VORWORT/PREFACE

Strategy of the IOQ for the next years

The research focus of the IOQ is the interaction of high-intensity laser radiation with matter. All relevant aspects of this novel field of relativistic optics are covered: laser technology as well as the diagnostic aspects of the experiments. Central is also the work in X-ray diagnostics as well as time-resolved measurements in the X-ray regime. The IOQ contributes substantially to the teaching activities of the physics department in experimental physics including introductory experimental physics, lab courses for beginners and advanced students, and lectures on high-intensity laser matter interaction, and X-ray physics.

Presently two faculty positions at the IOQ are occupied. A new assistant professor position has been filled with Dr. Kaluza at the beginning of 2006. A new W2-professorship is presently not occupied. The search to fill this position is presently underway.

In recent years the IOQ has required an international reputation for its work in the field of the interaction of high-intensity laser radiation with matter, and time-resolved X-ray techniques. This field will also be central to the further development of the IOQ. Particularly helpful for the further work are the new laboratories that were constructed by the university at the Froebelstieg. They will be the home for the new POLARIS laser which will become available as a petawatt laser in 2007/2008. This laser facility is the central project for the future of the IOQ at present. With respect to the field of ultra optics the IOQ has a strategic cooperation with the Institute of Applied Physics and the Fraunhofer Institute which shall be expanded in the future. We have excellent theoretical support from the groups of Prof. Lederer, and Prof. Wipf for our experimental activities. Nevertheless it is necessary to establish a theoretically oriented faculty position at the IOQ with research focus on ultra optics, and relativistic optics.

The IOQ acquires external funding from a number of sources. Of particular importance is the DFG Transregio TR 18, the Zentrum fuer Innovationskompetenz “Ultra optics”, and LASERLAB Europe as well as the two virtual institutes of the Helmholtz-Gemeinschaft (DESY and GSI). Furthermore, the IOQ participates in a DFG-Forschergruppe and a DFG-Schwerpunkt.

Strategic objective of the IOQ for the next year is an extension of the funding basis, in particular, with respect to European projects within the 7th framework program of the European Union. Through the collaboration within LASERLAB Europe we are establishing presently important connections to other European groups with whom we perform joint experiments. This will improve our possibilities to participate in other European activities. Important is also the participation in the COAST program of the Japanese government which supports the international exchange between laboratories engaged in high-
intensity laser-matter interaction physics. This project has recently been renewed, and we are also applying for a similar project with the Chinese government.

**Research Highlights**

Generation of monoenergetic, laser-accelerated protons
In 2005 the IOQ was able to produce laser-generated, monoenergetic protons with good emittance for the first time. The results have been presented at several conferences. A first publication will appear in January 2006 in *Nature*.

Thomson backscattered X-rays from laser-accelerated electrons
The JETI laser at the IOQ was used to accelerate electrons to energies of several MeV. A counter propagating laser pulse was Thomson scattered from these electrons. In these experiments we could observe for the first time Thomson backscattering into the X-ray regime from laser accelerated electrons. The results were published, and have appeared in *Physical Review Letters*.

Generation of monoenergetic electrons accelerated by high-intensity lasers
The Jena Titanium:Sapphire 10 TW laser system was used to generate monoenergetic electrons with energies up to 50 MeV, and a relative energy width of about 1 %. The experiments were done in conjunction with the Heinrich Heine University in Duesseldorf, and the Max Planck Institute for Quantum Optics in Garching, as well as Strathclyde University in Glasgow. The results have been accepted for publication by *Physical Review Letters*.

Generation of energies in the 10 J range with a diode-pumped laser
The POLARIS laser has generated energies of 8 J in the amplifier A4. The POLARIS laser is a novel, diode-pumped Ytterbium:glass laser which is supposed to reach petawatt powers in a few years. Also it was possible for the first time with this laser to demonstrate a tiled grating compressor. The results have been published in *Applied Physics B*.

Measurement of the autocorrelation function of a high-intensity laser pulse at full intensity.
So far it was only possible to measure the pulse duration of high-intensity lasers at low intensities, and then extrapolate to high intensities. In 2005 we demonstrated for the first time that nonlinear Thomson scattering can be used to obtain an autocorrelation function of the high-intensity laser pulses at full intensity. The results have been published in *Applied Physics Letters*.

Time-resolved investigations of the isostructural phase transition in Samarium sulfid.
We have performed the first time-resolved measurement of the phase transition of Samarium sulfid by means of time-resolved X-ray diffraction. The metal semiconductor transition was investigated as a function of time. We have detected fast structural changes within one picosecond as well changes in the crystal structure over a longer time.
Investigation of the generation and propagation of phonons with subpicosecond time resolution
Electron hole pairs were generated in a semiconductor and by time resolved X-ray diffraction. We observed the energy transfer from the electronic to the phonon system of the crystal.

Measurement of extremely high magnetic fields with a novel X-ray spectrometer
High-intensity lasers are probably able to generate extremely high magnetic fields in solids. We have developed a new polarization sensitive X-ray spectrometer with spatial resolution in the micron region. Magnetic fields that have been estimated theoretically from this interaction should be large enough to generate Zeeman broadening in the Kα spectral lines. Large line broadenings were, in fact, observed which are polarization dependent.

By means of time-resolved X-ray diffraction the response of the lattice of high temperature superconductor (YBaCuO) was investigated when a second laser was used to break up the Cooper pairs very rapidly. We were able to observe for the first time the dynamic effects in the lattice structure for a superconductor phase transition.

Organisation of the 355th Wilhelm and Else Heraeus Seminar “Ultrafast dynamics of collective excitations in solids” by Prof. Klaus Sokolowski-Tinten of the IOQ in collaboration with U. Bovensiepen from the Freie Universitaet Berlin
ANNUAL REPORT 2005

VORWORT / PREFACE

STAFF MEMBERS
  SCIENTIFIC STAFF
  ADMINISTRATION
  TECHNICAL STAFF
  STUDENTS

TEACHING ACTIVITIES
  LECTURES
  LABORATORY COURSES
  SEMINAR
  DOCTOR THESIS

PROJECTS

QUANTUM ELECTRONICS

X-RAY OPTICS

X-RAY PHYSICS

ULTRAFAST X-RAY SCIENCE

ACTIVITIES

VISITORS

COOPERATIONS

PUBLICATIONS

CONFERENCE CONTRIBUTIONS
STAFF MEMBERS

SCIENTIFIC STAFF

Sauerbrey, Roland; Prof. Dr. Director of the Institute
Förster, Eckart; Prof. Dr.
Sokolowski-Tinten, Klaus; Prof. (until 10/2005)

Walther, Heinz-Günter; Priv. Doz. Dr.
Welsch, Eberhard; Priv. Doz. Dr.

Bödefeld, Ragnar; Dr.
Cao, Leifeng; Dr.
Heerdegen, Wolfgang-D.; Dr. (until 2/2005)
Hein, Joachim; Dr.
Kräusslich, Jürgen; Dr.
Morak, Andreas; Dr. (until 9/2005)
Nazarkin, Alexander; Dr.
Schwoerer, Heinrich; Dr.
Uschmann, Ingo; Dr.
Yang, Jiamin; Dr.

Amthor, Kay-Uwe
Brauner, Thomas
Debus, Alexander (from 3/2005)
Kämpfer, Tino
Hotzel, Mario (until 6/2005)
Krasniqi, Faton
Liesfeld, Ben
Lübcke, Andrea
Paunescu, Gabriela
Podleska, Sebastian
Schlenvoigt, Hans-Peter (from 11/2005)
Siebold, Mathias
Nguyen, Xuan Truong (until 5/2005)
Zamponi, Flavio

SCHOLARSHIPS

Wemans, Joao Marie Curie Stipendiat
STAFF MEMBERS

ADMINISTRATION

Koss, Gabriele
Rauschelbach, Elsbeth

TECHNICAL STAFF

Bechstein, Dagmar
Beleites, Burgard
Brusberg, Jana
Geiling, Regina
Hellwing, Marco
Hein, Doris
Hornung, Marco
Kind, Reinhard
Marschner, Heike
Mämpel, Petra
Neitzel, Renate
Perner, Frank
Quednau, Gisela
Redlich, Katrin
Richter, Petra
Ronneberger, Falk
Rühle, Klaus
Schnepp, Matthias
Seifert, Reinhard
Teufer, Gabriele
Triebel, Kristina
Unbereit, Wolfgang
Wehrhan, Ortrud; Dr.
Zentgraf, Torsten
Ziegler, Wolfgang

STUDENTS

Albach, Daniel
Behmke, Michael
Beutler, Marcus
Brückner, Matthias
Budde, Fabian
Haupt, Katrin
Höfer, Sebastian
Jäckel, Oliver
Jochmann, Axel
Lötzsch, Robert
Pfotenhauer, Sebastian
Sävert, Alexander

HiWi:
Bock, Stefan
Diedrich, Claudius
Harz, Stephanie
Teaching Activities

Lectures

"Experimental Physics (I, III)"
(mandatory for students in Physics)
   Prof. R. Sauerbrey

"Seminars on Experimental Physics (I, II, III)"
(mandatory for students in Physics)
   PD Dr. E. Welsch

"Atomic and Molecular Physics"
   Dr. H. Schwoerer

“Seminars on Atomic and Molecular Physics”
(mandatory for students in Physics)
   K.-U. Amthor

"Introduction in Experimental Physics (I, II, III)"
(mandatory for students in Chemistry)
   Prof. E. Förster

"Fundamentals of Laser Physics"
   Prof. R. Sauerbrey, Prof. A. Tünnermann

"Matter in intense light fields"
   Prof. R. Sauerbrey, Dr. H. Schwoerer

"Fundamentals of Nonlinear Optics"
   Prof. R. Sauerbrey

"Time-resolved X-Ray diffraction"
   Prof. K. Sokolowski-Tinten

"Spectroscopy of Atoms, Molecules and Plasmas"
   Prof. E. Förster

"Atomic Physics in Hot Plasma"
   Prof. E. Förster
Teaching Activities

Laboratory Courses

Advanced Laboratory Course on Experimental Physics  
(Students in Physics)  Prof. Dr. R. Sauerbrey

Fundamental Laboratory Course on Experimental Physics  
(Students in Physics)  Prof. Dr. E. Förster,  
Priv. Doz. Dr. H.-G. Walther

Fundamental Laboratory Course on Experimental Physics  
(Students from other Faculties)  Dr. J. Kräusslich
Teaching Activities

Quantum Optics Seminar (Prof. Dr. R. Sauerbrey)

Prof. Dr. D. Blaschke  
Universität Bielefeld  
"Versteckte Produktion von Elektron-Positron-Paaren in Pulsen optischer Laser"

Dr. K. Cook  
Heriot-Watt University Edinburgh, Scotland  
"Coherence properties and control of supercontinuum filaments in condensed media"

Prof. Dr. M. Garcia  
Universität Kassel, Theoretische Physik  
"Manipulation von Nanostrukturen mit Hilfe von Femtosekundenlaserpulsen"

Prof. Dr. V. Malka  
Research Director at CNRS, Palaiseau, France  
"Laser-plasma accelerators: status, applications and perspectives"

T. Scheidt  
IPHT Jena  
"Ladungsträgerdynamik und Defektgeneration an der Si/SiO₂-Grenzfläche, untersucht mittels Erzeugung der optischen 2. Harmonischen durch ultrakurze Lichtimpulse"

Dr. Antonio Di Piazza  
Max-Planck-Institut für Kernphysik Heidelberg  
"Probing the QED vacuum by means of strong laser fields: an experimental proposal"

Dr. N. Zhavoronkov  
Max-Born-Institut Berlin  
"Efficient fs-laser based K-shell radiation source operated at 1 kHz repetition rate and its first application for time-resolved diffractometry"

Ultrafast X-Ray Science Seminar (Prof. Dr. K. Sokolowski-Tinten)

Dr. E. H. Lehmann  
Paul-Scherrer-Institut, Villigen PSI, Switzerland
"Bildgebung mit Neutronen, der gegenwärtige Status und künftige Optionen"

X-Ray Physics Seminar (Prof. Dr. E. Förster)

Prof. M. Braden | Physikalisches Institut, Universität zu Köln
"Elektron-Gitter-Kopplung in Kuprat-Hoch-Tc-Supraleitern und verwandten Perovskit-Verbindungen"

Dr. O. Renner | Institute of Physics of the Czech Academy of Sciences, Prag, Czech. Republic
"Spectral Line Decomposition and Frequency Shifts in AlHe$_a$ Group Emission from Laser Produced Plasma"

Dr. I.A. Vartanyants | HASYLAB at DESY, Hamburg
"Looking Inside the Matter with Coherent Waves"
Teaching Activities

Doctor Thesis

Mario Hotzel
"Untersuchung der nichtlinear-optischen Koeffizienten dritter Ordnung von konjugierten Polymeren und auf Telluroxid basierenden Gläsern"
May 2005

Faton Krasniqi
"Diagnostik von laserproduzierten Plasmen und Untersuchung von Laser-Festkörper Wechselwirkungen unter Verwendung der Röntgenbeugung mit gebogenen Kristallen"
November 2005
PROJECTS

**Title:** Harte Röntgenstrahlung aus lasererzeugten Festkörperplasmen und deren Anwendung; Schwerpunktprogramm "Wechselwirkung intensiver Laserfelder mit Materie

**P. I.**:
Prof. Dr. R. Sauerbrey, Dr. H. Schwoerer

**Support:** DFG

**F. P.**:
2/2002 - 2/2005

**Title:** Teramobile

**P. I.**:
Prof. Dr. R. Sauerbrey, Prof. L. Wöste, Dr. A. Mysyrowicz, Prof. J.-P. Wolf

**Support:** DFG

**F. P.**:
6/99 - 12/2005

**Title:** Getriggerte, punktförmige Ultrakurzpulsröntgenquellen für Analytik und Medizintechnik

**P. I.**:
Prof. Dr. R. Sauerbrey, Dr. H. Schwoerer

**Support:** BMBF

**F. P.**:
1/2001 – 12/2005

**Title:** TRANSREGIO / TR18-04 "Relativistische Laser-Plasma-Dynamik"
Düsseldorf/Jena/München; Teilprojekte B2, B6, B7

**P. I.**:
Prof. Dr. R. Sauerbrey, Dr. H. Schwoerer, Dr. I. Uschmann, Prof. A. Wipf

**Support:** DFG

**F. P.**:
2004 – 2008

**Title:** Optimierung und Charakterisierung von laserbasierten EUV-Quellen

**P. I.**:
Prof. Dr. R. Sauerbrey

**Support:** XTREME technologies GmbH

**F. P.**:

**Title:** Fälschungssichere Münzen durch Laser-Nanoprägungen von Hologrammen (SIMULAN)

**P. I.**:
Prof. Dr. R. Sauerbrey, Dr. J. Hein, Dr. E. Welsch

**Support:** VDI

**F. P.**:

---

1Principle Investigator
2Funding Period
Title: POLARIS Diödengepumpter Laser der Ein-Petawatt-Klasse
P. I.: Prof. Dr. R. Sauerbrey, Dr. J. Hein
Support: TMWFK
F. P.: 2004 – 2005

Title: Forschergruppe „Nichtlineare raum-zeitliche Dynamik in dissipativen und
diskreten optischen Systemen“, Teilprojekt G „Raumzeitliche
Lokalisierung hochintensiver Lichtpulse“
P. I.: Prof. Dr. R. Sauerbrey
Support: DFG

Title: "Integrated European Laser Laboratories" Laserlab-Europe
P. I.: Prof. Dr. R. Sauerbrey, Dr. J. Hein
Support: Europäische Union

Title: Marie Curie-Stipendium
P. I.: Prof. Dr. R. Sauerbrey
Support: Europäische Union

Title: Investigation of Plasmas under Pulsed Energy Deposition
P. I.: Prof. Dr. R. Sauerbrey
Support: BMBF (DLR)

Title: Investigation of Plasmas under Pulsed Energy Deposition
P. I.: Prof. Dr. E. Förster, Dr. I. Uschmann
Support: BMBF (DLR)

Title: Virtual Institute – Generation of intense Particle Beams by ultra-intense
Lasers (VIPBUL)
P. I.: Prof. Dr. R. Sauerbrey
Support: Helmholtz-Gemeinschaft

Title: Virtual Institute – Plasma Physics Research Using FEL Radiation
P. I.: Prof. E. Förster
Support: Helmholtz-Gemeinschaft
<table>
<thead>
<tr>
<th>Title</th>
<th>Support</th>
<th>F. P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. I. : Prof. Dr. E. Förster, Dr. I. Uschmann</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support: DFG, Max-Born-Institut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of X-ray crystal diagnostics</td>
<td>University or York</td>
<td>7/2003 – 2/2005</td>
</tr>
<tr>
<td>P. I. : Prof. Dr. E. Förster, Dr. I. Uschmann</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support: University or York</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. I. : Dr. J. Kräußlich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support: BMBF / INNOVENT e.V.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
 Recent advances in electron acceleration with high-intensity table-top lasers demonstrated the high potential for further studies towards applications. However, complex acceleration processes have been uncovered. To date, the acceleration process can only be understood via PIC simulations. In contrast, conventional diagnostic methods like magnet-based electron spectrometers only allow for the spectral analysis of a small solid angle of the electron beam outside of the laser plasma after the acceleration process is complete. This underlines the need for a time-resolved in-situ diagnostics.

The setup is shown in figure 1. The main laser pulse is divided by a 90/10 beam splitter into an intense pump pulse and a weak probe pulse. Each pulse is focused into a pulsed He gas jet, such that the beams are counterpropagating. The setup is located in a vacuum chamber and is fully computer controlled in order to adjust the tilt of the parabolic mirrors, to move them for special overlap, and for adjusting the time delay of the pulses by moving the beam splitter as indicated in figure 1. The nominal intensities were determined to $2\times10^{19}$ W/cm$^2$ ($a_0=3$) and $<10^{18}$ ($a_0<0.8$) for the pump and the probe pulse, respectively.

The pump pulse is focused into the rising edge of the gas jet, which has a density profile of Gaussian shape along the laser propagation axis with a peak density of $6\times10^{19}$ atoms/cm$^3$. From earlier experiments it is known that under these conditions electrons will efficiently be accelerated via the self-modulated laser wake field acceleration. In contrast, the probe pulse propagates a long distance through gas, resulting in a filamented transverse profile (observed via shadowgraphy), unable to generate a plasma channel. Therefore the intensity given above is an upper limit.
The backscattered photon energies were expected to cover the soft x-ray range. Additionally, a strong dependence on the angle of scattering was perceived, resulting in a separate measurement of this angle. The x-ray spectra, from which the electron spectra were derived, could only be acquired in a single shot experiment due to shot-to-shot fluctuations. Therefore a method for converting CCD images into spectra was deployed and improved. It is based on recognizing single photons. In earlier experiments, it was used for peaked spectra at some few keV photon energy. Now, the spectra are broadband, so the exposure must be as high as possible. However, pixel-splitting occurs, that means a single photon will generate charges in several neighbouring pixels. The new algorithm performs a pattern matching. Each pattern must have a bright, central pixel, contains 0 to 4 secondary pixels in various arrangements around the central pixel, and must be surrounded by empty pixels to reject overlapping patterns. The algorithm was tested with characteristic line emission of several elements in the soft x-ray range. The ratio of recognized photons to the total number of photons was measured, in order to calculate the spectra accurately. The energy calibration and the energy resolution were also determined by these prerequisite experiments.

In the experiment, a large amount of background radiation was generated by bremsstrahlung processes of the electrons, ions hitting the gas nozzle resulting in characteristic line emission, and radiation from betatron oscillations of electrons inside the plasma channel. All these processes depend only on the pump pulse. In order to identify the backscattered radiation, background spectra were recorded without the probe pulse, and were subtracted from spectra recorded with both pulses.

![Figure 2: Dependency of total photon yield on delay time](image-url)
In a first step, the spectra of backscattered radiation have been integrated in order to get information on the total photon yield. The total photon yield shows a significant dependency on the time delay. This behaviour is shown in figure 2, and was confirmed in a number of single experiments under varying conditions. This curve is understood as the acceleration of electrons along the plasma channel.

In a second step, the x-ray spectra have been converted into electron spectra. They show (figure 3), that the electron distribution consists of two contributions, one with a low temperature of about 1 MeV and a second with a higher temperature of about 6 MeV. These temperatures do not change significantly with the delay time. From earlier experiments the high temperature part is known, whereas the one with the lower temperature could not be detected.

To our knowledge, this experiment was the first which provided time-resolved electron spectra from the acceleration process. This work is published and was a main part of a PhD thesis and a diploma thesis.

References:


**MONOENERGETIC PROTON BEAMS FROM LASER PLASMAS**

O. Jäckel, S. Pfotenhauer, K.-U. Amthor, H. Schwoerer, B. Liesfeld, W. Ziegler, R. Sauerbrey, K.W.D. Ledingham, T. Esirkepov

Particle acceleration based on high intensity laser systems has lately received considerable attention because of its large potential for applications in science and technology (recently reviewed in [1, 2]). The interaction of an ultrashort laser pulse with a thin foil target leads to the generation of a relativistic plasma and the subsequent, forward-directed acceleration of electrons through the foil [3 – 5]. The expelled electrons leave behind a strongly ionized target and constitute a quasi-static, target normal electric field, which accelerates protons and ions from the back surface until they compensate the electron charge – a process known as “target normal sheath acceleration” (TNSA) [6] (Fig. 1).

![Figure 1: Laser acceleration of protons from the back side of a microstructured target.](image.png)

The resulting energy spectrum is strongly correlated to the spatial distribution of the protons on the target surface. Hitherto generated proton beams all displayed a broad, quasi-exponential spectrum, because the accelerating field is transversely inhomogeneous over the proton source (contamination layer on the backside [7]). It was derived from simulations that, if the proton source could be confined to the central, homogeneous part of the acceleration field, the protons will all experience the same potential, yielding an intrinsically monoenergetic spectrum. Consequently, the use of a
bilayered microstructured target was suggested, consisting of a thin high-Z metal foil and a small, proton rich dot on the back surface with dimensions of the order of the laser’s focal spot or less (Fig. 2) [2, 8].

![Structured area with polymer dots](image)

Figure 2: Microscopic picture of the microstructured doublelayer target foil. One can see the bright squares of PMMA on top of the darker titanium foil.

Here we present first experimental evidence of laser accelerated proton beams with quasi-monoenergetic energy distribution, utilizing structured targets as proposed above [9]. A 5 µm thin Titanium foil was coated on the back surface with a 0.5 µm layer of PMMA and subsequently microstructured, leaving behind PMMA dots of (20 x 20) µm² with free space around. A high intensity laser pulse from the JETI 10 TW Titanium:Sapphire laser at the University of Jena ($I = 3 \times 10^{19}$ W/cm²; $\tau = 80$ fs; $E = 0.6$ J) was then focused on the front surface of the foil exactly opposite to one of the dots. Accurate positioning could be achieved with the help of an alignment laser. The same laser was also used for controlled ablation in the vicinity of the dot in order to reduce the impact of parasitic protons [10]. Protons and ions, accelerated from the back surface in normal direction, were analyzed by a Thomson spectrometer and detected either online with microchannel plates (MCP) or by nuclear track detectors (CR39).

Fig. 3 presents the result of the irradiation of the microstructured target foil at the position of a dot in contrast to unstructured material. The blue curve resulting from dot irradiation exhibits a distinct narrow band feature, peaked around $E_{\text{max}} = 1.2$ MeV on top of a broad exponential background. For comparison, the black data represent an average over several proton spectra recorded if the laser hits a blank position on the same target, where protons can only originate from an unstructured hydrogen contamination layer. No narrow band feature appears and the exponential shape of the spectrum can be approximated by a temperature of about 0.5 MeV. The data are given as number of protons per energy interval of 0.05 MeV, which corresponds to the MCP resolution, and per 24 mSr, which is the solid angle of emission that results from the simulations described below. The displayed feature contains about 108 protons per 24 mSr and has a $\Delta E_{\text{FWHM}} = 300$ keV or 25 % of its absolute value. The position of the peak as well as its width varies from shot to shot by about 20 %.

The occurrence of peaked spectra proved to be a very reliable and reproducible phenomenon. Both the MCP and CR39 detection confirm that a maximum in the proton
Figure 3: Proton spectra from the Thomson spectrometer (MCP observation), simulation and scalability of the technique. The blue squares show a spectrum obtained from irradiating the foil at the position of a dot and exhibits a peak at an energy of 1.2 MeV, as opposed to exponential spectra (red squares) in the case of irradiating unstructured foil. The experimental data (blue squares) is in excellent agreement with results obtained from a 2D-PIC simulation (black line) for our experimental parameters. The inset shows a simulation for a petawatt laser system and smaller dot size, demonstrating the scalability of presented technique. The spectrum then exhibits a narrow peak at 173 MeV with $\Delta E/E \approx 1\%$.

spectrum is reproduced consistently, if a microstructure on the rear of the target is irradiated. We ascribe the observed narrow band spectra to the homogeneous acceleration of the dot protons within the center of the quasi-static electric field, set up by the laser accelerated electrons beyond the thin target as described above. If the scale of the inhomogeneity of the electric field is larger than the proton rich spot, these protons all experience the same potential.

Our analysis is supported by two-dimensional PIC simulations based on a code presented in [11]: Fig. 3) plots the numerically calculated proton spectrum resulting from experimental parameters (solid line). It is dominated by a narrow band structure around 1.2 MeV. Simulation and experiment are in excellent agreement with respect to both the existence of the narrow structure as well as its position and width. In order to investigate the scalability of our results and their feasibility for future application, the parameters for the simulation have been changed to smaller dot sizes (5 µm² x 0.1 µm), and higher intensities ($10^{21}$ W/cm²). A high repetition rate table-top laser system with such characteristics will be available within the next years (POLARIS) [12]. Simulations performed with these parameters result in a peak proton energy at 173 MeV and relative width $\Delta E/E \approx 1\%$ (see inset Fig. 3). Such proton beams will be suitable for medical proton therapy [2, 8].

We have demonstrated for the first time the feasibility of laser-plasma accelerators for producing intrinsically monoenergetic proton beams utilizing microstructured targets. Our first steps towards monoenergetic protons show a distinct improvement over the exponential energy spectra published to date. In the longer term, future laser accelerators will be in reach of medical proton and heavy ion therapy.
ELECTRON BUNCH DURATION MEASUREMENTS – RESULTS FROM ASTRA

Alexander Debus

With the availability of high-intensity laser systems generating intensities well above $10^{19}$ W/cm² Laser Wakefield Experiments have evolved in recent years. Now they offer almost on a routinely basis electron energies of several tens of MeV, beams with low emittance and with a careful choice of the experimental conditions quasi-monoenergetic features can be obtained. In order to characterize these electron bunches, usually electron spectra and transverse profiles from fluorescent screens are measured. But with the emergence of more advanced experiments such as “free-electron” type laser accelerators generating ultra-short and coherent radiation, information on the temporal structure of electron bunches experiences an increase in attention.

Electrons almost always showed monoenergetic features (at ~40 MeV)

Fig. 1: Experimental setup of a gasjet-type Laser Wakefield Accelerator with transition radiation diagnostics at the ASTRA facility (RAL). When the optical spectra were taken, the tape drive and the cross-correlator were not in use.

Traditional e-bunch duration diagnostics as used in high energy physics are often based on multi-shot scanning techniques or require an in advance knowledge of the electron distribution. For those methods are plagued by large shot-to-shot fluctuations in e-beam quality, a single-shot approach is required for plasma-based electron beams. Electro-Optical (EO) measurements relying on a) transition radiation (TR) of an electron bunch at the plasma-vacuum boundary and b) the Pockel’s Effect in a ZnTe crystal that modifies the polarization state of a chirped probe pulse due to the E-field of the TR, which lies in the THz range. An optical spectrum [2] or measurements by a
cross-correlator [1] (modulated chirped probe beam + delta-function-like short pulse) then yield information on the bunch’s length characteristics.

After promising first results from the MPQ Garching and the IOQ Jena, a European experiment has been conducted under the lead of Stefan Karsch (MPQ Garching) at the ASTRA Laser Facility of the Rutherford-Appleton Laboratories (UK) in June 2005. A broad collaboration between different institutions consisted of the MPQ Garching, the Friedrich-Schiller Universität Jena, the University of Strathclyde, the Heinrich-Heine Universität Düsseldorf and the Imperial College, London.

Here we present the data analysis of the recorded spectra obtained at that experiment. The experimental setup is shown in Fig 1.. An ultra-short, high-intensity laser beam ($10^{19}$ W/cm$^2$, 300-600 mJ, 45 fs) was focused into a gasjet. The resulting plasma reached maximum electron densities of $1.5\times10^{19}$ cm$^{-3}$ and the energy spectrum of the accelerated electron almost always showed monoenergetic features around ~40 MeV. These electrons in turn generated transition radiation at the plasma vacuum boundary. After THz radiation was imaged by two parabolas into a ZnTe crystal. In between, a Teflon filter blocked out the laser light.

A portion of the intense drive beam was split off, stretched to over 5ps and brought to spatial and temporal overlap with the THz signal in the crystal. Without a THz pulse an optical pulse passes the crystal without change in polarization and is then blocked off by a crossed polarizer. The correct polarization was fine tuned for minimum transmission with a $\lambda/2$-plate in front of the crystal. When on the other hand a THz field as is present in Fig. 2, while a laser pulse passes through the crystal, there is a phase shift between the ordinary and extraordinary axis due to the Pockel’s effect resulting in a rotated polarization with $\theta \sim E_{THz}$, which in turn gets transmitted through the polarizer in proportion to the changed polarization.

Because of the chirped probe pulse the temporal modulation is also encoded into the spectrum, so it reveals the modulus square of the THz E-field. With the help of TR theory which is well understood, it is possible to deduce characteristics of the original electron bunch such as its length.
About 20 interesting (i.e. narrow) THz-fields could be extracted out of the data and an accurate time calibration was established by stepper motor readings of the delay stage. Two narrow, but still representative examples are shown in Fig 3. From TR theory [3] and the assumption of 40 MeV monoenergetic electrons we could infer the electron bunch length (rms) from the THz pulse length (FWHM). According to theory that relation is only weakly dependent on the exact electron distribution. The minimum THz-pulse length is 498fs which immediately gives an upper limit of 271fs (rms) for the length of an electron bunch in experiment.

Since for LWFA electrons theoretical studies have predicted electron bunch lengths ranging from the laser pulse length down to plasma wavelength, TR pulses are expected to have widths of below 100fs.

However there are some severe constraints that limit our resolution, as it exists a time-bandwidth relationship between the bandwidth of the chirp and the minimum bunch length that can be resolved [4]. For bipolar THz signals one can derive a measure for the shortest pulse length $T_{\text{min}}$ resolvable.

$$T_{\text{min}} = \sqrt{T_{\text{chirp}} \cdot T_0} ; \quad T_0: \text{ laser pulse length; } T_{\text{chirp}}: \text{ length of chirped pulse}$$

In our case we arrive at a resolution limit of about 500fs which matches the upper limit from experiment.

Furthermore there are some weaker constraints that arise from EO-effects in a ZnTe crystal. Besides an amount of dispersion and absorption in the crystal that distorts the THz pulse, there is a limit to its pulse length due to a walk-off between THz phase velocities at different frequencies and the group velocity of the optical chirped pulse. By that smearing out of the temporal profile the maximum resolution that the crystal can still practically resolve is limited to about 200fs. Detailed calculations on that topic can be found at the TESLA Report 2005-01 [5] from Sara Casalbuoni et al.

All doubly-peaked spectra have very similar shapes and peak amplitude ratios, indicating stable electron bunch acceleration and THz radiation processes. The single
peaked spectra were shorter than the doubly peaked ones. The fact that we measured single peaked spectra doesn’t necessarily indicate truly single peaked THz pulses, because at those measured pulse lengths our spectral resolution of approx. ±0.5nm can smooth out the “valley” of such a double peak.

In this analysis we could show that the method is a powerful single-shot diagnostic with sub-ps resolution. An upper limit of 498fs (FWHM) for the THz pulse width and 271fs (rms) for the electron bunches could be established. However we clearly have reached the resolution limit due to time-bandwidth constraints. Preliminary results of the cross-correlator diagnostic with the more favourable resolution limit due to EO-effects of the crystal show THz signal widths down to 200 fs. Because much shorter LWFA electron bunches (<100fs) are expected, it is necessary for accurate measurements of bunch structures to bring down the resolution limit in further investigations. Advanced single-shot schemes could either involve using other eo-materials (for ex. GaP instead of ZnTe) or completely different approaches such as imaging Thomson scatter.


FEEDBACK-CONTROLLED OPTIMIZATION OF THIRD HARMONIC GENERATION FROM FEMTOSECOND LASER-PRODUCED WHITELIGHT FILAMENTS

Alexander Sävert, Sebastian Höfer, Marcus Beutler and Roland Sauerbrey

Whitelight filaments have become of great interest in recent years especially for techniques like LIDAR. They can be used to create an broad spectrum of radiation from the UV to IR to investigate the atmosphere spectroscopically. These filaments also generate Third Harmonic Radiation effectively. Controlling the phase modulation of the laser pulses via a Spatial Light Modulator (SLM) can even bring higher conversion rates of Third Harmonics.

In our experiment the phase-modulated pulses were focused with a lens to produce a filament. This filament was observed with a spectrometer producing the feedback signal for a self-optimizing algorithm which controls the SLM.

Given this experimental setup we were able to optimize our filament to generate either maximum peak intensity at one specified wavelength, maximum intensity between 250nm and 350nm or to receive a preferred spectral shape of the third harmonic (i.e. gaussian profile).

The optimized filament was simultaneously laterally observed by a camera. Differences in the intensity distribution of the filament were measured depending on the optimization. The optimized pulse was characterized by a SHG-FROG to gather information about E-field and both spectral and temporal phase. Differences between both optimizations are obvious.
Our investigations show that optimizing the filament for special resulting features always needs rather complex pulse trains to be effective.
FIRST TIME RESOLVED X-RAY DIFFRACTION MEASUREMENTS ON SUPERCONDUCTING YBCO THIN FILMS

A. Lübcke, F. Zamponi, I. Uschmann, E. Förster, R. Sauerbrey, V. Große, F. Schmidl

P. Seidel

YBa$_2$Cu$_3$O$_7$ is the high temperature superconductor most studied, but still the mechanisms that lead to its superconductivity are not yet understood. Its transition temperature $T_c$ is around 90 K. It is known that the superconducting phase transition in YBCO is not accompanied by any structural phase transition, but several works observed anomalies in the temperature dependence of the structure factor and linewidth for higher order reflections [1,2] as well as in the temperature dependence of the lattice constants [3,4]. Especially for the last point, anomalies occur close around the transition temperature. If these changes are associated with the superconducting phase transition they must show up not only when superconductivity is switched off by temperature but also when cooper pairs are broken optically. Optical pump probe measurements of the reflectivity suggest that broken cooper pairs recombine after only several ps [5,6,7,8]. Therefore, to study the lattice response of YBCO following the breaking of cooper pairs one need to measure the lattice parameters at very short times (< several ps). A suitable tool is the optical pump X-ray probe measurement. Ultrashort X-ray pulses are provided by a laser produced plasma: The Jena multi-TW laser is focused onto a thin metal tape target (in our case titanium). We use pulses of several hundred mJ with a pulse duration of about 80 fs. The pulse is focused by an off-axis parabolic mirror to intensities of about $10^{18}$ W/cm$^2$ to create a hot and dense plasma giving rise to the emission of ultrashort characteristic Ka bursts. The Ka radiation is emitted isotropically. We use part of the radiation transmitting the tape target. It is monochromized and refocused to the sample by a toroidally bent GaAs(100) crystal. The diffracted radiation is detected by a deep depletion X-ray CCD camera providing a very high detection efficiency for Ti-Ka and the capability to detect single photons, which was essential for this experiment since the signal from YBCO was formed exclusively by single photon events. The optical pump pulse is produced by splitting the laser pulse in front of the parabola in 2 parts. The weaker (10% of the energy) is used as the pump pulse. The optical delay between both pulses can be varried by changing the path length of the pump pulse, which at the end is also focused onto the sample. The spatial overlap of both pulses is aligned optically, the temporal overlap is adjusted by a cross-correlation measurement.

The samples were preperated by the Insitut fur Festkorperphysik (IFK) in Jena. The samples were grown as thin films on SrTiO$_3$ (STO) substrates. Both, the film and the substrate were c-oriented. We used film thicknesses of about 250 nm. The film quality was examined by means of standard X-ray diffraction techniques. It turned out that the samples were of very high crystal quality and had an orientation deviation of much less than 0.06°. For the experiment we used meander-like structured samples allowing to
X-RAY OPTICS

monitor the resistance of the pumped and probed volume in the YBCO. This was necessary to immediately note any damage of the sample as a result of optical pumping. First damages of the superconductor are indicated, not by a change of crystal structure, thus the rocking curve profile, but by oxygen diffusion. This means, that oxygen atoms leave the crystal, leading to a fast reduction of $T_c$. It is to be made sure during the experiment that the crystal remains in the superconducting phase. For cooling the sample we used a Stirling machine, which allowed working temperatures as low as 70 K, with a stability of about 1 K. We measured the YBCO(006) reflection of Ti-Ka with a Bragg angle very close to 45°. Due to a very good lattice matching in the ab plane between thin film and substrate and the fact, that $C_{YBCO} \sim 3 C_{STO}$ this reflection is very close to the STO(002) reflection. By carefully controlling the surface misorientation of layer and substrate it is possible to choose the samples in such a way that both reflections are well separated. Doing this it should be possible to use the substrate reflection for normalization.

In order to break all the cooper pairs but not to create changes in the crystal structure originating from other effects but breaking cooper pairs the pump flux must be chosen very carefully. An easy estimation shows that pump fluxes as low as about 20 $\mu$J/cm$^2$ should be already enough to break the cooper pairs. For our experiment we chose 80 $\mu$J/cm$^2$. We realized that low pump flux by passing the pump beam through 2 crossed polarizers. The absorption depth of the thin YBCO layer at 800 nm is of the order of 200 nm, while the substrate for this pump laser wavelength is transparent, thus an excitation of the STO is practically excluded. Thus, any effect measured on STO can only be explained as being mediated by YBCO.

To obtain the rocking curves we had to accumulate over 2000-3000 pulses. One example is shown in figure 1.

![Figure 1: Typical rocking curve. The signal was accumulated over 2000 pulses. The angle of the abzissa corresponds to the angle between diffracted beam from STO and diffracted beam from YBCO and is therefore given by the difference between Bragg angles $\Delta \theta$ and orientation deviation $\Delta \omega$.](image)

To prove the capability of using the STO peak as reference we analyzed the time dependence of the STO peak only. Due to a lack of stability of X-ray emission we had to normalize the peak intensity to 1 and then analyze the integral of the peak. This is a
measure of the line width. Since later only the ratio between the integrals over YBCO and STO peak is of interest, the normalization should not restrict the analysis. Surprisingly, it turned out, that there is a strong time dependence of the STO peak (see figure 2a), which does not allow to use that peak as reference. With this knowledge apparently, normalization of the STO peak restricts the analysis, since no conclusions on the integral reflectivity and therefore the structure factor can be drawn. Nevertheless, the analysis gives data for the linewidth of the rocking curves. At this point it should be stated that the temporal zero position is known only within a precision of about 700 fs. The data points at -1000 fs correspond to unpumped exposures.

In figure 2b the time dependence of the position of the STO peak is shown together with the time dependence of the normalized peak integral. Both show the same temporal behaviour.

Figure 2 The normalized peak integral with linewidth (figure 2a) and peak position (figure 2b) in dependence on time. As described in the text, the normalized peak intensity is a measure of the linewidth, therefore it is not surprising that both quantities show the same time dependence, while it is very surprising that there is a temporal dependence at all and that the peak position changes in the same way as the line width: After excitation of the sample the quantities decrease very rapidly and recover on time scales of only few ps. Data points at -1000 fs correspond to unpumped exposures. The temporal zero position is known only with a precision of about 700 fs.

In the same way as for the substrate the time dependent rocking curves for the thin film were analyzed. Results are shown in figure 3. In figure 3a the normalized peak integral of YBCO and STO is shown. In both cases the normalization factor is the same. For YBCO the normalized peak intensity is therefore indeed a measure of the integral compared to the STO peak. The peak position of the YBCO peak follows also temporally the STO peak (see figure 3b). Furthermore, it seems that there are some oscillations in the peak position and therefore the lattice parameter.

For the linewidth of the YBCO peak no clear conclusions can be drawn in the limit of experimental precision. The YBCO linewidth does not show a clear decrease as the other values.
Figure 3 The temporal dependence of the normalized peak intensity (figure 3a) and the peak position (figure 3b) for the YBCO peak in comparison with the corresponding quantities for STO. Even though the experimental errors are rather large (see the variation in the unpumped values) both peaks seem to follow very well the same temporal dependence. In case of the peak position for both materials some kind of oscillatory behaviour occurs.

To summarize, we made the following observations:

- The integral of the normalized STO peak shows at short times after pumping a strong decrease and recovers after about 1-2 ps. Due to normalization of the peak, this corresponds to a decrease of linewidth. A detailed analysis of the linewidths forces the same conclusion. In addition, the STO peak position changes temporally and shows the same time dependence as the linewidth.
- The integral of the normalized YBCO peak (same normalization factor as for STO) shows the same time dependence as the STO peak within the precision of the experiment. Also the YBCO peak position behaves as the STO peak position, while for the linewidth no correlation to the other parameters was found.

To draw scientific conclusions from these observations more experimental results are necessary. Especially the question arises, whether the changes are induced in the thin layer or in the substrate. Why does the substrate change temporally? One possible explanation for the fact that both, the substrate and the layer, behave similarly, is that the induced changes in one material induce a strain that couples also to the other material. Further experiments must also clarify the scientific origin of the changes. If the changes are induced in the YBCO layer the oxygen atoms could play an outstanding role, in the sense that the oxygen concentration determines the position of the heavy Ba and Cu ions, which in term determine the structure factor [9]. In case that the observed changes can be attributed to the superconducting transition a measurement at temperatures higher than the transition temperature should lead to very different results. To answer these questions we plan to probe the substrate only and to do experiments with YBCO samples of different oxygen doping as well as to study the lattice behaviour at different temperatures.

1. Shi et al., phys. stat. sol. (b), 203, 305 (1997)
Laser produced plasmas are able to produce X-ray flashes of hard X-ray radiation within some hundred femtoseconds duration. The plasma is created by focusing an ultra-short laser pulse with intensity $>10^{15} \text{W/cm}^2$ on a target. Instantaneously free electrons are accelerated in the matter, ionize the atomic K shell and, from the following recombination process, $K_\alpha$ and $K_\beta$ radiation, as well as Bremsstrahlung, are produced. Here we can show that the existing kHz Ti-Sapphire Laser at the IOQ was used as efficient X-ray source with 1 kHz repetition practical for laser-pump X-ray probe experiments.

The laser system provides pulse a energy of 3.5mJ and a pulse duration of 55fs. The outgoing beam has a diameter of about 15mm. With this beam a minimum focal spot size of 12µm could be achieved. The intensity was not high enough to reach a high conversion rate of laser energy into x-ray. By a reflective telescope the beam diameter was expanded by a factor of three. Then the laser beam could be focused down to a focal spot diameter of 4µm which yield to an intensity above $10^{17} \text{W/cm}^2$. After this improvement the x-ray conversion was increased by a factor of ten. The X-ray source was carefully characterized. For this aim, a deep depletion back illuminated CCD camera working in single photon regime was used as non-dispersive spectrometer [1]. Typical spectra for different target materials are shown in figure 1.

From these spectra the total number of $K_\alpha$ and $K_\beta$ photons per second are obtained and a maximum conversion from laser radiation into $K_\alpha$ radiation of $5.4 \times 10^{-6}$ was determined. From the exponential tail of the Bremsstrahlung spectra one can also obtain electron temperatures. For titanium we measured $5 \times 10^{10}$ characteristic photons/s and an electron temperature of about 10keV at an intensity of $2 \times 10^{17} \text{W/cm}^2$. At the same intensity for copper we found $1.2 \times 10^{10}$ photons/s and an electron temperature of about 8 keV. These numbers must be compared to photon numbers and efficiencies obtained at the Jena multi-TW laser system. Here, with laser pulse energies of 600mJ and an optimal intensity of about $5 \times 10^{17} \text{W/cm}^2$, $3 \times 10^{12}$ Ti-photons/s and $5 \times 10^{11}$ Cu-photons/s were measured.

Fig. 1  X-ray spectra of the 1 kHz x-ray source by using Ti, Cu tape target

These numbers must be compared to photon numbers and efficiencies obtained at the Jena multi-TW laser system. Here, with laser pulse energies of 600mJ and an optimal intensity of about $5 \times 10^{17} \text{W/cm}^2$, $3 \times 10^{12}$ Ti-photons/s and $5 \times 10^{11}$ Cu-photons/s were measured.
Further we built up an experiment using the pump-probe scheme with the kHz X-ray source. X-rays which are emitted from the plasma are collected, spectrally selected and refocused by an appropriate X-ray optic onto a sample crystal. The X-ray beam is guided in a new designed vacuum beam line out of the target chamber to the x-ray optic and then through a vacuum window to the sample crystal which is positioned outside the vacuum for flexibility reasons. Only 200µJ of the uncompressed beam of the first 1kHz amplifier (total energy 1.3mJ) is used as a seed pulse for the second Multi Pass Amplifier. The other part of the laser energy (1.1mJ) is compressed and is used as optical pump pulse. Recompressed, the pump pulse has energy of about 800µJ and a pulse duration of about 50fs. This set up has the advantage that all the laser energy coming from the output of the second Multi Pass Amplifier can be used for X-ray production. A first time resolved experiment was performed at the 1 kHz x-ray source. Acoustic phonons were studied in Germanium by using the 400 reflection and Ti Kα radiation. Using an excitation flux of 3mJ/cm² the temporal response was recorded at delays between 0 ps and 250 ps. The time resolved rocking curves can be seen in figure 2. The exposure time for one rocking curve was 400 s (400000 pulses). The dynamic range achieved in this first experiment was better than about 3000. One can see the typical lattice expansion in the first 50ps. For the first time we see a detectable expansion already at 5ps. These deformations at very short delay times are very interesting to study how fast the excited electrons are transferring their energy to lattice.

---

**Fig. 2**  
a) Transient rocking curves show acoustic phonons of a Germanium crystal, excited by ultrashort laser pulses. The experiment was carried out with the Jena 1kHz x-ray source. Flux 3mJ/cm², Ge 400 reflection, Ti Kα radiation.   
b) Simulation of time-dependent Germanium 400 rocking curves using the microphysics model for transient strain [2] and dynamical x-ray diffraction theory in a deformed lattice [3, 4].

Further measurements at earlier times can provide more information about this. Detailed analysis of the rocking curves will provide information of the thermal and electronic stress. New insights of the behavior of different semiconductors, i.e. diffusion, recombination, and deformation potential at very high carrier densities can be exploited from such analysis.
ULTRAFAST STRUCTURAL DYNAMICS IN SAMARIUM MONO-SULPHIDE (SmS)

F. S. Krasniqi, T. Kämpfer, A. Morak, I. Uschmann, F. Zamponi, E. Förster and R. Sauerbrey

Samarium mono-sulphide (SmS) was shown to be an unstable valence material which undergoes pressure-induced semiconductor-metal phase transition at a pressure of about 0.65 GPa [1]. The phase transition is associated with the conversion of Sm ion from Sm\(^{2+}\) toward Sm\(^{3+}\). Fluctuating valence in Sm ion directly causes fluctuation in the ionic diameter, which consequently may induce lattice distortion around the Sm ion. Thus, time resolved investigation of structural changes in SmS can be a useful tool in providing insights into the interplay between atomic motions in bulk media and valence fluctuations. We have performed two time resolved x-ray experiments studying the response of laser excitation of the two phases of Samarium mono-Sulphide.

In a first experiment we demonstrate the time resolved X-ray diffraction from expansion/compression regions in SmS, launched by perturbing the crystal by infra-red laser pulses. The data obtained are used to investigate the interplay between low frequency acoustic phonons and valence fluctuations. The scheme of the experimental set up is shown in [2].

The impulsive heating of the crystal by fs pulses produce electrons and holes (i.e., the light will change the population of electrons and holes) which transfer their excess energy to the lattice by generating acoustic phonons across a range of wave vectors near the Brillouin zone centre of width \(\sim 3\times10^7\ \text{m}^{-1}\). This change in electron and phonon distribution drives a thermal stress which in turn lunches an expansion/compression strain pulse into the bulk at the speed of sound \(v_s \approx 4700\ \text{m/s}\) [3]. As the strain pulse propagates in the crystal, different phonon modes are selected, which subsequently cause oscillation in the diffraction signal observed at smaller angular positions.

Fig. 1 Measured (crosses) and simulated (solid lines) rocking curves at the pump-probe delay of 30 and 80 ps, respectively (laser fluence: 10 mJ/cm\(^2\)). Insets: Strain profiles [3] used to simulate rocking curves at the corresponding pump-probe delays.
The influence of the transient strain on the measured rocking curve is modelled by using the dynamical theory [4,5] for deformed crystals. The wave equation describing the X-ray propagation in a deformed lattice formulated by Takagi-Taupin theory is solved for the one dimensional case of a strain gradient. The depth dependent strain profile for a given time is taken into account by corresponding shift in the Bragg angle (due to the corresponding change in 2d-spacing). To account for the instrumental broadening, the calculated rocking curves were convolved with a Gaussian function of a 133 arcsec FWHM. The comparison of the measured rocking curves and those calculated by the above mentioned model are summarized in Fig. 1. It is evident that the simulations reproduce well the features of the experimental data, suggesting that the propagation of coherent acoustic phonons in semiconducting SmS is observed and this demonstrates observation of atomic motion in bulk media during picosecond time scale. The discrepancies at the wings of the rocking curves may be attributed to the underestimation of the carrier-lattice thermalization by the model used and errors introduced in evaluation of rocking curves as well. Since the approach used to interpret our results does not take into account any interplay between lattice vibrations and valence fluctuation, we can conclude that, at the used laser fluence, SmS behaves like a standard semiconductor. This conclusion is based on the fact that, the interaction between acoustic phonons and valence fluctuations include ion size effects (in the extreme case the radii of the Sm ion decreases to about 16%) and thus lattice constant reduction. This subsequently would yield to modification (introduction of an asymmetry) of the rocking curves in the compression side (higher angular positions) or in the extreme case decrease of the semiconductor-phase signal and a signature (signal) at about 1-1.4°. All these signatures were not observed in our diffraction signal. At laser fluences above 12mJ/cm², a permanent decrease of the measured signal is observed, which indicates permanent damage of the crystalline region used.

Recently a second time resolved diffraction experiment was performed to investigate, for the first time, the temporal evolution of the metal-semiconductor phase transition. Such a phase transition was achieved many years ago by shining a ns-laser pulse having a high laser flux of about 500 mJ/cm² on metallic SmS [6]. In this experiment the phase transition was detected by the color of the SmS layer. There was no time resolution detecting the process. By grinding of semiconductor SmS crystals and providing a sufficient pressure it was possible to obtain a quite homogeneous layer of metallic state. The thickness of the layer is in the order of 100 nm. Such a layer can be well detected by x-ray diffraction. The layer consists of small grains having still the orientation like the semiconductor bulk crystal. Nevertheless the grains are tilted slightly to each other having an angular distribution of about 4°. We can show, that this metallic SmS layer disappears by exposure of fs-laser pulses having an energy flux in the range of (100...500) mJ/cm². This process was studied by time resolved x-ray diffraction.
Fig. 2 Time evolution of the metal-semiconductor phase transition of SmS for the first 250 ps after excitation. Left short times, right longer times, laser flux: 500 mJ/cm², the lines are only a help guided for the eye.

Because the transition is not reversible the experiment was done in single pulse exposures. That is why as much as x-ray photons as possible were used in a single pulse by the Jena-Multi-Terawatt-laser system. For each sample position three x-ray diffraction patterns were recorded. At first the diffracted signal of the unperturbed metallic layer as well as the signal of the semiconductor bulk crystal was recorded. Then the time dependent x-ray signal was measured applying the laser pump pulse at a given delay time. After the excitation again the signal of metallic and semiconducting SmS were measured. From these three data the temporal change was obtained for each single sample position. From the x-ray diffraction pattern three states could be distinguished: first the quasiperfect curve of the crystal bulk, second the metallic polycrystalline layer and third a signal coming from polycrystalline SmS. To obtain a good statistics 50 exposures were performed for one delay time. The flux was chosen to be 500 mJ/cm². For this flux the strongest change of the phases could be observed with x-ray diffraction after excitation. In Figure 2 the temporal evolution during the first 250ps after excitation is plotted. Here the integrated reflectivity from two states are compared, the semiconductor bulk and the metallic layer. Before excitation only contribution of these two states are visible. After excitation the metallic phase almost disappeared. Further a new diffraction peak coming from polycrystalline Semiconductor SmS was detected. In addition a broadening of the bulk peak can be observed at this flux. One can see a fast variation of the diffracted x-rays coming from the metallic phase in the first 2ps. Two data points show a strong reduction and surprisingly two other points show an increase of the reflected signal. At this time the signal from the bulk material remains constant. Nevertheless after 10ps the signal from the metallic layer was decreased by 20%. Up to this time no polycrystalline SmS which would show direct solid-solid transition was observed. At later times 100ps both the signal from bulk and layer drops by 30%. At these times a signal from polycrystalline SmS can be observed which is slightly growing. Further analysis and comparison with simulation will provide us more insights to this experiment.
MEASUREMENT OF THE MAGNETIC FIELD PRODUCED BY THE INTERACTION OF ULTRA-SHORT, ULTRA-INTENSE FS LASER PULSE WITH MATTER

F. Zamponi, A. Lübcke, I. Uschmann, E. Förster, R. Sauerbrey, E. Kroupp [1], E. Stambulchik [1], Y. Maron [1]

[1] Weizmann Institute of Science, Rehovot 76100, Israel

When ultrashort high power laser pulses are focused to intensities of $10^{18}$ W/cm$^2$ onto a solid target, a very dense plasma layer is created ($10^{21}$-10$^{24}$ cm$^{-3}$). Charged particles in this plasma, mainly electrons, are accelerated up to relativistic energies by the intense laser field. Because of the ultrashort laser pulse duration the acceleration time is only about 100 fs. An expected current of several MA should induce very strong magnetic and electric fields inside the dense plasma and the solid material. Such high fields ($5\times10^4$ T have been predicted [1]) are very difficult to diagnose by conventional methods since the dense plasma is not transparent for light in the visible range. Therefore the transient characteristic X-ray emission induced by the electrons in small regions of the dense plasma has to be diagnosed. Fundamental processes in ultra dense plasmas can only be studied by using advanced X-ray diagnostics, i.e. the investigation of spectral, spatial and temporal X-ray emission. The Zeeman Effect [2] for X-ray transitions ($E > 1$ keV) has never been observed. The reason for this is relatively easy to see. The achievable spectral resolution in the x-ray range has an upper limit of about $E/\Delta E \sim 10^4$ for the x-ray energies of $E > 1$ keV. Since the Zeeman splitting is on the order $\Delta E \sim \mu B*B \sim 10^{-4}$ eV/T*B, a magnetic field that is substantially larger than $B = 10^3$ T would be required to observe the Zeeman Effect, such fields are not commonly available in laboratories. In the experiment reported here a high-intensity laser with intensity well in excess of $10^{18}$ W/cm$^2$ is focused onto a solid target and capable of producing these ultra-high magnetic fields. To study such strong magnetic field in laser produced plasmas a new generation of X-ray spectrograph combining high spectral resolution with brightness and high spatial resolution is necessary. Especially, a good spatial resolution is required, since we expect the highest magnetic fields in a very small area (on the order of 3 µm) close to highest laser intensity.

The experiment was performed at the Jena multi-TW Ti:sapphire laser system. The laser pulse with 600 mJ pulse energy and pulse duration of 90 fs (FWHM) was focused by an off-axis parabolic mirror down to focal spot sizes of 5 µm$^2$ onto thin metal foils. As targets we used 25 µm thick titanium foils as well as layered targets (25 µm titanium + 200 nm copper). Within a layer at the target surface with thickness close to the skin depth a thin plasma layer is created. In this layer the electrons are accelerated by the laser field to relativistic energies and give rise to emission of characteristic X-rays as well as to creation of a large current inducing strong magnetic fields, which influence the spectral distribution of the emitted lines. The line shape of the titanium K$_{\alpha1}$ and K$_{\alpha2}$ lines were used for studying the influence of the magnetic field. It was chosen for compromise: On the one hand, since the absolute value of Zeeman splitting is independent on Z, high Z target elements require an unreasonably high energy resolution. On the other hand, low Z materials suffer a low fluorescence yield and a stronger line broadening induced by additional ionization states in outer shells. For the
\(K_\alpha\) lines of medium Z elements crystals are available providing a spectral resolution of about \(\lambda/\Delta\lambda \sim 5000\). The spectra are recorded by a doubly focusing bent crystal spectrograph. The bending radii in dispersion plane and perpendicular to the dispersion plane are chosen in such a way that on the Rowland circus a focused X-ray spectrum not broadened by the source size is produced. Perpendicular one gets a 1D image of the source. In the experiment a toroidally bent GaAs (100) crystal was used in the 4th order reflection. This provides a high Bragg angle of \(\theta = 76.6^\circ\), allowing high spectral resolution. Due to this Bragg angle the diffracted spectra are nearly unpolarized. To distinguish between the different polarization states of the x-ray emission an additional spectrum was recorded which is linearly polarized [3]. This is done by a flat crystal combined with the toroidally bent crystal to a non-dispersive double crystal spectrometer setup [4].

The diffracted intensity of a flat crystal depends on the polarization state:

- P-polarization: \(I \sim \cos (2\theta_B)\), \(\theta_B\) - Bragg angle
- S-polarization: \(I \sim 1\).

Using the flat crystal at a Bragg angle of 45° only s-polarized radiation will be recorded. The flat crystal is positioned between the bent crystal and the Rowland circle in such a way that only a part of the vertical X-ray beam fan is reflected by the flat crystal; the other part is still sent to the Rowland circle. Recording simultaneously polarized and unpolarized spectra should help to distinguish changes induced by Zeeman Effect and from resulting from Stark broadening or different ionization states. For the experiment the combination of a toroidally bent GaAs(400) crystal and a flat Si(220) crystal were used.

As detector we used X-ray film. We found no differences between polarized and non-polarized spectra probably due to the too low spatial resolution, as explained later. The \(K_\alpha_2\) line was slightly cut, due to a small misalignment of the bent crystal; so it couldn’t be used in the data analysis. We found also no differences between layered targets (Cu on Ti) and simple targets (only Ti).

In fig. 1 a typical spectrum is reported: the horizontal direction is the spectral direction, in the vertical one is the 1-D imaging.

In fig. 2 one of the most important results of these measurements is presented: the spectrum with solid line was acquired with an intensity of \(5\times10^{18}\) W/cm\(^2\) on the target; also a small prepulse, 150 ps before the main pulse with one thousandth of the main pulse energy, was present. The dotted spectrum was acquired with an intensity of \(5\times10^{19}\) W/cm\(^2\); no prepulse was present. The increase in linewidth is clearly visible and amounts to 30%. Both spectra were non-polarized.

Because the comparison polarized non-polarized spectra doesn’t allow any conclusions, it’s important to know which processes can cause a line broadening. The Stark Effect created by the microfields in dense plasmas [5] and by the creation of a space charge could have given important contribution to the observed linewidth increase. We are still working to find out which role it could have played. The second important process is broadening by the satellites. If there is a vacancy in the M-shell while a recombination process is taking place, the outcoming radiation is blue shifted. If all electrons 3\(d\) and 4\(s\) are removed, the shift is in the order of 0.5 eV; for every M-shell electron the shift is about 4 eV.

If we assume that the linewidth increase comes only from the Zeeman Effect, then a magnetic field of about 5000 Tesla is to be expected.
Figure 1: A typical spectrum. In the horizontal direction the spectral direction in the vertical the 1-D imaging

![Figure 1: A typical spectrum. In the horizontal direction the spectral direction in the vertical the 1-D imaging](image1)

Figure 2: A lineout of the $K_{α1}$ line for two different irradiation conditions. With solid line a spectrum acquired with intensity on the target of $5 \times 10^{18}$ W/cm$^2$ and a small prepulse, with dotted line a spectrum relative to an intensity of $5 \times 10^{19}$ W/cm$^2$, without prepulse.

![Figure 2: A lineout of the $K_{α1}$ line for two different irradiation conditions. With solid line a spectrum acquired with intensity on the target of $5 \times 10^{18}$ W/cm$^2$ and a small prepulse, with dotted line a spectrum relative to an intensity of $5 \times 10^{19}$ W/cm$^2$, without prepulse.](image2)

The following report summarizes the results of our XRD investigations of the laser-cut Si samples and gives answer to the questions posed by the company A.L.S.I. Advanced Laser Separation International.

**Objective:** To measure stress in Si wafer material - qualitatively or quantitatively

**Research method:** X-ray topography using Lang’s technique

The x-ray diffraction topographs of laser-cut Si(001) samples, etched and not etched, were recorded by the Lang technique in transmission mode [1, 2, 3, 4, 5]. The symmetric 220 reflections with MoKa1-radiation (λ=0.071nm) were used in each case.

![Schematic set-up for the X-ray diffraction topography in transmission using Lang’s technique.](image)

The monochromatic and well collimated X-ray beam ‘scans’ the crystal by a simultaneous translation of the aligned crystal and the photographic film. The aligned crystal has to fulfil the Bragg’s reflection condition $n\lambda=2d\sin(\Theta_{hkl})$.

The diffracted beam $K_{(hkl)}$ gives the image contrast of crystal defects which is not caused by the by absorption effects but by the modified extinction due to the $\Delta\Theta$ nearby the crystalline defects (changing oft the local lattice parameter in order of magnitude until $10^{-3}$ relatively).

**Used parameter:**
- Mo X-ray tube, point focus 1x1 mm$^2$, 40kV/30mA,
- MoKα1-radiation, $\lambda = 0.071$nm, $\Delta\lambda = 3.6\cdot10^{-4}$
  → beam collimation to separate MoKα1 from MoKα2
- lateral beam divergence $1.1\cdot10^{-3} \approx 0.065^\circ$
- exposure time 3 – 6 hours with nuclear photo plate Ilford L4 50µm
Imperfections in the crystalline structure are displayed by the so called extinction contrast \cite{2,5} under the condition that the scalar product of the deformation vector $\mathbf{b}$ and the diffraction vector $\mathbf{g}$ is not zero ($\mathbf{b} \cdot \mathbf{g} \neq 0$).

**Results:**

Due to the extinction contrast a strong pointlike distortion at the border of the Laser-diced wafer is seen in Fig 2b. Evidently, the Laser dicing is not carried out with continuous Laser beam but with pulsed Laser power. Along the Laser dicing edge the strength and distance of the pointlike distortions change noticeably. The pointlike distortion contrast is only seen at the left and right side border, that means we have here a strong deformation vector component $\mathbf{b}$ parallel to the diffraction vector $\mathbf{g}(220)$. But at the top border, no point like distortion contrast appears. Here, the deformation vector $\mathbf{b}$ should be perpendicular to $\mathbf{g}(220)$. The XRD-topograph of the 90° turned sample shows the same behaviour. Hence, the Laser dicing process induces strong distortion components perpendicular to the dicing border, not homogeneous but pointlike arranged along the dicing border.
On the basis of the XRD topos only the qualitative description of the crystalline distortion concerning strength and location is possible. The crystalline distortion is caused in each case by a local closely limited deformation of the X-ray diffracting crystalline lattice planes. By Hook’s law there is an interaction between the local closely limited deformation and the internal stress components. A quantitative evaluation of the internal stress components requires resuming more high-sensitive measurements.

XRD-topographs of the not etched Si sample (Fig. 3) showed generally higher diffracted intensity than the topos of the etched samples due to the homogeneously polished (distorted) surfaces. As well the edges showed an extreme strong contrast due a more intensive lattice distortion without emphasize-worth details at the left and right side border. Single defects due to the Laser dicing cannot be resolved. The wavelike edge contrast, caused by strong pointlike distortion above already mentioned, is remarkable.
[7] INTERNATIONAL TABLES for CRYSTALLOGRAPHY
[8] Volume C – Mathematical, Physical and Chemical Tables
[10] \( \rightarrow \) Chapter 2.7 Topography by A.R.Lang
[12] Diffraction from Materials
[14] \( \rightarrow \) Chapter 8.11 X-ray Topography, Chapter 8.11.2 Contrast Mechanisms
Activities

2\textsuperscript{nd} International Workshop on High Energy Class Diode Pumped Solid State Lasers (HEC-DPSSL) Jena, 10 – 12 June 2005

Session 1 - Laser Programs presentation

Dr. A. Bayramian, LLNL, United State of America.
“System Operations of Mercury; A Diode-Pumped Solid-State Laser“,

Dr. T. Kawashima, ILE, Osaka University, Japan.
“Recent progress of HALNA DPSSL driver development”

Dr. J.-C. Chanteloup, LULI, Ecole Polytechnique, France
“Status of the 10Hz/100J DPSSL LUCIA program”,

Dr. J. Hein, IOQ FSU, Germany
“Status of the POLARIS Project and planned installations”

Session 2 - Extraction architectures

Dr. J. Kawanaka, ILE, Osaka University, Japan.
“A cryo-cooled Ytterbium-doped laser materials for IFE driver”

Dr. G. Bourdet, LULI, Ecole Polytechnique, France.
“LUCIA laser head”,

Dr. A. Bayramian, LLNL, United State of America
“Activation of a Temporal, Spectral, and Spatially-Shaped Front End for the Mercury Laser”,

S. Podleska, IOQ FSU, Germany
"POLARIS multipass and regenerative amplifiers"

R. Bödefeld, IOQ FSU, Germany
"Pulse chirp management and the tiled grating compressor"
Session 3 - Modelling

Prof. F. Wyrowski, IAP FSU, Germany
"Laser pulse propagation modelling"

Dr. T. Kawashima, ILE, Osaka University, Japan
“Thermo-optical modelling for the HALNA slab amplifier”

H. Yu, LULI, Ecole Polytechnique, France
“Temperature dependent energy extraction and thermal distortions of Lucia amplifiers”

Dr. S. Tokita ILE, Osaka University, Japan
“High-power cryogenic Yb:YAG CW disk laser”

Session 4 - Materials / Laser damage issues

Dr. A. Bayramian, LLNL, United State of America
“Growth and Scaling of High-Quality Yb:S-FAP for the Mercury Laser”

Dr. J.-C. Chanteloup, LULI, Ecole Polytechnique, France
“Laser Damage issues management for the LUCIA program”

Dr. D. Ehrt, OSI FSU, Germany.
"Yb-doped fluoride phosphate laser glass"

B. Le Garrec, ILP, France
“Solid-state laser design for inertial confinement fusion: trends toward power production”
**Session 5 - Pumping architectures**

Dr. D. Wolff, Jenoptik Laserdiode GmbH, Germany  
"Advanced High Power Diode Lasers: New Ways to Long-Time Operation and Higher Brightness"

Dr. T. Kawashima, ILE, Osaka University, Japan  
“Design of optical pump delivery system for HALNA”

Le Moal, LULI, Ecole Polytechnique, France  
“LUCIA 100 Joules Pumping Head”

M. Siebold, IOQ FSU, Germany  
"Concepts of homogeneous pump delivery for the POLARIS amplifiers A1-A5",

**Session 6 - HEC DPSSL Applications**

Dr. A. Bayramian, LLNL, United State of America  
“Scaling of High Average Power Frequency Conversion for the Mercury Laser”

Dr. A. Bayramian, LLNL, United State of America  
“Short Pulse Capabilities and Future Applications of the Mercury Laser System”

Dr. J.-C. Chanteloup, LULI, Ecole Polytechnique, France  
“Lucia, used as a pump source for ~PW range / 10 Hz laser systems”

Prof. R. Sauerbrey, IOQ FSU, Germany  
"High intensity laser applications"
### IOQ Workshop  20 – 21 June 2005

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Dino Jaroszynksi</td>
<td>&quot;Harnessing plasma waves as radiation and particle sources&quot;</td>
</tr>
<tr>
<td>Prof. Roland Sauerbrey</td>
<td>&quot;Teramobile&quot;</td>
</tr>
<tr>
<td>Michael Geissler</td>
<td>&quot;Laser electron acceleration in the bubble regime&quot;</td>
</tr>
<tr>
<td>Ben Liesfeld</td>
<td>&quot;Laser nuclear experiment at LULI&quot;</td>
</tr>
<tr>
<td>Bernhard Ersfeld</td>
<td>&quot;Raman backscattering of a chirped pump pulse in plasma&quot;</td>
</tr>
<tr>
<td>Kay-Uwe Amthor</td>
<td>&quot;Time resolved laser plasma diagnostics&quot;</td>
</tr>
<tr>
<td>Wolfgang Hollik</td>
<td>&quot;Der Blick ins Atto-Universum - Status und Perspektiven der Teilchenphysik&quot;</td>
</tr>
<tr>
<td>Sebastian Pfotenhauer</td>
<td>&quot;Proton acceleration from thin foils&quot;</td>
</tr>
<tr>
<td>Prof. Klaus Sokolowski-Tinten</td>
<td>&quot;Ultrafast X-ray science&quot;</td>
</tr>
<tr>
<td>Dr. Joachim Hein</td>
<td>&quot;Progress of diode pumped petawatt laser project POLARIS&quot;</td>
</tr>
<tr>
<td>Dr. Heinrich Schwoerer</td>
<td>&quot;Counterpropagating laser beams&quot;</td>
</tr>
<tr>
<td>Prof. Eckhart Förster</td>
<td>&quot;X-Ray optics&quot;</td>
</tr>
<tr>
<td>Mark Wiggins</td>
<td>&quot;The Alpha-X Project&quot;</td>
</tr>
<tr>
<td>Name</td>
<td>Institution and Location</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Ken Ledingham</td>
<td>Carl Zeiss Visiting Professorship at the physikalisch-astronomische Fakultät, Department of Physics, University of Strathclyde, Glasgow, Scotland</td>
</tr>
<tr>
<td>Prof. J. Chen</td>
<td>China Academy of Engineering Physics, Mianyang, Sichuan, China</td>
</tr>
<tr>
<td>Prof. S. L. Chin</td>
<td>Department of Physics, Laval University Quebec, Canada</td>
</tr>
<tr>
<td>Dr. F. Ewald</td>
<td>ENSTA, Laboratoire d’Optique Appliquée, Chemin de la Huniére, Palaiseau, France</td>
</tr>
<tr>
<td>J. Faure</td>
<td>ENSTA, Laboratoire d’Optique Appliquée, Chemin de la Huniére, Palaiseau, France</td>
</tr>
<tr>
<td>Prof. H. Fiedorowicz</td>
<td>Institute of Optoelectronics, Military University of Technology, Warsaw, Poland</td>
</tr>
<tr>
<td>Prof. Dr. G. Figueira</td>
<td>Centro de Fisica de Plasmas, Instituto Superior Tecnico, Lissabon/Portugal</td>
</tr>
<tr>
<td>Prof. Dr. H. Giessen</td>
<td>4th Physics Institute, University of Stuttgart</td>
</tr>
<tr>
<td>Yannick Glinek</td>
<td>ENSTA, Laboratoire d’Optique Appliquée, Chemin de la Huniére, Palaiseau, France</td>
</tr>
<tr>
<td>Prof. D. Habs</td>
<td>Ludwig-Maximilian-Universität München</td>
</tr>
<tr>
<td>Dr. Bernd Hahn</td>
<td>Quantronix/Continuum Laser, Büro Berlin</td>
</tr>
<tr>
<td>Prof. P. R. Hermann</td>
<td>Department of Electrical and Computer Engineering, University of Toronto, Canada</td>
</tr>
<tr>
<td>Dr. Hesse</td>
<td>OSNA Technologien GmbH, Georgsmarienhütte</td>
</tr>
<tr>
<td>Emer. Prof. H. Hora</td>
<td>South Hurstville, Australia</td>
</tr>
<tr>
<td>Prof. W. T. Hill</td>
<td>Institute for Physical Science &amp; Technology and Department of Physics, University of Maryland</td>
</tr>
<tr>
<td>Clemens Höninger</td>
<td>Amplitude Systèmes, Talence, France</td>
</tr>
<tr>
<td>Prof. G. Huang</td>
<td>China Academy of Engineering Physics, Mianyang, Sichuan, China</td>
</tr>
<tr>
<td>Prof. Jan Jabczynski</td>
<td>Military University of Technology, Warsaw, Poland</td>
</tr>
<tr>
<td>Dr. S. Karsch</td>
<td>Rutherford-Appleton Laboratory, Oxfordshire, United Kingdom</td>
</tr>
<tr>
<td>E. Kroup</td>
<td>Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel</td>
</tr>
<tr>
<td>Prof. Shoichi Kubodera</td>
<td>Dept. of EEE, University of Miyazaki, Japan</td>
</tr>
<tr>
<td>Prof. G. Ravindra Kumar</td>
<td>Tata Institute of Fundamental Research, Mumbai, India</td>
</tr>
<tr>
<td>Mr. Tom McCanny</td>
<td>Department of Physics, University of Strathclyde, Glasgow, Scotland</td>
</tr>
<tr>
<td>Name</td>
<td>Institution and Location</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dr. Paul McKenna</td>
<td>Department of Physics, University of Strathclyde, Glasgow, Scotland</td>
</tr>
<tr>
<td>Dr. Victor Malka</td>
<td>ENSTA, Laboratoire d’Optique Appliquée, Chemin de la Hunièvre, Palaiseau, France</td>
</tr>
<tr>
<td>Dr. Katsumi Midorikawa</td>
<td>RIKEN, Japan</td>
</tr>
<tr>
<td>Prof. André Mysyrowicz</td>
<td>École Polytechnique – ENSTA, Palaiseau, France</td>
</tr>
<tr>
<td>Dr. H. Nishimura</td>
<td>Institute of Laser Engineering, Osaka University, Japan</td>
</tr>
<tr>
<td>Mr. James Norby</td>
<td>Quantronix/Continuum Laser</td>
</tr>
<tr>
<td>Dr. Oldrich Renner</td>
<td>Institute of Physics of the Czech Academy of Sciences, Prag, Czech Republic</td>
</tr>
<tr>
<td>Lynne Robson</td>
<td>Department of Physics, University of Strathclyde, Glasgow, Scotland</td>
</tr>
<tr>
<td>Dima Osin</td>
<td>Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel</td>
</tr>
<tr>
<td>Dr. C. Rose-Petruck</td>
<td>University of California, San Diego, USA</td>
</tr>
<tr>
<td>Prof. H. Peng</td>
<td>China Academy of Engineering Physics, Mianyang, Sichuan, China</td>
</tr>
<tr>
<td>PD Dr. G. Plunien</td>
<td>Technische Universität Dresden, Institut f. Theoretische Physik</td>
</tr>
<tr>
<td>Dr. L. A. Vern Schlie</td>
<td>Technology Laser Division, Albuquerque, USA</td>
</tr>
<tr>
<td>PD Dr. Ch. Schroer</td>
<td>II. Physikalisches Institut der RWTH Aachen</td>
</tr>
<tr>
<td>Prof. G. O'Sullivan</td>
<td>Department of Exp. Physics, University College Dublin, Ireland</td>
</tr>
<tr>
<td>Dr. Tran Anh Vu</td>
<td>Institute of Materials Science, Hanoi, Vietnam</td>
</tr>
<tr>
<td>Prof. P. Wachter</td>
<td>ETH Zürich</td>
</tr>
</tbody>
</table>
COOPERATIONS

Prof. Maron, Weizmann Institute of Science, Rehovot, Israel, DIP Projekt

Teramobile:

Prof. Dr. Jean-Pierre Wolf, Dr. Jérôme Kasparian Université Claude Bernard Lyon, LASIM;
Prof. Dr. André Mysyrowicz, X-ENSTA Palaiseau, Laboratoire d'Optique Appliquée, équipe "interactions laser-matière", Study of long-distance propagation of fs-TW laser pulses in air, and atmospheric applications: Lidar remote sensing, lightning control

Prof. See Leang Chin, Department of Physics, Laval University, Quebec, CANADA

Prof. L. Wösthe, Freie Universität Berlin, Institut für Experimentalphysik

Dr. Reinhard Ebert, FGAN-FOM Ettlingen

Prof. Dr. Artie P. Hatzes, Thüringer Landessternwarte Tautenburg

Laserlab Europe:

The “Integrated Initiative of European Laser Infrastructures in the 6.th Framework Programme of the European Union

Partner:

MBI: Max Born Institute for Nonlinear Optics and Short-Pulse Spectroscopy, Berlin, Germany (Co-ordinator) Dr. P. Nickles

LOA: Laboratoire d’Optique Appliquée, Palaiseau, France

LULI: Laboratoire pour l’Utilisation des Lasers Intenses, CNRS, Palaiseau, France

CELIA: Centre Lasers Intenses et Applications, University of Bordeaux-I, CNRS, Bordeaux, France

SLIC: Saclay Laser-Matter Application Centre, CEA, Saclay, France

CESTA: Centre d'Etudes Scientifiques et Techniques d’Aquitaine, CEA, Le Barp, France

CLEF: Central Laser Facility, Rutherford Appleton Laboratory, CCLRC, Oxfordshire, United Kingdom

FCH: Fachinformationszentrum Chemie GmbH, Berlin, Germany

ULF-FORTH: Institute of Electronic Structure and Laser, Ultraviolet Laser Facility, Foundation for Research and Technology-Hellas, Heraklion, Greece

GSI: Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany

LENS: Laboratorio Europeo di Spectroscopie Non Lineari, Sesto Fiorentino (Florence), Italy

LLC: Lund Laser Centre, Lunds Universitet, Lund, Sweden

ALS: Prague Asterix Laser System, Institute of Physics, Prague, Czech Republic

CUSBO: Centre for Ultrafast Science and Biomedical Optics, Politecnico di Milano, Dipartimento di Fisica, Milano, Italy

MPQ: Max-Planck-Institute for Quantum Optics, Garching, Germany

VULRC: Quantum Electronics Department and Laser Research Center, Vilnius University, Vilnius, Lithuania

GSI: Gesellschaft für Schwerionenforschung mbH, Darmstadt, Dr. T. Kühl, Entwicklung von Petawattlasern

MPQ Garching, Prof. Ferenc Krausz, Prof. D. Habs
COOPERATIONS

Entwicklung von Petawattlasern

MPI für Kernphysik Heidelberg, Prof. Keitel,
Quantenelektrodynamik in starken Lichtfeldern

Sonderforschungsbereich Transregio – TR18, Universität Düsseldorf
Relativistische Laser–Plasma–Dynamik

Department of Physics, University of Strathclyde John Anderson Building, Glasgow, Scotland,
Prof. Ken W. D.Ledingham
Laserkernphysik

Institute of Physics, Chinese Academy of Sciences Laboratory of Optical Physics, Beijing, P.R.
China
Propagation hochintensiver Laserpulse

Centre etude nucleaire Bordeaux, Dr. Fazia Hannachi, Gradignan, CENBG, Frankreich/
Kooperation zu laserinduzierter Kernphysik

Fazia HANNACHI, Directrice de Recherche CNRS Responsable du groupe
Centre d'Etudes Nucléaires de Bordeaux Gradignan Unité mixte UMR5797 du CNRS/IN2P3 et
de l'Université Bordeaux
Laserkernphysik

General Atomics Inc., Mike Perry, San Diego, Ca., USA
fs-Laserentwicklung für POLARIS

Camille Bibeau, Lawrence Livermore National Laboratory, USA,
diodengepumpter Hochleistungslaser

Jean-Christophe Chanteloup, Laboratoire pour l’Utilisation des Lasers Intenses, CNRS,
Palaiseau, France
diodengepumpter Hochleistungslaser

Institute of Laser Engineering Osaka, Japan, T. Kunabe
diodengepumpter Hochleistungslaser

Otto-Schott-Institut (OSI), Dr. D. Ehrt, Prof. Dr. C. Rüssel
Lasergeräteentwicklung

Jenoptik, LOS GmbH, Dr. Hollemann
ps-Laserentwicklung

Jenoptik Laserdiode GmbH, Dr. D. Wolff,
Laserdiodenentwicklung

Czech. Academy of Sciences, Inst. Of Physics, Prague, Dr. O. Renner,
High-Resolution X-ray Spectroscopy

Laboratoire d’Optique Appliquée, Palaiseau, France, Dr. A. Rousse, DR. Ph. Zeitoun, ENSTA,
Forschungsvereinbarung: X-ray and VUV optics for brilliant short-pulse sources

University of York, Department of Physics, Heslington, York, U.K. Prof. N. Woolsey, Projekt:
Development of X-ray crystal diagnostics

Intense Laser Irradiation Laboratory, Pisa, Prof. A. Giuletti
Austausch von Doktoranden: Röntgendiagnostik von Laserplasmen

ESRF (European Synchroton Radiation Facility) in Grenoble / France,: Dr. N. Schell
Characterization of CuGaS2 thin films epitaxially grown on Si(111)´ an der Beamline BM20 (ROBL)

Universita Roma "La Sapienza", Dipartimento di Energica, Roma, Italia, Prof. M.Bertolotti

Physicotechnical Institute, Russian Academy of Sciences, St. Petersburg, Russia, Dr. K.L. Muratikov, A.F.Ioffe

Fraunhofer-Institut für Feinmechanik und Optik Jena, Prof. Dr. A. Tünnermann

Institut für Transurane (ITU), Karlsruhe Dr. Joseph Magill

Lund Institute of Technologie, Lund, Schweden, Prof. S. Svanberg

Fa. Layertec, Mellingen H. Heyer
PUBLICATIONS

Number with accumulated impact factor

<table>
<thead>
<tr>
<th>Journal</th>
<th>Impact Factor</th>
<th>Anzahl</th>
<th>Produkt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Optics</td>
<td>1,799</td>
<td>1</td>
<td>1,799</td>
</tr>
<tr>
<td>Appl. Phys. Lett</td>
<td>4.308</td>
<td>2</td>
<td>8.616</td>
</tr>
<tr>
<td>Chem. Phys.</td>
<td>2.316</td>
<td>1</td>
<td>2.316</td>
</tr>
<tr>
<td>Journal of Quantitative Spectroscopy and Radiative Transfer</td>
<td>1.661</td>
<td>3</td>
<td>4.983</td>
</tr>
<tr>
<td>J. Opt. Soc. Am.</td>
<td>2.649</td>
<td>1</td>
<td>2.649</td>
</tr>
<tr>
<td>Opt. Lett.</td>
<td>3.882</td>
<td>2</td>
<td>7.764</td>
</tr>
<tr>
<td>Review of Scientific Instruments</td>
<td>1,226</td>
<td>1</td>
<td>1,226</td>
</tr>
<tr>
<td>Science</td>
<td>31.853</td>
<td>1</td>
<td>31.853</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>94.075</td>
</tr>
</tbody>
</table>

Publications

(publications belong to the top ten list of our institute)


CONFERENCE CONTRIBUTIONS


  "Acceleration of electrons and protons from thin foils"

• **U. Schramm, D. Habs, R. Sauerbrey, H. Schwoerer**
  "Pair production in a laser driven electron-electron collider"

• **F. Zamponi, T. Kämpfer, R. Netz, Truong Nguyen Xuan, A. Lübcke, A. Morak, I. Uschmann, E. Förster, R. Sauerbrey**
  "Optimization of a laser-plasma-based X-ray source"

• **B. Liesfeld, K.-U. Amthor, J. Bernhardt, H. Schwoerer, R. Sauerbrey**
  "A photon-collider at relativistic intensities"

• **S. Volkmer, H. Schwoerer, F. Ewald, Ch. Reich, R. Sauerbrey**
  "Intensitätsabhängigkeit charakteristischer Röntgenstrahlung aus relativistischen laserinduzierten Plasmen"

• **K.-U. Amthor, B. Hidding, B. Liesfeld, S. Karsch, L. Veisz, G. Pretzler, H. Schwoerer, R. Sauerbrey**
  "Monoenergetic electron bunches from a high-density laser-plasma accelerator"

• **S. Karsch, S. Jamison, K.-U. Amthor, Jordan Gallacher, B. Liesfeld, Ch. Murphy, B. Hidding, L. Veisz, F. Krausz, R. Sauerbrey, H. Schwoerer**
  "Time resolved observation of THz emission by laser-accelerated electrons in a gas jet"

• **A. Lübcke, I. Uschmann, F. Zamponi, H. Wald, F. Schmidl, P. Seidel, E. Förster, R. Sauerbrey**
  "Röntgenbeugung an YBCO in der Nähe des Übergangs vom supra- zum normalleitenden Zustand"
Transient Chemical Structures in Dense Media, Paris, France, March 14 – 16, 2005

  "Study of transient crystal lattice behaviour of superconductors by time-resolved X-ray diffraction experiments"

- F. Zamponi, T. Kämpfer, A. Morak, A. Lübcke, R. Netz, E. Förster, I. Uschmann, R. Sauerbrey
  "Experimental set up using a 1 kHz repetition source for time resolved X-ray experiments with fs time resolution"

"SUPA (Scottish Universities Physics Alliance): A Partnership for Excellence”, Edinburgh, Scottland, 25 April 2005

- R. Sauerbrey
  “The Force of Light – Physics with High–Intensity Lasers”

Conference on Lasers and Electro-Optics Quantum Electronics and Laser Science Conference (CLEO /QELS 2005), Baltimore, Maryland, USA, May 21 - 27, 2005

- R. Sauerbrey, B. Liesfeld, K.-U. Amthor, H. Schwoerer
  "Experiments with Counter-Propagating Laser Pulses at Relativistic Intensities"

- K.-U. Amthor, B. Liesfeld, F. Ewald, H. Schwoerer, R. Sauerbrey, L. Robson, P. McKenna, K. Ledingham
  "Electron and Proton Acceleration from Targets by High-Intensity"

  "High-Intensity Laser Induced Photo-Proton Reactions"

Third International Conference on "Superstrong Fields in Plasmas", Varenna, Italy, September 19-24, 2005

- K.-U. Amthor, O. Jäckel, S. Pfotenhauer, H. Schwoerer, W. Ziegler, R. Sauerbrey, K.W.D. Ledingham
  "Quasi monoenergetic Proton beams from a laser plasma accelerator using structured, polymer coated target"

  "Measurement of magnetic field produced by the interaction of ultra-short, ultra-intense fs laser pulse with matter"

• K. Sokolowski-Tinten, U. Bovensiepen