Inertial Confinement Fusion and Related Technology

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Abstract

Present status with future prospects and related technologies of the inertial confinement fusion are described. The required temperature and density of plasma have been achieved independently using 10 kJ laser system. 100 kJ laser with the wavelength of 350 nm could demonstrate the breakeven condition of fusion.

Introduction

If we want to achieve the enough fusion gain by imploding a DT solid fuel pellet with several MJ energy driver or laser, a 10^3 times liquid DT density plasma with average temperature of less than keV is required. Where the laser efficiency of 10 % and the coupling efficiency from laser to fusion plasma of 10 % are assumed. The reason why we need such a high density, low temperature plasma is that the required laser energy to produce a plasma with the fixed gain is proportional to inverse square of the plasma density and to plasma temperature$^{1)}$. The plasma with temperature of less than 5 keV never ignites even if the density is high enough. For ignition of fusion we have to produce plasma with high temperature core at the center of the fusion plasma, α particles from which heat the surrounding cold main fuel.

From the above arguments the following issues are coming out. 1) How much fraction of laser energy is absorbed at the surface of the fuel pellet? 2) How percentage of absorbed laser energy is transfered to the fusion plasma produced by the implosion process? 3) Is it possible to produce the high temperature enough for fusion reaction? 4) Is it possible to create 10^3 liquid DT density plasma with low temperature preventing the hydrodynamic instability in the compression phase. Those are the first step of ICF and can be studied using a 10 kJ class laser system.

The second phase is the demonstration of ignition plasma where the fuel is heated up to higher temperature by the α particles of DT reaction. For this we have to produce the plasma with ρR of 0.3 g/cm^2 and temperature of 5 keV, where the ρR of 0.3 g/cm^2 is the range of α particle. The required energy for this experiments is estimated to be 100 kJ at the wavelength of 350 nm. Final issue in plasma physics is the demonstration of high fusion gain plasma using a mega joule laser or other energy drivers such as light ion beam (LIB) and heavy ion beam (HIB). For commercial reactor development we have to develop efficient, repetitive energy driver.

Here we describe the present status and some future prospects of ICF and the spin-off as the related technologies.

Present status and future prospects

The laser wavelength scaling on absorption coefficient of plasma was completely studied and showed that the laser energy is absorbed more than 90 % at laser intensity of 10^{14} W/cm^2 for wavelength of 530 and 350 nm which are the higher harmonics of 1 μm glass laser$^{2)}$. 6% of hydrodynamic efficiency was demonstrated by Gekko XII experiments, which is the energy transfer coefficient from absorbed laser energy at pellet surface to energy of the compressed fusion plasma as shown in Figure 1$^{3)}$. Temperature of 10 keV and 10^{13} DT neutron yield which correspond to the fusion output energy of 1/500 of used laser energy were achieved using the 10 kJ, 530 nm laser$^{4)}$. In the experiments glass microballoons filled with DT gas were used. The diameter and wall thickness were ~1mm and ~1.5 μm respectively. Figure 2 shows the progress and prospect of laser fusion$^{1)}$.

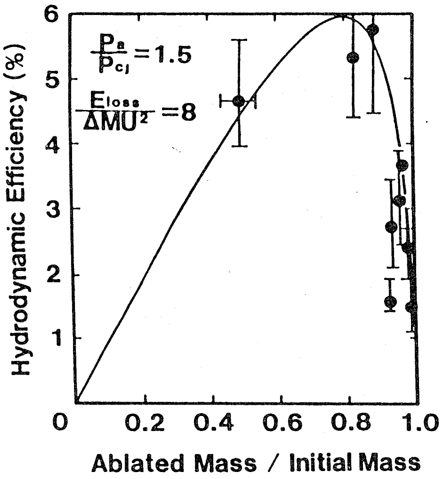

Fig. 1 The experimental hydrodynamic efficiency η_h is compared with the rocket model as a function of ablated mass/initial mass.

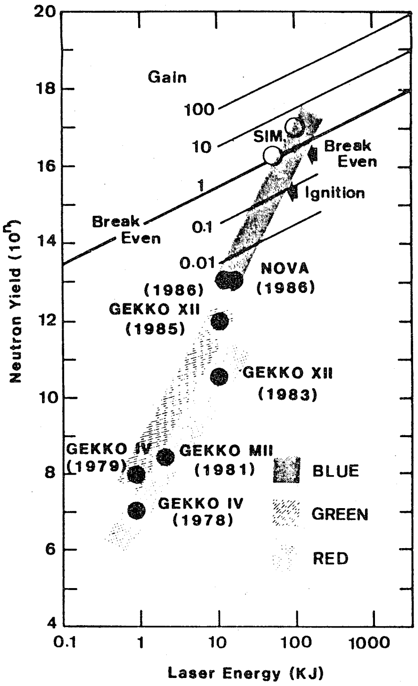

Fig. 2 Progress and prospect of laser driven fusion. The solid circles are from experiments with Gekko lasers and Nova laser, while the open circles are from the present simulation. This figure suggests the possibility of breakeven experiment by 100 kJ class blue laser system.

The high density compression have been recently demonstrated using a CDT(Si) shell target with diameter of 0.5 mm at ILE Osaka as shown in Figure 3. The density was determined from the measured areal mass density ρR and mass of fusion plasma, where ρ and R are the density and radius of plasma. The ρR was measured by silicon activation method. In which the Si tracers are activated to ^{28}Al by the 14 MeV DT neutrons. The amount of activated Si is proportional to DT neutron yield and ρR. The mass of compressed fusion plasma was determined by measuring the ablated mass. The obtained density is over 600 times of solid density which corresponds to 4 times higher density of the center of the sun. Figure 4 shows the achieved plasma region by Gekko XII in the usual nτ-T diagram.

From these experimental results and the theoretical research with aid of computer simulation we have been confident that 100 kJ blue laser (λ = 530 nm) could achieve the ignition or breakeven condition. The design and required technologies to fabricate 100 kJ laser are completed already.

As for the mega joule energy driver US people are doing R & D research, and the construction will start from 1991 FY. For reactor driver a semiconductor laser pumped solid state laser is studying which could work with the efficiency of more than 10 % and high repetition rate of about 10 Hz. KrF laser, free electron laser, LIB and HIB are still candidate for the reactor driver.

ICF related technologies

Inertial confinement fusion (ICF) using a high power pulsed laser could open the new technological fields useful for scientific research and industrial applications as well as the release of new energy. The laser produced midium atomic number plasmas have been used successfully for x-ray laser midium. The super dense plasmas produced by implosion have provided the interior of stars on the earth. This could be useful to understand the physics in the stars. High power laser could realize a new particle accelerator. Plasma wave excited by the beat wave of high power laser is one method. Another is the use of free electron laser (FEL) for the acceleration field. Of course FEL is a candidate of fusion energy driver. A peta-watt femto-second laser which could achieve the power density over the 10^{20} W/cm^2 at the focal point might open the new methods in the nuclear physics research. Femto-second lasers of 10^{17} w/cm^2 have already opened the new area in the atomic and molecular physics. The technologies developed relating to the fusion lasers have been contributed to the industrial technologies. In the contray the accelerator technology could contribute the heavy ion beam fusion driver which is the alternative of laser.

References

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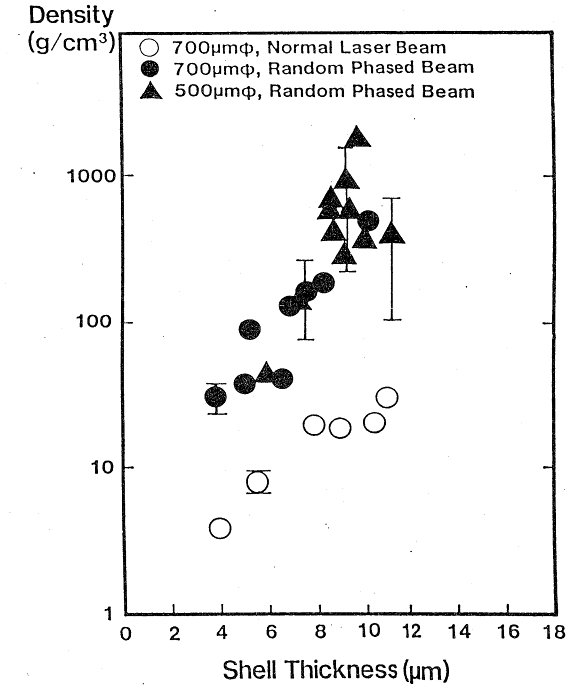

Fig. 3 Achieved density vs pellet shell thickness. CDT(Si) plastic shell targets are used.
Laser: Gekko XII 530 nm, 9 kJ, in rectangular pulse.
Random Phased Beam: special distribtution of laser intensity on pellet is improved using R.P.P.
Normal Laser Beam: not improved.

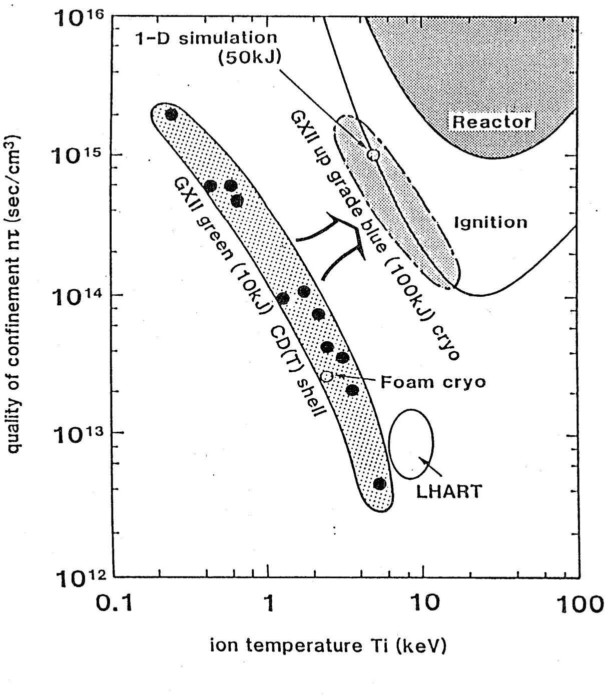

Fig. 4 Achieved Plasma region in nτ-T diagram using Gekko XII laser at ILE Osaka.