2022年　光・量子ビーム科学合同シンポジウム

The Joint Symposium on Optical and Quantum Beam Science 2022

OPTO 2022

Abstracts

On-line/In person at KPSI　28,29. June. 2022

Kansai Photon Science Institute,
National Institutes for Quantum Science and Technology
and
Institute of Laser Engineering, Osaka University

Terahertz time-domain ellipsometry with high precision for semiconductor evaluation

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Abstract

Terahertz (THz) waves correspond to electromagnetic radiation between the infrared and millimeter waves in the electromagnetic spectrum. The wavelengths covered by the THz band are between 3 mm (0.1 THz) and 30 μm (10 THz). Within the THz region, low-energy excitations in semiconductors can be observed, such as free carriers, phonons, plasmons, and cyclotron resonance. Hence, THz waves can be used to probe semiconductor properties [1,2]. THz time-domain ellipsometry is a technique that measures the change in the polarization state of THz waves upon reflection on a sample. The measurement values, called the ellipsometric parameters, are the amplitude ratio and the phase difference between the *p* and *s* components of the polarization. From the ellipsometric parameters, the optical constants of the sample can be obtained. Free-carrier properties can then be extracted using the optical constants. Based on this principle, THz time-domain ellipsometry can be used to determine the carrier concentration, mobility, and conductivity of semiconductors.

In our THz time-domain ellipsometer, a femtosecond laser is split into pump and probe beams to excite two photoconductive antennas for THz generation and detection, respectively. The time-dependent electric field of the THz wave is measured by sweeping an optical delay between the pump and probe beams. The *p* and *s* polarization components are detected by using a rotating polarizer analyzer. Our ellipsometer has a high measurement precision owing to the rotating analyzer. By nonlinear regression analysis of the electric field amplitude as a function of the analyzer angular position, the *p* and *s* time-domain waveforms are obtained accurately. Fourier transformation is then applied to acquire the frequency spectra and subsequently the ellipsometric parameters. We have investigated different semiconductors using THz time-domain ellipsometry. With the high precision of our ellipsometer, we were able to measure GaN bulk crystals with very high carrier concentrations. We were also able to characterize the subtle difference between the optical response of undoped and doped InSb narrow-bandgap semiconductor wafers at room temperature. We also investigated ultrawide-bandgap semiconductor β-Ga_2O_3 bulk and film samples and determined their carrier concentration and mobility. For semiconductor evaluation, THz time-domain ellipsometry is advantageous over electrical characterization methods because of its all-optical, nondestructive approach.

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June 28, 2022
KPSI, Kyoto, JAPAN
OPTO2022, KPSI-QST & ILE-Osaka-U

非線形レーザー物質相互作用の理論及び数値計算による研究

Theoretical and numerical studies for the nonlinear laser-matter interactions

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Abstract

The first stage of the laser-matter interaction, in as–fs time-scale, is the electron dynamics under the laser fields and/or electromagnetic (EM) field dynamics in the material. This process is important in atto-science and material control by light fields. After that, collisional processes (electron-electron and electron-lattice) occur. The collisional processes are important in the laser-processing. In our group, we have been developing the following three numerical approaches to understand the laser-matter interaction from the atto- to picosecond time scale.

For the ultrafast phenomena, we have been developing the electron and EM-field dynamics simulator "SALMON" (Scalable Ab-initio Light-Matter simulator for Optics and Nanoscience, https://salmon-tddft.jp) [M. Noda, *et al.*, Comput. Phys. Commun. **235**, 356 (2019)]. The SALMON solves the time-dependent Kohn-Sham equation and Maxwell's equations simultaneously, which enables us to simulate the nonlinear electron excitation process together with the propagation of the laser field. Recently, we implement the spin-orbit interaction in the SALMON to study the spin-dependent phenomena. As the first step, we have demonstrated the valley polarization control by the CEP of a linearly polarized laser pulse [A. Hashmi *et al.*, PRB **105**, 115403 (2022)].

Although the SALMON is the most precise approach, it takes huge computational costs. We have found that the electron dynamics and EM-field dynamics can be described by employing the semi-classical Vlasov equation. We mimic the Vlasov equation as the dynamics of quasi-particles which satisfies the Pauli-blocking. I'd like to present that the semi-classical simulation reproduces the SALMON and experiments for the Al [M. Tani *et al.*, PRB **104**, 075157 (2021)]. The interesting points of this approach are that we can include the electron-electron collision and ion dynamics by implementing some new routines.

The most difficult stage of the laser-matter interaction is the time-scale of 10s ps. In this time scale, lattice dynamics and energy flow in the material play important roles. Although the 10s ps is an important stage in laser processing, it is too long for the quantum-mechanical simulation. We have developed the three-temperature (electron, hole, and lattice temperatures) model to study the laser damage process in silicon. Our simulation reproduces the pulse duration dependence of the damage thresholds. We also found that the melting energy and the electron emission from the silicon surface are the key conditions in the damage process [P. Venkat and T. Otobe, APEX **15**, 041008 (2022)].

I'd like to discuss how we can develop the feasible multi-scale simulation method by combining various approaches in the future as a summary.

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高エネルギー密度科学における日米協力と NIF 実験のインパクト

Japan-U.S. Cooperation in High Energy Density Science and the Impact of NIF Achivement on IFE

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Abstract

A Japan-U.S. project agreement was signed in January 2019 (topics covered by the project: high power lasers, high energy density science with large laser facilities, XFEL and High Energy Density Science by XFEL and High Power Laser). It is expected that the Japan-U.S. research collaboration in high-energy density science will be further promoted in accordance with this project agreement. Currently, Institute of Laser Engineering (ILE) of Osaka University and Lawrence Livermore National Laboratory (LLNL) serve as the lead organizations and are promoting research collaborations and educations. In the United States, the Department of Energy (DOE) supports a laser facilities network (LaserNetUS) and provides experimental opportunities to researchers and graduate students who wish to conduct experimental research using intense lasers. The LaserNetUS is also opened to Japanese researchers/students under the Japan-U.S. Program Agreement. In this presentation, current and future developments of the Japan-U.S. collaboration will be introduced.

I will also present the brief summary of the NIF experiment conducted last August, which had demonstrated 1.3 MJ fusion energy production, as well as the new Inertial Fusion Energy (IFE) movement in US initiated by the NIF achievement.

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雷活動に起因した高エネルギー放射線の発生とそのメカニズム

Generation of energetic radiation due to lightning activity and its mechanism

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Abstract

Lightning is a type of electrical phenomenon in the atmosphere and has been studied primarily in the fields of high-voltage electrical engineering and meteorology. However, energetic radiation that may be caused by lightning and/or thunderstorm activity has been observed at several locations around the world. In Japan, radiation fluctuations were first observed during winter thunderstorms that occur along the Sea of Japan in winter. Many nuclear power plants are located on the Sea of Japan side, and environmental radiation monitors are installed around the plants to monitor dose-rate fluctuations. As a result, a number of events were observed in which dose rates increased during winter thunderstorms. Subsequently, it was found that such radiation was also observed during summer thunderstorms in high mountains such as the top of Mt. Fuji and Mt. Norikura in the Northern Alps. The energies of such radiation ranged from a few MeV to over 10 MeV, which is higher than the environmental radiation normally observed. It has also been reported that high-energy radiation has been observed by satellites far above thunderclouds, creating new contacts with various fields such as radiation physics, nuclear physics, and astrophysics.

Here, in addition to observations of radiation generated by thunderclouds and lightning activity, the generation of electromagnetic showers within the thundercloud electric field, and the possibility that lightning discharges are caused by high-energy radiation are also outlined.

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プラズマミラーによる J-KAREN-P レーザーの高コントラスト化

Improvement of temporal contrast with plasma mirror at J-KAREN-P laser

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Abstract

With the development of chirped pulse amplification (CPA) technology invented in 1985, research using high-intensity lasers has evolved for various applications. Recently, the development of higher energy by increasing the diameter of optics and spatio-temporal control techniques, has enabled the focused intensity to exceed $10^{22\text{-}23}$W/cm^2. In laser-plasma experiments, pre-plasma formation owing to pre-pulse and pedestal has become a significant problem as the focused intensity increase. To solve this problem, Plasma mirrors (PMs) have been adopted in many experimental facilities. The principle of PMs is that the main pulse is reflected by the self-generated plasma, while pre-pulse and pedastal is reflected by anti-reflective coating on the mirror substrate, which improves the temporal contrast.

Here, we report on characterisation of the plasma mirror system installed on the J-KAREN-P laser at Quantum Science and Technology (QST) Kansai Photon Science Institute. The results showed that the reflectivity of a single plasma mirror system exceeded 80%. Additionally, the temporal contrast was improved to approximately ~1/100 of that of a conventional one at 1 ps before the main pulse. Furthermore, the spatial distribution after the plasma mirror was kept constant at <100 kJ/cm^2. We also show the results of investigating the difference in energy, pulse width with and without the plasma mirror system.

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大面積自立グラフェンの J-KAREN レーザー直接照射による高エネルギーイオン加速

Energetic ion acceleration by direct irradiation of large-area suspended graphene with J-KAREN laser

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Abstract

Graphene is a single atomic layer carbon allotrope in a form of two-dimensional hexagonal lattice. Graphene has several unique properties suitable for a target of laser-driven ion acceleration, such as thinnest, strongest, lightest, and transparent. In order to irradiate the graphene by an intense laser, we have developed a free standing, large-area suspended graphene (LSG) target by transferring graphene on a substrate with a hole with the diameter of several hundred μm (micrometer = 10^{-6} m). The thickness of single-layer LSG is typically 1 nm (nanometer = 10^{-9} m), resulting in the diameter to thickness ratio of > 10^5. We can control the thickness of LSG by transferring graphene layer by layer with the accuracy down to 1 nm.

In the conventional laser driven ion acceleration, the thinner target considered to be better to accelerate the higher energy of ions. However, the thinner targets are easily broken by pre-pulse and pedestal prior to the laser peak arrival. Therefore, plasma mirrors are often used to reduce the pre-pulse and pedestal and to produce energetic ions with relatively thin target regime, say < 100 nm. Using the LSG, we have conducted a series of experiments using intense lasers over the world. In this talk, we report our recent challenges to realize energetic ion acceleration by direct irradiation of LSG with the ultra-intense laser, J-KAREN without plasma mirror. We realize energetic ion acceleration without plasma mirror from sub-relativistic to relativistic intensities. Currently our double-layer LSG (2 nm thickness) is the thinnest target ever generated energetic ions by an intense laser [1].

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レーザー中性子による元素の起源と太陽系形成の研究

The study of the solar system formation and the origin of laser-devin neutrons

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Abstract

Recent progress in laser physics has enabled us to generate various particle acceleration through laser plasma interactions. The energies of these radiations become higher than 10 MeV and thus they can interact with atomic nuclei. These laser-driven particles have a potential to be used for the study of nuclear physics. Neutrons can be also generated by the secondary reactions with the primary particles accelerated by the laser plasma interactions. The neutron has important roles for the history of our solar system and the galactic chemical evolution of materials in the universe. Most elements heavier than the iron have been considered to be synthesized by two stellar neutron capture chains in high temperature environments. Furthermore, it has been found that astrophysical event such as core-collapse supernova affects the formation of the early solar system. At present, such phenomena have been studied using accelerator-neutron sources such as J-PARC (for example see [1]). Laser-driven neutron pulses have following features: the continues energy spectrum, short pulse duration, and high intensity. The continuous energy pulse is suitable for simulation of the stellar energy spectrum, which can be described by Maxwellian distribution. Short pulse is effective for explosive events in short time. It was reported that isotopic abundance anomalies found in primitive meteorites could be explained by a neutron burst. This suggests that a supernova occurred near the proto solar system before the solar system formation. To explore the origin of heavy elements and early solar system history, we have studied laser neutron generation and interaction with materials using LFEX laser system at LIE. Neutron energy spectra have been measured using the time-of-flight method, but its absolute values have not been well confirmed. Thus, we measured the absolute flux using an activation method, which has been known as a method to measure precisely the number of the radioisotope in a sample, with the time-of-flight method [2]. One of the advantages of the use of laser-neutrons is to obtain short pulse. To keep relatively short pulse, we generated thermal neutrons using a small moderator [3]. The absolute number of these thermal neutrons also measured using the cadmium differential method [4], which has been used in nuclear reactor experiments. These results can give us a tool to study stellar neutron induced reactions. These are also useful for various analysis with neutron resonance method [3] and for hydrogen density [5].

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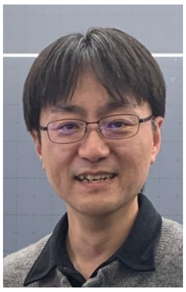
激光 XII 号による磁化プラズマ中を伝播する無衝突衝撃波の生成実験

High-power laser experiment forming a supercritical collisionless shock in a magnetized plasma



Ryo Yamazaki

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Abstract

Collisionless shocks are ubiquitous in astrophysical objects like supernova remnants, solar-terrestrial, and laboratory plasmas. When the upstream low-entropy flow comes into the shock, the kinetic energy is converted into various forms like high-temperature ions and electrons, magnetic turbulence, and nonthermal particles. Currently, detailed mechanism of the shock dissipation is not fully understood, because the system is highly nonlinear and multi-scale coupling may be essential.

We present a new experimental method to generate quasi-perpendicular super-critical magnetized collisionless shocks. In our experiment with GXII HIPER Lasers, ambient nitrogen (N) plasma is at rest and well-magnetized, and it has uniform mass density. The plasma is pushed by laser-driven ablation aluminum (Al) plasma. Streaked optical pyrometry and spatially resolved laser collective Thomson scattering clarify structures of plasma density and temperatures, which are compared with one-dimensional particle-in-cell simulations. It is indicated that just after the laser irradiation, the Al plasma is magnetized by self-generated Biermann battery field, and the plasma slaps the incident N plasma. The compressed external field in the N plasma reflects N ions, leading to counter-streaming magnetized N flows. Namely we identify the edge of the reflected N ions. Such interacting plasmas is forming a magnetized collisionless shock.

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