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Frontier of Plasma Physics Opened by Fast Ignition Fusion Research

超高強度レーザー核融合の展開するフロンティア科学

K.Mima, R.Kodama, and H. Nagatomo
三間圀興, 兒玉了祐、長友英夫

Institute of laser Engineering, Osaka University, 2-6 Yamada-oka, Suita, Osaka 565-0871 Japan
大阪大学レーザーエネルギー学研究センター、〒565-0871　吹田市山田丘 2-6

Research status of ultra-intense laser plasma physics is reviewed. The related researches are on fast ignition laser fusion with the GEKKO XII and PW lasers and the related high energy density plasma physics. Recent new findings are generation of a very high relativistic electron current, heating of high density plasma , high energy ion generation, and so on.

1. Introduction

Since the CPA (Chirped Pulse Amplification) was invented by G. Murou etal in 1985, the short pulse ultra-intense laser technology has developed rapidly. The peak power of laser increased by factor 2 every year from giga watt to Peta Watt. At present, laser peak power reaches 1 peta watt. When such a laser beam is focused to a 10 μm x 10μm spot, the peak laser intensity is about 10^{21} W/ cm^2 and the electron quiver energy is higher than 10MeV. This new technology open up a new laser fusion scheme so called Fast Ignition. In the fast ignition, an imploded high density core plasma with a density higher than 1000 times solid density is instantaneously heated up by a multi-10kJ peta watt laser. We have been studying the fast ignition scheme by the GEKKO XII and PW lasers since 1996. In 2002, It was reported that the neutron yield increased from 10^4 to 10^7, when a 400 J/0.6 ps PW laser was injected into a compressed CD shell. For the progress of fast ignition research, it is necessary to understand physics of relativistic laser plasma interactions. Researches on relativistic laser plasma interaction are opening a new laser fusion but also a frontier of plasma physics such as high field science like laser particle acceleration.

2. Ultra-intense laser plasma physics and related computer simulations

With the simulation system, we will describe global phenomena of the high density plasma interactions with ultra intense laser and related high energy particle generations, as shown in Fig. 1. When a peta watt laser is focused onto a solid target, the photon pressure of the order of 10Gb is applied to the plasma and a high density relativistic electron beam is generated on the surface plasma. The ultra intense relativistic electron beam (REB) induces very strong magnetic fields through the electro-magnetic two stream instabilities when it interacts with dense plasmas[1]. Furthermore, the REB produces hard X-ray, γ– ray, Mega eV electron and ion, and neutron and meson through collisions of high energy ions and electrons with high Z nucleus [2][3]. Those high energy photons and particles produced by peta watt lasers are applicable not only to fast ignition laser fusion [4][5][6], but also to nuclear science, laboratory astrophysics, positron emission tomography (PET), heavy ion cancer therapy, and so on [2][3]. Since the relativistic electron generation and subsequent electromagnetic phenomena occur in femto second time scale and sub-micron space scale, it is extremely difficult to measure and analyze the physical process precisely and directly by experiments. Therefore, the data analysis assisted by various simulations is very necessary for interpretation of experimental results and comprehensive understandings of peta watt laser plasma physics. Since the high energy particles spread over the wide area and propagate for long distance in a long scale plasma before arriving detectors, the large scale plasma simulations are also necessary.

The precise laser plasma interactions are simulated by a microscopic simulation code like PIC, where the special resolution is smaller than the dense plasma skin depth which is less than 0.1μm. If a few hundreds μm scale plasmas are simulated by the PIC, the total number of mesh would be 10^{12} which will require the memory of the computer greater than 100Tbits. So, the speed of the computer would be required faster than 100T flops. Such a super computer does not exist yet. In order to overcome this difficulty, we are developing a new simulation system which consists of interconnected multi-simulation codes. As shown in Fig.1, simulations of four codes; particle in cell code, PIC-electron fluid hybrid-code, Fokker Planck code, and hydro simulation code are coupled. The detail of the interconnection will be described in the following report.

3. Future prospects

As the next step of the fast ignition research, we started the FIREX (Fast Ignition Realization Experiment) project toward demonstrating the fast ignition with a new high energy PW laser, LFEX (Laser for Fast Ignition Experiment) which is currently under construction. This high energy peta watt laser will produce large scale and higher energy relativistic plasmas and present new findings in the relativistic plasma physics. In the talk, the future scope of the development of this research field is discussed.

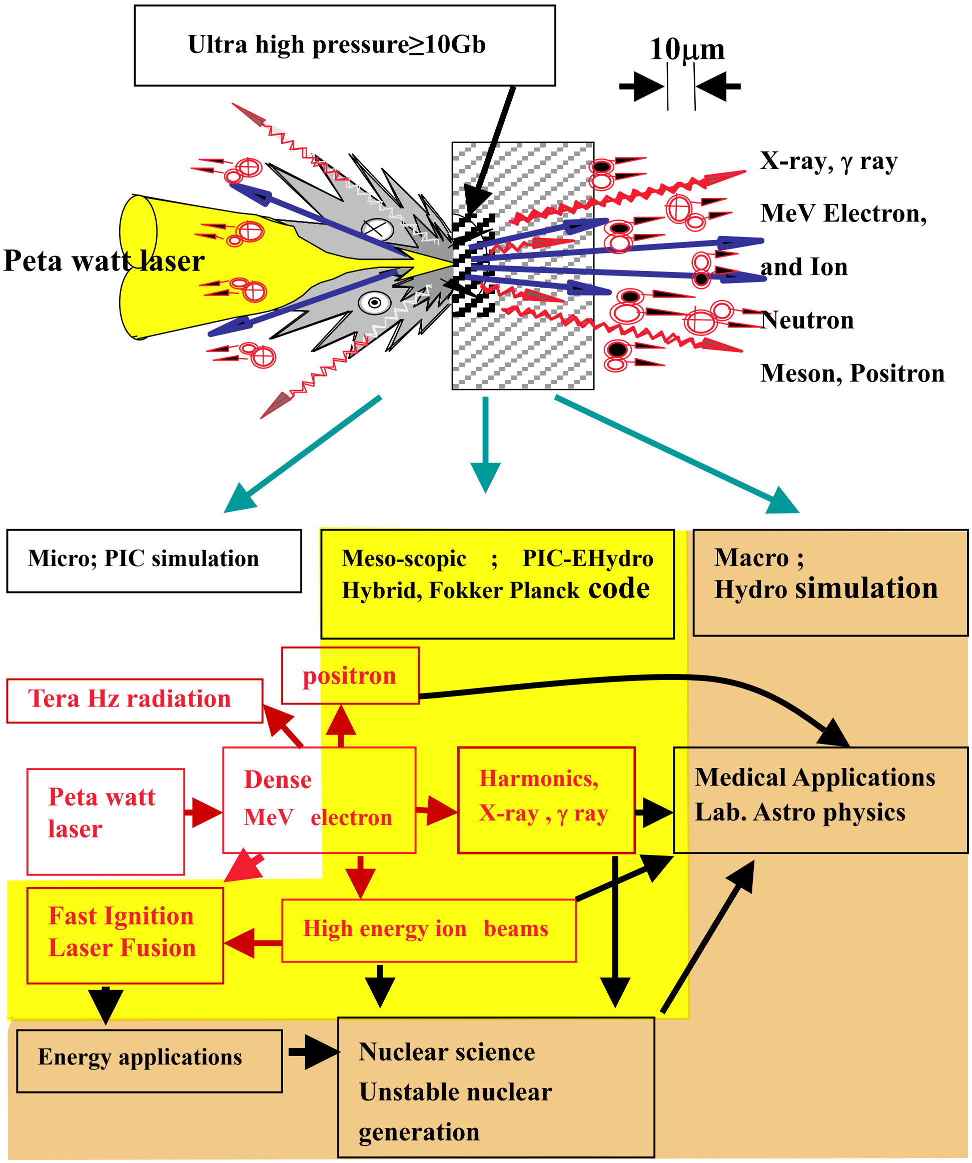

Fig.1 Physics of ultra intense laser plasma and related simulation schemes

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