Abstract We present the characterization of ultrashort laser pulses by using the plasma-induced frequency resolved optical switching (PI-FROSt) technique, implemented in ambient air. This recently developed method allows for a temporal reconstruction of a pulse at its focal spot by utilizing a moderately intense pump laser pulse for generating a ionization-induced ultrafast defocusing lens. When propagating through the produced plasma lens, the probe beam to characterize experiences an increase of its size in the far field. The spectrum of the defocused probe field, measured as a function of the pump-probe delay, allows for a comprehensive characterization of the temporal and spectral attributes of the pulse. We report herein the ability of this technique, initially designed for use in rare gases, to operate in ambient air conditions with similar performance. The method is remarkably straightforward to implement and requires no additional optical component other than a focusing mirror, while delivering laser pulse reconstructions of high reliability.

Temporal characterization of laser pulses using an air-based knife-edge technique

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1. Introduction

After over three decades of continuous development in ultrafast laser technologies, a wealth of diagnostic tools has emerged for the characterization of femtosecond optical pulses [1–7]. For an intensive review of this topic, we invite the reader to refer to [8, 9]. In this context, nearly all optical devices designed for pulse characterization require the use of transmissive optics (such as nonlinear crystals, lenses, polarizers, thin glass pieces, and so forth), which can potentially introduce undesired effects on the pulse measurement. For instance, transmissive optics inherently imparts additional spectral phase (which can be nevertheless limited by minimizing the total thickness of the optics) to the pulse under examination, potentially posing challenges, especially for ultra-broadband laser fields measurements. Moreover, in the case of intense laser pulses, transmissive optics may introduce a nonlinear temporal phase due to nonlinear effects or, in the worst scenario, may be subject to optical damage. Lastly, an optical characterization device does not provide the temporal profile of the laser pulse at the exact location where experiments are carried out. Specifically, in pump-probe experiments, the critical pulse characteristics are those at the point where the pump and probe interact, namely, at their focal positions. Recently, a characterization method directly working in air has been developed [10]. This technique, called tunneling ionization with a perturbation for the time-domain observation of an electric field (TIPTOE), allows for the direct time sampling of the field to characterize at the focal point. However, since this technique has to resolve the carrier frequency oscillations of the field, it requires to acquire a signal with a sub-cycle resolution. Moreover, the approach can only be applied for moderately chirped input pulses [11]. Recently, we demonstrated that photo-induced free electrons left in the wake of a moderately intense laser pump can be advantageously exploited for characterizing the temporal properties of a pulse [12]. As recently shown in [13], the key idea of this phase-matching free method was to produce a temporal analogue of the knife-edge technique widely used for determining the spatial intensity distribution of a beam. When created by a bell-shaped pump beam, a plasma distribution is known to act as a negative lens, simply because the refractive index modification induced by free electrons is negative [14, 15]. As a consequence, when propagating in this low-density plasma, a probe beam will experience a defocusing leading to an increase of its size in the far field. In the time domain, since the plasma is created almost instantaneously by the pump and provided that its lifetime (typically tens to hundreds picoseconds) is longer than the probe duration, only the trailing edge of the probe will be defocused. Combined with a coronagraph placed in the far field so as to obstruct the probe path when it propagates alone, the induced-plasma then acts as a switch that can be viewed as a temporal blade. More particularly, it was shown that measuring the spectrum of the signal propagating around the coronagraph as a function of the pump-probe delay allows for a comprehensive retrieval of the temporal and spectral characteristics of the probe field. This approach, called plasma-induced frequency resolved optical switching (PI-FROSt), features a number of remarkable assets. It is straightforward to implement, free from phase-matching issues, can operate over an exceptionally broad spectral range, in both self- or cross-referenced configurations, at ultra-high repetition rates with no damage threshold [12]. In order to assess the performance of the method, a noble gas (argon) was used during our first demonstration. Such

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Temporal Characteristics Of Laser Pulses

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Temporal Characteristics of Laser Pulses and Interaction of Laser Radiation with Matter ,1977 **Laser Pulse Phenomena and Applications** F. J. Duarte,2010-12-30 Pulsed lasers are available in the gas liquid and the solid state These lasers are also enormously versatile in their output characteristics yielding emission from very large energy pulses to very high peak power pulses Pulsed lasers are equally versatile in their spectral characteristics This volume includes an impressive array of current research on pulsed laser phenomena and applications Laser Pulse Phenomena and Applications covers a wide range of topics from laser powered orbital launchers and laser rocket engines to laser matter interactions detector and sensor laser technology laser ablation and biological applications **Temporal Characteristics of Laser Pulses and Interaction of Laser Radiation with Matter. Proceedings of the P. N. Lebedev Physics Institute Vol.84. (Stichworte Teil 2)** N. G. Basov,1977 Temporal Characteristics of Laser Pulses and Interaction of Laser Radiation with Matter. Proceedings of the P. N. Lebedev Physics Institute Vol.84. (Stichworte Teil 1) N. G. Basov,1977 **Ultrafast Spectroscopy of Semiconductors and Semiconductor Nanostructures** Jagdeep Shah,2013-11-21 The field of ultrafast spectroscopy of semiconductors and their nanostruc tures continues to be an active field of research Exciting new developments have taken place since the first edition of this book was completed in 1995 This revised edition includes a discussion of many of these recent develop ments in the field This is accomplished by adding a chapter on Recent De velopments at the end of the book This approach was selected to provide a discussion of results while they are still relatively recent Results published before the end of May 1998 were considered for inclusion in this book The objective of this revised edition remains the same as before to provide a co hesive discussion of the many diverse contributions of ultrafast spectrosco py to the field of semiconductors Extensive cross references are made to earlier chapters in order to accomplish this goal The chapter on Recent Developments begins with a brief discussion of new lasers new techniques of ultrafast spectroscopy and novel nanostruc tures This is followed by a section on Coherent Spectroscopy where some of the most interesting recent developments have taken place These include observation of quantum kinetic effects effects that require going beyond the mean field approach of the semiconductor Bloch equations coherent control of populations and current in semiconductors exciton continuum interac tions and many diverse aspects of coherent spectroscopy including studies of microcavities Bragg structures quantum dots and quantum wires **PULSED LASERS AND LASER APPLICATIONS (AMPL-2021)** , The book contains the materials on the fundamental and applied problems of pulsed lasers May be interesting for researches and engineers working in the sphere of quantum electronics spectroscopy plasma physics medicine remote sensing and laser technologies *Laser Induced Damage in Optical Materials* ,1986 *Laser - Surface Interactions* Rashid A. Ganeev,2013-10-17 This book is about the interaction of laser radiation with various surfaces at variable parameters of radiation As a basic principle of classification we chose the energetic or intensity level of interaction of laser radiation with

the surfaces These two characteristics of laser radiation are the most important parameters defining entire spectrum of the processes occurring on the surfaces during interaction with electromagnetic waves This is a first book containing a whole spectrum of the laser surface interactions distinguished by the ranges of used laser intensity It combines the surface response starting from extremely weak laser intensities 1 W cm 2 up to the relativistic intensities 1020 W cm 2 and higher The book provides the basic information about lasers and acquaints the reader with both common applications of laser surface interactions laser related printers scanners barcode readers discs material processing military holography medicine etc and unusual uses of the processes on the surfaces under the action of lasers art conservation rangefinders and velocimeters space and earth explorations surface engineering and ablation and others The scientific applications of laser surfaces interactions surface optical nonlinearities surface enhanced Raman spectroscopy surface nanostructuring nanoripples and clusters formation X ray lasers and harmonic generation from the surfaces are discussed from the point of view of the close relations between the properties of surface and matter which is a cornerstone of most of studies of materials The novelty of the approach developed in Laser Surface Interactions is related with the interconnection of scientific studies with numerous applications of the laser surface interactions separated in different chapters by the ranges of laser intensities We present most recent achievements in this field The book provides valuable information for different ranges of reader s preparedness to the laser related topics from unprepared readers to students engineers and researchers professionals and academics **Laser Induced Damage in Optical Materials: 1984** U.S Department fo Commerce,1986

Nonlinear Optical Properties of Materials Rashid A. Ganeev,2013-01-09 This book is mostly concerned on the experimental research of the nonlinear optical characteristics of various media low and high order harmonic generation in different materials and formation and nonlinear optical characterization of clusters We also demonstrate the inter connection between these areas of nonlinear optics Nonlinear optical properties of media such as optical limiting can be applied in various areas of science and technology To define suitable materials for these applications one has to carefully analyse the nonlinear optical characteristics of various media such as the nonlinear refractive indices coefficients of nonlinear absorption saturation absorption intensities etc Knowing the nonlinear optical parameters of materials is also important for describing the propagation effects self interaction of intense laser pulses and optimisation of various nonlinear optical processes Among those processes one can admit the importance of the studies of the frequency conversion of coherent laser sources The area of interest for nonlinear optical characterization of materials is also closely related with new field of nanostructures formation and application during laser matter interaction We show how the nonlinear optical analysis of materials leads to improvement of their high order nonlinear optical response during the interaction with strong laser fields Ablation induced nanoparticles formation is correlated with their applications as efficient sources of coherent short wavelength photons From other side recent achievements of harmonic generation in plasmas are closely related with the knowledge of the properties of

materials in the laser plumes All of these studies are concerned with the low order nonlinear optical features of various materials The novelty of the approach developed in present book is related with inter connection of those studies with each other *Laser Induced Damage in Optical Materials, 1984* ,1986 **Physical Methods of Chemistry, Investigations of Surfaces and Interfaces** Bryant W. Rossiter,Roger C. Baetzold,1993-01-12 Each volume of this series heralds profound changes in both the perception and practice of chemistry This edition presents the state of the art of all important methods of instrumental chemical analysis measurement and control Contributions offer introductions together with sufficient detail to give a clear understanding of basic theory and apparatus involved and an appreciation of the value potential and limitations of the respective techniques The emphasis of the subjects treated is on method rather than results thus aiding the investigator in applying the techniques successfully in the laboratory **Laser Induced Damage in Optical Materials** Brian E. Newnam,David Milam,1986 **Progress in Ultrafast Intense Laser Science** Kaoru Yamanouchi,Katsumi Midorikawa,2013-02-14 The PUILS series delivers up to date reviews of progress in Ultrafast Intense Laser Science a newly emerging interdisciplinary research field spanning atomic and molecular physics molecular science and optical science which has been stimulated by the recent developments in ultrafast laser technologies Each volume compiles peer reviewed articles authored by researchers at the forefront of each their own subfields of UILS Every chapter opens with an overview of the topics to be discussed so that researchers unfamiliar to the subfield as well as graduate students can grasp the importance and attractions of the research topic at hand these are followed by reports of cutting edge discoveries This ninth volume covers a broad range of topics from this interdisciplinary research field focusing on ultrafast molecular responses to an intense laser field advanced techniques for attosecond pulse generation atomic and molecular responses to attosecond pulses photoelectron spectroscopy of atoms and molecules interacting with intense light fields and attosecond pulse interaction with solid materials **Laser-Induced Breakdown Spectroscopy** Reinhard Noll,2012-01-14 This book is a comprehensive source of the fundamentals process parameters instrumental components and applications of laser induced breakdown spectroscopy LIBS The effect of multiple pulses on material ablation plasma dynamics and plasma emission is presented A heuristic plasma modeling allows to simulate complex experimental plasma spectra These methods and findings form the basis for a variety of applications to perform quantitative multi element analysis with LIBS These application potentials of LIBS have really boosted in the last years ranging from bulk analysis of metallic alloys and non conducting materials via spatially resolved analysis and depth profiling covering measuring objects in all physical states gaseous liquid and solid Dedicated chapters present LIBS investigations for these tasks with special emphasis on the methodical and instrumental concepts as well as the optimization strategies for a quantitative analysis Requirements concepts design and characteristic features of LIBS instruments are described covering laboratory systems inspections systems for in line process control mobile systems and remote systems State of the art industrial applications of LIBS systems are presented demonstrating the

benefits of inline process control for improved process guiding and quality assurance purposes **Safety with Lasers and Other Optical Sources** D. H. Sliney,J. Mellerio,2013-11-11 Nearly a decade aga a general review article on the evaluation of optical radia tion hazards was published in Applied Optics Sliney and Freasier 1973 This arti cle received many favorable comments but also prompted many inquiries regarding specific optical hazard problems From this it became evident that a monograph rather than a supplemental and expanded article was needed to fill this literature gap relating to laser and optical radiation hazards The present work is designed to fill that gap and is structured to permit either classroom or self study use Much of the material in this book was developed in eonnection with short courses on laser safety and radiometry in which we have participated as weIl as from our previous articles In particular the sequenee of chapters is based upon the experiences which we have had in lecturing in courses with different schedules One of the great difficulties in developing a text of this nature is that a broad multidisciplinary background must be included in order that the reader can comprehend all of the subjeet matter readily For this reason the material presented on anatomy and physiology is orien ted toward the engineer or physical scientist while the review material on basic optical physics is intended more for the physician or life scientist **X-Ray Lasers 2004** J Zhang,2005-06-15 X Ray Lasers 2004 comprises invited contributed and poster papers presented at the 9th International Conference on X Ray Lasers ICXRL2004 held in Beijing in May 2004 Some 120 participants from 13 countries and regions met in Beijing to compare results and exchange views on future developments in x ray lasers and related fields The book covers the following topics overviews of x ray lasers research collisionally pumped x ray lasers capillary discharge pumped x ray lasers OFI and photo pumped x ray lasers high order harmonics XUV radiation grazing incidence pumping x ray lasers theory and simulations of x ray lasers and plasma media free electron lasers and accelerator based x ray sources alternative pumping schemes for x ray lasers applications of x ray lasers and other bright x ray sources x ray optics and instrumentation investigations of x ray laser media and developments of x ray laser drivers X Ray Lasers 2004 provides not only an overview and an up to date progress report on this fast moving field but also important reference material on which future work can be built Ultrafast Dynamics Driven by Intense Light Pulses Markus Kitzler,Stefanie Gräfe,2015-07-24 This book documents the recent vivid developments in the research field of ultrashort intense light pulses for probing and controlling ultrafast dynamics The recent fascinating results in studying and controlling ultrafast dynamics in ever more complicated systems such as bio molecules and structures of meso to macroscopic sizes on ever shorter time scales are presented The book is written by some of the most eminent experimental and theoretical experts in the field It covers the new groundbreaking research directions that were opened by the availability of new light sources such as fully controlled intense laser fields with durations down to a single oscillation cycle short wavelength laser driven attosecond pulses and intense X ray pulses from the upcoming free electron lasers These light sources allowed the investigation of dynamics in atoms molecules clusters on surfaces and very recently also in nanostructures and solids in new

regimes of parameters which in turn led to the identification of completely new dynamics and methods for controlling it Example topics covered by this book include the study of ultrafast processes in large molecules using attosecond pulses control of ultrafast electron dynamics in solids with shaped femtosecond laser pulses light driven ultrafast plasmonic processes on surfaces and in nanostructures as well as research on atomic and molecular systems under intense X ray radiation This book is equally helpful for people who would like to step into this field e g young researchers for whom it provides a broad introduction as well as for already experienced researchers who may enjoy the exhaustive discussion that covers the research on essentially all currently studied objects and with all available ultrafast pulse sources

High-Energy Molecular Lasers V. V. Apollonov,2016-08-08 This book displays the physics and design of high power molecular lasers The lasers described are self controlled volume discharge lasers The book explains self sustained discharge lasers self initiated discharge lasers and technical approaches to laser design Important topics discussed are laser efficiency laser beam quality and electric field homogeneity The book contains many new innovative applications *Nonlinear Optical Materials for All-Optical Switching Applications* Rajesh Sharma,2025-06-24 This book highlights the background and fundamentals of nonlinear optical materials in relation to all optical switching applications It explains major aspects of nonlinear refractive index and the nonlinear absorption phenomena which are essential to decide the figure of merit of various materials for the all optical switching Autocorrelation technique frequency resolved optical gating spectral phase interferometry for direct electric field reconstruction grating eliminated no nonsense observation of ultrafast incident laser light e fields are discussed to measure the temporal and spectral profiles of the ultrafast pulsed lasers Advanced nonlinear optical characterization methods such as single and dual arm Z scan pump probe and beam deflection techniques are also discussed at length The transmission signal obtained in the majority of the nonlinear optical effects is found to be weak which creates hiccups to obtain faster switching speeds Various solutions are discussed to overcome these existing limitations of the all optical switching based devices Optical nonlinearities in semiconductors organic molecules and challenges in all optical switching devices are also addressed in the book

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