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科研費 KAKENHI

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研究課題名（和文）Microscale radiography of complex hydrodynamics phenomena in high-density laser plasma

研究課題名（英文）Microscale radiography of complex hydrodynamics phenomena in high-density laser plasma

研究代表者

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研究成果の概要（和文）：XFELとLiF 結晶検出器および CCD の相互使用に基づく同軸マルチイメージング検出システムを統合した新しい位相コントラストイメージング（PCI）プラットフォームの開発を行った。PCI 法は、フレネル回折モードでの放射線撮影と同時に初めて使用され、複雑な形態を持つ物体の密度測定の精度向上に貢献した。これを利用したSACLA BL3 の実験では固体の衝撃波ダイナミクスに関する先駆的なデータ、乱流までの RTI の詳細な視覚化、乱流パワースペクトルの新しい特徴の発見、動的に圧縮されたダイヤモンドの弾塑性衝撃分裂のシミュレーションの実行、ダイヤモンドの遷音速転位の伝播の研究が行われた。

研究成果の学術的意義や社会的意義
Delivered new knowledges on problem of hydrodynamic instabilities important for ICF, astrophysical objects, Earth's magnetosphere and mantle. X-ray radiography of RTI and shock compression in solids were studied with record spatial resolution 0.8 microns needed for verification theory and codes.

研究成果の概要（英文）：Developed conceptually new phase-contrast imaging (PCI) platform with XFEL and coaxial multi-imaging detection system based on two LiF crystal detectors and CCD. For the first time, the PCI method was supplemented by simultaneous radiography in Fresnel diffraction mode, significantly improving the accuracy of the density retrieval procedure for objects with complicated morphology.
The platform was successfully applied at SACLA BL3. At 10 experimental runs were obtained: (a) pioneering radiographic data about dynamics of shock waves in solids relevant to HEDP; (b) detailed visualization of Rayleigh-Taylor instabilities (RTI) at all stages of evolution from initial interface to the turbulent flow; (c) measured the power spectrum of RTI and found the feature never observed before; (d) developed theory and performed comprehensive simulations of elastic-plastic shock waves splitting in dynamically compressed diamond; (e) transonic dislocation propagation in diamond observed for first time.

研究分野：Physics

キーワード：X-ray radiography　Phase-contrast imaging　XFEL　Shock compression　Hydrodynamic phenomena　LiF crystal　Shock waves　Hydrodynamic instability

１．研究開始当初の背景 **Background at the beginning of the study**

The basic concept of sub-micron resolution radiography based on merging the XFEL beam with photoluminescence (PL) LiF crystal detector was proposed and metrologically developed in the frame of KIBAN(C)17K05729 project. Experimentally it was demonstrated that combination of unique properties of XFEL radiation (hard x-ray spectral range 5 -20 keV, extremely high brightness, fs-duration of pulse, full spatial coherence) with unique imaging properties of Lithium Fluoride (LiF) crystal ((generation of color centers (CCs) under irradiation with photon energy > 14 eV which are stable on the room temperature), allows to provide the phase-contrast x-ray imaging of dense plasma objects with *unprecedent spatial resolution <1 μm* over the *square-mms field-of-view* in very *simple and compact setup* (Fig.1(a)) [1].

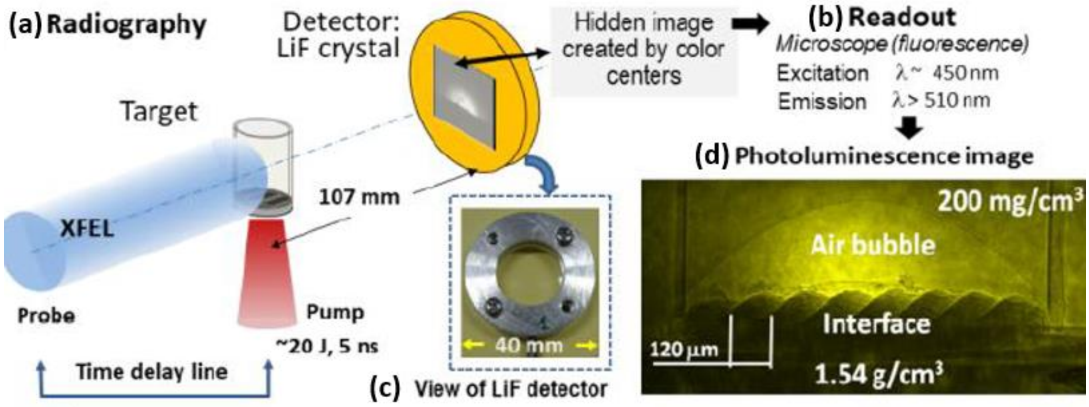

Fig.1. (a). The basic concept of XFEL-LiF imaging platform and experimental setup; (b) readout procedure; (c) view of LiF detector; (d) PL image of the RTI target initial interface (without shock driving laser pulse) obtained at XFEL photon energy 10 keV; magnification 40X [1].

Nevertheless, the scheme shown in Fig. 1(2) has a *crucial drawback*: recording and readout of radiographic image are separated processes. For the readout of the recorded on the LiF images the fluorescence scanning confocal microscope should be used (Fig.1(3, 4)). That procedure performed after experiment, *outside the vacuum chamber*. That excluded the possibility for on-line control of the current experimental conditions which is highly demanded, especially, if to consider a high cost of the targets under the study. Another point is that, in fact, the PCI enhances boundary of the shock wave fronts or step density variation in instabilities and gives *uncertain information about the density gradients*.

２．研究の目的 **Purpose of the study**

By means of the high spatial resolution X-ray radiography we acquired *new knowledges* on the miscellaneous problem of *hydrodynamic instabilities* (HDI) and *shock waves* (SW) generated in matter under *strong compression*. That phenomena play important role in many physical systems, for instance at atmospheric pressure, in the oceans or the Earth's magnetosphere, at high pressure, in the Earth's mantle, in inertial confinement fusion (ICF), and in numerous of astrophysical objects. In laboratory, a high-power laser pulses turn a matter to the extreme conditions of high temperature and density with developing of fast evolving hydrodynamic phenomena. At such conditions the *high spatial resolution X-ray radiography becomes fundamental*, often unique, method of diagnostics in the high energy density physics (HEDP) because it enables studying at micrometer-scale the temporal evolution of matter which is usually opaque to the visible light.

３．研究の方法 **Research method**

The mention above problems of the imaging method had been overcome *together with significant improvement on diagnostics ability of the basic approach* by implementation of the coaxial imaging (CI) principle which is consisted of simultaneous recording the coaxial radiographic images of the object at different distances from the investigated object. This work was done in two steps.

At the first step the *double LiF + CCD* scheme was developed. In additional to the LiF detector, located inside the vacuum chamber at the optimal distance for the PCI conditions, the special hard x-ray CCD camera was mounted coaxially to the LiF detector outside of the chamber (Fig.2a). The CCD camera was recently developed at SACLA on the base of the thin-layer transparent ceramic scintillator [T. Kamishima et al. Optics Lett. 44, 1403 (2019)]. It has the spatial resolution < 1 μm comparable with spatial resolution of LiF detector, but cannot be used in vacuum. On the CCD camera the radiographic image is created after passing the XFEL radiation through the LiF crystal. The thickness of the LiF crystal plate selected to transmit enough photons to be detected by CCD with good signal/noise ratio. Thus, during a single XFEL pulse *two conjugated images* of the object are *recoded simultaneously* (Fig. 2b). The image on the CCD provide the *on-line data*. As it is seen in the image 2, at the distance from the object larger

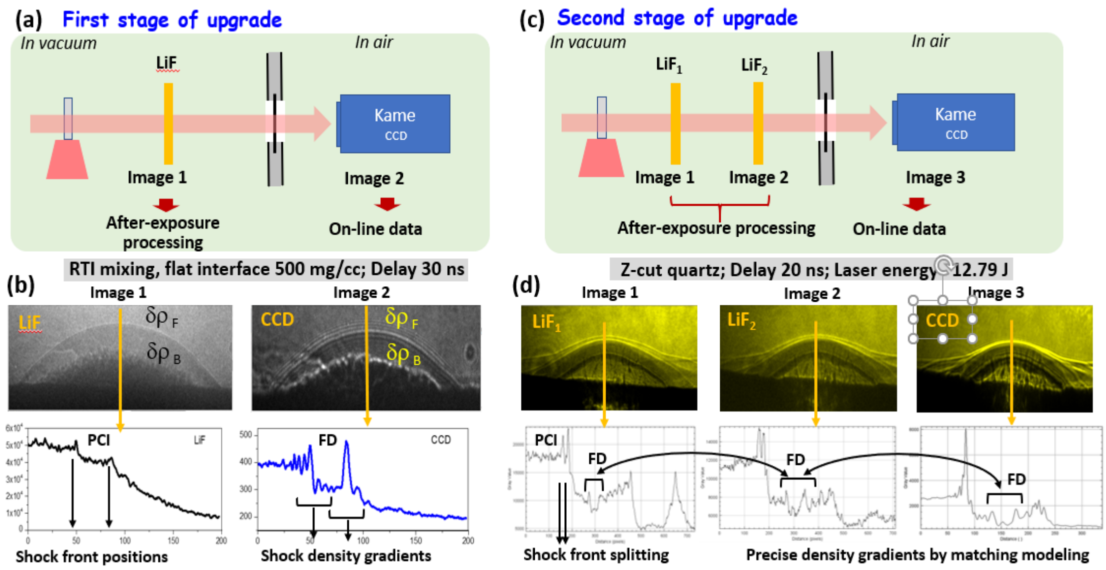

Fig. 2. Development of a new multi-imaging approach of the coaxial imaging (CI): (a) the LiF-CCD scheme; (b) the example of two conjugate images of the RTI in the mixing obtained for the flat interface at delay of 20 ns after high-power laser shock loading with the density layouts using for the density analysis; (c) the LiF-LiF-CCD scheme; (d) the conjugate images of complicated shock structure in the Z-cut quartz with correspondent density layouts show difference in transformation of the diffraction fringes at sides of shock fronts with increasing the distance from the target.

compared to the optimal one for PCI (see image 1), the single PCI diffraction picks corresponding to the position of shock front is transformed to the Fresnel diffraction (FD) pattern. The profile of diffraction fringes contains the information about the width and the density gradients in the shock wave. In assumption of the zero width, the density gradients can be measured with higher accuracy by matching modeling theoretical PCI and FD patterns with experimental ones.

In summary, the *LiF +CCD approach* has the following *advantages*: (i) the online control of current experimental conditions; (ii) the observation of coaxial radiographic images coaxial radiographic images at the distances of PCI and FD; (iii) the measurement of the density gradients with higher accuracy.

At the second step, the CI approach was extended to the *triple LiF-LiF-CCD* imaging scheme (Fig 2 c). As it was mention above, the shock front is characterized not only by the gradient of the density but also by the width of shock front. For every shock configuration the evolution of the pattern during XFEL beam free propagation after the target occurs in the unique way. However, the role of the shock width and the density gradients on the formation of the FD patterns is mutual and cannot be distinguished on the base of single FD pattern. A quite low threshold of the LiF detector sensitivity and the LiF high transmittance in the 5 -12 keV range of photon energy allowed to insert the second LiF crystal in front of CCD without losing the quality of CCD image (Fig. 2d). In presents of two experimental FD image, the matching modeling can be performed for both of them using *the shock width and gradients of the density* as independent parameters. In the good correspondence of calculation and experimental results the accuracy of shock front gradients and width measurements becomes more evident. In additional, the multi-images data provide more detailed and accurate information about the shocks as in the casecan be seen in Fig. 2d for images 1 and 3 for the Z-cut quartz. At 20 ns delay after loading the laser pulse (pulse energy of ~12.8 J) the complicated configuration of shocks with large difference of the density gradients was formed. The elastic-plastic splitting of the shocks is resolved only in the LiF images 1 and 2 and is unresolved in the CCD image number 3.

In summary, *the LiF+LiF CCD approach additionally to the LiF + CCD scheme allows*: (i) the observation of coaxial radiographic images at three distances; (ii) the measurement of the shock waves gradients along with measurements of the density gradients; (iii) the optimization of PCI and FD radiographic conditions for observation dynamic processes with complicated structures and large difference in the density gradients.

４．研究成果 **Research results**

The project is completed according to the plan and even beyond it with high-level scientific achievements. Under the main objectives of the project to enhance the diagnostic capabilities of X-ray imaging methods and study complex hydrodynamic phenomena in high-density laser plasma with a spatial resolution < 1 μm in a 1- 2 mm^2 field of view the following *achievements have been obtained*:

- developed a *conceptually new imaging platform* based on coupling the XFEL probe with *the coaxial multi-imaging detection system* consisting of a combination of one or two LiF crystal detectors and CCD (LiF - CCD, LiF-LiF-CCD schemes);

- for the first time, the PCI radiography method is supplemented by the *simultaneous registration of images in the Fresnel diffraction mode* that allowed to study the of objects with very complicated morphology and significantly improves the accuracy of the density reconstruction procedure;

- the developed *experimental platform was implemented* at the HED station of SACLA XFEL and *successfully used* during 10 beamtimes;

- the use of the CCD made it possible to radically improve the operational characteristics of the experimental setup through the possibility of *online image registration and control of experimental conditions*;

- the numerous *pioneering radiographic data* about the formation and evolution of shock waves in solids (diamond, α-quartz, silica, z-cut quarts, sapphire, plastics, Al, etc.) had been accumulated in the frame of the SACLA proposals 2021A8004, 2021A8623, 2021A8036, 2022A8064, 2022B8611, 2023A8057;

- performed the *detailed visualization of RTI at all stages of evolution* from initial interface morphology, to the turbulent flow; *measured the spatial energy spectrum of RTI* and found *the feature never observed before* (Figs.3, 4) (SACLA proposals 2021A8605, 2021B8002, 2022A8010, 2023B8029) [2, 3];

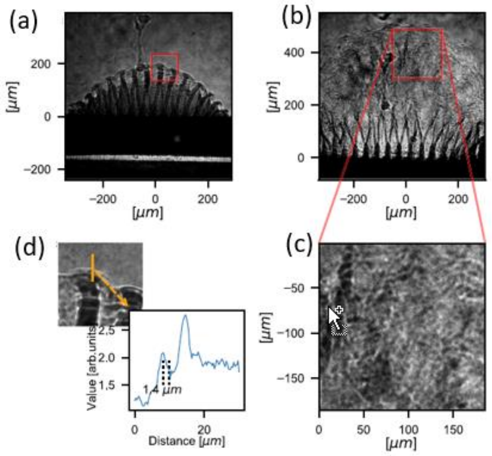

Fig. 3. Experimental radiographs of RTI target at 10 keV photon energy. The selected images of mono-mode interface obtained before (40 ns (a) and (d)) and after (60 ns (b) and (c)) the transition to turbulence between 50 and 60 ns. Following the initial Rayleigh–Taylor growth and expansion the system turns to turbulence. The structure becomes blurry and the power spectrum nearly isotropic, as can be observed on the zoom of the 60 ns radiograph (c). The high resolved PCI fringes are shown on the zoom and line-out of the 40 ns radiograph (d).

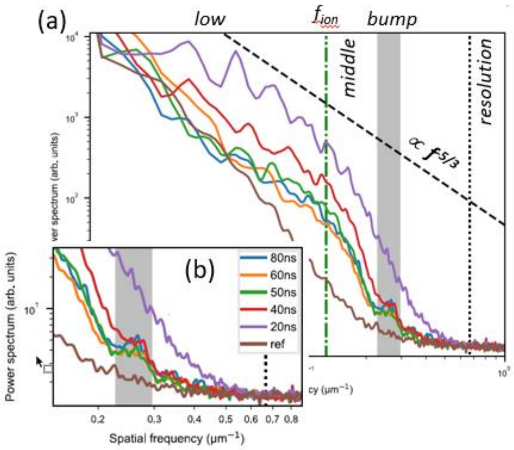

Fig.4. Spatial power spectrum (a) and *first observation of the bump morphology* (b). The spatial frequency corresponding to the ion inertial range at 50 ns, f_{ion}, is marked by the dash-dot line and is near the inflexion of the spectrum. The nearly flat spectrum, for spatial frequency above the bump, corresponds to the resolution limit of our diagnostic. The dotted line corresponds to *the simulated Kolmogorov scale* calculated for the hydrodynamic mono-mode case. The green dash-dotted line corresponds to the theoretical ion inertial range. The greyed zone highlights the bump position.

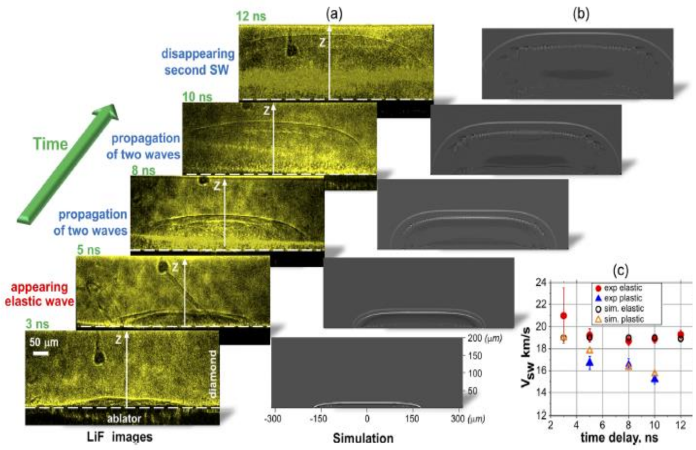

Fig. 5. Shock wave profiles in diamond under the laser intensity 1 × 10^{13} W/cm^2: The experimental data (a) for maximal compression detected during shock propagation are placed at positions calculated with a fixed shock speed V = 20.6 km/s (within the range 19.9 ± 1.7 km/s). The 1D Smoothed Particle Hydrodynamics (SPH) simulation (b) performed using the calibrated diamond model [4] and perfectly match the experiment. The SPH reveals the existence of a plastic wave at early times, which should completely decay by 0.6 ns. First time observation.

- developed *theory and comprehensive simulations of elastic-plastic shock waves splitting and dissipation* in dynamically compressed *diamond* on the base of *molecular dynamics* (MD) and *smoothed particle hydrodynamic* (SPH) codes (Fig. 5) [4];

- for the first time was observed the *transonic dislocation propagation in diamond* (Fig. 6) [5];

- the *photoluminescence response* and *damage threshold* of lithium fluoride (LiF) crystal detector was investigated for the hard x-ray spectral range [6-8, 10-11].

- the LiF crystal detector applied for *direct imaging diagnostics on refractive X-rayt focusing* at the EuXFEL High Energy Density instrument [9].

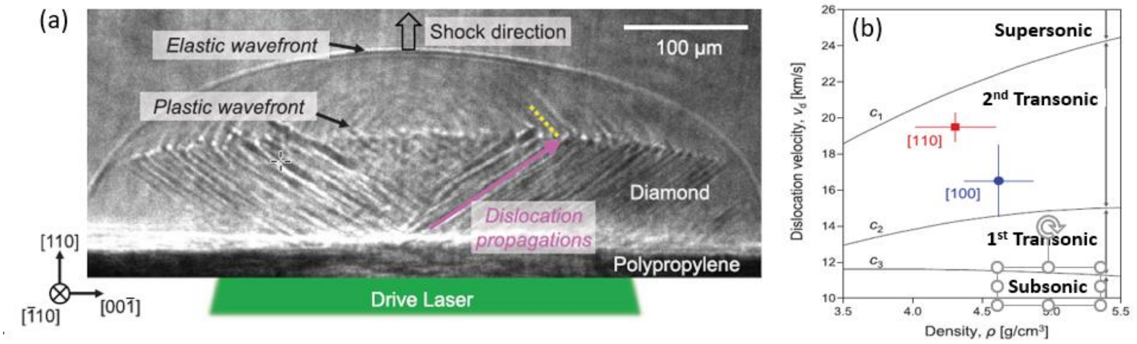

Fig. 6. (a) X-ray radiography on shocked diamond obtained on the LiF crystal detector. The diamond sample was stressed by shock waves driven by optical laser irradiation. The image visualizes the elastic-plastic shock wavefronts (WF) propagating along the shock direction. The stacking faults appear as dark and light bands, indicating the existence of partial dislocations that travel with the plastic shock WF (magenta arrow).(b) theoretical dependences of dislocation velocity versus diamond density at the shocked states. Black curves are the calculated sound velocity along [110] directions; the blue c and red points represent the experimental results for the [100] and [110] shock directions, respectively.

The results of the work were published in 10 peer-reviewed articles, including one article in Science [5] and one article in Nature Communications [2]. The article published in Matter and Radiations at Extremes [4] was awarded as one of three best publications in 2023. 10 reports were presented at the international conferences and 6 at the national conferences.

Publications related to the project:

1. T. Pikuz, <他 5 人>.K. Miyanishi, <他 19 人, T. Ishikawa, R. Kodama. Development of new diagnostics based on LiF detector for pump-probe experiments, *Mater and Radiation at Extremes*, 3, 197 – 206 (2018) https://doi.org/10.1016/j.mre.2018.01.006

2. G. Rigon, B. Albertazzi, T. Pikuz <他 2 人>. N. Ozaki <他 8 人>. K. Miyanishi, <他 7 人 R. Kodama, A. Casner, M. Koenig. Micron-scale phenomena observed in a turbulent laser-produced plasma, *Nature Communication*, 12:2679 (2021) https://doi.org/10.1038/s41467-021-22891-w

3. G. Rigon, B. Albertazzi <他 6 人>. T. Pikuz, Y. Sakawa, T. Sano, H, Shimogawara, S. Tamatani, A. Casner, M. Koenig. Hydrodynamic instabilities in a highly radiative enviroment, *Physics of Plasmas*, 29, 072106 (2022 https://doi.org/10.1063/5.0089994

4. S. Makarov, S. Dyachkov, T. Pikuz, K. Katagiri, H. Nakamura, <他 9 人>. M. Keiichi Sueda, <他 6 人>. M. Koenig, N. Ozaki· Direct imaging of shock wave splitting in diamond at Mbar pressure, *Matter Radiat. Extremes*, 8, 066601 (2023) https://doi.org/10.1063/5.0156681

5. K. Katagiri, T. Pikuz <他 9 人> K. Miyanishi, H. Nakamura, , <他 12 人> N. Ozaki. Transonic Dislocation Propagation in Diamond, *Science*, 382 (6666), 69-72 (2023) DOI:https://www.science.org/doi/10.1126/science.adh5563

6. S. Makarov <他 3 人> T. Pikuz, N. Ozaki, <他 11 人> E. Brambrink, J.-P. Schwinkendorf, I. Mohacsi, V. Vozda, V. Hajkova, T. Burian, J. Chalupsky, L. Juha, V. Zhakhovsky, U. Zastrau, S. Pikuz. Damage threshold of LiF crystal irradiated by femtosecond hard XFEL pulse sequence, *Optics Express*, 31 (16),26387 (2023) DOI:https://doi.org/10.1364/OE.486868

7. M. A. Vincenti <他 8 人> T.Pikuz, N. Ozaki <他 3 人>.R. M. Montereali. Visible Radiophotoluminescence of Color Centers in Lithium Fluoride Thin Films for High Spatial Resolution Imaging Detectors for Hard X-rays, *ECS Journal of Solid State Science and Technology*, 12, 066008 (2023) DOI:10.1149/2162-8777/acdd9b

8. M.A. Vincenti <他 11 人> T. Pikuz, Ozaki, S. Makarov, S. Pikuz and B. Albertazzi. Optical characterization of lithium fluoride thin-film imaging detectors for monochromatic hard X-rays, 5th International Conference Frontiers in Diagnostics Technologies ENEA Frascati Research Center. Frascati, Italy, 19-21 October 2022, *Journal of Instrumentation*, 18, C04012 (2023) DOI:10.1088/1748-0221/18/04/C04012

9. S. Makarov <他2人>, T. Pikuz, <他14人> U. Zastrau, S. Pikuz. Direct LiF imaging diagnostics on refractive X-rat focusing at the EuXFEL High Energy Density instrument, *Journal of Synchrotron Radiation*, 30, 208 (2023) doi: 10.1107/S1600577522006245

10. M A Vincenti, <他 12 人> T Pikuz, N Ozaki, <他 2 人> B Albertazzi. Advanced spectroscopic investigation of colour centres in LiF crystals irradiated with monochromatic hard x-rays, *J. Phys.: Condens. Matter*, 36, 205701 (2024) DOI:10.1088/1361-648X/ad2796

11. F. Bonfigli, N.J.Hartley, Y. Inubushi, K .Katagiri, M. Koenig, T. Matsuoka, S. Makarov, R.M. Montereali, E. Nichelatti, N.Ozaki, M. Piccinini, S. Pikuz, T. Pikuz, D. Sagae, M.A.Vincenti, T. Yabuuchi. Photoluminescent radiation-induced color centers in lithium fluoride for detection of pulsed 10 keV XFEL beam, Il Nuovo Ciento, 44 C (2021) DOI:146 10.1393/ncc/i2021-21146-x

５．主な発表論文等

〔雑誌論文〕　計10件（うち査読付論文　10件／うち国際共著　10件／うちオープンアクセス　2件）

１．著者名 G. Rigon, B. Albertazzi, P. Mabey, Th. Michel, P. Barroso, A. Faenov, R. Kumar, C. Michaut, T. Pikuz, Y. Sakawa, T. Sano, H, Shimogawara, S. Tamatani, A. Casner, M. Koenig	４．巻 29
２．論文標題 Hydrodynamic instabilities in a highly radiative environment	５．発行年 2022年
３．雑誌名 Physics of Plasmas	６．最初と最後の頁 072106-1-10
掲載論文のDOI（デジタルオブジェクト識別子） 10.1063/5.0089994	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 S. Makarov, M. Makita, M. Nakatsutsumi, T. Pikuz, N. Ozaki, T.R. Preston, K. Appel, Z. Konopkova, V. Cerantola, E. Brambrink, J.-P. Schwinkendorf, I. Mohacsi, T. Burian, J. Chalupsky, V. Hajkova, L. Juha, V. Vozda, B. Nagler, U. Zastrau, S. Pikuz	４．巻 30
２．論文標題 Direct LiF imaging diagnostics on refractive X-rat focusing at the EuXFEL High Energy Density instrument	５．発行年 2023年
３．雑誌名 Journal of Synchrotron Radiation	６．最初と最後の頁 1-9
掲載論文のDOI（デジタルオブジェクト識別子） 10.1107/S1600577522006245	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 G. Rigon, B. Albertazzi, T. Pikuz, P. Mabey,V. Bouffetier, N. Ozaki, T. Vinci, F. Barbato、E. Falize Inubushi Y., Kamimura N., Katagiri K., Makarov S. , Manuel M. J.-E. , Miyanishi K., Pikuz S., Poujade O., Sueda K. , Togashi T., Umeda Y., Yabashi M., T. Yabuuchi, G. Gregori, R. Kodama, A. Casner, M. Koenig	４．巻 12
２．論文標題 Micron-scale phenomena observed in a turbulent laser-produced plasma	５．発行年 2021年
３．雑誌名 Nature Communications	６．最初と最後の頁 2679_1-9
掲載論文のDOI（デジタルオブジェクト識別子） 10.1038/s41467-021-22891-w	査読の有無 有
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１．著者名 F. Bonfigli, N.J.Hartley, Y. Inubushi, K .Katagiri, M. Koenig, T. Matsuoka, S. Makarov, R.M. Montereali, E. Nichelatti, N.Ozaki, M. Piccinini, S. Pikuz, T. Pikuz, D. Sagae, M.A.Vincenti, T. Yabuuchi.	４．巻 44 C
２．論文標題 Photoluminescent radiation-induced color centers in lithium fluoride for detection of pulsed 10 keV XFEL beam	５．発行年 2021年
３．雑誌名 IL Nuovo Cimento	６．最初と最後の頁 146-150
掲載論文のDOI（デジタルオブジェクト識別子） 10.1393/ncc/i2021-21146-x	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 S. Makarov, S. Dyachkov, T. Pikuz, K. Katagiri, H. Nakamura, V. Zhakhovsky, N. Inogamov, V. Khokhlov, A. Martynenko, B. Albertazzi, G. Rigon, P. Mabey, N. Hartley, Y. Inubushi, K. Miyanishi,K. Sueda, T. Togashi, M. Yabashi, T. Yabuuchi, T. Okuchi, R. Kodama, S. Pikuz, M. Koenig, N. Ozaki	4．巻 8
2．論文標題 Direct imaging of shock wave splitting in diamond at Mbar pressure	5．発行年 2023年
3．雑誌名 Matter and Radiation at Extremes	6．最初と最後の頁 066601 (1-11)
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1．著者名 K. Katagiri, T. Pikuz, L. Fang, B. Albertazzi, S. Egashira, Y. Inubushi, G. Kamimura, R. Kodama, M.l Koenig, B. Kozioziemski, G.Masaoka, K. Miyanishi, H. Nakamura, M. Ota, G. Rigon, Y. Sakawa et al.	4．巻 382
2．論文標題 Transonic Dislocation Propagation in Diamond	5．発行年 2023年
3．雑誌名 Science	6．最初と最後の頁 69-72
掲載論文のDOI（デジタルオブジェクト識別子） 10.1126/science.adh5563	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 S. Makarov, S. Grigoryev, N. Inogamov, E. Filippov, T. Pikuz, N. Ozaki, M. Ishino, M. Nishikino, T.-H. Dinh, T. Kawachi, M. Zanaveskin, M. Makita, M. Nakatsutsumi, T.R. Preston, K. Appel, Z. Konopkova, V. Cerantola et al.	4．巻 31 (16)
2．論文標題 Damage threshold of LiF crystal irradiated by femtosecond hard XFEL pulse sequence	5．発行年 2023年
3．雑誌名 Optics Express	6．最初と最後の頁 26383-26397
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1．著者名 M.A. Vincenti, R.M. Montereali, E. Nichelatti, V. Nigro, M. Piccinini, M. Koenig, P. Mabey G. Rigon, H.J. Dabrowski, Y. Benkadoum, P. Mercere, P. Da Silva, T. Pikuz, Ozaki, S. Makarov, S. Pikuz and B. Albertazzi	4．巻 18
2．論文標題 Optical characterization of lithium fluoride thin film imaging detectors for monochromatic hard X-rays	5．発行年 2023年
3．雑誌名 Journal of Instrumentation	6．最初と最後の頁 C04012 4 pp
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1．著者名 M. A. Vincenti, E. Nichelatti, V. Nigro, M. Piccinini, B. Albertazzi, Y. Benkadoum, H. Dabrowski, M. Koenig, G. Rigon, P. Mabey, P. Mercere, P. Da Silva, T.Pikuz, N. Ozaki, E. Filippov, S. Makarov, S. Pikuz, .R. M. Montereali	4．巻 12
2．論文標題 Visible Radiophotoluminescence of Color Centers in Lithium Fluoride Thin Films for High Spatial Resolution Imaging Detectors for Hard X-rays	5．発行年 2023年
3．雑誌名 ECS Journal of Solid State Science and Technology	6．最初と最後の頁 66008
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1．著者名 M. A. Vincenti, R. M. Montereali, F. Bonfigli, E Nichelatti, V. Nigro, M. Piccinini, M. Koenig, P. Mabey, G. Rigon, H. J .Dabrowski, Y. Benkadoum, P. Mercere, P. Da Silva, T. Pikuz, N. Ozaki, S. Makarov, S. Pikuz, B. Albertazzi	4．巻 36
2．論文標題 Advanced spectroscopic investigation of colour centres in LiF crystals irradiated with monochromatic hard x-rays	5．発行年 2024年
3．雑誌名 J. Phys.: Condens. Matter	6．最初と最後の頁 205701
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〔学会発表〕　計17件（うち招待講演　2件／うち国際学会　11件）

1．発表者名 M.A. Vincenti, R.M. Montereali, E. Nichelatti, V. Nigro, M. Piccinini, M. Koenig, P. Mabey, G. Rigon, B. Albertazzi, Y. Benkadoum, T. Pikuz, N. Ozaki, S. Makarov, S. Pikuz
2．発表標題 Optical characterization of lithium fluoride thin-film imaging detectors for monochromatic hard X-rays
3．学会等名 6th International Conference Frontiers in Diagnostic Technologies, Oct 19-20, 2022, Frascati, Italy
4．発表年 2022年

1．発表者名 N. Ozaki, T. Pikuz, G. Masaoka, H. Nakamura,Y. Hironaka,R. Kodama,T. Okuchi. K. Miyanishi, T. Sueda, T. Yabuuchi, M. Yabashi, B. Albertazzi, M. Koenig
2．発表標題 XFEL super-high resolution radiographic observation of high-intensity laser-induced ultrahigh pressure
3．学会等名 The 63rd High Pressure Conference in Japan, Dec.13-15, 2022, Ibaraki, Japan
4．発表年 2022年

１．発表者名
G. Masaoka, T. Pikuz, K. Katagiri, R. Kodama, T. Okuchi, B. Albertazzi, M. Koenig, K. Miyanishi, K. Sueda, T. Yabuuchi, M. Yabashi

２．発表標題
XFEL radiographic observation of quartz during shock compression processes

３．学会等名
The 63rd High Pressure Conference in Japan, Dec.13-15, 2022, Ibaraki, Japan

４．発表年
2022年

１．発表者名
H. Nakamura , H. Ogura , D. Kamibayashi , G. Kamimura , D. Murayama , L. Rapp , E. Gamaly , A. Rode , T. Matsuoka , D. Sagae , Y. Seto, T. Shobu , A. Tominaga , T. Somekawa , T. Pikuz , R. Kodama , N. Ozaki

２．発表標題
Research on freezing of materials under high pressure by Bessel-beam driven micro-explosions in transparent materials

３．学会等名
International conference on High Density Science 2022 (HEDS2022), OPIC, April 18-22, 2022, Pacifico Yokohama, Japan

４．発表年
2022年

１．発表者名
Rigon G., Albertazzi B., Pikuz T., Mabey P., Bouffetier V., Ozaki N., Vinci T., Falize E., Inubushi Y., Kamimura N., Katagiri K., Makarov S., Manuel M., Miyanishi K., Pikuz S., Poujade O., Sueda K., Togashi T., Umeda Y., Yabashi M., Yabuuchi T., Gregori G., Kodama R., Casner A., Koenig M.

２．発表標題
Exploring the late evolution of a Raleigh-Taylor unstable system - an experimental insight on turbulence

３．学会等名
International conference on High Energy Density Sciences 2021 (HEDS2021), online, April 19-21（招待講演）（国際学会）

４．発表年
2021年

１．発表者名
Rigon G., Albertazzi B., Pikuz T., Mabey P., Bouffetier V., Ozaki N., Vinci T., Falize E., Inubushi Y., Kamimura N., Katagiri K., Makarov S., Manuel M., Miyanishi K., Pikuz S., Poujade O., Sueda K., Togashi T., Umeda Y., Yabashi M., Yabuuchi T., Gregori G., Kodama R., Casner A., Koenig M.

２．発表標題
Exploring the late evolution of a Raleigh-Taylor unstable system - an experimental insight on turbulence

３．学会等名
5th Asia-Pacific Conference on Plasma Physics (AAPPS-DPP 2021), online, Sept 26 - Oct 01（招待講演）（国際学会）

４．発表年
2021年

１．発表者名 T. Pikuz, G. Rigon, B. Albertazzi, P. Mabey, V. Bouffetier, N. Ozaki, T. Vinci, E. Falize, Y. Inubushi, N. Kamimura, K. Katagiri, K. Watanabe , S. Makarov, M. Manuel, K. Miyanishi, T. Kameshima, S. Pikuz, O. Poujade, Y. Umeda, M.Ota, Y. Sakawa, K. Sueda, T. Matsuoka, T. Togashi, et al.
２．発表標題 High resolution x-ray imaging of plasma hydrodynamics phenomena with LiF detector and XFEL probe: advantages and limits
３．学会等名 The international school and workshop on Matter in Extreme Conditions: from MATerial science to Plasmas for Laboratory Astrophysics(MECMATPLA), Mid-term-meeting, October 12-13, 2021, France（国際学会）
４．発表年 2021年

１．発表者名 T. Pikuz, G. Rigon, B. Albertazzi, P. Mabey, M. Thibault, T. Vinci, Y. Benkadoum, M. Manuel, K. Katagiri, E. Falize, Y. Inubushi, K. Miyanishi, T. Yabuuchi, T. Togashi, K. Sueda, Y. Umeda, V. Bouffetier, A. Casner, O. Poujade, S. Makarov, S. Pikuz, A. Pirozhkov, M. Ishino, G. Gregori, M. Ota, Y. Sakawa, et al.
２．発表標題 Advanced x-ray imaging diagnostics for pump-probe experiment,
３．学会等名 The 62nd High Pressure Conference of Japan, Oct. 18-20, 2021, Himeji, Japan（国際学会）
４．発表年 2021年

１．発表者名 V. Bouffetier, G. Perez-Callejo, T. Goudal, D. Mancelli, J.J. Santos, A. Casner, A. Debayle, P. Loiseau M.P. Valdivia, D. Stutman, G. Rigon, T. Pikuz, N. Ozaki, M. Ota, S. Fujioka, H. Morita, L. Ceurvorst, B. Albertazzi, T. Vinci, P. Mabey, M. Koenig, K. Miyanishi, K. Sueda, T. Togashi, T. Yabuuchi.
２．発表標題 Development of Talbot interferometry for the study of laser generated HED plasmas at SACLA XFEL
３．学会等名 The 63rd Annual Meeting of the APS Division of Plasma Physics, November 8-12, 2021, Pittsburgh. PA, USA（国際学会）
４．発表年 2021年

１．発表者名 Makarov S.S., Pikuz S.A., Pikuz T.A., Chernyaev A.P., Vagovic P., Mikes L., Grunert J., Kujala N., Schropp A., Nagler B., Lee H., David C., Seniutinas G., Bougiatioti P., Chalupsky J., Hajkova V., Burian T., Vozda V., Juha L., Nakatsutsumi M., Zastrau U., Makita M.
２．発表標題 Hard x-ray focus characterization at the European X-ray Free Electro Laser using a fluorescent crystal detector
３．学会等名 XXXVI International Conference on Interaction of Intense Energy Fluxes with Matter (ELBRUS 2021) , March 1-6, 2022, Kabardino-Balkaria, Russia（国際学会）
４．発表年 2022年

１．発表者名 B. Albertazzi, T. Pikuz, G. Rigon, P. Mabey, T. Vinci, E. Falize, K. Katagiri, K. Watanabe, N. Kamimura, Y. Umeda, T.Matsuoka, V. Bouffetier, M. Manuel, S. Makarov, S. Pikuz, Y. Inubushi, K. Miyanishi, T. Kameshima, O. Poujade, K. Sueda, T. Togashi, T. Yabuuchi, et al.
２．発表標題 High resolution x-ray radiography with LiF detector at HEDP experiments with XFEL
３．学会等名 The international school and workshop on Matter in Extreme Conditions: from MATerial science to Plasmas for Laboratory Astrophysics (MECMATPLA), Marach 12-19, 2022, Montgenevre, France（国際学会）
４．発表年 2022年

１．発表者名 T. Pikuz, S. Makarov, S. Dyachkov, K. Katagiri, V. Zhakhovsky, N. Inogamov, V. Khokhlov, A. Martynenko, B. Albertazzi, G. Rigon, P. Mabey, N. Hartley, H. Nakamura, Y. Inubushi, K. Miyanishi, K. Sueda, T. Togashi, M. Yabashi, T. Yabuuchi, T. Okuchi, R. Kodama, S. Pikuz, M. Koenig, and N. Ozaki
２．発表標題 High-resolution PCI radiography with XFEL: observation of shock wave splitting in diamond at Mbar pressures
３．学会等名 The 11 International Workshop on Warm Dense Matter, June 25-30, 2023, Awaji Island, Hoygo, Japan（国際学会）
４．発表年 2023年

１．発表者名 M.A. Vincenti, R.M. Montereali, E. Nichelatti, V. Nigro, M. Piccinini, M. Koenig, P. Mabey, G. Rigon, B. Albertazzi, Y. Benkadoum, T. Pikuz, N. Ozaki, E.D. FIlippov, S. Makarov, S. Pikuz
２．発表標題 Photoluminescent colour centres in lithium fluoride film imaging detectors for monochromatic hard X-rays
３．学会等名 The 109 National Congress of Italian Physical Society, September 11-15 2023, Salerno, Italy（国際学会）
４．発表年 2023年

１．発表者名 M.A. Vincenti, R.M. Montereali, F. Bonfigli, E. Nichelatti, V. Nigro, M. Piccinini, M. Koenig, P. Mabey, G. Rigon, H.J. Dabrowski, Y. Benkadoum, P. Mercere, P. Da Silva, T. Pikuz, N. Ozaki, S. Makarov, S. Pikuz, B. Albertazzi
２．発表標題 Advanced Spectroscopic Investigation of Colour Centres in LiF Crystals Irradiated with Monochromatic Hard X-rays
３．学会等名 The 14th international conference on SiO2, advanced dielectrics and related devices (SiO2-2023, June 12-14, 2023, Palermo, Italy
４．発表年 2023年

1．発表者名 中村 浩隆、太田 裕也、竹歳 加偉、山形 直毅 、中西 悠輔1、 Pikuz Tatiana 、菖蒲 敬久 、冨永 亜希 、Rapp Ludovic 、Rode Andrei 、瀬戸 雄介 、染川 智弘5、兒玉 了祐、尾崎 典雅
2．発表標題 ベッセルビーム微小爆発による透明結晶内部での高圧物質凍結に関する研究
3．学会等名 レーザー学会学術講演会第44回年次大会，January 1,2024，Tokyo，Japan
4．発表年 2023年

1．発表者名 V. Bouffetier, M.P. Valdivia, G. Perez-Callejo, C. Stoeckl, L. Ceurvorst, M. Koenig, B. Albertazzi, G. Rigon, M. Makita,...T. Pikuz, N. Ozaki et al.
2．発表標題 Talbot X-ray deflectometry and applications at HED facilities
3．学会等名 The 49th European Conference on Plasma Physics，July 3-7，2023 Bordeaux（国際学会）
4．発表年 2023年

1．発表者名 H. Nakamura
2．発表標題 Research on freezing of materials under high pressure by Bessel-beam driven microexplosions in transparent materials
3．学会等名 The 11 International Workshop on Warm Dense Matter，June 25-30，2023，Awaji Island，Hoygo， Japan（国際学会）
4．発表年 2023年

〔図書〕 計0件

〔産業財産権〕

〔その他〕

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6．研究組織

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7．科研費を使用して開催した国際研究集会

〔国際研究集会〕 計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関