# Q 22: Ultrakurze Laserpulse: Anwendungen 1

Time: Tuesday 10:30–13:00 Location: SCH A01

Q 22.1 Tue 10:30 SCH A01

**Erzeugung Harmonischer Strahlung mit Goldnanoantennen** — •Nils Pfullmann[1,2], Carsten Clever[1,2], Christian Waltermann[1,2], Milutin Kovacev[1,2], Tobias Hanke[3], Rudolf Bratschitsch[3], Alfred Leitenstorfer[3] und Uwe Morgner[1,2] — [1]QUEST Centre for Quantum Engineering and Space-Time Research — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Department of Physics and Center for Applied Photonics, University of Konstanz

Nanoantennen aus Metall zeigen im optischen Bereich ähnliche Eigenschaften wie makroskopische Antennen im Radiofrequenz-Bereich. Durch eine passend gewählte Geometrie kann eine Überhöhung des elektrischen Feldes um mehrere Größenordnungen in einem kleinen Volumen erreicht werden. Die Feldstärken können dabei so hoch werden, dass die Erzeugung Hoher Harmonischer Strahlung demonstriert wurde. Damit würden EUV-Pulse mit Multimegahertz-Repetitionsraten für viele Anwendungen zur Verfügung stehen. Wir zeigen unsere Experimente zur Wechselwirkung ultrakurzer Laserpulse mit unterschiedlichen Geometrien von Nanoantennen. Bisher konnte schon Strahlung mit niedriger harmonischer Ordnung erzeugt werden, und eine Abschätzung der Feldüberhöhung ist möglich. Dies gibt wichtige Hinweise für die Erzeugung Hoher Harmonischer Strahlung.

Q 22.2 Tue 10:45 SCH A01

**Generation and characterization of femtosecond-laser induced nanostructures on thin gold films** — •Conny Axel Hulverscheidt, Martin Reininghaus, and Dirk Wortmann — RWTH Aachen University, Lehrstuhl für Lasertechnik, Steinbachstr. 15, D-52074 Aachen

Femtosecond (fs)-laser radiation focused on a silicon substrate with a 60 nm thin gold film induces the formation of conical nanostructures, nanobumps and nanojets. Since the formation dynamics of these nanostructures are still not understood, the step for a theoretical understanding of this phenomenon has been done by means of Molecular Dynamics simulations. The comparison of theory and experiments with high temporal und spatial resolution gives an opportunity to have a microscopic view on the nanostructure formation kinetics. Therefore a pump-probe-experiment consisting of a combination of fs-laser and EUV-microscope is constructed. Time-resolved measurements in a pump-probe-setup require a reproducible generation of the nanobumps and nanojets. Additionally, debris or plasma-generation has to be avoided to prevent damage on the EUV-optics. The influence of the laser-parameters pulse-energy, pulse-duration and focus on the generation of nanobumps and nanojets is investigated. Previous experiments have shown that the morphology and thickness of the gold film has also an impact on the formation of nanostructures, thus its influence on the formation dynamics is determined. The laser-parameters and gold film characteristics define the required parameter window allowing ablation-free generation of nanobumps and nanojets.

Q 22.3 Tue 11:00 SCH A01

**Zeptosecond precision pulse shaping** — •Jens Köhler, Matthias Wollenhaupt, Tim Bayer, Cristian Sarpe, and Thomas Baumert — Universität Kassel, Institut für Physik und Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

We investigate the temporal precision in the generation of an ultrashort laser pulse pair. To this end, we combine a femtosecond polarization pulse shaper [1] with a polarizer and employ two linear spectral phase masks to mimic an ultrastable common-path interferometer. In an all-optical experiment we study the interference signal resulting from two temporally delayed pulses. Our results demonstrate a $2\sigma$-precision of 300 zs = $300 \times 10^{-21}$ s in pulse-to-pulse delay. This corresponds to a variation of the optical path length in conventional delay stage based interferometers of 0.45 Å. In addition, we apply these precisely generated pulse pairs and furthermore pulse sequences generated by sinusoidal spectral phase modulation to strong-field quantum control. In a coherent electronic excitation experiment we show ultrafast switching of photoelectron spectra via Photon-Locking by temporal phase discontinuities [2,3] on the few attosecond timescale.

[1] M. Wollenhaupt et al., Applied Physics B, 95(2), 245–259, (2009)
[2] M. Wollenhaupt et al., Phys. Rev. A, 73(6), 063409, (2006)
[3] T. Bayer et al., J. Phys. B, 41, 074007, (2008)

Q 22.4 Tue 11:15 SCH A01

**Parametervariation femtosekunden-geschriebener Wellenleiter in YAG-Kristallen** — •Anna-Greta Paschke, Thomas Calmano, Jörg Siebenmorgen, Klaus Petermann und Günter Huber — Universität Hamburg, Institut für Laser-Physik, Hamburg

Durch die Bestrahlung mit ultrakurzen Laserpulsen können wellenleitende Strukturen in dielektrischen Materialien erzeugt werden.

In YAG-Kristallen wird aufgrund nichtlinearer Absorptionsprozesse im Fokus des fs-Laserpulses die kristalline Struktur zerstört. Das modifizierte Material übt Spannungen auf das umgebende Material aus. Dies führt dort aufgrund des elasto-optischen Effekts zu einer lokalen Erhöhung des Brechungsindex um $\Delta n \approx 10^{-3}$. Wird der Laserpuls in die Probe fokussiert und diese während der Bestrahlung verfahren, können im Kristall Doppelspuren aus zerstörtem Material erzeugt werden, in deren Zentrum die Führung von Licht möglich ist. Die Eigenschaften der Wellenleitung sind dabei von verschiedenen Parametern abhängig.

Um optimale Wellenleiter herzustellen wurden in undotierten YAG-Proben Doppelspuren mit unterschiedlichen Spurabständen, Verfahrgeschwindigkeiten und Pulsenergien geschrieben. Die Spurabstände variierten dabei zwischen $14\,\mu m$ und $30\,\mu m$ , die Geschwindigkeiten zwischen $10\,\mu m/s$ und $100\,\mu m/s$ und für die Pulsenergien sind verschiedene Werte entsprechend der jeweiligen Zerstörschwelle gewählt worden. Die Untersuchung der erzeugten Strukturen erfolgte mit Hilfe lichtmikroskopischer Aufnahmen. Zur Charakterisierung der Wellenleiter wurden die Modenprofile aufgenommen und die Verluste untersucht. Diese liegen für die besten Wellenleiter im Bereich von 0,8 dB/cm.

Q 22.5 Tue 11:30 SCH A01

**Superresolved femtosecond nanosurgery of cells** — •Matthias Pospiech[1], Moritz Emons[1], Kai Kütemeyer[2], Alexander Heisterkamp[2], and Uwe Morgner[1,2] — [1]Leibniz Universität Hannover — [2]Laserzentrum Hannover e.V.

We report on femtosecond nanosurgery of fluorescent labeled structures in cells with a spatially superresolved laser beam. The focal spot width is reduced below the diffraction limit using phase filtering applied with a programmable phase modulator. These superresolved focal spots are analyzed theoretically and experimentally. Cutting of cell structures is performed within an inverted Microscope and high NA Objectives. A comprehensive statistical analysis of the resulting cuts is presented, which demonstrates an achievable average resolution enhancement of 30 %

Q 22.6 Tue 11:45 SCH A01

**Combining fs-pulse tailoring and self-phase modulation for nonlinear microscopy** — •Tillmann Kalas, Jens Köhler, Cristian Sarpe-Tudoran, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), Heinrich-Plett-Str. 40, D- 34132 Kassel, Germany

Nonlinear label-free microscopy is a powerful tool for the investigation of physical and biological samples with high spatial resolution. Often intrinsic Second- or Third-Harmonic Generation as well as Coherent Anti-Stokes Raman Scattering is used as contrast mechanism.
We make use of fs pulse shaping in combination with self-phase modulation (SPM) in order to generate the nonlinear signals [1, 2]. Extending our previous studies [1], fs laser pulses are amplitude and phase modulated in a narrow spectral interval and focused into transparent samples. SPM leads to a redistribution of the power spectral density (PSD) depending on the nonlinear index of refraction. In particular the intensity of previously removed spectral components is recovered. Hence, observation of these intensities holds the possibility to distinguish between different materials. We demonstrate high nonlinear contrast and resolution in technical samples combining the fs pulse shaping technique with a commercial laser-scanning-microscope. Moreover, the influence of additional spectral phases on the self-phase modulated PSD is studied and results are given.
[1] A. Präkelt *et al.*: Appl. Phys. Lett. **87**(12), 121113(2005)
[2] M. C. Fischer *et al.*: Opt. Lett. **30**(12), ,1551(2005)

Q 22.7 Tue 12:00 SCH A01

**Optimization of Characteristic X-Ray Emission Generated by sub-10-fs Laser Pulses** — •Fabian Gaussmann, Dirk Hemmers, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

We present the generation of characteristic K$\alpha$ radiation in the energy range from 1.5 keV to 25 keV by focusing of few-cycle laser pulses (sub-10-fs pulse duration, intensity $10^{16}$ W/cm$^2$) on solid targets. The influence of various laser parameters was measured and discussed. One key parameter to optimize the x-ray emission is the control of the preplasma formation. For this purpose, we analyzed the influence of laser pre-pulses with an intensity of about $10^{14}$ W/cm$^2$ and a variable delay in the ps range. Two different techniques were used for the pre-pulse generation. First a spectral modulation of the laser beam with an acousto-optical modulator (DAZZLER) and second two beam-splitters in combination with a delay unit. The advantages as well as the disadvantages of both techniques are discussed. While a hydrodynamic code was used to estimate the pre-plasma formation, the laser absorption was calculated with a PIC simulation. Both numerical methods in combination with the experimental results provide a quantitative understanding of the x-ray generation.

Q 22.8 Tue 12:15 SCH A01

**Ultra-broadband third-harmonic generation in fs-filamentation** — •Tobias Vockerodt[1,3], Daniel Steingrube[1,3], Emilia Schulz[1,3], Milutin Kovačev[1,3], and Uwe Morgner[1,2,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Laserzentrum Hannover e.V. — [3]QUEST Centre for Quantum Engineering and Space-Time Research, Hannover

Optical filamentation is a scheme often used for supercontinuum generation of short laser pulses as an alternative to gas filled hollow-core fibres. Filaments are well studied with respect to temporal and spectral evolution in the visible and infrared region. However, little attention has been given to the ultraviolet (UV) parts of the spectrum.

In this work, we present our studies of UV and third harmonic generation within a filament generated by a 35 fs, 800 nm laser pulse in argon. The filament is probed along its length by establishing an abrupt transition to vacuum by a pinhole. Amongst broadening of the fundamental pulse spectrum throughout the visible and near infrared, third harmonic (TH) generation extends the spectrum into the UV. The unperturbed filament emits TH off-axis on a cone around the filament core. However, if the filament is truncated, the TH conversion efficiency on-axis increases significantly and the TH spectrum broadens. The central part contains pulse energy of up to one microjoule, opening prospects for strong few-cycle-pulses in the UV.

Q 22.9 Tue 12:30 SCH A01

**Application of the multiple rate equation** — •Oliver Brenk, Nils Brouwer, and Bärbel Rethfeld — TU Kaiserslautern, 67663 Kaiserslautern, Germany

Material processing with ultrashort laser pulses is in the focus of experimental and theoretical research. The multiple rate equation, introduced in [1], is a tool to numerically simulate the effects of ultrashort laserpulse irradiation on dielectrics. The MRE allows to investigate the temporal evolution of the electronic density in the conduction band with very good agreement to a full kinetic approach [2] using Boltzman's equation, but with considerably less computational effort. We expanded the MRE model to include reflectivity at the surface and the recombination into Self-Trapped Excitons (STE-States). The reflectivity, depending on the electronic density, influences the laser intensity inside the material. STEs are localized electron-hole pairs formed by free electrons having recombined with localized holes, energetically lying between valence band and conduction band. Re-excitation out of these states is considered as well. We added a spatial dimension to the already implemented time evolution, in order to study the spatially resolved evolution of the electronic densities. Counting the absorbed laser photons allows us to estimate the absorbed energy per spatial layer.

[1] B. Rethfeld. Phys. Rev. Lett., 92:187401, 2004.

[2] A. Kaiser, B. Rethfeld, M. Vicanek, and G. Simon. Phys. Rev. B,61(17):11437*11450,2000.

Q 22.10 Tue 12:45 SCH A01

**Monochromatizing a Femtosecond High-Order Harmonic VUV Photon Source with Reflective Off-Axis Zone Plates** — •Mateusz Ibek[1], Torsten Leitner[1], Alexander Firsov[2], Alexei Erko[2], and Philippe Wernet[1] — [1]Institute for Methods and Instrumentation for Synchrotron Radiation Research, Helmholtz-Zentrum Berlin — [2]Institute for Nanometer Optics and Technology, Helmholtz-Zentrum Berlin

High-harmonic generation (HHG) of femtosecond lasers pave the way for such applications as table-top imaging and spectroscopy using femtosecond light pulses from the VUV to the x-ray range. Due to the comparably low output of HHG sources the necessity of efficient optical elements arises while the amount of said elements must be minimal. A solution is found with off-axis reflection zone plates (RZP). They allow focusing and monochromatizing the VUV and x-ray radiation with only one single element while preserving the pulse duration. At the HHG setup at HZB/BESSYII we have characterized the properties of RZPs for the monochromatization and focusing of a femtosecond VUV photon source. The setup is generating 50 fs pulses and here we used photon energies between 15 and 30 eV. Three RZPs were each calculated and designed for a specific harmonic wavelength on a gold coated plane substrate. As each RZP focuses a different wavelength to the same spot so this arrangement can be easily used to select and focus a desired laser high-order harmonic. The diffracted light i.e. focal point and spectrum was recorded on an x-ray CCD camera and spectral resolution and focal characteristics were determined.