Q-BASIS 2024

Quantum Beam Application for Sciences and Industres2024

11-14 November 2024

SANKEN, Osaka University, Japan

Quantum Beam Application for Sciences and Industries 2024 (Q-BASIS2024) **2024 Nov. 11(Mon) -14 (Thu) @ SANKEN Osaka Univ.**

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November 11 (MON)

Time	Session / Chair	No.	Speaker	Affiliation	Title of talk
9:00 - 9:30 (each 5 - 10min)	Opening (Chaired by Y. SANO, T. HOSOKAI)		Conference Chair		Opening, welcome to Q-BASIS 2024
			Shun'ichi KURODA	SANKEN, Osaka U., Japan	Welcome to SANKEN, Osaka University
			Masataka KAMBE	MEXT, Japan	Greetings from MEXT (Ministry of Education, Culture, Sports, Science and Technology)
9:30 -10:00	Plenary (Chaired by T. HOSOKAI)	11PL-01	Carl SCHROEDER	LBNL, USA	Plasma photocathodes for high-brightness electron beam generation
10:00 -10:30	Laser-driven particle acceleration and radiation sources 1 (Chaired by T. HOSOKAI)	11A-01	Marie-Emmanuelle COUPRIE	SOLEIL Synchrotron, France	The LPA driven COXINEL test experiment
10:30 -11:00	Break				
11:00 -11:30	Laser-driven particle acceleration and radiation sources 2 (Chaired by M-E. COUPRIE)	11A-02	Sam BARBER	LBNL, USA	Reliable operation of a laser plasma accelerator driven free electron laser
11:30 - 12:00		11A-03	Ke FENG & Wentao WANG	SIOM, China	Recent progress of compact LWFA-driven FELs at SIOM
12:00 -12:30		11A-04	Zhan JIN & Masaki KANDO	SANKEN, Osaka U,. / KPSI, QST, Japan	Development of a LWFA-based Table-top XUV-FEL
12:30 - 14:00	**LUNCH TIME** **12:30 ～ Group Photo**				
14:00 - 14:30	Laser-driven particle acceleration and radiation sources 3 (Chaired by S. KOJIMA)	11P-01	Jerome FAURE	LOA, France	High-repetition rate laser-plasma accelerators: present and future prospects
14:30 -15:00		11P-02	Jared De CHANT	LBNL, USA	Exploration of ultra-high dose rate radiobiology with laser-driven protons at BELLA
15:00 -15:30		11P-03	Hironao SAKAKI	KPSI, QST, Japan	Development of Ion Injector with Laser-driven ion acceleration
15:30 - 16:00	Break				
16:00 -16:30	Q-LEAP STELLA (Chaired by T. SANO)	11P-04	Kenichi ISHIKAWA	The University of Tokyo, Japan	Overview of Q-LEAP ALICe STELLA Project
16:30 - 17:00		11P-05	Tomohito OTOBE	KPSI, QST, Japan	First-principles simulation of laser-matter interaction by SALMON
17:00 -17:30		11P-06	Rakesh D. SHIKNE & Hitoki YONEDA	ILS, Univ. Electro-Communications, Japan	Broadband reflectivity dynamics of copper during intense ultrashort pulse laser irradiation
17:30-18:00		11P-07	Yohei KOBAYASHI	The University of Tokyo, Japan	The world's smallest hole drilling on semiconductor substrates with a DUV laser

November 12 (TUE)

Time	Session / Chair		Speaker	Affiliation	Title of talk
9:00 - 9:30	Plenary (Chaired by Y. SANO)	12PL-01	Kaoru YAMANOUCHI	The University of Tokyo, Japan	Frontiers in attosecond and intense field sciences
9:30 - 10:00	Applications for imaging and inspection 1 (Chaired by J. FAURE)	12A-01	Eric ESAREY	LBNL, USA	Laser-plasma accelerator research and applications at the BELLA Center
10:00 - 10:30		12A-02	Haruo MIYADERA	Toshiba Corporation, Japan	Muon imaging and application
10:30 - 11:00					Break
11:00 -11:30	Applications for imaging and inspection 2 (Chaired by Z. Jin)	12A-03	Matt FREEMAN	LANL, USA	Laser-Plasma Accelerator Driven Electron Radiography
11:30 -12:00		12A-04	Martin SCHANZ	GSI, Germany	PRIOR-II – the first proton and heavy-ion particle radiography facility for probing ns-scale HED physics and material science experiments
12:00 - 12:30		12A-05	John SCHMIDT	LANL, USA	Experimental Results and the Future of Achromatic Imaging at LANSCE
12:30 - 14:00					**LUNCH TIME**
14:00 -14:30	Medical and biological science & engineering 1 (Chaired by M. YAGI)	12P-01	Shinichi SHIMIZU	Osaka U., Japan	Quantum Beams as a Weapon Fight Against Cancer - New Theory, New Technology and Implementation.
14:30 - 15:00		12P-02	Kazumasa MINAMI	Osaka U., Japan	The biological effects of ultra-high dose rate irradiation on cells.
15:00 -15:30		12P-03	Jamie INMAN	LBNL, USA	Sparing of healthy tissue in FLASH radiotherapy experiments using laser-accelerated ion beams
15:30 - 16:00					Break
16:00 - 16:30	Medical and biological science & engineering 2 (Chaired by K. MINAMI)	12P-04	Tomonao HOSOKAI	SANKEN, Osaka U., Japan	Drug discovery with high-energy electron beams Explore novel application for laser wakefield acceleration e-beams
16:30 - 17:00		12P-05	Keitaro TANOI	The University of Tokyo, Japan	Applications of Radiation Imaging in Plant Research and Bioscience
17:00 -17:30		12P-06	Takeharu NAGAI	SANKEN, Osaka U., Japan	Toward Enhancing Bioluminescence in Engineered Plants Using Quantum Beams for Sustainable Bioimaging and Lighting Applications

19:00 - 21:00	**Banquet（Senri Hankyu Hotel）**

November 13 (WED)

Time	Session / Chair		Speaker	Affiliation	Title of talk
9:00 - 9:30	Plenary (Chaired by K. ISHIKAWA)	13PL-01	Takashi NAKANO	RCNP, Osaka Univ.	From Fundamental Physics to Real-World Applications: Research Highlights from Research Center for Nuclear Physics
9:30 - 10:00	High-power laser and applications1 (Chaired by K. ISHIKAWA)	13A-01	Daniele MARGARONE	ELI Beamlines, Czech Rep.	Laser Plasma Sources of Charged Particles and Radiation, and Their Applications at ELI Beamlines
10:00 - 10:30		13A-02	Tomas MOCEK	APRI-GIST, Korea & HiLASE, Czech Rep.	High-Average Power Laser Technologies: Status, Innovations, and Prospects
10:30 - 11:00	Break				
11:00 -11:30	High-power laser and applications2 (Chaired by R. L-MARTENS)	13A-03	Liming CHEN	SJTU, China	Enhancement of electron acceleration for plasma exciter/reactor
11:30 -12:00		13A-04	Jie FENG	SJTU, China	Enhancing electron acceleration for nuclear applications
12:00 -12:30		13A-05	Yanjun GU	SANKEN, Osaka U., Japan	Numerically assisted stability optimization for laser plasma electron acceleration
12:30 - 15:30	**LUNCH TIME** / **Poster presentations at SANKEN CReA (Chaired by Y. GU)**				
15:30 - 16:00	Quantum beam applications and relativistic plasmas (Chaired by T. MOCEK)	13P-01	Fesseha MARIAM	LANL, USA	The Future of Proton Radiography
16:00 -16:30		13P-02	Rodrigo LOPEZ-MARTENS	LOA, France	KAIO ACCELERATOR: A project for developing commercial high repetition rate laser-plasma accelerators
16:30 - 17:00		13P-03	Gerrit BRUHAUG	LANL, USA	Experimental Designs for Probing the Quantum FEL Regime

November 14 (THU)

Time	Session / Chair		Speaker	Affiliation	Title of talk
9:00 - 9:30	Material science and industry (AMADA Session) (Chaired by Y. SANO)	14-A01	Domenico FURFARI	Airbus Operations GmbH, Germany	Manufacturing with Light in Aerospace Industries: An overview of Potential Applications using High-Intensity pulsed Lasers
9:30 - 10:00		14A-02	Tomokazu SANO	Dept. Eng, Osaka U., Japan	Femtosecond Laser Shock Compression of Solids: Fundamentals and Applications
10:00 - 10:15	Break				
10:15 -10:45	Material science and industry (AMADA Session) (Chaired by M. KANDO)	14A-03	Laurent BERTHE	PIMM, CNRS, France	Shock produced by laser for adhesion test : New advances and perspectives for industrial applications.
10:45-11:15		14A-04	Yuji SANO	IMS/ SANKEN Osaka U., Japan	Service Life Extension of Infrastructure with Intense Laser Pulses from Monolithic Microchip Lasers
11:15-11:45	Closing (Y. SANO, T. HOSOKAI)				
13:00 - 15:00	**Optional tour(Research Center for Nuclear Physics (RCNP) , Osaka University, Japan)** **(Research Center for Nuclear Physics (RCNP) , Osaka University, Japan)**				

Poster presentations at SANKEN CReA (November 13 (WED), Chaired by Y. GU)

Poster No.	Presenter	Affiliation	Title
PO-01	**Song Li**	**Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences**	High-brightness betatron X-ray source driven by SULF-1PW laser
PO-02	**Yasunobu Yamashita**	**SANKEN, Osaka University**	Prodrug activation triggered by relativistic electron beam
PO-03	**Yoshio Mizuta**	**SANKEN, Osaka University**	Potential of laser peening to improve residual stresses and fatigue strength of additive manufactured alloys
PO-04	**Shinichi Watanabe**	**Faculty of Science and Technology, Keio University**	Frequency-comb based asynchronous optical sampling for rapid optical pump and optical probe experiments
PO-05	**Ayaka Okuuchi**	**Osaka University**	Fractionated medium-dose carbon ion beams with anti-CTLA-4 antibody induces the abscopal effect in murine pancreatic cancer model
PO-06	**Shuri Tsuda**	**Osaka University**	Elucidation of the mechanisms of radioresistance acquisition in TNBC that has acquired radioresistance.
PO-07	**Kazuyuki Sakaue**	**The University of Tokyo**	Particle acceleration by photoelectric fields using dielectric microstructures (DLA)
PO-08	**Shohei KATSUKI**	**Osaka University Graduate School of Medicine**	The impact of ultra-high dose rate (FLASH) carbon ion irradiation on antitumor immunity
PO-09	**Zhenzhe Lei**	**SANKEN, Osaka University**	The Study of the Hydrodynamic Instabilities Impacts on Electron Beam Stability in Laser Wakefield Acceleration
PO-10	**Ai Harako**	**Osaka University**	Can dopamine suppress the metastatic potential of radiation and create a better therapeutic effect of radiation?
PO-11	**Keigo Kawase**	**KPST, QST**	Design study for intense THz pulse extraction by cavity dumping of SANKEN THz-FEL
PO-12	**Shingo Sato**	**SANKEN, Osaka University**	High temporal-spatial resolution schlieren measurement for LWFA plasma target development
PO-13	**Tomoya Murakami**	**Osaka University / School of Medicine**	Investigation of the mechanism of radiotherapy resistance in tumors by cellular senescence
PO-14	**Haruya Matsumoto**	**QST / Kyushu University**	Evaluation of Space Charge Neutralization in Laser-Driven Ion Acceleration Beams
PO-15	**Thanh Hung, Dinh**	**KPST, QST**	Development of a Compact, High-Intensity Laser for Generating High-Energy Photon and Particle Beams
PO-16	**Masayasu Hata**	**KPST, QST**	Laser requirements for ion injector in the quantum scalpel project
PO-17	**Kazuki Fujita**	**Osaka University**	THE ULTRA-HIGH DOSE RATE CARBON ION IRRADIATION IMPACTS TO GENERATE HYDROGEN PEROXIDE
PO-18	**Kana Nagata**	**Osaka University**	Sparing effect on cell survival under normoxia using Ultra-high dose rate proton beams
PO-19	**Karin Oniwa**	**Osaka University Graduate School of Medicine**	Effect of ultra-High dose rate particle irradiation on cell invasion in breast cancer cells
PO-20	**Kai Huang**	**KPST, QST**	Electro-optic spatial-temporal characterization of the laser wakefield accelerated kilo-ampere electron bunches
PO-21	**Jinfeng Yang**	**SANKEN, Osaka University**	Ultrafast imaging with relativistic femtosecond electron pulses
PO-22	**Konika Rani**	**Graduate School of Engineering, Osaka University**	Prediction of the Laser Absorption Threshold Using Hybrid Deep Learning Model
PO-23	**Yusa Muroya**	**SANKEN, Osaka U.**	TBD
PO-24	**Nobuhiko Nakanii**	**KPSI, QST**	Highly monoenergetic bunch generation via laser wakefield acceleration using near-field shaped laser pulse with structured density target
PO-25	**Eiyu Gushiken**	**The University of Tokyo**	Ab-initio calculations of energy transfer from femtosecond laser pulse to amorphous silicon
PO-26	**Yoshihide Honda**	**SANKEN, Osaka University**	Current Status of RLQBS in SANKEN
PO-27	**Tianyun Wei**	**KPST, QST**	Laser Driven Quasi-monoenergetic Deuteron Acceleration with in-situ D2O-deposited target
PO-28	**Hiroaki Sano**	**Osaka University**	Simulation study of the effect of blade in LWFA using Shock Injection
PO-29	**Hiroki Katow**	**The University of Tokyo**	Topological Data Analysis of the Ultrafast Melting Process
PO-30	**Toshiya Muto**	**Tohoku University**	Stabilization of Radiation Wavelength on Energy Spread and Jitter of driven beam using Transverse Gradient Undulator

PLENARY SPEAKERS

Plasma photocathodes for high-brightness electron beam generation

Carl B. Schroeder[1,2]

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Keywords: Q-BASIS, laser-plasma accelerators, laser-triggered injection, high-brightness beams

Laser-driven plasma-based accelerators sustain large acceleration gradients (10-100 GV/m demonstrated in experiments), several orders of magnitude larger than in conventional RF accelerators, enabling compact accelerating structures. Laser-plasma accelerated electron beams with energies up to 10 GeV have been achieved with plasma-based laser guiding. Beams generated from electrons injected from the background plasma are intrinsically ultra-short (1-10 fs), a fraction of the plasma wavelength, with low (sub-micron) normalized emittance, yielding high beam brightnesses at or beyond conventional sources. Controlling the electron capture in the plasma wave enables control of the properties of the accelerated electron beam. Utilizing laser-triggered injection, tens of nm emittance beams can be generated, with the corresponding increase in beam brightness. In this talk, I will review electron injection techniques in laser-plasma accelerators and the path to higher beam brightness, and I will discuss recent experimental work at the BELLA Center at Berkeley Lab.

Frontiers in attosecond and intense field sciences

Kaoru Yamanouchi

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The University of Tokyo, Japan

E-mail: kaoru@chem.s.u-tokyo.ac.jp

Keywords: ultrashort-pulsed laser, intense laser fields, attosecond science, laser machining

When atoms, molecules, and materials are irradiated with light, the electrons respond to the light field and the energy absorbed by the electrons is transferred to the motion of the nuclei in the next stage, resulting in a variety of dynamical phenomena, such as vibrational excitation, chemical bond breaking, and evaporation of atoms from the surface. Therefore, in order to clarify the mechanism of the dynamical processes and control them, we need to understand how the electrons move in the attosecond time domain, during which the fate of the system in the later stage is determined. Recent advances in ultrashort pulse laser technology made it possible to generate attosecond light pulses whose temporal width is as short as several tens of attosecond. Therefore, by pump and probe measurements using attosecond laser pulses, we are able to probe in real time how electrons and nuclei start moving in response to the stimulus given by photons.

Indeed, the importance of generation and characterization of attosecond laser pulses was evidenced by the Nobel Prize in Physics 2023. It should also be stressed that the invention of the chirped-pulse amplification, for which the Nobel Prize in Physics 2018 was given, enabled us to generate ultrashort intense laser pulses, which promoted investigations of strong field phenomena such as dressed-state formation, Coulomb explosion, above-threshold-ionization, high-order harmonics generation, and attosecond pulse generation.

In the past 25 years, I have been engaged in researches on ultrafast phenomena in intense laser fields as well as in the promotion of attosecond and intense field sciences. In 2018, we launched a ten-year term research project of Attosecond Lasers for Next Frontiers (ATTO) as one of the two divisions in Advanced Laser Innovation Center (ALICe) supported by Q-LEAP (Quantum Leap Flagship Program and it's a R&D program) of MEXT. In the ATTO division, we aim to establish attosecond laser technologies by academia-industry cooperation and explore the frontiers in attosecond science using advanced attosecond light sources. To achieve these goals, we have been developing high-repetition attosecond light sources, high-power attosecond light sources, and measurement systems and methodology for investigating ultrafast phenomena occurring in the attosecond time domain as well as for submicron focusing by taking advantage of the fact that the attosecond pulses are in the extreme ultraviolet wavelength region. A total of as many as 80 researchers from twelve universities, five research institutions, and three companies from all around Japan participate in the ATTO projects. We also cooperate closely with STELLA (Science and Theory Enabling Intelligent laser manufacturing), the other division in ALICe, to develop innovative laser-machining technologies.

INVITED SPEAKERS

11A-03

Laser wakefield accelerators (LWFA), with the ultrahigh accelerating gradient exceeding 100 GV/m, hold significant potential for driving compact and cost-effective X-ray free electron lasers (XFELs). The realization of compact LWFA-driven FELs have been identified as one of the major challenges in this decade. Despite the successful proof-of-principle demonstration of free electron lasing driven by a LWFA in our previous work [Nature 595, 516–520 (2021)], achieving further improvement in compact FEL to saturate regime still remains challenges due to the un-sufficient electron-beam qualities. In this presentation, we identify the key physics and optimization strategies for LWFA-driven FEL, and give the recent process of the LWFA-driven FEL at SIOM. We also give a brief description of the future prospects and plan for China compact FELs.

Development of a LWFA-based Table-top XUV-FEL

Z. Jin[1,3], Y-J. Gu[1,3], Z-Z. Lei1,[3], S. Sato[1,3], A. Zhidkov[1,3], A. Rondepierre[1,3], K. Huang[2,3], N. Nakanii[2,3], I. Daito[2,3], M. Kando[2,3], and T. Hosokai[1,3]

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[2] Kansai Institute for Photon Science (KPSI), QST, Japan
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Keywords: Laser wakefield acceleration, Free electron laser

To develop a stable laser wakefield acceleration (LWFA)-based accelerator and demonstrate FEL generation, the unique LWFA platform was constructed in the RIKEN SPring-8 center, financially supported by ImPACT (2013-2017) and JST MIRAI (2018-) programs. To improve the electron pointing stability and energy fluctuations, shock injection scheme was applied together with better plasma stability. This development enables precise injection control and has dramatically improved the reproducibility and stability of the LWFA electron beam. The preliminary proof-of-concept experiment has recently demonstrated the clear amplification of the undulator radiation and the possibility of LWFA based FEL in XUV range. The talk will be presenting the outline of the LWFA platform, the setup of a proof-of-concept experiment focusing on key improvements and obtained results [1-4].

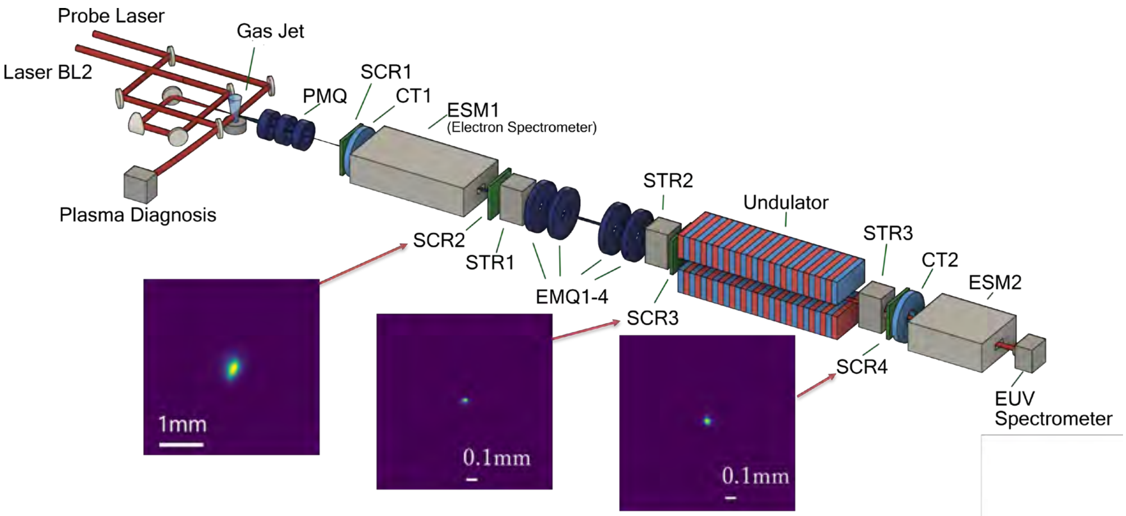

Fig.1 Schematic experimental setup

References

[1] Z. Jin et. al. Scientific Reports 9, 20045 (2019)
[2] Z-Z. Lei, Z. Jin et. al. Prog. Theor. Exp. Phys. 2023, 033J01 (2023)
[3] Z-Z. Lei, Y-J. Gu, Z. Jin et. al. Prog. High Power Laser Science and Engineering, 11, e91 (2023)
[4] Z-Z. Lei, Z. Jin et. al. Rev. Sci. Instrum. 95, 015111 (2024)

11P-03

Development of Ion Injector with Laser-driven ion acceleration

H. Sakaki[1,4], S. Kojima[1], T. -H. Dinh[1], M. Hata[1], K. Ohtomo[2], H. Tsutsui[2], H. Kuroki[3], N. Inoue[3], H. Matsumoto[4], S. Oishi[5], A. Okano[5], K. Ishii[5], M. Nishikino[1], T. Shirai[1], K. Kondo[1]

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Keywords: Laser-driven acceleration, prototype injector, beam commissioning

A quarter of a century has passed since the discovery of the acceleration mechanism of laser-driven ion acceleration [1, 2]. This mechanism makes a compact ion accelerator than the present accelerators, and many applications, especially ion therapy, are proposed on the ion user's studies. To develop the ion applications, it is necessary to increase the beam delivery efficiency using in the beam line adapted to the characteristics of the energetic ions transported. However, 25 years after the discovery of laser-driven ion acceleration with ultrashort pulsed high-current ions, there are currently no benchmark codes to simulate its transport system for application. We are beginning to construct a prototype of laser-driven ion injector for benchmarking and to investigate the beam parameters in a simulation. In this presentation, we describe our ongoing application project for heavy [3] ion therapy using laser-driven ion acceleration and the commissioning of prototype ion injector for this application (Fig.1).

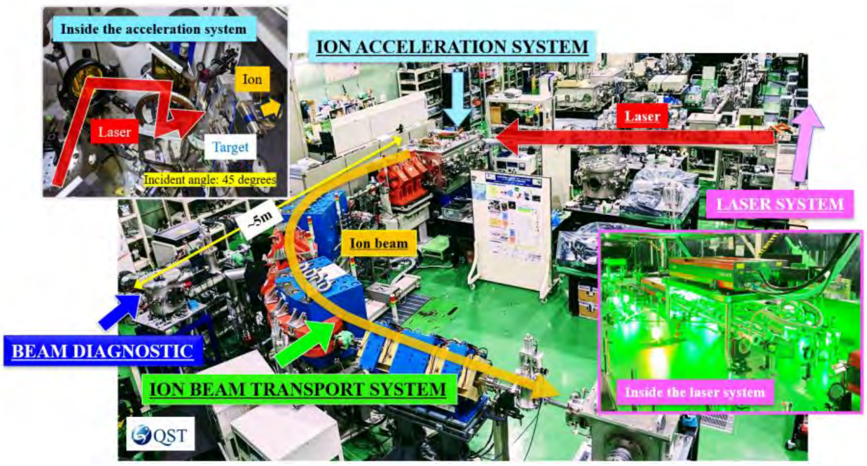

Fig.1 The prototype of laser-driven ion injector at QST kpsi

References

[1] E. L. Clark, et al., Phys. Rev. Lett. 85, 1654 (2000).

[2] R. A. Snavely, et al., Phys. Rev. Lett. 85, 2945 (2000).

[3] Y. Iwata, et. al., Nucl. Inst. and Meth., A, 1053, 168312 (2023).

Overview of Q-LEAP ALICe STELLA Project

Kenichi L. Ishikawa[1,2] (on behalf of ALICe STELLA network)

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Keywords: Ultra-short pulse laser, Laser material processing, Cyber-physical system

Laser processing is a versatile technique with numerous adjustable parameters, such as wavelength, pulse duration, and pulse energy. Currently, these parameters are optimized through human experience and intuition. However, to address the growing need for mass customization in the emerging super smart society, we aim to replace these methods with data-driven approaches, artificial intelligence (AI), and scientifically grounded theories that highly integrate cyberspace and physical space (CPS) [1]. To facilitate smart production, we develop CPS laser manufacturing that propose optimal processing parameters based on simulations in cyberspace.

Laser processing is a complex, cutting-edge field that spans multiple scales and disciplines. For example, how atoms, molecules, and materials behave under intense laser irradiation is at the forefront of atomic, molecular, optical, and condensed matter physics, involving highly nonlinear, dynamical processes. One of our focuses is to understand and simulate these strong laser-matter interactions by employing various techniques, including AI and even starting from the first principles of quantum mechanics. With support from the Quantum Leap Flagship Program (Q-LEAP) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, we have established a nationwide ALICe (Advanced Laser Innovation Center) STELLA (Science and Theory Enabling inteLligent LAser manufacturing) network of about 100 researchers, including both theorists and experimentalists, with the latter specializing in advanced data collection and operando measurement techniques [2].

In this talk, I will present an overview of the Q-LEAP ALICe STELLA Project [2]. For example, the deep learning simulators developed within our network are capable of accurately and efficiently replicating the laser drilling process in physical space. We are currently developing and have developed a range of innovative methods to precisely calculate the laser-driven electron dynamics and energy transfer from the laser to the materials. Furthermore, for example, by combining first-principles and molecular dynamics calculations, we can quantitatively reproduce the ejection of atoms from laser-irradiated surfaces. On a macroscopic scale, our research also involves the study of multiphysics modeling for complex thermal multiphase flows, which provides valuable guidance for additive manufacturing.

References

[1] Y. Kobayashi, T. Takahashi, T. Nakazato, H. Sakurai, H. Tamaru, K.L. Ishikawa, K. Sakaue, and S. Tani, IEEE Journal of Selected Topics in Quantum Electronics 27, 8900108 (2021).

[2] K.L. Ishikawa, Proc. SPIE 12873, Laser-based Micro- and Nanoprocessing XVIII, 128730D (2024); https://doi.org/10.1117/12.2692788

11P-05

Development and application of SALMON for laser processing

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Keywords. : *Ab-inito* calculation, Electron dynamics, Material processing

Laser processing is a multi-scale phenomenon related to time and space that is very difficult to understand and simulate. Our group studies laser-matter interactions using various approaches such as quantum mechanics, anti-classical theory, temperature modeling, and molecular dynamics. One of the most important processes in laser processing is the nonlinear interaction between laser and electrons.

We have developed and maintain SALMON, the world's first open-source program capable of simulating nonlinear interactions between lasers and electrons, ions, and spins [1,2]. With SALMON, we can solve electron dynamics based on time-dependent density functional theory (TDDFT), a first-principles theory, and electromagnetic fields based on Maxwell's equations (Figure), enabling the simulation of experimental conditions in a computer. Because of its high-precision first-principles calculations, it contributes to the elucidation of not only laser processing but also attosecond science, nonlinear optical processes, valley-tronics, and the nonlinear response of meta-surfaces. In this talk, I will introduce the contents, functions, and applications of SALMON, as well as the importance of quantum mechanical effects in laser processing processes, which we have recently revealed [3].

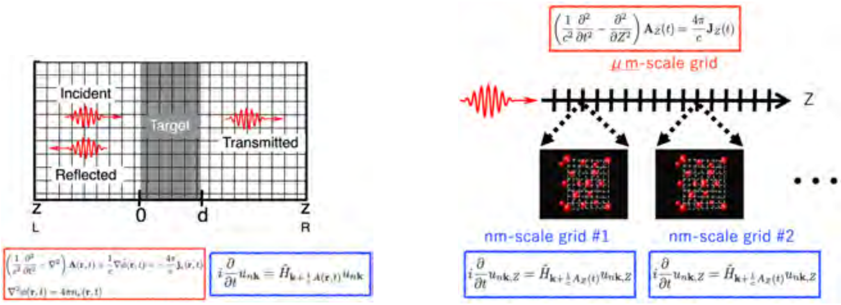

Figure (Left) Single-scale mode: Slab and vacuum are considered, and the electromagnetic field is calculated with the same mesh. (Right) Multiscale mode: The electromagnetic field is calculated on a macro mesh and the electrons on a micro mesh. It is approximated that there is no transfer of the wavefunction between the macro meshes.

References

[1] K.Yabana, T. Sugiyama, Y. Shinohara, T. Otobe, and G. F. Bertsch, Phys. Rev. B 85, 045134 (2012)
[2] M. Noda. et. al., Comput. Phys. Commun. 235, 356 (2019)
[3] S. Yamada and T. Otobe, arXiv:2409.02440 (2024)

11P-06

Broadband reflectivity dynamics of copper during intense ultrashort pulse laser irradiation

Rakesh Shikne[1], Hitoki Yoneda[1], Shivanand Chaurasia[2]

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Keywords: broadband reflectivity, nonequilibrium dynamics, warm dense matter, laser material processing

Copper is widely used in material processing applications. The behavior of Cu in nonequilibrium conditions created by the irradiation with the intense ultrashort pulse lasers is necessary for the accurate laser-matter interaction modeling as well as for the fundamental interest in extreme conditions such as warm dense matter (WDM), with solid-like density and temperatures greater than 1 eV. Under such conditions, the electrons from filled 3*d*-orbital can transition above the Fermi level and contribute significantly to the heat capacity, thermal conductivity, and electron-phonon coupling. As a result, the temperature evolution is different than those predicted using the transport properties derived from the free-electron gas model. Here, we studied the broadband reflection dynamics of copper in a nonequilibrium, warm dense state. The detailed analysis of the reflectivity data provides a deeper insight into the excited 3*d* electron behavior and subsequent effects on optical, thermophysical properties, and electron density of states. The measured data is used to test the predictions of the density functional calculations in two temperature regimes. The pseudopotential with 11 valence electrons in $3d^{10}\,4s^{1}$ configuration and a frozen core, overestimates the effects of the atomic polarizability on the reflection dynamics.

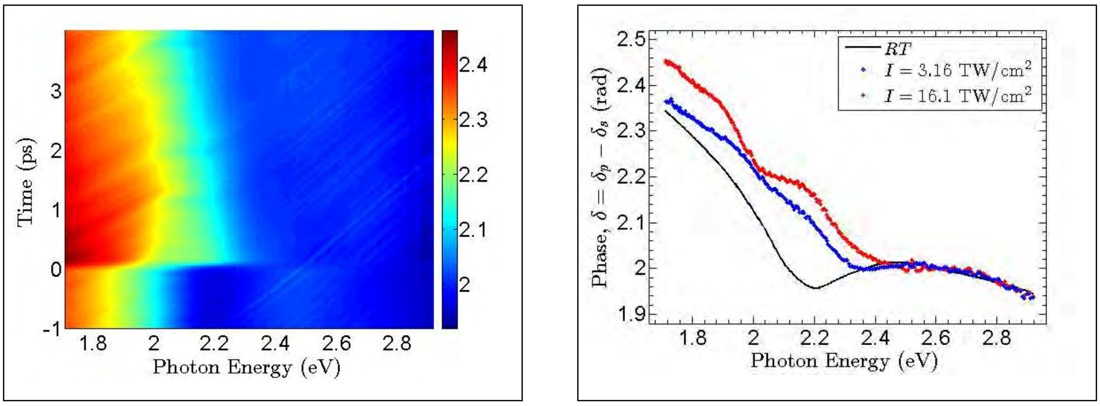

Fig.1 The broadband reflection phase dynamics (left) of warm dense Cu and its evolution at ~ 200 fs after irradiation with 30-fs ultrashort pulse with the intensity $I \sim 1.6 \times 10^{13}$ W/cm^2. The slow relaxation of the excited 3*d* electron and absorption edge shift towards the higher photon energies can be seen.

12A-03

Laser-Plasma Accelerator Driven Electron Radiography

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Keywords: laser plasma accelerator, electron radiography, magnetic lens

Fast electron radiography is useful for imaging plasma-like states, due to the ability to accurately characterize material areal densities, as well as to the sensitivity to magnetic fields. Electron radiography driven by a laser plasma accelerator (LPA) provides a bright flash of 10^14 polychromatic electrons in <1 ps. Results from recent trials of projection radiography at OMEGA EP will be shown, an example is in Fig. 1. Modeling and simulation work towards the implementation of a magnetic lens system within the confines of OMEGA EP to increase spatial resolution and provide quantitative magnetic field information will also be presented.

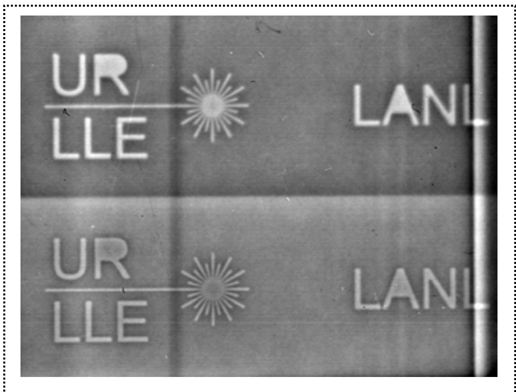

Fig.1 LPA-driven electron radiograph of our first target, highlighting the collaboration between University of Rochester's Laboratory for Laser Energetics, and Los Alamos National Laboratory. Each letter is 3 mm high.

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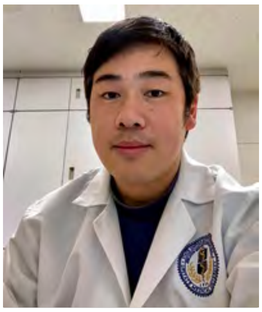
Experimental Results and the Future of Achromatic Imaging at LANSCE

John Schmidt

September 2024

Proton radiography has established a reputation as an imaging modality best suited to multi-frame imaging of dense materials up to 50 g cm-2, at timescales down to inter-frame spacing of 100 ns. However, it is limited by chromatic effects that degrade the resolution of off-energy protons. An achromatic lens can mitigate these chromatic effects using a novel lens design that adds a 14 degree bend and uses sextupoles to tamp down these second order chromatic terms. Our team designed, optimized, and constructed at 25-MeV electron radiography prototype achromatic lens capable of producing -I radiographs. This talk aims to address the challenges faced, the data we obtained, and the future of achromatic imaging at LANSCE.

The biological effects of ultra-high dose rate irradiation on cells.



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Keywords: ultra-high dose rate irradiation, FLASH effect

The ultimate goal of radiation oncology is to eradicate tumors without causing toxicity to surrounding non-malignant tissues. FLASH radiotherapy, which involves ultra-high dose rate irradiation (40 Gy/s or more), has emerged as a promising method for maintaining tumor control while minimizing toxicity to adjacent healthy tissues [1]. Preclinical studies in recent years have demonstrated that FLASH radiotherapy can deliver radiation in extremely short bursts, significantly broadening the therapeutic window of radiation therapy. This ultra-fast delivery not only enables dose escalation due to its toxicity-sparing advantages but also helps reduce issues related to patient movement and organ misalignment during treatment, ultimately increasing the number of patients who can be treated. Consequently, FLASH radiotherapy is recognized as one of the most promising breakthroughs in radiation oncology.

In present, several challenges remain to bring FLASH radiotherapy into clinical application, including a need for a deeper understanding of its biological mechanisms, parameter optimization, and addressing technical issues. To achieve clinical implementation of FLASH radiotherapy, it is essential to understand the beam parameters that induce the FLASH effect and the underlying radiobiological mechanisms involved. Currently, the FLASH effect is believed to occur only in vivo. One suggested reason for this is that differences in immune responses or cell-specific metabolic rates, driven by dose rates, play a role [2]. Thus, it has been considered challenging to observe the FLASH effect in vitro, where the complex biological systems found in vivo—such as metabolism, immune responses, and other commonly cited contributors to the biological FLASH effect—are absent [3].

However, it is difficult to elucidate the mechanisms behind the cell- and tissue-sparing effects of ultra-high dose rate irradiation using only in vivo models. Appropriate in vitro studies employing simpler experimental systems are therefore needed to identify optimal beam parameters and clarify the biological mechanisms involved. Here, we will discuss the current status of in vitro assays used in preclinical studies of FLASH radiotherapy and highlight some findings from our research group.

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Drug discovery with high-energy electron beams

Explore novel application for laser wakefield acceleration e-beams

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Keywords: LWFA, Chemotherapy, Radiation therapy, Drug discovery, Prodrugs,

Since the quality of Laser Wakefield Acceleration (LWFA) electron beams have been dramatically improved by the progress of the LWFA-based free-electron laser (FEL) research in the XUV wavelength range, we decided to explore applications of LWFA that can be implemented in society at an early stage in parallel with the FEL research, and started research on drug discovery using high-energy electron beams and prodrugs with our teams in beam physics, organic chemistry, radiation chemistry and radiation oncology.

A prodrug is a drug whose chemical structure is converted to an inactive form so that the drug does not work after it enters the body and before it reaches the site of disease in chemotherapy. After administration, an external or internal stimulus (trigger) at the site of disease (affected area) converts the chemical structure back to the active form and causes the drug to function, so that the drug is effective only at the target site and is expected to reduce systemic side effects. When the human body is irradiated, free radicals and reactive oxygen species are generated in body tissues through the ionization or excitation of water molecules. The use of chemical reactions based on the indirect action of these reactive molecular species for prodrug activation has been investigated, and recently there have been reports of prodrug activation using x-ray irradiation as an external trigger [1]. However, when targeting localized lesions deep in the human body, an external trigger of beams with high enough energy to penetrate and reach deep into the trunk, and with sharp directivity that does not spread in the body, is required. Furthermore, from the point of view of reducing the side effects of radiation, it is required to induce the activation of prodrugs with the lowest possible exposure dose.

In order to investigate the potential of high energy electron beams of tens to hundreds of MeV as external triggers, we first started to study prodrug activation using the ~30 MeV electron beams of the L-band LINAC at SANKEN and the ~300 MeV electron beams of the LWFA at the LWFA platform in SPring-8. The target is irradiated with the electron beams at clinically acceptable doses of 4 Gy or less; in vitro experiments prodrug activation and growth inhibition of human cervical cancer HeLa cells or human pancreatic cancer cell PANC-1 were investigated, and in vivo experiments inhibition of tumor growth in xenograft mouse models were investigated.

This work was supported and funded by the JST-MIRAI Program Grant No. JPMJMI17A1.

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12P-05

Applications of Radiation Imaging in Plant Research and Bioscience

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Keywords: *radioisotope imaging, ion transport, plant physiology, salt tolerance, quantum beam technology*

In plant science, understanding how nutrients and minerals move inside plants is important for better plant growth. This study shows how useful radiation imaging, especially with radioisotope tracers, can be for observing these movements. By labelling ions with isotopes, we can analyze the pathways and destinations of nutrients, which helps to understand key processes in plants. For example, controlling sodium in plants is necessary, especially in saline soils where excess sodium prevent its growth. Radioisotope techniques allow us to follow sodium through different parts of the plant, giving us details that are difficult to get with other methods.

In Japan, several imaging systems have been developed for plant science, including the Real-time Radioisotope Imaging System (RRIS). This system takes pictures of ions as they move inside plants, using a fiber optic plate with a scintillator that converts radiation into visible light, which is then detected by a CCD camera (Sugita et al., 2016). With RRIS, we can track ions like sodium-22 in real-time, allowing us to study their behavior under different conditions. This information is helpful for knowing how plants regulate sodium levels and how we might improve this ability to grow salt-resistant crops.

Recently, we have also found fluorescent proteins that are activated by radiation, which could open new doors in not only plant imaging and also other techniques such as optogenetics. These proteins, when exposed to radiation, emit light, allowing us to study biological activities without traditional light sources, an optical fibers. The combination of electron beams and protein scintillators holds the potential to foster new technologies, including advancements in optogenetics. We plan to develop these technologies within a new academic field we are establishing, termed “radiation-driven bioprocess engineering.”

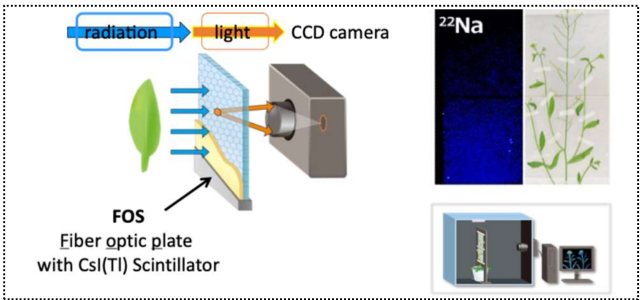

Fig.1 Experimental setup of the Real-time Radioisotope Imaging System (RRIS).

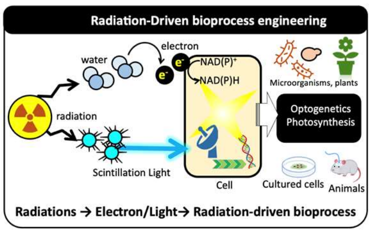

Fig.2 Radiation-driven bioprocess engineering

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12P-06

Toward Enhancing Bioluminescence in Engineered Plants Using Quantum Beams for Sustainable Bioimaging and Lighting Applications

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Keywords: Gamma-radiation, electron beam, mutagenesis, bioluminescence, BRET

There are many bioluminescent organisms in nature, such as fireflies, bacteria, and mushrooms; the luminescent proteins from these organisms have been used for numerous biological studies. Bioluminescence is produced during the catalysis of the oxidation reaction of the substrate (luciferin) by the luminescent enzyme (luciferase). The genes that produce luciferin and luciferase have been elucidated from the glowing mushroom species [1], and we cloned and introduced these genes and other genes from luminescent bacteria into the plant genome to create autoluminescent plants that can be used for various applications including bioimaging. However, the current luminescence intensity is insufficient to observe intercellular or intracellular phenomena. As an approach to increase the luminescence intensity, we will irradiate the seeds of the autoluminescent plant with gamma rays or electron beams to induce random mutations in the genome to create a population of various mutants. We aim to find a mutant with enhanced traits that can be used to further analyze and identify the mutated genes that lead to luminescence enhancement. In combination with a technique to enhance luminescence intensity by the fusion of a fluorescent protein (Nano-lantern-X technology)[2], we aim to produce a bright and multi-coloured autoluminescent plant that can be used not only for various biological studies, but also as an electricity-free light source with augmented CO_2 absorption ability and useful material production capability to help build a sustainable society.

Fig.1 Autoluminescent bacteria and plants generated by intdoducing the multicolor autonomous bioluminescence system, Nano-lantern-X .

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Laser Plasma Sources of Charged Particles and Radiation, and their Applications at ELI Beamlines

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The ELI Beamlines Facility is a pillar of the ELI (Extreme Light Infrastructure) ERIC pan-European Research Infrastructure hosting the world's most intense laser sources. ELI Beamlines developed and operated four cutting edge high-peak, high-average power femtosecond laser systems and offers a unique combination of primary (lasers) and secondary (high-energy particles and X-rays) sources to the international user community. Currently, several beamlines are operational and being upgraded to reach their full performances, while other beamlines are in their commissioning phase.

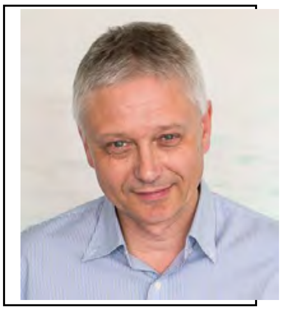
Laser-driven particle accelerators have gained interest in recent years thanks to their versatility and innovative features. This interest has pushed forward the development of beamlines where users can exploit the unique parameters (e.g. ultrashort bunch duration and ultrahigh dose rate) of laser-driven particle accelerators (ion and electron beams) and radiation (XUV to gamma-ray sources) for a wide range of applications.

The current performance of particle and radiation sources available at the ELI Beamlines user facility will be presented and discussed along with their use for multidisciplinary applications. The combination of optical, X-ray, and particle beams for user experiments related to inertial confinement fusion and shock physics will also be presented in relation to the availability of a unique kJ-class, nanosecond laser beam operating at unprecedented repetition rate (~1 shot/min). The high repetition rate capability of the available primary and secondary sources will be highlighted in combination with a range of advanced target delivery solutions and diagnostics in operation in extreme laser-plasma conditions ($>10^{21}$ W/cm^2 at >1 Hz).

13A-02

High-Average Power Laser Technologies:

Status, Innovations, and Prospects



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Keywords: high-average power lasers, DPSSL, beam shaping, optical isolation, mid-IR lasers

This talk provides an overview of recent advancements in high-average power laser technologies at HiLASE, showcasing groundbreaking innovations and future prospects in the field.

A major breakthrough is the demonstration of optical isolation for a kilowatt average power pulsed laser. We developed a Faraday isolator capable of protecting a laser amplifier chain delivering 100 J nanosecond pulses at 10 Hz [1]. The isolator achieved an isolation ratio of 30.46 dB during a one-hour full-power test, with no significant thermal degradation. This innovation enables new applications for high-energy, high-repetition-rate lasers in industrial and scientific domains.

In our high-energy kilowatt-average-power nanosecond laser system, BIVOJ, we implemented a fully automatic fail-safe beam shaping system [2]. This system, based on a liquid crystal on silicon spatial light modulator, corrects for gain nonuniformity and wavefront aberrations. The system's versatility extends to creating non-standard beam shapes and imprinting cross-references.

We report stable, long-term operation of a diode-pumped solid-state laser amplifying 15 ns pulses at 1030 nm wavelength [3]. The system delivers 10 J pulses at 100 Hz, achieving 1 kW average power with 25.4% optical-to-optical efficiency. Notably, the laser operated at this level for over 45 minutes without user intervention and with 1% RMS energy stability.

Advancements in our PERLA platform for kW-class thin-disk lasers include a 2μm modification targeting space industry and atmospheric communication applications. This longer wavelength offers advantages in atmospheric transmission and eye-safety for certain space-based applications. A pilot experiment, supported by the European Space Agency, explored these space-related applications, marking our entry into this critical domain.

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Enhancement of electron acceleration for plasma exciter/reactor

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Keywords: Laser wakefield acceleration, Isomeric state, nuclear excitation

Laser plasma acceleration is not only suitable for advanced accelerator, but also possess great potential for plasma nuclear exciter or collider. At present, most of research topics in this field focus on the quality improvement of accelerated particle beams. On the other hand, the laser plasma accelerator also has extremely high density which will produce high brightness gamma ray source and intense neutron source, resulting in powerful tool for nuclear physics research.

Recently, our team has carried out systematic studies on electron acceleration with large charge. For example, we used a solid target to realize relativistic electron acceleration of 100 nC [1] with very small divergence angle; And achieved stable acceleration of ~ 20 nC with electron energy tens MeV using high-density gas targets, through a novel efficient injection that the atom inner shell electrons are ionized and continuously injected into multiple plasma bubbles [2]. Micro-C level electron beam produced via combination of near critical density plasma and PW lasers [3].

Based on new experimental results of electron acceleration, we have carried out the research about "laser-plasma exciter/reactor". Firstly, a high brightness neutron source [4] is obtained by driving a solid target with an electron beam. And, with optimized high charge electron beam driven (γ ,n) reaction, the peak flux of neutron source reaches to 10^20 n/cm^2/s, which is comparable to Supernova [3]; Then, using the nonlinear resonance of Kr clusters excited by intense laser, the 83Kr isomeric state is achieved experimentally with peak efficiency 2x10^15 p/s [5]. After carefully measurement of the excitation cross section, the 83Kr excited from the ground state to the 3rd exciting state with cross section as small as 10s pbarn [6], which is usually have to measure them deep into ground to reduce the background; Using the enhanced electron accelerator, MeV-level ellectron beam has been introduced to excite high energy isomeric states such as In [2]. With the above novel method, a systematic nuclear excitation techniques have benn constructed covering low energy to high energy range, suitable for the study of BBN, steller and SuperNova nucleosysnesis.

In order to carry out the experimental verification of laser "laser-plasma exciter/reactor" based on extremely strong field QED, we will finalizing the construction of the "laboratory astrophysics research platform" (LAP) [7] in TsungDao Lee Institute, for the nuclear astrophysics research in relativistic.

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Laser plasma Accelerating Ultra-short Ultra-intense Electron Beam for Nuclear Applications

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Abstract. With the development of ultra-short and ultra-intense laser technology, laser driven plasma electron acceleration is becoming increasingly mature. Compared with traditional RF acceleration, this acceleration method has significant characteristics - an acceleration gradient three orders of magnitude higher. It is precisely because of its ultra-high acceleration gradient that the accelerated beam has characteristics such as ultra-short <10s fs, dense >1e19 cm^{-3}, and high current >10s kA. This talk will introduce our recent experimental progress in laser accelerated ultra-short and high current electron beams, and introduce their ultra-fast and ultra-intense characteristics into nuclear physics research, exploring their potential applications in ultra-fast and efficient nuclear isomer excitation, ultra-short pulsed neutron source, high energy-resolution neutron resonance absorption spectroscopy.

13A-05

Numerically assisted stability optimization for laser plasma electron acceleration

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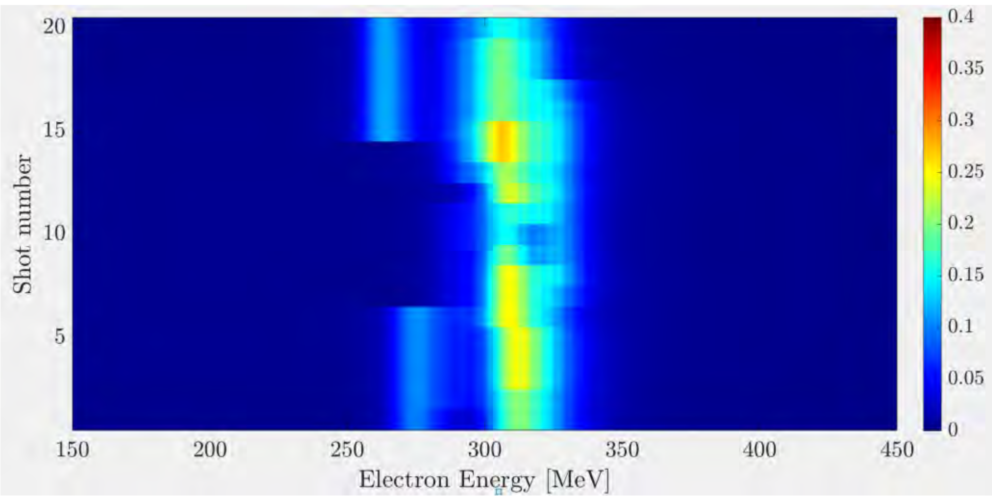
Laser wakefield acceleration (LWFA) with shock injection regime is sensitive to the parameters of the target. It is common to employ the supersonic nozzle in order to produce spatially well-defined gas targets with a plateau density profile and sharp gas-vacuum boundaries. To enhance the reproducibility of the accelerated electron beam, it is necessary that the laser-plasma interactions occur in a proper density region and the relative distance between laser focal position and the density shock doesn't shift too much from shot-to-shot. In this work, a numerical study aimed at stabilizing the laser-plasma interaction is presented. The gas target formation process has been well designed and optimized for highly reproducible plasma profile. Via both the numerical simulations and the Mach-Zehnder interferometric measurements, the instability originated from the nonlinear turbulence and the mechanism of suppression are studied. This study represents a significant step towards the development of a robust table-top laser-plasma based electron accelerator.



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The Future of Proton Radiography

(Abstract)

Since its invention at the Los Alamos National Laboratory (LANL) in the mid-90s, proton radiography (pRad) is now practiced in at least three countries primarily for purposes of flash radiography. At LANL, this practice has undergone incremental improvements in detectors, image recorders as well as the addition of magnifier imaging systems into the repertoire. In Germany and Russia, they were built to utilize higher beam energies while the LANL installation utilizes the available LANSCE beam of 800MeV. This presentation discusses the physics relevant to pRad and future possible improvements that one can undertake to achieve higher performance.

13P-03

Experimental Designs for Probing the Quantum FEL Regime

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N. Kabadi, D. Ramsey, D.A. Chin, D. Bishel, G.W. Collins
Laboratory for Laser Energetics, University of Rochester

This talk will outline proposed techniques to use laser undulator based free electron lasers (FEL) to probe the so called “quantum” FEL regime. The creation of a quantum FEL would probe the extremes of FEL physics, while also providing an FEL light source that has extremely narrow bandwidth and true longitudinal coherency. The use of a laser undulator will also allow for much smaller coherent x-ray sources, which could revolutionize x-ray diagnostics at many facilities that can’t currently fit a traditional x-ray FEL, such as the National Ignition Facility. To achieve these aggressive goals, we propose the use of either solid or plasma waveguides to better confine the beams and dramatically lengthen the interaction regime. Experimental design and simulations of the expected performance at the Brookhaven Accelerator Test Facility will be presented.

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Manufacturing with Light in Aerospace Industries: An overview of Potential Applications using High-Intensity pulsed Lasers

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Keywords: Laser Peening Forming, Laser Bond Adhesion, Laser Paint Stripping

The use of Laser Technologies as manufacturing process in Aerospace Industries can revolutionize the process for building aircraft providing a step change in the capability, efficiency, performance and versatility of manufacturing processes and technologies. A wide range of possible applications using High-Intensity pulsed lasers will be presented in this paper. Pressure shockwaves generated by surface plasma expansion induced by High-Intensity pulsed lasers can result in residual stresses into metallic materials (i.e. "*Laser Shock Peening*"). Residual stresses can be managed to either prevent degradation process occuring during the operational life of an aircraft (e.g. fatigue damages) or for advanced forming processes to shape 3D complex geometry [1], [2].
High-intensity pulsed lasers can be used for paint removal [3]; the advantages and challenges compared to state of the art techniques to remove paint will be presented. Aircraft structures are painted with several layers of coatings to ensure maximum protection against external environmental agents. During its operational life, the aircraft is subjected to regular removal of paint prior to standard restoration (e.g. livery repainting) or maintenance routine tasks. Aircraft paint consists of several coating layers: primers, base/top polymer coats as shown schematically in Fig. 1 a). Current techniques to remove the coating layers are based on mechanical abrasion, chemical paint stripping and laser paint stripping (i.e. ablation). Both mechanical abrasion and chemical stripping have as drawbacks the environmental impact due to the waste disposed (e.g. large quantities of dust and hazardous chemicals involved in the process). Mechanical stripping could be difficult to control in terms of microns of depth of layer removal. Laser paint ablation although very precise could result in thermal effects on the painted layers or the substrate [4].
Novel paint stripping process based on spallation phenomena produced by the pressure shock waves has been investigated in [3]. The use of pressure shock waves to induce stripping of paint layers with the laser source from the back side of the layer to be removed is shown in Fig. 1 b). The accessibility from the internal side of an aircraft could be difficult and for this reason in [3] the research focused on developing a setup providing the laser source from the same side of the aircraft coating to be removed, Fig. 1 c). Laser type and parameters to control the shock waves propagation to create the tensile stresses at the desired location to induce the separation of the layer to be removed plays an important role.

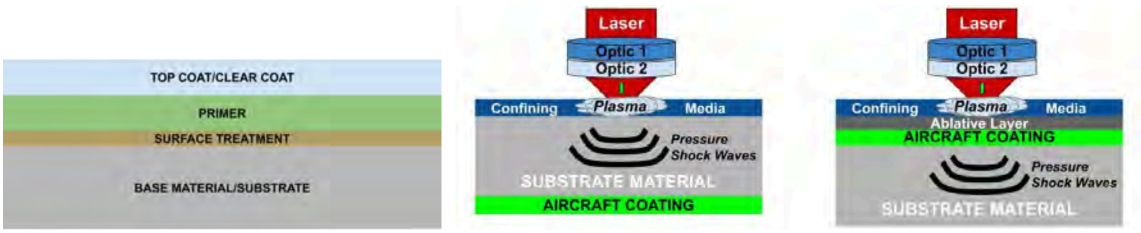

Fig.1 a) Schematic coating aircraft layers b) Shockwave from back surface c) Shockwave from top surface

The use of Composite material for aerospace applications have experienced a dramatic increase in the last two decades. Bonding technologies have been developed and deployed in the assembly process of aircraft component to enable high structural performance of airframes. Today's Aircraft certification rules [5] bring to the following possible approaches for adhesive bonded joints: 1) Repeatable and reliable Non-Destructive Techniques (NDT) that must be established to ensure the strength of each joint; 2) Full single part testing of bonded joints; 3) Disbonds of joint greater than the maximum critical disbonding to be prevented by design features (e.g. chicken fasteners). While the approach 2) is not practical and the approach 1) is not available at industrial scale, only approach 3) is currently used widely in aerospace

industry. This approach comes with its constraints: design complexity, costly manufacturing (drilling) and extra weight. However, Laser Shock Adhesion NDT is developed to reveal weaknesses in composite laminates or at bonded interfaces of structural joints. The magnitude and duration of the pressure pulse can be tailored by adjusting the laser parameters to calibrate stress waves propagating into the material. Such waves can then reveal weaknesses and be used to quantify the bonding strength of the structural joints otherwise not possible with conventional NDT. The compressive shock waves produced by the laser pulses travel into the material and reflect back at the rear surface with the opposite sign (tension). These propagating pressure waves (compression-tension) will determine the "opening" of the weak bonding if the out-of-plane material strength is exceeded. Below that limit, the material remains sound. By adjusting the laser parameters, it is possible to locate precisely the stress wave distribution into the joint [6].
The residual stresses induced by high-intensity lasers can be used as an advanced forming processes in aircraft manufacturing. Current metallic structures of commercial aircraft are built from panels which are shaped using complex and large specialized equipment (e.g. large hydraulic machines that stretch the materials and wrap it around a mould). Managing the residual stresses is possible to obtain complex 3D stiffened structures in the final material state while the state of the art technology (e.g. stretch forming) shall use the material to be shaped without stiffeners and in the soft material condition (i.e. prior final heat treatment). Moreover, laser peening forming allow to shape the structures after final thickness machined in flat condition which is not possible with state of the art forming process requiring 3D milling after forming. The key feature of the laser peening forming is the execution of a closed loop iteration of more peening sequences to achieve the final shape having the intermediate steps measured from an online monitoring/metrology system. Enabler of this production approach is the automatic definition of the peening strategy to bring the geometry of the part from the current measured geometry to the final shape. The peening strategy will be established by means of numerical simulation of the component subjected to the laser peening. Deviation in the response of the real part during the peening operation is mitigated with additional peening loops until the target geometry is within the tolerance defined for the component. The production process consists in this automatic definition of the peening strategy and execution without human intervention as summarized schematically in Fig. 2 [7].

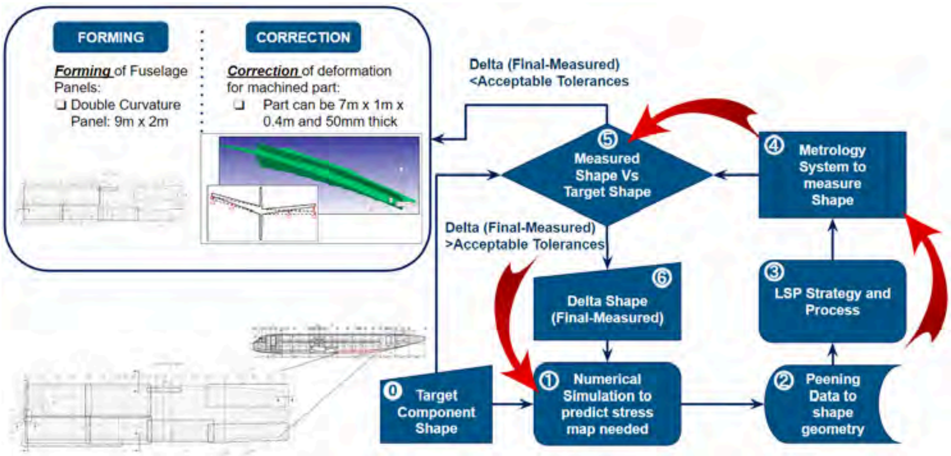

Fig. 2 Flow diagram of a contactless forming method using laser shock peening technology

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Service Life Extension of Infrastructure with Intense Laser Pulses from Monolithic Microchip Lasers

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Keywords: Laser peening, Handheld laser, Fatigue properties, Infrastructure, Life extension

The status of laser peening (LP) system development and the applications using monolithic microchip lasers will be reviewed. LP is expected to extend the service life of various load-bearing components and has been used to mitigate foreign object damage (FOD) on jet fighter engine fan blades. However, current LP systems are huge and laser systems are installed on vibration-resistant optical benches in clean rooms, limiting the applications. In the past decade, the Japanese national projects ImPACT [1] and JST-Mirai [2] have developed high-power monolithic microchip lasers that can be used for LP [3]. Taking full advantage of the robustness and compactness of the monolithic microchip laser, we have developed a robot-mounted LP system [4] that can be operated outdoors. An overview of the developed LP system, its impact on fatigue properties, and future prospects are presented.

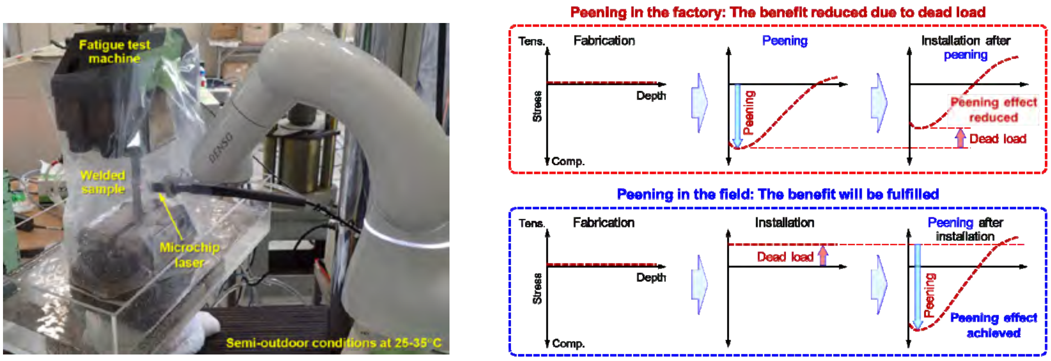

Fig.1 Laser peening (LP) of a weld sample under tensile loading simulating dead load (left) and the potential benefits of in-situ LP compared to LP in the factory (right).

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This work was partially supported by JST MIRAI Program (Grant number: JPMJMI17A1).

POSTER PRESENTERS

High-brightness betatron X-ray source driven by SULF-1PW laser

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Keywords: Betatron radiation, Laser wakefield accelerator, X-ray phase contrast imaging, SULF-1PW laser

With the progressive miniaturization and stabilization of laser wakefield accelerators, table-top X-ray radiation sources based on wakefield accelerators have shown enormous potential. The betatron radiation source, driven by ultrashort laser pulses, features a source size in the micrometer range, pulse duration in the femtosecond range, divergence angles in the milliradian range, and covers a broad spectrum exceeding tens of keV. It is applicable for high-contrast imaging of minute structures and for probing interdisciplinary ultrafast processes. Here we present the achievement of bright betatron hard X-ray radiation sources at Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences, utilizing a 1PW/0.1Hz laser system at Shanghai Superintense Ultrafast Laser Facility (SULF). Such a laser system can produce electron beams with charges above hundred pC and energies exceeding 1 GeV. Meanwhile, electron beams undergo the betatron oscillations in the wakefield, generating high-brightness X-ray radiation sources with critical energies ranging from 15 to 25 keV.

This advancement enables time-resolved imaging and spectroscopy at atomic and molecular scales, suitable for dense materials and biological specimens. The high brightness and energy levels enhance the efficiency and resolution, making these sources competitive with larger synchrotron facilities. The compact nature of table-top betatron X-ray sources offers significant cost and complexity reductions, fostering broader access and innovation across fields such as nuclear photonics, ultrafast chemistry, materials science, and biomedical research, etc. As this technology matures, its transformative impact on scientific and industrial applications is expected to grow.

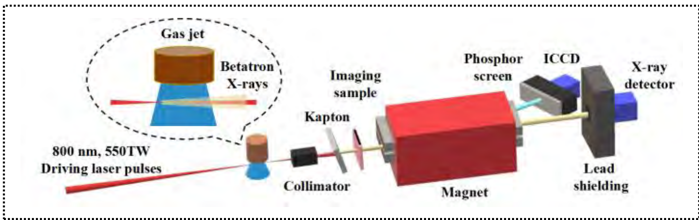

Fig.1 Experimental setup

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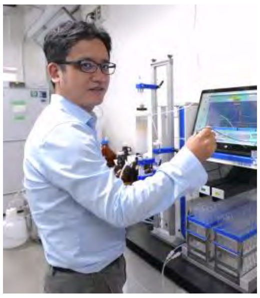
Prodrug activation triggered by relativistic electron beams



Yasunobu Yamashita[1,2], Yusa Muroya[1,2], Yoshio Mizuta[1,2], Kazumi Nakano[1], Kazumasa Minami[3,1], Jinfeng Yang[1], Yoshihide Honda[1], Yutaka Takahashi[3], Shinichi Shimizu[3], Masahiko Koizumi[3,1], Takayoshi Suzuki[1], Tomonao Hosokai[1,2]

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Keywords: prodrugs, quantum beams, pulse radiolysis, chemotherapy, pancreatic cancer

Chemotherapy, along with surgery and radiation therapy, is a key cancer treatment that uses anticancer agents to suppress tumor growth. However, even approved drugs often have limitations such as high toxicity and serious side effects on normal tissues due to their low selectivity for cancer cells. Prodrugs, which are inactive forms converted to active drugs by external or internal stimuli, have been developed to mitigate these side effects. Existing methods to activate prodrugs are limited by shallow skin penetration, making them unsuitable for treating deep-seated tumors. Recently, we proposed a novel approach using relativistic electron beams to activate prodrugs, enabling the treatment of cancers deep in the body.[1)] Studies combining prodrugs and electron beam irradiation have shown significant shrinkage of human cervical tumors (HeLa cells) and validated the method's pharmacological efficacy in both *in vitro* and *in vivo* models.

In this study, we apply this approach to pancreatic cancer, a challenging tumor with over 400,000 deaths reported annually. Surgery alone is insufficient for cure, and current treatments combining radiation and chemotherapy have limitations, such as increased radiation exposure to healthy tissues and severe side effects from chemotherapy. To address this, we synthesized a prodrug based on 5-FU, a drug commonly used in the clinical treatment of pancreatic cancer (Fig. 1). It efficiently generated 5-FU upon electron beam irradiation. Offline cell assays showed significantly lower cytotoxicity in human pancreatic cancer tumors (PANC-1 cells) compared to the parent drug, suggesting its potential as a prodrug. Ongoing experiments are further investigating its effects on PANC-1 cells.

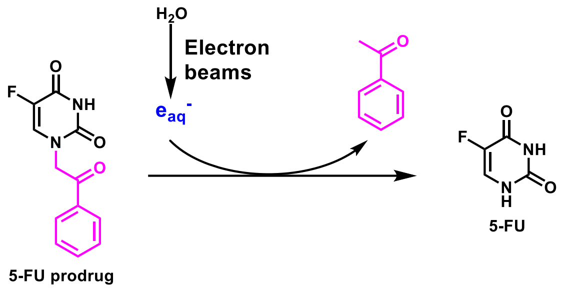

Fig.1 Activation of the 5-FU prodrug triggered by electron beams

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Potential of laser peening to improve residual stresses and fatigue strength of additive manufactured alloys

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Keywords: Laser peening, Residual stress, Fatigue strength, Additive manufactured alloys

In recent years, metal additive manufacturing (AM) techniques have attracted attention in medical, automotive, aerospace and other fields. A common metal AM technology is the fabrication of 3D objects by layering metal powders [1]. It is expected to be a new metal forming method in terms of reducing the production cost and time of products, as no moulds are required. However, the fatigue strength is lower than that of metallic materials produced by conventional methods due to defects generated in the lamination process. We have focused on Laser Peening (LP) as a solution to this problem. LP introduces compressive residual stresses on the surface of a metallic material covered with a transparent medium such as water by using the impact forces of the high-pressure plasma generated by the irradiation of a high-intensity laser beam on the surface of the material [2]. The compressive residual stresses on the surface of the material can increase the fatigue strength of the material and improve its resistance to stress corrosion cracking. In this study, laser peening treatment was carried out on a laminated Al-Mg-Sc alloy (One of the metal AM materials) using a compact high-power microchip laser. After laser peening, residual stress was measured using X-ray diffraction, and the formation of compressive residual stress on the material surface was confirmed (Fig. 1). Furthermore, compressive residual stresses were imparted from the surface of the material to about 200 μm (Fig. 2). Fatigue tests also showed the possibility of improving fatigue strength.

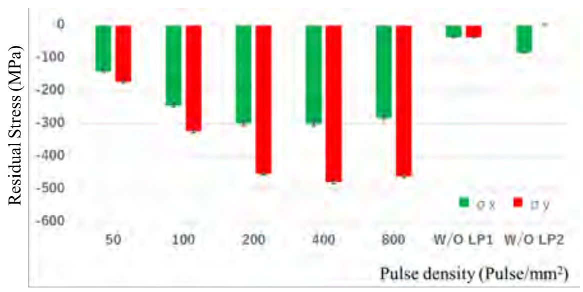

Fig.1 Surface residual stress of Al-Mg-Sc alloy

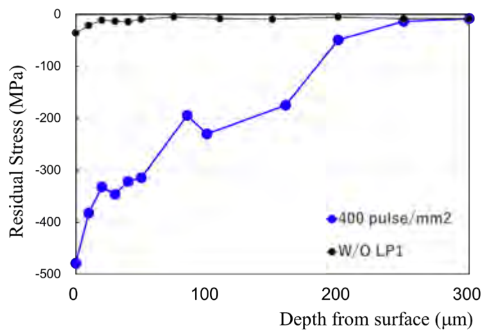

Fig. 2 Residual stress depth profile of Al-Mg-Sc Alloy (Pulse density: 400 pulse/mm^2)

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PO-04

Frequency-comb based asynchronous optical sampling for rapid optical pump and optical probe experiments

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Keywords: Q-LEAP STELLA, Optical frequency comb, Asynchronous optical sampling

In this poster presentation, we present our recent advancements in femtosecond optical frequency comb (OFC) technologies for ultrafast optical pump and optical probe (OPOP) experiments. A key development involves the mutual optical frequency stabilization of two OFCs, which allows precise control of their emission timings. This capability is particularly beneficial for asynchronous optical sampling (ASOPS) experiments for fast data acquisition of the OPOP experiments.

Ultrafast optical pump and optical probe (OPOP) technique is an effective method for observing surface modifications and changes in physical properties (e.g., refractive index) of materials subjected to intense laser pulse excitation. Conventional OPOP experiments rely on a mechanical delay line to adjust the timing between pump and probe pulses on the sample, which can be time-consuming. In contrast, the asynchronous optical sampling (ASOPS) technique automatically varies the irradiation timing of two independent laser pulses with slightly different repetition rates. When implemented using two phase-locked OFCs, ASOPS provides highly stable measurements for over half an hour [1], significantly improving experimental efficiency.

Figure 1 presents the spatiotemporal imaging of phonon generation induced by laser pulse excitation, obtained using the ASOPS technique with two phase-locked OFCs [2]. After laser pulse irradiation at the center (t = 0 ps), a clear ripple structure representing the outward propagation of surface acoustic waves was observed. The time-resolved measurement for each point took only about one second, demonstrating the potential of this rapid evaluation method for future studies on surface modifications induced by intense laser pulse irradiation.

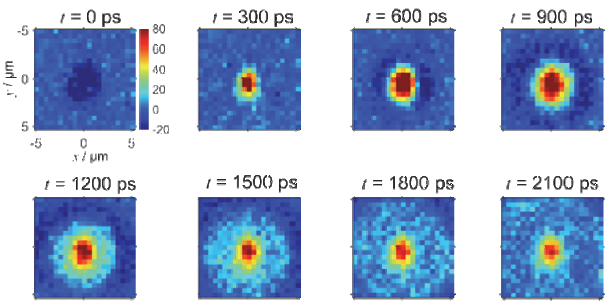

Figure 1: Spatial images of the optical phase change induced by surface displacement and refractive index variation at the sample surface, captured every 300 ps [2].

This work was partially supported by MEXT Q-LEAP, JST CREST, and JSPS KAKENHI.

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PO-05

Fractionated medium-dose carbon ion beams with anti-CTLA-4 antibody induces the abscopal effect in murine pancreatic cancer model

Ayaka Okuuchi[1], Shohei Katsuki[1], Shuri Tsuda[2], Tomoya Murakami[2], Wataru Takenaka[1], Kazumasa Minami[1], Masahiko Koizumi[1], Kazuhiko Ogawa[2], and Yutaka Takahashi[1]

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Keywords: Pancreatic ductal adenocarcinoma, Carbon ion, Abscopal effect

Pancreatic ductal adenocarcinoma (PDAC) has a high mortality rate and no effective treatment. Our previous study using a PDAC mouse model showed that the combination therapy of an immune checkpoint inhibitor, anti-CTLA-4 antibody (C4), and high-dose photon irradiation (16 Gy or 8 Gy x3 fractions) shrank not only irradiated tumor but also unirradiated tumor, which is known as the abscopal effect. However, the combination of C4 and medium-dose photon irradiation (10 Gy) failed to induce the abscopal effect. Given that carbon ion irradiation (CIR) is known to have stronger cell killing effects than photon irradiation, we investigated whether the combination therapy of C4 and medium-dose of CIR (5.1 Gy or 2.1 Gy x3 fractions, the biologically equivalent dose to 10 Gy with photon) induces the abscopal effect, along with changes in tumor microenvironment (TME).

CIR was conducted at National Institutes for Quantum Science. C57BL/6 mice inoculated PDAC cells at both legs were irradiated to one leg only. The mice were assigned to the following groups: no treatment (NoTx), C4, 5.1 Gy, 2.1 Gy x3 fractions, 5.1 Gy+C4, and 2.1 Gy x3 fractions+C4 groups. Mice in the C4, 5.1 Gy+C4, and 2.1 Gy x3 fractions+C4 groups were administered with C4 intraperitoneally 3 times every 3 days. The 5.1 Gy+C4 group was induced only local control. In contrast, mice in 2.1 Gy x3 fractions+C4 groups were induced local control and abscopal effect. Compared to 5.1 Gy+C4 group, the proportion of cytotoxic T lymphocytes (CTL) was significantly increased in CIR at 2.1 Gy x3 fractions+C4 group for both irradiated and unirradiated tumors, leading to the increased CTL/regulatory T cells (Treg) ratio at 5 days after the final treatment. These results suggest that not single but fractioned irradiation with C4 induces the abscopal effect and improves TME even at lower doses with CIR than photon irradiation.

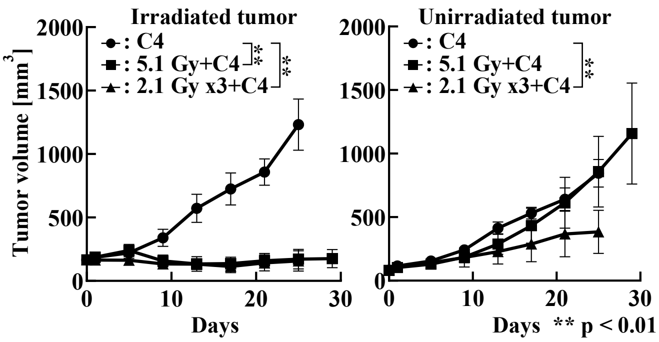

Fig 1. Tumor volume change

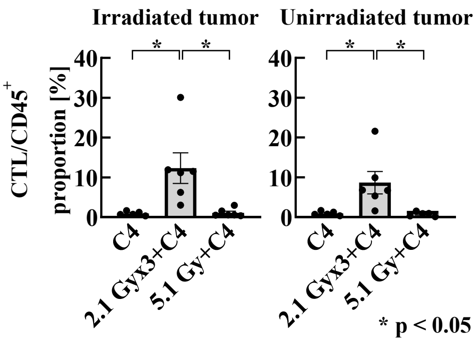

Fig 2. CTL proportion at 5 days after the final treatment

PO-06

Title: Elucidation of the mechanisms of radioresistance acquisition in TNBC that has acquired radioresistance.

Shuri Tsuda[1], Shohei Katsuki[2], Shotaro Tatekawa[1], Keisuke Tamari[1], Kazumasa Minami[2], Wataru Takenaka[2], Ayaka Okuuchi[2], Tomoya Murakami[1], Kentaro Doi[2,] Masahiko Koizumi[2], Yutaka Takahashi[2], and Kazuhiko Ogawa[1,]

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Keywords: Ultra Triple-negative breast cancer, radiation-resistant, RNA sequence, apoptosis

Triple-negative breast cancer (TNBC), which has no estrogen or progesterone receptors and HER2 protein, is aggressive and has a high metastasis rate. Some TNBC are radiation-resistant, resulting in repeated reccurence.

In this research, we established a radiation-resistant cell line (Res) of TNBC by irradiating 2 Gy repeatedly thirty times to identify the differential gene expression signatures between wild type (WT) and Res and to elucidate the underlying mechanism of radiation-resistance. For WT and Res cell lines, whole RNA sequence data was obtained by Research Institute for Microbial Diseases at Osaka University and was analyzed using Gene Set Enrichment Analysis. Based on the RNA sequence analysis, apoptosis assay was conducted for both cell lines 24 hrs after 8 Gy irradiation.

Colony formation assay confirmed that Res was significantly radiation-resistant compared to WT. Cell viability of Res is 1.4-fold at 6 Gy ($p<0.0001$), 2.2-fold at 10 Gy ($p=0.0015$), and 2.9-fold at 12 Gy ($p<0.0001$), respectively. RNA sequencing analysis identified upregulated genes, including those related to DNA repair (Normalized Enrichment Score: 2.63), and downregulated genes, including those related to apoptosis (NES: 3.21). Flow cytometric analysis revealed that 8 Gy-irradiation significantly reduced apoptosis in Res compared to WT. These result suggested that Res established by irradiation repeatedly to WT has differentially expressed genes related to DNA repair and apoptosis compared to WT. Nortably, apoptosis is an potential factor in radioresistant in TNBC.

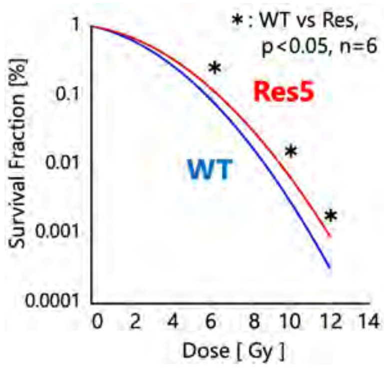

Fig 1. Cell survival curve

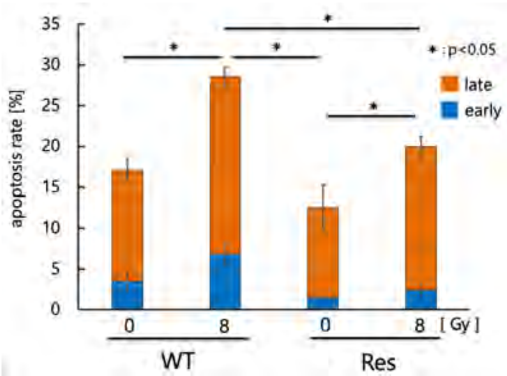

Fig 2. Apoptosis rate

Particle acceleration by photoelectric fields using dielectric microstructures (DLA)

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Keywords: Dielectric laser acceleration, Electron source, Drive laser, Dielectric structure

We have started research and development on DLA (Dielectric Laser Acceleration), which uses dielectric microstructures as light-driven acceleration. The acceleration gradient expected with DLA is about one order of magnitude greater than that of conventional RF acceleration, but it is an acceleration technology that is expected to significantly reduce the size of accelerator devices. DLA acceleration have been demonstrated in Germany [1] and the United States [2], and recently, "coherent acceleration" has been reported using an acceleration structure with a transverse focusing function [3]. In our laboratory, we have started to construct a DLA test stand consisting of three parts: (1) an electron source and beam diagnostics, (2) an acceleration laser system, and (3) an acceleration dielectric structure, as shown in the figure below. We aim to verify acceleration using DLA in near future, and ultimately be able to use DLA as an "accelerator". In this presentation, we will introduce an overview of DLA research at the University of Tokyo, and report on the current status of the DLA test stand and future prospects.

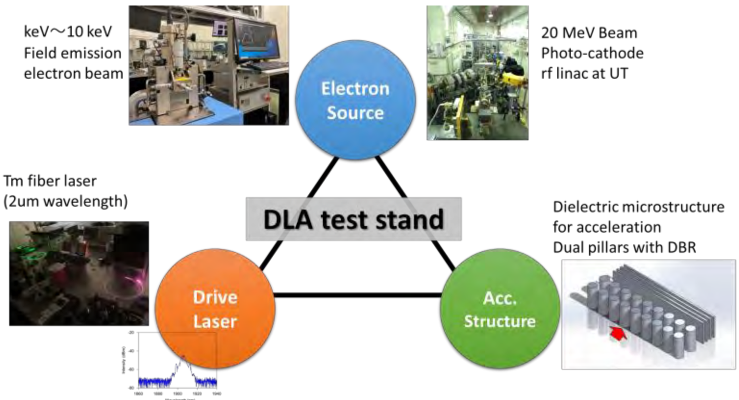

Fig.1 Schematic of DLA test stand

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PO-08

The impact of ultra-high dose rate (FLASH) carbon ion irradiation on antitumor immunity

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Keywords: carbon ion irradiation, FLASH, ultra-high dose rate, macrophage

Recently, some studies have indicated that ultra-high dose rate (uHDR: >40 Gy/s) irradiation with photon, electron, and proton can spare the damage to normal tissue while retaining the damage to tumors called the "FLASH effect" [1]. However, due to the limited number of facilities that can irradiate carbon ion (C-ion) under uHDR conditions, the impact of uHDR C-ion on antitumor immunity remains unclear. Therefore, this study aimed to investigate the effect of uHDR C-ion on cancer cells and immune cells.

Murine melanoma B16F10 and pancreatic adenocarcinoma Pan02 were used as cancer cell lines, and murine macrophage RAW264.7 cell line was used as an immune cell. Cells seeded into a well of a 24-well plate were irradiated with C-ion at uHDR (≒380 Gy/s) and normal dose rate (Conv; ≒1.0 Gy/min) at Osaka Heavy Ion Therapy Center (HIMAK) [3]. At 72 hrs post-irradiation, the expression of proteins on cancer and macrophage cells was evaluated by flow cytometry. As a control, cells were irradiated with photon using GammaCell.

Calreticulin expressed on the cancer cells, which works as an "eat me" signal, was upregulated by C-ion irradiation in both conditions. In contrast, an immune-suppressing protein PD-L1 expressed on Pan02 was downregulated by uHDR C-ion compared to Conv C-ion ($p = 0.06$) (Fig.1 left). In macrophage cells, the ratio of inflammatory (iNOS) to anti-inflammatory (Arg1) proteins was upregulated by 4.6-fold in uHDR C-ion irradiation (Fig.1 right). Moreover, the release of RANTES, which induces the immune cells' chemotaxis was significantly increased by C-ion irradiation.

In conclusion, uHDR C-ion has potential to induce effective antitumor immunity by influencing the expressions of immune-related proteins on cancer cells and leading inflammatory macrophages. We acknowledge members of HIMAK, HIMAK administration company, and Hitachi High-Tech Corporation.

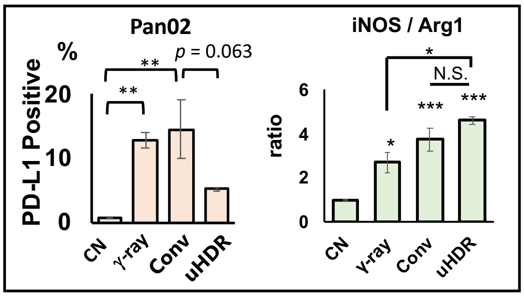

Fig.1. Left) The expression of PD-L1, an immune-suppressing protein, on Pan02 cells after irradiation. Right) The ratio of iNOS and Arg1 expressed on macrophage cells after irradiation. CN: Control.

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PO-09

Title: The Study of the Hydrodynamic Instabilities Impacts on Electron Beam Stability in Laser Wakefield Acceleration

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Keywords: Laser wakefield acceleration, Nozzle, computational fluid dynamics

After decades of development, laser wakefield acceleration (LWFA) techniques have shown great potential for the miniaturization of acceleration structures in next-generation electron accelerators. However, the stability of the electron beams generated via LWFA remains a significant challenge, hindering the medical and industrial applications of laser-driven accelerators. In this study, we present a systematic investigation of the effect of hydrodynamic instability on electron beams obtained in LWFA experiments.

We began with computational fluid dynamics (CFD) simulations, setting up two geometries: one with a fluid stabilizer and one without. We tested the outflow density fluctuations by applying a perturbation upstream. Our results showed that the gas flow from the geometry without a stabilizer suffers from density fluctuations around 10%, while the gas flow from the geometry with a stabilizer has density fluctuations of less than 1%. We then incorporated these findings into particle-in-cell (PIC) simulations and found that, under our experimental parameters, a 10% fluctuation in plasma density significantly impacts electron beam characteristics.

To validate the simulation results, we fabricated two nozzles based on the CFD geometries and tested them on our LWFA experimental platform at the RIKEN Harima campus. Fluid stability was assessed using a high-magnification Mach-Zehnder interferometer. We found that without a fluid stabilizer, the shock structure in the gas flow is unpredictable. In contrast, the supersonic jet from the stabilized hydrogen flow exhibited much smaller uncertainty. The electron beam characteristics from these two nozzles corroborated our conclusions: the electron beam is unpredictable when high instability exists in the gas target, whereas the stabilized gas target reduced the beam pointing instability to as low as 0.4 mrad and controlled the electron beam energy stability within 10% RMS.

PO-10

Can dopamine suppress the metastatic potential of radiation and create a better therapeutic effect of radiation?

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Keywords: Q-BASIS, cancer, metastasis, radiation biology,

Purpose: Previous studies have shown that dopamine receptor agonists exhibit anti-tumor and anti-metastatic effects on brain-metastatic breast cancer by modulating dopamine signaling pathways. We hypothesize that combining radiation with this therapeutic strategy may further enhance anti-tumor effects. Therefore, we investigated whether dopamine could suppress radiation-induced increases in invasive potential.

Materials and Methods: We used 4T1 mouse breast cancer cells. Cells were irradiated with γ-rays (Caesium-137, 662 keV). Carbon ion beams were used, delivered to the center of a 60 mm spread-out Bragg peak at the Osaka Heavy Ion Therapy Center. We used the dopamine receptor D1 agonist (DRD1a), A77636, at concentrations of 0.5 μM and 5.0 μM.

Results: We examined differences in surviving fraction between cells treated with both DRD1a and radiation and those without DRD1a treatment using a colony formation assay. There was no observed difference in surviving fraction with or without DRD1a. Based on colony formation assay results, we calculated doses resulting in 10% and 90% survival and conducted invasion assays at these doses. As the results of the invasion assay, control cells irradiated with the 90% survival dose of gamma radiation exhibited increased invasive ability compared to cells at 0 Gy and the 10% survival dose. However, no significant differences in invasion were observed for carbon ion beams at any dose. While carbon ion beams are generally known to increase invasive ability, we observed no differences in invasion with or without DRD1a.

We also investigated protein expression. E-cadherin, associated with epithelial-mesenchymal transition (EMT), showed no change between cells with and without DRD1a. Similarly, AKT, associated with cell motility, showed no difference. We hypothesize that differences may exist in MMP activation or integrin expression.

Conclusion: Dopamine may inhibit the increase in invasive capacity induced by radiation.

Design study for intense THz pulse extraction by cavity dumping of SANKEN THz-FEL

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Keywords: Free electron laser, Terahertz, Cavity dump

A long wavelength free-electron laser (FEL) driven by the low energy electron beam can be taken as an oscillator layout. It can then make a fully coherent optical pulse. In many oscillator FELs, the FEL beam is extracted through a small coupling hole at the center of the resonator mirror. The available intensity is, therefore, a few % of that inside the resonator. Cavity dumping can pick an intense single-pulse off from the micropulse train to extract an FEL pulse from the resonator more efficiently. Some FEL facilities developed cavity dumping to increase the extracted FEL pulse energy [1 - 3]. Cavity dumping is also useful for the CW FEL with the superconducting accelerator because it can drive intense FEL pulses with the repetition frequency of kHz order. It is developing at ELBE FEL in Dresden [4]. I will show the recent design study of cavity dumping for the THz FEL at SANKEN, Osaka University [5, 6].

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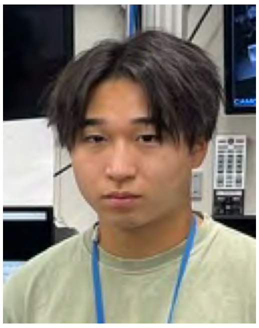
PO-12

High temporal-spatial resolution schlieren measurement for LWFA plasma target development



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Keywords: Laser Wakefield Acceleration, Schlieren imaging

In recent years, advances in electron injection methods in Laser Wakefield Accelerators (LWFAs) have enabled significant progress in research on free electron lasers (FELs) driven by LWFAs. Some research groups are exploring shock injection for the FEL driver beam, as this technique can produce highly monoenergetic and dense electron beams at rapid density down-ramp produced by a shock wave driven in a supersonic gas-jet target [1]. However, electron beam generation in this method is extremely sensitive to various parameters of laser pulse including it focusing, and to the position and the structure of the shock within the supersonic gas-jet target. Therefore, a stable laser and a target with stable shock are essential to achieve amplification in an LWFA-based.

In this study, we focus on the shock stability in the supersonic gas-jet target. Our gas target setup includes a horizontal blade and bow shock, where stagnation can occur, potentially leading to instabilities. To mitigate these, we developed a tilted blade to reduce stagnation-related shock instabilities. A schlieren measurement system, which is relatively sensitive to density transition in the gas, was installed to observe the shock within the gas target. To achieve high temporal and spatial resolution, we used a 30 fs pulse duration, 400 nm wavelength second-harmonic Ti: Sappier laser as probe laser pulses. We have studied the correlation between the shock stability and electron parameters.

Our results show that the tilted blade generates a shock with 1 μm greater stability than the vertical blade when using the same gas jet nozzle. Additionally, electron beam pointing stability improved by 0.3 mrad.

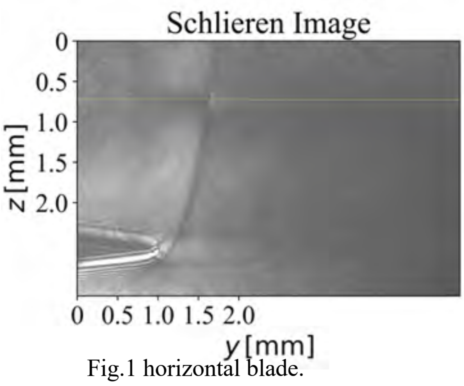

Fig.1 horizontal blade.

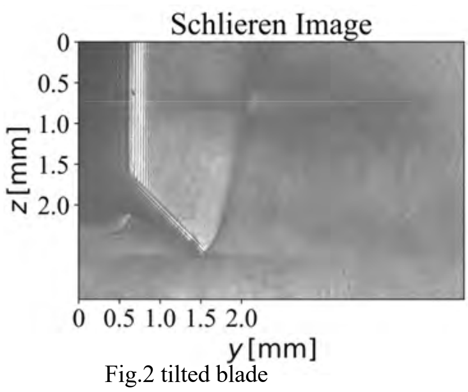

Fig.2 tilted blade

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PO-13

Title: Investigation of the mechanism of radiotherapy resistance in tumors by cellular senescence

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Keywords: Radiotherapy resistance, Cellular senescence, Senescence-associated secretory phenotype

Radiotherapy-resistant tumors can lead to local recurrence and distant metastases, resulting in decreased patient survival rates. While irradiation is indicated to induce cellular senescence in recent studies, which may promote tumor cell proliferation and metastasis through the senescence-associated secretory phenotype (SASP), the relationship between radioresistance and cellular senescence remains unclear. This study established radioresistant tumor cells (Res cells) to investigate the relationship between radioresistance and cellular senescence. Res cells were established by exposing mouse osteosarcoma cells (WT) to six rounds of 10 Gy γ-radiation. Radioresistance was evaluated using colony formation assays (in vitro) and mouse subcutaneous tumor models (in vivo). Post-irradiation cellular senescence was assessed using SA-β-gal staining (0, 4, 8 Gy), while apoptosis resistance was measured through Annexin V staining. IL-6 expression, a SASP factor, was analyzed using qPCR, and the expression of upstream factors phosphorylated NF-κB (pNF-κB) was evaluated by Western blotting. Radioresistance of Res cells was confirmed both in vitro and in vivo. SA-β-gal-positive cells increased in a dose-dependent manner in both WT and Res cells, with Res cells showing significantly higher levels. Annexin V staining confirmed apoptosis resistance in Res cells. IL-6 expression was significantly elevated in the Res group. pNF-κB levels were increased in the Res group. Radioresistant tumor cells exhibited decreased apoptosis and increased SASP factors following irradiation, suggesting that cellular senescence may play a crucial role in the mechanism of radioresistance.

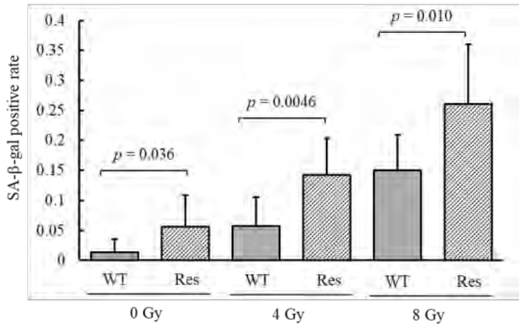

Fig 1. SA-β-gal positive rate (48hrs)

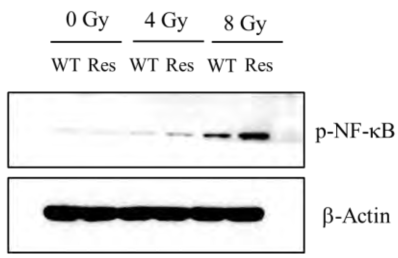

Fig 2. Expression of p-NF-κB (48 hrs)

Evaluation of Space Charge Neutralization in Laser-Driven Ion Acceleration Beams

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Keywords: Q-BASIS, Laser-driven ion acceleration, Quantum beams

Laser-driven ion acceleration generates a high ion density at the source, with a source diameter of less than one millimeter and bunch length of less than a few picoseconds. Such a low-energy and high-density beam explosive space-charge forces int both the longitudinal and transverse directions, resulting in significant emittance growth. However, the transverse emittance observed in the beam a few centimeters downstream of the source point is an order of over magnitude better than that of a typical RF accelerator beam. This is because the accelerated ion beam is transported in a ‘plasma-like’ state, with charge neutralized by moving electrons; however, detailed studies using particle transport simulations have not yet been conducted. To understand the beam dynamics, we diagnose the space charge neutralized beam by developing a novel PIC code that continuously and seamlessly simulates laser-driven ion acceleration from the source to the beam measurement point. In this presentation, we will report on the simulation results.

Development of a Compact, High-Intensity Laser for Generating High-Energy Photon and Particle Beams

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Keywords: TWs laser system, Laser ion acceleration, Plasma x-ray laser, Coherent EUV/x-ray sources

Recently, several petawatt-class lasers have been constructed worldwide, providing opportunities to investigate the behavior of matter in ultra-high electromagnetic fields. Additionally, there has been a keen demand for reliable terawatt-class laser systems for practical applications. At the National Institutes for Quantum Science and Technology (QST), we are developing the fifth generation of a heavy ion cancer therapy device, which consists of a laser ion injector, superconducting synchrotron, and superconducting rotating gantry [1]. In contrast to conventional linear accelerators, laser ion acceleration offers a larger acceleration gradient, enabling the miniaturization of ion injectors [2].

For such medical applications, the long-term stability of the laser system is a crucial issue. Here, we present a 60-TW platform laser developed in-house as the drive laser for the ion injector. The schematic setup of our laser system is shown in Fig. 1. We have constructed a double chirped pulse amplification (CPA) system with cross-polarized wave generation (XPW) technique to improve the temporal contrast. By optimizing the performance of the XPW and the amplification within the laser train, we achieved a temporal contrast better than 10^{11} at ~10 ps before the main pulse. Performance of the laser system and its applications in generating high-energy photon and particle beams will be discussed.

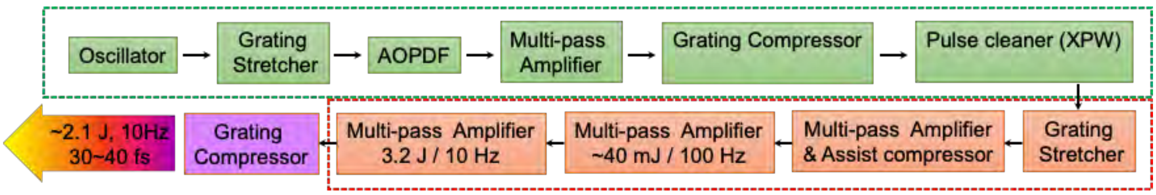

Fig.1 Schematic of the laser system.

Acknowledgements

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Laser requirements for ion injector in the quantum scalpel project

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Keywords: Laser ion injector, Carbon ion acceleration, Particle-In-Cell simulation

The National Institutes for Quantum Science and Technology (QST) is currently conducting the quantum scalpel project, which aims to improve the performance and miniaturization of heavy ion cancer therapy devices, which are highly effective in treatment [1,2]. The "Quantum scalpel" means cancer therapy using a quantum beam without a real scalpel in a body. It's a treatment method with minimal side effects, making it possible for patients to go to the hospital (day surgery) and be treated for cancer while working. The fifth generation of heavy ion cancer therapy devices, the Quantum Scalpel consists of the laser ion injector, super-conducting synchrotron, and super-conducting rotating gantry. Miniaturizing the ion injector and synchrotron is required to develop compact heavy-ion cancer therapy devices. In the quantum scalpel project, the synchrotron and injector will be miniaturized by introducing super-conducting technology and replacing the conventional linear accelerator with the laser ion injector, respectively. Laser ion acceleration has a large acceleration gradient and its technique is expected to develop a compact ion injector [3].

The requirement for the injector of the quantum scalpel is the 10 Hz generation of more than 10^8 of 4 MeV/u C^{6+} ions with 1% energy bandwidth. However, at the point of the laser acceleration, the 10% energy bandwidth of these ions is allowable. Carbon ions are compressed from 10% to 1% of their energy bandwidth by the phase rotation technique after the laser acceleration and are then transported to the synchrotron.

We have conducted quasi-1D and 2D PIC simulations to verify the condition of C^{6+} generation. These simulation results agree with the simple model that roughly predicts the maximum sheath strength and achievable ionization degree. We have also conducted 3D PIC simulations to quantitatively evaluate the number of generated carbon ions. Finally, we have discussed the laser requirements for a laser ion injector in the quantum scalpel project.

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PO-17

Abstract 161

THE ULTRA-HIGH DOSE RATE CARBON ION IRRADIATION IMPACTS TO GENERATE HYDROGEN PEROXIDE

Type: Abstract Submission

Topic: ASB. Mechanisms / ASB03. Biology 1 in vitro studies

Authors: Kazuki Fujita, Kazumasa Minami, Masashi Yagi, Kana Nagata, Ryo Hidani, Takahiro Yamada, Masumi Umezawa, Yasuo Okabe, Shinichi Shimizu, Kazuhiko Ogawa; Japan

Background and Aims

The ultra-high dose rate (uHDR) irradiation can spare normal tissue damage while remaining the damage to cancer. However, the mechanism of its sparing effect remains unclear. We set up a system irradiating uHDR carbon ion beam. Using this system, we investigated the differences in reactions of OH radicals between uHDR and normal dose rate (NDR) irradiation based on the density of radical production. To study that, we have focused on glutathione (GSH), an antioxidant that acts as a radical scavenger that removes H_2O_2. When GSH reacts with H_2O_2, it forms oxidized glutathione (GSSG). In this study, we aimed to estimate oxidative stress caused by H_2O_2 after uHDR irradiation based on GSSG/ GSH ratio.

Methods

HSGc-C5 (Human salivary gland cancer cells) and Nuli-1 (bronchial epithelial cells) were used in this study. At Osaka HIMAK, both cell lines were irradiated with carbon ion beams at 10 Gy at uHDR (100 Gy/ sec) and NDR (1.16 Gy/ sec). After four hours irradiation, the total GSH and GSSG concentrations were measured using a GSH measurement kit (GSSG/GSH Quantification Kit, DOJINDO, Japn). Based on these results, we calculated GSSG/ GSH ratio.

Results

In HSGc-C5, there were no significant differences of GSSG/ GSH ratio between uHDR and NDR. The ratio was higher at uHDR than at NDR in Nuli-1. In other words, uHDR irradiation may contribute to increasing H_2O_2 in Nuli-1, leading to elevated the oxidative stress.

Conclusions

These results suggested that in Nuli-1, highly reactive radicals generated by carbon ion irradiation at uHDR were reduced because of the reaction between them. Therefore, we could observe the possibility that DNA damage was reduced with uHDR irradiation in vitro.

Print

PO-18

Background and Aims

The ultra-high dose rate (uHDR) radiation refers to irradiation at dose rates 1,000 times higher than conventional dose rates is currently used in clinical radiotherapy, and FLASH effect has gained popularity worldwide in recent years.

FLASH effect is defined that irradiation at ultra-high dose rates of 40 Gy/s or higher can maintain local tumor control while reducing damage to surrounding normal tissues.

Proton beam is characterized by their superior dose concentration to tumors, compared to X-rays and electron beams, which are the main types of radiation therapy. Although studies have been reported on the FLASH effect in electron beams, X-rays, and proton beam, we have developed an ultra-high dose rate irradiation system using a superconducting cyclotron. Therefore, we aimed to identify the threshold dose at which cell sparing effect occurs by proton irradiation from low to high doses.

Methods

HSGc-C5 (human salivary gland tumor line) and Nuli-1 human lung bronchial epithelial cells, and HDF human dermal fibroblasts were selected in this study.

Proton beam irradiation was performed at Sumitomo Heavy Industries. Average dose of uHDR and conventional dose rate irradiation (Conv.) were 1, 2, 4, 8, 10, 15, 20, and 24 Gy.

Colony formation assay was performed to evaluate cell proliferation. Survival fraction obtained from colony formation assay were fitted by the Linear Quadratic model.

Results

In colony assay, there was no predominant difference in the survival fraction between Conv. and uHDR when irradiated with low doses. However, there was a significant difference at doses higher than 15 Gy for HDF, 24 Gy for Nuli-1, and 20 Gy for HSGc-c5.

Conclusions

Our results suggest that FLASH effect does not occur at low doses even under atmospheric conditions but at high doses in both cancer cells and normal cells.

Title: Effect of ultra-high dose rate particle irradiation on cell invasion in breast cancer cells

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Keywords: Ultra-high dose rate, Particle, Invasion, Breast cancer cell

【Background and Aims】
Currently, normal tissue sparing and local tumor control at ultra-High Dose Rate (uHDR) irradiation have been reported with particles and photons. Our group is interested in the effect of radiation to metastatic potentials on irradiated cells. We focused on the comparison of cell invasive capabilities between uHDR and normal dose rate (NDR) irradiated cells with carbon ion beams and proton beams on breast cancer cell lines.

【Methods】
MDA-MB-231 (MM231: triple negative human breast cancer cells) and MCF-7 (estrogen receptor positive human breast cancer cells) were used. Cells were irradiated with 1.63, 4.36 and 5.65 Gy by carbon ion under uHDR (> 90 Gy/sec) or NDR (1.16 Gy/sec) at Osaka Heavy Ion Therapy Center (HIMAK), they were irradiated with proton (4.0, 12.0 and 15.0 Gy) under uHDR (250 Gy/sec) and NDR (1 Gy/sec) at Sumitomo Heavy Industries, Ltd. E-cadherin, a type of invasion suppressor protein, was measured by western blotting. Matrigel invasion assays were conducted using living cells after 24 hours of irradiation.

【Results】
In the results with carbon ion irradiation, MCF-7 showed increased expression of E-cadherin under all uHDR irradiation compared to NDR. This result suggested that Epithelial-mesenchymal transition (EMT) can be suppressed in uHDR irradiation. However, EMT-related invasion was not observed in MM231. When cells were irradiated with 4.36 Gy at 19 keV/μm under uHDR, cell invasion was inhibited by 66% (MCF-7) compared to NDR. When irradiated at LET 50 keV/μm, cell invasion was suppressed by 71% (MM231) and 48% (MCF-7) with uHDR compared to NDR. In the results with proton irradiation, there were no significant changes to the cell invasive capabilities between uHDR and NDR.

【Conclusions】
Cell types exhibited varying response to EMT, and E-cadherin expression was influenced by uHDR carbon ion irradiation.

Electro-optic spatial-temporal characterization of the laser wakefield accelerated kilo-ampere electron bunches

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Keywords: Ultra-short pulse laser, electron acceleration, beam diagnostics, EO

Laser wakefield acceleration (LWFA) [1] is a compact acceleration method capable of generating GeV-level electrons over a distance of just a few centimeters. We developed electro-optic (EO) [2] sampling techniques suitable for diagnosing the temporal characteristics of electrons in LWFA. For single-shot measurements of timing, peak current, and the 3D density profile of the electron bunches, EO spatial decoding of coherent transition radiation (CTR) was performed, generated as electrons passed through a metal foil. Timing fluctuations of the electron beam were measured at 7 fs [3], and bunch durations of a few tens of femtoseconds were demonstrated. The electron bunch was observed to have a peak current exceeding 1 kilo-ampere, with a peak 3D number density of approximately 9×10^{21} m^{-3} [4]. A numerical code for polychromatic TR imaging and EO signal analysis was developed to support data interpretation [5].

This research not only highlights the effectiveness of EO sampling as a real-time diagnostic tool for laser-driven electron sources but also demonstrates the ultra-fast and high-brightness characteristics of these sources, offering potential for various applications.

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PO-21

Ultrafast imaging with relativistic femtosecond electron pulses

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Keywords: Ultrafast electron diffraction, Ultrafast electron microscopy, Femtosecond electron pulses, Structural dynamics

Femtosecond atomic-scale imaging is a most challenging subject in materials science and has long been a cherished dream tool for scientists wishing to study structural dynamics in materials. In this research, we have developed two innovative ultrafast imaging techniques with relativistic femtosecond-pulsed electron beams: ultrafast electron diffraction (UED) and ultrafast electron microscope (UEM) as shown in Fig. 1. A photocathode-based radio-frequency (RF) electron gun was used in the two imaging techniques to generate a relativistic femtosecond pulsed electron beam with the energy of 2~3 MeV and the pulse duration of 90 fs at the pulse charge of 100 fC. UED has successfully used to study the irreversible structural dynamics in materials with single-shot diffraction measurement. With our UEM, we succeeded to observed TEM images of gold nanoparticles with multi-pulse integration. In the low-magnification observation, the single-shot imaging with the femtosecond electron pulse is available. In the poster presentation, topics related to our development and demonstrations including the potential of ultrafast imaging with relativistic electron pulses will be reported and discussed.

This work was supported by a Basic Research (A) (No. 21H04654, No. 22246127, No. 26246026, and No. 17H01060) of Grant-in-Aid for Scientific Research from MEXT, Japan.

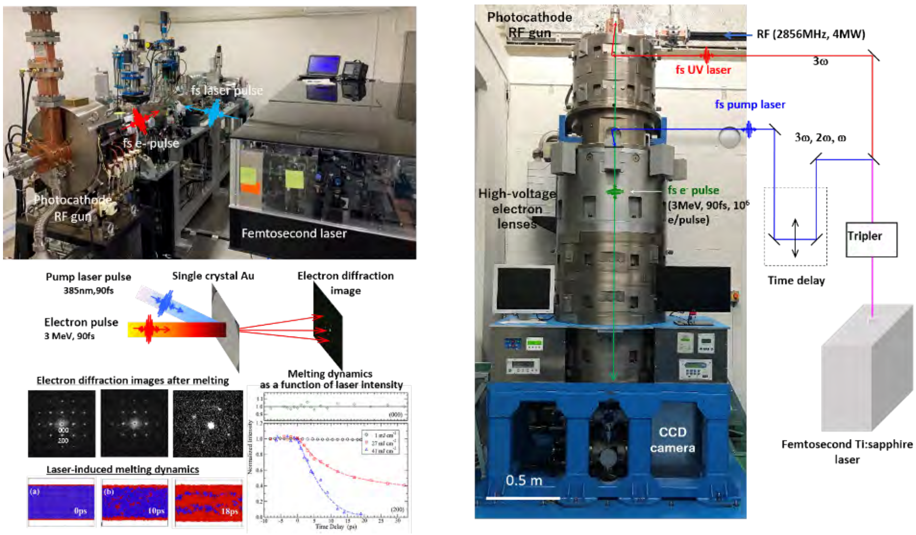

Fig.1 (Left)Ultrafast electron diffraction (UED) and (right) ultrafast electron microscope (UEM)

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PO-22

Prediction of the Laser Absorption Threshold Using Hybrid Deep Learning Model

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Keywords: Laser surface processing, Deep learning model, Laser absorption threshold

This study explores the efficiency of a hybrid deep learning model, integrating a Convolutional Neural Network (CNN) with a Multi-Layer Perceptron (MLP) network [[1],[2]], to achieve superior precision in predicting the laser absorption threshold of diverse materials in high-power laser surface processing (LSP) [[3]]. The CNN is designed to extract intricate features from laser-irradiated surface images (LISI) of materials, capturing crucial information about surface irregularities, while the MLP processes numerical/categorical information to understand the complex relationships between these features and the corresponding process outcomes. The deep CNN-MLP model successfully overcomes the difficulties of complex laser-mater interactions and process variability in LSP. Utilizing a mixed dataset comprising numerical/categorical information and single-shot laser-irradiated surface images, comparing other hybrid models our proposed model achieved over 95% accuracy for trained materials and over 90% for untrained materials in predicting the laser absorption threshold. Figure 1 shows the prediction of the uncertainty level of the laser absorption threshold for diverse metals. Despite the diverse data types used, the model demonstrated robust performance. This research offers significant contributions to material science and highlights the potential of hybrid deep learning to LSP by enabling more precise control, improved efficiency, and enhanced product quality in various industrial applications.

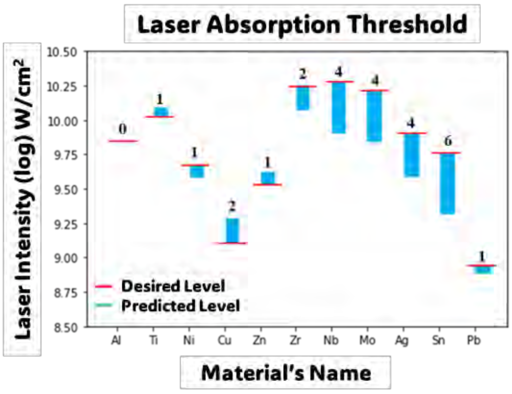

Fig. 1 The uncertainty level of the laser absorption threshold for different metals

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Study on radiation-induced reaction mechanisms of candidate materials for relativistic electron beam induced chemotherapy (REBIT)

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Keywords: Beam-induced reaction mechanism, Prodrugs for chemotherapy, Pulse radiolysis – time resolved measurement, Reaction kinetic simulation

Historically, various kinds of radiation techniques have been developed for cancer therapy. On the other hand, it is expected to use prodrugs in chemotherapy as alternative drugs as they can avoid systemic side effects of chemotherapy. In this technique, since the prodrugs are generally inactive, how to activate them in vivo efficiently will be a critical issue. In order to address this issue, it was proposed a relativistic electron beam induced chemotherapy (REBIT) in which hundreds MeV electron beam is employed to activate prodrugs deep in the body. Having high penetration power of tens cm in water, such high energy beam is expected to be a powerful tool to activate prodrugs deep in our body. As the basis to improve and optimize the REBIT technique, to understand fundamental radiation effects of the prodrug materials should be of great importance. However, details of the reaction mechanisms are not studied and therefore not known well. So, in this work, electron beam-induced fundamental processes of some candidate materials of prodrug and the analogous (4-Acetamidobenzenesulfonylazide (S1), pazopanib, sulphanilamide (SA) etc.) in aqueous solutions were investigated by using a nanosecond time-resolved electron pulse radiolysis method (established at L-band linac facility at Osaka Univ.) and a numerical simulation method.

On primary processes of the radiation-induced reactions, reactivities of the prodrug materials with main primary radiolytic products of water such as hydrated electron (e^-_{aq}) and hydroxyl radical (OH) were evaluated by the nanosecond pulse radiolysis method. Transient species induced by the electron pulse could be directly measured in nanosecond to microsecond time scale. Most of the candidate materials were found to react rapidly with e^-_{aq} whose rate constants were generally more or less than 10^{10} [$M^{-1}s^{-1}$]. Those materials also exhibited high reactivity with OH whose rate constants were generally more or less than 5×10^9 [$M^{-1}s^{-1}$]. Considering that our body mostly consists of electrophobic matters, e^-_{aq} is supposed to be the key radiolytic specie to activate the prodrugs. Accordingly, subsequent reactions were also measured by the pulse radiolysis. Transient absorption bands assigned to electron adducted radicals exhibited quick blue shift, that will be probably due to proton transfer. Moreover, in longer time scale, it was found 2nd order decay of the products in high dose rate condition, that indicates that the products are possible to recombine together to form the dimer. Introducing the obtained experimental data, a numerical simulation code based on spur diffusion kinetic model was newly developed. Details will be presented in our session.

Highly monoenergetic bunch generation via laser wakefield acceleration using near-field shaped laser pulse with structured density target

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Keywords: Laser wakefield acceleration, Monoenergetic electron bunch

Laser wakefield acceleration (LWFA) uses high-intensity lasers to create electron plasma waves, achieving accelerating fields much stronger than conventional accelerators. That is expected to be used as a compact high-energy electron accelerator. Since its theoretical proposal, LWFA has achieved significant milestones, such as 10-GeV generation, 24-hour operation, and free electron lasering. Stable high-quality beams are required for many applications.

Highly monoenergetic single electron bunch of several hundred MeV with good stability was produced by using a near-field shaped ultrashort laser pulse with structured density target at laser electron acceleration platform, LAPLACIAN. The electron bunch had a narrow energy spread of less than 3%. The contrast ratio of background in the wide-range energy spectra to the monoenergetic peak was as low as $\sim 10^{-2}$ or less. The concentration of the charge at the peak exceeded 50% of the total charge over 10 pC. The monoenergetic electron bunch can be obtained by precise density control with parameter scans. This fine-tuning was possible because by laser shaping using an aperture, the pointing fluctuation of electron beam was suppressed, and its pointing direction was controlled [1]. These low-background high-quality bunch is useful for many applications because they do not cause unnecessary beam loss or radiation noise during transportation.

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Ab-initio calculations of energy transfer from femtosecond laser pulse to amorphous silicon

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Keywords: Time-dependent density functional theory, TDDFT, Femtosecond laser, Ablation, Amorphous silicon

Ablation utilizing ultrashort laser pulses has been integrated into numerous industrial manufacturing procedures owing to its capability for precise processing while incurring minimal thermal repercussions. Upon the irradiation of a semiconductor with ultrashort pulses, electron excitation by optical absorption occurs within an exceedingly brief time, leading to irreversible modifications through various physical mechanisms. Ablation occurs in the irradiated region where the fluence is sufficiently high, whereas non-ablation phenomena, such as amorphization in the irradiated area where the fluence is comparatively low [1].

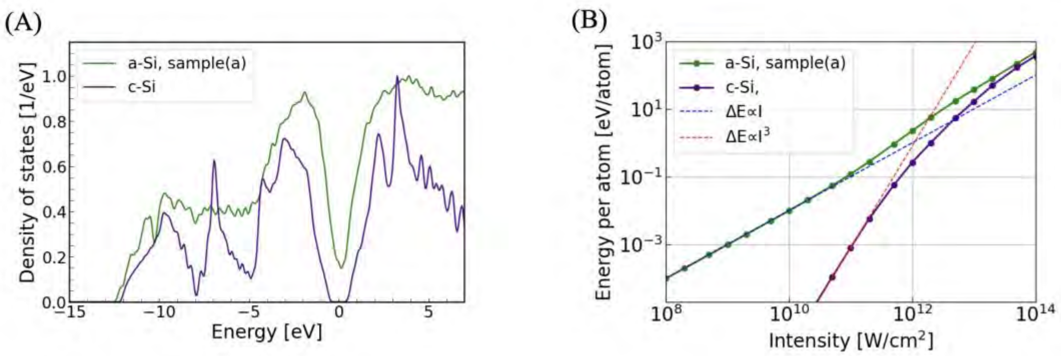

Fig.1 (A) Density of states of a-Si and c-Si (normalized for comparison). 0 eV corresponds to the Fermi level. (B) Intensity dependence of the energy absorption from pulses with pulse widths of 14.4 fs and wavelength of 1030 nm to a-Si and c-Si.

In this study, we examine the optical response of amorphous silicon (a-Si) employing a first-principles calculation. We extracted substructures comprising 512 atoms randomly from a large amorphous configuration containing 4096 atoms, which was derived from the research using the classical molecular dynamics simulations with machine-learning-based interatomic potential [2]. The atomic arrangement is optimized employing density functional theory (DFT). Using the obtained supercell, the ground state and energy absorption of a-Si under femtosecond laser pulses were investigated by time-dependent density functional theory (TDDFT) using the open-source calculation program SALMON [3]. We observed that the amorphization of single-crystal silicon (c-Si) results in the closing of the band gap, as illustrated in Fig.

1(A), implying metallic optical responses. TDDFT calculations indicate that a-Si experiences single-photon absorption at lower intensities, whereas electrons are excited by multi-photon absorption in c-Si as shown in Fig. 1(B). At high intensities, the energy absorbed by both a-Si and c-Si approaches an equivalent level.

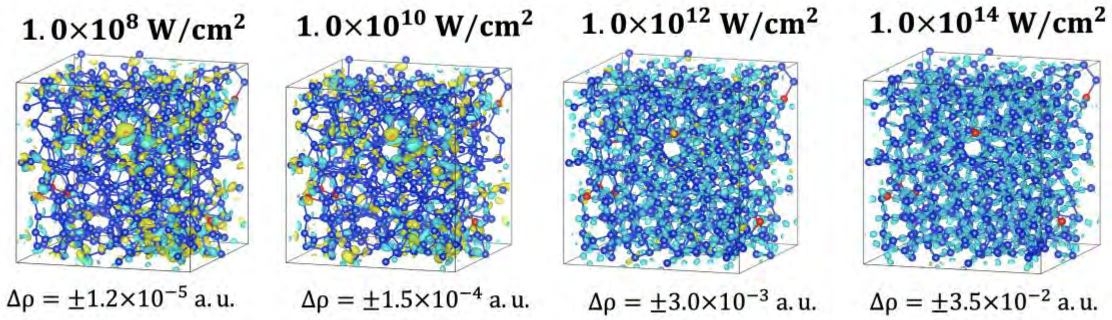

Fig.2 Change of electron density from the ground state in a-Si after the pulse irradiation. The red atoms represent Si atoms with a coordination number of 3 (dangling bond). The cyan and yellow isosurface indicate $\Delta\rho$ of plus and minus value, respectively. Figures were visualized by VESTA [4].

We show the spatial profile of the difference of electron density $\Delta\rho(r) = \rho_{t=50fs}(r) - \rho_{t=0fs}(r)$ for various peak intensity ranges from 1.0×10^{8} to 1.0×10^{14} W/cm^2 in Fig. 2. For moderate intensities (1.0×10^{8} and 1.0×10^{10} W/cm^2), the change is mostly localized around few Si sites characterized by coordination number 3 which is highlighted by red color. The localization of $\Delta\rho$ may originate from the dangling bond hosted by those sites. As intensity increases (1.0×10^{12} and 1.0×10^{14} W/cm^2), however, $\Delta\rho$ becomes delocalized and extends uniformly over the entire system. The change in the excited areas with intensity corresponds to the result in Fig. 1(B), where the difference between amorphous and crystalline becomes more pronounced at low intensities and the difference between the two becomes smaller at high intensities.

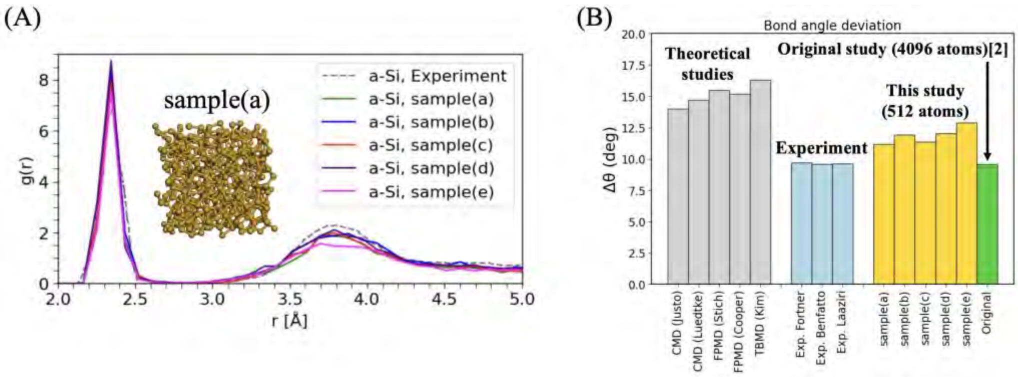

Fig.3 (A) Radial distribution of function and (B) bond angle deviation of a-Si after structural optimization.

Finally, we show (A) the radial distribution function (RDF) and (B) the bond angle deviation ($\Delta\theta$) of optimized structures in Fig. 3. Despite the random sampling, RDF and $\Delta\theta$ of the obtained structures are found to be in good agreement with the experimental values, indicating that our target system reproduces well the real a-Si bulk system.

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PO-26

Current Status of RLQBS in SANKEN

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Keywords: electron linac, pulse radiolysis, photocathode

Research Laboratory for quantum beam science [1] is a laboratory used to study the interaction of radiation and matter. In addition to using a cobalt-60 gamma-ray irradiation device, in particular, a unique measurement method called pulse radiolysis that combines an electron accelerator capable of generating short electron pulses has been used to conduct research on the time structure of chemical reactions. Meanwhile, new fields of use have recently emerged, especially in medicine. The electron accelerator required here is not the conventional ultrashort electron pulse, but an electron beam accelerator with a wide dynamic range of charge. The L-band linac has been functioning as a device capable of irradiating large amounts of charge since its installation in 1978. Since its installation in 2003, the RF electron gun linac has been used to generate ultrashort pulse beams, taking advantage of the characteristics of the photocathode electron gun, but the charge is more than one order of magnitude smaller than that of the L-band linac. In the future, a photocathode C-band linac is also planned to be installed as a complementary accelerator. One method of increasing the charge on a photocathode is to evaporate Cs-Te onto the cathode surface. At the end of last year, we received such Cs-Te evaporation device from Waseda University, and have begun experiments using this. This makes it possible to generate an electron beam that is an order of magnitude stronger than conventional copper electrodes, but to generate a greater amount of charge, we need to device a way to increase the number of incident laser pulses in a macro bunch. In line with such expansion of new research fields, the way the facility is used has also been reviewed. Once the ongoing construction is completed, it will look as shown in the figure, and we plan to remove part of the controlled area and make more effective use of this area.

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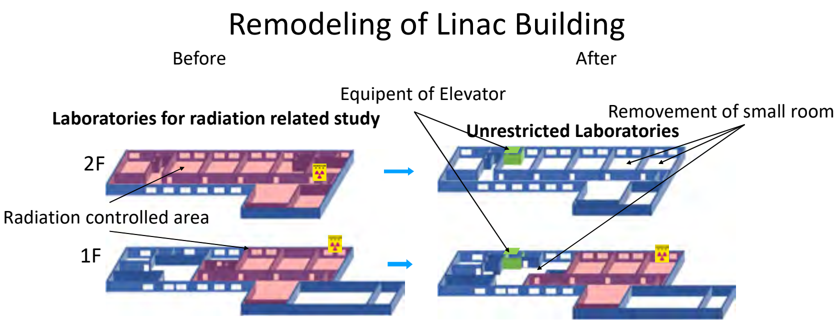

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PO-27

Laser Driven Quasi-monoenergetic Deuteron Acceleration with *in-situ* D_2O-deposited target

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Keywords: Laser ions, Deuterons, Laser driven ion acceleration

Laser driven ion acceleration attracts interest worldwide for the possibility to generate high flux pulse ions. Laser accelerated ions such as protons and deuterons have been applicated in some areas like Laser Driven Neutron Source [1,2]. Increasing the max energy and narrowing the energy spread of laser accelerated ions are the two main needs for further applications. Recently, the max energy of laser accelerated protons has already broken the limit of 100MeV [3], however, generating quasi-monoenergetic ions is still challenging.

In this work [4], we proposed a method to accelerate quasi-monoenergetic deuterons with high power laser with in-situ D_2O-deposited targets. The experiments are conducted with LFEX laser at ILE, Osaka Univ. We placed a D_2O capsule (shown in Fig.1a&b) near a natural Al target under vacuum for a while, some of the D_2O molecules can leak from the capsule for the porous structure of the plastic shell and deposit on the Al target (Fig.1c). The thickness of the D_2O layer on Al target can be controlled by the deposition time. And then the deuteron acceleration experiments are conducted by LFEX laser as shown in Fig.1d. As results, we obtained 10.8 MeV deuterons with an energy spread of 4.6% at the target normal direction in the most favorable shot. The details of the experiment and acceleration mechanism will be presented.

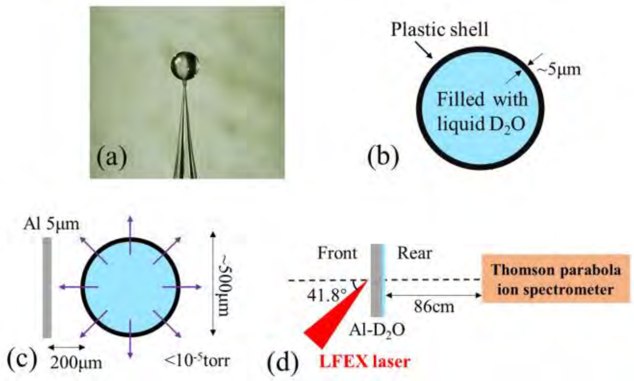

Fig.1 (a)Photo of the D2O capsule. (b)Structure of the capsule. (c)Depositing D2O on the Al target. (d) Acceleration setup.

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PO-28

Simulation study of the effect of blade in LWFA using Shock Injection

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Keywords: LWFA, Shock Injection, blade effect, bubble region, beam quality

Laser-plasma accelerators (LWFA) are an acceleration technology that has been actively studied in conjunction with recent advances in high-intensity ultrashort pulse laser technology. Compared to conventional RF accelerators, LWFAs can accelerate electrons to GeV-class energies over very short distances and are expected to find applications in a wide range of fields, including medicine, physics, and materials science. On the other hand, the quality of the electron beam is highly dependent on the laser and plasma parameters, and challenges remain in the stable control of the energy and quality of the accelerated electron beam. In general, it is known that the amount of charge contained in the electron bunch can be controlled by creating down- and up-ramps in the initial plasma density with a shock wave driven by a blade inserted in a supersonic gas target using Shock Injection. In this study, the effect of blade length is investigated using particle in cell (PIC) simulations. A local decrease in plasma density (down ramp) confines the electron bunch within the bubble region, where it is accelerated by the longitudinal electric field due to plasma waves, and a local increase in plasma density (up ramp) decreases the bubble volume, which reduces the charge in the trapped electron bunch together with the suppression of the beam loading effect and the broadening of the electron beam energy spectrum.

Topological Data Analysis of the Ultrafast Melting Process

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Keywords: *Ultra-short pulse laser, Material processing, Molecular dynamics, TTM+MD, Persistent homology*

Laser ablation process is inherently a multi-scale phenomenon. Various phenomenological models have been proposed for each spatial and temporal scale. One such model, TTM+MD, describes the electron system using the heat diffusion equation and the lattice system through classical molecular dynamics (MD). While this is an effective model that makes bold assumptions about the coupling between the electron and lattice systems, it has been widely used as a concise model capable of describing ablation processes at the atomic scale [1]. We have extracted universal features from a simpler model, the multi-component heat diffusion equation system by introducing the concept of an effective heat diffusion coefficient [2]. However, in general, opportunity of characterizing ablation processes in a universal manner is quite limited.

In this study, we implemented the TTM+MD model and performed a numerical simulation of the ultrafast melting of a thin Al slab induced by a femtosecond laser pulse irradiation (figure 1 (a, b)). Ablation appears as a seemingly disordered phenomenon where atoms fly off randomly, making it difficult to derive meaningful insights from microscopic structures. Therefore, we analyze the transient atomic structure using a mathematical tool called persistent homology (PH). Intuitively, PH captures the number and size of “voids” in the structure. PH can be projected histogram called a persistent diagram (PD) [3] as is given in figure 1 (c, d). In this presentation, we report the coexistence of “homogeneous” and “heterogeneous” melting during the ultrafast melting process and its structural characterizations based on the topological data analysis using persistent homology.

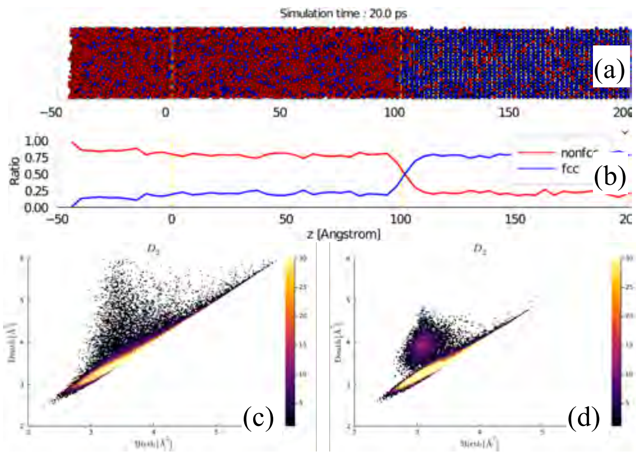

Fig. 1 Molten surface structure of Al thin slab (a) and the ratio of fcc and non-fcc structured Al atoms (b). PDs for uniform and heterogeneous melting layers are shown in (c) and (d.)

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PO-30

Stabilization of Radiation Wavelength on Energy Spread and Jitter of driven beam using Transverse Gradient Undulator

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Keywords: Undulator Radiation, Energy Compensation

Laser Wake-Field Acceleration (LWFA) is one of candidates of future accelerator, because of its higher accelerating gradient and ultra-short bunch generation. However, at the present, energy spread and jitter of electron beam produced by LWFA wouldn't reached that of conventional rf accelerator yet. The energy spread will increase the line-width of the spectrum and the jitter will cause the fluctuation of wavelength. Transverse gradient undulator (TGU) which has transverse field variation is one of solutions to reduce the effects of such energy spread and jitter[1]. When the dispersion function in the TGU region will be satisfied the resonant condition, then the radiation wavelength would become independent to beam energy. The experimental study of TGU have been prepared at test Accelerator as Coherent THz Source (t-ACTS), RARiS, Tohoku University[2]. The validity of TGU was estimated by numerical calculations. By using the TGU with the appropriate dispersion in the TGU region, we confirmed that undulator wavelength became constant value regardless of beam energy. The result of numerical calculations shows in Fig.1. Without dispersion correction, the radiation frequency from TGU (blue) was varied by beam energy same as normal undulator. On the other hand, the radiation frequency with the appropriate dispersion (red) was not affected by beam energy. And also the line-width, radiation intensity from TGU will be presented.

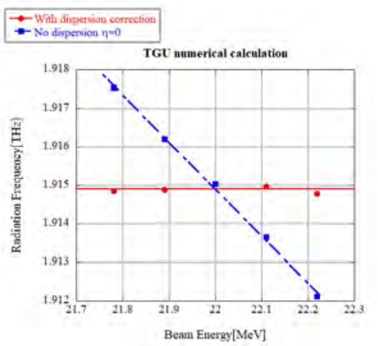

Fig.1 The radiation frequency from TGU. Blue: No dispersion case, Red: Appropriate dispersion case. With appropriate dispersion, the radiation frequency from TGU became independent to beam energy.

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