RAGING LIGHT!

THE NEW WORLD OF

I ZEST

International Zettawatt Exawatt Science and Technology

EXTREME LIGHT LASER CONFERENCE :

FROM FUNDAMENTAL PHYSICS TO SOCIETAL APPLICATIONS

東京 Tokyo

At the French Embassy and the University of Tokyo

November 18, 2013 - November 20, 2013

CUILS cea KEK HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

PRELIMINARY Agenda

From Fundamental Physics to Societal Applications at the Embassy of France – Tokyo - Japan

November 18 & 19, 2013

Monday November 18, 2013

08 :30	Opening	Jacques Maleval, Counsellor for Science & Technology at the Embassy of France in Tokyo Professor Atsuto Suzuki, General Director, KEK
08:55	**Session 1 : What is IZEST/ICAN all about now ?**	
08:55	G. Mourou	Introduction
09:45	T. Tajima	IZEST High Field Science: From Fundamental Physics to Societal Applications
10:10	**Session 2 : Acceleration**	
10:10	C.H. Nam	Towards 100 MeV proton generation using ultrathin targets irradiated with petawatt laser pulses
10:35	*Coffee break*	
10:50	K. Nakajima	IZEST 100 GeV Ascent Project aiming at Table-Top to Large-Scale Applications
11:15	X. Yan	Instability free ion acceleration regime by using a concave fiber laser
11:40	**Session 3 : Nuclear Applications**	
11:40	S. Gales	Extreme Light Infrastructure – Nuclear Physics A new research infrastructure at the interface of Laser and Subatomic Physics
12:05	T. Hayakawa	Nuclear astrophysics with new gamma-ray sources
12:30	*Lunch*	
13:45	N. Nakashima	Ionic valence change of metal ions by ns and fs lasers applicable for nuclear waste treatment
14:10	R. Hajima	Development status of non-destructive assay of nuclear material by using laser Compton scattered gamma-rays
14:35	**Session 4 : Exawatt**	
14:35	H. Azechi	LFEX High Energy Peta-Watt Laser and Its Potential for High Field Science
15:00	*Coffee break*	
15:15	R. Li	Development of high energy OPCPA and 2 PW lasers at 800 nm
15:40	T. Ebisuzaki	Astrophysical ZeV acceleration in the relativistic jet from an accreting supermassive blackhole
16:05	P. Chen	Laboratory Astrophysics using High Power Lasers
16:30	**Round table** *Chairman Yoshiaki Kato*	
16:30	Y. Kato	Collaboration between Academia and Industry
16:40	D. Perret-Gallix	Energy for large scale research infrastructures
16:50	M. Mariton	Large size and high performances diffraction gratings for Ultra-Intense Laser Pulse Compression
17:00	A. Soujaeff	Latest results on PetaWatt lasers and future developments
17:15 / 17:45	Wrap-up – Conclusion of the Round Table	
18:00	**Welcome by Christian Masset, Ambassador of France in Japan**	

- G. Mourou, Director of IZEST
- signature of 3 Memorandum of Understanding
- Launch of “Kampai” by Hiroshi Azechi Director of **ILE in Osaka**

Tuesday November 19, 2013

08 :30	**Session 5 : ICAN International Coherent Amplification Network**	
08:30	W. Brocklesby	ICAN – a new laser paradigm for applications in particle physics
08:55	A. Brignon	High speed interferometric technique for coherent beam combining of large number of fiber amplifiers
09:20	**Session 6 : ICAN Experiments**	
09:20	P. Zeitoun	New paradigm for X-ray sources driven by ICAN lasers
09:45	D. Ros	LASERIX facility: Achievements and prospective opened by ICAN
10:10	*Coffee break*	
10:35	L. Corner	Applications of high energy fibre lasers to gamma-gamma collider Higgs factories
11:00	K. Homma	Low energy stimulated gamma-gamma collider toward laboratory search for dark fields
11:25	H. Hora	Collective Ion Acceleration Mechanism with Petawatt-subpicosecond Laser pulses
11:50	**Session 7 : Extreme Light experiments**	
11:50	A. Sergeev / I. Kostyukov	Prospects for High Efficient Gamma-Ray Sources with Laser Facility XCELS
12:15	*Lunch*	
13:30	J. Koga	Delbrück scattering as a High Precision Vacuum Probe
13:55	S. Mueller	Higgs Boson Creation in Laser-Boosted Lepton Collisions
14:20	Kumar G. Ravindra M. Krishnamurthy	A short overview of the intense laser Increasing intensity of intense laser science in India: a short overview
14:45	*Coffee break*	
15:00	**Session 8 : Laser technology**	
15:00	T. Tanaka	New scheme to generate a multi-terawatt and attosecond laser pulse in X-ray free electron lasers
15:25	S. Weber	Amplification of ultra-short light pulses by ion collective modes in plasmas: simulations
15:50	J. Fuchs	Amplification of ultra-short light pulses by ion collective modes in plasmas: experiments
16:15	K.I. Ueda	Thermal-Lens-Free Cooling of Solid State Lasers for Coherent Beam Combining

There is no specific slot reserved to the presentation of the posters;
this will be done over the 2 days during breaks.

From Fundamental Physics to Societal Applications at the University of Tokyo – Hongo Campus - Japan

November 20, 2013

Wednesday November 20, 2013

09:00 **Welcome by Professor Kaoru Yamanouchi,**
Department of Chemistry, School of Science and Director, CUILS - The University of Tokyo

(Auditorium 5th floor)

09:05 **Plenary session - IZEST Projects**

09:05	G. Mourou / T. Tajima	Progress in the IZEST Projects
09:20	J.L. Miquel	
09:45	K. Nakajima	
10:10	K. Homma	
10:35	J. Fuchs	

11:00 **Kick off of the 3 parallel workshops (100 GeV, C^3, Dark Fields)**
(Auditorium 5th floor)

11:30 *Working lunch of each workshop*
(Meeting room & Foyer 5th floor)

12:30 Workshops in parallel :
- 100 GeV *(Classroom 3rd floor) See details next page*
- C3 *(Classroom 4th floor)*
- Dark fields meeting *(Meeting room 5th floor)*

16:00 Wrap up and conclusion of the Conference – next actions

16:00 Participant Council meeting (for IZEST partners)
(Meeting room 5th floor)

18:00 End of the PaC meeting and Conference

Agenda of 100 GeV Ascent Workshop
20th November, 2013, University of Tokyo

In the workshop on 100 GeV ascent at the satellite meeting at University of Tokyo, we will embody 100 GeV laser plasma electron acceleration experiment employing the CEA PETAL laser. Continuing the previous workshops at CEA Bordeaux and University of Strathclyde in 2012, we will confirm the progress and discuss the coming plan in depth on 6 working packages; managing & design, injector, plasma waveguide, diagnostics, integration & interaction and implementation. We will also discuss the latest results of laser plasma acceleration and future organization of the international team for enhancing the progress of the project.

I. Workshop kickoff (11:00-11:30)

Kazuhisa Nakajima (KEK)
"Introduction and invitation to 100 GeV Ascent workshop"

II. Working lunch discussion (11:30-12:30)

Comments and open discussions related to 100 GeV Ascent
Unscheduled short talks (less than 10 minutes) on recent results are welcome in this session. Please let us know the title in advance, if you intend to give a talk.
Topics

- Management and Design
- Injector
- Plasma waveguide
- Diagnostics
- Integration and Interaction
- Implementation
- Schedule etc.

III. Workshop (12:30-15:30) – Convener: Kazuhisa Nakajima

Each talk has 20 minutes and 5-10 minutes discussion

1. **Mark Quinn** (CEA Saclay):
"Development of laser driven injector for electron acceleration at CEA, Saclay"

2. **Tatsuo Shoji** (Nagoya Univ):
"Preliminary Experiment on Plasma Wave Guide for PWFA"

3. **Mitsuhiro Yoshida** (KEK)
"Experimental test plan for long plasma waveguide in the conventional accelerator facility"

4. **Hyon Taek Kim** (GIST):
"Multi-GeV electron-beam generation using petawatt laser pulses"

5. **Laura Corner** (JAI):
"Activities at the John Adams Institute for Accelerator Science in laser plasma wakefield acceleration"

6. **Jean-Luc Miquel** (CEA Bordeaux)
"Overview of the PETAL laser facility and its equipment"

7. **Liming Chen** (IOP)
"Electron acceleration and oscillation via laser Hose-Modulation Instability"

8. **Matteo Tamburini** (MPI)
"Electron dynamics controlled via self-interaction"

IV. Wrap up- Conclusions (15:30-16:00)

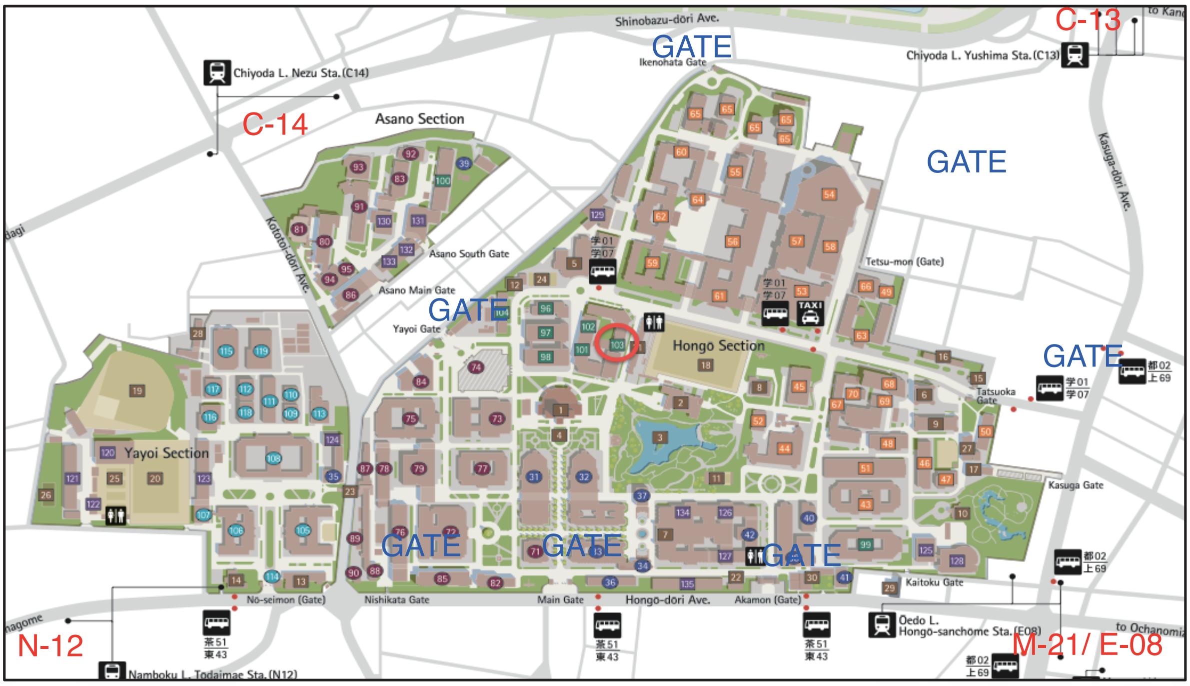
100 GeV Ascent workshop results – **Kazuhisa Nakajima**

POSTER SESSION

Hora Heinrich	Collective Ion Acceleration Mechanism with Petawattsubpicosecond Laser pulses
Moustaizis Stavros	Towards an Alternative Mono-Energetic Neutron Source for Material Tests Based on High Efficiency Exawatt Laser Systems
Kim Sang Pyo	Perspective of QED Phenomena at IZEST
Liang Xiayo (presented by R. LI)	A Hybrid CPA and OPCPA Laser system generating 0.61PW
Murakami Masakatsu	Proton Beams from Nanotube Accelerator
Qian Lijia	Single-shot measurement of extreme high pulse-contrast
Sakabe Shuji	Plasma Mirror for Contrast Improvement of Intense Femtosecond Laser Pulses
Tamburini Matteo	Plasma-based generation and control of a single few-cycle,high-energy and ultrahigh intensity laser pulse”
Wada Satoshi	Laser- and Accelerator-driven Neutron sources

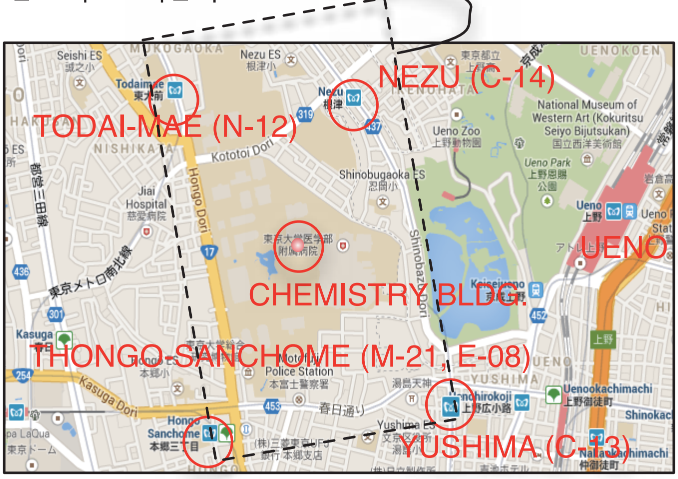
Workshops at the University of Tokyo

20th November, Chemistry Building, The University of Tokyo



http://www.u-tokyo.ac.jp/en/about/documents/Hongo_CampusMap_E.pdf

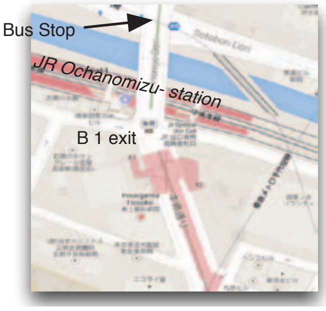
Nearest subway stations to the campus are
"Todai mae (N-12)", "Nezu (C-14),
" Yushima (C-13)" ,
"Hongo-sanchome (M-21, E-08)".
10 to 15 min walking from stations.



Timetable and train/subway route search;
http://www.hyperdia.com/en/ .

The Celestine hotel is located near the subway station "Mita (I-04) or Shiba-koen (I-95)" (a few min.min walk).
* There are three subway routes ; 260 JPY for one way,
The Homepage of TOKYOMETRO is *http://www.tokyometro.jp/en/index.html*
Toei Subway is *http://www.kotsu.metro.tokyo.jp/eng/services/subway.html*
(a) change train at "Otemach (I-09) to MARUNOUCU-LINE (M-18) and get off at M-21. <25 min.>
(b) change train at "Otemach (I-09) to CHIYODA-LINE (C-11) and get off at C-13 or C-14. <22 min.>
(c) change train at SHIROKANE-TAKANAWA (I-03) to NANBOKU-LINE and ge off at N-12. <29 min.>

* A fixed-route bus brings you to beside the building.
(a) Get off at "Shin-0chanomizu (C-12) of CHIYODA-LINE and go up to the ground at B-1 exit.
(b) Take a bus(学07) at the bus stop (OCHANOMIZU) on the HIJIRI-BASHI-overpass.
(c) Get off at the final bus stop.



Monday

November 18, 2013

Introduction

Gérard Mourou

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After Europe, and the USA , it is the turn of the Asian and Oceanian Extreme Light Community in Australia, China, Japan, India, Korea, Taiwan, to welcome IZEST. IZEST pursues its ascent toward subatomic physics with an emphasis on nuclear, particle physics and astrophysics. IZEST aspires to pursue the development of novel laser, Petawatt, Exawatt, Zettawatt architectures that will provide the highest peak power, average power and efficiency.. Their applications will include fundamental physics, dark matter neutrino generation , Higgs factory. Societal applications will also be front and center with identification and treatment of nuclear waste, medicine, sub critical reactor based on Thorum cycle and nuclear pharmacology.

IZEST High Field Science: From Fundamental Physics to Societal Applications

T. Tajima
IZEST and University of California, Irvine

Fundamental high energy physics has been mainly driven by the high-energy charged particle colliding beam approach. Today the possibility to amplify laser to extreme energy and peak power offers, in addition to possibly more compact and cheaper way to help HEP, a complementary new alternative underpinned by single shot, large field laser pulse, that together we could call (Laser-based) High Field Fundamental Physics. As an example, a Higgs factory using a gamma-gamma collider, as well as the usage of the laser field to probe the nonlinearity of vacuum. We envision that seeking alternative paradigm without large luminosity of an $e^+ e^-$ collider substantially shorten our time-line. We further accelerate the time-line of the research by adopting the existing large energy laser PETAL-LMJ. The accelerated research on the non-collider paradigm in TeV and beyond could, however, stimulate innovation in collider thinking such as lower luminosity paths, novel radiation cooling, and gamma-gamma colliders as mentioned already. The advancement of intense short-pulsed laser energy by 2-3 orders of magnitude empowers us a tremendous potential of unprecedented discoveries. These include: TeV physics, physics beyond TeV, new light-mass weak-coupling field discovery potential.

In addition to the high field mentioned above (with limited average power), we emphasize the importance of high average power laser. This is certainly needed for the future $e^+ e^-$ collider based on laser acceleration, which was the first reason for us to start the CAN laser research. The breakthrough in CAN laser research, however, entails not only a path toward laser-based $e^+ e^-$ collider, but also expanded possible applications in fundamental physics (such as an expanded parameter space of dark field search) as well as enabled societal applications such as with very high flux of laser Compton gamma rays and even with high flux proton beams all driven by high flux lasers. This development is making us seriously seek a variety of new applications impacting on our society such as nuclear transmutation by high flux neutrons and gammas, laser-driven proton therapy, high flux proton diagnosis, gamma-beam based nuclear pharmacology, identification of spent fuel in general and the exposed one in particular (Fukushima) by portable gamma sources, detection for the homeland security, mechanical and electronic engineering industries.

Towards 100 MeV proton generation using ultrathin targets irradiated with petawatt laser pulses

Chang Hee Nam*[1,2], I Jong Kim[1,3], Ki Hong Pae[1,3], Chul Min Kim[1,3], Hyung Taek Kim[1,3],
Il Woo Choi[1,3], Jae Hee Sung[1,3], Seong Ku Lee[1,3], and Tae Moon Jeong[1,3]
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Particle acceleration using ultraintense, ultrashort laser pulses is one of intensively investigated topics in relativistic laser-plasma research. It opened a new gateway to produce high quality particle beams comparable to those obtained using conventional acceleration techniques. We report proton/ion acceleration from ultrathin polymer targets by irradiating linearly polarized, 30-fs laser pulses. The laser intensity applied was from 5×10^{19} W/cm^2 to 3.3×10^{20} W/cm^2 and the target thinkness was from 10 nm to 100 nm. The transition of proton energy scaling from $I^{1/2}$ to I with respect to laser intensity I was observed, and a maximum proton energy of 45 MeV was obtained [1]. In addition, in a recent experiment we succeed in obtaining the maximum proton energy of 80 MeV by irradiating circularly polarized laser pulses on 15-nm-thick target with the intensity of 5.7×10^{20} W/cm^2 .

[1] I J. Kim et al., Phys. Rev. Lett. **111,** 165003 (2013).

IZEST 100 GeV Ascent Project aiming at Table-Top to Large-Scale Applications

Kazuhisa Nakajima[1, 2*]

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The advent of extremely intense ultrfast lasers has created a breakthrough in particle acceleration and radiation that facilitate advance of basic and applied sciences as new tools as well as new physics and technology in laser science. In this decade, vital researches on laser-driven plasma-based acceleration [1] of electrons and ions have achieved great progress in production of high-energy, high-quality electron beams with energies of a multi GeV-level in a cm-scale plasma, and 100 MeV-level ion beams from thin foil targets. These high-energy high-quality particle beams make it possible to open the door for a wide range of applications on a table top in fundamental, medical and industrial sciences. On the other hand, there are also great interests in applications for high-energy physics and astrophysics that explore unprecedented high-energy frontier.

We are undertaking to initiate the experimental research on laser-plasma accelerators aiming at 100-GeV ascent of electron beams, under the network of IZEST associate labs. Experiments will be implemented by employing a multi-PW laser PETAL delivering 3.5 kJ, 500 fs pulses at CEA-LMJ, Bordeaux. Here design concept [2] and methodology achieving 100 GeV electron acceleration are presented.

As one of table-top scale applications of fiber laser-driven plasma accelerators [3], a EUV light source based on a FEL for lithography technology in semiconductor manufacturing is presented. Based on current achievements of laser plasma accelerators, we propose a kW-level EUV light source at 13.5 nm and 6.7 nm wavelengths generated by a table-top FEL employing GeV-level electron beams from a 1 MW-level fiber laser-driven plasma accelerator.

As one of attractive applications of 100-GeV large-scale laser plasma accelerators to high energy physics, laser plasma-based colliders could provide us with a very compact, low cost option of the Higgs factory, harnessing fiber lasers pumped by high average-power, high efficiency semiconductor laser diodes and coherent combination of massive number of fiber amplifiers [3]. Here we present a strawman design of fiber laser-based Higgs factory for a gamma-gamma collider comprised of two 5-m long 80 GeV electron laser plasma linacs to produce 64 GeV Compton gamma beams via interactions with high average power fiber lasers.

[1] T. Tajima and J. M. Dawson, Phys. Rev. Lett. **43** (1979) 267.
[2] K. Nakajima et al., Chinese Optics Letters, **11** (2013) 013501.
[3] G. Mourou et al., Nature Photonics, **7** (2013) 258.

Instability free ion acceleration regime by using a concave fiber laser

X.Q.Yan[1,2*].M.L.Zhou[1], S.Zhao[1], H.Y.Wang[5], B.Liu[1], C.Lin[1], H.Y.Lu[1], Y.R.Lu[1], Y.Q.Gu[4],
T.Tajima[2,3], X.T.He[1], C.E.Chen[1]

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Radiation pressure acceleration has been proposed as a promising route to obtain high-quality ion beams in a much more efficient way, which normally require extremely high laser intensity (> 10^21 W/cm^2), a sharp rising front, and high temporal laser contrast (> 10^10). we report on a laser-driven plasma lens that can transversely focus the laser beam to the sublaser wavelength in the radius and enhance the laser intensity by more than 1 order of magnitude, while temporally steepening the Gaussian pulse and improving the laser contrast. In the critical dense plasma a novel self-matching resonance acceleration (SMRA) is also discovered, in which a collimated relativistic electron beam with overcritical density, helical structure, and plateau profile energy spectrum, can be generated. These energetic dense electron beam might be very promising for MeV hard photon (X/ γ ray) production or ion acceleration.

Along with the proposal of the fiber laser, which can afford high pulse repetition rates, high average laser power as well as multiple pulse waveforms, it becomes practical to gain a new efficient “quite long distance” ion accelerate regime, which could be a new milestone in the development of laser ion acceleration.

We show a stable long distance ion acceleration regime by using two parallel circularly polarized Gaussian laser pulses at an intensity of I=6.8×10^21W/cm2, normally incident on a hydrogen foil. The special structure of the equivalent wave front of those two pulses, which contains Gaussian peaks in both sides and a concavity in the centre, can suppress the transverse instabilities and hole boring effects, finally constrain a high density ion clump in the centre of the foil to a quite long distance and gain ion bunches above 1GeV/u.

1. H. Y. Wang, ..., X.Q.Yan, **Phys. Rev. Lett.** 107, 265002 (2011)
2. B. Liu,..., X. Q Yan et al., **Phys. Rev. Lett.,** (110, 045002 (2013))
3. H. Y. Wang, ..., X.Q.Yan, PHYSICS OF PLASMAS 20, 013101 (2013)
4. M.L.Zhou, ..., X.Q.Yan, in preparation, 2013
5. B. Liu,..., X. Q Yan et al., in preparation, 2013

Extreme Light Infrastructure – Nuclear Physics

A new research infrastructure at the interface of Laser and Subatomic Physics

Sydney Gales[1,2)] for the ELI-NP team

[1)] "Horia Hulubei" National Institute for Physics and Nuclear Engineering, 30 Reactorului Street, RO-077125 Măgurele, jud. Ilfov, Romania;
[2)] IPN Orsay/IN2P3/CNRS and University ParisXI, 91406 Orsay cedex, France

Extreme Light Infrastructure (ELI) is a pan European research initiative selected on the European Strategy Forum on Research Infrastructures Roadmap that aims to close the gap between the existing laboratory-based laser driven research and international facility-grade research center. We report on the status of Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility, one of the three ELI pillars under construction, to be operational in 2017. Placed in Romania, ELI-NP has as core elements a couple of new generation 10PW laser systems and a narrow bandwidth Compton backscattering gamma source with photon energies up to 19MeV. ELI-NP will address nuclear photonics, nuclear astrophysics and quantum electrodynamics involving extreme photon fields. Prospective applications of High Power laser in accelerator physics , in particular towards future Accelerator Driven System and Nuclear waste as well as in nuclear photonics, for detection and characterization of nuclear material, for nuclear medicine and for material science will be discussed.

Nuclear astrophysics with new gamma-ray sources

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One of the most important phenomena, in which photonuclear reactions have a critical role, is supernova explosions in the universe. The peak temperature at outer layers in progenitor stars reaches to 109 K. In such environments, high energy contributions of plank distribution of thermal photons are in energies of MeV. With such gamma-rays with energies of MeV, syntheses of rare isotopes occur, so-called gamma-process (or p-process). There are about 35 p-process isotopes. Understanding the origins of these isotopes are critical for the chemical evolution in our Galaxy as well as explosion mechanism of supernovae. P-isotopes are produced by photodisintegration reactions on pre-existing seed nuclides. In addition, gamma-rays with energies lower than the neutron separation energy contribute to synthesis of rare isotopes via meta-stable isotopes with (gamma, gamma') reactions [1]. These processes are studied using available gamma-ray sources, laser Compton scattering gamma-ray beam and laser driven high-intense photons. These two gamma-ray sources have unique features. I will present the present status for supernova nucleosynthesis with photons and the perspective of laboratory experiments using new generations of gamma-ray sources in the near future.

[1] T. Hayakawa, et al., Phys. Rev. C 81, 052801(R) (2010)

Ionic valence change of metal ions by ns and fs lasers applicable for nuclear waste treatment

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nakashima@toyotariken.jp

The ionic valence of metal ions can be changed by laser irradation. Two photon and femtosecond filament chemistries will be shown and relations to nuclear waste and thorium atomic energy will be discussed.

1. Yb^{3+}ions in alcohol were found to be reduced to Yb^{2+} ions upon laser irradiation with a stepwise two-color two-photon excitation [1]. The infrared (975-nm) pulse with a duration of 4 ns pumps the ground state to the 4f excited state and the second photon (355-nm) generates the charge transfer (CT) state; the reduction then occurs. Laser energy and excitation wavelength dependencies well-explain the above mechanism. The absorption spectrum of the intermediate in the two-photon chemistry was measured. The reaction yields for single-photon UV (266 nm) excitation and the second photon in the two-photon excitation were 0.1–0.2, indicating that the reactive states are a common CT state. These reaction mechanisms would occur in some lanthanide and actinide ions in solution.

2. Three lanthanide ions (Ln^{3+}), Ln=Eu, Sm, and Yb, and two transition metals, Fe^{3+} and Ag^{+}, were found to be reduced to the corresponding Ln^{2+}, Fe^{2+}, and Ag_n in methanol or aqueous solution upon irradiation with intense femtosecond laser pulses [2]. Whenever the white-light laser was generated, the reductions were observed. The reduction mechanisms would be explained in terms of femtosecond filament formation, where solvated electron forms followed by the reduction. The electron ejection under focused beam conditions in solution has been known to be accompanied by white-light laser. The reactions have been studied using differnt excitation wavelenghs of 800, 970, 1190, and 1930 nm. As an exception, a two-photon excitation mechanism for Fe^{3+} at 800 nm was observed.

3. The laser reactions of ionic valence change and thorium atomic energy could be the key technologies for nuclear waste treatment.

[1] "Reduction of Yb(III) to Yb(II) by two-color two-photon excitation", N. Nakashima, K. Yamanaka, T. Yatsuhashi, *J. Phys. Chem. A*, **117** (2013)8352-8359.
[2] "Ionic valence change of metal ions in solution by femtosecond laser excitation accompanied by white-light laser", N. Nakashima, K. Yamanaka, T. Yatsuhashi, *Chinese J. Phys. for Special issue on 'ultrafast intense laser science'*, submitted.

Development status of non-destructive assay of nuclear material by using laser Compton scattered gamma-rays

Ryoichi Hajima[1,*]

[1] *Quantum Beam Science Directorate, Japan Atomic Energy Agency*
* hajima.ryoichi@jaea.go.jp

Generation of energy-tunable gamma-rays via laser Compton scattering (or Compton back scattering) is of great interest for exploring science and applications of „MeV" photons, which interact with nuclei. Non-destructive detection and assay of nuclide is one of the promising applications of such energy-tunable gamma-rays. Detection of nuclear materials hidden in cargos is an urgent issue for the counterterrorism [1]. A gamma-ray-based detection system is able to detect nuclear material behind a shield. Non-destructive assay of nuclear and radioactive material becomes an essential tool for the management of nuclear waste and the nuclear safeguards [2].

In JAEA, we are developing technologies relevant to the gamma-ray non-destructive assay, which include a high-brightness gamma-ray source based on modern laser and accelerator technologies, a Monte Carlo simulation code to deal with nuclear resonance fluorescence, and gamma-ray measurement techniques optimized for highly radioactive samples.

The gamma-ray source under development utilizes an energy-recovery linac (ERL) for a relativistic electron beam of small emittance and high average current. A test facility, Compact ERL, is under construction in collaboration with KEK to demonstrate the generation of high-brightness photons from laser Compton scattering [3]. A laser system for the laser Compton scattering is also under development at Kansai Photon Science Institute of JAEA. The laser is designed to produce a train of mode-locked laser pulses with an average power above 100 W. We have paid special attention to achieve narrow laser bandwidth to prevent spectral broadening in laser Compton scattered gamma-rays.

In the non-destructive assay of nuclear material, gamma-ray signals from coherent scattering may become a background to obstacle the measurement of nuclear resonance fluorescence. In order to overcome the issue, two approaches have been investigated: measurement of integral resonance transmission [4] and measurement of nuclear decay to non-ground levels [5].

In this presentation, status of the above R&D's is described in detail.

[1] H. Ohgaki et al., J. Korean Phys.Soc. 59,3155 (2011).
[2] R. Hajima et al., J. Nucl. Sci. Tech. 45(5) 441-451 (2008).
[3] S. Sakanaka et al., Proc. Int. Particle Accelerator Conference, WEPWA015 (2013).
[4] C.T. Angell et al., Proc. Ann. Mtg. Institute of Nuclear Material Management (2013)
[5] T. Shizuma et al., to be submitted.

LFEX High Energy Peta-Watt Laser and Its Potential for High Field Science

Hiroshi AZECHI
Institute of Laser Engineering, Osaka University

A high energy peta-watt laser called LFEX (Laser for Fusion EXperiment) has been commissioned at the Institute of Laser Engineering, Osaka University; It consists of a 4-beam and 4-path Nd:glass amplifier system with a 40-cm square aperture in each beam; The design goal of LFEX is to deliver 10-kJ energy in 10-ps width at 1-μm wavelength, while it also delivers 4-kJ energy in 1-ps width; The focusing optics is an off-axis parabola mirror with f/10 speed in each beam. Currently, 3 among 4 beams are in operation, and the fourth beam will be completed in the year of 2014. The focus-ability to diffraction limit and pulse contrast ratio of more than ten billionth are the targets of effort.

The primary purpose of using LFEX is to explore fast ignition concept in the program called Fast Ignition Realization Experiment (FIREX). The goal of its first phase is to demonstrate ignition temperature of 50 million degree, followed by the second phase aiming at ignition-and-burn. The decision of the second phase will be made in a review committee at the Council for Science and Technology in the year of 2016. After this process, LFEX laser will be fully open to the world for basic science study including relativistic plasmas, particle acceleration, radiation damping, and non-linear QED.

So far, 1 keV achieved.
Ignition temperature to be achieved.

Development of high energy OPCPA and 2 PW lasers at 800 nm

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The optical parametric chirped pulse amplification (OPCPA) based on large aperture nonlinear optical crystals is promising for the implementation of ultra-high peak-power laser system of 10PW and beyond. We demonstrated the highest energy broadband OPCPA at 800nm, to the best of our knowledge, by using a 80-mm in diameter LiB3O5(LBO) amplifier, with an output energy 28.68 J, a bandwidth of 80 nm (FWHM) and a conversion efficiency of 25.8%. After compression, the peak power of 0.61 PW with a pulse width of 33.8 fs is produced [1].

The laser facility is a CPA and OPCPA hybrid laser system. A commercial 75 MHz, sub-20 fs Ti:sapphire oscillator is used to provide seed pulses for an aberration-free all-reflective Öffner-triplet-type stretcher with a 1200 groove/mm grating. After pulse stretching, the laser pulse is sequentially amplified in a regenerative amplifier and two multi-pass amplifiers all of which are based on Ti:sapphire crystal. The amplified laser pulses of 3 J in energy and 1.6 ns (FWHM) in length are sent to an OPCPA booster amplifier based on LBO crystal.

The OPCPA booster amplifier is pumped by the second harmonic generation of an Nd:glass laser. The pump laser is seeded by a laser pulse sliced out of a CW-SLM laser at 1 Hz. This pulse is amplified from ~280 pJ to 3 mJ by a diode-pumped Nd:YLF regenerative amplifier. Then, the output pulse is temporal shaped by a high-speed electro-optic modulator with an adjustable rising edge to compensate for the pulse-shape transformation caused by the gain saturation in the subsequent Nd:glass amplifiers. Meanwhile, it is spatially shaped to produce a nearly flat spatial profile. Subsequently, the laser pulse is amplified in the following Nd:glass amplifiers. After frequency doubling, the second harmonic is down-collimated to 55 mm diameter. Finally, pump energy of up to 102 J with nearly flat spatial-temporal profiles at 526.5 nm is available in 2.89 ns pulse duration at a repetition rate of one shot every 20 min.

We will also report a 2 PW laser system by using Ti:sapphire-based chirped pulse amplification scheme. The parasitic lasing in the 100 mm in diameter Ti:sapphire is effectively suppressed at the pump energy of 140 J. The 800 nm laser energy from the final amplifier is 72.6 J, corresponding to a conversion efficiency of 47.2%. The recompressed pulse duration is 26 fs and the transmission efficiency of the compressor is 72%. The technology of cross-polarized wave (XPW) is applied in a broadband front end, and the pulse contrast is improved to ~1.5×10-11 (-100 ps before the main pulse).

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Astrophysical ZeV acceleration in the relativistic jet from an accreting supermassive blackhole

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An accreting supermassive blackhole, the central engine of active galactic nucleus (AGN), is capable of exciting extreme amplitude Alfven waves whose wavelength (wave packet) size is characterized by its clumpiness. The pondermotive force and wakefield are driven by these Alfven waves propagating in the AGN (blazar) jet and accelerate protons/nuclei to extreme energies beyond Zetta-electron volt (ZeV=10^{21} eV)[1]. Such acceleration is prompt, localized, and does not suffer from the multiple scattering/bending enveloped in the Fermi acceleration that causes excessive synchrotron radiation loss beyond 10^{19} eV. The production rate of ZeV cosmic rays is found to be consistent with the observed gamma-ray luminosity function of blazars and their time variabilities.

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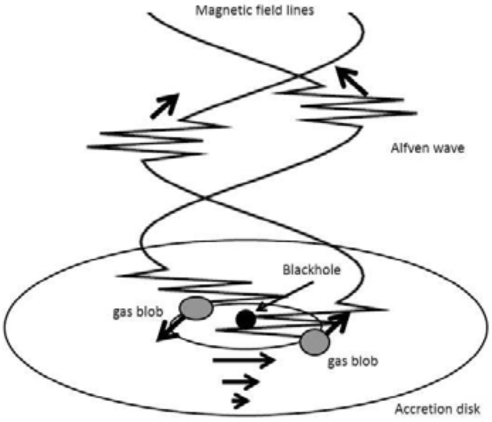

Figure 1 Schematic diagram of the production of intensive Alfven waves in an accretion disk. A gas blob formed near the inner edge of the accretion disk severely shakes the magnetic fields and excites relativistic Alfven waves, which propagate along the magnetic field line of the jet.

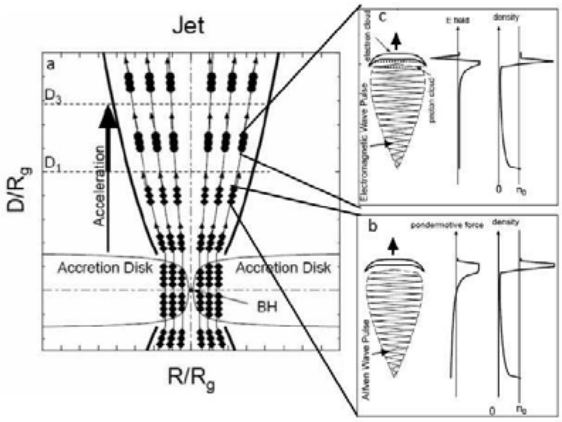

Figure 2 a) Schematic cross section of an disk/jet system around an accreting black hole (BH). Alfven waves (diamonds) are excited in the accretion disk and propagates along the magnetic field (thin solid curves) in the relativistic jet (thick solid curves). b) In the pondermotive region ($\omega'_c > \omega'_p > \omega_A$), the pondermotive force of the intense Alfven wave pulse produces a bubble and accelerate particles. c) The Alfven waves turn into electromagnetic waves (circles) as ω_A approaches and exceeds ω'_p and excites the accelerating structure whose pondermotive force fields accelerate charged particles longitudinally along the jet. We anticipate that in the extremely large a, the domain of wakefield acceleration is dwarfed by that of pondermotive acceleration in the 1D situation. In 2-3D, wakefield acceleration takes a greater role than in 1D.

Laboratory Astrophysics using High Power Lasers

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Recent years have seen tremendous progress in our understanding of the extreme universe, which in turn points to even deeper questions to be further addressed. History has shown that the symbiosis between direct observations and laboratory investigation is instrumental in the progress of astrophysics. Current frontier astrophysical phenomena related to particle astrophysics and cosmology typically involve one or more of the following conditions: (1) extremely high energy events; (2) very high density, high temperature processes; (3) super strong field environments. Laboratory experiments using high power lasers can calibrate astrophysical observation or detection processes, investigate underlying dynamics of astrophysical phenomena, and probe into fundamental physics in extreme limits. We provide examples of possible laboratory astrophysics experiments using high power lasers.

Collaboration between Academia and Industry

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Close collaboration between academia and industry is essential for opening frontiers of both science and industry. Newly developed high performance photon detectors played key roles in the discoveries of neutrino oscillation and Higgs particles, for example. Alternatively, many advanced industrial and medical products came out of research in basic science. Development of extremely high-average and high-peak power lasers for high field science will require close collaboration with industry. I will present a few topics which might contribute to discussion on this issue.

In the Photon Frontier Network Program, scientific research as well as fostering young scientits are undertaken as the 10-year program (2008-2017) as the network activities centered at APSA (Adavanced Photon Science Alliance, PD: M. Gonokami, U. Tokyo) and C-PhoST (Consortium for Photon Science Alliance, PD: R. Kodama, Osaka U.). Among various R&D under PFN, most of them related to high power and ultrashort pulse lasers, the PCSEL (photonic crystal surface emitting laser diode) developed by S. Noda of Kyoto U. has produced high power with diffractioin limited divergence in his university lab as well with the commercialized product. Since it has potential to be scaled to very high power, it may lead to new types of high power solid state lasers.

Scientists at GPI (The Graduate School for the Creatrion of New Photonics Industries) are working with Hamamatsu Photonics, Inc. on laser fusion research in order to devlelop new energy source in a long term and various applications of high power lasers in a short term. Neurons have been generated repetitively with the 10-Hz, 20-TW, 60-fs laser pumped by 10-Hz, 4-J DPSSL. Developments of scientific research as well as industrial applications will lead to progress in both sectors.

Energy for large scale research infrastructures: Round table discussion

IZEST Tokyo Conference 2013

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Several large scale research infrastructures are on the agenda of the research community to target frontier science. They are in various stages of development from basic R&D to advanced design, from long term planning to freshly running. They target the high-energy frontier with the ILC (International Linear Collider), the high-intensity beams with the ESS (European Spallation Source), the high density plasma with the fusion ITER program or the laser ignition studies at NIF or even the ultra-high energy density with the zeta-exa scale lasers.

All these facilities have a common requirement: a large, stable, reliable and flexible electricity supply. CERN running the highest energy particle collider, the LHC, is yearly consuming 1.2 TWh, 40% of the electricity needs of the half-million residents Geneva region. ILC, in its basic stage will be in the same ballpark and will almost double this figure in its highest energy stage.

Energy has become a major issue in the world both in terms of supply and of carbon footprint. Although not a major issue in the past, the new research infrastructure must take into account this new paradigm.

After a short presentation of the ILC and ESS cases, the discussion will address some of the main energy issues in the field of high intensity laser and plasma acceleration.

Large size and high performances diffraction gratings for Ultra-Intense Laser Pulse Compression

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For the IZEST colloquium, we present an overview of diffraction gratings technology and perspectives for Exawatt-class laser chirped pulse compression. The two main grating types: gold-coated and Multi-Layer Dielectric (MLD) are introduced and described. Diffraction gratings are a key optical component in a high-intense and high-energy laser. They have to exhibit high performances in diffraction efficiency, damage threshold, wavefront quality.

MLD GRATINGS FOR SUB-PICOSECOND PULSE COMPRESSION

The use of the chirped pulse amplification (CPA[1]) is widely employed to produce high-energy laser pulses in the femtosecond and picosecond regimes. The compression stage is based on diffraction gratings, usually two or four gratings working in reflection. Traditional diffraction gratings for pulse compression are often holographically mastered gratings.

These laser systems require high efficiency and high damage threshold gratings in the picosecond regime. In order to enhance the damage threshold of gratings for pulse compression, HORIBA Jobin Yvon has developed and manufactured diffraction gratings engraved into the upper layer of a high-damage-threshold Multi-Layer Dielectric (MLD) coatings to work at 1µm. These MLD gratings exhibit damage thresholds higher than classical gold coated gratings in the picosecond pulse regime and high efficiency.

GOLD-COATED GRATINGS FOR FEMTOSECOND PULSE COMPRESSION

Another type of high-intense laser is based on TiSa at 800nm or OPCPA, femtosecond pulses, high repetition rate. These lasers require shorter pulse duration and therefore an ultrabroadband spectrum to be able to compress in femtosecond regime. Petawatt laser pulse compressor and especially diffraction gratings, as the final stage of the laser system, have to exhibit the highest performances:

- high diffraction efficiency to transmit the precious amplified energy,
- broadband efficiency to preserve the amplified spectrum and recompress to the Fourier transform-limit pulse duration,
- high wavefront quality to be able to focus in a diffraction-limited spot,
- high laser damage threshold (LDT) to resist to the highest energy and intensity in the laser system.

HORIBA Jobin Yvon has developed and produced for almost 30 years gold-coated gratings and MLD gratings in large dimensions and continues to increase production capabilities to be able to produce high-performances gratings for the next laser generation.

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Latest results on PetaWatt lasers and future developments

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High peak power ultrafast laser sources are required by the scientific community for a increasing number of applications like particle generation and acceleration , secondary radiation generation in UV, X and Gamma bands and many others.
The requirements lead to higher peak power, higher repetition rates and ease of operation in order to consider those installations as „turn-key systems" permanently available for the researchers to do their experiment.
Titanium Sapphire based CPA is the ideal technology to meet such requirements considering the gain bandwidth of this material which allows extremely short pulse duration, down to 25 fs, and the excellent thermal properties of the crystal allowing operation at „high" repetition rates.
We report on the results on two PetaWatt laser systems, one installed at Berkeley in 2012 for the BELLA project of LBNL[1] and the other one installed in Romania for the CETAL project of INFLPR[2] in 2013.
The BELLA laser is the first „commercial" PetaWatt laser to have been demonstrated and currently the sole PetaWatt laser system in the world to operate at 1 Hz thanks to a new generation of high energy YAG pump lasers (GAIA).
The CETAL laser is the PetaWatt laser with the shortest pulse duration ever achieved from a PetaWatt laser, as low as 23.7 fs, thanks to unique expertise of Thales in providing innovative high performance designs for such lasers.
We present also what are the perspectives for the evolution towards multi-PetaWatt laser systems and up to 10 PetaWatt in the frame of ELI project.

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Tuesday

November 19, 2013

ICAN – a new laser paradigm for applications in particle physics

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The ICAN concept of using massively parallel optical fibre lasers[1] to provide the pulse energy and power necessary for applications in particle physics has been developed over the last few years by a consortium led by Prof. Gérard Mourou, with Ecole Polytechnique, Friedrich-Schiller University Jena, the University of Southampton, and CERN as its principal members. During this time, ICAN has gone from an original idea to a well-focused design. This talk will give a brief summary of the ICAN concept, to indicate how the high peak and average powers will be reached while retaining the efficiency necessary for economic variation, and go on to give detail of some of the many potential applications.

The modular nature of the laser means that output suitable for different experiments can be produced by scaling the laser design. Several potentially exciting new possibilities will be used as examples. A laser source suitable for a Higgs factory is technically the most accessible, because of the relatively low pulse energy needed. As laser pulse energy is scaled up, high-energy (GeV) wake field acceleration becomes feasible, with potential applications in new accelerator technolgies, as well as compact FEL sources. With further significant laser scaling, the production of relativistic protons would be possible, opening up both new scientific applications and also important societal applications, such as the development of compact proton therapy accelerators and ADS-based neutron sources.

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High speed interferometric technique for coherent beam combining of large number of fiber amplifiers

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The challenge of producing the next generation of particle accelerators, both for fundamental research, or for more applied tasks such as proton therapy or nuclear transmutation has been taken up by the high intensity laser community [1]. In order to reach the ultrahigh peak power and the high repetition rate (typically >10kHz) needed for these applications, coherent beam combination [2] of thousands of fiber amplifiers has to be envisaged.

This cutting edge technology requires i) innovative methods for ensuring simultaneous measurement of phase errors between the numerous output beams and ii) a large bandwidth (typically 1kHz) control loop to suppress these errors. In this Talk, we will present the implementation of an interferometric method allowing collective measurement of the phase errors between all the fibers with a single image captured on a fast camera. As the complexity of the measurement is inherently independent of the number of fibers, this approach is therefore naturally more suited for phase locking of very large number of fibers. We demonstrate coherent combining of 64 fibers by using this method [3].

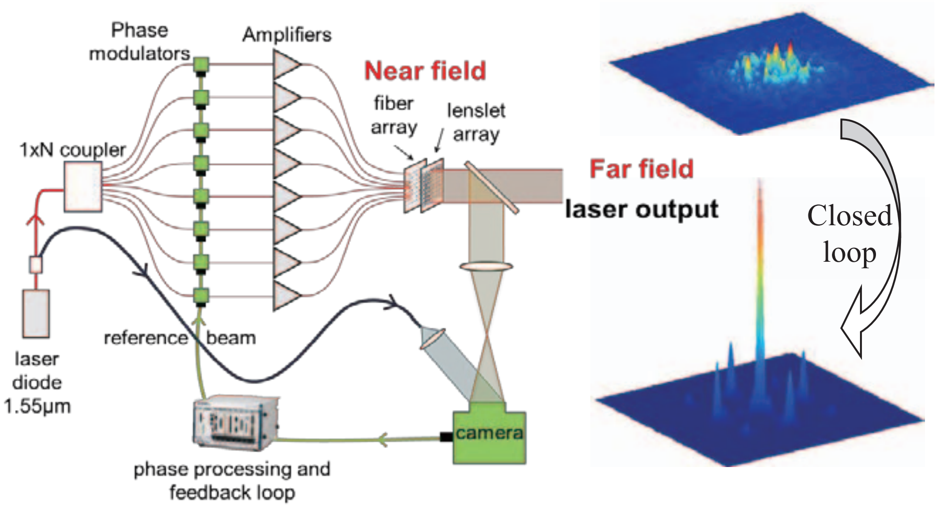

Fig. 1: Principle of beam combining using interferometric technique (left) and experimental demonstration of the intensity enhancement in the far field thanks to phase locking of 64 fibers (right).

By using a high speed camera and an optimized algorithm, phase locking at a repetition rate of 1kHz has been achieved. Furthermore, we show that a minimum of 8 pixels per fiber on the camera is enough to guarantee precise phase locking with a residual phase error as low as λ/20 rms. The consequence of this result is that more than 10,000 fiber amplifiers could be coherently combined with a commercially available high speed megapixel camera.

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New paradigm for X-ray sources driven by ICAN lasers

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Since about a decade and half, laser-driven X-ray sources demonstrated to have the potentiality to replace the conventional X-ray sources (X-ray tubes and synchrotron mainly) with better properties, being compacter, more coherent and faster. High harmonics emitted during the interaction of femtosecond laser with gaz demonstrated the shortest pulse duration ever with about 70 as (1 as = 10^{-18} s) [1]. Also they exhibt full spatial coherence and diffraction-limited wavefront around 30 nm. Both properties, spatial and temporal, opened the way to many applications on metrology and coherent imaging [2]. Soft x-ray laser driven by laser produces most energetic X-ray pulses up to 10 mJ/pulse (to be compare to 1 μJ/pulse for high harmonic) and full coherence and diffraction-lilited wavefront if seeded by high harmonic [3,4]. Applications range from laboratory astrophysics, femto-magnetism, solid-state physics, biology and non-linear physics. X-ray sources driven by laser-accelerated electrons shown very high photon energy up to several 100's keV with collimated beam and very high compactness as compared to synchrotrons [5,6]. Several applications have been demonstrated, the most important being the phase-contrast imaging taking advantage of the micrometer source size (i.e. leading to μm resolution) [7]. The very high photon energy may deserve for radiography of bulk systems like plane turbines.

Currently, all these sources failed to emerge in the real market i.e. out of scientific demonstration, due to three major limitations, poor robustness, very low average power and weak efficiency, due to the old technology used for the laser drivers. ICAN is the only project that has the capacity to unlock these three botlenecks at once [8] leading to like a revolution in the development and use of laser-driven x-ray sources. Computer industry will get benefit for actinic metrology or even mass-production with short-wavelength steppers, medicine will be dramatically changed with new 3D single-shot X-ray imaging technic, industrial X-ray radiography and tomography will become real...

Ican may open a new paradigm for laser-driven X-ray sources triggering many new industrial and societal applications.

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LASERIX facility: Achievements and prospective opened by ICAN

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LASERIX facility has been funded by French Ministry of Research in the early 2000's. At this time, the choice of Ti:Sapphire amplifiers using the Chirped Pulse Amplification technique was a kind of revolution. Indeed, soft x-ray lasers, the heart of LASERIX facility, were pumped by infrared laser delivering at least several 10's of Joules while at this time Ti:Sapphire lasers were at best reaching few Joules.

Thanks to development undertaken with Laboratoire d'Optique Appliquée and the LUIRE project large Ti:Sapphire crystal were developed enabling to reach up to 40J in a single 100's ps long pulse. This first-of-a-kind laser system opens the way to several industrial developments. Moreover for the soft X-ray laser community it produced a big step forward pushing the repetition rate from 0.001 Hz to 10 Hz at 2 J level and 0.1 Hz at full energy. Such high repetition-rate opened the way to unprecedented statistical developments on soft x-ray laser physics. It also promoted LASERIX facility to the level of achievement and easiness to run of any laser facility, attracting for the first time external users on a plasma-based soft x-ray laser. Applications on Biology, plasma physics, solid-state physics were successfully conducted or are under consideration.

After nearly a decade of developing and running LASERIX facility and after outstanding progresses, we learned that LASERIX as the prototype of any plasma-based soft x-ray laser facility needs two in-depth evolutions that only ICAN may offer. First, the repetition-rate is still too low at both low and full energies. At low energy reaching kHz repetition-rate will ensure LASERIX to be very attractive to synchrotron users. At full energy reaching 100 Hz or more will place the facility at the level of some free-electron lasers. In both cases, active control of the full X-ray system and much higher reliability is foreseen. At such high average power, several kW for the driving laser, wall-plug efficiency will become a key issue that only stacked fibre lasers may solve.

Applications of high energy fibre lasers to gamma-gamma collider Higgs factories

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The recent discovery of the HIggs boson and subsequent Nobel prize award for its prediction has stimulated research on Higgs factories, machines capable of producing many Higgs events a year for detailed study of its properties. The major proposals in the HEP/accelerator community for future colliders to explore the Higgs are for linear electron-positron colliders such as the International Linear Collider (ILC) or Compact Linear Collider (CLIC). However, now the Higgs mass is known there has been a resurgence of interest in facilities to create Higgs bosons by gamma-gamma collisions, where the high energy photons are created by scattering a visible or uv laser pulse from an electron bunch. I shall discuss some suggested gamma collider proposals such as SAPPHiRE and HFiTT, concentrating on the required laser parameters, and looking at whether recent developments in high energy, high repetition rate fibre lasers mean that they could be suitable sources for a gamma-gamma Higgs factory.

Low energy stimulated gamma-gamma collider toward laboratory search for dark fields

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Understanding a large fraction of dark components in the universe is the one of the most fundamental problems in moder physics. In high energy scales, several neutral bosons have been discovered. It is well known that the neutral pion and the Higgs-like particle can couple to two photons via the decay processes at QCD and EW energy scales, respectively. These facts encourage further experimental searches for similar type of fields via two-photon coupling in very different energy scales in general. For instane, there are theoretical rationales to expect sub-eV particles such as the axion (pseuodscalar boson) and the dilaton (scalar boson) associated with breaking of fundamental symmetries in the context of particle physics and cosmology. Furthermore, the advent of high-intensity laser systems and the rapid leap of the intensity encourage the approach to probe weakly coupling dark fields with optical photons by the enhanced luminosity factor. With high-intensity lasers, we might be able to unveil the different aspects of the quantum vacuum at different space-time scales based on analogous observables in quantum optics [1-4]. We present the novel approach to realize the laboratory search for low-mass and weakly coupling dark fields which can be dark components of the universe by detecting four-wave mixing of two-color laser fields in the vacuum. This can be interpreted as a kind of quasi-parallel photon-photon collider whose interaction rate is enhanced by the resonant production of a sub-eV neutral boson and also by the stimulated decay in the coherent laser fields[5]. We emphasize the advantage to utilize high-rep rate and high-intensity laser systems such as ICAN.

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Collective Ion Acceleration Mechanism with Petawatt-subpicosecond Laser pulses

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Within the mechanisms of ion acceleration up to GeV energy, one is the collective process with extreme power and sub-picosecond laser radiation interaction, based on Doppler measurements and detailed numerical evaluations including shock generation and dynamic build-up properties [1]. This is different from the fast ion generation by relativistic self-focusing and from TNSA results and explained the ultrahigh acceleration and the ultrahigh current densities of space-charge-free plasma blocks. The new fundamental aspect is the direct conversion of optical energy of the laser pulse into macroscopic plasma motion where thermalization is excluded for the ps in contrast to ns interaction with heat losses, delays, instabilities for generating ion pressures and the problems of complex physical systems. Consequences to applications are discussed.

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Prospects for High Efficient Gamma-Ray Sources with Laser Facility XCELS

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One of the important goals of XCELS project [1] is generation of extreme bright gamma-ray radiation at laser-matter interaction. The XCELS laser intensity will exceed 10^{24} W/cm^2. At such intensity level the electrons and positrons become very efficient radiators of X-rays and γ-quanta while the particle dynamics is governed by radiation reaction. We have studied ultra-high intensity laser-plasma interaction numerically and analyticality for various configuration of laser fields and plasma targets.

One of the most promising configurations is the "e-dipole" wave converging towards the focus [2]. Such configuaretion provides the maximum possible light intensity at a given laser power. We have shown that for the parameters of the XCELS laser with such a configuration it is possible to obtain a photon beam narrow-collimated along the dipole axis with photon energy over 1 GeV [3]. Incoherent emission of γ-rays at laser-foil and laser-solid interactions has been studied for wide range of laser and plasma parameters [4]. Regimes of laser-foil interactions are studied in the framework of a simple analytical model. It is shown that in the case of oblique incidence of a 3 PW, 10 fs laser pulse on a thin foil about 10^8 photons/0.1% bandwidth are produced at the energy level of 1 MeV that significantly exceeds performance of the modern Compton gamma-ray sources. The energy partition, γ -ray emission, and high-energy photon angular distribution dependence on laser intensity and polarization for thick, high-density and low-density targets has been also systematically studied. For configuration of counterpropagating circularly polarized laser pulses and a plane plasma target of nanometer thickness, the conversion efficiency from the optical to the gamma range can be significantly enhanced [5]. At laser intensities higher than 10^{24} W/cm^2 QED cascading becomes one of the key processes accompanying laser-matter interaction. We have studied the effect of laser polarization on the cascade dynamics [6].

It is worth noting that even in the fields of simplest configuration like a plane traveling or standing wave, the particle trajectories demonstrate astonishing features [7]. One of them is radiation trapping of emitting particles [3]. This effect allows concentrating the emitting particles in space and synchronizing their motion in time, thus providing maximum efficiency and directivity of the γ-ray sources.

[1] www.xcels.iapras.ru.

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Delbrück scattering as a High Precision Vacuum Probe

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The scattering of photons off the Coulomb field of nuclei due to virtual electron-positron creation/annihilation, Delbrück scattering, was first suggested in a comment by M. Delbrück in the 1930's [1] and has been been measured extensively [2]. Most work on it stopped in the 1990's [3]. For the MeV order energy range the scattering of photons off nuclei is a coherent sum of Thomson scattering off the nucleus, Atomic Rayleigh scattering, nuclear scattering and Delbrück scattering [4]. Previous measurements used unpolarized γ-ray sources and as a result all processes were measured in the scattering with fairly large uncertainty in the data [3]. However, high flux tunable linearly polarized γ-ray sources will be available in the near future [5]. As a result precision measurement of mainly the Delbrück scattering cross section and, therefore, the vacuum contribution may be possible by appropriately choosing the scattering angle and photon energies.

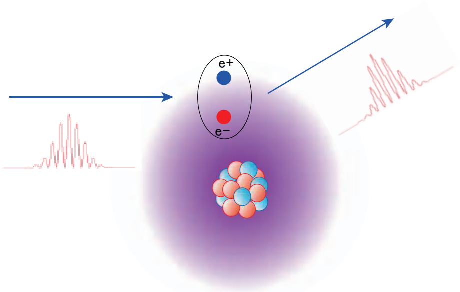

Fig. 1 Schematic of Delbrück scattering

The most complicated component is the Delbrück scattering. Although tabular data exist [6], for precision measurements finer data will be needed. So our independent calculations of the Delbrück scattering in the lowest order Born approximation using the LoopTools package of routines [7] and CUBA Monte Carlo methods package of routines [8] and prospects for measuring the vacuum will be presented.

[1] L. Meitner and H. Kösters, Z. Phys. **84** (1933) 137
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Higgs Boson Creation in Laser-Boosted Lepton Collisions

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The associated creation of a Higgs and a Z^0 boson in relativistic lepton-antilepton collisions taking place in a strong laser field is studied. The energy of the pre-accelerated particles may be vastly increased by their interaction with the intense laser field. The total cross section as well as the produced Higgs boson's energy distribution are calculated and related to field-free collisions of corresponding center-of-mass energy. Possible qualitative differences with regard to the detection of the Higgs bosons are presented. The required laser paramters and other experimental challenges are specified [1].

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A short overview of the intense laser

Increasing intensity of intense laser science in India: a short overview

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The diverse and exciting prospects of the world of intense laser science have attracted the imagination of many research endeavors in India. Several institutions have now established active groups in this area of research both in experimental efforts and in understanding the underlying physics with theoretical/computational models. Different groups are planning to expand this activity further and establish even more ambitious programs by upgrading the laser facilities both in pursuit of the basic physics and applied aspects of the intense laser science. I will give a brief overview of the current status of the research and high light some of the research contributions. I will also give a summary of the future plans that are in progress.

New scheme to generate a multi-terawatt and attosecond laser pulse in X-ray free electron lasers

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The x-ray free electron laser (XFEL) is a kind of laser sources, which is based on coherent emission of radiation from a relativistic electron beam having a periodic density modulation. The advantage of XFEL is that it does not have any theoretical limitations on the available wavelength. For example, the Japanese XFEL facility "SACLA" is now operating in an angstrom wavelength region, which is about 4 orders of magnitude shorter than what is available with conventional laser schemes.

Although the XFEL has extended the wavelength availability of laser sources to angstrom wavelength regions, there still remains several technical challenges to be overcome. Among them, the pulse compression technique to enhance the peak power as well as shorten the pulse length, which is commonly applied to optical lasers to produce a femtosecond-terawatt light pulse, is an important target. In fact, the shortest pulse length currently available in XFEL facilities in operation is about several femtoseconds, about 4 orders of magnitude longer than the theoretical limit (several hundreds of zeptoseconds).

Recently, a new scheme has been recently proposed[1], which compresses the XFEL pulse, i.e., shortens the pulse length and enhances the peak power by means of inducing a periodic current enhancement with an optical laser and applying a temporal shift between the X-ray and electron beams. In this paper, detailed mechanism of the new scheme is explained together with numerical results applied to the SACLA facility.

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Amplification of ultra-short light pulses by ion collective modes in plasmas: experiments and simulations

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The use of plasmas provides a way to overcome the damage threshold of classical solid-state based optical materials which is the main limitation encountered in producing extreme power laser pulses. In particular one can use plasmas to directly amplify ultra-short laser pulses to very high intensities. Multi-dimensional kinetic simulations [2,3] and first proof-of-principle experiments [1,4] show the feasibility of using plasma instabilities involving ion waves, such as e.g. stimulated Brillouin backscattering, in a controlled way to transfer energy from a long pump pulse to a short seed pulse and thereby increase the intensity of the latter. Plasma parametric amplification, and the use of plasma mirrors for focusing, is part of the newly developing domain of plasma optics, which eventually will pave the way to Exawatt lasers.

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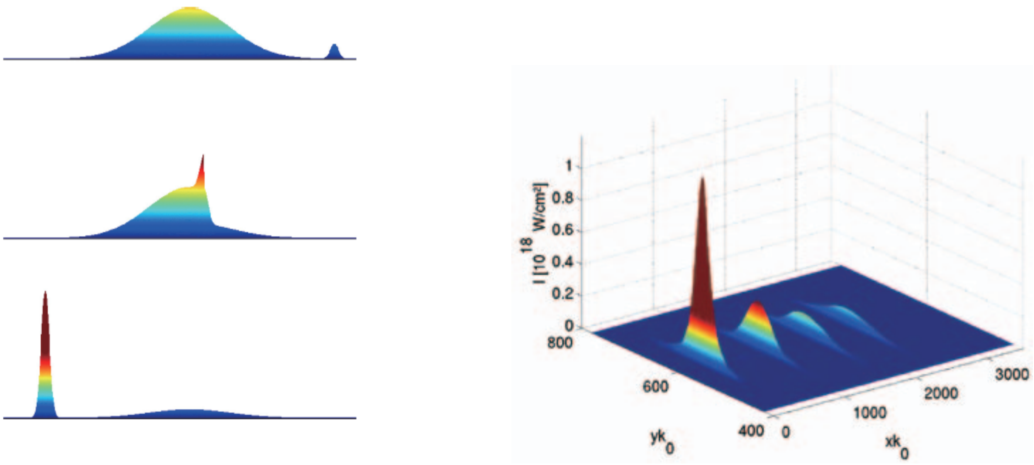

Figure. Left: schematic view of the interaction between pump and seed (time sequence from top to bottom). Right: PIC-simulation of an amplification process.

Thermal-Lens-Free Cooling of Solid State Lasers for Coherent Beam Combining

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A paradigm shift of power scaling of high power lasers are comming soon, because the aperture scaling is limited by ASE loss. A coherent beam combining technique is essential for the unlimited power scaling for future application like laser-driven high energy physics. We concentrate our effort to demonstrate coherent beam combining by fiber laser array. I believe this is a correct way today. But we need alternative techniques every time for our future science. I propose new concepts for the thermal-lens-free cooling techniques of solid state lasers.

A compact solid state laser can generate 1000 times larger pulse energy easily than a large mode area fiber laser because the pulse energy is limited by damage threshold and aperture size. However, the high beam quality beam is most critical for beam combining. Until today any solid state laser has a thermal lens problem. Even thin disk lasers are not free from thermal lens and the beam quality is not so good for beam combining techniques. We need quite new concept for thermal lens free solid state lasers.

Until today, we concentrated high efficiency cooling intensively. But, we should change the philosophy on the solid state laser cooling. I propose a cooling management concept, uniform cooling is the first, and efficient cooling is the second for the future thermal lens free solid state lasers. Combination of end cooling and thermal insulation of side surface of rod and disk laser is shown in Fig.1 as an example of 1D axial thermal flow, and thermal lens free concept. When the rod length is shorter, the cooling efficiency is higher. So, thin disk laser with thermal insulation layer for laternal thermal flow is a key concept.

In addition, the thermal lens is a function of thermal flow rate, axial flow/lateral flow. How to realize the higher cooling efficiency in the axial thermal flow, it is the second issue. For the second issue, I propose a high seed rotary thin disk concept in coorperate with commercial HD technology. HD technology is a great high technology to combine advanced mechanical, electronics, and optical techniques. A simple calculation gives us a result that the cooling efficiency of more than 1600 is possible without any degradation of optical homogeneity. I believe thermal lens free solid state laser technology should be a key for our future laser power scaling.

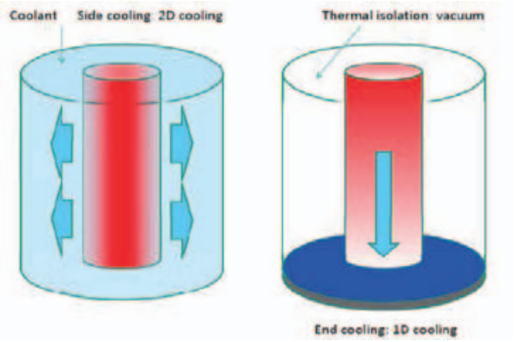

Fig 2: 2D cooling to 1D cooling

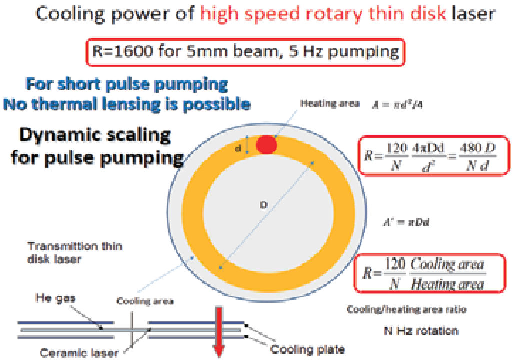

Fig 1:High efficiency cooling by high speed rotary thin disk

Wednesday

November 20, 2013

Progress in the IZEST Projects

T. Tajima and G. Mourou
IZEST

Fundamental high energy physics has been mainly driven by the high-energy charged particle colliding beam approach. Today the possibility to amplify laser to extreme energy and peak power offers a complementary new alternative underpinned by single shot, large field laser pulse in addition to possibly more compact and cheaper way to help HEP. We also envision to use the laser field to probe the nonlinearity of vacuum. We envision that seeking alternative paradigm without large luminosity of an $e^+ e^-$ collider first teaches us how to approach high energy regimes such as the low density plasma operation as well as substantially shortens our time-line. We further accelerate the time-line of the research by adopting the existing large energy lasers around world to coordinate and collaborate the necessary research components in an organic fashion, including PETAL-LMJ.

Thus in IZEST we started three Research Projects, i.e. (a) 100GeV Ascent, (b) Dark Field Search, (c) C^3 (Cascaded Compression Conversion) and Damageless Optics, besides ICAN. In each of these three Projects, it takes ascendancy of laser parameters and sophistications in order to push the envelope of the experimental frontier. It is beyond the ability and capacity of one single lab or group to do so. That is why at IZEST we have formed a network organization of world-wide associated laboratories whose missions are interconnected and coordinated to reach our aspirations. For example, in the 100GeV Ascent Project, starting from the current GeV level experimental platform using a J energy level laser as a base camp, we need to increase the laser energy level a notch higher to 10-100J class. This should constitute the second base camp. In such experiments (at several world labs) not only do we need larger energy lasers, experimental techniques need to be expanded, including the lower plasma density devices and higher energy diagnoses. Each world associate lab can bring in its won unique capability in carrying out such. After we learn how to do such, we can further increase the laser energy level to kJ and beyond. Since such kJ laser at this time come in with a limited rep rate, experimental parameters and techniques need to be honed well in advance of the experiments at kJ and beyond. These are the spirit of each Project that makes our ascendancy.

Development of laser driven injector for electron acceleration

CEA - Saclay - France

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An overview of recent developments at CEA, Saclay will be given concerning electron acceleration for IZEST. The commissioning of a new target area is in the final stages of completion. Once achieved, tests will begin involving electron injection with a newly built variable length gas cell. The specifications of which will be discussed together with details on the planned experiments at Saclay using the UHI 100 TW laser facility.

Preliminary Experiment on Plasma Wave Guide for PWFA

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We are developing a hollow density (10^{15-16} cm^{-3}) plasma wave-guide by the combination of helicon plasma and laser discharge. The two steps of discharge scenario is adopted to get a radially hollow density profile of fully ionized small diameter plasma: For the first step, the helicon discharge [1] with external axial magnetic field of ~1kG produces the plasma peaked at the center and the ionization of the plasma makes the hollow neutral density. The dip of the neutral density is much larger than that of helicon plasma at the center due to the difference in temperature of neutrals and plasma. Then the intense laser is injected to ionize the neutrals to make fully ionized hollow density plasma in the tube.

The experiment of helicon discharge with m=1 antenna has been performed on the narrow glass tube of 4mm in diameter and 50cm in length with helium gas in a few tens of mtorr range. The Rf power is up to 3kW (duration and duty cycle are 1ms and 10Hz, respectively) and the frequency is 13.56MHz. The density measured by Langmuir probe is peaked at the center (~10^{13} cm^{-3}) and the hollow neutral density profile is observed by measuring the neutral emission line profile.

More detail neutral profile measurement will be performed by laser absorption method. The simulation of the neutral density profile by the helicon plasma is now underway.

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Experimental test plan for long plasma waveguide in the conventional accelerator facility.

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The long plasma waveguide with lower density plasma is required for the high energy laser plasma acceleration using the kJ-class laser.

The quadratic plasma distribution is required for the laser guiding. The quadrupole microwave plasma is one candidate to make the long plasma waveguide. Also the pulsed high voltage is another candidate. We are developing the power supply and the plasma channel.

Further the after burner test facility is under construction using the compressed femtosecond bunch from the conventional accelerator. We will test the plasma channel in this facility.

Multi-GeV electron-beam generation using petawatt laser pulses

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Seong Ku Lee,[1,2] **Jae Hee Sung,**[1,2] **Tae Moon Jeong**[1,2] and **Chang Hee Nam,**[1,3]

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Laser-wakefield acceleration (LWFA) has a potential to realize the production of a 100-GeV electron beam using the huge field gradient induced by an intense laser pulse. The enhancement of electron energy in LWFA has a constraint on the power of the driving laser. The recent progress of high-power laser technology has realized an output power over 1 PW, which can provide a chance to enhance the electron energy to a multi-GeV level. Two PW Ti:Sapphire laser beamlines have been developed at GIST with outputs of 1.0 PW and 1.5 PW at 30 fs [1,2]. Here we summarize our recent results on LWFA achieving 3-GeV electron beam using the PW laser [3].

In the LWFA experiment, we applied a dual-stage acceleration scheme with a PW laser pulse in order to obtain multi-GeV electron beam. Two helium gas jets of 4-mm and 10-mm length were used for the dual-stage acceleration. A 400-MeV electron beam was generated from the first 4-mm gas jet and injected into the 10-mm jet for further acceleration to achieve multi-GeV electron energy. We observed a substantial enhancement of electron energy over 3 GeV after the second acceleration stage. The divergence of the electron beam after the acceleration stage was about 4 mrad, and the charge of the electron beam for energies over 2-GeV is estimated to be about 10 pC. The electron spectrum has two separate peaks at 1.1 and 2.7 GeV while the maximum energy of the electron spectrum reached 4 GeV. We performed three-dimensional particle-in-cell simulations that confirmed the multi-GeV electron generation from the dual-stage acceleration with a PW laser pulse.

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Activities at the John Adams Institute for Accelerator Science in laser plasma wakefield acceleration

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The John Adams Institute for Accelerator Science (JAI) is a centre of excellence in the UK for advanced and novel accelerator technology, providing expertise, research, development and training in accelerator techniques, and promoting advanced accelerator applications in science and society. The JAI is formed of academic groups from Oxford University, Royal Holloway (University of London) and Imperial College London, and members of staff from the Diamond Light Source at the Rutherford Appleton Laboratories. It is also part of many collaborations with major accelerator centres worldwide, including CERN, DESY, SLAC, KEK and ESS amongst others.

In this talk I shall outline the structure and activities of the JAI, especially in the areas of laser plasma acceleration and particle beam diagnostics.

Overview of the PETAL laser facility and its equipment

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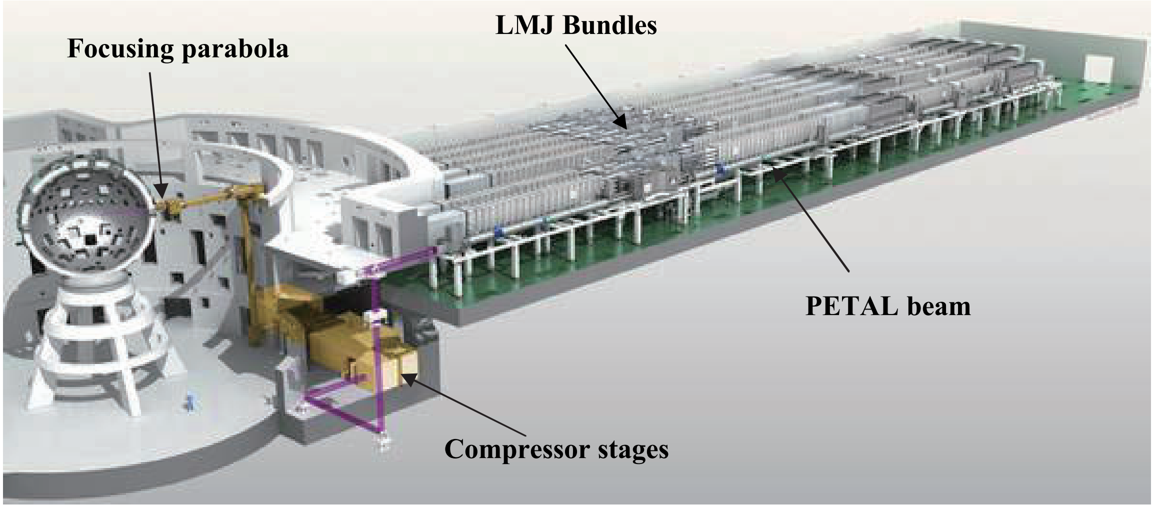
The PETAL project, part of the Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) opening policy, consists in the addition of one short-pulse (500 fs to 10 ps) ultra-high-power, high-energy beam (a few kJ compressed energy) to the LMJ facility. PETAL will offer a unique combination of a very high intensity multi-petawatt beam, synchronized with the nanosecond beams of the LMJ. This combination will extend the LMJ experimentations field on High Energy Density Physics. The PETAL/LMJ facility will be an exceptional tool for basic science as well as for the physics of ignition.

The PETAL design is based on the chirped pulse amplification (CPA) technique combined with optical parametric amplification (OPA). Further, it takes the benefits of the laser developments made for the high-energy LMJ facility allowing it to reach the kilojoules level.

This paper presents an overview of the PETAL facility, together with the development of the first specific plasma diagnostics of PETAL, i.e. a charged particle spectrometer and a hard X-ray spectrometer, and accompanying equipment.



Implementation of PETAL in the LMJ Facility.
The Petal beam is focused in the equatorial plane of the target chamber.

The PETAL project is being performed under the auspices of the Conseil Régional d'Aquitaine, of the French Ministry of Research and of the European Union and with the scientific support of the Institut Lasers et Plasmas.

The diagnostics for PETAL are provided through the Equipex PETAL+ project, funded by ANR (French National Research Agency).

“Electron dynamics controlled via self-interaction”

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The dynamics of an electron in a strong laser field can be significantly altered by radiation reaction. This usually results in a strongly damped motion, with the electron losing a large fraction of its initial energy [1]. We show that RR effects can provide a route to the control of the electron dynamics via the nonlinear interplay between the Lorentz and the RR force [2]. This is achieved in a setup where an ultrarelativistic electron is exposed to a strong either few-cycle [3] or bichromatic laser pulse. Our exact analytical calculations for a plane-wave pulse and our more realistic numerical simulations for a focused laser pulse show that, already at the intensities achievable with state-of-the-art laser systems, an ultrarelativistic electron colliding head-on with a bichromatic laser pulse can be deflected in an ultrafast and controlled way within a cone of about 8 degrees aperture independently of the initial electron energy as long as quantum effects remain small [2]. Remarkably, at still higher intensities the interplay between the RR and the Lorentz force can even overcome the radiation losses themselves, resulting in a RR assisted electron acceleration instead of damping.

[1] J. Koga *et al.*, Phys. Plasmas **12**, 093106 (2005); C. Harvey *et al.*, Phys. Rev. D **84**, 116005 (2011); C. Harvey *et al.*, Phys. Rev. A **85**, 013412 (2012); A. G. R. Thomas *et al.*, Phys. Rev. X **2**, 041004 (2012).
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[3] M. Tamburini *et al.*, Phys. Rev. Lett, *submitted;* arXiv:1208.0794 (2012).

POSTER SESSION

Collective Ion Acceleration Mechanism with Petawatt-subpicosecond Laser pulses

Embassy of France Tokyo Japan

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Within the mechanisms of ion acceleration up to GeV energy, one is the collective process with extreme power and subpicosecond laser radiation interaction, based on Doppler measurements and detailed numerical evaluations including shock generation and dynamic buildup properties [1]. This is different from the fast ion generation by relativistic selffocusing and from TNSA results and explained the ultrahigh acceleration and the ultrahigh current densities of spacechargefree plasma blocks. The new fundamental aspect is the direct conversion of optical energy of the laser pulse into macroscopic plasma motion where thermalization is excluded for the ps in contrast to ns interaction with heat losses, delays, instabilities for generating ion pressures and the problems of complex physical systems. Consequences to applications are discussed.

[1] Paraskevas Lalousis, Heinrich Hora, Shalom Eliezer, JoseMaria MartinezVal, Stavros Moustaizis , George H. Miley & Gerard Mourou. Shock mechanisms by ultrahigh laser accelerated plasma blocks in solid density targets for fusion. Physics Letters A, **377**, 885888 (2013).

Towards an Alternative Mono-Energetic Neutron Source for Material Tests Based on High Efficiency Exawatt Laser Systems

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In the present work we consider a new approach to the production of high flux neutrons based on both the well established physical process of plasma block acceleration [1,2,3] and recent advent of lasers of picosecond duration of several hundred PW to exawatt (EW) power [4] including relativistic effects [5]. The interaction of these ultrahigh intensity laser pulses with solid targets shows a direct conversion of laser energy into direct plasma blocks with accelerations up to $2x10^{20}$ cm/s^2, measured for the first time by Sauerbrey [6] from the Doppler effect of the motion of the generated plasma moving against the laser beam. The application of plasma blocks acceleration for the case of thin targets enables high ion acceleration with ultrahigh ion current density up to $10^{12} – 10^{13}$ A/cm^2 [7,8]; millions times higher than those of the best ion accelerators. The use of an advanced genuine multi-fluid hydrodynamic model [9,10] allows detail studies on the process and the ion acceleration. Numerical results of the code show high energy accelerated D ions with particles beam density up to $2x10^{21}$ cm^{-3} [11]. The interaction of this D beam with solid D (or T) target exceeds nuclear reactions with the production of 10^{15} mono-energetic neutrons per laser shot. Recent experimental results using different physical process for neutrons production by laser interactions with solid targets confirms important neutron fluxes [12].

The study of Materials capable to support important neutron fluxes is under investigation for near future fusion machines for both the inertial and the magnetic fusion scheme. EURATOM proposes the development of an accelerator [13] for neutron production in order to test the materials which will be used in the blanket of the torus of the future Tokamak.

We propose an alternative mono-energetic neutron source for material test and medical applications based on the above described physical process of high intensity short laser beam interaction with thin solid D target. The IZEST and ICAN [4,5] projects for laser development with efficiency up to 30% and rep-rate of 100 Hz could be the appropriate and adaptive proposition for a high flux mono-energetic neutron source.

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Perspective of QED Phenomena at IZEST

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Physics of quantum electrodynamics (QED) has been intensively investigated theoretically since Heisenberg-Euler, Weisskopf, and Schwinger found the one-loop effective actions in a constant electromagnetic (EM) field. The quantum vacuum in EM fields has been an interesting and hot issue from both an observational view point in astrophysics and from an experimental view point in ultra-strong laser sources, such as ELI and IZEST.

In this talk I will critically review the progress and perspective of QED phenomena in strong EM fields since review talks by Dunne [1] and Gies [2], which was targeted for ELI. The quantum vacuum becomes polarized due to interactions between the virtual electron-positron pairs and the photons from the background and, furthermore, sufficiently strong electric fields provide electron-positron pairs in the Dirac sea with energy to separate into real ones. The vacuum polarization and Schwinger pair production beyond constant EM fields has been a challenging task. Considering profiles of lasers at ELI and IZEST, it is absolutely necessary to have QED actions in the localized, pulsed EM fields and at least understand them quantitatively to provide templetes for possible experimentations in the near future.

One of such attempts has been made, in which QED actions are expressed in terms of the Gamma-function and the regularization method is introduced, recovering the Heisenberg-Euler-Weisskopf-Schwinger actions in constant EM fields [3-5]. Remarkably, the new formalism could find QED actions in localized or pulsed EM fields of a certain profile [3-5] and allow one to find QED actions at finite temperature [6]. Schwinger pair production in various EM fields could be effectively computed using the phase-integral method, which was beautifuly reviwed by Dunne [1]. An alternative method has been advanced, in which the pair production rate is the sum of contours over all possible independent paths in the complex plane [7-9], and an algorithm is addressed to compute the pair production rate in pulsed electric fields [10]. Finally, the physics and QED phenenoma will be discussed from the view point of IZEST.

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A Hybrid CPA and OPCPA Laser system generating 0.61PW

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The technique of chirped pulse amplification (CPA) and optical parametric chirped pulse amplification (OPCPA) have been regarded as a powerful scheme for obtaining ultra-high energy and ultra-short laser pulse [1,2]. To date, petawatt level laser systems based on Ti:sapphire crystal and CPA technology have been held in several laboratories [3-5]. Meanwhile, OPCPA systems have generated energies as high as 35 J near 1053 nm based on a DKDP crystal with a potential power of 300 TW [6], and 38 J near 910 nm based on a DKDP crystal with a peak power of 0.56 PW [7]. The combination of OPCPA and CPA is already used with the OPCPA used as pre-amplifier and the CPA as boost amplifier, however, the parasitic lasing is unavoidable in this configuration.

We proposed a hybrid system with a CPA front end and an OPCPA final amplifier, which is not constrained by the parasitic lasing and could be a potential design for building compact 10 PW laser. Our hybrid laser system consists of three stages of Ti:sapphire - CPA as the front - end and a large aperture LBO non-collinear OPCPA as the final amplifier. The size of LBO is 80 mm×80 mm×12 mm for critically phase-matched type I ($\theta=90^\circ$, $\varphi=13.85^\circ$). Amplification was arranged in non-collinear geometry with 1.26° non-collinear angle between the pump and signal beams in the crystal. In the end, an amplification of the full 80nm width of the seed spectrum for 28.68J pulse energy is obtained with conversion efficiency of 25.8%. After compression, it produced a peak power of 0.61PW with 33.8fs pulse duration. Our results confirmed that the framework of a hybrid CPA-OPCPA laser system provides a new approach to achieve several tens of petawatt laser system

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Proton Beams from Nanotube Accelerator

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Ion acceleration driven by ultraintense ultrashort laser pulses has been intensively studied in the past decade because a number of future applications are expected. For practical use of the accelerated ions, it is crucial to produce high-quality beams that are monoenergetic and collimated. We here propose a novel ion acceleration scheme using carbon nanotubes (CNTs), in which embedded fragments of low-*Z* materials are irradiated by an ultrashort intense laser to eject substantial numbers of electrons. Due to the resultant unique electrostatic field, the nanotube and embedded materials play the roles of the barrel and bullets of a gun, respectively, to produce highly collimated and quasimonoenergetic ion beams.

Figure 1 shows the schematic view of a nanotube accelerator. The double nested nanotubes are irradiated by an ultrashort intense laser pulse. The outer carbon nanotube is chemically adsorbed with heavy atoms such as gold, while the inner nanotube is made of light materials such as hydrogen and carbon to form the projectiles. After blowing off the electrons, the remaining nanotubes composed of positive ions generate a unique electrostatic Coulomb field so that the inner ions are accelerated along the axis symmetrically toward both ends of the outer nanotube.

Figure 2 shows temporal evolution of the proton energy spectrum in the axial (solid curves) and radial (dashed curve at $T = 5$) directions obtained by three-dimensional molecular-dynamic simulations, where T denotes time normalized by the laser cycle. The size of CNT is only 30 nm. As a result quasimonoenergetic protons with an energy of 1.5 MeV are produced. If the hydrogen atoms are replaced by carbon atoms, the maximum ion energy increases to 10 MeV for the same target structure. The maximum energy can also be increased by enlarging the target size.

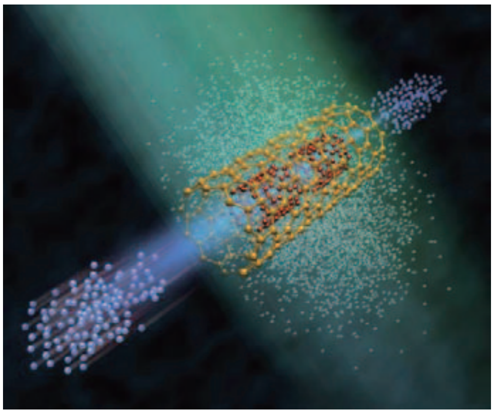

Fig. 1: Schematic of a nanotube accelerator

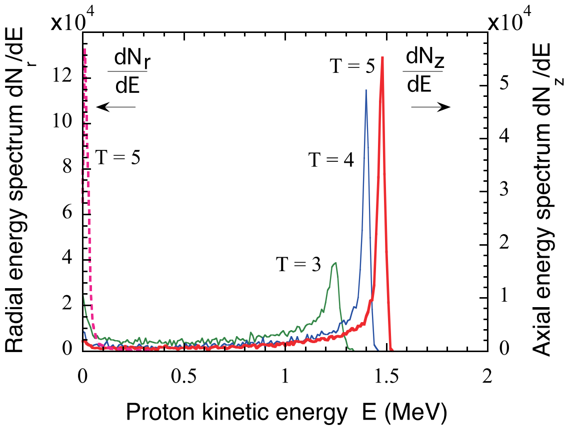

Fig. 2: Temporal evolution of energy spectrum.

Single-shot measurement of extreme high pulse-contrast

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For current high-intensity lasers with power levels of petawatt, one would require pulse-contrast of ~10^{10} at a few picoseconds before the main pulse. This requirement may climb to >10^{13} for the planned Extreme Light Infrastructure (ELI). Real-time pulse-contrast observation with a high dynamic range is a prerequisite to tackle the contrast challenge in high-intensity lasers. However, the commonly used delay-scanning cross-correlator (DSCC) can only provide the time-consumed measurements for repetitive lasers. Single-shot cross-correlator (SSCC) becomes essential in optimizing laser systems and exploring contrast mechanisms. Here we report our progress in developing SSCC towards its practical use. By integrating both the techniques of scattering-noise reduction and sensitive parallel detection into SSCC, we demonstrate a high dynamic range of >10^{10}, which, to our best knowledge, is the first demonstration of an SSCC with a dynamic range comparable to that of commercial DSCCs. The comparison of high-dynamic measurement performances between SSCC and a standard DSCC (Sequoia, Amplitude Technologies) is also carried out on a 200 TW Ti:sapphire laser, and the consistency of results verifies the veracity of our SSCC.

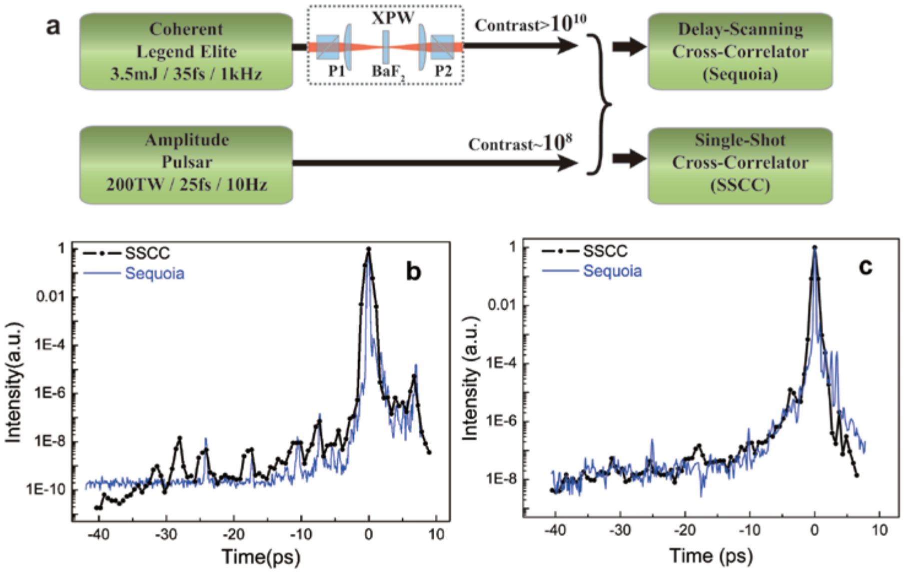

Fig. 1. The SSCC measurement (black line with symbols) versus Sequoia measurement (blue line) for the femtosecond pulse profiles. (a) Experimental setup, including two laser systems and two cross-correlators (Sequoia and SSCC). (b) The measurement results for the cleaned pulses from XPW. (c) The measurement results for the 200 TW Ti:sapphire laser (Pulsar, Amplitude Technologies).

The scalability to higher dynamic-range will be also addressed. We have developed the technique to effectively eliminate the measurement contamination on pulse background, thus the dynamic range can be linearly scaled up. Higher dynamic-range, e.g., ~10^{12} to 10^{13}, can be anticipatied by the present route. Such a device will be promising in constructing and optimizing high-intensity laser systems with power beyond petawatt.

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Plasma Mirror for Contrast Improvement of Intense Femtosecond Laser Pulses

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An intense short pulse from a chirped-pulse amplification (CPA) laser system brings rather long pulse in its base. It is called “pre-pulse”, which is originated from amplified spontaneous emission from the amplifiers in the laser system and group velocity dispersion through the system. The former yields a rather long pulse as short as some nanoseconds and the later makes a picosecond order pulse. The ratio of peak to pre-pulse intensity is usually defined as “contrast ratio (or simply contrast)”. Typical contrast of the pulse from a CPA laser is 10^{6-8}. The progress of laser technology drives remarkable increase of laser intensity, and consequently the pre-pulse intensity is increasing. For instance a 10^{18}-W/cm^2 pulse has a pre-pulse of 10^{10-12} W/cm^2 for typical tabletop TW lasers, and 10^{14-16} W/cm^2 for large facility PW lasers to generate a 10^{22}-W/cm^2 pulse. The pre-pulse is rather intense enough to interact with any targets. Recently the sciences of high field or high energy with EW-ZW lasers open to be discussed and will activate development of intense laser technology. However for such ultra intense lasers it is a crucial issue to make a pre-pulse free pulse. An optical technology such as a crossed-polarized wave generation is available to reduce a nanosecond pre-pulse, while a picosecond pre-pulse cannot be reduced without a plasma mirror (PM).

Reviewing PM’s reported in literatures, the reflectivity is currently up to 70-80% with 10^{2-3}-contrast improvement. The maximum contrast improvement of $5\text{x}10^4$ is realized with two PM’s, however the reflectivity is only 50%. This work is to demonstrate a high performance of PM for future ultra-intense laser technologies.

The PM system is installed in the beamline of the 10-TW Ti-sapphire system (T^6-laser) of ICR, Kyoto University. The laser delivers 40-fs, 400-mJ pulses in 10Hz repetition. The center wavelength is 800nm, the bandwidth is 40nm, and the beam diameter is 50mm. The laser beam is focused onto the PM by a concave gold mirror of 5-m focal length (F=100) and the beam reflected from the PM comes back to the beam line by an equivalent concave and a dielectric planar mirrors. The PM damaged by each shot is replaced with fresh surface for laser shot by shot. A 100-mm diameter PM is used to be rotated and to be shifted automatically to get a fresh surface for each laser shot. The interspace between the last and the next shots is kept 1mm enough to avoid the influence of optical damage or debris adherence by the last shot. To improve the contrast more 10^4, the antireflection coat on a transparent glass substrate must have the performance of <0.01% reflections. We have then adopted multilayered AR coat produced by ion beam sputtering. The AR coat substrates have been made by Showa Optronics Co., Ltd. The reflectivity of the PM has been measured by changing the incidence energy. The reflectivity is increasing up to 70% as the fluence increases to 500J/cm^2. The pulse contrast has been measured with a third-order cross correlator. By controlling the nano prepulse with a Pockels cell switch. the PM could start operation at -900fs and switches on at -300fs. Before -900fs, the contrast is enhanced to 10^4.

With only a single mirror, the enhancement of pre-pulse contrast has been successfully demonstrated to be 10^4, keeping the reflectivity of 70%. This achievement allows us to expect extensibility for future 100PW lasers, that is, by doubling this plasma mirror system, the contrast will be enhanced in 10^8 without serious reduction of energy (as much as 50%).

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“Plasma-based generation and control of a single few-cycle, high-energy and ultrahigh intensity laser pulse”

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A method based on the reflection of an ultraintense laser pulse by a counterpropagating laser-boosted relativistic `mirror' is proposed for generating a single sub-three-cycle and multi-petawatt laser pulse [1]. The generated pulse can reach several joule energy and a peak intensity exceeding 10^{23} W/cm^2 [1]. In addition, its carrier-envelope-phase can be tuned provided that the carrier-envelope-phase of initial counterpropagating pulse is controlled. Such laser pulse is suitable for probing and potentially controlling ultrarelativistic and nonlinear quantum electrodynamics processes in the yet unexplored regime of ultrashort duration, where qualitatively different features are expected [2]. Multi-dimensional PIC simulations show that the proposed set-up is feasible employing next-generation 10-PW laser systems [1,3] and even already few-cycle laser pulses can be further shortened (both temporally and in the number of laser cycles) and considerably amplified.

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