Investigation toward Laser Driven IFE Power Plant

S. Nakai 1), Y. Kozaki 1), Y. Izawa 1), M. Yamanaka 1), T. Kanabe 1), Y. Kato 1), K. Mima 1), H. Nagatomo 1), H. Furukawa 2), K. Yamamoto 1), M. Kabetani 1), T. Norimatsu 1), K. Nagai 1), M. Nakatsuka 1), T. Jitsuno 1), T. Yamanaka 1), C. Yamanaka 2)

1) Institute of Laser Engineering, Osaka University, Osaka, Japan
2) Institute for Laser Technology, Osaka, Japan

e-mail contact of main author : nakai@ile.osaka-u.ac.jp

Abstract. Inertial fusion energy (IFE) is becoming feasible due to the increasing understanding of implosion physics. Reactor technology issues have begun to be developed. Based on the conceptual design of Laser Driven IFE Power Plant, the technical and physical issues have been examined. R&D on key issues that affect the feasibility of power plant have been proceeded taking into account the collaboration in the field of laser driver, fuel pellet, reaction chamber and system design. It is concluded that the technical feasibility of IFE power plant seems to be reasonably high. Coordination and collaboration scheme of reactor technology experts in Japan on Laser Driven IFE Power Plant is being proceeded.

1. Introduction

The establishments of gain scaling of implosion fusion with the evaluation of the tolerable conditions on driver and fuel pellet is the most important issue. The worldwide efforts to clarify the implosion physics have given us a feasible prospect toward the achievement of fusion ignition, burning and energy gain. It is also expected to be demonstrated within next decade by the MJ laser which is under construction.

The reactor technologies for IFE (Inertial Fusion Energy) power plant have been identified and evaluated through the conceptual design studies. Various kinds of power plants can be designed with different selections and combinations of elements such as implosion scheme (that is fuel pellet), driver, and chamber. Typical candidates of each element to set up a specific power plant are listed in TAB I. Power plant "SENRI" was reported in 1981 [1].

TAB.I. DESIGN SELECTION OF IFE POWER PLANT AND DESIGN STUDIES AT ILE.

Implosion	Driver	Chamber	Power Plant
Direct	DPSSL	Dry Wall	New Design
Hybrid	KrF	Wetted Wall (+thick guided flow)	KOYO
Fast Ignition	Pulse Power	Peble	
Indirect	HIB	Thick liq. flow	SENRI

Although it was so primitive to utilize direct drive implosion with CO_2 laser, it is unique to utilize magnetically guided thick Li flow to form cavity protecting the first wall. Replacing the CO_2 laser with DPSSL (Diode Pumped Solid State Laser), this concept is still interesting to refine with modern knowledge on reactor technology."KOYO" was reported in 1992 [2], which was designed taking into account the newest gain scaling of direct drive at that time, and the progress and perspective of DPSSL technology. A wetted wall that is formed with seeped out LiPb layer from guided flow in woven SiC pipes is the key concept of the chamber. The feature of system design of KOYO is the arrangement of multiple chambers to one driver. This gives us wide flexibility in optimizing the system design. The key elements of KOYO have been developed and investigated with a world widecollaboration [3].

Fast ignition concept has interesting feature in power plant design. That is high gain with relatively small drive laser energy and smaller energy release. Instead, higher repetition is required to get reasonable average power of electricity. Dry wall concept of reaction chamber has been begun to be reexamined for the fast ignition concept and also for the central ignition concept.

Technologies for IFE power plant spans over wide fields of engineering. Nation wide collaborative system such as R&D network or virtual laboratory, together with an international coordinated research program will be effective and beneficial for the progress of the IFE and also for related experts. The Japanese activities and international relation in the IFE reactor technologies are reviewed.

2. Driver

2.1 DPSSL Development

A diode pumped solid state laser (DPSSL) is a promising candidate of reactor driver for IFE. We have newly designed a DPSSL driver HALNA 1k (High Average-Power Laser for Nuclear-Fusion Application) based on a water-cooled zig-zag path slab amplifier module, which can deliver 10 kJ output energy at 350 nm with 12 Hz repetition.

A 10 J x10 Hz module,HALNA 10, has been constructed to investigate and confirm the technical key issues of this concept of DPSSL such as thermal effects, beam quality, energy flow and efficiency, and life of key elements such as cooling surface, laser slab, and diode. It can be scaled up as shown in Fig.1 to reach to a 10 kJ x 10 Hz module which consists of 15 beamlet with phase coupled beam combining.

The details of 10 J x 10 Hz module and its first results are reported by M. Yamanaka at IAEA-CN-77-IFP/03 in this meeting [4]. The progress of single shot based laser for ICF research and high average power laser with repetitive operation of IFE power plant is shown in Fig.2.

2.2 Uniformity Improvement for Solid State Laser Driver

The applicability of solid state laser as to the reactor driver strongly depends on the capability to achieve uniform irradiation onto the fuel pellet for its stable implosion. Several important concepts and technologies for a better irradiation are under investigation such as pulse shape control with PCL (partially coherent light) foot and coherent main pulse, and phase and spectral control of high power main beams.

Fuel pellet design in conjunction with the driver specification for a better fusion implosion is one of the most important issues in the near future for the laser fusion energy development. Better uniformity than 1 % can be expected with increasing beam number and spectral width of glass laser. Figure 3 shows some combination of driver beam and fuel pellet structures [5] to mitigate driver nonuniformity for uniform implosion.

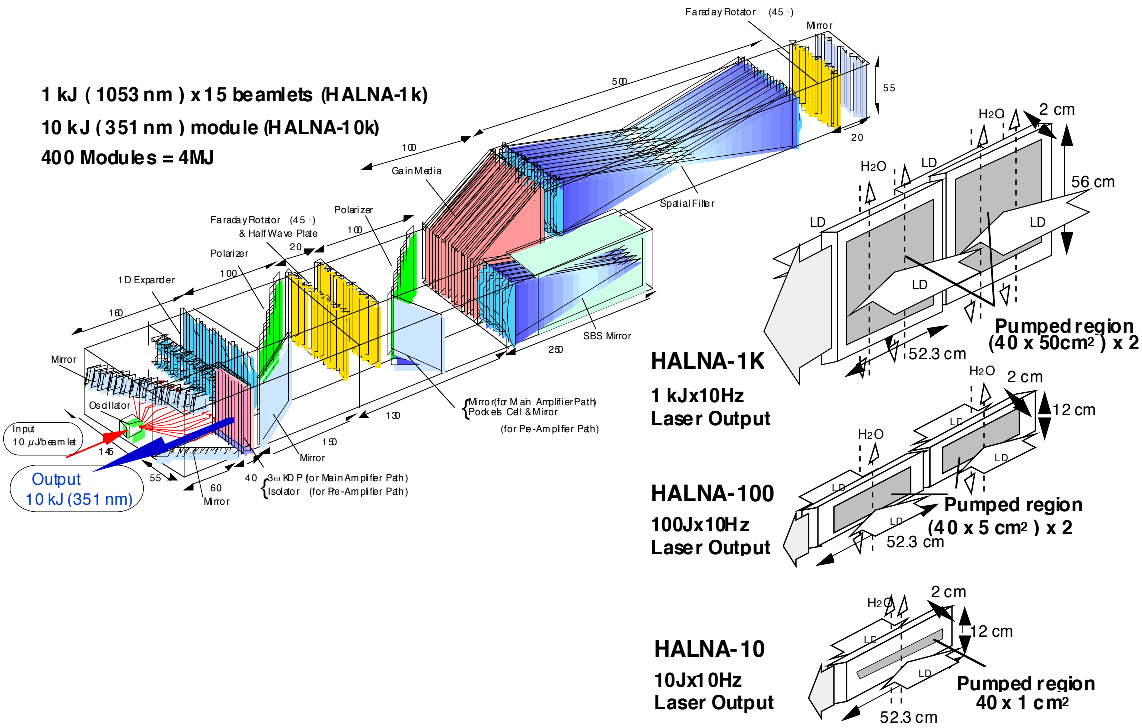

Fig.1 Development plan for reactor driver module of 10 kJ x 10 Hz starting from equivalent mini-module of 10 J x 10 Hz .

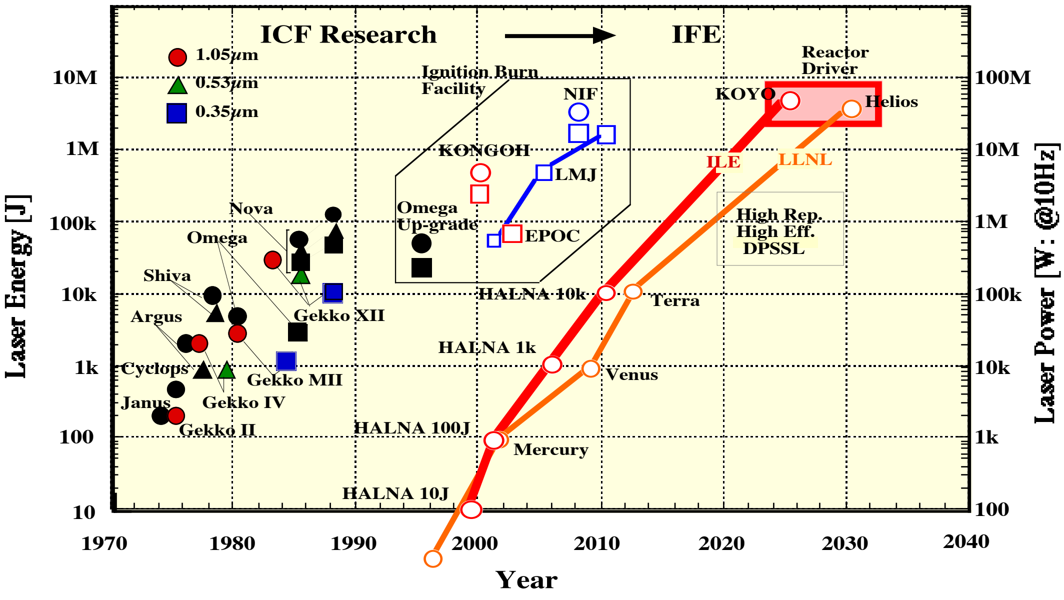

Fig.2 Progress of ICF and IFE laser drivers.

3. Reaction Chamber

3.1 Evaporation, Condensation, and Clearing of Wetted Wall Chamber

The evaporation and following condensation of LiPb were investigated for estimating the recovery time of the chamber vacuum in KOYO design study. The evacuation speed of the chamber was calculated as a function of the chamber radius, and it was within 0.1s to be evacuate to 0.5 mTorr for the radius of 4 m. The condition for the generation of LiPb mist was also investigated, and if the gas pressure is less than 10 mTorr at the gas temperature of

1000˚K, the mist would not be generated. For the dynamic analysis in high vacuum region better than 10 mTorr, we developed a simulation code, in which the Boltzman equation is solved with the Monte-Carlo analysis for the particle dynamics. The detailed dynamic behaviors including gas flow and wall particle interaction are now investigated with this code, and reported by Y. Kozaki at IAEA CN-77-FTP1/27(R) in this meeting [6].

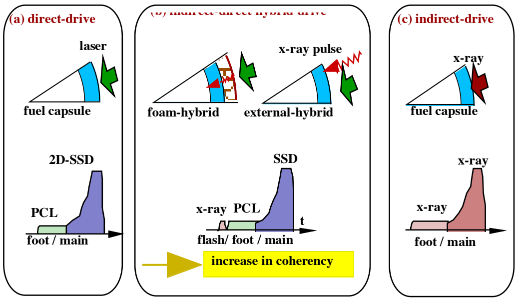

Fig.3 Combination of various fuel pellet and structure of driver radiation to mitigate he effect of drive nonuniformity.

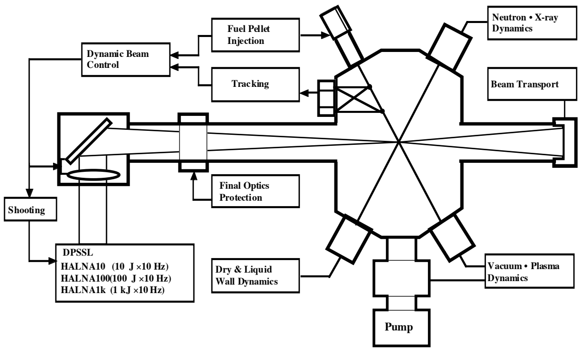

Fig.4 Integrated Reactor Engineering R&D for IFE power plant.

3.2 Reexamine the Dry Wall Concept

If the dry wall chamber can contain the repetitive micro-explosions which release reasonable average fusion power for longer period than several years, we can design very attractive power plant with less ambiguity on liquid wall chamber.

Following to the implosion and fusion explosion of a fuel pellet, a successive pulse energy flow hits the first wall of the chamber. They are reflected or scattered laser light, X-ray from fusion plasma, neutrons, and the plasma debris. The energy spectrum and pulses shape of each energy species for typical high gain implosion are estimated with burning simulation code. The dynamic responses of several dry wall materials such as C, V, Fe, and Ta are analyzed to examine the possibility to be used as the first wall of a reaction chamber.

The dry wall seems to survive against the energy fluxes of laser light, X-ray, and neutrons emitted from moderate fusion explosion with reasonable separation of the first wall. The heating and sputtering of the wall surface by plasma debris need more investigations to clear the response and life of the first wall. It should be noticed, however, that a distributed magnetic field or low-pressure gas in the cavity could mitigate the plasma flow hitting the wall for a longer life of a wall.

The capability of higher repetition of a dry wall chamber, together with multiple chamber concepts, can reduce over all cost of power plant by increasing the utility of the expensive laser driver. We are now proceeding detailed evaluation of the dry wall chamber and conceptual design of a laser driven dry wall power plant as shown in TAB.I.

4. Fuel Pellet

Precision fabrications of plastic fuel pellet to contain fuel inside have been well developed [T. Norimatsu : IAEA-CN-77-FTP/07] [7]. The DT fuel layering technologies are under developments.

The next step toward the power plant development is to demonstrate repetitive injection, tracking and shooting with repetitively fired laser. Mass production of fuel pellet with low cost is also important issue for realistic IFE power plant.

The effects of residual gas in the chamber onto the flying pellet are evaluated. They are coating effect on low temperature fuel pellet, heat flow by gas and radiation, disturbance to the flight trajectory. It can be concluded that 3 Hz operation of a liquid wall chamber is acceptable. The pressure of protecting gas for dry wall chamber must be optimized to increase the protection effect.

5. Conclusion

The key components and issues for IFE power plant are shown in Fig.4 illustratively for planning the Integrated Reactor Engineering experiment. With the progress of driver HALNA development from 10 J to 100 J and 1 kJ, the chamber and fuel pellet issues can be investigated more precisely and quantitatively. The quality of Integrated Design Code and ESE evaluation will be also preformed in parallel. The Monbusho (Ministry of Education, Science and Culture) has given a grant in aid in 1999 fiscal year to coordinate a collaboration organization for IFE power plant technology in Japan and to respond to the international collaboration schemes for IFE development which are under investigation of several international organization such as IAEA, IEA, and bilateral agreement.

Demonstration of ignition, burning and energy gain in the next decade will surely accelerate the reactor technology development. Interactions between industry, IFE and MFF are useful and beneficial for all the partners in their progresses.

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