Fast Ignition Realization Experiment and Prospect to Inertial Fusion Energy in Japan

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Magnetic and Laser Fusion

Magnetic Fusion

- Coil
- Magnetic Field
- Fusion Plasma

One Billionth of Solid Density \((10^{-9})\)
Fuel Diameter: 10 m
Steady State Reactor → Base-load

ITER Organization
Japan Atomic Energy Agency
National Institute for Fusion Science

Laser Fusion

- Laser
- Lens
- Fusion Plasma

Thousand Times Solid Density \((10^3)\)
Fuel Diameter: mm → Compact
Pulse Reactor → Peak-load

Lawrence Livermore National Laboratory
French Atomic Energy Commission
Osaka University
Central and Fast Ignition Schemes

Central Ignition proposed by J. Nuckolls in 1972

Diesel Engine
- Compression
- Ignition
- Burn

Fast Ignition proposed by T. Yamanaka in 1983

Gasoline Engine
- Spark Plug
- Forced Ignition
- Compactness

Compact fusion will accelerate inertial fusion energy development.
Fast Ignition Realization EXperiment

Nano-sec Implosion Laser GEKKO-XII

Pico-sec Heating Laser LFEX: World largest pico-sec laser

So far, 1-keV is demonstrated.

FIREX-I Heating to 5 keV
FIREX-II Ignition and burn
Approach to ignition temperature

Fiscal Year
2013 Heating Basics
2014 4-Beam operation Heating Scaling
201x 5-keV Heating
201x Check-and-Review of FIREX-I

1: increasing laser energy
2: increasing heating efficiency

Fast Electron Guiding by B Field
LFEX: 1 beam to 4 beams

Ignition Temperature

Temperature (keV)

Heating Laser Energy (kJ)

10

1

0.1

0.01

0.1

1

10
1: increasing laser energy

Giant Lasers developed in the past 40 years

Peta Watt 1996

GEKKO-II 1983

GEKKO-MII 1979
GEKKO-IV 1977
GEKKO-II 1973

2 kJ 1ns

0.5 kJ 0.5 ps

Precision gratings ensure high energy output.

LFEX 2009

2014
4 beams
10 kJ /10ps

2013
3 beams

2011
2 beams

2009
1 beam

10 kJ 10 ps

180 cm

Photograph by Joe Nishizawa
2: increasing heating efficiency

Fast Ignition Target
Nature 2001, 2002

High B Field

Fast Electron Guiding by B Field
⇒ Efficient heating

Heating Laser

Fuel Gain > 2 (2014)

Worldwide collaboration on new concepts

Ignition

Fujioka, Thu Morning

NIF-0909-17173.ppt
Moses, Plenary talk IFSA 30
Atomic Energy Commission of Japan reported (Oct. 2005): “Based on its (FIREX-I) achievement, decide whether it should be advanced to the second-phase program aiming at the realization of ignition and burning”

*Laboratory Inertial Fusion Test
Two innovations for high repetition laser

From Flush Lamps to Diodes

Flash Lamps
Broad spectra → Inefficiency

Laser Diodes
Emission lines ≈ absorption lines

100 times efficiency

From Glasses to Ceramics

Laser Glasses
• Large optics
• Low thermal conductivity

Yb: YAG Cooled Ceramic Crystal
• Large optics
• High thermal conductivity

1000 times thermal conductivity

DiPOLE (UK Rutherford Lab.)
10J, 10Hz

Outflow

Lucia (France LULI)
>10J, 10Hz

ELI Beamlines (Czech)
L2: 100J, 10Hz

GEMBU Laser 1J, 100Hz

Cooled Ceramic Crystal Laser developed in ILE becomes Global Standard.
EUV project has already demonstrated Target Injection and Beam Pointing.

Unsynchronized Backlight

Synchronized

Laser

**never miss the target**
First Fusion Target Injection


4 posters on Thursday
Cascade Liquid Wall

Laser fusion chamber has
• Cascaded liquid wall
• Beam port protection

Demo of reactor core plasma is critical
Experimental Test Facility, LIFT for power generation

- Implosion Laser 500 kJ 4Hz
- Heating Laser 150 kJ 4Hz
- Fusion output 300 MW
- Electric output 100 MW

Diagram:
- Laser fusion
- Fuel pellet injection
- Electric power transmission
- Steam turbine
- Electrical generator
- Water vapor
- High power laser
Experimental reactor (i-)LIFT integrates all physics and engineering activities.

(i-)LIFT is Laser based Fast Track. Revised in 2014
Strategy to Practical Use (Plan)

【Guidelines】
・国産技術の活用と光技術の進展
・確実な目標設定とスケーラビリティ
・新産業基盤技術の創成
・既存産業におけるイノベーション

Non-destructive test by trailer-top γ source

Space debris elimination

Fusion Laser >MW

Optical technology evolution

Industrial Innovation

*Optical material
*Polishing
*Multi layer coating

CFRP manufacturing

Solar Battery・FPD (PolySi, Cutting)

GENBU Yb:YAG Ceramic 1J, 100Hz
HALNA 20 20J, 10Hz

Beam Cancer Therapy

約10m
Alliance with

International
Industrial
Academic

Communities
World Centers for High Power Lasers

- **CEA: LMJ** (France)
- **EP: LULI** (France)
- **RAL: CLF** (UK)
- **EU: ELI** (Europe)
- **Russia: UFL-2M** (Russia)
- **Russia: XCELS** (Russia)
- **JAEA: J-KAREN** (Japan)
- **Japan: GEKKO/LFEX**
- **OSAKA UNIVERSITY**
- **USA: UofR: LLE** (US)
- **LLNL: NIF** (US)
- **US**
- **UFL-2M** (Russia)
- **UFL-2M** (Russia)
- **XCELS** (Russia)
- **OSAKA UNIVERSITY**
- **NATIONAL JOINT USAGE/RESEARCH CENTER**

**Notes:**
- Asia
- Europe
- Japan
- LLNL: NIF
- US
- UofR: LLE
- World Centers for High Power Lasers
- Europe
- Russia
- Asia
- Japan
- UFL-2M
- XCELS
- OSAKA UNIVERSITY
- National Joint Usage/Research Center
- RAL: CLF (UK)
- EP: LULI (France)
- EU: ELI (Europe)
- Russia: UFL-2M (Russia)
- Russia: XCELS (Russia)
- JAEA: J-KAREN (Japan)
- Japan: GEKKO/LFEX
- USA: UofR: LLE (US)
- LLNL: NIF (US)
- World Centers for High Power Lasers
- ORION (UK)
- HiPER (EU)
- Vulcan (UK)
- LMJ (France)
- SG-III (China)
- FIREX (Japan)
- UFL-2M (Russia)
- NIF Laser

**28 2012-041814.pptx**
Photon Industries in Japan

Laser Technologies created in GEKKO Series

Random Phase Plates
Kato, PRL1984

Large Format Grating

Laser Glasses
Yamanaka, Izumitani

Nonlinear Cristal
Sasaki, APL1995

Ceramic Crystal
Ueda, Appl. Phys. Lett. 2001

Contribution to Growth of Industries

World-class photon industries and engineers are created.
Industry’s Engagement into Laser Fusion

TOYOTA’s President Emeritus, Sho-ichiro Toyoda, visited ILE, Osaka

TOYOTA is not a company just to make automobiles. TOYOTA has responsibility to generate energy.

HAMAMATSU and TOYOTA demonstrated compact laser fusion system “TERU”

Latest Looming Machine has
Wept injection: >10 Hz, 80 m/s
pointing accuracy: better than mm

Diode pumped laser
100 J, >10 Hz
Contributions to basic science

Hydrodynamics

- Implosion

Science

- Meteorite Collision

High Field

- Efficient Heating

- Nonlinear Zeeman
- Landau Quantization
- Vacuum Breakdown

Plasma Phys.

- Electron Stream

Nature Geosci. 2014


Nature Physics 2012
**Meteorite Collision**

**Sulphate-rich vapor**

Murchison vs Anhydrite
Impact velocity (km/s)

![Diagram showing impact velocity and sulphate ratio](image)

- **SO_3** dominated
- Shock pressure (GPa)
- Global acid rain, destroying the ecosystem

**Laser Ablation Acceleration**

- **SUS支柱**
- **CH燃料** 50μm
- **タンタル** 飛翔体30μm

**Chicxulub crater at Yucatan**

**Dynasours Extinction**

A huge quantity of sulphur trioxide made sulfuric acid ocean.
Our mission

Near Future
- Industry
- Energy
- Science

Present
- Laser Development
- High Energy Density Science
- Laser Astro/Planets
- Fusion
Summary

• Fast ignition scheme is steadily ongoing as FIREX I project. We will achieve 5-keV temperature within a few years, with the increase of heating efficiency by magnetic field guiding of electron beam and the full performance operation in LFEX.

• Toward future power plant, we are developing high rep. rate laser technologies including ceramic lasers invented by ILE.

• Our activities toward fusion energy are also contributing to enlarge photonics industry, basic science research with intense lasers, and the education of people for all of these related society.