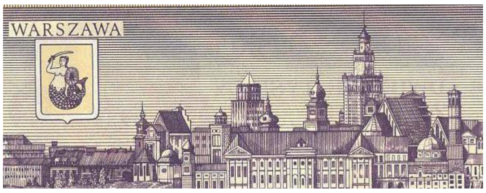

1st Workshop on Application of Laser Plasma Sources of X-rays and Extreme Ultraviolet (EUV) in Technology and Science – ALPS 2015

6 - 9 July 2015, Warsaw, Poland

BOOK OF ABSTRACTS

Institute of Optoelectronics
Military University of Technology
Warsaw, Poland

1st Workshop on Applications of Laser Plasma X-ray and EUV Sources in Technology and Science - APLS 2015 Workshop

The **ALPS 2015 Workshop** is organized as a joint initiative under the LASERLAB-EUROPE project and the EXTATIC programme.

The LASERLAB-EUROPE project (http://www.laserlab-europe.eu/ is the „Integrated Initiative" of European Laser Research Infrastructures. Application of laser-driven secondary sources, including sources of X-rays and extreme ultraviolet (EUV) is one of the main topics addressed in the project.

The EXTATIC programme (www.extatic.eu) is an Erasmus Mundus Joint Doctorate programme of the European Union that offers high-level training in extreme ultraviolet (EUV) and X-ray science (www.extatic.eu).

The aim of the **ALPS 2015** Workshop is to provide an international forum for the doctoral candidates and post-docs participating in the LASERLAB-EUROPE project and the EXTATIC Programme involved in the research on application of laser plasma sources of X-rays and extreme ultraviolet (EUV) in various fields of technology and science, including nanolithography, micro- and nanoprocessing of materials, modification of polymers for biocompatibility control, radiation damage of solids, imaging of nanostructures, microradiography and tomography, radiobiology, photoionization of small quantum systems, etc.

The main technical issue to be considered and discussed during the workshop will be the practical application of laser plasma sources of X-ray and EUV that are developed under the LASERLAB EUROPE project and demonstration of their capabilities and suitability for potential users.

Laserlab Europe

EXTATIC

The **ALPS 2015 Workshop** is organized by the Laser-Matter Interaction Group from the Institute of Optoelectronics, Military University of Technology in Warsaw, Poland.

Organizing Committee

Henryk Fiedorowicz
Karolina Płatek
Przemysław Wachulak

The workshop will take place in the Military University of Technology Library.

http://www.ztl.wat.edu.pl/zoplzm/alps2015/

Invited Lecturers

Andrzej BARTNIK (Warsaw, Poland)
Investigation of photoionized plasmas produced using laser plasma soft X-ray EUV sources

Silvia CIPICCIA (Glasgow, UK)
Betatron radiation from electrons in resonant motion in the laser wakefield accelerator bubble regime

Marta FAJARDO (Lisbon, Portugal)
XUV optical properties of XFEL created warm dense matter

Eckhart FOERSTER (Jena, Germany)
(Ultrashort X-ray pulses)

Christoph HEYL (Lund, Sweden)
Attosecond source development and applications in Lund

Krystyna Jabłońska (Warsaw, Poland)
(X-ray absorption spectroscopy)

Malgorzata LEKKA (Cracow, Poland)
Atomic force microscopy in characterization of single cells

Janusz LEKKI (Cracow, Poland)
Bio–objects irradiation using low energy X-ray pulses

Hans HERTZ (Stockholm, Sweden)
X-ray micro- and nanoimaging with laboratory sources

Karol JANULEWICZ (Gwangju, Korea)
Laser plasma-based source of ultra-short X-rays for application in time-resolved XAS

Masataka KADO (Kyoto, Japan)
Live cell imaging with a soft X-ray microscope using a laser-plasma soft X-ray source

Tetsuya MAKIMURA (Tsukuba, Japan)
Ablation and micromachining using EUV radiation from laser-produced plasma

Klaus MANN (Goettingen, Germany)
Applications of laser driven EUV/soft X-ra y sources and wave front measurements at short wavelengths

Marta MARSZALEK (Cracow, Poland)
Application of laser sources in materials science - laser lithography and fabrication of new materials

Piergiorgio NICOLOSI (Padova, Italy)
Multilayer optics for space and laboratory applications and their characterization

Holger STIEL (Berlin, Germany)
Application of high brightness laser plasma based X-ray sources in nanoscale imaging

Josif SVEKLO (Białystok, Poland)
EUV modification of Pt/Co/Pt trilayers: structural, morphological and magnetic studies

Przemysław WACHULAK (Warsaw, Poland)
Imaging techniques using laser plasma soft X-ray and EUV sources

Scientific Programme

Monday, July 6th, 2015

15.00-16.00 Registration

16.00-16.15 Opening

16.15-17.00 **K. Jabłońska** (Invited lecture)
X-ray absorption spectroscopy

17.00-17.45 **M. Marszałek** (Invited lecture)
Application of laser sources in materials science - laser lithography and fabrication of new materials

17.45-18.30 **J. Sveklo** (Invited lecture)
EUV modification of Pt/Co/Pt trilayers: structural, morphological and magnetic studies

Tuesday, July 7st, 2015

09.00-09.45 **C.M. Heyl** (Invited lecture)
Attosecond source development and applications in Lund

09.45-10.30 **H. Hertz** (Invited lecture)
X-ray micro- and nanoimaging with laboratory sources

10.30-11.00 Coffee break

11.00-11.45 **M. Lekka** (Invited lecture)
Atomic force microscopy in characterization of single cells

11.45-12.30 **M. Kado** (Invited lecture)
Live cell imaging with a soft X-ray microscope using a laser-plasma soft X-ray source

12.30-13.00 **M. Ayele**
Compact laser plasma soft X-ray source for contact microscopy experiments

13.00-15.00 Lunch break

15.00-15.45 **H. Stiel** (Invited lecture)
Development and application of high brightness laser plasma based X-ray sources for nanoscale imaging

15.45-16.30 **P.W. Wachul**ak (Invited lecture)
Imaging techniques using laser plasma soft X-ray and EUV sources

16.30-17.00 Coffee break

17.00-17.45 **K. Mann** (Invited lecture)
Applications of laser driven EUV/soft X-ray sources and wave front measurements at short wavelengths

17.45-18.30 **T. Makimura** (Invited lecture)
Ablation and micromachining using EUV radiation from laser-produced plasma

Wednesday, July 8th, 2015

09.00-09.45 **S. Cipiccia** (Invited lecture)
Betatron radiation from electrons in resonant motion in the laser wakefield accelerator bubble regime

09.45-10.30 **M. Fajardo** (Invited lecture)
XUV optical properties of XFEL created warm dense matter

10.30-11.00 Coffee break

11.00-11.45 **E. Foerster** (Invited lecture)
Ultrafast structural changes in crystals studied by pump-probe experiments

11.45-12.30 **K. Janulewicz** (Invited lecture)
Approaching 100 fs benchmark for pulse length of high-repetition laser plasma-based X-ray source; application for time-resolved XAS

12.30-13.00 **K. Witte**
Broadband laser produced plasma source for X-ray spectroscopy applications in the soft X-ray region

13.00-15.00 Lunch break

15.00-15.30 **F. Scylla**
Exploring the near-critical regime with dense gas jets

15.30-16.00 **G. Bayene**
Laser-discharge hybrid EUV source: comparison of ns vs ps-laser triggering

16.00-20.00 Excursion and Dinner

Thursday, July 9st, 2015

09.00-09.45 **A. Bartnik** (Invited lecture)
Investigation of photoionized plasmas produced with the use of laser plasma sources of soft X-rays and extreme ultraviolet (EUV)

09-45-10.30 **P. Nicolosi** (Invited lecture)
Multilayer optics for space and laboratory applications and their characterization

10.30-11.00 Coffee break

11.00-11.45 **J. Lekki** (Invited lecture)
Bio–objects irradiation using low energy X-ray pulses

11.45-12.15 **D. Adjei**
DNA strand breaks induced by soft X-ray pulses from a compact laser plasma source

12.15-12.45 **A. Torrisi**
Development and optimization of a compact "water window" microscope using a SXR gas puff target source

12.45-13.00 Summary & Closing

13.00-17.00 Lunch

Posters

Daniel Adjei

DNA strand breaks induced by soft X-ray pulses from a compact laser plasma source

Inam Ul Ahad

EUV modification of polymers for biocompatibility control using a laser plasma source

Mesfin Ayele

Soft X-ray contact microscopy using a compact laser plasma source

Henryk Fiedorowicz

Laser plasma sources of soft X-rays and EUV based on a gas puff target

Tomasz Fok

High-order harmonic generation from a laser-irradiated multi-jet gas puff target

H. Lu

Photoionization Cross Section of Calcium Computed using TDLDA and RTDLDA Codes

Tomas Parkman

Table-top instrumentation for time-resolved SXR excited luminescence spectroscopy

Alfio Torrisi

Development and optimization of a compact "water window" microscope using a SXR gas puff target source

Łukasz Węgrzyński

Ultra-short X-ray pulses produced using a NOPCPA femtosecond laser

Time Schedule

Monday, July 6, 2015		Tuesday, July 7, 2015		Wednesday, July 8, 2015		Thursday, July 9, 2015	
		09.00-09.45	Lecture 4 **Christoph HEYL**	09.00-09.45	Lecture 12 **Silvia CIPICCIA**	09.00-09.45	Lecture 16 **Andrzej BARTNIK**
		09.45-10.30	Lecture 5 **Hans HERTZ**	09.45-10.30	Lecture 13 **Marta FAJARDO**	09.45-10.30	Lecture 17 **Piergiorgio NICOLOSI**
		10.30-11.00	Coffee break	10.30-11.00	Coffee break	10.30-11.00	Coffee break
		11.00-11.45	Lecture 6 **Malgorzata LEKKA**	11.00-11.45	Lecture 14 **Eckhart FOERSTER**	11.00-11.45	Lecture 18 **Janusz LEKKI**
		11.45-12.30	Lecture 7 **Masataka KADO**	11.45-12.30	Lecture 15 **Karol JANULEWICZ**	11.45-12.15	Oral 5 **Daniel ADJEI**
						12.15-12.45	Oral 6 **Alfio TORRISI**
		12.30-13.00	Oral 1 **Mesfin AYELE**	12.30-13.00	Oral 2 **Katharina WITTE**	12.45-13.00	Closing
		13.00-15.00	Lunch	13.00-15.00	Lunch	13.00-15.00	Lunch
15.00-16.00	Registration	15.00-15.45	Lecture 8 **Holger STIEL**	15.00-15.30	Oral 3 **Francois SCYLLA**		
				15.30-16.00	Oral 4 **Girum BAYENE**		
		15.45-16.30	Lecture 9 **Przemysła w WACHULAK**				
16.00-16.15	Opening			16.00-20.00	Excursion & Dinner		
16.15-17.00	Lecture 1 **Krystyna JABŁONSKA**	16.30-17.00	Coffee break				
17.00-17.45	Lecture 2 **Marta MARSZAŁEK**	17.00-17.45	Lecture 10 **Klaus MANN**				
17.45-18.30	Lecture 3 **Josif SVEKLO**	17.45-18.30	Lecture 11 **Tsetuya MAKIMURA**				
18.30-20.00	Reception						

Invited Lectures

X-ray absorption spectroscopy

Krystyna Lawniczak-Jablonska*

Institute of Physics, Polish Academy of Sciences, Lotnikow Str 32/46, 02 668 Warsaw, Poland

The X-ray absorption spectroscopy (XAS) is a synchrotron base technique widely used in solving scientific problems and offering unique possibility. Few examples will be shown how this technique can be applied for characterisation of novel materials and understanding chemical reactions at the atomic level. XAS technique can be considered as a finger print of chemical bonding of element under consideration. Therefore, can be used to find the neighborhood of given element (number, distances and kind of surrounding atoms), the location of given element in the crystal structure, it's chemical bonding, and to estimate the proportion between few compounds of the same element in composite materials. This information can be of great importance in many scientific and technological problems.

The magnetic semiconductors have attracted considerable attention due to the expectation that manipulation of the electron spin, as an alternative to manipulation of the electron charge, can be used for the storage of information in semiconducting devices. In spite of the effort of many technologists and scientists, till now the magnetic semiconductors with uniformly distributed magnetic ions do not exhibit ferromagnetic properties at room temperature, therefore the granular materials are now under increasing interest. It was shown that such materials can be used in constructions of electronic devices. The location of magnetic ions in the host matrix is crucial for magnetic properties. This unique information can be provided by XAS and X-ray magnetic circular dichroism (XMCD).

Double metal cyanide (DMC) catalysts are commonly applied at industrial ring opening polymerization of the epoxides. Nevertheless, the knowledge on the molecular nature of their high activity and selectivity is limited. XAS studies were performed to look for possible catalytic centre in this family of catalysts. EXAFS analysis established that only Zn atoms are the active metallic centers in DMC catalyst. The coordination around Zn was changed from octahedral in reference non catalytic material to tetrahedral in catalysts and Cl atoms were detected near some of Zn atoms.

According to the World Health Organization half of the human population is at risk of malaria. Currently, there is no licensed vaccine against malaria and the treatment is totally based on the use of anti-malarial drugs, like the traditionally used chloroquine (CQ). Despite of many efforts, however, the exact mechanisms of CQ action by which malaria parasites become CQ-resistant remain elusive. Clearly, understanding of the mechanism by which CQ exerts its action at the molecular level will contribute to designing of new anti-malarials and overcoming of the drug resistance. In this example, XAS was applied to shine the light to understanding of this mechanism.

Recently a lot of attention is paid to transition metal-organic structures based on natural polymers, like chitosans. The results of XAS studies of several chemically modified Fe-chitosan complexes and models of Fe binding constructed on the base of these studies will be presented.

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L -2

Application of laser sources in materials science - laser lithography and fabrication of new materials

Marta Marszałek*, Marcin Perzanowski, Yevhen Zabila, Żaneta Świątkowska-Warkocka

Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland

In this contribution the application of laser sources in materials science will be presented. The first example concerns the application of Direct Laser Interference Lithography (DLIL) for fabrication of ordered arrays of magnetic structures. Patterns obtained by interference of two, three or more Nd:YAG laser beams allow direct heating of the metal surface, leading to the formation of periodic structures. Experimental studies were performed on FePt and FePd thin alloy films. Characterization showed that the crystal structure of films was strongly affected at the location of interference maxima, exhibiting the phase transition from fcc to fct structure. The influence of laser beam energy on structural and magnetic properties of disordered as well as chemically ordered FePt and FePd films was investigated. The results show that by careful adjustment of laser beam energy it is possible to induce the phase transformation of chemically disordered alloy during patterning.

In the other case the laser beam was used for structural ordering of FePdCu thin alloy films by direct laser annealing which gives high heating and cooling rates of the irradiated material, and it cannot be obtained with other methods. The gradual change of the number of laser pulses allowed to investigate the structural and magnetic properties at early stages of the transformation and ordering process.

The last case describes the synthesis of new metastable nanoalloys of immiscible metals with a pulse laser technique. A simple but powerful strategy for the generation of a new metastable alloy of immiscible metals will be demonstrated. $Au_{1-x}Ni_x$ 3D particles with 56 at% of nickel in gold were successfully manufactured by the pulsed laser irradiation of colloidal nanoparticles. This technology can be used for preparing different metastable alloys of immiscible metals. The irradiation of colloidal solutions of nanoparticles leads to the formation of submicron alloy particles likely through the agglomerations of nanoparticles, very fast heating, and fast cooling/solidification.

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EUV modification of Pt/Co/Pt trilayers: structural, morphological and magnetic studies

J. Sveklo[1*], A. Bartnik[2], I. Jacyna[3], D. Klinger[3], J.B. Pełka[3], R. Sobierajski[3], M.T. Klepka[3], P. Dłużewski[3], A. Wawro[3], J. Kisielewski[1], Z. Kurant[1], A. Maziewski[1]

[1]*University of Bialystok, Ciolkowskiego 1L, Bialystok 15-245, Poland*
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Thin magnetic films with perpendicular magnetic anisotropy (PMA) have a great importance for industrial fields of magnetism-based data storage media and spintronics. Transition from in-plane to out-of-plane state (PMA) of magnetic anisotropy in Pt/Co/Pt thin trilayers upon femtosecond pulse laser irradiation has been recently reported [1]. We have also very recently shown induction of PMA by application of extreme ultraviolet (EUV) pulses. A study of morphological and magnetic changes in Pt/Co/Pt under EUV pulse light irradiation is the purpose of the current work.

The epitaxial trilayers were grown with molecular beam epitaxy and have the following structure: substrate-Al2O3(00.1))/(Pt(111) 5nm)/(Co(00.1) 3nm)/(Pt(111) 5 nm. As grown samples exhibit smooth surface and in-plane magnetic anisotropy.

A laser-plasma extreme ultraviolet (EUV) source is based on a double-stream gas puff target formed in a vacuum [2]. The target is formed by pulse-injected mixture of Kr and Xe into a hollow stream of helium. The gas puff target is irradiated with 3ns Nd:YAG (wavelength 1.06 mkm) laser pulses with energy of 0.8 J and repetition rate of 10 Hz. The EUV radiation is focused by means of a grazing incidence gold-coated ellipsoidal mirror. Spectrum of the reflected radiation consists of a narrow peak with intensity maximum at wavelength of 10–11 nm. This EUV source is capable to irradiate in vacuum a sample with single/multiple pulses repetition with energy density up to 100 mJ/cm^2 and duration about 3 ns. Using this technique the spots of modified magnetic properties, about 1mm diameter, were created.

Pt/Co/Pt samples were exposed to a single and multiple EUV pulse(s). Depending on the value of maximum irradiation energy density, either circular or ring-shape spots with out-of-plane magnetization were observed on the remanence polar magneto-optical Kerr (PMOKE) images. In case of the single shot exposures the formation of PMA state corresponds to radiation fluence in the range of 60 to 75 mJ/cm^2. Above this value magnetization returns to in-plane state. Detailed atomic force microscopy study of the center of the irradiated spot revealed the appearance of micrometer range holes. The depth of these holes can be bigger than trilayers thickness. Magnetic force microscopy revealed a tiny domain structure in PMA induced areas with periodicity depending on the irradiation energy density. Using PMOKE we have determined the dependence of magnetic parameters as a function of a distance from the spot center. Structural modifications of the EUV irradiated Pt/Co/Pt trilayers were also studied by High Resolution TEM. Atomic interlayer diffusion and modifications of the lattice parameters were observed.

Acknowledgments: This work was supported by: NCN project HARMONIA Nr 2012/06/M/ST3/00475 and SYMPHONY project (Polish Science Team Programme, European Regional Development Fund, OPIE 2007–2013.

[1] J. Kisielewski et al., JAP 115, 053906 (2014)
[2] A. Bartnik et.al, Nuclear Instruments and Methods in Physics Research A 647 (2011) 125

L-4

Attosecond source development and applications in Lund

Christoph M. Heyl

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High-order harmonic and attosecond sources, nowadays used in many laboratories, are becoming indispensable tools for measuring ultrafast electron dynamics in various systems and promise new possibilities for other applications including high-resolution imaging and high-precision spectroscopy. In this talk, recent advances in attosecond source development in Lund will be discussed. This includes a new technique for attosecond pulse gating [1,2] as well as the concept and implementation of different intense attosecond beam lines [3,4]. Furthermore, applications including the measurement of double ionization dynamics initiated by intense extreme ultraviolet pulses will be presented [4].

[1] C. Heyl *et al*., New Journal of Physics **16**, 052001 (2014)
[2] M. Louisy *et al*., accepted for publication in Optica (2015)
[3] P. Rudawski *et. al*., Rev. Sci. Instr. **84**, 073103 (2013)
[4] B. Manschwetus *et al*., manuscript in preparation

L-5

X-ray micro- and nanoimaging with laboratory sources

Hans M Hertz

Biomedical and X-Ray Physics, Dept of Applied Physics, KTH/Albanova, Stockholm, Sweden

Advances in laboratory-scale X-ray micro- and nano-imaging in Stockholm are reviewed. In the soft X-ray regime we demonstrate laboratory water-window microscopy for high-resolution 3D nanotomography of cryo-fixed biological samples. The synchrotron-like image quality relies on our high-resolution and high-efficiency diffractive optics and exposure times are approaching that of bending-magnet microscopes with a new laser-plasma source based on a 2 kHz diode-pumped slab laser. Recent work include improved modelling and reconstruction for higher-resolution 3D imaging at soft X-ray microscopes, where depth of focus is typically smaller than the sample size. In the hard X-ray regime (10-50 kV) we exploit the power and spatial coherence of our new the liquid-metal-jet anode X-ray tube, and invention that is now being commercialized. This new source concept provides a microfocus tube with unprecedented brightness. Present applications include, e.g., biomedical phase-contrast imaging with particularly focus on small-animal applications. Here, e.g., the 3D microvasculature in mouse kidney and ear has been imaged with very high spatial resolution, down to 8 μm vessels, and the soft-tissue structure of zebrafish has been mapped with sub-10 μm detail.

L-6

Atomic force microscopy in characterization of single cells

Małgorzata Lekka*

Institute of Nuclear Physics PAN, Cracow, Poland

Cancerous progression involves numerous processes causing alterations in cellular morphology, structure, growth profiles, cytoskeletal organization, and also in surface receptors, which are responsible for the interactions with both the neighboring cells and cellular environment. These alterations are depended on the stage of tumor progression. Despite numerous studies, the mechanism of metastasis is still not completely understood. Therefore, the combined microscopic and spectroscopic approach, applied to characterize the properties of individual cells, is helpful in description of cancer-related changes.

In our studies, the properties of single cancer cells were characterized by various microscopic techniques. Cell surface imaging was carried our using atomic force microscopy (AFM) complemented by both scanning electron microscopy (ESEM) and fluorescence microscopy (MF). The chemical composition of cell surface was evaluated basing on Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). The effect of mechanical alterations, induced by oncogenic transformation, was examined by AFM-based force spectroscopy: it was quantified through the Young's modulus changes induced in actin cytoskeleton organization and through interaction forces the adhesive properties of single cells. The obtained results enabled to fully characterize and correlate the properties of cancerous cells.

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Live cell imaging with a soft X-ray microscope using a laser-plasma soft X-ray source

Masataka Kado[1*], Maki Kishimoto[1], Masahiko Ishino[1], Satoshi Tamotsu[2], Keiko Yasuda[2], Masato Aoyama[2], Shigenobu Tone[3], Kunio Shinohara[1, 4]

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[2] *Nara Women's University, Kitauoyahigashimachi, Nara, Nara 630-8263, Japan*
[3] *Kawasaki Medical School, 577 Matsushima, Kurashiki, Okayama 701-0192, Japan*
[4] *Tokai University, 4-1-1 Kitakaname, Hiratsuka, Kanagawa 259-1292, Japan*

Laser-plasma soft X-ray source produced by a high power pulsed laser is extremely bright and very suitable for biological X-ray microscopy to capture an image of living specimens for which require a single flash exposure to avoid imaging any damages on the specimens. A bright laser-plasma soft X-ray source has been produced irradiating a highly intense laser pulse generated by a Nd:glass laser system onto a thin foiled gold target. The output energy of the Nd:glass laser system was about 20 J and pulse duration was about 600 ps. Several thicknesses of the gold foiled targets have been tried and the highest intensity was obtained at the thickness of 400 nm and the photon flux was measured to be about 1.3×10^{15} photons/sr. The photon flux on the specimens was estimated to be about 4.4×10^{5} photons/μm^2 and it will be enough to give the spatial resolution of about 80 nm [1].

We have developed a laser-plasma soft X-ray microscope composed of an intense short pulsed soft X-ray source and a contact microscopy system in which soft X-rays are irradiating onto biological cells directly cultivated on a recording media, an X-ray photo resist, and succeeded in observing inner structures of living biological cells [2]. Using a fluorescence microscope with the soft X-ray microscope to observe the same biological cells at the same time, accurate identification and high resolved observation of cellular organelles have been achieved such as inner structure of Leydig cells from mouse testis, structural deformation of apoptotic HeLa S3 nuclei [3] and mouse immune cells [4]. In the case of the immune cells we have found structural changes possibly attributed to the activation of immune function.

[1] D. Sayre et al., Ultramicroscopy **2** (1977) 337.
[2] M. Kado et al., J. Phys. Conf. Ser. **463**, 012056 (2013).
[3] M. Shinohara et al., X-ray Imaging Optics News Letter, No. 41 (2015).
[4] M. Kado et al., Laser Physics Letters **3**, 205 (2006).

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L-8

Development and application of high brightness laser plasma based X-ray sources for nanoscale imaging

Holger Stiel[1,2*], Anne Blechschmidt[1,3], Aurélie Dehlinger[1,3], Robert Jung[1,2], Christoph Pratsch[4], Christian Seim[1,2], Johannes Tümmler[2]

[1]*Berlin Laboratory for innovative X-ray Technologies (BLiX) , 10623 Berlin, Germany*
[2]*Max-Born Institute (MBI), 12489 Berlin, Germany*
[3]*Technische Universität Berlin (TUB), 10623 Berlin, Germany*
[4]*Helmholtz-Zentrum Berlin (HZB), 12489 Berlin, Germany*

Nanoscale imaging of biological samples in the lab as well as mask inspection in extreme ultraviolet lithography near the production line with sub 30 nm resolution require high spectral brightness soft X-ray sources. Laser produced plasma (LPP) sources and plasma based X-ray lasers (XRL) emit soft X-ray radiation in the wavelength region of interest between 2 nm and 20 nm. Whereas LPP sources easily can be tuned to the so called water window (2.2 - 4.4 nm) the output of an XRL is restricted to relatively few fixed wavelengths in the extreme ultraviolet range. However due to the relatively high degree of coherence the XRL is well suited also for nanoscale imaging using coherent techniques like coherent diffraction imaging (CDI) or Fourier transform holography (FTH).

In this talk we report on the development of high brightness LPP and XRL sources based on high average power solid state pump lasers. We present a full field laboratory transmission X-ray microscope (LTXM) based on a high brightness LPP source operating at the short wavelength edge (2.48 nm) of the water window [1]. Nanoscale imaging of biological samples in its natural environment is demonstrated. We compare the performance of our method with coherent imaging techniques such as CDI and FTH. In conclusion we discuss a new FTH setup for our high repetition rate XRL operating at 18.9 nm.

[1] Legall H, Blobel G, Stiel H, Sandner W, Seim C, Hertz, H, et al. Opt Expr. (2012) **20** 18362-9.

Imaging techniques using laser plasma soft X-ray and EUV sources

Przemyslaw Wachulak,[1*], Alfio Torrisi [1], Muhammad Fahad Nawaz [2], Šárka Vondrová [3], Jana Turňová [3], Andrzej Bartnik [1], Daniel Adjei [1], Jerzy Kostecki [1], Lukasz Wegrzynski [1], Tomasz Fok [1], Roman Jarocki [1], Mirosław Szczurek [1], Zdenko Zápražný [4], Dusan Korytár [4], Alexandr Jancarek [2], Henryk Fiedorowicz [1]

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Visualizing small objects in the nano-meter scale with high spatial resolution or very low density is very important from the point of view of modern science and technology. To extend the diffraction limit associated with the wavelength of radiation, one way is to reduce the wavelength, allowing smaller features to be resolved.

This requires short wavelength sources, capable of delivering sufficient flux to achieve high signal-to-noise ratio images. Those sources are synchrotrons, free electron lasers, but also compact sources, such as laser-plasma, discharge-pumped, or high harmonic generation sources plasma, among others.

A special place in these endavours have laser plasma sources of extreme ultraviolet (EUV) and soft X-ray (SXR) radiation. They offer a possibility to perform imaging experiments, previously restricted to large-scale facitities, offering often similar capabilities and results. Many different imaging experiments, employing laser-plasma EUV and SXR sources, performed at the Institute of Optoelectronics, Military University of Technology, will be mentioned in the presentation, including: full field EUV and SXR microscopes, pinhole camera imaging, radiography and tomography of low density objects.

Of course this brief lecture cannot address all available techniques and experiments related to the EUV and SXR imaging, however, it might be a good introduction to this interesting topic.

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L-10

Applications of laser driven EUV/soft X-ray sources and wavefront measurements at short wavelengths

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The progress in development of laboratory-scale soft X-ray sources in recent years has enabled experimental techniques that could be performed before almost exclusively at synchrotrons. In this contribution various metrological applications of a compact and long-term stable laser-driven plasma source emitting in the extreme UV and soft X-ray range are presented. Based on a pulsed gas jet target, the system produces clean radiation in the spectral region from 1 to 20nm. In dependence of the chosen target gas, both quasi-monochromatic as well as broad-band spectra can be obtained. Broad-band radiation is used for polychromatic absorption spectroscopy in the ´water window´ spectral region, investigating the fine-structure of absorption edges of various elements (NEXAFS spectroscopy for chemical analysis). The performance of this NEXAFS spectrometer is demonstrated for a variety of different organic and inorganic samples. In addition to the carbon K-edge, also the fine-structure of other elements as oxygen, nitrogen, calcium, iron, copper and manganese can be probed. Excellent agreement with corresponding synchrotron data is achieved. On the other hand, monochromatic radiation at a wavelength of 2.88nm produced from a nitrogen plasma is employed for soft X-ray microscopy, accomplishing a spatial resolution of 50nm. In addition, EUV reflectometry and material interaction studies are performed at 13.5nm.

The imaging performance of short wavelength optics is characterized with the help of a Hartmann-type wavefront sensor developed for the EUV/soft X-ray range. In cooperation with DESY / Hamburg this device is applied for fine-tuning of beam line focusing optics of the free electron lasers FLASH / Hamburg and FERMI / Triest. Wavefront aberrations introduced by optics misalignment can be strongly reduced, leading to smaller foci and enhanced peak intensities. The wavefront sensor is being employed also for beam and optics characterization of High Harmonic (HHG) and plasma-based sources emitting in the EUV range.

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Ablation and micromachining using EUV radiation from laser-produced plasma

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We have investigated a practical technique for micromachining a wide range of materials, by means of photo-direct machining (ablation) using extreme ultraviolet (EUV) radiations [1]. Photo-direct machining have a potential capability for effective, deep machining of a wide range of materials. Furthermore, fine/precise and non-thermal machining could be achievable due to short wavelength and high photon energy, respectively, as compared to the conventional techniques. In our work, we employed (a) laser-produced plasma sources and (b) optics for focusing the wide spectral band EUV radiation, in order to ablate a wide range of materials.

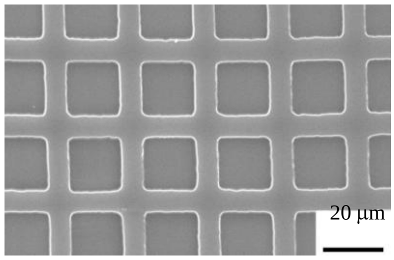

Figure 1: SEM image of microstructures fabricated by EUV irradiation on a PDMS sheet.

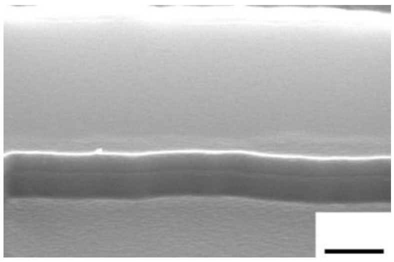

Figure 2: SEM image of edge of the structure observed at 45°.

The EUV radiations were obtained by irradiation of Ta, Sn and Xe targets with Nd:YAG (10 ns) and pulsed TEA CO_2 laser (50 ns) light. The generated EUV radiation around 100 eV (10 nm) were focused on samples at a typical power density of 10^8 W/cm^2, using an ellipsoidal mirror. Contact masks were placed on top of samples for fabricating designed structures. Figure 1 shows square holes fabricated on polydimethylsiloxane (PDMS) rubber surface. The fabricated edges have steep walls as shown by Fig. 2. A PDMS sheet is ablated at a typical rate of 200 nm/pulse. It is interesting that the ablation depth is scaled by power density for all of the EUV sources used in the present work. The result indicate faster process without thermal diffusion than the pulse durations. The analysis of the ablation depth suggests that PDMS surface is decomposed into small fragments by EUV irradiation. It should be noted that no chemical modification was observed on the PDMS surface after the EUV irradiation. All these properties are suitable for micromachining. In addition to the PDMS, the machining properties has been achieved for a wide range of materials such as SiO_2, Al_2O_3, PMMA.

[1] Appl. Phys. Lett., **86**, 103111 (2005); Appl. Phys. Lett., **89**, 101118 (2006); Appl. Phys. Express, **3**, 066502 (2010).

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L-12

Betatron radiation from electrons in resonant motion in the laser wakefield accelerator bubble regime

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Laser plasma wakefield accelerators (LWFAs) are a new generation of table-top accelerators which utilise plasma as the accelerating medium. In the LWFA, an ultra-intense laser pulse passes through plasma to excite plasma waves. Electrons are injected into the wake and accelerate to very high energies over short distances. The unprecedented accelerating gradients are in excess of 100 GV/m, more than a thousand times higher than in conventional accelerators based on radio frequency cavities. During the acceleration process, while electrons accelerate longitudinally they oscillate transversally and emit synchrotron-like "betatron" radiation into a narrow on-axis cone. When electrons interact with the electromagnetic field of the laser pulse trapped in the bubble, their motion is dramatically altered from natural betatron motion: the betatron motion is resonantly driven at a harmonic of betatron frequency, which alters to keep it resonant with the Doppler downshifted laser frequency which leads to an enhancement of the emission rate and an increase in the critical energy of the synchrotron-like radiation.

Here we describe the betatron emission process with a particular emphasis on the betatron harmonic resonance mechanism and discuss its scalability and applications.

L-13

XUV optical properties of XFEL created warm dense matter

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The extreme ultra-violet (XUV) optical response of warm dense aluminium is a subject of much theoretical interest, yet lacking in experimental data. Recent experimental results pertaining to the optical properties of warm dense aluminium are reported. Thin foils of aluminium were heated with 60 fs pulses of X-rays above the aluminium K-edge at the LCLS to create an iso- chorically heated volume. A probe pulse of XUV light from high harmonic generation (HHG) was used to measure optical properties (absorption and refraction) during the transition from a cold solid, to the warm dense regime, and the plasma conditions were inferred from X-ray emission spectroscopy. The short pulse heating mechanism naturally separates the ion and electron temperatures in time, giving a unique insight into the contribution of each to the optical proper- ties. An overall increase in absorption with increasing temperature was observed, in agreement with model. This work sets an important benchmark for future theoretical and numerical approaches to warm dense matter, as well as future experiments.

L-14

Ultrafast structural changes in crystals studied by pump-probe experiments

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Non-thermal melting of semiconductor crystals, phase transitions on a sub-picosecond scale can be studied by Optical Pump X-ray Probe Experiments. Powerful femtosecond lasers deliver brilliant ultrashort K alpha pulses on a time scale from 100 fs to 1 ps that can be optimized for such pump probe experiments. These experiments consist of (i) high luminosity point-to-point imaging by a toroidal crystal and (ii) X-ray diffraction of ultra-short monochromatic pulses by the sample crystal.

To optimize design of the instruments, theoretical codes have been developed. X-ray topographic cameras and diffractometers were modified for fabrication and characterization of 2-D bent crystals as diffracting elements. Best results were obtained when structurally perfect wafers of Si, Ge, and quartz crystals were prepared whilst monitored by X-ray topography and diffractometry. After final check of X-ray imaging as well as reflection properties of toroidal crystals, monochromatic X-ray focus and laser pump beam are adjusted spatially to coincide on the sample crystal.

Ultrafast processes have been studied in bulk semiconductors, such as InSb, and in Ge films. As the penetration depths of optical pump beams are usually much shorter than the X-ray extinction depths, best sensitivity to ultrafast structural changes is obtained for minimum X-ray extinction depths. This can be achieved by selecting samples containing heavy elements, thin crystalline film samples and by using asymmetric Bragg reflections, respectively.

Approaching 100 fs benchmark for pulse length of high-repetition laser plasma-based X-ray source; application for time-resolved XAS

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Advances in the 3*rd* generation synchrotrons and the X-ray free electron lasers (XFELs) offer X-rays of unprecedented parameters enabling new class of experiments in materials and life sciences. These expensive and of limited access largescale facilities were accompanied by laser plasma-based X-ray sources (LPXS) for more than the last 25 years. One of the most promising and challenging applications is time-resolved X-ray spectroscopy in the form of X-Ray Absorption Near-Edge Structure (XANES) and Extended X-ray Absorption Fine Structure (EXAFS). This, however, requires precise determination of the source temporal characteristics, especially those of the Bremsstrahlung continuum. As compact LPXSs implementing the pump-probe techniques attract more attention as complementary X-ray sources for the large scale facilities, precise knowledge of their emission duration, determining the measurement temporal resolution, became indispensable. We report here for the first time that the pulse width of X-rays from such a compact source approaches the predicted 100 fs benchmark. The measured pulse duration of the line emission from the Cu-*K*-shell and that of the relevant high-energy-end Bremsstrahlung continuum were differentiated, and spanned the time interval between 160±9 fs and 110±6 fs. In addition, we introduce a measurement scheme adopting the recently revealed ultra-fast response of X-ray absorption (XAS) to the non-equilibrium electronic distribution generated by femtosecond excitation in the transition metals to the cross-correlation method. Application of this source to the XAS and X-ray fluorescence (XRF) of nickel and iron sample will be presented as well.

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L-16

Investigation of photoionized plasmas produced with the use of laser plasma sources of soft X-rays and extreme ultraviolet (EUV)

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Photoionized plasmas are not produced in normal conditions on Earth, but are common in Space. Photoionization of gases is a key process in formation of different kinds of astrophysical plasmas, especially located close to strongly radiating compact objects. Spectral investigations of these plasmas can provide information about astrophysical objects emitting X-ray radiation that irradiate surrounding gases. Interpretation of the observed spectra require constructing of physical models and performing laboratory experiments that support the accuracy of the models.

Photoionization of gases is also an important process for planetary science. Photoionization of atoms and molecules is one of the dominant processes that occur in upper atmospheres. In the case of molecules, ionization can result in further dissociation to ionic and neutral species. Ionization of O_2, N_2 and other simple molecules by solar radiation is one of the most important ion production channels on Earth’s and Titan’s upper atmospheres. Modelling of the upper atmosphere requires knowledge of the composition and reactions that occur among its constituents.

In this work investigations of photoionized plasmas were performed using using laser-produced plasma extreme ultraviolet/soft X-ray (LPP EUV/SXR) sources with different parameters. The sources were based on three different laser systems with pulse energies ranging from 0.8 J to 500 J and pulse duration 0.2 - 10 ns. Laser plasmas were produced by irradiation of double stream gas puff targets with Xe or KrXe mixture as the working gas. EUV or SXR radiation was focused using grazing incidence collectors of different types. The collectors were based on multifoil, ellipsoidal or paraboloidal mirrors optimized for specific wavelength ranges.

Different gases were injected into the interaction region, perpendicularly to an optical axis of the irradiation system, using an auxilary gas puff valve. Irradiation of the gases resulted in ionization and excitation of atoms and molecules forming photoionized plasmas. Spectra in SXR/EUV range were measured using a grazing incidence, flat-field spectrograph (McPherson Model 251), equipped with a 450 lines/mm toroidal grating and a home made spectrograph based on free standing transmission grating 5000 lines/mm. Spectra in UV/Vis range were measured using an Echelle Spectra Analyzer ESA 4000. Density distribution of photoionized plasmas was measured using laser interferometry. In all cases the most intense emission lines in EUV/SXR range were assigned to singly charged ions. Other spectral lines corresponding to doubly, triply and even quadruply charged ions were also recorded. In case of UV/Vis spectral measurements, however, atomic or molecular spectra were dominating.

L-17

Multilayer optics for space and laboratory applications and their characterization

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EUV multilayers (ML) are studied for a wide range of applications from the most important field of EUV-Lithography, in order to improve the actual present limit of IC components density, to Space missions, mainly devoted to the study of the SUN, now within the context of SPACE WEATHER forecasting, to Synchrotron Beam lines sources and laboratory experiments. In the development of ML coatings extremely important are the various characterization measurements which are fundamental in order to fully understand the ML performances and the related effects due to the structure characteristics.

Laser Plasma interactions and ML's together have a great long story. LPP can be used for example as EUV radiation sources for ML characterization in reflectometer laboratory based systems. On the other hand ML's have been applied in HHG experiments where high order harmonics are generated in the interaction of ultrashort laser pulses with a gas and the very wide bandwidth and frequency chirping poses considerable challenging requirements on the ML coating design.

In this lecture ML characteristics, their applications and characterization will be presented.

L-18

Bio–objects irradiation using low energy X-ray pulses

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Low energy X-rays are of special interest for radiobiology studies. Independent of the energy of the primary radiation, most of DNA damage is caused by the secondary species, like electrons or ions, with energies of several tens of electronvolts only. As the photon absorption cross-section of DNA has its maximum around ~15 eV, it has been demonstrated that photons at energies below 10 eV are capable to induce both single– and double strand breaks in plasmid DNA. However, studies using plasmid DNA cannot fully reflect damage processes that occur during irradiation of living cells.

In recent years one can observe a growing interest and expectations in application of intense, laser produced X–ray pulses in radiobiology studies and for medical purposes. Low energy X–rays of this origin have many advantages over other low–energy sources, like electron guns or synchrotrons, traditionally applied in such studies. Laser X–ray sources do not require large infrastructure and are rather easily accessible for many research groups. This is in clear contrast with requirements that must be fulfilled in case of synchrotron–based studies. One should also note that synchrotron radiobiology experiments suffer usually from relatively low dose rates, what extends the experiment time needed to produce a biological effect. Pulsed irradiations are free from this limitation. Moreover, high dose rate corresponding to a single pulse does not create qualitatively different experimental conditions (like an elevated radiation hazard) and several studies show that biological effects stay at the same level, as in case of conventional X–ray sources.

In cells studies, the low penetration depth of the soft X–rays confine their deposition volume in the cell to the membrane and cytoplasm only, minimizing the possible interaction with the nucleus and DNA, what opens another area for investigations. Finally, another benefit is that the intense X–ray pulse provides a potential for simultaneous imaging, while its short time of duration (pico/femtoseconds region) opens possibility of temporal studies (like electron dynamics during DNA strand break induction).

Parallel to the discussion of the above issues, together with presentation of main experimental techniques, findings and expected benefits, several design concepts will be shortly introduced, aiming at the construction a living cells irradiation system using a soft X-ray laser.

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Contributed Presentations

Contact microscopy using a compact laser plasma soft X-ray source

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Application of a compact laser plasma soft X-ray source for contact microscopy in the 'water window' spectral range (λ = 2.2 nm – 4.4 nm) is presented. The source is based on a double-stream gas puff target, irradiated with nanosecond laser pulses from commercial Nd: YAG laser (EKSPLA), which generates laser pulses of 4 ns time durations and energy up to 740 mJ at 10 Hz repetition rate. The source delivers nanosecond pulses of Soft X-rays with photon and energy fluences of about $4x10^4$ photon/μm^2 and 0.25 mJ/cm^2 for a sample placed at 2 cm away from the source. As first steps, fixed and dried human bladder cancer cells (HCV29 and T24) cultured with and without nano-gold beads on PMMA photo-resists are imaged using the soft X-ray contact microscopy (SXCM). The samples are exposed to 150 pulses of soft X-rays in the 'water window' spectral range. The developed photo-resists exhibit high resolution in the AFM images which indicated the potential application of SXCM to examine small features. The details of contact microscopy together with laser plasma soft X-ray source will be presented and discussed. In addition, the preliminary results of contact microscopy of biological specimens will be presented.

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O-2

Broadband laser produced plasma source for X-ray spectroscopy applications in the soft X-ray region

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For applications in soft X-ray spectroscopy two basic source requirements have to be fullfilled: high spectral brightness and high average photon flux. Furthermore, a flexible source setup should give the opportunity to realize various spectroscopic methods in the laboratory. In comparison to common X-ray tubes, which suffer power limitations due to heat problems in the soft X-ray region, the utilization of X-ray sources based on laser- produced plasmas (LPP) is promising. Besides the requirements already mentioned, long-term stability ensuring continous operation is crucial for applications in spectroscopy.

We are presenting a compact LPP source, which emits soft X-ray radiation in the range between 80 and 1200 eV (1 - 20 nm) [1]. The radiation emission relies on the formation of a hot localized plasma on a target through the focusing of a short laser pulse. At present the source is featured with a solid copper target. The plasma is generated using a Yb:YAG-thin disk laser system (TRUMPF Laser Technology). The laser system has been equipped with a diode-laser seed with adjustable pulse duration in the ns and ps time scale and a repetition rate of 100 Hz – 200 Hz. Depending on the target material and the applied laser settings, the source offers the possibility to use characteristic line emission for X-ray emission spectroscopy (XES) or the whole broadband spectrum for X-ray absorption spectroscopy (XAS). The LPP source is designed for the operation of two independent beamlines. Two experiments can be conducted simultaneously. Continous operation of more then 8 hours per day is feasible, downtime for changing the target is typically around 2 hours per day.

Within the generated energy range both the K absorption edges of light elements (C, N, O) and L absorption edges of transition metals can be investigated and the corresponding fluorescence lines can be excited. We will present successful XAS investigations of thin metal foils at their L3,2 absorption edges and spectra of various polymeres at the carbon K edge. In addition, we show an experiment for XES with angle-resolved geometry by using a beam focusing optic and an energy dispersive CCD- camera. Samples of investigation were multilayer systems with a thickness gradient. An outlook for future plans concerning time resolved measurement will be given.

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O-3

Exploring the near-critical regime with dense gas jets

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New gas targets with unique properties of size and density have been recently developed at the Laboratoire d'Optique Appliquée (France) to explore the physics of laser plasma interaction within in a wide range of plasma density [1]. With these versatile systems, a new mechanism by which the flow of relativistic electrons strongly magnetize the boundary between the plasma and the non-ionized gas is unveiled, leading to magnetic field up to 10-100 Tesla (micro-Tesla in astrophysical conditions) [2]. Close to the critical density to the critical density, the efficient laser self-focusing leads to a localized energy deposit, that entails an ultrafast electron expansion (within one picosecond) and the growth of an intense magnetic dipole heating further the electrons [3].

By implementing these innovative jets, an original technique of compact plasma-based X-ray lasers, based on “Collisional Ionization Gating”, was demonstrated [4]. This scheme allows not only to achieve femtosecond pulse duration for the first time, but also to report a boost in output energy. The combination of those made possible a remarkable enhancement of total peak intensity by about two orders of magnitude compared to the present state of the art. Our scheme relies on increasing the plasma density to quench the gain duration of the plasma amplifier, which also leads to an increase in saturation intensity and laser gain [5]. At the reported high densities, guiding techniques prove to be pivotal to counterbalance refraction [6]. The demonstrated plasma-based soft X-ray laser was implemented focusing an ultra-intense IR pulse into a krypton gas and pumping the atomic transition of Ni-like species at 32.8nm [7]. Tailoring the plasma waveguide for higher densities and longer amplifiers holds great promises to further outdistance previous performances of plasma-based soft X-ray lasers.

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O-4

Laser-discharge hybrid EUV source: comparison of ns vs ps-laser triggering

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The lack of EUV light sources with industrial level power and brightness has remained among the major bottlenecks for the delay of high-volume chip manufacturing. Major drawbacks of traditional Discharge Produced Plasma (DPP) sources are low conversion efficiency (CE) and high associated heat load compared to Laser Produced Plasmas (LPP). The hybrid Laser-triggered Discharge Plasma (LDP) source combines the scalability, stability and high CE features of these two methods. The present report substantiates this claim by providing experimental demonstration from laser triggered discharge ignited between liquid-tin-coated rotating electrodes. Time resolved visible imaging and EUV spectroscopy combined with temporal characterization were used to diagnose the EUV photons. The EUV output was found to correlate with the localized ablation of the thin film. This was studied by tailoring laser parameters, mainly the pulse duration and energy density, using two Nd:YAG lasers of ~170ps and ~7ns, each 1064nm, with energy range of ~1-100 mJ. The picosecond (ps)-laser showed an increase in CE and spectral purity compared to ns-triggering. The difference is mainly due to the expanding plasma dynamics.

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O-5

DNA strand breaks induced by soft X-ray pulses from a compact laser plasma source

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Soft X-rays (<12 keV) in radiobiology has been demonstrated in various experiments to understand the mechanism interaction of low energy radiations with biological samples. The high absorption and relatively low penetration (as compared with hard X-rays) of the radiation in cells and cellular components allow high proportion of the energy to be deposited per unit mass of the sample. This particularly applies to soft X-rays in the unique spectral region between the oxygen K-edge at 2.3 nm and the carbon k-edge at 4.4 nm, called “water window”, where the carbon-containing proteins show much larger absorption than the oxygen-containing water, thus allowing a high number of photons to be delivered to the sample. Radiations in these experiments were generated with X-ray tubes and synchrotrons, however, the latter sources have limited access. Recently, application of laser plasma soft X-ray sources in radiobiology has attracted much interest, because of the possibility irradiation of a sample at high-dose loads and rates. Additionally, the very short pulses of radiation emitted from these sources may be useful to understand the mechanism underlying the biological response to radiation. Over the past two decades, laser plasma soft X-rays sources for radiobiology experiments were proposed, however, such sources were based on the use of a laser interacting with a solid target. Laser plasma sources based on solid targets produce debris which may cause degradation to the optical elements of the system and the sample under irradiation.

A compact desk-top laser-produced plasma source of soft X-rays for radiobiology research is presented. The source is based on a double-stream gas puff target and delivers nanosecond pulses of soft X-rays in the “water window” spectral range at a fluence of about $4.23x10^3$ photon/μm^2 per pulse on a sample placed inside the vacuum source chamber and about $2.60x10^2$ photon/μm^2 per pulse on a wet sample located outside the chamber in the He- environment. The source has been used to irradiate pBR322 plasmid DNA both in vacuum and the He-environment conditions. Single and double strand breaks were quantified by gel electrophoresis. The number of strand breaks increased with increasing dose of the “water window” soft X-rays. The strand breaks of plasmid solution irradiated in helium condition may be associated with damage from water free radicals.

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O-6

Development and optimization of a compact "water window" microscope using a SXR gas puff target source

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A significant progress has been made in the last years in soft X-ray microscopy (SXR) trying to develop technologies that will increase the spatial resolution of the acquired images. At the Military University of Technology, in Warsaw, Poland, a very compact microscope has been developed that, uses a gas-puff target compact source and allows to obtain a half-pitch spatial resolution of 60 nm.

Soft X-ray radiation from the "water window" spectral range (λ = 2.3 - 4.4 nm) permits to enhance the contrast of biological and inorganic materials, due to a selective absorption of radiation by carbon, water and other constituents of the biological material.

SXR microscopy has been successfully employed in transmission mode, operating at He-like nitrogen spectral line, at λ = 2.88 nm, and using a Fresnel zone-plate diffractive optic.

In this work we present details about compact SXR source employed for high resolution "water window" imaging as well as the recent imaging results and measurements acquired in order to improve the signal-to-noise ratio in our "water window" microscopy system for various acquisition conditions, in order to characterize this compact microscopy setup.

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P-1

Photoionization Cross Section of Calcium Computed using TDLDA and RTDLDA Codes

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A significant body of work exists on the study of photoionisation processes in rare gas atoms, where electron correlation is revealed as a key physical process leading to the observation of giant photoionisation resonances, single photon-multiple electron excitations and/or ionization, etc. In contrast metal atoms and ions have been studied to a lesser extent. The work presented here centres on a study of Vacuum-UV photoabsorption of metal atoms and ions using radiation from laser produced plasmas at DCU [1]. We focus specifically on calcium as it has an exceptionally high total cross section in the region of 3p-3d resonances. The relativistic time dependent local density approximation (RTDLDA) [2] and the time dependent local density approximation (TDLDA) [3] are used to calculate the absolute photoabsorption cross sections of neutral calcium (CaI) and singly ionized calcium (CaII). The calculations are based on the excitation and ionisation of the 3p shell, which is easily accessed in the VUV spectral region. The broad features of the ionisation cross section of calcium were obtained. The next steps will be to compare the calculated values with experimental relative cross sections, which will be measured in DCU using the well-established Dual Laser Plasma (DLP) photoabsorption technique [1].

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P-02

Time-resolved soft X-ray excited luminescence spectroscopy of solids state scintillators

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We present the measurement of luminescence kinetics of scintillators, excited by a table-top soft X-ray source – laser produced plasma. Plasma is induced by Q-switched Nd:YAG laser (λ = 1064 nm, 600 mJ, 7 ns pulse) focused into argon gas-puff target. Scintillators as photon energy converters constitute the foremost X-ray detection component in a wide variety of medical X-ray imaging systems. Thus, their properties are determinative for performance of such devices. Practical use of scintillators is often limited by their luminescence kinetics, i.e. by the speed of radiative deexcitation of luminescent centers. Thus, the investigation of luminescence kinetics plays one of the major role in the development of new scintillation materials.

Our contribution to this research consists in development and application of a new spectroscopic technique [1], which would allow us to measure the luminescence decay within a very wide temporal range (ten ns to > ms), with nanosecond temporal resolution and very high signal-to-noise ratio (> 10^5). We meet these requirements by exploiting a combination of an intense nanosecond soft X-ray excitation pulse, a very short absorption length of the soft X-rays, and a fast photomultiplier-based detection.

Our instrumentation allows us to measure different types of samples, such as powders, single crystals [2], and ceramics. Here we present a demonstration of measured luminescence response of rare-earth doped lutetium aluminum garnet (LuAG:Ce) with/out Mg. The temporal instrumental response function (IRF) was detected by a fast ZnO:Gd scintillator (τ_i = 0.8 ns) [3].

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Laser plasma sources of soft X-rays and extreme ultraviolet (EUV) based on a gas puff target

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Laser plasma sources of soft X-rays and extreme ultraviolet (EUV) developed in our laboratory for application in various areas of technology and science are presented. The sources are based on a laser-irradiated gas puff target approach. The targets formed by pulsed injection of gas under high-pressure are irradiated with nanosecond laser pulses from Nd:YAG lasers. We use commercial lasers generating pulses with time duration from 1ns to 10ns and energies from 0.5J to 10J at 10Hz repetition rate. The gas puff targets are produced using a double valve system equipped with a special nozzle to form a double-stream gas puff target which secures high conversion efficiency without degradation of the nozzle. The use of a gas puff target instead of a solid target makes generation of laser plasmas emitting soft X-rays and EUV possible without target debris production. The sources are equipped with various optical systems, including grazing incidence axisymmetric ellipsoidal mirrors, a “lobster eye” type grazing incidence multi-foil mirror, and an ellipsoidal mirror with Mo/Si multilayer coating, to collect soft X-ray and EUV radiation and form the radiation beams. In this paper applications of these sources in various fields, including optical metrology, imaging in nanoscale, pulsed radiography and tomography, materials processing and modification of polymer surfaces, photoionization of gases, radiobiology and contact microscopy are reviewed.

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P-04

Wetting behavior control by extreme ultraviolet (EUV) surface modification

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Wetting behavior of materials transpired to be of significant importance in fabrication of membranes for separation technologies and substrates for micro fluidic lab-on-a-chip (LOC) devices or artificial muscles etc. Multiscale surface structuring or functionalization of surfaces could provide control over wettability. The surface modification techniques (such as surface coating, chemical or plasma treatment, and ultraviolet irradiation) often used to control the surface wettability. These techniques usually require multistep processing and often produce undesireable effects (e.g. lack of stability, surface contamination, and bulk material alterationm etc.). We report a singlestep surface modification tool for surface modification to ehnace the hydrophobicity or hydrophilicity of polyvinylidene fluoride (PVDF) films.

The surface modification of PVDF films was performed by a laser-plasma extreme ultraviolet (EUV) source based on double-stream gas puff target. The PVDF films were irradiated with 100 EUV pulses in the presence of non-reacting (helium) or reacting (nitrogen or oxygen) environment. The surface modifications were investigated by atomic force microscopy (AFM), x-ray photoelectron spectroscopy (XPS), and water contact angle (WCA). The EUV modified surfaces exhibit strong modifications to the surface morphology and the chemistry. The EUV treatment of PVDF films in the helium environment induced multiscale conical structures and increased surface roughness. The surface structuring resulted in an increase of WCA from 82° to 116°, making the surface more hydrophobic. Increased hydrophobicity could be useful for separation applications such as particle removal, osmotic distillation, membrane distillation, etc. The EUV treatment of PVDF films in the reacting environment (nitrogen or oxygen) strongly modified the surface chemisty and the wettability of the surface was increased due to incorporation of nitrogen or oxgygen based functional groups. The WCA was decreased to 62° and 44° in PVDF films treated in nitrogen and oxygen environments respectively. The EUV mofidied PVDF films with increased hydrophilicity could be used as artificial muscles with intact bulk material mechanical and piezoelectric properties.

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The influence of periodic gas puff target parameters on high-order harmonics generation

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High-order harmonic generation (HHG), resulting from the interaction of ultra-short laser pulses with gases, is one of the most promising methods to obtain coherent radiation in the soft x-ray (SXR) and extreme ultraviolet (EUV) regions [1, 2]. Pulses of such radiation with femtosecond to attosecond time duration are highly attractive for applications in various areas of science and technology.

One method to improve the efficiency of the HHG process is to use a gaseous medium with a variable spatial distribution of gas density, where the harmonic generation occurs in the area of higher medium density, while in the lower density a phase matching is obtained [3, 4].

In this paper we present the recent results on HHG experiments with the use of a multi-jet gas puff target, developed at the Institute of Optoelectronics, MUT, Poland [5]. The results should be useful for the development of an efficient, quasimonochromatic source of coherent EUV radiation [6]. The research was conducted at Prague Asterix Laser System, Czech Republic, in the frame of Short Term Scientific Mission, COST Action MP1203.

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P-06

Ultra-short X-ray pulses produced using a NOPCPA femtosecond laser

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K-alpha X-ray sources from laser-matter interaction are presented. To produce X-rayradiation, femtosecond NOPCPA (*Noncollinear Optical Parametric Chirped Pulse Amplifier*) laser and solid targets are used. Device has been constructed at Institute of Optoelectronics, Military University of Technology with collaboration of Institute of Physical Chemistry, Polish Academy of Science. By tightly focusing femtosecond pulses (15 fs, high energy - more than 80mJ before compressor, 10 Hz repetition) on solid circular targets, X-ray k-alpha emission is observed. The targets were placed on rotation stages in a vacuum chamber. To control the position of the focal point on the target, translation stages with short focal distance lens was used. By changing the material of the targets, different k-alpha energies are observed. The intensity of the generated X-rays depends of the laser polarization. The X-ray emission has been detected by an X-ray scintillator *P43* with a standard CCD camera and a dedicated X-ray camera : *Andor iKon-L SO*. To estimate the spectral range of the X-ray emission two methods has been used: indirect absorption method and direct method using X-ray spectrometer on a single ADP crystal. K-alpha X-ray source can be very useful for X-ray imaging of fast process and X-ray tomography.

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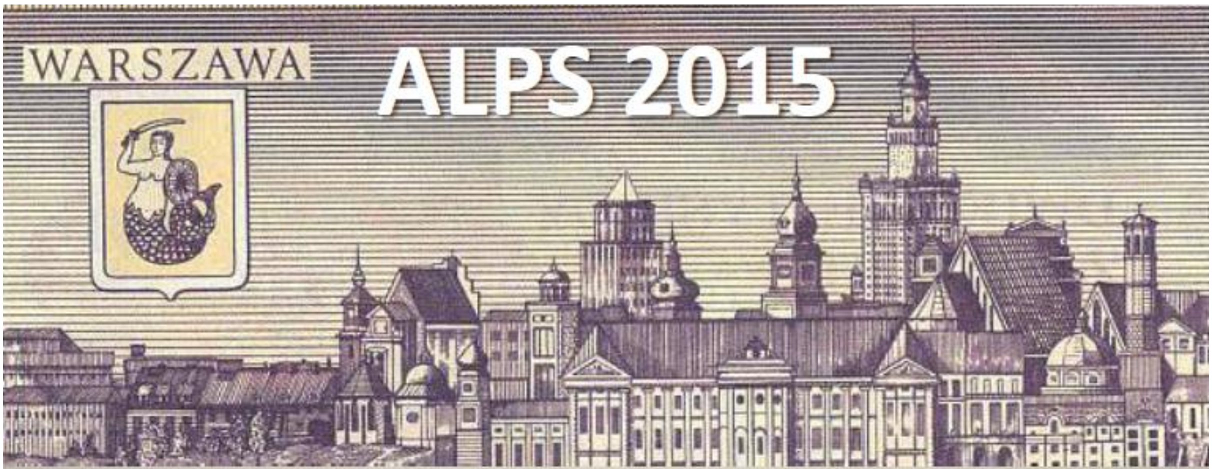

1st Workshop on Application of Laser Plasma Sources of X-rays and Extreme Ultraviolet (EUV) in Technology and Science – ALPS 2015
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Hans HERTZ (Stockholm, Sweden)
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Masataka KADO (Kyoto, Japan)
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