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INTERNATIONAL SYMPOSIUM ON
CHIRPED PULSE AMPLIFICATION

PROGRAM

Tuesday, November 16th, 2010

15:00 – 18:00  Registration
18:00 – 19:30  Reception
Place: Atrium Jean-Guy-Paquet
         Ground Floor, Pavillon Alphonse-Desjardins

From Wednesday, November 17th to Sunday, November 21st, 2010

SYMPOSIUM
Place: Amphithéâtre Hydro-Québec
       2nd Floor, Pavillon Alphonse-Desjardins

Wednesday, November 17th, 2010

08:30 –12:00  Registration
09:15 – 9:30  Opening remarks
Session I   Public talks
9:30– 10:15  Chair: Nadia Ghazzali, NSERC-Industrial Alliance Chair
             for Women in Science and Engineering in Quebec,
             Department of Mathematics and Statistics, Université Laval

         Donna Strickland
         Department of Physics & Astronomy, University of Waterloo, Canada
         Title: CPA, The Early Years – En Route Vers le Petawatt

10:15 – 10:45  Coffee break
10:45 – 11:30  
**Chair:** Réal Vallée, Centre for Optics, Photonics and Lasers (COPL), Université Laval, Canada

Gérard Mourou  
Institut Lumière Extrême, Laboratoire d’ Optique Appliquée at Ecole Nationale Supérieure de Technique Avancée (ENSTA), Palaiseau, France  
**Title:** Chirped Pulse Amplification is 25: from Atom to Nothingness

11:30 – 12:00  
Chris P. J. Barty  
Lawrence Livermore National Laboratory, USA  
**Title:** A World Tour of Ultrahigh Intensity CPA Laser Facilities

12:00 – 13:30  
Lunch break

**Session II  
Rochester days (I)**

13:30 – 14:00  
Joseph H. Eberly  
Department of Physics and Astronomy, University of Rochester, USA  
**Title:** Multiple ionization physics: with the T³ laser and now in 2010, a theorist's view

14:00 – 14:30  
David Meyerhofer  
Laboratory for Laser Energetics and Departments of Mechanical Engineering and Physics, University of Rochester, USA  
**Title:** Initial Experiments on the OMEGA EP High-Energy Petawatt Laser System

14:30 – 14:45  
Sponsor presentation I  
Catalin Neacsu  
Femtolasers Produktions GmbH, Austria  
**Title:** Generation of intense carrier-envelope phase stabilized few-cycle optical pulses

14:45 – 15:15  
Martin Richardson  
The Center for Research and Education in Optics and Lasers (CREOL), University of Central Florida, USA  
**Title:** The violent interaction of ultra-fast laser light with matter

15:15 – 15:45  
Coffee break and group photo at the Atrium.
Session III  Rochester days (II)

Chair: Pierre-André Bélanger, Département de Physique, Génie Physique et Optique, Centre d’Optique Photonique et Laser (COPL) Université Laval, Canada

15:45 – 16:15  Jeff Squier
Department of Physics, Colorado School of Mines, USA
Title: Imaging and Manipulating Neuronal Tissue with Femtosecond Laser Pulses

16:15 – 16:45  Philippe Bado
Translume Inc., USA
Title: Using femtosecond lasers to micromachine glass

16:45 – 17:15  John Nees
Center for Ultrafast Optical Science (CUOS), University of Michigan, USA
Title: From a V/µm to a MV/µm and where to find a TV/µm

17:30  Lab visit. Sign up at Registration Desk. Limited space. First come, first serve.

Thursday, November 18th, 2010

08:30 – 12:00  Registration

Session IV  High field chemistry

Chair: Huailiang Xu, College of Electronic Science and Engineering, Jilin University, China

09:00 – 09:30  Kaoru Yamanouchi
Department of Chemistry, School of Science, University of Tokyo, Japan
Title: Ultrafast dynamics of molecules in intense laser fields studied by momentum imaging and gas electron diffraction

09:30 – 10:00  Sheng Hsien Lin
Department of Applied Chemistry, National Chiao Tung University, Taiwan
Title: High-Power Laser Chemistry

10:00 – 10:30  André Bandrauk
Département de Chimie, Université de Sherbrooke, Canada
Title: Maxwell-Schrödinger-Dirac Equations for Ultrashort Intense Laser Pulse Propagation in Molecular Media or FAZSST-Femto-Atto-Zepto Second Simulations and Theory

10:30 – 11:00  Coffee break
**Session V**  
**Micro-processing and high field science**

*Chair:* Ying Yin Tsui, Department of Electrical and Computer Engineering, University of Alberta, Canada

11:00 – 11:30  
Peter Herman  
Department of Electrical and Computer Engineering, University of Toronto, Canada  
*Title:* Burst filament laser machining

11:30 – 12:00  
Aleksey Zheltikov\textsuperscript{a} and Ching-Yue Wang\textsuperscript{b}  
\textsuperscript{a} International Laser Center, Moscow State University, Russia  
\textsuperscript{b} Ultrafast Laser Laboratory, Key Laboratory of Opto-electronic Information Science and Technology of Ministry of Education, College of Precision Instruments and Opto-electronics Engineering, Tianjin University, China  
*Title:* Photonic Crystal Fiber Femtosecond Laser Amplifier

12:00 – 12:30  
Andrius Baltuska  
Photonics Institute, Vienna University of Technology, Austria  
*Title:* Multi-mJ Few-Cycle Mid-IR OPCPA: Current Status and Challenges

12:30 – 14:00  
Lunch break

**Session VI**  
**High field physics**

*Chair:* Barry Walker, Department of Physics and Astronomy, University of Delaware, USA

14:00 – 14:30  
Bernd Witzel  
Centre for Optics, Photonics and Lasers (COPL), Université Laval, Canada  
*Title:* Visualization of xenon double ionization as a function of the wavelength (from 500 nm to 2200 nm)

14:30 – 15:00  
Luis Roso  
Centro de Láseres Pulsados (CLPU), Universidad de Salamanca, Spain  
*Title:* The Chirp: A Great Parameter for the High Energy Regime in Filamentation

15:00 – 15:15  
Sponsor presentation II  
Coherent

15:15 – 15:45  
Deepak Mathur  
Tata Institute of Fundamental Research, India  
*Title:* Strong-field dynamics of clusters in the few-cycle domain

15:45 – 16:15  
Coffee break
Session VII  High field physics and biology

Chair: Tie-Jun Wang, Centre for Optics, Photonics and Lasers (COPL), Université Laval, Canada

16:15 – 16:45  Roland Sauerbrey
Forschungszentrum Dresden-Rossendorf (FZD), Germany
Title: Laser Acceleration of Protons for Cancer Therapy

16:45 – 17:15  Daniel Côté
Centre for Optics, Photonics and Lasers (COPL), Université Laval, Canada
Title: Use of amplified pulses in biological imaging

17:15 – 17:45  Charles K. Rhodes
Laboratory for X-ray Microimaging and Bioinformatics, Department of Bioengineering, Department of Computer Science, Department of Electrical and Computer Engineering, University of Illinois at Chicago, USA
Title: History of the 50 Year Ascent → 1960 – 2010. Nonlinear Path to High-Intensity Interactions and Giant keV X-Ray Nonlinearities

18:00    Lab visit. Sign up at Registration Desk. Limited space. First come, first serve.

Friday, November 19th, 2010

08:30 –12:00  Registration

Session VIII  Atto-science (I)

Chair: François Légaré, Institut National de la Recherche Scientifique (INRS), Centre Énergie, Matériaux et Télécommunications, Canada

09:00 – 09:30  Paul Corkum
Department of Physics, University of Ottawa and National Research Council of Canada, Canada
Title: Observing Intra-atomic Electron Correlation by Tunnelling and Re-collision

09:30 – 10:00  Dimitris Charalambidis
Department of Physics, University of Crete, Greece
Title: CPA: An Indispensable Technology for Intense Attosecond Pulses

10:00 – 10:45  Coffee break and posters

Session IX  Atto-science (II)

Chair: Ravi Bhardwaj, Department of Physics, University of Ottawa, Canada
10:45 – 11:15  Ursula Keller  
Physics Department, Eldgenösslsche Technische Hochschule Zürich (ETHZ), Switzerland  
**Title:** Attoclock: A New Technique to Measure Attosecond Dynamics in Strong Field Ionization

11:15 – 11:45  Katsumi Midorikawa  
Extreme Photonics Research Group, RIKEN Advanced Science Institute, Japan  
**Title:** Recent progress on intense high harmonic generation and its application at RIKEN

11:45 – 12:15  Chang Hee Nam  
Department of Physics and Coherent X-ray Research Center, Korea Advanced Institute of Science and Technology (KAIST), Korea  
**Title:** Attosecond High Harmonics: Temporal Characterization and Applications

12:15 – 14:00  Lunch break and posters

**Session X**  
**Filamentation and high field science (I)**  
*Chair:* Francis Théberge, Recherche et développement pour la défense, Canada (Valcartier), Canada

14:00 – 14:30  André Mysyrowicz  
Laboratoire d’Optique Appliquée (LOA), France  
**Title:** Recent developments in filamentation

14:30 – 14:45  Sponsor presentation III  
Thales

14:45 – 15:15  Howard M. Milchberg  
Institute for Research in Electronics and Applied Physics, University of Maryland, USA  
**Title:** Effect of the atmospheric nonlinearity on filamentation

15:15 – 15:45  Coffee break sponsored by the Quebec Photonic Network and poster session

**Session XI**  
**Filamentation and high field science (II)**  
*Chair:* John Ozaki, Institut National de la Recherche Scientifique (INRS), Centre Énergie, Matériaux et Télécommunications, Canada
15:45 – 16:15  Marc Châteauneuf  
Recherche et développement pour la défense, Canada (Valcartier), Canada  
**Title:** Defence R&D Canada research achievement with CPA laser

16:15 – 16:45  Koshichi Nemoto  
Central Research Institute of Electric Power Industry, Japan  
**Title:** Interaction of Ultra-short Laser Pulse with Plasma in Atmospheric Condition

16:45 – 17:15  Heping Zeng  
State Key Laboratory of Precision Spectroscopy, East China Normal University, China  
**Title:** Plasma grating and plasma lattice for high-intensity nonlinear optics

17:15 – 19:00  Posters/free discussion

**Saturday, November 20th, 2010**

**Session XII**  **Laser acceleration**  
**Chair:** Zhiyi Wei, Institute of Physics, Chinese Academy of Sciences (CAS), China

09:30 – 10:00  Robert Fedosejevs  
Department of Electrical and Computer Engineering, University of Alberta, Canada  
**Title:** Wakefield Acceleration of Multi-100 MeV Electrons using 100 TW Laser Pulses

10:00 – 10:30  Tae Moon Jeong  
Advanced Photonics Research Institute, Gwangju Institute of Science and Technology (GIST), Korea  
**Title:** Petawatt CPA Ti:sapphire Laser System for Particle Acceleration

10:30 – 11:00  Anatoly Maksimchuk  
Center for Ultrafast Optical Science (CUOS), University of Michigan, USA  
**Title:** Ionization Seeded Electron Trapping and Synchrotron Radiation Generation in Laser Wakefield Accelerator

11:00 – 11:30  Coffee break and posters

**Session XIII**  **High field laser science and technology (I)**  
**Chair:** Pierre Galarneau, Institut National d'Optique/National Optics Institute (INO), Canada
11:30 – 12:00  Koichi Yamakawa  
Japan Atomic Energy Agency (JAEA), Japan  
**Title:** Cryogenically-cooled Ytterbium-doped Solid-state Laser and Its application

12:00 – 12:30  Jyhpyng Wang  
Institute of Molecular Sciences, Academia Sinica, Taiwan  
**Title:** Development and Application of Plasma-waveguide Based Soft X-ray Lasers

12:30 – 14:00  Lunch break

Session XIV  
**High field laser science and technology (II)**  
*Chair:* Gilles Roy, Recherche et développement pour la défense, Canada (Valcartier), Canada

14:00 – 14:30  Algis Piskarskas  
Quantum Electronics Department & Laser Research Center, Vilnius University, Lithuania  
**Title:** Trends in Optical Parametric Chirped Pulse Amplification

14:30 – 15:00  Zhizhan Xu and Ruxin Li  
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, China  
**Title:** Recent progress on high field ultrafast lasers and their applications at SIOM

15:00 – 15:30  Shuntaro Watanabe  
Institute for Solid State Physics, University of Tokyo, Japan  
**Title:** 5-fs, multi-mJ, CEP-locked parametric chirped-pulse amplification system at 1 kHz

15:30 – 16:00  Coffee break and posters

Session XV  
**High field laser science and technology (III)**  
*Chair:* Roberto Morandotti, Institut National de la Recherche Scientifique (INRS), Centre Énergie, Matériaux et Télécommunications, Canada

16:00 – 16:30  Takahisa Jitsuno  
Institute of Laser Engineering, Osaka University, Japan  
**Title:** Activation of LFEX Laser System with Image-rotating Pulse Compressor
16:30 – 16:45 Sponsor presentation IV
Institut National d'Optique/National Optics Institute

16:45 – 17:15 Michel Piché
Centre for Optics, Photonics and Lasers (COPL), Université Laval, Canada
Title: Pathways for extreme lasers

17:15 – 18:45 Posters and free discussions

19:00 – 22:30 Conference banquet (Same building: 4th floor, Pavillon Alphonse-Desjardins)

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Sunday, November 21th, 2010

Session XVI High field laser science and technology (IV)
Chair: Pierre Mathieu, Recherche et développement pour la défense, Canada (Valcartier), Canada

09:30 – 10:00 Gerhard Paulus
Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena, Germany
Title: POLARIS: A Petawatt-class All-diode Pumped Solid-state Laser

10:00 – 10:30 Xiaofei Lu, Ben Clough, I-Chen Ho, Jingle Liu, Jianming Dai, and X.-C. Zhang
Center for Terahertz Research, Rensselaer Polytechnic Institute, USA
Title: Recent Progress of THz Generation and Detection in Ambient Air or Gases

10:30 – 11:00 Coffee break

Session XVII High field laser science and technology (IV)
Chair: Liming Chen, Laboratory of Optical Physics, Institute of Physics, Chinese Academy of Sciences (CAS), Beijing, China

11:00 – 11:30 Jean-Claude Kieffer
Institut National de la Recherche Scientifique (INRS), Centre Énergie, Matériaux et Télécommunications, Canada
Title: That’s ALLS: Our Advance in CPA Science and Technology

11:30 – 12:00 Peter Dombi
The Extreme Light Infrastructure (ELI), Hungary
Title: The Extreme Light Infrastructure (ELI) Attosecond Facility in Hungary

12:00 – 12:15 Closing remarks
Twenty-five years ago, I had the opportunity to help develop Chirped Pulse Amplification. We first reported CPA at the OSA annual meeting in 1985. At the time, we had generated 1 GW of power, but we knew that this was the technique to amplify picosecond pulses in the Kilowatt lasers used for fusion, to generate $10^{15}$W, but we had to look up the word Petawatt before the conference. As this symposium shows, Petawatt laser power is now a reality and leading to incredible scientific discovery. I will highlight the early development of the first CPA laser. As it turned out, the external users of the first CPA laser happened to come from Quebec, both from Laval and INRS and so it is very fitting that we celebrate, here in Quebec, the science that CPA has enabled.

I have also been asked to talk about being a female in one of the last male dominated professions. I will discuss how I have handled situations from being the first female ever hired into a research group, while still an undergrad, to being told that research shows, that the female professors who get good teaching ratings are the ones perceived as motherly.
Chirped Pulse Amplification is 25:
from
Atom to Nothingness
by
Gérard A. Mourou
Institut Lumière Extrême
ENSTA, Palaiseau, 91761 France

2010 marks the 50 years of the laser and the 25 years of the CPA. This simple technique circumvents the deleterious nonlinear effects that prevent efficient energy extraction by short optical pulses in high-energy storage amplifiers. It improves the peak power by more than 4 orders of magnitude from the GW to the multiterawatt level and bettered the average power from the mW to the watt level; an improvement of 3-4 orders of magnitude over dye amplifiers.

This large increase in peak and average powers signaled a watershed in optical science. It made possible high harmonic generation and attosecond science. It also gave birth to nonlinear relativistic optics. The former opens the possibility to take snapshot pictures of the electrons around the nucleus. The latter gave access to formidable field gradients $10^4$-$10^6$ greater than we can produce today. Laser particle acceleration, starts to be considered as the replacement technology to present accelerator technology. In addition, relativistic optics opened the way to new incoherent and coherent sources of high-energy radiations, i.e. x and gamma rays.

Looking onwards, with the implementation of the Extreme Light Infrastructure by the European Community in the next few years, extreme light, will help us to explore ultrafast phenomena in the attosecond-zeptosecond domain and be the gateway of a new regime in laser-matter interaction: the ultra relativistic regime that could reach into Nuclear Physics and the Non Linear Quantum Electrodynamics field, where elementary particles from vacuum could be created. Eli’s overall scientific mission will be the investigation of matter from atoms to vacuum.
The applications made possible by CPA-laser are numerous. In atmospheric science the possibility to create high intensity filaments over long distances, beating diffraction has made possible the analysis of molecular atmospheric species and pollutants. The possibility to machine materials with exquisite precision opened the field of micro and nanomachining. Applied to ophthalmology, it is used for myopic corrections and as a precision optical “trephine” to replace part of the cornea. In the future we expect high intensity to be applied to understand material aging in areas like nuclear reactors to increase their life span. In addition it could play a role in nuclear waste treatment by transmuting the harmful isotopes into ones with much shorter life.
A World Tour of Ultrahigh Intensity CPA Laser Facilities
C. P. J. Barty
Lawrence Livermore National Laboratory

Abstract:
The development of chirped pulse amplification 25 years ago enabled the peak power of laser pulses to increase rapidly from the gigawatt regime to beyond a petawatt. The development of terawatt and petawatt laser pulses has in turn enabled the pursuit of a wide range of new science and high impact applications that are based upon the interaction of lasers with matter at ultrahigh intensities. Lasers that are capable of approaching and surpassing intensities of $10^{20}$ W/cm$^2$ are now the cornerstone of numerous large scale international facilities. This presentation will review the evolution of ultrahigh intensity laser capability worldwide and will provide an overview of the more than 70 active ultrahigh intensity laser facilities and projects that are currently represented on the International Committee on Ultrahigh Intensity Lasers’ (www.ICUIL.org) world map. These projects represent more than a $B of cumulative activity and a remarkable variety of laser architectures all employing the CPA technique.
Multiple ionization physics: with the T³ laser, and now in 2010, a theorist’s view.

Joseph H. Eberly University of Rochester, USA

Abstract: I will briefly recall some of the earliest atomic multiple ionization results recorded with a CPA laser. Other participants (a number of them expected to be in the audience) will eagerly explain that, as a theorist, my participation in their experimental work with the original T³ system was strictly limited. The results were striking, and our joint publication is still being noticed even 20 years later. I deserve no credit and remain grateful to have been included. However, the topic of multiple ionization of atoms has had a strong life of its own in the following years, and the correlated electron surprises discovered in laboratory studies of multiple ionization have provided long-term gainful employment to a widely distributed tribe of theorists. I will mention recent attempts to jump ahead of the experimental teams and provide some predictions of additional new phenomena that can be tested.
Initial Experiments on the OMEGA EP High-Energy Petawatt Laser System

D. D. Meyerhofer

Laboratory for Laser Energetics and Departments of Mechanical Engineering and Physics
University of Rochester
250 East River Rd.
Rochester, NY 14623

The OMEGA EP Laser System, with four NIF-like beams, was completed in April 2008. Two beams can be operated as high-energy petawatt (HEPW) lasers using chirped-pulse amplification, with each ultimately producing up to 2.6 kJ in a 1053-nm, 10-ps pulse. OMEGA EP began operating as a User Facility in October 2008. A number of experiments have taken advantage of OMEGA EP’s unique capabilities. Highlights of the research that has been carried out and future prospects will be described. The current and projected status of the laser system will be presented. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.
Imaging and manipulating neuronal tissue with femtosecond laser pulses

Jeff Squier
Physics Department
Department of Physics, Colorado School of Mines

Using spatio-temporal focusing of femtosecond pulses, we have been able to achieve large area tissue ablation through substantial path lengths underwater for the first time. Previously prohibitive nonlinear optical effects are mitigated through careful control of the spatio-temporal focal profile. At lower intensities, we use differential-multiphoton laser scanning microscopy which enables the simultaneous acquisition of multiple focal planes to characterize the tissue. The unique characteristics of this new imaging modality will be described.
Using femtosecond lasers to micromachine glass
Philippe Bado (a), Mark Dugan (a), Ali A. Said (a), and Yves Bellouard (b)

(a) Translume Inc., 655Phoenix Drive, Ann Arbor, MI, 48108, USA.
(b) Eindhoven University of Technology, PO Box 513, 5600 MB Eindhoven, the Netherlands

ABSTRACT
Over the last decade we have used direct-write processes based on the use of femtosecond pulses to fabricate small instruments made of fused silica glass. These instruments (fluid optical analyzers, flow cytometers, particle counters, hybrid fiber-waveguide lasers, force sensor, FTNIR, linear stage, etc.) incorporate optical and micro-mechanical functionalities which are enable only through the use of ultrafast lasers. Potential commercial applications, as well as technical and economic challenges are reviewed.
From a V/µm to a MV/µm and where to find a TV/µm

John Nees* in collaboration with Bixue Hou, Aghapi Mordovanakis, James Easter, Gérard Mourou, Natalia Naumova, Igor Sokolov, and Karl Krushelnick

*Center for Ultrafast Optical Science, University of Michigan Ann Arbor MI 48109-2099

Ultrafast Science has progressed across a terrain marked with paths cleared by short pulse lasers. Two capabilities recommending these lasers over electronic devices have been their primacy in pulse brevity and their superiority in field strength. Along our course of research we have marked a trend of increasing field strength from the range of a V/µm, corresponding to the breakdown limit typical of surface electrodes on dielectrics or semiconductors to strengths of MV/µm in dense plasmas. The capabilities of the laser, and the physics accessed to date, have been sufficiently striking that they have sparked questions regarding the extension to fields of a TV/µm.

Photoconductive switches can be biased to their breakdown limit in air with a dc electric field of ~1V/µm. Pressing to pulsed bias fields of ~10V/µm presents the ability to switch ~1kV in ~1ps, by optically inducing a solid-state plasma between two electrodes. However much greater fields can be generated when material breakdown ceases to be a limit. This is the case in materials that are already broken down into plasma.

We will discuss two experiments in the 'λ^3' domain where MV/µm fields were demonstrated to form ~MeV beams of electrons or ions in ~1µm-long accelerators using ~mJ pulses from a CPA laser. Such accelerating capability enters the domain of relativistic behavior on the part of electrons reacting to the forces of the incident light and the driven plasma.

If we extend the concept of interaction to the maximum strength of lasers that either exist today, or are planned for the next several years, we must begin to treat the problem that the vacuum in which the plasma is presumed to reside becomes ionized by strong fields interacting with electrons. We will discuss where we may be able to develop TV/µm fields and how our physical views on these experiments must be framed.
Ultrafast dynamics of molecules in intense laser fields studied by momentum imaging and gas electron diffraction

Kaoru Yamanouchi

Department of Chemistry, School of Science, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

When molecules are exposed to an intense laser field, a variety of characteristic dynamical processes are induced. Among them, ultrafast hydrogen migration processes are noteworthy. In our series of studies on decomposition processes of hydrocarbon molecules by the coincidence momentum imaging method, we found that the hydrogen migration proceeds extremely rapidly within 10–20 fs when hydrocarbon molecules are exposed to an intense laser field [1], and that not only one but also two protons migrate and their distributions are spread so widely within a molecule, showing the wave nature of protons [2]. These experimental findings have shown that we need to develop a new theoretical framework beyond Born-Oppenheimer approximation. We have proposed a new theoretical approach in which protons as well as electrons are treated as wave functions [3]. We have also developed a new experimental technique called light-assisted electron scattering (LAES) for probing extremely rapid nuclear dynamics within a molecule as a series of snapshots of gas electron diffraction patterns with temporal resolution comparable with a pulse duration of ultrashort laser pulses (1–100 fs) [4]. In the present talk, I introduce these new developments in research on molecules in intense laser fields.

References
Abstract

For the treatment of ionization of molecules, the molecular orbital theory and the Born-Oppenheimer approximation have been applied to the ADK theory, Keldysh theory and KFR theory. For dissociation of polyatomic molecules, in the time scale of 100fs (that is, the pulse duration), the field-assisted dissociation will be used by employing the time-dependent adiabatic approximation and beyond 100fs the ab initio RRKM theory will be employed to calculate the mass spectra. As applications, the high-power laser ionization-dissociation of alleme and cyclopentanone will be presented.

Laser trapping has been observed by Chin’s group for inert gases and small molecules. Its theoretical treatment will be presented and applied to xenon.
Maxwell-Schrödinger-Dirac Equations for Ultrashort Intense Laser Pulse Propagation in Molecular Media or FAZSST-Femto-Atto-Zepto Second Simulations and Theory

André D. Bandrauk (Université de Sherbrooke) / Emmanuel Lorin (Carleton University)


Interaction of ultrashort intense pulses with molecular media leads to highly nonlinear nonperturbative effects which can only be treated by large scale computation on massively parallel computers. Single molecule response to such pulses leads to Molecular High Order Harmonic Generation, MHOHG, (1), from which one can synthesize new “attosecond” pulses necessary to control electron dynamics at the natural time scale of the electron, the attosecond \((10^{-18}\text{ s})\), (2). The single molecular response can be obtained from high level quantum Time-Dependent Schrödinger, TDSE, simulations. The collective macroscopic response of a molecular medium requires solving many TDSE,s \((>10^5)\) coupled to the classical laser (photon) Maxwell equations (3). We will present the numerical methods necessary to achieve this goal, especially the problem of transparent and artificial boundary condition techniques in view of the different time scales, photon vs electron. Results will be shown for attosecond pulse generation and pulse filamentation in an aligned molecular medium, the one electron H2+ system(4). Relativistic effects require Maxwell-Dirac equation simulations on zeptosecond \((10^{-21}\text{ s})\) time scale(5).

Photonic Crystal Fiber Femtosecond Laser Amplifier

Bo-Wen Liu, Xiao-Hui Fang, Ming-Lie Hu, Ching-Yue Wang

Ultrafast Laser Laboratory, Key Laboratory of Opto-electronic Information Science and Technology of Ministry of Education, College of Precision Instruments and Opto-electronics Engineering, Tianjin University, 300072 Tianjin, China

Abstract
It has been shown by intensive research activities in the optics and optoelectronics fields that many novel properties unimagined with conventional optical fibers can result from the photonic crystal fibers (PCFs). Recently, basing on some of these properties, photonic crystal fibers have been successfully applied in femtosecond laser technology and pushed the performance of femtosecond fiber laser to match with the solid-state femtosecond laser system. A brief review of recent work on high power femtosecond photonic crystal fiber laser oscillator, amplifier and their applications is presented. Some new conceptions are applied in this amplification system, compact nonlinear amplification without stretcher, phase locked amplification with multi-core large mode area PCF, cubic dispersion compensation, et. al.. A 150 MW peak power and 50 W average power femtosecond laser are obtained respectively, which shown the PCFs have great potential in high power femtosecond laser system. We believe that a feasible scenario in future applications of high pulse energy femtosecond PCF laser will come soon.
Multi-mJ Few-Cycle Mid-IR OPCPA: Current Status and Challenges

A. Baltuska

 Photonics Institute, Vienna University of Technology, Gusshausstrasse 27-387, A-1040, Vienna, Austria
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Recent discoveries in theoretical and experimental strong field physics have stimulated the quest for intense long-wavelength few-cycle driver sources which promise distinct advantages with respect to traditional Ti:sapphire-based amplified ultrashort pulse systems at 800 nm. The increase of the optical cycle duration plays a crucial role in many areas: the development of secondary sources of radiation, in particular coherent sources of extreme UV and X-ray pulses, laser-driven elementary particle acceleration, femtosecond mass spectroscopy, etc. The key advantages for such applications are the $\lambda^2$ scaling of the ponderomotive energy in a strong-field interaction and the ability to suppress multiphoton ionization in favor of the tunneling ionization mechanism.

In the talk we will discuss several schemes developed at TU Vienna that are based on the mix of a fs Ytterbium CPA technology and chirped pulse optical parametric amplification (OPCPA) in KTP/KTA crystals. The first configuration is a three-color waveform synthesizer (pump, signal and idler waves) based on a double CEP locking technique, i.e. an active CEP locking of an Yb CPA system and a passive CEP stabilization in the parametric amplifier. The prototype 10−20-kHz system generating 150-$\mu$J multicolor pulses with a base wavelength of 2.1 or 3.1 $\mu$m was successfully applied to generate continuously tunable Mid-IR and THz pulses from laser-induced plasma in air and to directly record the electron energy spectra of the tunneling microcurrents responsible for the long-wave emission from plasma.

The second configuration of our KTP/KPA OPCPA operates at a 20 Hz repetition rate and delivers $\sim$20 mJ in a CEP-stable 1.5-$\mu$m signal wave and $\sim$8.5 mJ in the 3.6−3.8 $\mu$m idler wave. We show that a fraction of the signal pulse can be post-compressed in a filament in Ar to a duration of 20 fs at $\sim$2 mJ energies. The idler pulses with a FWHM bandwidth of 350 nm were coarsely compressed to $\sim$100 fs with the pulse energy of $\sim$5 mJ after the grating compressor. The 3.6-$\mu$m pulses were used to generate intense water-window higher-order harmonics in Ar, which is the first successful HHG experiment using a mid-IR driver pulse. Finally, we will discuss the prospect of constructing a kHz-repetition-rate TW-peak-power Mid-IR parametric system based on a diode-pumped solid-state Yb amplifier that is being developed in our lab.
Visualization of xenon double ionization as a function of the wavelength 
(from 500 nm to 2200 nm) 
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We have studied the frequency dependence of single and double ionization of xenon in the multiphoton and tunnelling regimes, by using a HE-TOPAS (traveling-wave optical parametric amplifier) system [1,4,6]. A portable mass spectrometer was used to measure the ionization yield of xenon single and double ionization in a wavelength regime between 500 nm and 2200 nm at laser intensities from $2 \times 10^{13}$ W/cm$^2$ to $1 \times 10^{15}$ W/cm$^2$. The 3D- plots (Xe$^+$ - and Xe$^{2+}$- ion yield versus Intensity and wavelength) obtained from our measurement will be compared with calculations from the PPT – theory [2]. For intensity calibration we used electron imaging spectra at different wavelengths.

We can identify regimes of sequential and non-sequential ionization and calculate the cross-section of a possible Xe$^+$ electron impact ionization/excitation with the Lotz formula [5]. In addition we will discuss the influence of the multiphoton driven ionic transition $5s2\ 5p^5 + m\hbar \omega \rightarrow 5s\ 5p^6$ [4] on the non-sequential double ionization process [6].

In addition we will discuss the influence of the laser pulse length to the ionization process and want to demonstrate the influence of atomic exited states to the single and multiple ionization process.

[1] HE-Topas at the ALLS – laser center Verennes (INRS)
The chirp: a great parameter for the high energy regime in filamentation

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Abstract

We present here part of the research done at Salamanca in order to find strategies to increase the energy throughput in a filament. In particular we proved that the chirp of the input pulse is a very good parameter to enhance the energy of stable single filaments in a post-compression scheme.

Back in 1985, Gerard Mourou introduced the idea of chirp to amplify laser pulses towards unexpected limits, breaking the Terawatt barrier with a table-top laser. This discipline on its own has been a major breakthrough in laser science. During more than two decades, many groups have been working throughout the world in developing new techniques to produce, control, and recompress chirped pulses. Now not only as a simple measurable characteristic of the pulses produced but also as a tuneable and well-controlled parameter, ingenious devices and ideas based on chirp opened its impact in many fields of science.

During the last years the nonlinear propagation research at Salamanca has been devoted to study possibilities to generate and control high-energy filaments. The reasons why this regime began to be relevant are: the fact that high-power lasers are nowadays widely present in most laboratories, with pulses surpassing the energy usually used in filamentation applications [1], and the necessity of improving the throughput energy of the filaments, to generate more powerful short laser pulses. Among the different strategies that we have been proposed [2, 3], we present here the one based on input-pulse-chirp as a control parameter [3].

We present the experimental results obtain from a broad scan in pulse energy and chirp values, showing that for any energy we were able to find values of the pulse chirp where stable single filaments were observed. These regions appeared when the input peak power was of the order of 2-4 times the critical power and this for positive and negative chirp values. Using higher energy input pulses maintaining a single filament formation allowed reaching much higher energy throughput, the energy coupled in the filament being always of the order of the 30% of the total input energy. The spectral broadening obtained in this stable region was significant, especially in the positive chirp cases, showing that this method could be used as high-energy post-compression scheme.

While performing the scan in pulse energy and chirp values, we also identified specific energy-chirp pair values for which a single stable filament was obtained together with self-compression process. This is observed for any input energy in the range of 3 to 5 mJ, where the self-compression regime was achieved for two opposite sign chirps. The output pulses produced are 6 and 8 times shorter [4].

The future research in this line in Salamanca will be held in the new Laser Centre (CLPU) facility that will be completely operative in 2012 [5]. An overview of the CLPU, the Spanish National Center for the CPA technology will be presented and its future applications discussed. Upon which, the facility will offer several high peak power (well above the TW) laser outputs and a long (about 60 meters) tube to develop and study atmosphere controlled nonlinear propagation experiment in this high energy regime.

References

[5] For more information see the web page www.clpu.es
Laser Acceleration of Protons for Cancer Therapy

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Experiments in recent years have shown that it is now possible to generate high brightness ion beams by high-power CPA lasers. Ion beams with approx. $10^{12}$ ions per pulse with energies reaching several 10 MeV are now available. We report on experiments which aim at using such laser accelerated ion beams for radiation therapy of cancer in the future. First irradiation experiments of \textit{in vitro} tumour cells with laser accelerated proton pulses were carried out. The experiments focus on radiobiological studies and show that laser-accelerated proton beams can reliably deliver doses up to a few Gray within a few minutes. We demonstrate a beam transport and filtering system and an in-air irradiation site. Furthermore, a dosimetry system providing both online dose monitoring and absolute dose information is described.
Functional wide-field multi-photon imaging of cellular dynamics by temporal focusing and patterned illumination

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Université Laval

Wide-field temporal focusing is a novel technique to get optical sectioning without the need of a scanning unit. This is achieved essentially by imaging a diffraction grating at the object plane of an objective. However, spreading the laser beam intensity over large region greatly reduces the photon density and functional imaging of large regions in biological sample has not been shown. Here we present a microscopy setup that combines beam shaping with temporal focusing of amplified pulses (10 microjoules/pulse) for calcium dynamics imaging in cells from hippocampus acute slices and cultured. Multi-photon video-rate (30 fps) imaging of areas as wide as 8100 microns squared with an optical sectioning under 10 microns at 800nm is achievable with our setup. To choose regions of interest in the field of view without any mechanical parts, we use a spatial light modulator (SLM). Because the grating surface is imaged onto the sample, the SLM can easily be integrated into such imaging system by shaping the illumination pattern on the grating. Coupling wide-field temporal focusing with a spatial light modulator for patterned illumination is straightforward and results in an imaging tool very well adapted to functionally probe biological samples over a wide area without delays associated with beam scanning.
History of the 50 Year Ascent → 1960 – 2010

Nonlinear Path to High-Intensity Interactions and Giant keV X-Ray Nonlinearities
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ABSTRACT

The history of nonlinear high-intensity interactions, that commenced in 1961 with the observation of second harmonic radiation [1] at 347.2 nm in crystalline quartz, spans a range of ~10^{18} in experimental intensity and the area of study remains a stable, robust province of fundamental laser-based research after a half century. As an example of this effort, over a period of ~25 years, a path of research was cut through this field of nonlinear phenomena that led to the development of a multikilovolt (~ 4.5 keV) x-ray amplifier of exceptional peak brightness [2] whose experimentally based power-scaling limit for a compact laboratory instrument falls in the multi-petawatt realm [3]. This presentation highlights a brief history of these nonlinear interactions and explores their extension into the keV x-ray regime.

Acknowledgement

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References

Observing Intra-atomic Electron Correlation by Tunnelling and Re-collision

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Tunnelling imposes two highly selective filters on a quantum system – a directional filter in momentum space and an ionization potential filter. Together they allow us to preferentially address specific orbitals and to launch valence wave packets in the ion. Since each electron that tunnels is correlated with the hole it leaves behind, sequential ionization transfers the correlation from the system to the continuum were we can measure it. We show how the tunnel ionization rate is modulated by correlation dynamics. We also show how circular polarized light can image electron correlations in rare gas atoms and HCl [1]

In linear polarized light the tunnelled electron recollides. During the recollision it can probe its correlated hole through high harmonic generation [2]. If the hole moves rapidly, dynamics shows up in the structure of the high harmonic spectrum created under two-colour light. We show how attosecond dynamics can be observed experimentally.


CPA: an indispensable technology for intense attosecond pulses

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The highest attosecond pulse energies reach today 40\,\mu J in the form of a pulse train (~2.5\,\mu J mean burst energy) [1] or sub-100\,nJ in the form of a coherent continuum [2], generated using the interferometric polarization gating technique [3], forming an isolated attosecond pulse [4]. These developments have allowed the observation and exploitation of non-linear (NL) XUV processes, pivotal to the metrology of attosecond pulses [5] and time domain applications [6].

The generation of such pulses is by high peak power many cycle laser systems, incorporating a chain of chirped pulse amplification stages. CPA is the pivotal technology underlying intense attosecond pulse generation.

Here we review I) the generation of the most energetic sub-fs pulse trains [1] and isolated attosecond pulses [2], including a CEP monitoring and on-line shot-to-shot single asec pulse selection approach [7], II) recent comparative studies of attosecond pulse metrology approaches, that showed severe discrepancies in the results obtained by NL-XUV-autocorrelation and IR-XUV cross-correlation measurements [5] and III) and VUV/XUV time domain applications, including two-VUV-photon time resolved molecular dynamics [6] and ultra-broadband XUV Fourier Transform spectroscopy, tracking autoionizing electron wave-packet dynamics at the 1\,fs temporal scale [4].

Attoclock: a new technique to measure attosecond dynamics in strong field ionization

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Previously, we have used attosecond angular streaking (i.e. the attoclock technique) to place an intensity-averaged upper limit of 12 attoseconds on the tunneling delay time in strong-field ionization of a helium atom in the non-adiabatic tunneling regime [1]. To the best of our knowledge this has been the fastest measurement done directly in the time domain so far. A temporal resolution as accurate as only a few attoseconds can be achieved because the measurement is based on a “peak search”. The experimental results gave a strong indication that there is no real tunneling delay time, which was further confirmed with numerical simulations using the time-dependent Schrödinger equation. This measurement was done over a Keldysh parameter variation of 1.45 to 1.17 for which we could apply a small Coulomb field correction using a semi-classical picture based on the length gauge.

We extended these measurements to higher intensities for both He and Ar atoms using both ion and electron detection in a COLTRIMS. Below the OBI (over barrier ionization) with higher intensities we would expect a stronger Coulomb correction because the electron exits the tunnel closer to the core. This however was not observed. TDSE calculations in this regime however are in agreement with our measurements. We believe that attosecond angular streaking is an ideal tool to study Coulomb corrections and we will discuss the different models in more details.

More recently we have investigated electron correlation and release time in strong field double ionization. With close to circularly polarized laser pulses recollision is avoided and the electrons are usually assumed to be field ionized without mutual interaction. Here we present coincidence momentum measurements of the doubly charged ion and the two electrons that are in contradiction with the independent electron assumption for close to circularly polarized fields. These experiments demonstrate that recollision is not the only reason for electron correlation in strong field double ionization. In addition, we are interested in the release time of the two electrons. Preliminary results indicate that the ionization of the second electron occurs significantly earlier than predicted.

Recent progress on intense high harmonic generation and its application at RIKEN

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There has been growing interest in applying high-order harmonic (HH) fields to atomic/molecular physics in the XUV region. The identification of ionization and dissociation pathways of CO$_2$ by two-photon absorption of HH field by our group [1], is one of novel studies on the nonlinear response of molecules in the XUV region. The unique feature of this study was the use of the autocorrelation technique for measuring the pulse shape of an attosecond pulse train (APT) and relied on the extremely broad harmonic spectra of the APT ranging from visible to extreme ultraviolet region. We identified two-photon ionization processes by analyzing the frequency components of the interferometric fringes appearing in the interferometric autocorrelation traces. We call this method nonlinear Fourier transform spectroscopy (NFTS). The NFTS is useful for investigating the ionization/dissociation process which is induced by a two or more photon process induced by an ATP. Recently, we also demonstrated the feasibility of the NFTS by determining the three distinct ionization/dissociation pathways of deuterated hydrogen molecules (D$_2$) irradiated by the APT ranging from the 1st to the 19th harmonic order. A velocity map image of the D$_2^+$ ions was successfully decomposed into three images depending on the three distinct ionization/dissociation pathways [2].

This spectroscopy would be also beneficial for other intense extreme ultraviolet (XUV)-soft X-ray light sources, such as X-ray free electron lasers, which are utilized for exploring the nonlinear interaction of high-energy photon with matter, because we can eliminate the strong background signals due to ions or electrons produced by one-photon absorption if we apply this spectroscopy.

References
High harmonics, emitted from gaseous atoms driven by intense femtosecond CPA laser pulses, can form an attosecond pulse train or an isolated single attosecond pulse. The temporal characterization of attosecond high harmonic pulses can be carried out using the photoionization of atoms by harmonic and femtosecond laser pulses, giving the cross correlation information between two pulses. The high harmonics exhibit a positively chirped structure, called ‘atto chirp,’ due to the inherent harmonic generation process of short-trajectory harmonics. We proposed to use material dispersion for the compensation of atto chirp and demonstrated the generation of near transform-limited 63-as pulses using the RABITT (attosecond beating by interference of two-photon transitions) measurement [1-3]. We also demonstrated the complete temporal characterization of attosecond pulse trains using the FROG CRAB (frequency-resolved optical gating for complete reconstruction of attosecond bursts) method, and could show the detailed temporal structure of attosecond pulse trains [4]. Applying this method, we could analyze the interference of electron wave packets in He between a reference electron wave packet produced directly by a harmonic pulse and a signal electron wave packet generated through a resonant excitation by a harmonic pulse and then photoionization by IR laser pulse. Consequently, proper temporal characterization of attosecond high harmonic pulses can boost the advancement of ultrafast atomic dynamics.

Effect of the atmospheric nonlinearity on filamentation
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Abstract: The first direct spatially and temporally resolved measurement of the electron density of a femtosecond filament allows investigation of the details of the atmospheric filamentation formation mechanism.

The ability to directly measure the electron density with good resolution along and across the propagation axis allows sensitive tests of the physics of filament propagation. However, since the first femtosecond laser filamentation experiment by G. Mourou’s group in 1995 [1], this had not been done. Our recent measurement of the filament’s electron density has allowed study of the air nonlinearity leading to beam collapse and contributing to the dynamic stabilization. Part of the nonlinearity is the instantaneous response owing to electron cloud distortion in randomly oriented N₂ and O₂ molecules (plus argon). Molecular rotation in the laser field contributes a delayed nonlinearity as the molecular axis is torqued toward the laser polarization. We have determined that the orientational effect is in fact dominant at the typical ~100 fs pulse lengths used for a majority of air filamentation experiments [2, 3]. Figure 1 illustrates the strong effect of changes in the laser pulsewidth on air (single) filamentation, for two different focusing geometries, keeping the peak laser power fixed for each. Accompanying simulations (not shown) reproduce these results well, and confirm the dominant role of rotation. The presence of the second (filament regeneration) humps in panels (a) and (b), demands the presence of the rotational nonlinearity.

References
Defence R&D Canada research achievement with CPA laser

Marc Châteauneuf, Francis Théberge, Jacques Dubois, Gilles Roy, and Pierre Mathieu.

About 20 years following the invention of CPA, Defence R&D Canada (DRDC) launched a research program involving TW laser systems. In the first years of the project, DRDC acquired a CPA laser system and installed it in a sea container converted in a portable laboratory. This Canadian portable TW laser system, the T&T, can therefore be moved in the field and be used in the various laser ranges available at DRDC. These include an indoor 250m long corridor and a series of exterior ranges up to 2.5 km long.

Moreover, the invention of CPA indirectly created strong collaborations between research laboratories; in order to keep up with the numerous new research areas and applications based on the CPA systems, collaborations are essential. Within its research program, DRDC developed solid collaborations with Laval University, Institut National de la Recherche (INRS), General Direction for Ordnance (DGA), Laboratoire d'Optique Appliquée (LOA), ONERA, Institut franco-allemand de recherches de Saint-Louis (ISL), and other groups.

One of the projects that DRDC pushed forward is the guiding of energy using a laser beam. Done in collaboration with INRS, it led to the first demonstration of guiding microwave within a waveguide formed by laser induced filaments [1]. Work on guiding electrical current is also on going.

Exploitation of the supercontinuum is also of interest for DRDC. The characterization of the white light generated by the filament in air [2] has complemented the work previously done [3]. Moreover, different approaches are being studied to increase the efficient of the supercontinuum in the infrared (IR) e.g. [4]. Furthermore, within a strong collaboration, DRDC supports the work of Laval University the generation of THz by filamentation [5]. Results in these different research projects will be presented.

References

Interaction of ultra-short laser pulse with plasma in atmospheric condition

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After the invention of Chirped Pulse Amplification by Gerard Mourou and Donna Strickland, researchers in many fields, not only science but also industry, have got the most powerful tool for investigating nonlinear physics. Even only propagation in the atmosphere shows us astonishing phenomena such as filament plasma, which has never been observed using a conventional laser. Especially, under a strong external electric field, the laser filament plasma shows many physical aspects attractive for various applications such as the discharge triggering, the generation of terahertz radiation, and the measurement of electric fields in the atmosphere [1]. Moreover, the filament plasma is an excellent tool to investigate discharge physics, because it can produce space charges instantaneously to control the initiation of atmospheric ionization precisely. In this presentation, characteristics of filament plasma under external electric field in atmospheric condition are mainly reported.

Plasma grating and plasma lattice for high-intensity nonlinear optics

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It is of ever-growing interest to create wavelength-scale periodic plasma micro-structures as plasma gratings or waveguides or plasma photonic lattices to guide intense femtosecond (fs) pulses, which can in principle be realized by creating one-dimensional (1D) or two-dimensional (2D) periodic plasma density modulation to change the local refractive index periodically in the surrounding gas-phase media. By focusing spatially modulated intense laser pulses after a spatial light modulator, 1D periodic plasma structures could be generated for relativistic quasi-phase-matched third harmonic (TH) generation. Plasma mirrors of periodic structures were also demonstrated at optically polished surfaces hit by intense laser pulses, which were used to significantly improve the pre-pulse contrast of intense laser pulses.

We discuss in this report that nonlinear interaction of multiple non-collinearly overlapped intense fs filaments could assist filament coalescence into a lattice of strongly-coupled parallel self-channels with abundant self-action and cross-coupling nonlinearities. For non-collinearly overlapped intense fs pulses, the spatial interference mediates local filamentation in the spatially overlapping region. Kerr self-focusing occurs around the interference peaks, resulting in a further increase of the local peak intensity, which is accompanied by an increase of the multi-photo-ionization probability, generating increased plasma densities therein. Accordingly, Kerr self-focusing and plasma defocusing reach counterbalance along the interference peaks at first, where parallel plasma channels are generated. As a consequence, the spatial interference fringes are self-projected along a relatively long distance, and a wavelength-scale periodic lattice of plasma microstructures are generated with plasma density modulation.

In our experiments, 1D periodic plasma structures were generated with the spatial period of several tens micrometers by controlling nonlinear interaction of two non-collinear fs filaments in air. Coherent interactions of the interfering non-collinear filaments were controlled.
to exhibit enhanced energy transfer and nonlinear diffraction from the plasma grating. We demonstrated that strong spatiotemporal couplings in the 1D plasma grating enhanced TH generation at least two orders in energy conversion, and that nonlinear diffraction from the 1D plasma grating induced noticeable energy transfer from one filament to the other. Three intersected filaments were observed to induce 2D plasma photonic lattices in air. The plasma microstructures were evidenced to last a few tens picoseconds after the excitation pulses, in agreement with the plasma lifetime. The 2D plasma density modulation was accompanied by periodic changes of the refractive index in the encircling air, 2D plasma density gratings were thus created, which was clearly verified by diffraction of a time-delayed pulse. The 2D diffraction properties and time evolution of the diffracted TH pulses confirmed the existence of 2D plasma density gratings.

On the other hand, far-delayed incoherent filaments could be coupled through quantum wakes of molecular alignment and hydrodynamic expansion of plasma waveguide. We experimentally observed nonlinear interactions of incoherent and far-delayed fs filaments through rotational Raman wake of the pre-excited diatomic molecules. For parallel filaments delayed far away without spatiotemporal overlapping, filament repulsion and attraction were observed as the probe pulse was properly delayed after the pump filaments at the molecular alignment revivals. Mutual fusion of incoherent synchronized filaments was also observed for ultrashort light bullets of orthogonal polarizations.

The observed filament interaction, grating-assisted filament coalescence, and plasma photonic lattices may open an avenue to control nonlinear filament interactions and filamentation nonlinear optics. High-intensity ultrafast laser physics demands tightly focusing or guiding intense fs pulses. Nevertheless, nonlinear propagation of intense fs filaments encounters multi-photo-ionization-induced plasma defocusing that sets clamped limits for the peak intensity. With nonlinear interaction of multiple intersected filaments to establish plasma gratings or lattices, various interesting applications are anticipated in high-intensity ultrafast optics, ultrashort ultraviolet pulse generation, and ultrafast pulse compression.
Wakefield Acceleration of Multi-100 MeV Electrons using 100 TW Laser Pulses

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The development of ultrashort high power CPA lasers has opened up the possibility of generating and accelerating high energy particles in the strong relativistic fields that can be produced. Laser wakefield acceleration (LWA) is one technique to generate high brightness, MeV to GeV electron beams using ultrashort multi-terawatt laser pulses focused into underdense plasmas. Over the past 6 years there has been much progress in the generation of electrons with energies of 100’s of MeV up to a GeV and current research is focused on reducing the energy spread of the beam and improving the maximum energy, maximum charge per bunch and stability. An important aspect of such a scheme is the optimal injection of the electrons into the acceleration region. We are currently carrying out studies of wakefield acceleration in the self injection and ionization injection regimes using the 200TW laser facility at the Advanced Laser Light Source (ALLS) located at INRS, Québec. Laser pulses with energies of 2.1 J and pulsewidths of 30 fs are focused using an off axis parabola onto a variety of gas targets. Helium, nitrogen and mixed gas targets were used with nozzles of 2 mm to 10mm diameter, yielding electron densities in the range of $10^{18}$ cm$^{-3}$ to $10^{20}$ cm$^{-3}$. In addition, passive capillary gas channel targets with a length of 10 mm were also explored. Electron energies, were measured using an electron spectrometer consisting of permanent magnets deflecting the electrons onto fluorescent screens imaged onto sensitive CCD cameras. Transverse shadowgraphy of the interaction region and imaging of the laser beam at the exit of the plasma interaction region was also carried out in order to characterize the interaction in detail. Electron energies of several hundred MeV can easily be achieved in such systems. Current experimental results will be presented and compared to particle in cell modeling of the laser-plasma interaction and future directions in Laser Wakefield Acceleration will be discussed.

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Petawatt CPA Ti:sapphire Laser System for particle acceleration

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Ultrashort high power laser system is used for the generation of energetic particle beams such as electron and proton. Chirped pulse amplification (CPA) technique enables one to build an ultrashort high power laser system having a power greater than petawatt (PW) level. In this paper, the output performance of a 0.1-Hz, 1 PW CPA Ti:sapphire laser system at APRI that will be used as a particle accelerator is presented. The PW CPA Ti:sapphire laser system consists of an ultrashort laser oscillator, a 1-kHz multi-pass amplifier system, a grating stretcher, a pre-amplifier, two power amplifiers, a final booster amplifier, and a grating compressor. In the final booster amplifier, the energy of a laser pulse is amplified up to 47 J with a pump energy of 96 J at a repetition rate of 0.1 Hz.

After the amplification, the laser pulses are expanded to have 200-mm in diameter through an achromatic beam expander before the grating compressor. An adaptive optics (AO) system is installed in front of the achromatic beam expander to compensate for a wavefront aberration in an amplified laser pulse. The grating compressor consists of four 1480-grooves/mm gold-coated holographic gratings. The pulse duration after compression is about 30 fs. Because of the compressor throughput efficiency of 70%, the peak power after compression reaches 1.1 PW (33 J in energy and 30 fs in pulse duration. The temporal contrast is one of important parameters when we apply an ultrashort high power laser system to studies on relativistic laser-matter interactions. The measured contrast is $10^{-7}$ at 200 ps before a main pulse arrives. Various techniques including nonlinear intensity filtering, Optical Parametric Chirped Pulse Amplification (OPCPA), and cross polarized wave (XPW) are under test for improving the temporal contrast of the PW CPA Ti:sapphire laser system.
We perform experimental studies on electron trapping in a laser wakefield accelerator initiated by ionization of target gas atoms. Targets composed of helium and controlled amounts of various gases were found to increase the beam charge by as much as an order of magnitude compared to pure helium at the same electron density and decrease twice the electron beam divergence. These measurements were supported by particle-in-cell modeling including ionization [1].

We show that a laser wakefield accelerator operated in the highly non-linear “bubble” regime produces monoenergetic electron beams with energy up to 500 MeV and hundreds of pC charge. The bubble acts at the same time as a miniature undulator, causing betatron motion of electrons which produces x-rays with milliradian divergence, few microns source size, 1-100 keV photon energy and peak brightness of $10^{22}$ ph/mm$^2$/mrad$^2$/s/0.1% BW approaching 3-rd generation of synchrotrons [2].


Cryogenically-cooled Ytterbium-doped Solid-state Laser and Its application

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Abstract: Development of emerging diode-pumped, cryogenically-cooled Yb-doped solid-state CPA lasers is described. A simple and robust OPCPA scheme in which an even order dispersion of an idler pulse is compensated by passing through an identical positive dispersive material used for temporal stretching a signal pulse is also discussed.

The technique of chirped pulse amplification (CPA) has opened new avenues for the production of high-energy ultrafast laser pulses without optical damage to amplifiers and optical components [1, 2]. The combination of CPA and ultrabroad-band solid-state laser materials has made it possible to produce terawatt and even one hundred terawatt femtosecond pulses with ever increasing average powers [3-6]. The CPA technique has been demonstrated with a variety of laser materials such as Nd:glass [7-10], alexandrite [11, 12], Ti:sapphire [3-6], Cr:LiSAF [13, 14]. These materials all have relatively large saturation fluences of the order of joules per square centimeter or even more, relatively long upper state lifetimes and broad bandwidths.

While the first generation of CPA systems were based on Nd:glass amplifiers and generated high energy picosecond pulses, the relatively narrow bandwidth of Nd:glass has limited amplified pulse duration to a few 100’s of femtoseconds. To date, pulses as short as 450-fs with a peak power of 1.5-PW have been generated by using a large scale, single-shot-per-hour, inertial-confinement-fusion, Nd:glass laser [15]. While Nd:glass amplifiers have good energy storage and can easily be scaled to large volumes, they are in general limited to low repetition rates and low average power operation because of the poor thermal characteristics of laser glasses.

Using larger gain bandwidth materials such as Ti:sapphire [16] and Cr:LiSAF [17], however, permits the amplification of sub-100 femtosecond pulses from the Kerr-lens mode-locked oscillators [18, 19]. In particular, Ti:sapphire has several desirable characteristics including a high saturation fluences (~ 0.9-J/cm\(^2\)), a high thermal conductivity (46-W/mK at 300 K) and a high damage threshold (> 5-J/cm\(^2\)) for producing high-peak and high-average power pulses [20]. Its gain bandwidth of ~ 230-nm at Full width at half maximum (FWHM) could in principle support transform limited pulses of ~ 3-fs. In a single-shot operation, petawatt-class Ti:sapphire laser systems have been developed [21-23].

Ytterbium (Yb\textsuperscript{3+}) doped gain media are one of promising laser materials for the next generation of directly diode-pumped high-power lasers [24, 25]. Such Yb-doped media have numerous advantages. First, it has wide absorption bandwidth which is suitable for direct diode pumping. Second, a low quantum defect enables efficient and high repetition rate operation. Third, the simple electronic structure avoids processes such as excited-state absorption, upconversion and concentration quenching. Cryogenic cooling of Yb-doped solid-state lasers can further offer a number of benefits, including the enhancement of absorption and emission spectral properties, and thermal and thermo-optic properties under the four-level laser operation [26-28]. For example, cryogenically-cooled Yb:YLF (Yb:YLF) is suitable for the high energy amplification with the emission cross section of 15 times higher than that at room temperature [29]. We have built a diode-pumped, cryogenically-cooled Yb:YLF chirped pulse regenerative amplifier in 2003 [30]. The output pulse energy of 30 mJ was achieved at a 20-Hz repetition rate. A high effective extraction efficiency of 68% was obtained, which was attributed to reduced saturation fluence at low temperature. After pulse compression, pulses with 18-mJ energy and 795-fs pulse duration were obtained. In addition, cryogenically-cooled Yb: YAG [31], Yb:KY(WO\(_4\))\(_2\) (Yb:KYW) [32] and Yb:LuLiF\(_4\) (Yb:LLF) [33] with diode pumping have unique characteristics. We are continuously working on the generation of pulses with higher energy, higher repetition rate and shorter pulse duration using Yb-doped gain media.

Alternatively, optical parametric chirped-pulse amplification (OPCPA) is one of another candidates to the generation of ultrahigh peak power ultrafast laser pulses [34, 35]. Its major advantages include high gain,
high contrast and high beam quality while maintaining ultrabroad spectral bandwidth. A multi-terawatt OPCPA system pumped by a high energy Nd:glass laser has been developed to produce pulses longer than 100-fs [36]. At the same time, a multi-terawatt, few-cycle (< 10-fs) OPCPA system has also been constructed [37]. Combined with these high energy and few-cycle OPCPA techniques would offer the possibility of generating peak powers of ~100-PW in ~5-fs duration. By using a modern high-power Yb-doped solid-state CPA lasers as a pump source for OPCPA, it will open a new route to the generation of intense few-cycle pulses with high repetition rates [38]. We have demonstrated ultra-broadband optical parametric chirped-pulse amplification of more than 550-nm bandwidth by using the diode-pumped, cryogenically-cooled Yb:YLF chirped-pulse amplification pump laser at degeneracy [39]. Figure 1 shows the measured amplified spectrum of OPCPA at the pump intensity of ~ 50 GW/cm². The spectrum ranging from 850-nm to 1400-nm was amplified, corresponding to a calculated, transform-limited pulse duration of 6.5-fs or less than 2 optical cycles. We have also proposed and demonstrated a very simple and robust optical-parametric chirped-pulse amplification scheme in which an even order dispersion of an idler pulse is compensated by passing through an identical positive dispersive material used for temporal stretching a signal pulse. By compressing the idler pulses having a negatively chirp in this manner, high power sub-100 fs pulses were successfully obtained with only a transparent glass block used for the stretcher and compressor. A feasible design of real world femtosecond laser systems employing this scheme is also discussed.

References

Two Pump Beams
Daniel Herrmann
R. pumped picosecond regenerative amplification at 999 nm in wavelength with a cryogenically cooled Yb:LuLiF
Development and application of plasma-waveguide based soft x-ray lasers

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Optical-field ionization by femtosecond multi-terawatt laser pulses is an efficient method for creating plasma of hot electrons and close-shell ions in the sub-picosecond timescale. The hot electrons in such plasma collide with the ions to produce population inversion that leads to x-ray lasing. A major limitation of this x-ray laser pumping scheme is the defocusing of the pump pulse by ionization-induced refraction. Our solution to this problem is fabricating a transient plasma waveguide into the gain medium to confine the pump pulse. By this method we achieved dramatic enhancement of 32.8-nm x-ray lasing in an optically preformed krypton plasma waveguide. An output level of $8 \times 10^{10}$ photon/shot was reached at an energy conversion efficiency of $2 \times 10^{-6}$. The same method was used to achieve x-ray lasing for the high-threshold low-gain transition of 46.9 nm in neon-like argon. We have also demonstrated seeding of Ni-like Kr lasing at 32.8 nm by high harmonic generation. Seeding with high harmonics yields much smaller divergence, enhanced spatial coherence, and controlled polarization. In application, we demonstrated single-shot digital holographic microscopy with an adjustable field of view and magnification by using the plasma-waveguide based 32.8-nm x-ray laser. A new configuration of imaging was developed to overcome the pixel-size limit of the recording device without reducing the effective numerical aperture. The ultrashort x-ray pulse duration combined with the single-shot capability offers great advantage for flash imaging of delicate samples.
Trends in Optical Parametric Chirped Pulse Amplification

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Since the proof-of-principle demonstration of optical parametric amplifier to efficiently amplify chirped pulses in 1992 [1], optical parametric chirped pulse amplification (OPCPA) became a widely recognized and rapidly developing technique for high power femtosecond pulse generation. In the meantime, we are witnessing an exciting progress in the development of powerful and ultrashort pulse laser systems that employ chirped pulse parametric amplifiers. These systems cover a broad class of femtosecond lasers, with output power ranging from a few gigawatts to hundreds of terawatts, with a potential of generating few-optical-cycle pulses at the petawatt power level (see Fig. 1). In this paper, we discuss the main issues of optical parametric chirped pulse amplification and overview recent progress in the field.

Fig. 1 Progress of OPCPA-based laser systems toward petawatt pulses.

ABSTRACT FOR INTERNATIONAL SYMPOSIUM ON
CHIRPED PULSE AMPLIFICATION

Recent progress on high field ultrafast lasers and their applications at SIOM

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Abstract

We will report the recent progress on high field ultrafast lasers and their applications at Shanghai Institute of Optics and Fine Mechanics (SIOM).

We will review the development of CPA and OPCPA lasers at SIOM in the past 20 years, including the first demonstration of a 10 TW level OPCPA laser system in 2002 and the 890TW CPA laser facility in 2006, as well as the generation of intense 800nm and the mid-infrared laser pulses lasting for less then two optical cycles more recently.

We will show the typical applications of the high field ultrafast lasers, including the table-top fusion experiment due to the energetic Coulomb explosion of large size heteronuclear deuterated methane clusters and highly efficient generation of neutrons, and the experimental demonstration to accelerate electrons up to 1.8 GeV energy in a laser wakefield accelerator, etc.

We will also present some results of the generation of high order harmonics and attosecond pulses, including the dynamic control over the intrinsic chirp of attosecond pulses by using a two-color field, and the new scheme for the robust generation of isolated attosecond pulse against the large variation of carrier-envelop-phase of the driving laser pulses, etc.
Title: Activation of LFEX laser system with image-rotating pulse compressor

Abstract

The LFEX laser system is a short pulse CPA laser for fusion research with output energy of 10 kJ at 1 ps. This laser system has 4 beam-lines of 37 x 37 cm beam size. Due to this beam size, the system requires about 1.8 m long gratings for pulse compression. For this purpose, we developed 91 cm long diffraction gratings and large-scale mirrors on the fused-silica substrates.

For maintaining good wavefront, 2 deformable mirrors are installed in each beam-line. Three-stage OPCPA amplifiers are used in pre-amplifier chain, and a phase modulation system is introduced to control the temporal waveform. Several attempts are made for obtaining good contrast in temporal waveform.

Special pulse compressor using diamond-shape beam propagation with image-rotation is designed for this laser as shown in Fig.1. This compressor uses 2 sets of segmented grating systems with 2 gratings. Each grating is hit 2 times with image-rotated geometry, and several alignment errors are automatically compensated such as tilt and piston of element grating. There is no position sensor or interferometer for the alignment of segment-gratings, which are used in other laser system. The compressor system is very stable and easy to adjust.

The detail of activation of LFEX laser will be presented. The problem and solution in degradation of damage threshold of optics in the compressor chamber will be also reported.

Figure 1. Large-scale image-rotation pulse compressor for LFEX laser.
Pathways for extreme lasers

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ABSTRACT

The first operation of a laser device 50 years ago was followed by a number of advances in laser physics which have paved the way to ultrafast science and high field physics. In 50 years, the duration of laser pulses was reduced from microseconds to attoseconds, with peak powers now exceeding one petawatt. We will present an overview of some of the key physical interactions that have made it possible to generate ultrashort laser pulses. To push the pulse duration and peak power even further, we will discuss some alternative approaches such as two-photon amplification and electron acceleration. The availability of pulses of extremely short duration could allow to examine fundamental processes such as radiation damping in electrodynamics.
We report on the design and construction of the fully diode pumped ultrahigh peak power laser system POLARIS at the Friedrich Schiller University and the Helmholtz Institute Jena, Germany. Presently, this laser system reaches a peak power of several tens of terawatt. The last amplifier, which will boost the output energy to the 100-J level, is nearly completed and will be soon commissioned. The applied technology and the basic design are reviewed.
Recent progress of THz generation and detection in ambient air or gases

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Since the early 90s, THz time domain spectroscopy has been largely applied on the measurement of semiconductor, electro-optic crystals, and selected chemical, biological, and explosive materials. Ambient air, when excited with intense femtosecond laser beams, exhibits a remarkable ability to generate and detect pulsed THz waves through an optical nonlinear process.

The most recent results of using air (and selected gases) as the emitter and sensor material for both generation and detection of broadband THz waves will be reported. Air, especially ionized air (plasma), has been used to generate intense peak THz waves (THz field $> 1.5$ MV/cm) with a broadband spectrum (10% bandwidth from 0.1 THz to 46 THz). The previously developed technique of THz air-biased-coherent-detection (ABCD) provides ultra-broadband sensing capability; however, it requires electrodes or wires near the target, so it cannot be used for remote measurements.

We have developed THz radiation-enhanced-emission-of-fluorescence (REEF) and THz-enhanced acoustic (TEA) techniques which circumvent high attenuation of THz by atmospheric water vapor absorption. By “seeing” the fluorescence, or “hearing” the sound emitted from a laser-plasma, coherent detection of THz waves at a standoff distance is feasible. Remote generation at 30 meters and remote detection at 10 meters are demonstrated.
The Extreme Light Infrastructure (ELI)
Attosecond Facility in Hungary

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The primary mission of the Extreme Light Infrastructure Attosecond Light Pulse Source (ELI-ALPS) is to provide the international scientific community with a broad range of ultrafast sources, especially with coherent XUV and X-ray radiation, including single attosecond pulses. ELI-ALPS, to be built in Szeged, Hungary, will be operated also as a user facility and hence serve fundamental and applied research in physical, chemical, material and biomedical sciences as well as industrial applications. The laser system serving these goals will consist of 2 synchronized amplifier chains. One of them will be based on a high repetition rate (1 kHz) OPCPA amplification chain with a final pulse energy target of 1 J delivering the shortest possible pulse length (possibly few-cycle pulses). The other branch will be aiming at 10 PW peak power starting with OPCPA booster stages. The final amplifiers will be Ti:sapphire with sub-Hz repetition rate operation and 15-25 fs pulse length. Both laser systems will be built based on the experience of various national prototype laser projects in Europe (Apollon, Astra Gemini, the Petawatt Field Synthesizer and Vulcan 10 PW upgrade) as well as various pumping solutions that are being currently developed in different groups for CPA/OPCPA lasers. Even before reaching final specifications, the laser systems will be suitable for carrying out a number of groundbreaking experiments in gas and solid high harmonic generation, production of high repetition rate particle, THz and X-ray beams etc. The unique feature of offering synchronized femto- and attosecond sources covering the spectral range from THz to X-ray will provide users an opportunity to carry out novel time-resolved experiments.
Neutral dissociation of simple molecules through Super Excited States

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Spectra of several molecules (H\textsubscript{2}, O\textsubscript{2}, NO, CH\textsubscript{4}) exposed by strong laser field are observed. Based on the predicted potential energy surfaces, neutral dissociation through Super Excited States is the responsible mechanism in all of the investigated gases. In methane, spectra from CH fragments as well as atomic hydrogen, in Oxygen atomic Oxygen, in Nitric Oxide atomic Nitrogen and Oxygen, in Hydrogen atomic hydrogen lines were detected clearly. The minimum number of photon participated in each process was obtained experimentally by finding the slope of each fluorescence signal versus laser intensity in a log – log scale. Total energy absorbed is higher than the first ionization potential energy in all of the studied molecules. Pump and probe experiment demonstrate very short lifetime of these states, as well. A new direction opens up in which one can make use of an intense fs laser pulse to excite molecular superexcited states.
Inelastic rescattering processes in molecules measured with few-cycle laser pulses

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Abstract

We study electron recollision processes induced in D2 by the nonlinear interaction with 800nm few-cycle laser pulses. We show that sequential double ionization is suppressed at intensities below $2 \times 10^{14} \text{W/cm}^2$, and the inelastic rescattering processes (electronic excitation and double ionization) become dominant and can be investigated as a function of intensity and ellipticity. At $1 \times 10^{14} \text{W/cm}^2$, the D$^+$ kinetic energy spectrum arises from recollision-induced electronic excitation and is explained by the contribution of two dissociative excited states of D$^2$+. 
Correlated electron-nuclear motion visualized using a wavelet time-frequency analysis

by

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We have solved numerically the time-dependent Schroedinger equation describing dissociative-ionization of a hydrogen molecule exposed to intense short-pulse laser light in one dimension. From the time dependent wave function we calculated the total average acceleration of the two electrons and the relative proton acceleration. We find that the general shape of the power spectra of electrons and protons is very similar except that the for the electrons the peaks occur at odd harmonics whereas for protons the peaks occur at even harmonics. The wavelet time-frequency analysis shows that, surprisingly, time profiles of electron and proton accelerations are nearly identical for high harmonics. The wavelet time profiles confirm predictions of the three-step quasi-classical model of harmonic generation by identifying several (up to three) electron return times with high precision.
Terahertz Detection Utilizing Ultrafast Laser-Induced Photoacoustics

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Terahertz enhanced acoustics (TEA) is a recently developed method for detecting terahertz (THz) radiation. When a high energy 800 nm optical pulse is focused into the air, it generates a plasma. This nearly instantaneous heating of the gas emits a shock wave that quickly relaxes to an acoustic wave. The acoustic wave contains a broad spectrum of frequencies that extend well beyond the range of human hearing (20 Hz to 20 kHz) into the ultrasonic range. When a broadband THz pulse is focused collinearly and simultaneously onto the aforementioned plasma region, free electrons in the plasma experience the high electric field from the THz pulse, causing them to accelerate rapidly. The acceleration of these electrons produces more frequent collisions between them and the adjacent molecules inside the gas. This additional translational energy results in a local heating of the plasma, and therefore a change in the local pressure where the acoustic wave is initiated. This THz field-induced energy transfer gives rise TEA. The enhancement of acoustic waves, from audible into the ultrasonic range, is a linear function of the THz intensity incident on a laser-induced plasma, making TEA useful for THz wave detection. By using a dual-color laser field to produce the plasma detector, THz spectroscopic information can be encoded into the acoustic emission, making it possible to obtain the electric field profile of the THz pulse by simply “listening” to the plasma. This provides a method for performing remote THz spectroscopy that circumvents high intrinsic water-vapor absorption of THz in air.
Formation and evolution of intense, post-filamentation, ionization-free low divergence beams


Abstract: The mechanisms related to the formation and propagation of post-filamentation intense light channels were rigorously investigated experimentally and numerically. It was found that they originate from a hot spot formed by diffraction of the pulse energy reservoir onto the plasma. Once the hot spot was formed, a channel with intensity estimated at 0.5 TW/cm² could maintain its diameter over several tens of meters such that air was not ionized, but the self-focusing produced was sufficiently high to balance linear diffraction. This propagation regime is of high interest to propagate high intensity laser pulses with limited losses.
Nanograting formation on the surface of fused silica

Feng Liang, Daniel Gingras, Réal Vallée, and See Leang Chin

The characteristics of nanograting formation on the surface of fused silica have been studied. By controlling laser intensity and pulse to pulse spacing, a well-shaped nanograting can be formed with the laser intensity slightly higher than the threshold intensity of ~1.9×10^{13} W/cm^2. The nanograting period increases with the pulse to pulse spacing. The depth of the nanograting is about hundreds of nanometer.
IONIZATION OF XENON WITH OPTICAL GATED LASER PULSES AND WAVELENGTH DEPENDENCY OF NON-SEQUENTIAL DOUBLE IONIZATION

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Single and double ionization of xenon with linear polarized and optical gated short laser pulses has been studied with a time of flight spectrometer. In a first step we have recorded the Xe+ and Xe2+ yield as a function of the laser intensity (2 x 10^{13} W/cm^2 to 1x 10^{15} W/cm^2) and the wavelength (500nm-2200nm) [1,2]. We can demonstrate that the PPT model [3] fits well the yield of the single ionization process and the yield of double ionization at laser intensities near saturation. At lower laser intensities < 2 x10^{14} the Xe^{2+} yield is increased by non-sequential ionization. We can show that this contribution results from impact excitation. The process can be understood in three steps. Firstly an electron is freed by tunnel or non-resonant single ionization. This electron is driven back from the laser field to the nucleus by the laser and cause an impact excitation. This process is only possible with linear polarized light. We have calculated the cross-section of a possible impact excitation and impact ionization as a function of the wavelength and the laser peak intensity with the Lotz formula.

Different from ionization processes with linear polarized light, circular polarized light would not allow a non sequential ionization process. With a second experiment we have created a laser pulse with a temporal modulated polarization [4]. This pulse is only linearly polarized centered at the envelope peak intensity (a gate of length from multiple to less than one optical cycle can be defined). Ion yield curves of doubly charged xenon as a function of the gate length allow us to measure non-sequential ionization of multiple as well as sub-cycle pulses.

References
Monitoring electron motion in polyatomic molecules with ultrashort intense laser pulses

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We present real-time electronic dynamic imaging of polyatomic molecules in ultrashort intense laser pulse. The study of polyatomic molecules is necessary to investigate dynamic imaging of chemical processes. In a fully quantum description of the molecular system, we investigate the influence of the nuclear motion on the photoionization process. We apply this study on H3+, which is the simplest stable polyatomic molecule and the most abundant charged molecular specie in interstellar clouds. Such a triatomic molecule present a conical intersection of the potential energy surfaces of electronic states. At this intersection, the non-adiabatic coupling becomes singular, the Born-Oppenheimer approximation breaks down and a multitude of non-adiabatic effects appear. In particular, we illustrate these non-adiabatic effects on the High-order Harmonics spectra. Conical intersections are ubiquitous in numerous photochemical and photobiological processes and this study opens the route to establish benchmarks of real-time dynamics of polyatomic molecules.

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Continuously adjustable polarization gating technique for ionization study and electron spectroscopy: theory and experiment

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Polarization gating [1] is an important technology to obtain a modulation of the polarization along a laser pulse. Numerical simulations of the few-cycle laser pulse propagation beyond the carrier-envelope approximation provide an advanced understanding of the temporal polarization state of the pulse. Our goal is to obtain a continuously adjustable temporal shape, where the center part of the pulse is linearly polarized and the two wings are circularly polarized. Two-dimensional maps of several relevant pulse properties such as the ellipticity, the major axis orientation and the intensity are presented in both frequency and time domains.

Continuously adjustable polarization gating has been realized experimentally with a new setup consisting of two pairs of two quartz wedges and one λ/4 wave plate. The duration of the gate and the temporal ellipticity is given by the relative quartz insertion of the two wedge systems. We have compared our experiment with our computer simulation. The robustness of the method against non-ideal laser pulse parameters (spectrum, chirp, chromaticity of the quarter-wave plate, etc.) has been verified numerically. This work opens the way to polarization gate width dependent electron and ion spectroscopy with carrier-envelope phase stabilized few-cycle laser pulses.

Figure 1 – Simulation of the temporal characteristics of a 750 nm, 5.6 fs Fourier transform limited laser pulse as a function of the quartz insertion in a polarization gating scheme. (a) Intensity profile. (b) Ellipticity.

Non Perturbative Time-Dependent Density Functional Theory, TDDFT: Study of Ionization and Harmonic Generation in Linear Di-(N2) and Tri-(CO2, OCS, CS2) Atomic Molecules with Ultrashort Intense Laser Pulses-Orientational Effects

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ABSTRACT

In the present work, we find that at equilibrium and at intensities \( I_0 > 3.5 \times 10^{14} \text{ W/cm}^2 \), lower inner highest occupied molecular orbitals of CO2, OCS, CS2 contribute significantly to ionization and to the MHOHG process. Even though such lower inner shell orbitals have higher ionization potentials, IP, ionization and MHOHG processes occur when orbital densities are maximal with laser polarization direction. Our simulations also reveal that the direction of laser polarization, \( \theta \), with respect to the molecular axis of the linear molecule can have a significant effect on MHOHG.

These findings are confirmed with the time dependent electron localization function, TDELF, representation through the analysis in term of density perturbations appearing on the TDELF images of each molecule. For \( \theta < 90^\circ \) and at lower laser intensity (\( I_0 = 10^{14} \text{ W/cm}^2 \)), one sees that the HOMO is the most affected by the laser field and a large asymmetry density is found, i.e., we clearly see that during each half cycle, the perturbation occurs alternatively from one nucleus to another (favouring minimal interference) while for \( \theta = 90^\circ \), both nuclei simultaneously feel the same perturbation from the laser field (favouring maximal interference).
Ultrafast Molecular Imaging by Laser Induced Electron Diffraction

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We address the feasibility of imaging geometric and orbital structure of a polyatomic molecule on an attosecond time-scale using the Laser Induced Electron Diffraction, LIED, technique (Zuo et al. Chem. Phys. Lett. 259, 313 (1996)). We present numerical results obtained for N₂ and CO₂ molecules using a Single Active Electron model. The molecular geometry (bond-lengths) is determined within 3 % of accuracy from a diffraction pattern which also reflects the nodal properties of the initial molecular orbital. Signatures of two-center and three-center diffraction are examined. Robustness of the structure determination is discussed with respect to nuclear motions and to the exciting pulse duration with a complete interpretation of the laser-induced mechanisms.

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Chirped Pulse Amplification based High Power Laser Development Activity at RRCAT, Indore, India

Raja Ramanna Centre for Advanced Technology (RRCAT), Indore 452 013, India

Since the invention of the chirped pulse amplification (CPA) technique\(^1\), ultrashort pulse high power laser systems\(^2\) have been built and laser systems capable of delivering laser peak power much beyond petawatt level are under construction in several laboratories around the world. The CPA lasers operate in the regime of low energy ultrashort laser pulses as well as high energy short laser pulses, and both these regimes have their own applications. In particular, high energy high power laser systems facilitate high density science studies\(^3\) such as radiation opacities at very high densities and temperatures, processes relevant to fast ignition, and generation of single shot, high flux sources of radiation (x-rays, $\gamma$ rays) and particles (electrons, protons, neutrons and also ions) for various applications.

The CPA technique involves temporal stretching, amplification, and then recompression of ultrashort laser pulse. Laser pulse amplification over many orders of magnitude in laser amplifiers results in spectral bandwidth narrowing and also contributes to additional dispersion to the laser pulse, which makes ultra broadband amplification and recompression a challenging task. Optical parametric amplifier (OPA) has been demonstrated as an alternative high-gain amplifier for chirped laser pulses in a scheme known as optical parametric chirped pulse amplification\(^4\) (OPCPA). While OPAs have generally low conversion efficiency, they offer ultra-broad amplification bandwidth over smaller temporal window (governed by the pump pulse duration) on a much smaller interaction length (crystal thickness), thus leading to a prepulse-free ultra-broadband amplification and recompression.

Laser Plasma Division of RRCAT, Indore has indigenously developed a 1 J / 1 ps CPA based Nd:glass laser system and is presently working on development of a 50 TW class laser system involving hybrid optical parametric and laser amplification to tap advantages of both types of amplifiers. Fig. 1 depicts schematic diagram of the proposed 50 TW laser system. Present laser design mainly involves a commercial 100fs laser oscillator, pulse stretcher, single pulse selector, multistage OPAs, laser power amplifiers and finally a large aperture tiled pulse compressor. Output from OPAs will be amplified to 50 J level using laser amplifiers of one arm of existing two-beam 200 J / 1 ns Nd:glass laser chain. Various sub-systems, except OPAs and synthetic aperture or tiled pulse compressor, have already been built in-house. We have also successfully built a synchronizable Nd:glass pump laser system and initial experiments on OPA have been carried out.

To develop and maintain the laser system, one requires various types of diagnostics to characterize the laser pulses in spatial, spectral and temporal domain. Several ultrashort laser pulse diagnostics have been developed. The details of our laser system, laser diagnostics and our future plans in OPCPA based high power laser development will be presented.

References:

Intense terahertz generation from two-color filaments in air

Tie-Jun Wang,1* Shuai Yuan,1 Claude Marceau,1 Yanping Chen,1,2 Jean-François Daigle,1 Zhen-Dong Sun,1,4 Francis Théberge,2 Marc Châteauneuf,2 Jacques Dubois,2 and See Leang Chin1

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As a branch of filamentation nonlinear optics, intense terahertz (THz) pulse generation with large bandwidth from inside the filament in air is an active area of current research on THz science. Such broadband and rather powerful THz pulses would provide a new prospective tool for remote THz nonlinear optics and spectroscopy because the technique allows the generation of intense near single-cycle THz pulses at long distance by controlling the remote onset of the filament via controlling the initial laser parameters: beam diameter, divergence and pulse duration. Two-color filamentation in air induced by a femtosecond Ti:sapphire laser pulse (fundamental wave, FW) and its second harmonic wave (SHW) has been demonstrated as an efficient technique to generate an intense THz emission.

We present our recent progress on THz emission from two-color filaments in air.

1. Micro-joule level of THz emission from two-color filaments was obtained by optimizing the pump pulse duration. Under a fixed high energy pump of 24 mJ from a Ti-sapphire laser, we observed more than 4 times enhancement of THz pulse energy by chirping the 42 fs transform limited pump pulse either negatively or positively to around 150 fs. Multiple filaments competition and cooperation could be responsible for the enhancement mechanism.

2. External DC electric field effect on THz emission from two-color filaments was systematically investigated. The total THz emission could be interpreted as a sum of two contributions. One is the linearly polarized THz component induced by the external DC field with polarization parallel to the direction of the DC field; it corresponds to the plasma frequency of the filament. The other is an emission from the two-color laser-induced filamentation due to the neutrals; i.e. 4-Wave-Mixing (4WM).

3. We demonstrate a method to control the THz emission from a two-color filament in air based on molecular alignment due to rotational Raman excitation. By tuning the delay time between rotational Raman excitation and THz excitation around the air molecule revival time, a significant modulation of THz emission is observed. The phenomenon is attributed to molecular alignment induced refractive index change, resulting in the changes of the nonlinearity ($\chi^{(3)}$) in neutrals and laser intensities inside the filaments.

4. Toward remote high energy THz generation, so far, we demonstrate a record of THz generation from two-color filaments at a distance of 16 m. Pulse energy more than 250 nJ in the frequency range below 5.5 THz is recorded using the current detection system with a pyroelectric energy meter.

5. Toward remote sensing of THz emission, we demonstrate back-scattered nitrogen (N$_2$) fluorescence signal inside two-color filaments remotely measured with a lidar is linearly proportional to the THz emission, which would provide a more practical method to characterize the THz pulses.
Molecular ionization by an intense attosecond XUV pulse: Is a Franck-Condon approximation acceptable?

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We investigate the use of a Franck-Condon ansatz to model the ionization of $H_2$ under the action of an XUV pulse as assumed in previous studies of the dissociative ionization of the molecule[1]. To this end, time-resolved electronic dynamics are described using a multi-scale time-dependent configuration interaction method which includes both bound and continuum electronic states[2]. Considering single attosecond pulses of a Ti:Saphir laser ($\lambda = 800\, nm$) High Harmonics, we found that the Franck-Condon factors can describe in a good approximation the vibrational distribution of the newly formed $H_2^+$ molecular ion. When longer pulses are used, dissociative continuum is populated to the detriment of low lying vibrational quantum states.

References


PUBLIC TRANSPORTATION TO OLD QUÉBEC

By taxi: one way, ~ $20, depending on traffic.

By bus: From in front of the Symposium building (Pavillon Desjardins), bus number 800 (Beauport) and bus number 801 (Charlesbourg) travel directly to Old Québec. Stop at D'Youville bus stop. Also, busses 800 and 801, when taken from the stop across the street from Pavillon Desjardins, travel on Boulevard Laurier, which is convenient for participants residing in hotels located on that street or for those wishing to visit the shopping malls.

From across the street from Hôtel Universel (on chemin Sainte-Foy), bus number 7 travels directly to Old Québec. Stop at D'Youville Terminal.

Bus fare:

Pay on the bus with exact change: $2.60/ride

OR

Purchase a bus card at the convenience store (Chez Alphonse) on the ground floor of the Symposium building (Pavillon Desjardins). The card costs:

- $10 for 4 rides
- $20 for 8 rides
- $30 for 12 rides
MEALS

There is a cafeteria on the ground floor of Pavillon Desjardins open from 7 a.m. to 7 p.m., Monday to Friday, and from 8:30 a.m. to 7 p.m., on Saturday and Sunday. It serves a variety of food (breakfast, lunch and supper) at decent prices.

Pavillon Desjardins also has a casual dining restaurant on the ground floor called the Pub, which is open for lunch and dinner.

On the 4th floor, it is possible to have a buffet lunch at Le Cercle restaurant. However, reservations are mandatory. The cost for this buffet lunch is just under $20 (including taxes and tip). Conference organizers will be pleased to make reservations for you. Le Cercle is the restaurant where Saturday’s banquet will be held for all Symposium participants.

Should you wish to go outside the campus for lunch, we suggest the nearest shopping mall, Place Sainte-Foy. It is a 10-minute walk from Pavillon Desjardins. There you will find a food fair serving everything from hamburgers, to pasta, soups, salads and sandwiches. To get there, exit Pavillon Desjardins through the main front doors and turn left. Keep walking in the same direction until you reach the mall.
OTHER USEFUL INFORMATION

BANK and ATMs
There is a bank located on the ground floor of Pavillon Desjardins with several ATM machines.

WIRELESS INTERNET
Wireless Internet is available throughout the Université Laval campus. You will require an access code that will be valid for the duration of the Symposium. Please inquire at Registration Desk.

LASER POINTERS
Université Laval has a very strict policy regarding the use of laser pointers on its premises. It is strongly recommended that only class 1 or class 2 pointers be used. The Symposium will abide by this policy and will provide to all speakers laser pointers that are compliant.

LAB VISITS
We have scheduled visits of the laser labs of Université Laval’s Centre for Optics, Photonics and Lasers (COPL). These visits will be held at the conclusion of the talks on Wednesday (leaving Pavillon Desjardins at 5:30 p.m.) and on Thursday (leaving Pavillon Desjardins at 6:00 p.m.). Space will be limited (first come, first serve). Interested participants are required to sign up for the visits at the Registration Desk. The COPL is located on the other side of the campus (about a 10-minute walk). Students will be accompanying the groups on this tour departing from the registration desk.

BANQUET
Kindly let Symposium organizers know of any food allergies and dietary restrictions so that adjustments can be made in time for Saturday evening’s banquet.
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