5th European Conference on Applications of Femtosecond Lasers in Materials Science

FemtoMat 2013

March 18 – 20, 2013
Mauterndorf Castle, Mauterndorf, Salzburg, Austria
http://www.nanoandphotonics.at/

Chair: Wolfgang Kautek

Organization Committee: Oskar Armbruster, Slavica Koprivica, Hannes Pöhl

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), and the

4th FemtoMat 2011, Mauterndorf, Salzburg, Austria, March 2011, is the basis of the present

5th FemtoMat 2013, 18 - 20 March 2013, at Mauterndorf, Salzburg, followed by the Nano and Photonics Conference Mauterndorf 2013, March 20 -22, 2013, 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 2013

Wolfgang Kautek
(University of Vienna)

Sponsors

Erwin Schrödinger Society for Nanosciences
Währinger Straße 42
A-1090 Vienna, Austria
Wolfgang Kautek
Tel.: +43 1 4277 52470
wolfgang.kautek@univie.ac.at
http://www.esg-nano.ac.at/

3D-Micromac AG
Technologie-Campus 8
D-09126 Chemnitz
Uwe Wagner
Tel.: +49 371 40043 14
gebhardt@3d-micromac.com
www.3d-micromac.com

PROTECT-Laserschutz GmbH
Mühlhofer Hauptstraße 7
D-90453 Nürnberg
Reinhard Naumann
Tel.: +49 911 96447 38
reinhard.naumann@protect-laserschutz.de
www.protect-laserschutz.de

LaserSkill Ltd.
Dóm tér 9.
H-6720 Szeged, Hungary
Tamás Szörényi
Tel: +36 30 536 6639
t.szorenyi@physx.u-szeged.hu
infoline@laserskill.com
http://www.laserskill.com/

Austrian Chemical Society
Working Group „Physical Chemistry“
Nibelungengasse 11/6
A-1010 Vienna, Austria
Wolfgang Kautek
Tel: +43 1 427 52470
wolfgang.kautek@univie.ac.at
http://www.goech.at/

European Association for Chemical and Molecular Sciences
EuCheMS Physical Chemistry Division
Avenue E. van Nieuwenhuyse 4
B-1160 Brussels, Belgium
Eckart Ruehl
Tel.: +49 30 838 52396
ruehl@chemie.fu-berlin.de
http://www.euchems.eu/divisions/physical-chemistry.html

University of Vienna
Department of Physical Chemistry
Währinger Straße 42
A-1090 Vienna, Austria
Wolfgang Kautek
Tel: +43 1 427 52470
wolfgang.kautek@univie.ac.at
http://pchem.univie.ac.at/

Conference Chairs

Eric Audouard
Université Jean Monnet, St. Etienne, France

Wolfgang Kautek
University of Vienna, Vienna, Austria

Javier Solis
Consejo Superior de Investigaciones Científicas (CSIC)
Madrid, Spain

Tamás Szörényi
College of Dunaújváros, Dunaújváros, Hungary

Programme

Monday, 18 March 2013

08:30 – 09:00 **Registration**

09:00 – 09:15 **Opening and Greetings**

09:15 – 09:45 MoM1 **N. Bulgakova**, V.P. Zhukov, Y.P. Meshcheryakov (University of Southampton, UK); Invited
"Ultrashort-pulse laser modification of transparent materials: Insight from inside"

09:45 – 10:15 MoM2 **W. Kautek**, O. Armbruster (University of Vienna, Wien, A)
"Non-thermal material response to laser energy deposition"

10:15 – 10:45 MoM3 **J. Boneberg**, A. Kolloch, P. Leiderer, E. Scheer (University of Konstanz, D); Invited
"Optical nearfield photography of nanostructures"

10:45 – 11:00 **Coffee**

11:00 – 11:30 MoM4 **N.A.Inogamov**, S.I. Anisimov, Yu.V. Petrov, V.A. Khokhlov, V.V. Zhakhovsky, Yu.N. Emirov, I.I. Oleynik, S.I. Ashitkov, M.B. Agranat, K.P. Migdal, D. Ilnitskiy (Russian Academy of Sciences, Moscow, RUS); Invited
"Femtosecond ablation: two-temperature stage, super-elastic shocks, and frozen nanostructures"

11:30 – 12:00 MoM5 **K. Sokolowski-Tinten** (University of Duisburg-Essen, D); Invited
"Time-resolved X-ray scattering studies of ultrafast phase transitions in laser-excited materials"

12:00 – 12:30 MoM6 **C. Spielmann** (Friedrich Schiller University Jena, D); Invited
"Towards studying femtosecond ablation dynamics with time-resolved x-ray spectroscopy"

12:30 – 16:00 **Free Discussion**

16:00 – 16:30 **Coffee**

16:30 – 17:30 **Poster Presentations.** Oral presentations, 5 min each

17:30 – 18:00 MoA1 **G. Grabner**, A. Dexl, J. Ruckhofer, H. Kraker, P. Sperl (Paracelsus Medical University Salzburg, A); Invited
"Femtosecond-Laser Surgery in Ophthalmology"

18:00 – 18:30 MoA2 **B. Chichkov** (Laser-Zentrum Hannover e.V., D); Invited
"Laser Printing of Nanoparticles and Living Cells"

18:30 – 19:00 MoA3 **J. Stampfl**, J. Torgersen, A. Ovsianikov, and R. Liska (Vienna University of Technology, A); Invited
"Functional photopolymers for two-photon-lithography"

Tuesday, 19 March 2013

08:30 – 09:00 TuM1 **M. Sentis**, O. Utéza, N. Sanner, M. Lebugle, R. Clady, N. Varkentina (Aix-Marseille University, Marseille, F); Invited
"Control of ultrafast energy deposition at the surface of dielectrics"

09:00 – 09:30 TuM2 **M. Lebugle**, N. Sanner, R. Clady, D. Grojo, O. Utéza, M. Sentis (Aix-Marseille University, Marseille, F)
"Femtosecond laser pulse absorption at the surface of dielectrics"

09:30 – 10:00 TuM3 **J. Siegel** (Instituto de Optica, CSIC, Madrid, SP); Invited
"Femtosecond microscopy of laser-produced plasmas in dielectrics: A tool for optimized fs laser processing"

10:00 – 10:30 TuM4 **C. Sarpe**, J. Köhler, T. Winkler, M. Wollenhaupt, **T. Baumert** (University of Kassel, D); Invited
"Real time observation of transient electron density in water irradiated with tailored femtosecond laser pulses"

10:30 – 10:45 **Coffee**

10:45 – 11:15 TuM5 **K.-M. Weitzel** (Philipps-Universität Marburg, Chemistry Department, D); Invited
"Chirality analysis of molecules by means of laser ionization employing circularly polarized fs laser pulses"

11:15 – 11:45 TuM6 **E. Stankevicius**, E. Balciunas, D. Baltriukiene, V. Bukelskiene, M. Malinauskas, G. Raciukaitis (Center for Physical Sciences and Technology, Vilnius, LIT); Invited
"Fabrication of scaffolds by interference lithography"

11:45 – 12:15 TuM7 **R. Carley**, J. Bowlan, K. Döbrich, B. Frietsch, M. Teichmann, J. Wolter, **M. Weinelt** (Freie Universität Berlin, D); Invited
"Ultrafast magnetisation dynamics of Gadolinium and Terbium viewed from their non-equilibrium band-structures"

12:15 – 16:00 **Free Discussion**

16:00 – 16:30 **Coffee**

16:30 – 17:00 TuA1 **H. Masuhara**, T. Sugiyama, K. Yuyama, A. Usman (National Chiao Tung University, Hsinchu, Taiwan); Invited
"Laser trapping assembling, scattering, and crystallization by CW and femtosecond lasers"

17:00 – 17:30 TuA2 **P. Simon**, J.-H. Klein-Wiele, J. Ihlemann (Laser-Laboratorium Göttingen e.V., D); Invited
"Laser writing of periodic nano-structures"

17:30 – 18:00 TuA3 **P. Kubis**, N. Li, T. Stubhan, F. Machui, **C.J. Brabec** (i-MEET Friedrich-Alexander-Universität Erlangen-Nürnberg, D); Invited
"High Resolution Laser Patterning of Organic Photovoltaic Devices"

18:00 – 18:30 TuA4 **J. Krüger**, C. Symietz, R. Gildenhaar, G. Berger (Federal Institut for Materials Research and Testing, Berlin, D); Invited
"Covering Ti6Al4V implant material with bioactive ceramics using femtosecond laser processing"

18:30 – 19:00 TuA5 **G.M. O'Connor**, N. Haustrup, C. McDonnell, A. Collins, D. Rostohar (National University of Ireland, Galway, IRL); Invited
"Short pulse laser ablation of very thin films on dielectric substrates for display applications"

Wednesday, 20 March 2013

08:30 – 09:00 WeM1 **J. Reif**, O. Varlamova, M. Bounhalli
(Brandenburgische Technische Universität, Cottbus, D); Invited
"Influence of Irradiation Dose on Laser-Induced Surface Nanostructures on Silicon"

09:00 – 09:30 WeM2 **E. Rebollar**, J.R. Vázquez de Aldana, I. Martín-Fabiani, M. Hernández, D.R. Rueda, C. Domingo, T.A. Ezquerra, P. Moreno, M Castillejo
(Instituto de Química Física Rocasolano, CSIC, Madrid, SP); Invited
"Assessment of Femtosecond Laser Induced Periodic Surface Structures on Polymer Films"

09:30 – 10:00 WeM3 **C. Mauclair**, Y. Di Maio, R. Stoian, D. Pietroy, E. Baubeau, E. Audouard
(Université Jean Monnet & Impulsion SAS, Saint-Etienne, F); Invited
"Increasing speed and flexibility of ultrafast laser micromachining with spatial beam shaping"

10:00 – 10:30 WeM4 **J. Heitz**
(Johannes Kepler University Linz, A); Invited
"Application of Laser-Induced Periodic Surface Structures (LIPSS) for activation of biological cells cultivated on polymer substrates and formation of gold nano- wires"

10:30 – 10:45 **Coffee**

10:45 – 11:15 WeM5 **E.L. Gurevich**
(Ruhr-Universität Bochum, D); Invited
"Turing-like Mechanism of Laser-Induced Periodic Surface Structures"

11:15 – 11:45 WeM6 **O. Armbruster**, M. Lovric, W. Kautek
(University of Vienna, A)
"The Role of Surface Energy on the Formation of High Spatial Frequency Laser-Induced Periodic Surface Structures"

11:45 – 12:00 **Closing Words**

Oral Abstracts

MoM1

Invited

Ultrashort-pulse laser modification of transparent materials: Insight from inside

N.M. Bulgakova,[1,2] V.P. Zhukov,[3] and Y.P. Meshcheryakov[4]

[1] University of Southampton, Optoelectronics Research Center, United Kingdom
[2] Institute of Thermophysics SB RAS, Novosibirsk, Russia
[3] Institute of Computational Technologies SB RAS, Novosibirsk, Russia
[4] Design and Technology Branch of Lavrentyev Institute of Hydrodynamics SB RAS, Novosibirsk, Russia

The processes initiated in transparent dielectrics by ultrashort pulse irradiation upon focusing inside the bulk are analyzed. The analysis is based on the modeling in the frames of Maxwell's equations supplemented with the equations for electron plasma formation and laser-induced electric current. On the case of fused silica, important features of laser beam propagation in the regimes of dense electron plasma generation are revealed such as complete displacing of laser light from the plasma region followed by beam refocusing. Density levels of free electron plasma generated inside bulk glass by ultrashort laser pulses are discussed. The energy balance of excited matter is considered with introducing a diagram matching the level of transient excitation with the maximum temperature of material matrix. The temperature and laser-induced stress upon material excitation are mapped which allow making conclusions on modification routes. We propose the mechanisms responsible for the formation of volume nanogratings in a number of transparent solids under the action ultrashort laser pulses. Finally the question on the material properties favorable for nanograting imprinting is addressed.

MoM2

Non-thermal material response to laser energy deposition

W. Kautek, O. Armbruster

University of Vienna, Department of Physical Chemistry, Vienna, Austria

A review on non-thermal material response processes to laser energy deposition is presented. Chemical reactions, phase transitions, and surface processes occur on timescales comparable to the natural oscillation periods of atoms and molecules, in the range of femtoseconds to picoseconds.

Ultrafast pulse laser energy deposition investigations have revealed that heat-affected zones become minimum because the excitation takes place faster than the electron-phonon-relaxation followed by several processes leading to ultraprecise machining results, but also new classes of physical, chemical and biological reactions, in which directed, deterministic motions of atoms have a key role. This contrasts with thermally activated processes across activation barriers that typically determine kinetic rates on slower timescales. On excitation with femtosecond laser pulses, the electrons and the lattice are driven far out of equilibrium and disordering of the lattice can occur.

Examples are the ultrafast melting of insulating and semiconducting solids arising from a strong modification of the inter-atomic forces owing to the laser-induced promotion of a fraction of the valence electrons to the conduction band. The atoms immediately begin to move and rapidly gain sufficient kinetic energy to induce melting at a time scale faster than that required to convert the electronic energy into thermal motions. Observables for such processes below or near the ablation threshold fluence F_{th} can be e.g. laser-induced periodic surface structures or ultrafast time-resolved X-ray diffraction that provides a direct probe of the changing atomic structure.

MoM3

Invited

Optical nearfield photography of nanostructures

J. Boneberg, A. Kolloch, P. Leiderer, and E. Scheer

University of Konstanz, Germany

The optical properties of nanostructures are a topic of current investigations. In analogy to the near-fields around a Hertz dipole we expect near-fields in the surrounding of all nanostructures. To visualize these near-fields we use a method called “optical near-field photography”. In our experiments we use e.g. silicon as substrate. The nanostructures, in this case gold triangles, on the substrate are illuminated with a single femtosecond laserpulse. The intensity is adjusted such that no influence of the illumination is detectable on the bare substrate. When illuminating arrays of nanostructures we observe ablation of the substrate below the gold triangles due to the local intensity enhancement in the optical nearfield. We show that the optical nearfield distribution depends critically on the size, shape and height of the structures.

MoM4

Invited

Femtosecond ablation: two-temperature stage, super-elastic shocks, and frozen nanostructures

N.A. Inogamov,[1] S.I. Anisimov,[1] Yu.V. Petrov,[1] V.A. Khokhlov,[1] V.V. Zhakhovsky,[2] Yu.N. Emirov,[2] I.I. Oleynik,[2] S.I. Ashitkov,[3] M.B. Agranat,[3] K.P. Migdal,[4] and D. Ilnitskiy[4]

[1] Russian Academy of Sciences, Landau Institute for Theoretical Physics
[2]University of South Florida, USA
[3] Russian Academy of Sciences, Joint Institute for High Temperatures
[4] Dukhov All-Russian Science Research Institute of Automatics, Moscow, Russia

We consider processes caused by femtosecond laser irradiation. Femtosecond laser pulse, with absorbed fluence higher than few mJ cm^{-2}, transfers metal into two-temperature state. We consider properties of this state. Two-temperature relaxation lasts few picoseconds. Heating by laser initiates formation of shocks propagating into solid. We show that crystal survives in an uniaxially compressed state behind such shocks at unusually high stresses. Ablation of metals is also addressed. Processes of melting, cavitation, rupture of nanofoam, and freezing of surface structures are described.

MoM5

Invited

Time-resolved X-ray scattering studies of ultrafast phase transitions in laser-excited materials

K. Sokolowski-Tinten

University of Duisburg-Essen, Germany

Irradiation of solid materials with intense femtosecond laser pulses can induce phase transitions on very short time scales, and often along non-equilibrium pathways. The advent of ultrafast diffraction techniques has made it possible to directly follow the associated structural changes with spatial and temporal atomic scale resolution. This contribution will report about experiments carried out at the Linear Coherent Light Source (LCLS), the world's first hard X-ray free electron laser. Using time-resolved diffuse X-ray scattering we studied the structural response of materials undergoing rapid phase transitions after strong femtosecond excitation. Thin films of solid materials deposited onto free standing Si_3N_4-membranes have been irradiated by 50 fs, 800 nm optical laser pulses. Subsequently the scattering of a time-delayed 50 fs, 9.5 keV X-ray pulse from the LCLS has been observed in normal-incidence transmission geometry. The measurements covered a large range of scattering angles and the scattering data provide, therefore, information about the transient structural changes of the irradiated material on different length scales. Examples to be discussed include laser-induced melting and ablation, as well as the structural dynamics in phase change materials used for optical recording.

MoM6

Invited

Towards studying femtosecond ablation dynamics with time-resolved x-ray spectroscopy

C. Spielmann

Friedrich Schiller University Jena, Institute of Optics and Quantum Electronics,
Abbe Center of Photonics, Jena, Germany

The advent of ultrafast lasers opened up the way to ultrahigh-precision material ablation allowing sub-micron resolution with minimized heat affected zone. Future research in this area will be centered on optimization of the process parameters to achieve the best performance and understand the underlying physics of the laser matter interaction. In the latter topic are many open questions, which must be addressed prior to a systematic optimization. E.g. to remove material from the surface a change of the fundamental state of aggregation must take place. Transitions between aggregation states are often accompanied by other changes of the physical and chemical character of the material and must be studied on their natural time and length scale, which are femtoseconds and Angstroms, respectively. However, due to long wavelength and/or the accompanying plasma absorption time-resolved optical spectroscopy has its limitation. Further insight can only be gained by probing the dynamics with time resolved x-ray spectroscopy. In this talk I will report on the recent progress on the development of matched femtosecond x-ray sources and report on the first x-ray spectroscopic investigations.

MoA1

Invited

Femtosecond-Laser Surgery in Ophthalmolgy

G. Grabner, A. Dexl, J. Ruckhofer, H. Kraker, and P. Sperl

Paracelsus Medical University, University Eye Clinic, Salzburg, Austria

The fs-laser has found broad clinical applications in ophthalmology since more than a decade. First in corneal and refractive surgery (in use at the clinic over five years), but over the last two years also new, very complex systems have been developed for cataract surgery. The later system has been in use at the Salzburg eye clinic since 5 months. The results and implications for a wider acceptance in the field of eye surgery will be presented and discussed.

MoA2

Invited

Laser Printing of Nanoparticles and Living Cells

B. Chichkov

Laser Zentrum Hannover e.V., Hannover, Germany

I will report on our recent progress in the development of laser printing technologies for applications in photonics and regenerative medicine.

MoA3

Functional photopolymers for two-photon-lithography

J. Stampfl, J. Torgersen, A. Ovsianikov, and R. Liska

Vienna University of Technology, Austria

Additive manufacturing techniques (AMT) have found increasing interest for the fabrication of 3D scaffolds. The constructs can be produced reproducibly and in accordance to a CAD model. Lithography based techniques are especially interesting, since they allow the fabrication of scaffolds with excellent feature resolution down to 100 nm. In addition, the manufacturing process can be performed in the presence of living cells. The cells can be introduced by two different ways into the construct: seeding of cells onto the surface after the fabrication and incorporation of cells into the fabrication process. The latter might allow higher cell densities and better control over the distribution.

Two-photon polymerisation (2PP) is a rapidly emerging platform for the 3D microfabrication of biocompatible scaffolds. Most biological tissues exhibit a window of transparency at the wavelength of the applied femtosecond laser.

In this work, two classes of photopolymers, both of them compatible with lithography-based AMT, are presented. Hydrogels based on synthetic (PEGDa) and natural monomers (Gelatine Hydrolisate, Bovine Serum Albumin) are presented. Using novel water-soluble 2PP initiators (4,4'-dialkylamino bis(styryl)benzene core), complex 3D constructs can be fabricated reproducibly in environments with high water contents. As second class of materials, photopolymers with low toxicity, based on vinylesters and vinyl-carbamates as reactive group, are introduced.

The biocompatibility of the presented compounds is evaluated and reported. We demonstrate the feasibility and potential of two-photon polymerisation for the bio-fabrication of 3D tissue constructs directly in the presence of living cells.

TuM1

Invited

Control of ultrafast energy deposition at the surface of dielectrics

M. Sentis, O. Utéza, N. Sanner, M. Lebugle, R. Clady, and N. Varkentina

Aix Marseille Université, CNRS
LP3 – Laboratoire Lasers, Plasmas et Procédés Photoniques, UMR 7341, France

Efficient use of lasers for material processing at submicron scale requires a deep knowledge of complex phenomena such as carrier excitation, thermalization, carrier removal, thermal and structural effects governing the interaction of laser radiation with matter and the mechanisms of laser ablation. For this goal, numerous experimental and theoretical studies of laser-matter interaction have been carried out by many researchers. Considering femtosecond laser interaction with dielectrics, the laser field excites the electrons from valence to conduction band by two phenomena: photoionization (including multiphoton ionization and tunnel effect) followed by Joule heating and avalanche (impact) ionization. The laser energy deposition in the material is a highly non-equilibrium process, meaning that the free electron plasma is "hot" and lattice is "cold" or "frozen" during laser-matter interaction (T_e >> T_i). In order to gain deeper insights of mechanism of laser-matter interaction and ablation dynamics in femtosecond regime, the present talk will be focused on the precise determination of the balance of energy deposition of femtosecond lasers with dielectrics. The results are particularly relevant to high precision 2D and 3D laser micromachining.

TuM2

Femtosecond laser pulse absorption at the surface of dielectrics.

M. Lebugle, N. Sanner, R. Clady, D. Grojo, O. Utéza, and M. Sentis

Aix Marseille Université, CNRS
LP3 – Laboratoire Lasers, Plasmas et Procédés Photoniques, UMR 7341, France

The interaction of intense, ultra-short laser pulse with a dielectric medium is studied experimentally (ASUR facility). Peak intensities achieved at the focal point are typically between 100 and 1000 TW cm^{-2}. The possible combination of non-linear photoionization channels and impact ionization process leads to the formation of a self-generated plasma in a very thin layer at the dielectric boundary. During the propagation of the laser pulse, the electron plasma density evolves from sub-critical to over-critical, leading to a strong spatio-temporal dependence of the linear and non-linear absorption by the medium. If the peak intensity is high enough, the over-dense plasma may act as an Ultra-fast Optical Shutter (UOS), reflecting the trailing part of the pulse and saturating the absorption in an effective optical skin depth, which stops any further energy deposition.

Recent experimental results concerning the energy balance of a single 30 fs-pulse interacting at the surface of dielectrics are presented. We measure observables as the fractional transmission and reflection (specular and diffuse), leading to the estimated material absorbed fraction. Fluence is varied over a wide range (from a few mJ cm^{-2} up to 10 J cm^{-2}) to put into evidence absorption and ionization mechanisms potentially leading to damage and/or ablation of the material. Input pulse second-order spectral phase is also varied to analyse effects linked to the pulse duration. Excitation mechanisms and their possible influences will be then discussed.

Finally, a morphological analysis of our samples is performed, in order to provide practical guidelines for optimization of ultrafast micromachining applications.

TuM3

Invited

Femtosecond microscopy of laser-produced plasmas in dielectrics: A tool for optimized fs laser processing

J. Siegel

Consejo Superior de Investigaciones Científicas (CSIC)
Laser Processing Group, Instituto de Optica, Madrid, Spain

The talk will provide an overview of our recent work on the use of femtosecond time-resolved microscopy for studying the interaction of ultrashort laser pulses with glasses and other dielectrics. The technique constitutes a powerful tool for imaging laser-induced free-electron plasmas, assessing their dynamics (formation and decay) and spatial distributions, as well as quantifying their densities. This technique can be adapted to experimental configurations of fs-laser processing for the fabrication of high precision micro-/nanostructures as well as integrated photonics devices.

Applied to surface processing, fs microscopy has the capability to establish a relation between transient local plasma densities and the crater depth or changes in the optical properties of the material. This becomes especially important when searching for an optimum temporal pulse shape for tailored processing. When applied to bulk processing inside dielectric materials, the technique proves to be a powerful tool for optimizing the structures produced. In particular, it has unveiled a number of complex interaction mechanisms including non-linear self-focusing, multiple beam filamentation, and pre-focal energy depletion, which act as important energy loss channels and deteriorate the spatial distribution and confinement of the deposited laser energy. We show how these undesirable effects can be minimized by adjusting the processing parameters. As a consequence, the energy can be deposited much more efficiently and confined in the linear focal volume region, leading to structures with optimized performance.

TuM4

Invited

Real time observation of transient electron density in water irradiated with tailored femtosecond laser pulses

C. Sarpe, J. Köhler, T. Winkler, M. Wollenhaupt, and T. Baumert

Universität Kassel, Institut für Physik und CINSaT, Kassel, Germany

Ionization mechanisms in water irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry. By using a novel common-path interferometer with an enlarged temporal measurement window we observe directly the dynamics of a free electron plasma generated by shaped pulses. We found that a temporally asymmetric pulse and its time reversed counterpart address multiphoton and avalanche ionization mechanisms in a different fashion. Positive third-order dispersion shaped pulses produce a much higher free electron density than negative ones at the same fluence, instantaneous frequency and focusing conditions. From the experimental data obtained after irradiation with bandwidth-limited and shaped pulses the multiphoton and avalanche coefficients were determined using a generic rate equation. We conclude that temporal tailored femtosecond pulses are suitable for manipulation of the initial steps in laser processing of high band gap materials.

TuM5

Invited

Chirality analysis of molecules by means of laser ionization employing circularly polarized fs laser pulses

K.-M. Weitzel

Philipps-Universität Marburg, Department of Chemistry, Marburg, Germany

The distinction of enantiomers in chemical mixtures is one of the key challenges in modern chemical analytics. We have recently demonstrated the determination of circular dichroism (CD) in ion yields by femtosecond laser ionization mass spectrometry (fs LIMS) [1] and investigated the influence of the pulse duration on the CD in ion yield [2]. In that investigation, and in comparable ns laser experiments [3], a resonance enhanced multiphoton ionization (REMPI) process has been employed. Consequently, the value and the sign of the observed CD effect are dominated by the initial resonant absorption step. Since it is impossible to simultaneously match the resonance conditions of all chiral compounds in a mixture, we became interested in the feasibility of observing CD effects in non-resonant ionization processes. For this purpose we have studied the CD in ion yield for fs LIMS of propylene oxide at central laser wavelength between 740 and 880 nm [4]. We were able to demonstrate pronounced CD effects. However, the sign of the CD observed was not compatible with resonance excitation schemes. Most recently, we have been able to demonstrate that the sign of the CD in fs LIMS of propylene oxide at 810 nm is identical for all fragment ions, but different from that of the parent ion [5]. This observation is different from all information available from photoelectron CD (PECD) spectroscopy [6] or any other resonance situation. The origin is probably connected to the peculiarities of femtosecond excitation possibly involving the generation of electronic wavepackets.

References:

[1] ChemPhysChem 10 (2009) 1199
[2] Phys. Chem. Chem. Phys. 13 (2011) 2378
[3] ChemPhysChem 12 (2011) 1940
[4] Z. Phys. Chem. 225 (2011) 587
[5] Chirality 24 (2012) 684
[6] J. Phys. Chem. A 114 (2010) 847

TuM6

Invited

Fabrication of scaffolds by interference lithography

E. Stankevicius,[1] E. Balciunas,[2] D. Baltriukiene,[2] V. Bukelskiene,[2] M. Malinauskas,[3] G. Raciukaitis[1]

[1] Center for Physical Sciences and Technology, Vilnius, Lithuania
[2] Vilnius University, Institute of Biochemistry, Vilnius, Lithuania
[3] Vilnius University, Laser Research Center, Vilnius, Lithuania

Scaffolds fabricated from di-acrylated poly(ethylene glycol) with the molecular weight of 258 (PEG-DA-258) over a large area by interference lithography technique are presented in this presentation. This approach significantly reduces the scaffolds fabrication time due to ability to form a periodic structures over a large area by a single laser exposure. By extending the periodic structure it is possible to form 2D scaffold with appropriate size for surgery (dimensions of 5 mm x 5 mm and more) in a few minutes.

The PEG-DA scaffolds fabricated by interference lithography showed good cytocompatibility for rabbit myogenic stem cells. It was observed that adult rabbit muscle-derived stem cells grew onto PEG-DA-258 scaffolds. They were attached to the pillars and formed cell-cell interactions. It demonstrates that the fabricated structures have potential to be an interconnection channel network for cell-to-cell interactions, flow transport of nutrients and metabolic waste as well as vascular capillary ingrowth.

TuM7

Invited

Ultrafast magnetisation dynamics of Gadolinium and Terbium viewed from their non-equilibrium band-structures

R. Carley,[1,2] J. Bowlan,[1] K. Döbrich,[2] B. Frietsch,[1,2] M. Teichmann,[1,2] J. Wolter,[1] and M. Weinelt[1]

[1] Freie Universität Berlin, Germany.
[2] Max-Born-Institut, Berlin, Germany.

The laser-driven ultrafast demagnetization dynamics of the rare earth ferromagnets gadolinium and terbium show distinct behavior. We have studied the non-equilibrium band structures of Gd and Tb in the 3rd Brillouin zone with time and angle-resolved photoemission experiments, using high-order harmonics as a source of femtosecond XUV pulses. By following the temporal evolution of the spin-split valence bands individually, we are able to separate the different processes acting during demagnetization, namely spin transport and electron-phonon scattering, while simultaneously monitoring the magnetization via the exchange splitting. We find that the dynamics of the electron-phonon scattering is very similar in Gd and Tb, while the spin transport accounts for their differences.

TuA1

Invited

Laser trapping assembling, scattering, and crystallization by cw and femtosecond lasers

H. Masuhara, T. Sugiyama, K. Yuyama, and A. Usman

National Chiao Tung University, Taiwan, and
Instrument Technology Research Center, Taiwan

Most of laser trapping studies have been carried out by focusing CW laser inside solutions and assembling of various kinds of polymers and nanoparticles are demonstrated. In our laboratory we focus trapping lasers at the solution surface and the interface between solution and sample cell, and have achieved successfully crystallization and liquid-liquid phase separation of amino acids, respectively. This laser trapping crystallization provides one single crystal at the focus, realizes crystallization from unsaturated solution, and makes it possible to control crystal polymorph [1]. Concerning laser trapping by femtosecond laser, it is believed that its dynamics is similar to those by CW laser. Most of the experiments were carried out for microparticles, however, quite recently we have found for nanometer-sized targets that unconventional tapping behaviors are induced by pulsed lasers. These resent results will be presented and discussed [2].

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TuA2

Invited

Laser writing of periodic nano-structures

J.-H. Klein-Wiele, J. Ihlemann, and P. Simon

Laser-Laboratorium Göttingen e.V., Göttingen, Germany

It is well known that micro and nano-structured surfaces give rise to a variety of new functionalities including super-hydrophobic behaviour, particular tribological properties, field amplification capability, etc., holding great potential for numerous novel applications. Various processing strategies facilitating the generation of micro- and nano-structures on the surface of technologically important materials will be surveyed.

Special emphasis is put on the fabrication of deterministic nano-structures with strictly periodic features. In order to ensure a high spatial resolution for the generation of sub-micron structures, in all cases short wavelength (ultraviolet) radiation is used. Special benefits of the combination of short pulses with short wavelength radiation will be pointed out.

For the processing of surfaces, different types of interference techniques will be presented. The applied schemes include the use of special multi-level diffractive optical elements, immersion proximity printing, phase controlled multiple beam interference, and grating-interferometer arrangements. The unique capabilities of the various processing techniques will be discussed. The presented new approaches facilitate rapid generation of periodic surface structures via parallel laser processing.

TuA3

Invited

High Resolution Laser Patterning of Organic Photovoltaic Devices

P. Kubis, N. Li, T. Stubhan, F. Machui, and C.J. Brabec

Friedrich-Alexander-University Erlangen-Nuremberg
Institute of Materials for Electronics and Energy Technology (I-MEET), Erlangen, Germany

We demonstrate that laser patterning of organic solar cells by ultrafast laser systems (pulse length < 350 fs) is an attractive process to produce photovoltaic modules with outstanding high geometric fill factors. Moreover, in terms of precision, registration, debris generation and in terms of keeping the damage to the underneath layers at a minimum, ultrafast laser patterning with a pulse length of few 100´s of femtoseconds turn out to yield superior results. Ablation of all three different solar cell layers (electrodes, interfaces & semiconductor - P1, P2, P3) is achieved with a single wavelength simply by an adjustment of the laser fluence and the patterning overlap. Camera positioning allows a precise registration between the various processing steps and to reduce the width of the overall interconnection regime to the hundreds of micrometers dimension, resulting in high geometrical fill factors of over 83 % for monolithically interconnected organic solar cell modules.

TuA4

Invited

Covering Ti_6Al_4V implant material with bioactive ceramics using femtosecond laser processing

C. Symietz, R. Gildenhaar, G. Berger, and J. Krüger

Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany

Bone implants often made of titanium or a titanium alloy need to be surface treated to become bioactive. This enables the formation of a firm and durable connection of the prosthesis with the living bone. We present a new method to cover the alloy Ti_6Al_4V with a thin layer of a ceramic that imitates bone material. Calcium alkali phosphates (called Ca10 and GB14) are applied to the metal by dip coating into an aqueous slurry containing the fine ceramic powder. The dried samples are illuminated with a 800 nm femtosecond laser. If the laser fluence is set to a value just below the ablation threshold of the ceramics the 30 fs laser pulses penetrate the partly transparent ceramic layer without damaging it. The remaining laser fluence at the ceramic-metal interface is high enough to generate a thin metal melt layer. Only the ceramic particles in contact with and fixed onto the metal withstand ultrasonic cleaning, the rest of the layer is washed off. The main advantage of this new method is its gentle treatment of the material. There is no melting of the ceramic. Additionally, recent measurements of the rotating bending fatigue strength prove that the metal is left mechanically unharmed.

TuA5

Invited

Short pulse laser ablation of very thin films on dielectric substrates for display applications

G.M. O'Connor, N. Haustrup, C. McDonnell, A. Collins, and D. Rostohar

National University of Ireland, NCLA Laboratory, School of Physics, Galway, Ireland

New touch sensitive display technologies are transforming the way information is obtained and shared throughout the connected world. The developments are principally based on the deposition and structuring of very thin films on high quality, and increasingly thin, dielectric substrates. The objective of this presentation is to explore the opportunities for short pulse laser material interactions in the future production of such components.

High average power short (nanosecond) and ultra short (picosecond, femtosecond) pulse lasers offer significant potential to realize new solutions for future sustainable and adaptable production of new display technologies. The ability to structure very thin films (thickness < 50 nm) with minimal damage to the dielectric substrates on which they are deposited is a key technical challenge; these opportunities and challenges will be first described. A discussion on the range of current and future materials will follow. The absorption of laser light by such materials is a key consideration in the optimal ablation of very thin materials with minimal damage to substrates. The thermalisation of the absorbed laser energy will then be considered. This is particularly important in materials with characteristic length scales on the order of nanometers; it also determines the ablation mechanism. Finally, the post ablation of reconstruction of the laser structured surface will then be described. The review of the laser ablative process will highlight the importance of tailoring the delivery of laser energy to suit the ablation of very thin materials. The hypotheses presented will be supported by new experimental results on ablation of indium tin oxide, nickel and gold thin films deposited on dielectric substrates.

WeM1

Influence of Irradiation Dose on Laser-Induced Surface Nanostructures on Silicon

O. Varlamova,[1] M. Bounhalli,[1,2] and J. Reif[1]

[1] Brandenburgisch Technische Universität (BTU) Cottbus and Cottbus JointLab, Germany
[2] Université Jean-Monnet, Laboratoire Hubert Curien, St.Etienne, France

The irradiation-dose greatly influences the features of laser-induced surface nanostructures ("ripples", LIPSS). At comparably low dose, most of the irradiated area is covered by a pattern of rather regular fine ripples, perpendicular to the laser polarization. Additionally, a coarser, almost perpendicular, over-structure is cutting the ripples into sectional domains. The ripples are interconnected with uncorrelated ladders of fine lines parallel to the polarization. At higher total dose, the edge (in the wing of the Gaussian beam profile), which was not affected at low dose, displays similar features as the center at low dose. In the center, however, the former interconnects evolve to a coarser pattern parallel to the polarization, the former ripples now acting as an interconnecting ladder structure. At very high dose, a crater is formed, still showing regular structures: at the slopes there are still long ripples-like features, oriented again perpendicular to the polarization. This crater is surrounded by a ring of tip-like features, continuing the tops of the wall structures. The outer edge shows low-dose fine ripples.

WeM2

Invited

Assessment of Femtosecond Laser Induced Periodic Surface Structures on Polymer Films

E. Rebollar,[1] J.R. Vázquez de Aldana,[2] I. Martín-Fabiani,[3] M. Hernández,[3] D.R. Rueda,[3] C. Domingo,[3] T.A. Ezquerra,[3] P. Moreno,[2] and M. Castillejo[1]

[1]Instituto de Química Física Rocasolano, IQFR-CSIC, Madrid, Spain
[2]Grupo de Investigación en Microprocesado de Materiales con Láser, Universidad de Salamanca, Spain
[3]Instituto de Estructura de la Materia, IEM-CSIC, Madrid, Spain

Laser induced periodic surface structures (LIPSS) obtained upon femtosecond irradiation are being studied intensively in the last few years in many different materials. However, very little work has been reported on polymers. In this study, thin films of different polymers were irradiated with the fundamental (795 nm) and the 3rd harmonic (265 nm) of a linearly polarized Ti:Sapphire laser at fluences well below the ablation threshold, giving rise to the formation of LIPSS with periods close to the laser wavelength and parallel to its polarization direction.

LIPSS were characterized by atomic force microscopy and grazing incidence small angle x-ray scattering (GISAXS), and comparison of experimental and simulated GISAXS patterns suggests that LIPSS can be suitably described considering a quasi-one-dimensional paracrystalline lattice, and that irradiation parameters influence the order of such a lattice. Fluorescence measurements provide information about the dynamics and structure of the polymer at molecular level during and after laser irradiation. For LIPSS formation the temperature reached at the surface upon laser irradiation, must surpass the glass transition temperature of the polymer.

WeM3

Invited

Increasing speed and flexibility of ultrafast laser micromachining with spatial beam shaping

C. Mauclair, Y. Di Maio, R. Stoian, D. Pietroy, E. Baubeau, and E. Audouard

Université Jean Monnet, Laboratoire Hubert Curien, Saint-Etienne, France
Impulsion SAS, Saint-Etienne, France

Femtosecond laser machining is a well known technique for bulk or surface modification of materials on a micrometer scale with reduced thermal effects. Spatial shaping of the laser beam with the help of a wave front modulator permits to modulate the intensity distribution on the sample. We have employed this technique to multiply the number of laser processing spots yielding a significant increase of the processing speed and flexibility. Results of laser machining for bulk modification of transparent materials, surface texturing of metals and cutting are presented. We also investigate the generation of continuous beam shapes of arbitrary forms and their effect on surface micro machining. These arbitrary intensity distributions appear as an efficient tool for advanced surface architectural design on a micrometer scale.

WeM4

Invited

Application of Laser-Induced Periodic Surface Structures (LIPSS) for activation of biological cells cultivated on polymer substrates and formation of gold nano-wires

J. Heitz

Johannes Kepler University Linz, Institute of Applied Physics, Austria

Frequently observed structures in laser-surface processing are ripples, also denoted as laser-induced periodic surface structures (LIPSS). Ripples originate from the interference of the incident/refracted laser light with the scattered or diffracted light near the surface. For many polymer surfaces, organized nano-ripple structures surfaces can be induced by irradiation with pulsed UV lasers with pulse lengths in the order of some nanoseconds at fluences well below the ablation threshold and with a large number of laser pulses *N*. After exposure to linearly polarized radiation at normal incidence, the lateral period of the observed LIPSS is close to the wavelength λ. This type of structures is usually called low spatial frequency LIPSS (LSFL). For femto-second laser light, ripples at polymer surfaces are also observed at a laser fluence above the ablation threshold, even with low numbers of laser pulses *N*. Under special conditions, another type of ripples with periods as small as λ/3 has been reported. This type of ripples is called high spatial frequency LIPSS (HSFL). I wil summarize our work on LIPSS generation at polymers. A special focus of the talk will be the potential applications of LIPPS structures on polymers for activation of biological cells cultivated on polymer substartes and for self-organized formation of gold nano-wires.

WeM5

Turing-like Mechanism of Laser-Induced Periodic Surface Structures

E.L. Gurevich

Ruhr-Universität Bochum, Applied Laser Technology, Bochum, Germany

Self-organised patterns also known as Laser-Induced Periodic Surface Structures (LIPSS) are often observed upon femtosecond laser ablation of metallic and insulating surfaces. However the mechanisms of pattern formation in this system as well as control strategies and properties of the pattern are still not understood. Commonly these surface structures are attributed to interaction between the incident laser light and surface plasmons excited on the surface.

Here we suggest a different mechanism, which may be responsible for the formation of the periodic pattern on the surface. In particular we adopt the theory developed for the self-organised patterns in the Belousov-Zhabotinski chemical reactions to the femtosecond laser ablation physics.

WeM6

The Role of Surface Energy on the Formation of High Spatial Frequency Laser-Induced Periodic Surface Structures

O. Armbruster, M. Lovric, and W. Kautek

University of Vienna, Department of Physical Chemistry, Austria

The mechanism of high spatial frequency laser-induced periodic surface structure (HSFL) formation is controversially discussed, such as by interference effects along with transient changes in the optical properties [1], second harmonic generation [2, 3], surface excited waves [4], transient nanoplasmonic near-field enhancements [5], or self-organization [6, 7].

The role of the surface energy on the HSFL formation on silicon was investigated by forming interfaces with various liquids upon 60 fs-laser pulse irradiation. The HSFL periodicity is ~100 nm and the orientation is perpendicular to the polarization direction. The periodicity does not depend on the pulse number. Interestingly, the formation and periodicity is independent of the interfacial energy.

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Poster Abstracts

Po1

Periodic structures self-formed on the surface of Si and SiC by femtosecond laser pulses

L. Gemini,[1,2,3] M. Hashida,[1] M. Shimizu,[1] Y. Miyasaka,[1] S. Tokita,[1] J. Limpouch,[2] T. Mocek,[3] and S. Sakabe[1]

[1] Kyoto University, Institute for Chemical Research and Graduate School of Science, Japan
[2] Czech Technical University in Prague, FNSPE, Czech Republic
[3] HiLASE Project, Institute of Physic of the ASCR, Prague, Czech Republic

Laser induced periodic structures (LIPSS) formation has been achieved on high purity *n*-type Si (111) and pulsed laser deposited SiC. A linearly polarized laser beam from a Ti:Shappire laser system (ICR, Kyoto University: 800 nm, 10 Hz, 40 fs) was shaped to be spatially flat at the target position. Experimental data on the spatial periodicity were plotted versus the laser fluence according to the parametric decay model proposed by Sakabe *et al.* [1] in order to verify that the behavior of periodic self-formed structure on semiconductors can be related to the same physic processes which bring to the formation of LIPSS on metals, i.e. the formation of plasma surface waves. On semiconductors, we have shown that it can be applied to classical ripples generated upon multi-shot irradiations. These experimental data lie just below the predicted curve showing only a slight variance from the values foreseen by the model. Consequently, a metal-like behavior of semiconductors under intense optical field due to multi-shot fs irradiations is to be expected.

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Po2

Invited

Pulsed laser deposition of nanomaterials for catalysis and the photocatalysis to produce hydrogen and purify water

A. Miotello, and N. Patel

University of Trento, Department of Physics, Trento, Italy

Catalysts and photocatalysts are key materials to face problems related to energy and the environment. To replace the expensive noble metals, new nanomaterials for (photo)catalysis should be developed.

We synthesized Co-B nanoparticles(NPs)-assembled coatings with ns Pulsed Laser Deposition (PLD) technique by taking advantage of the phase explosion process. Co NPs, embedded in B matrix, are composed of nano-size domains separated by grain boundaries with a width of 0.5-1.0 nm and with atoms having low coordination number. These grain-boundaries are highly catalytic active sites with basic, acidic or redox functionality. Electron transfer, from alloying B to vacant d-orbital of Co, stabilizes the Co NPs with B both acting as atomic diffusion barrier and O_2 trap. The deposited NPs exhibit catalytical properties comparable to that of precious metals in H_2 production by hydrolysis of chemical hydrides.

Co_3O_4 NPs-assembled coating have been synthesized by reactive PLD at various substrate temperatures. A systematic study of the PLD process parameters permitted to obtain Co_3O_4 NPs in a single step, at low substrate temperatures, and having mixed disordered-nanocrystalline structure that is relevant for catalysis. The efficiency of these Co_3O_4 NPs was assessed as heterogeneous catalyst in degradation of methylene blue solution, in water, via photo fenton reaction in presence of H_2O_2.

Po3

Analytical application of femtosecond laser-induced breakdown spectroscopy (LIBS) for hydrogen detection

S.-B. Olenici-Craciunescu, and R. Hergenröder

Leibniz Institut für Analytische Wissenschaften (ISAS), Dortmund, Germany

Hydrogen plays an important role for the metallurgy. It leads to failure in the material structure, called hydrogen embrittlement. This phenomenon occurs during manufacturing or operational use, anywhere the material comes in contact with atomic or molecular hydrogen and it is influenced by the level of diffusive hydrogen content, the stress field, the material hardness and the microstructure. In steel analytics a distinction is made between total, residual and diffusible hydrogen which is mobile around room temperature, whereas the remaining residual hydrogen is trapped in the metal. The most common methods for hydrogen analysis are designed to determine the residual or total hydrogen in a sample, without any spatial resolution. Also localised analysis of hydrogen is of great interest, and a number of experimental techniques have been developed and tested for this purpose. A special OES technique is represented by the Laser-Induced Breakdown Spectroscopy (LIBS) based on the plasma generated by irradiating a sample with intense laser pulses. Following each pulse, sample material is evaporated and optically excited, forming a short-lived luminous plasma. For successful application of mapping the hydrogen distribution in metallic samples is necessary an adequate sensitivity and selectivity and the prevention of thermo-diffusion induced redistribution of the element.

Po4

Pump-probe investigations and numerical simulation of the confined laser ablation of thin molybdenum films

J. Sotrop, S. Rapp, M. Domke, and H.P. Huber

Munich University of Applied Sciences, Munich, Germany

The transient behaviour of the laser lift-off of thin molybdenum films, initiated by glass substrate side irradiation with a 660 fs laser pulse, is investigated from the femtosecond to the microsecond range. For this purpose, a pump-probe microscopy setup is utilized to measure the transient relative reflectivity change of the irradiated spot at the molybdenum/glass interface. Moreover, the setup enables to measure the dynamic mechanical movement of the film by interferometry. In addition, a multi-physics and multi-time scale simulation was performed to simulate the electron and lattice temperature, the phase transitions, and the mechanical movement of the film. The experiment and the simulated data suggest that the film bulging is mainly driven by a volume expansion of about 10 % that occurs during the phase transition from solid to liquid. The acceleration of the film is in the order of 10^{10} m s^{-2}. The film then bulges to a dome at a constant velocity of about 70 m s^{-1}. The bulging continues for approximately 20 ns. Then an intact Mo disk shears, if the tensile stress limit is exceeded.

Po5

Time-resolved optical diffraction on quasi-periodical surface nanostructures

M. Zamfirescu,[1] C. Albu,[1] S. Simion,[1] J.-P. Colombier,[2] N. Faure,[2] and R. Stoian[2]

[1] National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania
[2] Université de Lyon, Université Jean Monnet, Lab. Hubert Curien, UMR 5516 CNRS, Saint Étienne, France

In this work we present an experimental investigation of formation of LIPSS structures by time-resolved optical diffraction measurement. A pump-probe set-up was configured for characterization of build-up time of periodical nanostructures. Two laser pulses are focused at the sample surfaces at different incident angles. The first pulse - the pump - creates periodical nanostructures on the sample surface. At delays of the order of few ps up to hundreds of ps, a second pulse - the probe - is reflected and diffracted by the created periodical structures. The diffracted signal grows rapidly within 200 ps timescale, and then slightly diminishes after 400 ps. These delays are comparable with the melting time (tens of ps) and cooling time (hundreds of ps) of metals irradiated by ultrashort laser pulses. The time-resolved diffraction measurements indicate that the nanostructures are formed by spatio-temporal ordering during the liquid phase of the material. The results reveal a formation time of the order of 200 ps for metallic nanostructures.

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Po6

Femtosecond pulse laser nearfield tip-enhanced nanoscale processing of graphene, metallic and polymeric thin films

C. Huber,[1] S. Koprivica,[1] O. Armbruster,[1] P. Grabner,[1] A. Trügler,[2] U. Hohenester,[2] C. Nowak,[3] W. Knoll,[3] and W. Kautek[1]

[1]University of Vienna, Department of Physical Chemistry, Austria
[2]University of Graz, Department of Theoretical Physics, Austria
[3]AIT Austrian Institute of Technology, Vienna, Austria

The mechanism of nanostructuring by fs-laser illumination of scanning probe tips was examined in respect to optical-near-field effects. Nanostructuring of metals down to < 10 nm by ns-laser illumination of STM tips was explained by near field enhancement [1]. However, this observation was explained by thermal expansion and direct contact even with pulses from 10 ns to 100 fs [2]. In contrast to STM probes, apertureless near-field scanning force probes with ns- [3] and fs-laser irradiation [4] were demonstrated to deliver morphological and structural changes in materials on the basis of a SFM tip plasmon response leading to a significant local field enhancement [5]. This study is concerned with optical-field enhancement and confinement for an asymmetrically SFM tip illuminated by 60fs-laser pulses over a single graphene sheet on silicon and various metal and polymer thin films. Local field effects, thermal and mechanical mechanisms are investigated and discussed.

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Po7

Hot Electron Electrochemistry induced by Femtosecond Laser Pulses

J.P. Waclawek, H. Pöhl, O. Armbruster, G. Trettenhahn, and W. Kautek

University of Vienna, Department of Physical Chemistry, Vienna, Austria

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]. The generation of high densities of electrons in matter by high intensity femtosecond laser pulses is being studied at interfaces between a solid and a fluid (electrolyte) as a function of laser and electrochemical parameters [5-8]. A High-Power femtosecond laser oscillator yielding 60 fs-pulses was employed. Hot electron current densities of up to 1000000 A cm^{-2} were analysed in dependence of electrochemical potentials (Fermi energies). Results lead to a new understanding in fields such as the fundamentals of fast hot electron electrochemical kinetics, intermediate species electrochemistry, and nanomedicine [9].

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