Progress of Inertial Confinement
Fusion Research in Japan

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1. Introduction

Fusion research is being vigorously pursued in the world with the ultimate goal of generating power from controlled thermonuclear reactions. The two major approaches are magnetic confinement fusion and inertial confinement fusion. The former has a long history to struggle with several difficulties. The latter has experience of only ten years. But the rapid advances have been performed. Now we can get a step to discuss the feasibility of breakeven. Recently

there become several drivers to be applicable for fusion research which will increase the possible ways to advance. This IAEA meeting of inertial confinement fusion dedicated for advances of systems is the fifth meeting of a series of these meetings. From the memory of these meetings we can certainly trace the advances of inertial fusion research.

Japanese effort on laser fusion has started since 1964. From the beginning, Osaka University is a center of research. In 1971, anomalous absorption was experimentally observed. In 1979 Project KONGOH aiming breakeven of inertial confinement fusion has been contemplated. During these eight years, the laser power has increased with four orders of magnitude. There are now in Japan several facilities for fusion research. The Institute of Plasma Physics of Nagoya University has a fundamental research group of laser interaction. Gifu University, Tokyo Institute of Technology, Kinki University, Government Industrial Research Institute of Osaka, Institute for Fusion Theory, Hiroshima University and several institutes have a cooperative research with ILE Osaka University. Electrotechnical Laboratory is also expecting to have a laser fusion facility. REB and particle beam drivers are contemplated in several places. These situations are shown in Fig.1.

2. Research Program

Inertial confinement fusion technology consists of energy driver engineering, pellet target design and fabrication, compression experiment and reactor system study. The level of investigation can be elevated by the development of energy drivers.

In 1970's we have developed lasers of a few kJ which are used for laser plasma interaction and exploding pusher mode compression experiments. In 1980's the age of a few 10kJ lasers is expected when ablative compression will be performed. Achieving scientific breakeven is the major and the most important step in inertial confinement fusion research.

The objective of Project KONGOH is to demonstrate scientific breakeven by using a high power laser system. Project KONGOH is divided into two phases. In the first phase, 20kJ glass laser system GEKKO XII is constructed during 1980-1982. From 1983 this laser will be used for ablative compression experiment to demonstrate significant compression: $\rho \sim 100\text{gr/cm}^3$ and $\rho r \sim 0.1\text{gr/cm}^2$. In the second phase during 1985-1989, a few 100kJ laser system will be constructed. This laser will drive complex shell structure targets to achieve scientific breakeven. Fig. 2 indicates the research program of laser fusion at ILE Osaka.

In 1990's we will be able to approach a reactor concept by choosing a suitable energy driver of 1MJ level.

3. Energy drivers

As for driver development, the glass laser is the most developed laser which is preferable to have high output power.

At ILE Osaka GEKKO program has three glass laser systems. GEKKO II has been operated since 1975. It is a two beam silicate glass laser system with 4π target illumination. Output power is 0.4TW at 50ps which is mainly used for laser plasma interaction experiments and development of diagnostics.

GEKKO IV is the world's largest phosphate glass laser which can deliver 4TW at 100ps and 2kJ in 1ns. It has been operated since 1977. Four beam tetragonal irradiation to the target is adopted. Target chamber consists of turning mirrors, a beam focusing system and a target positioner. The focusing lens is a f/1.1 aspheric lens having a diameter of 13cm. Computer system, OKITAC-50 is introduced to command the GEKKO IV laser-target chamber system and also to process the experimental data. The accumulated data and the status of controlled facilities are displayed on a graphic pattern.

GEKKO XII is under construction. The modules of GEKKO XII has been completed to deliver 2TW at 100ps and 2kJ in 1ns per beam. In Fig. 3, one line of GEKKO XII-modules is shown. At IPP Nagoya, glass laser HALNA is operated which is one beam of 0.1TW at 100ps. It is used for laser plasma interaction and X-ray radiation experiments. And Nd glass laser of 400J, 10 ~ 100ns is used for plasma production for magnetic confinement fusion.

At ETL Tokyo, a single beam glass laser of 0.3TW at 100ps has been completed using for laser plasma experiment.

Carbon dioxide lasers are very attractive in aspects of high efficiency and cost effectiveness. At ILE Osaka, LEKKO Program is persued. It has three laser systems. LEKKO I is a single beam astable cavity CO₂ laser which can deliver 1kJ in 80ns. It is mainly used for laser plasma coupling experiments.

LEKKO II is a two beam, multiline laser system of 1kJ in 3ns. It is working for compression experiment since 1977.

LEKKO VIII is an eight beam system of 10kJ in ns which will be completed in 1980. In Fig. 4, a model of LEKKO VIII laser is shown.

As for the advanced lasers, rare gas halide lasers have been investigated at ILE Osaka, ETL, University of Electro-Communications,

Institute of Physical and Chemical Research and several universities. HF laser is studied by Keio University.

Supporting technology for laser is promoted by the Laser Developing Committee which is organized by ILE Osaka and industry.

Electron beam driver can produce high energy at high efficiency. At ILE Osaka, REIDEN III had been constructed which has the beam performance of 500keV, 100kA and 4kJ in 80ns. It is mainly used for beam-plasma interaction and ion beam generation. REIDEN IV is completed to deliver the output power of 1MeV, 1MA and 100kJ in 50ns. In Fig. 5, REIDEN IV is shown.

At IPP Nagoya, PHOEBUS II is completed which delivers 0.8MeV, 270kA and 8kJ in 30ns which is used for intense REB ring for plasma confinement. Heavy ion driver is considered preliminarily.

4. Target design and Fabrication

Pellet design and Fabrication have an important role in performing inertial fusion. Exploding pusher targets are suitable to use for the high neutron yield. A scaling law of neutron yield was obtained for optimum combination of target size and laser pulse width, of which simulation is in good agreement with experimental data. We have also investigated energy relaxation of high energy electrons to a bulk plasma and their energy loss due to the generation of fast ions.

Using a thick polyethylene coated pellet target, we can have quasi ablative compression experiment by 4TW glass laser GEKKO IV.

Fig. 6 is typical result of ablative compression simulation of 1 dimensional 1 fluid 2 temperature Lagrangian code provided with laser

absorption due to classical and anomalous, hot electron temperature given by Fokker-Planck equation with multi-group flux limited diffusion model, ambipolar self-consistent electric field, relaxation between hot electron and bulk electron and ionization due to Saha equation.

We have been developing various kinds of techniques for pellet fabrication. The Pellet Target Committee is organized by ILE Osaka and industry. Government Industrial Research Institute of Osaka has been involved in the glass micro-balloon manufacturing using liquid and Gel systems. It has developed techniques of homogenous glass micro-balloon the diameter of which is a few 10 μm to 100 μm . Kinki University has made deuterated polystyrene micro-balloon by emulsion method. Cryogenic shell target is successfully tested at MAPI. ILE Osaka has target fabrication laboratory to assemble pellet targets for experiment. Double shell target and polyethylene shell with gas inlet pipe have been fabricated.

5. Compression experiment

Energy balance between input energy and distributed energy has been studied. Fast ion carries about 20 ~ 40% of absorbed energy. Thomson parabola ion analyser was widely used. The fast ion from polyethylene coated target has a sharp cut at the velocity of 4×10^8 cm/sec.

Dynamics of ablative compression have been investigated by the X-ray back lighting and X-ray streak photography. The deformation of the pellet under irradiation of laser light has firstly observed as shown in Fig. 8. Scaling law of compression velocity v to laser energy E is given by simulation: exploding pusher mode $v \propto E^{1/2}$ and ablative

compression mode $v \propto E^{4/5}$. Experimental results are in good accordance to the simulation data as shown in Fig. 9.

The compression density is estimated from the shift of emission band edge of Ne in pellet. When the 10 μm thick polyethelene coated glass micro-balloon of 80 μm in diameter was irradiated by 4TW, 100ps GEKKO IV system, the core reached $5\text{gr}/\text{cm}^3$. Fig. 10 shows the shift of emission band edge of Ne in pellet under compression.

Neutron and α particle yield has been studied. In the case of exploding pusher compression, neutron yied scaling is given as follows: model estimation is $N_y \propto P^{1.8}$, 1D simulation is $N_y \propto P^{1.7}$ and experimental result is $N_y \propto P^{1.6}$. Fig. 11 shows the experimental data of the neutron yield.

As for the diagnostics of fusion experiment, the experimental system becomes large enough to use the data aquisition and processing equipment. ILE Osaka has adapted computer Melcom Cosmo 700II (2MB, 1.68 μs) for this purpose.

6. Reactor Conceptual Design

To obtain a brief idea of future approach and the present situation, ILE Osaka has organized the Committee of Inertial Confinement Fusion Conceptual Design.

The items examined and designed are as follows.

1. Design and fabrication of high gain pellet
2. 1MJ energy driver
3. Concept of magnetically guided Li flow blancket reactor
4. Reactor materials
5. Safety and environment
6. Economics of ICF reactor

The results on this effort are shown in Table 1. Pellet gain is expected to be more than 200 and laser power is about 1MJ.

Magnetic guided Li liquid inner blanket, the thickness of which is 60cm indicates a very effective protection of reactor wall and Flibe outer blanket can give higher temperature for reheated cycle of the system.

7. Conclusion

Since ICF has made a big stride, progress of energy drivers, target fabrication, laser experiments and theoretical study are significant. We have gotten an increasingly large choice of energy drivers. Glass laser is the most advanced effective system for compression experiment. ILE Osaka is going to have GEKKO XII 20kJ 12 beam laser. CO₂ laser and other gas laser may be strongly attractive to the large scale driver design. We will have LEKKO VIII 10kJ 8 beam laser soon. REB is very simple to build, although it needs more fundamental study for fusion application. ILE has REIDEN IV, 1MV, 1MA, 100kJ system. Heavy ion beam is expected in future.

However, the scale of energy driver for fusion reactor becomes larger and larger when the research advances further. This tendency demands the international cooperation to reduce the duplication in research and to promote the effective progress. Design of target and development of compression code are at present some stringent issues. From the scientific point of views, these problems belong to the item of simple physics and are expected to discuss freely.

The compression experiment now comes to the beginning of ablative mode. ILE Osaka has recently succeeded in compressing pellet to a

density of 5 gr/cm^3 . In a few years, higher compression will be attained up to 100 gr/cm^3 . Even though the diagnostics of the compression core have large difficulty, measurements of high resolution in space and time should be developed to accomplish the high compression scheme. We have measured the deformation of the pellet surface during compression by X-ray back lighting method. The stability of the compression is a very interesting physics in ICF. High speed X-ray streak camera becomes very popular in experiments.

Conceptual design of ICF reactor may give us useful suggestion in the approach of present investigation. Magnetically guided liquid Li flow blanket give us a promising concept for inertial confinement fusion reactor.

R E F E R E N C E S

1. C. Yamanaka: Annual Progress Report on Laser Fusion Program (1978) ILE Osaka University
2. H. Azechi, C. Yamanaka et al: ILE Research Report ILE 7904P (1979)
3. H. Azechi, C. Yamanaka et al: ILE Research Report ILE 7905P (1979)
4. K. Mima et al: ILE Research Report ILE 7906P (1979)
5. K Nishihara et al: ILE Research Report ILE 7908P (1979)

Figure captions

- Fig. 1 Inertial confinement fusion facilities in Japan
- Fig. 2 Research program of laser fusion at ILE Osaka
- Fig. 3 Glass laser GEKKO XII-Modules
- Fig. 4 CO₂ laser LEKKO VIII Model
- Fig. 5 REB REIDEN IV
- Fig. 6 Simulation of glass microballoon with various coating
- Fig. 7 Lead mixed polyethylene coated glass microballoon
- Fig. 8 Deformation of pellet under laser irradiation measured
by X-ray back-lighting
- Fig. 9 Compression velocity of exploding pusher mode
- Fig. 10 Shift of emission band edge of Ne in pellet
- Fig. 11 Scaling law of Neutron yield
- Table 1 Conceptual design of laser fusion reactor

Inertial Confinement Fusion Facilities in Japan

ILE OSAKA	Glass laser, Theory, CO ₂ laser, REB
IPP NAGOYA	Glass laser
TOKYO INST TECH	REB
GIFU UNIVERSITY	Glass laser
HIROSHIMA UNIVERSITY	Theory
ELECTRO TECHNICAL LAB	Glass laser, CO ₂ laser
SEVERAL LABORATORIES	Lasers
INDUSTRIES	Related technology

Fig. 1

KONGOH PROJECT OBJECTIVES Scientific Breakeven

- 1st Phase 20kJ 40TW Glass Laser
1980-1984 GEKKO **XII**
Appreciable Compression
- 2nd Phase 100kJ Driver
1985-1989 Breakeven
1MJ Driver → Energy Yield

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

X - R A Y S H A D O W G R A P H Y

TARGET : CH₂ SHELL 150 $\mu\text{m}\phi$, 5 $\mu\text{m}t$

LASER POWER : 0.67 TW/ 120 PSEC

DELAY 200 PSEC

450 PSEC

350 PSEC

500 PSEC

DELAY 400 PSEC

DELAY 1000 PSEC

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Table 1. Conceptual design of laser fusion reactor

LASER	
OUT PUT (E_I)	1MJ
REPETITION	1Hz
EFFICIENCY (η_I)	10%
BEAM TRANSFER EFFICIENCY	100%— (90%)
PELLET GAIN (G)	1000
ENERGY FLOW	
THERMAL OUT PUT E_{TH}	1000(0.8M + 0.20)
	M: BLANKET GAIN
	$M_B: 0.8M + 0.2$
	M = 1.3
	CHOICE
	RATIO OF ${}^6\text{Li}$ TO ${}^7\text{Li}$
	T-BREEDING RATIO
	$E_{TH} = 1240\text{MJ}$
CONVERSION EFFICIENCY	40%
ELECTRIC OUT PUT	496MJ
CIRCULATING ENERGY	20MJ
OUTGOING ELECTRIC POWER	476MW
OVER ALL SYSTEM EFFICIENCY $\frac{E_e}{E_{th}}$	= 38.4%
REACTOR STRUCTURE	
MAGNETICALLY GUIDED L_I FLOW	
REACTOR CAVITY SUS 316	
OPERATION TEMPERATURE 400°C	