K 6: Laser-Beam Matter Interaction - Laser Applications I

Time: Thursday 10:30–12:15 Location: K-H4

Invited Talk K 6.1 Thu 10:30 K-H4

Front and rear surface ablation within gold films with variable film thickness induced by ultrafast laser radiation — •Markus Olbrich, Theo Pflug, and Alexander Horn — Laserinstitut Hochschule Mittweida, Technikumplatz 17, 09648 Mittweida

Irradiating gold films with a different film thickness ($d_z = 100$ - 8000 nm) on a glass substrate ($d_z \approx 1$ mm) with single-pulsed ultrafast laser radiation ($\tau_H = 40$ fs, $\lambda = 800$ nm) results in different ablation structures in dependence on the applied peak fluence H_0. Thereby, for thin films ($d_z \leq 200$ nm) the complete film is removed, whereby for thicker films ablation structures featuring a cupola-like shape with a height of several microns are observed. The ablation structures are explained by two-temperature hydrodynamic modeling (TTMHD) identifying the interplay of front and rear surface ablation as the origin. The formation of the ablation structures is induced either by spallation and phase explosion at the front surface, and at the rear surface by the propagation of the emitted shock and rarefaction waves, generating also spallation. The performed simulations are validated by ultrafast time and space resolved reflectometry ($\tau_H = 60$ fs, $\lambda = 440$ nm, and $\lambda = 480$ nm) at both surfaces of the films within a self-developed optical setup. The complementary combination of reflectometry at the front and rear surfaces portrays the dynamics of the induced temperature and pressure distributions as well as the dynamics of the front and rear surface by comparing the measured relative change of reflectance $\Delta R/R$ to the simulated dynamics of the named parameters.

K 6.2 Thu 11:00 K-H4

Spatially intensity profiles shaping of ultra-short laser for enhanced selective thin film test structure processing on silicon multilayers — •Stephan Krause[1,2], Stefan Lange[2], Hardik Vaghasiya[1,2], Christian Hagendorf[2], and Paul-Tiberiu Miclea[2,1] — [1]Centre for Innovation Competence SiLi-nano, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Halle (Saale), Germany

In this work, we applied spatially shaped ultra-short pulses for laser micro-machining on SiNx/c-Si layer system for the investigation of the selectivity ablation behavior of the sub-μm thick SiNx top layer. By the comparison to gaussian beams, intensity spatially shaped pulses have the potential for a minimization of the superfluous energy in the peak region over the ablation threshold fluence as well as a steeper intensity drop at the side edge of the pulses. This can lead to more precise lateral and vertical ablation properties of the top thin film layer and lower modification/damage to the silicon substrate and the adjacent region. We compare ablation thresholds variations due to beam shaping via light microscopic measurements on the μm-laser spot structures as well as the crystalline phases and stress modification via μ-Raman in the ablated spot, adjacent modified regions and untreated reference areas.

K 6.3 Thu 11:15 K-H4

Fundamental Study of Ablation Mechanisms in Crystalline Silicon and Gold by Femtosecond Laser Pulses: Classical Approach of Two Temperature Model. — •Hardik Vaghasiya[1,2], Stephan Krause[1,2], and Paul-Tiberiu Miclea[2,1] — [1]Martin Luther University Halle-Wittenberg, ZIK Sili-nano, Halle, Germany. — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Germany.

A fundamental study of the interaction between ultrashort laser pulses and the material will be valuable for studying ablation characteristics and ablation performance. A theoretical analysis of ultrashort laser-matter interaction can be represented by the two-temperature model which describes the temperature of the electron or carrier and lattice in non-equilibrium conditions when ultrashort laser pulses are applied. During ultrafast irradiation, due to peculiarities between the metal energy absorption to in contrast to semiconductor, a comparative study of silicon and gold ablation mechanism presented. A 2D axial symmetry simulated ablation profiles were compared with the experimental result at fluence ranging from 1 J/cm2 to 9 J/cm2 at the wavelength of 515 nm and 180 fs laser on the silicon and gold samples. The concordance between model calculations and experimental data demonstrates that fs laser ablation of silicon is thermal in nature in a low fluence regime, whereas it is non-thermal in a high-fluence regime. On the other hand, the phase explosion mechanism is prevalent to understand the ablation characteristics of gold with fs pulses.

K 6.4 Thu 11:30 K-H4

Simulating the optical response properties of solids using mean-field theory — •Kevin Lively[1], Guillermo Albareda[1], Shunsuke Sato[1,2], Aaron Kelly[1], and Angel Rubio[1,3,4] — [1]Max Planck Institut für Struktur und Dynamik der Materie, Hamburg Deutschland — [2]Center for Computational Sciences, University of Tsukuba, Japan — [3]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [4]Nano-Bio Spectroscopy Group and European Theoretical Spectroscopy Facility, San Sebastian, Spain

Capturing the interplay of electron and phonon dynamics is essential to achieve predictive power in simulating the response properties of materials. However, treating the interactions between these coupled degrees of freedom beyond a perturbative level in ab-initio simulations is extremely challenging. In this talk I will present a mean field method for periodic systems that is based on time dependent density functional theory coupled with an ensemble of Ehrenfest trajectories. I will demonstrate that this approach, which has recently been applied to study vibronic structure in molecular systems1, yields predictions for the absorption spectra of solids in agreement with static linear response approaches2, while also offering a viable path to simulate the dynamical response of driven solids.

[1] Lively, Albareda, Sato, Kelly, Rubio, J. Phys. Chem. Lett. 2021, 12, 3074-3081 [2] Zacharias, Giustino J. Phys. Chem. Lett. 2021, 12, 3074-3081

K 6.5 Thu 11:45 K-H4

The Fluence-Dependent Transient Reflectance of Stainless Steel Investigated by Ultrafast Imaging Pump-Probe Reflectometry — •Theo Pflug[1], Markus Olbrich[1], Jan Winter[2], Jörg Schille[1], Udo Löschner[1], Heinz Huber[2], and Alexander Horn[1] — [1]Laserinstitut Hochschule Mittweida, Mittweida, Deutschland — [2]Hochschule München, München, Deutschland

The ablation efficiency during laser processing strongly depends on the initial and transient reflectance of the irradiated material surface. This work reports on the transient relative change of the reflectance ΔR/R of stainless steel during and after ultrashort pulsed laser excitation (800 nm, 40 fs) by spatially resolved pump-probe reflectometry. The spatial resolution of the setup in combination with the spatial Gaussian intensity distribution of the pump radiation enables a fluence-resolved detection of ΔR/R. Within the first picosecond after irradiation with a peak fluence of 2 J/cm2, the spatially resolved ΔR/R of stainless steel evolves into an annular shape, in which the center almost remains at its initial reflectance, whereas the outer region features a decreased reflectance. The decreasing trend of ΔR/R is qualitatively supported by applying a two-temperature model, considering the transient optical properties of stainless steel from the literature. At larger fluences and thus higher electron temperatures, the experimental data deviates from the transient reflectance given in the literature. A decreased occupation of the states below the Fermi energy and the subsequent excitation of electrons into these new vacant states by the probe radiation is considered as the most probable origin for this behavior.

K 6.6 Thu 12:00 K-H4

Optical emission spectroscopy of laser-induced plasmas for rapid in-situ multi-element analysis of materials - basic physical processes and novel industrial applications — •Reinhard Noll — Fraunhofer-Institut für Lasertechnik, Steinbachstr. 15, 52074 Aachen

For nanosecond laser pulses (>10^9 W/cm2) focused at solid/liquid targets each material undergoes a rapid phase transition leading to a transient micro-plasma. The constituting species achieve significant population densities at excitation levels of up to 10 eV and more. During relaxation these species emit element specific optical radiation from deep UV to near IR. Tailored laser pulse bursts allow to penetrate non-representative surface layers and to generate optimized plasma states in terms of their optical emission features for spectro-chemical multi-element analysis (LIBS) [1].

Due to contactless excitation and measuring frequencies of 10 Hz to 1 kHz this method is predestinated for in-situ multi-element analyses in processing and producing fields of industry. An overview of novel applications of LIBS will be given ranging from metal producing industry to the fast identification of valuable materials for recycling processes. The worldwide first inverse production line will be presented to process printed circuit boards of end-of-life servers and cell phones for automized identification, extraction and sorting of valuable components based on laser 3D-measurements, LIBS, laser desoldering and cutting [2]. [1] C. Meinhardt et al, 2021, DOI: 10.1039/D0JA00445F; [2] R. Noll et al, doi.org/10.1016/j.sab.2021.106213