I is in final stage.
• One beam experiment is scheduled in 2007 and full beam experiment will start in 2008 with 10kJ/10ps LFEX.
• Foam cryogenic cone shell target has been fabricated.
• Preheating level of a foam cryogenic D₂ later is controlled by adding a thin high Z layer.
• Integrated simulation code for fast ignition was developed. The simulation code reproduces Kodama Exp. (Nature ‘01) and recent experiments.
• The simulations indicate \( \rho r = 0.2 \text{ g/cm}^2 \) and \( T=5\text{keV} \) (20% heating efficiency) under some assumptions.
• A new ion beam fast ignition concept “impact fusion” is on line of FIREX-project.
Plan of FIREX Project

Japan FY

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- **Heating Laser**: 1 PW, 1 kJ/1ps
- **Implosion Laser**: GEKKO XII, 10 kJ/2ns/0.53μm

**KD1**: FIREX-I has started based on 1-keV heating
**KD2**: FIREX-II will be started based on 5-10 keV heating

**NIF ignition**
In-situ test of liquid D2 target

Deuterium gas line

Transfer tubes

Target exchange area

Foam supplied by GA