6th European Conference on Applications of Femtosecond Lasers in Materials Science

FemtoMat 2015

March 16 - 17, 2015
Mauterndorf Castle, Mauterndorf
Salzburg, Austria

http://www.esg-nano.ac.at/page.php?content=femtomat
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Wolfgang Kautek

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Foreword

The science, technology, and application of femtosecond lasers matured to a level that a critical review of the state of the art is timely and possible to assist in signposting future trends of development.

The success of the series of the European Conferences on Applications of Femtosecond Lasers in Materials Science (FemtoMat) with

the 1st FemtoMat 2002, Visegrád, Hungary, October 2002,

the 2nd FemtoMat 2004, Bad Kleinkirchheim, Carinthia, Austria, February 2004,

the 3rd FemtoMat 2007, Vienna, Austria, April 2007, as special session of the 8th International Symposium on Laser Precision Microfabrication (LPM 2007),

the 4th FemtoMat 2011, Mauterndorf, Salzburg, Austria, March 2011,

and the 5th FemtoMat 2013, Mauterndorf, Salzburg, Austria, March 2013, is the basis of the present

6th FemtoMat 2015, March 16 - 17, 2015, at Mauterndorf, Salzburg, followed by the Photonics Austria and Nano and Photonics Conference at the same venue.

The FemtoMat conferences represent a topical conference devoted exclusively to the present status and application of femtosecond lasers in materials science. The participants are encouraged to explore the possibilities and problems of the field and exemplify these by their most important new results. The conference features active discussions at the oral and poster sessions, and plenty of time for in-depth discussions in an informal atmosphere amidst the Austrian high alps. Due to the coherent topic of the meeting and to allow full attendance, no parallel sessions are being organized.

Vienna, March 2015

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(University of Vienna)

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Program

Monday, March 16, 2015

08:30 – 09:00 **Registration**
09:00 – 09:15 **Opening and greetings**
09:15 – 09:45 **M1** C. Spielmann (invited)
Friedrich Schiller University Jena, D
"Laser induced damage of nanostructured materials"
09:45 – 10:15 **M2** T. Winkler
University of Kassel, D
"*Probing and modeling optical properties of high band gap dielectrics excited by temporally shaped femtosecond laser pulses"*
10:15 – 10:45 **M3** W. Perrie
University of Liverpool, UK
"On femtosecond laser inscription inside PMMA using a spatial light modulator"
10:45 – 11:00 **Coffee**
11:00 – 11:30 **M4** K. Sokolowski-Tinten (invited)
University of Duisburg-Essen, D
"Ultrafast time-resolved diffraction studies of laser-excited materials"
11:30 – 12:00 **M5** L. Zhiglei (invited)
University of Virginia, USA
"Atomistic modeling of material modification by femtosecond laser pulses and surface acoustic waves"

12:00 – 16:30 **Free discussion**

16:30 – 17:00 **Coffee**
17:00 – 18:30 **Posters:** Oral presentations and session
18:30 – 19:00 **M6** S.I. Kudryashov
Russian Academy of Sciences, RUS
"Fs-laser fabrication of plasmonic nano-elements"
19:00 – 19:30 **M7** L. Zhu
University of Vienna, A
"Femtosecond Yb-doped fiber oscillator and microjoule-level amplifier based on a novel polarization-maintaining higher-order-mode fiber"

Tuesday, 17 March 2015

08:30 – 09:00 **T1** J. Reif (invited)
Brandenburg University of Technology Cottbus-Senftenberg, D
"Formation of self-organized LIPSS by irradiation with an ultra fast white light continuum"

09:00 – 09:30 **T2** W. Husinsky
Vienna University of Technology, A
"Sub-100-nm periodic surface structures on titanium surface"

09:30 – 10:00 **T3** P. Simon (invited)
Laser-Laboratorium Göttingen e.V., D
"Laser-generated periodic nano-structures"

10:00 – 10:30 **T4** E.L. Gurevich (invited)
Ruhr-Universität Bochum, D
"*Analysis of surface profiles, observed in single-pulse femtosecond LIPSS experiments"*

10:30 – 10:45 **Coffee**

10:45 – 11:15 **T5** M. Battiato
Vienna University of Technology, A
"Superdiffusive spin transport: the route to ultrafast spintronics"

11:15 – 11:45 **T6** N.M. Bulgakova (invited)
HiLASE Center, CZ
"Modeling of modification of dielectric materials with ultrashort laser pulses: New advantages and challenges"

11:45 – 12:15 **T7** J. Heitz (invited)
Johannes Kepler University Linz, A
"Three-dimensional polymer scaffolds on flexible substrates for mechanical stimulation of bone-forming cells fabricated by two-photon polymerization"

12:15 – 16:30 **Free discussion**

16:30 – 17:00 **Coffee**

17:00 – 17:30 **T8** B. Chichkov (invited)
Laser-Zentrum Hannover e.V., D
"Laser printing of nanoparticles"

17:30 – 18:00 **T9** F. Sima (invited)
RIKEN-SIOM Joint Research Unit, JP
"Hybrid subtractive and additive femtosecond laser micro-machining for highly functional biochip fabrication"

18:00 – 18:30 **T10** J. Solis (invited)
Consejo Superior de Investigaciones Científicas, ES
"Ion migration assisted femtosecond laser writing for photonic devices"

18:30 – 19:00 **T11** C. Mauclair (invited)
Laboratoire Hubert Curien, F
"Advances in spatial shaping of ultrafast laser beam for enhanced surface processing of materials"

19:00 – 19:15 **Closing words**

Lecture Abstracts

M1

Laser induced damage of nanostructured materials

C. Kern, M. Zürch, Z. Samsonova, D. Kartashov, C. Spielmann

Institute for Optics und Quantum Electronics, Friedrich-Schiller-University Jena, D
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Nanostructured targets offer new possibilities in the studying the interaction of very intense laser pulses with matter. One on hand field enhancement by plasmonic nano-antennas has been claimed to boost local laser field strengths, at the site of the interaction. We show, by looking at a set of exemplary metallic structures, that the threshold fluence F_{th} of Laser-induced Damage is a greatly limiting factor for the proposed and tested schemes along these lines. On the other hand one of the main fundamental problems for realization of the full potential for dense and hot plasmas production in laser-solid interaction is the shielding of laser radiation by plasma. Advance in nano-technologies and possibility to design solid targets with nanostructured surface offers a possibility to overcome this problem and opens new groundbreaking perspectives. Here we report on the first damage measurements of ZnO nanowires with different geometries, and discuss its role for future experiments.

M2

Probing and modeling optical properties of high band gap dielectrics excited by temporally shaped femtosecond laser pulses

T. Winkler, C. Sarpe, N. Jelzow, J. Köhler, N. Götte, B. Zielinski, A. Senftleben, T. Baumert

Institute of Physics and CINSaT, University of Kassel, D

The generation of a high density free electron plasma is the first step in the laser ablation of high bandgap materials. We have demonstrated that tailored ultrashort laser pulses are suitable for robust manipulation of optical breakdown, increasing the precision of ablation to one order of magnitude below the optical diffraction limit [1-3].

In this study, ionization mechanisms in water, as a prototype for high band gap materials, irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry [4]. From the information about the electron plasma and its dynamics the multiphoton and avalanche coefficients were determined. Our measurements directly prove that temporally asymmetric shaped pulses control the ionization mechanisms through which the free electrons are generated in high band gap transparent materials. In our recent experiments, we extended the investigation by measuring transmission and reflection coefficient of the pump pulse in order to reveal spatial properties of the ionization process driven via the different temporal pulse shapes. The results obtained, correlate to results from material processing on solid samples, which is strengthened by additionally measuring the beam profile of the transmitted pump pulse. We performed simulations, based on a generic rate equation model combined with propagation, which may deliver a comprehensive picture of this highly complex and dynamic interplay.

References:

[1] L. Englert et al., Opt. Expr. 15, 17855 (2007)
[2] L. Englert et al. JLA 24, 042002 (2012)
[3] Wollenhaupt et al., JLMN (2009) 4 (3), S. 144–151
[4] C. Sarpe et al., NJP 14, 075021 (2012)

M3

On femtosecond laser inscription inside PMMA using a spatial light modulator

Z. Guangyu[1], L. Ye[1], D. Liu[2], W. Perrie[1], P. Scully[3], G. Dearden[1]

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[2] School of Mechanical Engineering, Hubei University of Technology, China
[3] The Photon Science Institute, University of Manchester, UK

Femtosecond laser pulses are ideal for internal modification of refractive index in dielectrics for creation of photonic components. At low NA, filamentation resulting from a balance between Kerr self-focusing and plasma de-focusing generates long filaments useful for creating thick efficient Volume Bragg Gratings. We demonstrate high quality devices in the pure polymer PMMA inscribed with parallel beam, 387 nm, 160 fs pulses generated with the aid of a Spatial Light Modulator (SLM) and BBO crystal, speeding fabrication. First order diffraction efficiency > 90% is achieved and linear polarisation produces higher refractive index contrast than with circular. This is consistent with measured critical powers for self-focusing, $P_c^{circ}/P_c^{lin} \sim 1.5$ related to polarisation dependent third order susceptibility χ^3 which is higher for linear than for circular polarization [1]. We also present experimental results on polarisation dependent filamentation in PMMA with Radial/Azimuthal polarisations and with twisted wavefronts carrying Optical Angular Momentum (OAM). Clear differences in inscribed filament geometries are observed. The critical power thresholds for self-focusing with OAM topological charge m scale ~ linearly with m, in accord with expectations. When using second harmonic conversion from the fundamental wavelength from 775 to 387 nm, OAM is conserved and thus $m_{2\omega} = 2\, m_{\omega}$.

References:

[1] R.W. Boyd, 2008, Non-linear Optics, third edition, (Burlington, MA:Academic)

M4

Ultrafast time-resolved diffraction studies of laser-excited materials

K. Sokolowski-Tinten

Faculty of Physics, University Duisburg-Essen, D

Ultrafast laser excitation of solids creates highly non-equilibrium states of materials, which subsequently may undergo very rapid phase transitions. Time-resolved diffraction using femtosecond X-ray or electron pulses allows to directly follow the associated structural changes with atomic scale spatial and temporal scale resolution. In this contribution I will discuss some of our recent work in this field including experiments carried out at the LCLS free electron laser as well as with ultrashort MeV electron pulses.

M5

Atomistic modeling of material modification by femtosecond laser pulses and surface acoustic waves

L.V. Zhigilei, C. Wu, M. Shugaev, V.Y. Zaitsev

Department of Materials Science and Engineering, University of Virginia, USA

Short pulse laser irradiation can trigger a cascade of structural and phase transformations in the region of direct laser energy deposition and can also generate strong acoustic pulses (bulk and surface waves) capable of affecting key processes responsible for material modification at a substantial distance from the absorption region. Large-scale atomistic simulations are used in this work to investigate both the direct femtosecond laser material modification and the acoustically-induced surface processes. In the case of direct laser modification of metal targets, the processes responsible for the formation of a sub-surface porous region covered by a nanocrystalline surface layer with random crystallographic orientation of nanograins and a high density of stacking faults, twins, and nanoscale twinned structural elements with five-fold symmetry will be discussed and related to the experimental observation of surface swelling and incubation effect in multi-pulse laser ablation. For the acoustic activation of surface processes, the conditions leading to the maximum enhancement of surface diffusion are analyzed and the implications for the design of new techniques where the acoustic energy serves as an effective substitution for thermal activation of surface processes are discussed.

M6

Fs-laser fabrication of plasmonic nano-elements

S.I. Kudryashov

Lebedev Physical Institute, Russian Academy of Sciences, RUS

Plasmonic nanoscale elements are the key ingredients in constructing plasmonic circuits, sensors and solar-cell coatings. Though their current fabrication is associated with rather expensive and non-“green” lithographic processes, large-scale direct ablative laser writing emerges as a promising novel approach. In this talk, basics of ablative femtosecond (fs) laser fabrication of plasmonic nanoelements on thin plasmonic films are presented with a few examples of their prospective applications and discussion of advanced nanoscale fs-laser ablation mechanisms.

M7

Femtosecond Yb-doped fiber oscillator and microjoule-level amplifier based on a novel polarization-maintaining higher-order-mode fiber

L. Zhu[1,2], A.J. Verhoef[2], A. Unterhuber[3], A. Baltuška[2], W. Kautek[1], A. Fernández[2,3]

[1] Department of Physical Chemistry, University of Vienna, A
[2] Photonics Institute, Vienna University of Technology, A
[3] Medical Physics and Biotechnology, Medical University of Vienna, A

All-integrated modelocked Yb-fiber lasers are attractive for a wide range of applications, including micromachining, spectroscopy, metrology, nonlinear imaging, clinical applications etc. However, environmental instabilities such as external temperature changes, fiber bending and other mechanical perturbations have severe influences on the birefringent properties of non polarization maintaining (non-PM) fibers and hence may eventually result in loss of laser modelocking. A straightforward approach towards robust fiber laser is the implementation of all PM fiber cavity.

In this contribution, we demonstrate a semiconductor saturable-absorber-mirror (SESAM) modelocked all PM femtosecond fiber laser. A PM higher-order-mode (HOM) fiber has been used for the first time for intracavity dispersion compensation. With a 40 cm long highly Yb-doped PM fiber as gain medium, the oscillator delivers 0.45 nJ pulses at repetition rate of 12.0 MHz. The net cavity dispersion is close to zero and the oscillator operates in the weak stretched pulse regime. The output laser pulse can be externally recompressed down to 97 fs. To the best of our knowledge, it is the shortest pulse that can be generated from an all-PM Yb-doped fiber oscillator.

This novel all-PM fiber oscillator based on PM-HOM fiber has also been employed for seeding an all-PM monolithic Yb-doped fiber amplifier. The oscillator output pulse are first stretched in 100 m of PM single mode (SM) fiber, and then further amplified to the μJ level with a pre-amplifier plus a main power amplifier. Pulse compression through a Grism pair allows for achieving 121 fs pulses, which to our knowledge are the shortest pulses generated from such all-PM master-oscillator power-amplifier (MOPA) systems. The amount of stretching, combined with the use of a 12 μm core diameter power amplification stage limits the energy achievable for good compressible pulses to about 1 μJ. The use of fiber based intracavity dispersion compensation allows for easily achieving a fully monolithic oscillator architecture, and hence achieving an all-PM Yb-fiber MOPA without any free-space optical path.

References:
[1] X. Liu, J. Lægsgaard and D. Turchinovich, IEEE J. Sel. Top Quant., 18, 1439 (2012)
[2] L. Zhu et al., Opt. Express 21, 16255 (2013)
[3] S.H.M. Larsen et al., Opt. Lett. 37, 4170 (2012)
[4] A. Fernández, et al., Laser Phys. 21, 1329 (2011)
[5] A.J. Verhoef, et al., Opt. Express 22, 16759 (2014)

T1

Formation of self-organized LIPSS by irradiation with an ultra fast white light continuum

J. Reif, O. Varlamova, M. Ratzke, S. Uhlig

Department of Physics and Chemistry, Brandenburg University of Technology Cottbus-Senftenberg, D

Typical LIPSS structures were produced on silicon (periods between 500 and 650 nm), brass, copper, and stainless steel (period around 400 nm) by irradiation with pulses from an ultra fast (100 fs) white light continuum, spreading in wavelength from 400 to 750 nm. The ripples structures are closely similar to those generated by coherent 800 nm laser pulses, with respect to both variety of shapes (HSFL, LSFL, grooves, cones) and feature size (ripples wavelength). The ripples periods depend, clearly, on both, the material and the irradiation dose (number of pulses), increasing with increasing dose on silicon, decreasing on stainless steel. Given the CONTINUOUS excitation spectrum with very moderate power in narrow spectral intervals, it appears unlikely to attribute the structure formation to any interference effect. Instead, the results are in full agreement with our dynamic model of self-organized structure formation.

T2

Sub-100-nm periodic surface structures on titanium surface

C.S.R. Nathala[1,2], A. Ajami[1], A.A. Ionin[3], S.I. Kudryashov[3,4], S.V. Makarov[3,5], T. Ganz[2], A. Assion[2], W. Husinsky[1]

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[3] Lebedev Physical Institute, Russian Academy of Sciences, RUS
[4] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), RUS
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We will report on laser-induced periodic surface structures (LIPSS) on a titanium surface upon irradiation by linearly polarized femtosecond (fs) laser pulses in air. In particular, the dependence of high-spatial-frequency-LIPSS (HSFL) characteristics on various laser parameters (fluence, pulse number/scanning speed, pulse duration, wavelength, and polarization) will be discussed in detail. In comparison with near-wavelength periodic structures i.e., the so-called low-spatial-frequency-LIPSS (LSFL), the HSFLs emerge at much lower fluence with orientation perpendicular to the ridges of LSFLs. We observed that these two types of LIPSS demonstrate different fluence, shot number and wavelength dependencies, which suggest their origin is different. Therefore, HSFLs cannot be described by the widely accepted interference model developed for LSFLs.

Laser-generated periodic nano-structures

P. Simon[1], J.-H. Klein-Wiele[1], A. Blumenstein[1], J. Ihlemann[1], B. Rethfeld[2], D.S. Ivanov[3], M.E. Garcia[3]

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[2] Technical University of Kaiserslautern and OPTIMAS research center, D
[3] Theoretical Physics (FB10), University of Kassel, D

Nano-structured surfaces have gained a lot of attention because of their ability to give rise to a variety of new functionalities. These include super-hydrophobic behavior, particular tribological properties, field amplification capability, etc., holding great potential for numerous novel applications.

Various illumination strategies including interference techniques facilitating the generation of micro- and nano-structures on surfaces will be surveyed, putting the emphasis on the fabrication of deterministic textures with strictly periodic features. As will be pointed out, the use of ultraviolet radiation ensures a high spatial resolution and an ultra-short pulse duration offers further benefits in terms of precision and fidelity of the generated structures.

For being able to tailor the submicron structures for specific applications, a detailed understanding of the involved processes during fabrication is necessary. A comprehensive modeling of the generation of the structures will be discussed and a comparison between theoretical simulations and experimental findings will be presented.

Analysis of surface profiles, observed in single-pulse femtosecond LIPSS experiments

E.L. Gurevich

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Laser-induced periodic surface structures (LIPSS) can be found on the surface of metals, dielectrics and semiconductor materials processed with single and multiple femtosecond laser pulses. The existing models of the femtosecond LIPSS formation try to describe periodic modulation of the electron and ion temperatures. However the mechanism how the temperature profile can result in a periodically-modulated surface profile in such a short time (less than 1 nanosecond) is still not clear. Estimations made on the basis of different hydrodynamic instabilities allow to sort out some mechanisms, which can bridge the gap between the temperature and the surface profile formation.

T5

Superdiffusive spin transport: the route to ultrafast spintronics

M. Battiato

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The debate over the origin of the ultrafast demagnetization [1] has been intensively active for the past 16 years. Several microscopic mechanisms have been proposed but none has managed so far to provide direct and incontrovertible evidences of their validity. In this context we have proposed an approach based on spin dependent electron diffusion as the driver of the ultrafast demagnetization [2].

Recent experimental findings have revolutionized the field by confirming the existence of spin superdiffusion. We have shown that 1) spin diffusing away from a layer undergoing ultrafast demagnetization can be used to create an ultrafast increase of magnetization [3] in a neighboring magnetic layer, 2) optical excitation is not a prerequisite for the ultrafast demagnetization [4] and that spin unpolarized electrons superdiffusing into a ferromagnetic layer can trigger ultrafast demagnetization, and 3) superdiffusive spin currents can be tailored by appropriate choice of materials and used to produce broadband THz emission via the inverse spin Hall effect [5].

The impact of these new discoveries goes beyond the solution of the mystery of ultrafast demagnetization. It shows how spin information can be, not only manipulated, as shown 16 years ago, but most importantly transported at unprecedented speeds. This new discovery lays the basis for femtosecond spintronics.

References:

[1] E. Beaurepaire, J.-C. Merle, A. Daunois, J.-Y. Bigot, Phys. Rev. Lett., 76, 4250 (1996).
[2] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. Lett. 105, 027203 (2010).
[3] D. Rudolf,* C. La-O-Vorakiat,* M. Battiato,* R. Adam, J. M. Shaw, E. Turgut, P. Maldonado, S. Mathias, P. Grychtol, H. T. Nembach, T. J. Silva, M. Aeschlimann, H. C. Kapteyn, M. M. Murnane, C. M. Schneider, and P. M. Oppeneer, Nature Comm. 3, 1037 (2012).
[4] A. Eschenlohr,* M. Battiato,* P. Maldonado, N. Pontius, T. Kachel, K. Holldack, R. Mitzner, A. Föhlisch, P. M. Oppeneer, and C. Stamm, Nature Mater. 12, 332 (2013).
[5] T. Kampfrath, M. Battiato, P. Maldonado, G. Eilers, J. Nötzold, I. Radu, F. Freimuth, Y. Mokrousov, S. Blügel, M. Wolf, P. M. Oppeneer, and M. Münzenberg, Nature Nanotechnol. 8, 256 (2013).

Modeling of modification of dielectric materials with ultrashort laser pulses: New advantages and challenges

N.M. Bulgakova[1,2], V.P. Zhukov[3,4], Y.P. Meshcheryakov[5], I. Mirza[1], D. Rostohar[1], T. Mocek[1]

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The model based on Maxwell's equations supplemented with the equations for free electron plasma formation and laser-induced electric current has been applied to study ultrashort laser beam propagation in transparent solids for the bulk modification regimes. A wide range of irradiation conditions is analyzed with varying beam energy, pulse duration, and numerical aperture. The question is addressed on the balance between photo-ionization and collisional ionization processes as the function of irradiation conditions. A more correct expression for description of collisional ionization is proposed. By applying the thermoelastoplastic model, the final modification geometries are predicted for single pulse actions. The timescale of modification is clarified, based on numerical data of stress evolution.

The second part of the talk will compare the regimes of light focusing into the bulk and on the sample surface on the example of fused silica. The regimes of so-called cold ablation are addressed with a thorough analysis of the processes responsible for a subtle boundary, which separates matter from formation of hot electron plasma. Modeling is supported with the experimental studies of fused silica ablation involving various characterization techniques, including plasma spectrometry.

T7

Three-dimensional polymer scaffolds on flexible substrates for mechanical stimulation of bone-forming cells fabricated by two-photon polymerization

J. Heitz[1], M. Wiesbauer[1], P. Freudenthaler[1], R.-A. Barb[1], T.A. Klar[1], B. Magnus[2], R. Marksteiner[2], S. Innerbichler[3], and J. Fill[3]

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The aim of this work is the mechanical stimulation of bone-forming cells for production of oriented mineralized proteins like those occurring in bones. This shall be achieved by means of progenitor cells derived from human tissue seeded onto polymer micro-structures, which are exposed to oscillating tension and compression in a cell-stretcher. The polymer micro-structures are written onto a flexible substrate by the technique of two-photon polymerization by a Ti-sapphire femtosecond-laser which is focused into a liquid acrylate-based resin containing a photo-initiator.

T8

Laser printing of nanoparticles

B. Chichkov

Laser Zentrum Hannover, D

I will report on our recent progress in the development of laser printing technologies for fabrication of complex nanoparticle structures. Fabrication, characterization, and sensing applications of the nanoparticle arrays will be demonstrated and discussed.

T9

Hybrid subtractive and additive femtosecond laser micro-machining for highly functional biochip fabrication

F. Sima, D. Wu, J. Xu, K. Midorikawa, K. Sugioka

RIKEN-SIOM Joint Research Unit, RIKEN Center for Advanced Photonics, JP

True three-dimensionally (3D) integrated biochips are crucial for realizing high performance biochemical analysis and cell engineering, which remain ultimate challenges. Femtosecond laser is a promising tool for fabricating 3D biochips, since it can modify the interior of transparent materials in a space-selective manner due to multiphoton absorption and thereby to directly form flexible 3D microstructures inside the materials. We propose herein the “ship-in-a-bottle” integration of 3D polymeric patterns inside closed glass microchannles by a hybrid subtractive - additive femtosecond laser micromachining. It consists of Femtosecond Laser Assisted Wet Etching (FLAE) of a photosensitive glass followed by Two-Photon Polymerization (TPP) of a negative epoxy-resin which combines advantages of the both techniques, while compensates some drawbacks. Ultrashort lasers (λ = 522 nm, τ = 460 or 360 fs, υ = 100 or 200 kHz) are employed as they are very efficient for material processing in a 3D manner with high precision. The process allows lowering the size limit inside channels to smaller details, below dimension of a cell, and improves the structure stability giving the necessary robustness for assembling a concrete lab-on-a-chip device. Taking advantage of the ability to directly fabricate 3D complex shapes, both glass channels and polymeric integrated patterns could be 3D spatially designed for a specific application. In addition, the polymeric micro and nanostructure pattern integration inside microfluidic systems ensures the scale-down/scale-up aspects of a multi-functional microfluidic device and offers concrete functionalities such as nanomechanical manipulation on both 2D and 3D environments, increases sensitivity, allows optical visualization and eventually increases the performance of assembled devices. Concretely, a multifunctional filter-mixer device was designed and fabricated by TPP inside Y-shaped glass microchannels [1]. The biochip exhibited a good mixing efficiency of about 87.2%, which was applied to synthesize ZnO flower-like microparticle from zinc nitrate and ammonia water and proved its chemical reaction capacity. High-quality 2D-3D microoptical devices embedded in 3D glass microchannels were successfully fabricated for coupling-free white-light cell counting [2,3]. Polymer 3D micro and nano patterns for cellular migration, guiding, trapping and analysis were also integrated inside glass micro-channels. The adjustable glass and polymeric channel geometries and sizes enabling flexible control of diffusible gradients which could help in understanding single cell-type specific mechanical as well as signaling aspects during migration.

References:
[1] D. Wu, S. Z. Wu, J. Xu, L. G. Niu, K. Midorikawa, and K. Sugioka, Laser & Photonics Reviews, 8(3), 458-467 (2014);
[2] D. Wu, J. Xu, L.-G. Niu, S.-Z. Wu, K. Midorikawa, and K. Sugioka, Light: Science & Applications, 4(1), e228 (2015).
[3] D. Wu, L.-G. Niu, S.-Z. Wu, J. Xu, K. Midorikawa, and K. Sugioka, Lab Chip (in press).

T10

Ion migration assisted femtosecond laser writing for photonic devices

J. Solis, T.T. Fernandez, J. del Hoyo, J. Siegel

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Refractive index changes upon femtosecond (fs) laser writing are related to a variety of mechanisms like changes of the glass density, point defects, photochemical changes, changes of polarizability, or, in the case of crystalline materials, laser induced damage. With just a few exceptions, the refractive index contrast achievable is below 10^{-2}. The feasibility of inducing controlled migration of ions by fs-laser irradiation would thus open up new prospects for fabricating efficient integrated optical devices inside glasses.

Indeed, although element redistribution has been observed upon fs-laser irradiation in a variety glasses (mostly silica-based), evidence of local compositional changes leading to light guiding in the written structures has not been provided. Only recently, it has been shown that changes of the glass composition induced by fs-laser irradiation lead to production of extremely efficient active/passive waveguides in phosphate glasses with aluminum and lanthanum oxide glass modifiers. The refractive index changes are due to the cross migration of La and K ions leading to values in the 1.5 x 10^{-2} range.

In the presentation we will review our recent results regarding the use of ion migration for the production of guiding structures in functional glasses with special emphasis in the control that can be exerted over their characteristics (size, refractive index change and local composition). For such purpose, we will describe different results regarding local morphological, compositional, luminescent and structural properties of the laser-written structures by a variety of characterization techniques including optical microscopy, micro-photoluminescence, micro-Raman, X-rays microanalysis and near field refractometry. Recent results regarding the use of in situ plasma emission imaging during the writing process will also be presented in order to discuss the origin of the ion cross-migration phenomenon.

T11

Advances in spatial shaping of ultrafast laser beam for enhanced surface processing of materials

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Femtosecond laser processing permits bulk or surface modification of materials on a micrometer scale with reduced thermal effects. With the help of a wave front modulator, it is possible to modulate the laser intensity distribution in the processing plane. We demonstrate the interest of the technique in reducing the processing time and increase the machining flexibility. With the generation of multiple laser focal spots, surface texturing, bulk photoinscription and rapid cutting is demonstrated and compared to single spot machining [1,2]. We also investigate processing with controlled intensity distribution (arbitrary shapes) [3,4] and draw perspectives for advanced surface functionalization.

References:

[1] Dynamic ultrafast laser spatial tailoring for parallel micromachining of photonic devices in transparent materials, C Mauclair, G Cheng, N Huot, E Audouard, A Rosenfeld, IV Hertel, ... Optics express 17 (5), 3531-3542 (2009)

[2] Ultrafast laser micro-cutting of stainless steel and PZT using a modulated line of multiple foci formed by spatial beam shaping, C Mauclair, D Pietroy, Y Di Maïo, E Baubeau, JP Colombier, R Stoian, ... Optics and Lasers in Engineering 67, 212-217 (2015)

[3] Intensity profile distortion at the processing image plane of a focused femtosecond laser below the critical power: Analysis and counteraction, D Pietroy, E Baubeau, N Faure, C Mauclair, Optics and Lasers in Engineering 66, 138-143 (2015)

[4] Ultrafast laser machining of micro grooves on stainless steel with spatially optimized intensity distribution, C Mauclair, S Landon, D Pietroy, E Baubeau, R Stoian, E Audouard Journal of Laser Micro/Nanoengineering 8 (1), 11-14 (2013)

Poster Abstracts

P1

Dynamic polarization control for improved laser micro- and nano-structuring of surfaces

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Laser Induced Periodic Surface Structures (LIPSS) were generated on a range of materials: metals (stainless steel, copper, titanium), semiconductor (silicon) and thin film (ITO on glass), with dynamic control of laser process parameters to optimize structuring over large surface areas.

A femtosecond laser beam with a 775 nm central wavelength, 160 fs pulse width and 1 kHz repetition rate was scanned on sample surfaces, near the ablation threshold of the materials. To optimize surface structuring, a range of scan speeds, overscans and polarization orientations were tested. By using a fast response, analogue, liquid-crystal polarization rotation device, the direction of the linear polarization of the laser beam could be dynamically controlled and synchronized to scanning direction during laser processing. As a result, a range of complex micro- and nano-scale patterns with orthogonal direction of LIPSS were created. Dynamic polarization switching has been achieved with up to 128 Hz, which results in changing LIPSS orientation along each laser scanned track with a step resolution below 20 µm. The produced surface structures were analyzed with an optical microscope and a Scanning Electron Microscope (SEM), to confirm that high quality LIPSS were produced over large surface areas. Furthermore, the experimental results showed that the orientation of the LIPSS is always perpendicular to the laser beam polarization. Within the structured areas, optical properties such as diffraction are affected by LIPSS, and can be controlled by optimizing laser polarization. Furthermore, to measure the LIPSS orientation without the need for high NA microscopy, the structured surface areas were illuminated at grazing incidence. Analyzing light diffracted from the surfaces allowed to detect the orientation of LIPSS.

P2

Femtosecond Yb-doped fiber oscillator and microjoule-level amplifier based on a novel polarization-maintaining higher-order-mode fiber

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All-integrated modelocked Yb-fiber lasers are attractive for a wide range of applications, including micromachining, spectroscopy, metrology, nonlinear imaging, clinical applications etc. However, environmental instabilities such as external temperature changes, fiber bending and other mechanical perturbations have severe influences on the birefringent properties of non polarization maintaining (non-PM) fibers and hence may eventually result in loss of laser modelocking. A straightforward approach towards robust fiber laser is the implementation of all PM fiber cavity.

In this contribution, we demonstrate a semiconductor saturable-absorber-mirror (SESAM) modelocked all PM femtosecond fiber laser. A PM higher-order-mode (HOM) fiber has been used for the first time for intracavity dispersion compensation. With a 40 cm long highly Yb-doped PM fiber as gain medium, the oscillator delivers 0.45 nJ pulses at repetition rate of 12.0 MHz. The net cavity dispersion is close to zero and the oscillator operates in the weak stretched pulse regime. The output laser pulse can be externally recompressed down to 97 fs. To the best of our knowledge, it is the shortest pulse that can be generated from an all-PM Yb-doped fiber oscillator.

This novel all-PM fiber oscillator based on PM-HOM fiber has also been employed for seeding an all-PM monolithic Yb-doped fiber amplifier. The oscillator output pulse are first stretched in 100 m of PM single mode (SM) fiber, and then further amplified to the µJ level with a pre-amplifier plus a main power amplifier. Pulse compression through a Grism pair allows for achieving 121 fs pulses, which to our knowledge are the shortest pulses generated from such all-PM master-oscillator power-amplifier (MOPA) systems. The amount of stretching, combined with the use of a 12 µm core diameter power amplification stage limits the energy achievable for good compressible pulses to about 1 µJ. The use of fiber based intracavity dispersion compensation allows for easily achieving a fully monolithic oscillator architecture, and hence achieving an all-PM Yb-fiber MOPA without any free-space optical path.

References:

[1] X. Liu, J. Lægsgaard and D. Turchinovich, IEEE J. Sel. Top Quant., 18, 1439 (2012)
[2] L. Zhu et al., Opt. Express 21, 16255 (2013)
[3] S.H.M. Larsen et al., Opt. Lett. 37, 4170 (2012)
[4] A. Fernández, et al., Laser Phys. 21, 1329 (2011)
[5] A.J. Verhoef, et al., Opt. Express 22, 16759 (2014)

P3

FP7 Project MSP: Multi sensor platform for smart building management - Status and progress

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The MSP project is focused on the development of sophisticated devices and sensors as elements of a “tool-box” that are required for the realization of innovative smart multi-sensor systems capable for indoor and outdoor environmental monitoring:

- Gas sensors for detection of potentially harmful or toxic gases
- Sensors for particulate matter and ultrafine particles
- Development of IR sensors for presence and fire detection
- Development of highly efficient photovoltaic and piezoelectric devices for energy harvesting
- Development of light sensor and UV-A/B sensors
- Development of humidity and temperature sensors.

Major objective is the development of a powerful technology and manufacturing chain enabling flexible “plug-and-play” 3D-integration of devices and sensors on CMOS electronic platform chips. The multi-sensor system includes devices providing wireless communication between MSP nodes and from MSP nodes to users.

We present the progress achieved within the MSP-project where a variety of devices ranging from commercially available products and demonstrators systems to highly sophisticated devices have been developed. Concerning gas sensors the MSP project is focused on novel devices based on SnO_2, ZnO and CuO nanowires, nanoparticles, graphene, carbon nanotubes and AlGaN/GaN on MEMS technology fabricated micro-hotplates for detection of potentially harmful or toxic gases (CO, CO_2, VOCs, NO_2, O_3). A preliminary integration concept enabling 3D-stacking of the developed devices on a common CMOS platform chip has been developed. The 3D-integration concept includes both devices with TSV-based contact plugs as well as components requiring wire bonding, and enables realization of a “hybrid” 3D-integrated encapsulated MSP demonstrator system.

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P4

Generation of Functional Structures in Dielectrics on the Nanometer Scale via Shaped Femtosecond Laser Pulses

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In our experiments temporally shaped near-infrared femtosecond laser pulses are used for high precision laser processing of wide band gap dielectrics. In previous studies we have shown that by applying temporally asymmetric pulse trains ablation structures with sizes well below the diffraction limit are generated with high robustness [1-3]. Furthermore, detailed characteristics of the structures are of particular interest. Currently, we investigate tailoring the aspect ratio employing various pulse shapes.

In this contribution we present functional structures on the 100 nm scale generated by direct laser writing and discuss the potential for nanophotonic applications, e. g. the fabrication of spectral filters based on Fano resonances [4].

References:
[1] L. Englert, B. Rethfeld et al., Opt. Express 15, 17855–17862 (2007)
[2] M. Wollenhaupt, L. Englert et al., JLMN 4, 144–151 (2009)
[3] L. Englert, M. Wollenhaupt et al., J. Laser Appl. 24, 042002 (2012)
[4] T. Meinl, N. Götte et al., Proc. of SPIE 9126, 91262B-1 (2014)

P5

High throughput analysis of LIPSS produced by ultra-short laser pulses with variable parameters

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The investigation of laser induced periodic surface structures (LIPSS, "ripples") has been an evergreen over the last few decades and there is still a lively discussion about the mechanisms behind LIPSS generation [1,2].

We present our protocol for high throughput production and characterization of LIPSS, which includes hundreds of individually irradiated surface spots per scan and yields thousands of data points and can be accomplished within a few days.

Our setup, consisting of a confocal microscope setup with a high precision 3D translation stage and a homebuilt ultra-stable liquid crystal modulator based pulse shaper, provides the possibilities of varying a large number of experimental parameters such as pulse energy, number of pulses and pulse-shape parameters like pulse length or double pulse delay [3]. Based on SEM images the LIPSS period and the size of areas of different kinds of surface modification is analyzed.

Exemplarily shown are our measurements of LIPSS periods created on fused silica and titanium utilizing femtosecond double pulses with different delays, ranging from 0 ps up to 3.5 ps.

References:

[1] S. Höhm, M. Rohloff, A. Rosenfeld, J. Krüger, J. Bonse, Appl. Phys. A 110, 553 (2013)
[2] J. Reif, O. Varlamova, S. Uhlig, S. Varlamov, M. Bestehorn, Appl. Phys. A 117, 179 (2014)
[3] J. Köhler, M. Wollenhaupt, T. Bayer, C. Sarpe, T. Baumert, Opt Express 19, 11638 (2011)

P6

Hot electron electrochemistry induced by femtosecond laser pulses

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High intensity laser pulses can generate high densities of electrons in matter [1]. One technologically important follow-up process is the deterministic multiphoton-electron coupling [2-4]. In the present work, the generation of high densities of electrons in a solid by high intensity femtosecond laser pulses, the subsequent emission of hot electrons into an electrolyte and the thusly triggered electrochemistry of intermediates are studied as a function of laser and electrochemical parameters [5-8]. Results may lead to a new understanding of the fundamentals of fast hot electron electrochemical kinetics, intermediate species electrochemistry, and nanomedicine [9]. Furthermore, the influence of hot electron emission on materials machining with femtosecond laser pulses is investigated. This may lead to further understanding of laser pulse induced periodic surface structure formation processes [10].

References:
[1] D. Bäuerle, Laser Processing and Chemistry (Springer Verlag Berlin Heidelberg New York 2000).
[2] W. Kautek, J. Krüger, M. Lenzner, S. Sartania, C. Spielmann, F. Krausz, Appl. Phys. Lett. 69, 3146 (1996).
[3] M. Lenzner, J. Krüger, S. Sartania, Z. Cheng, C. Spielmann, G. Mourou, W. Kautek, F. Krausz, Phys. Rev. Lett. 80, 4076 (1998).
[4] J. Krüger, W. Kautek, Advances in Polymer Science, Vol. 168 (Springer Verlag Heidelberg 2004), p. 247.
[5] A.G. Krivenko, J. Krüger, W. Kautek, and V.A. Benderskii, Ber. Bunsenges. Phys. Chem. 99 (1995) 1489.
[6] A.G. Krivenko, W. Kautek, J. Krüger, and V.A. Benderskii, Russian J. Electrochem. 33 (1997) 394
[7] A.G. Krivenko, V.A. Benderskii, J. Krüger, and W. Kautek, Russian J. Electrochem. 33 (1998) 1068.
[8] V.A. Benderskii and A.V. Benderskii, Laser Electrochemistry of Intermediates, CRC Press 1995.
[9] A. Vogel, J.Noack, G. Hüttman, G. Paltauf, Appl. Phys. B 81 (2005) 1015.
[10] E.V. Zavedeev, A.V. Petrovskaya, A.V. Simakin, G.A. Shafeev, Quant. Electron. 36 (2006) 978.

P7

Laser induced damage of nanostructured materials

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Nanostructured targets offer new possibilities in the studying the interaction of very intense laser pulses with matter. One on hand field enhancement by plasmonic nano-antennas has been claimed to boost local laser field strengths, at the site of the interaction. We show, by looking at a set of exemplary metallic structures, that the threshold fluence F_{th} of Laser-induced Damage is a greatly limiting factor for the proposed and tested schemes along these lines. On the other hand one of the main fundamental problems for realization of the full potential for dense and hot plasmas production in laser-solid interaction is the shielding of laser radiation by plasma. Advance in nano-technologies and possibility to design solid targets with nanostructured surface offers a possibility to overcome this problem and opens new groundbreaking perspectives. Here we report on the first damage measurements of ZnO nanowires with different geometries, and discuss its role for future experiments.

P8

Probing and modeling optical properties of high band gap dielectrics excited by temporally shaped femtosecond laser pulses

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The generation of a high density free electron plasma is the first step in the laser ablation of high bandgap materials. We have demonstrated that tailored ultrashort laser pulses are suitable for robust manipulation of optical breakdown, increasing the precision of ablation to one order of magnitude below the optical diffraction limit [1-3].

In this study ionization mechanisms in water, as a prototype for high band gap materials, irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry [4]. From the information about the electron plasma and its dynamics the multiphoton and avalanche coefficients were determined. Our measurements directly prove that temporally asymmetric shaped pulses control the ionization mechanisms through which the free electrons are generated in high band gap transparent materials. In our recent experiments, we extended the investigation by measuring transmission and reflection coefficient of the pump pulse in order to reveal spatial properties of the ionization process driven via the different temporal pulse shapes. The results obtained, correlate to results from material processing on solid samples, which is strengthened by additionally measuring the beam profile of the transmitted pump pulse. We performed simulations, based on a generic rate equation model combined with propagation, which may deliver a comprehensive picture of this highly complex and dynamic interplay.

References:

[1] L. Englert et al., Opt. Expr. 15, 17855 (2007)
[2] L. Englert et al. JLA 24, 042002 (2012)
[3] Wollenhaupt et al., JLMN (2009) 4 (3), S. 144–151
[4] C. Sarpe et al., NJP 14, 075021 (2012)

P9

Real-time observation of transient electron density in high band gap materials irradiated with tailored femtosecond laser pulses

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The first step in laser ablation of high band gap materials is the generation of a high density free electron plasma. We have shown that tailored ultrashort laser pulses are suitable for robust manipulation of optical breakdown. By using these pulses the precision of femtosecond-laser machining results in microstructures one magnitude order below the optical diffraction limit [1-3].

Here we present our studies to investigate the early-time dynamics of a free electron plasma created by shaped femtosecond laser pulses in water, as a prototype for high band gap materials, by using a robust spectral interference technique with an enlarged temporal measurement window [4]. The phase shift between a reference and a probe pulse produced in a common-path interferometer gives accurate information about the density of the free electron plasma. The temporal evolution of the plasma is accurately observed and its dependence on the laser intensity and temporal pulse shapes is analyzed.

Recently, we improved our experimental setup in order to record the spectral interference on a one-dimensional slice through the interaction area to also reveal the spatial distribution of the free electron plasma [1-3].

References:
[1] L. Englert et al., Opt. Expr. 15, 17855 (2007)
[2] L. Englert et al. JLA 24, 042002 (2012)
[3] M. Wollenhaupt et al., JLMN (2009) 4 (3), S. 144–151
[4] C. Sarpe et al., NJP 14, 075021 (2012)

P10

Reconstitution of Quinone B with high redox potential vitamin derivatives in photochemical reaction centers

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Photochemical reaction centers absorb light and transfer electrons into the quinone cycle to generate electrochemical energy. Current enhancement will be investigated upon reconstitution of quinone a and b with high redox potential vitamins such as vitamin E and K derivatives, benzoquinone, phylloquinone, menaquinone and napthoquinones. Differing energy emissions will be determined and reviewed across existing scientific literature.

P11

Sub-30 fs femtosecond pulse laser irradiation area dependence of the modification behavior of silicon and polystyrene

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Modification thresholds are core parameters in laser materials processing [1] as well as for optical components [2] and telecommunication systems [3]. The threshold energy density (fluence) was found to be a material constant for a given set of experimental parameters such as pulse duration, wavelength, number of pulses and repetition rate. The modification threshold fluence however shows a dependence on the area that the laser pulse irradiates, both for femtosecond [2,4] and nanosecond [3] pulses.

The irradiation area dependence of the modification behavior of silicon and polystyrene with sub-30 fs-laser is investigated for various sizes of the irradiated area and various number of pulses. The results show different incubation behaviors depending on the material class.

References:

[1] F. Brandi, N. Burdet, R. Carzino, and A. Diaspro: Very large spot size effect in nanosecond laser drilling efficiency of silicon, Optics Express 18, 23488-23494 (2010).
[2] N. Sanner, B. Bussiere, O. Utéza, A. Leray, T.E. Itina, M. Sentis, J.Y. Natoli, and M. Commandré: Influence of the beam-focus size on femtosecond laser-induced damage threshold in fused silica, Proc. SPIE 6881, W8810-W8810 (2008).
[3] G. Mann, S. Pentzien, and J. Krüger: Beam diameter dependence of surface damage threshold of fused silica fibers and preforms for nanosecond laser treatment at 1064nm wavelength, Applied Surface Science 276, 312-316 (2013).
[4] S. Martin, A. Hertwig, M. Lenzner, J. Krüger, and W. Kautek: Spot-size dependence of the ablation threshold in dielectrics for femtosecond laser pulses, Applied Physics A 77, 883-884 (2003).

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