DOE/ER/54590

Final Report: 0078437

Final Report for Period: 09/2000 - 08/2003
Principal Investigator: Antonsen, T. M. .
Organization: U of MD College Park
Title:
Ultra-Intense Laser Pulse Propagation in Gas and Plasma

Submitted on: 10/26/2004
Award ID: 0078437

Project Participants

Senior Personnel

Name: Antonsen, T. M.
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Taguchi, Toshihiro
Worked for more than 160 Hours: Yes
Contribution to Project:
Professor Taguchi is visiting on a one-year sabbatical from Japan. We have begun a collaboration on particle in Cell modeling of cluster expansion.

Post-doc

Graduate Student

Name: Wu, Jianzhou
Worked for more than 160 Hours: Yes
Contribution to Project:
Mr. Wu is currently doing calculations of laser pulse propagation in ionizing gasses.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

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Organizational Partners

Other Collaborators or Contacts

Collaborations
1. I collaborate extensively with Professor Howard Milchberg of UMD who is funded by NSF. We jointly perform research and supervise students. Professor Milchberg performs experiments on intense laser propagation in gas and plasma.

2 I have continued collaborated with Professor Warren Mori of UCLA who is supported by NSF. We are currently developing a 3-dimensional parallelized quasistatic PIC code base on the 2D version WAKE that was developed partially under NSF support.

Activities and Findings

Research and Education Activities:

It is proposed here to continue our program in the development of theories and models capable of describing the varied phenomena expected to influence the propagation of ultra-intense, ultra-short laser pulses with particular emphasis on guided propagation. This program will build upon expertise already developed over the years through collaborations with the NSF funded experimental effort lead by Professor Howard Milchberg here at Maryland, and in addition the research group at the Ecole Polytechnique in France. As in the past, close coupling between theory and experiment will continue.

The main effort of the proposed research will center on the development of computational models and analytic theories of intense laser pulse propagation and guiding structures. In particular, we will use our simulation code WAKE to study propagation in plasma channels, in dielectric capillaries and in gasses where self focusing is important. At present this code simulates the two-dimensional propagation (radial coordinate, axial coordinate and time) of short pulses in gas/plasma media. The plasma is treated either as an ensemble of particles which respond to the ponderomotive force of the laser and the self consistent electric and magnetic fields created in the wake of the pulse or as a fluid. The plasma particle motion is treated kinetically and relativistically allowing for study of intense pulses that result in complete cavitation of the plasma. The gas is treated as a nonliear medium with rate equations describing the various stages of ionization.

A number of important physics issues will be addressed during the program. These include: 1) studies of propagation in plasma channels, 2) investigation of plasma channel nonuniformities caused by parametric excitation of channel modes, 3) propagation in dielectric capillaries including harmonic generation and ionization scattering, 4) self guided propagation in gas, 5) studies of the ionization scattering instability recently identified theoretically and experimentally in our group, and 6) studies of propagation in cluster plasmas. New models will be developed for the harmonic generation of radiation and these will be incorporated in the modeling and simulation.

Findings:

Propagation and Harmonic Generation in Gas-Filled Capillaries

Studies of the propagation of short pulses in a glass capillary have been made. The propagation is simulated using the code WAKE, which we have modified to treat the case in which the simulation boundary is the wall of a capillary. The specific modification assumes that the laser light inside the capillary is obliquely incident on the capillary wall and as a consequence the rays in the wall are at the critical angle for total internal reflection. Simulation results are compared to similar

experiment conditions. Parameters that were examined include transmission efficiency of the waveguide as a function of gas pressure, laser intensity, and waveguide length, which is up to 40 Rayleigh lengths. The intensity on the inner wall of the capillary is monitored to assure the realistic simulations consistent with the optical breakdown of the waveguide material. Generally speaking the intensity on the wall increases with gas pressure due to scattering of the lowest order capillary mode. In the last year we have studies the conditions for generation of a plasma wake in a gas filled capillary. A paper is in preparation.

Pulse Splitting and Off-axis Guiding in Tenuous Argon

We study the nonlinear propagation of initially large spot size, low intensity laser pulses in tenuous Argon. The dynamics of these pulses will be affected by nonlinear focusing and dispersion due to the Argon gas, and by plasma induced refraction and dispersion. Different phenomena are found for different regimes of peak input power space. Laser propagation is studied numerically using the simulation code WAKE. For powers near the critical power, we see temporal pulse splitting which is affected by plasma generation. For slightly higher powers, we observe the formation of a trailing pulse, which is guided off axis by plasma refraction and nonlinear gas focusing. For even higher powers, we observe trapping and refraction of the laser pulse by the plasma. A paper is in preparation.

Self focusing in Cluster Plasmas

Recently active interest has been generated in the interaction of high intensity laser pulses with atomic clusters, having application in EUV lithography and EUV and X-ray microscopy. The aspect that we are interested in is the experimentally observed self-focusing or guiding effect through the plasma created by the irradiation of atomic clusters by intense femtosecond laser pulses. We are theoretically analyzing the propagation and guiding of laser pulses through the inhomogeneous plasma created by such laser-cluster interaction. We are examining the variation in the effective dielectric function of an ensemble of clusters, that is governed by the coupling of the laser pulse with an evolving cluster. In the last few months a PIC code has been developed in collaboration with a visitor (Toshihiro Taguchi) to study the expansion of clusters and the dynamics of the cluster polarization.

Resonant Heating of a Cluster Plasma by Intense Laser Light

The heating of a single argon (Ar) cluster by a strong laser field was studied using an electrostatic particle-in-cell code for a range of intensities and cluster sizes. Heating is dominated by a nonlinear resonant absorption process involving energetic electrons transiting through the cluster. This process gives rise to a threshold in field strength for strong absorption and controls the dielectric properties of the cluster. This work has been submitted to Physical Review Letters:

Formation of Modulated Channels

Plasma waveguides for guiding intense laser pulses have applications in particle acceleration and x-ray generation schemes. Waveguides can be formed using a variety of

methods. One method is to create a plasma channel by breaking down a gas with a laser pulse focused through an axicon. Ideally, the plasma channel will be axially symmetric and allow for guided single mode propagation of short laser pulses. However, for certain experimental conditions the channel develops periodic axial modulations. The onset of these modulations appears to correlate with the conditions for self-trapping and resonant absorption of the axicon pulse by the plasma waveguide. Resonant absorption occurs under the following scenario. As the channel is expanding the axial wave numbers of the modes of the leaky waveguide defined by the channel evolve as well. At certain times one of these axial wave numbers will correspond to that of the formation pulse, which is defined by the axicon. At this time the formation pulse couples linearly to the confined mode of the channel and is strongly absorbed. According to our model the modulations are due to a nonlinear coupling of the axicon field to the confined modes of the channel. Small axial modulations in the expansion rate of the channel can scatter the incident axicon field into the guided mode of the waveguide. The beating of the guided mode and the axicon field leads to modulations in the heating rate and ponderomotive force which reinforce the modulations in the expansion rate, in other words, there is a parametric instability. A simple model of this process will be presented. A paper has been submitted to Physical Review Letters.

Presentations 2002

[RP1.096] Three Dimensional Simulation of Laser and Particle Beam-Plasma Interactions Using QuickPIC, J Cooley, T. M. Antonsen (University of Maryland), C. Huang, W. B. Mori, V. Decyk (UCLA), T. Katsouleas (USC), 44 Annual meeting of the DPP-APS, Orland FL

[RP1.097] Self Focusing in a Cluster Plasma, A. Gupta, T. M. Antonsen, T. Taguchi, H. M. Milchberg (University of Maryland) 44 Annual meeting of the DPP-APS, Orland FL

RP1.100] Study of transient properties of a laser produced Ar cluster plasma using a hybrid simulation code, T. Taguchi, T. M. Antonsen, H. M. Milchberg (University of Maryland) 44 Annual meeting of the DPP-APS, Orland FL

[RP1.101] Self-Phase Modulation and Spectral Broadening in Tenuous Argon, Jianzhou Wu, T. M. Antonsen (University of Maryland)44 Annual meeting of the DPP-APS, Orland FL

Pulse Splitting and Off-Axis guiding in Tenuous Argon, Thomas Antonsen and Jiazhou Wu, 32 Anomalous Absorption Conference, Turtle Bay, Hawaii (July 2002).

Presentations 2001

[KP1.115] Calculation of Electromagnetic Quasistatic Plasma Waves*, J. Cooley, T. M. Antonsen Jr. (Institute for Research in Electronics and Applied Physics, University of Maryland, College Park MD 20742), W. Mori (Dept. of Physics and Electrical Engineering, UCLA, Los Angeles, CA 90095-1547) DPP-APS annual meeting, Nov. 2001.

[KP1.099] Self Focusing in Cluster Plasma, Ayush Gupta, Thomas Antonsen (Institute for Research in Electronics and

Applied Physics, University of Maryland, College Park), Howard Milchberg (Institute for Physical Science and Technology, University os Maryland, College park) DPP-APS annual meeting, Nov. 2001.

[KP1.101] Pulse Splitting and Off-axis Guiding in Tenuous Argon, Jianzhou Wu, Thomas M. Antonsen (APS) , DPP-APS annual meeting, Nov. 2001.

[QO2.008] Experimental Observation of Ionization Induced Instabilities of Short Intense Laser Pulse, I. Alexeev, K.Y. Kim, H.M. Milchberg (Institute for Physical Science and Technology, University of Maryland, College Park MD 20742), T.M. Antonsen (Institute for Plasma Research, University of Maryland, College Park, MD 20742) DPP-APS annual meeting, Nov. 2001.ibit Hall B,

Publications 2002

'GeV acceleration in tapered plasma channels', P. Sprangle, J. R. Pe±ano, B. Hafizi,, R. F. Hubbard, A. Ting, D. F. Gordon, A. Zigler, and T. M. Antonsen, Jr., Phys. Plasmas 9, 2364 (2002)

'Resonant self-trapping of high intensity Bessel beams in underdense plasmas', J. Fan, E. Parra, K. Y. Kim, I. Alexeev, H. M. Milchberg, J. Cooley, and T. M. Antonsen, Phys. Rev. E 65, 056408 (2002)

'Parametric Instability in the Formation of Plasma Waveguides', J. Cooley, T. Antonsen, H. Milchberg, J. Fan, E. Parra , L. Margolin, L. Pyatnitskii,, Submitted to Phys Rev. Lett.

Publications 2003

'Laser pulse splitting and trapping in tenuous gases', JZ Wu and TM Antonsen, PHYS PLASMAS 10 (6): 2254-2266 JUN 2003.

'Self-focusing of intense laser pulses in a clustered gas', I. Alexeev, TM Antonsen KY. Kim and HM Milchberg,, PHYS REV LETT 90 (10): Art. No. 103402 MAR 14 2003

Presentations 2000

'Generation of Axially Modulated Plasma Channels' J. Cooley, T. M. Antonsen Jr. and H. Milchberg, Presented at the Anomalous Absorption Conference, Ocean City Maryland June 2000.
'Guiding and High-Harmonic Generation of High Intensity Laser Pulses in a
Capillary', Zhigang Bian, Thomas Antonsen, Patrick Mora (Ecole Polytechnique, 91128 Palaiseau, France) [UP1.060] , Division of Plasma Physics of the APS, Oct. 26, 2000.
'Evaluation of Axially Modulations in Plasma Channels', James Cooley, Thomas Antonsen, Howard Milchberg, Jay Fan, Enrique Parra (The University of Maryland at College Park, MD 20742) [MP1.063] Division of Plasma Physics of the APS, Oct. 26, 2000.
'Generation of Axially Modulated Plasma Channels"
Lasers-2000, Albuquerque NM, Dec. 5, 2000.

'Simulations of LWFA', SNOWMASS2001, Snowmass Colorado, July 2001
'Quasi-Static PIC: Wake', SNOWMASS2001, Snowmass Colorado, July 2001

Training and Development:

1. This project along with a related one funded by the Department of Energy support the graduate education of three students who learn basic science as well as the techniques of computer simulation. One students who is about to comlete his Ph. D. has aquired a position with Lucent.

Outreach Activities:

In February 2002 I delivered a lecture at North Bethesda Middle School to a group of students participating in a Science Fair. The subject of the lecture was holograms, and it included a number of demonstrations of lasers, interference and holographic images.

For the years 2001, 2002, and 2003 I served as a judge at the Beverley Farms Elementary School science fair. Duties included interviewing students about there investigations and making awards.

Journal Publications

T. Taguchi, T. Antonsen Jr., C. S. Liu , Kunioki Mima, "'Structure Formation and Tearing of an MeV Cylindrical Electron Beam in a Laser Produced Plasma'", Physical Review Letters, p. 5055, vol. 86, (2001). Published

P.Sprangle, B. Hafizi, J. R. Peanno, T. M. Antonsen Jr., "'Stable laser-pulse propagation in plasma channels for GeV electron acceleration'", Physical Review Letters, p. 5150, vol. 85, (2000). Published

Z. Bian and T. M. Antonsen Jr., "'Ionization Instabilities of an Electromagnetic Wave Propagating in a Tenuous'", Physics of Plasmas, p. 3183, vol. 8, (2001). Published

', P. Sprangle, B. Hafizi, J. R. Pe±ano, R. F. Hubbard, A. Ting, C. I. Moore, D. F. Gordon, A. Zigler, D. Kaganovich, and T. M. Antonsen,Jr, "'Wakefield generation and GeV acceleration in tapered plasma channels'", Physical Review E, p. 056405, vol. E 63, (2001). Published

' C. Ren, BJ Duda, RG Hemker, W. Mori, T. Katsouleas, T. M. Antonsen, Jr., and P. Mora, "'Compressing and focusing a short laser pulse by a thin plasma lens'", Physical review E, p. 6302, vol. E63, (2001). Published

P. Sprangle, J. R. Pe±ano, B. Hafizi,, R. F. Hubbard, A. Ting, D. F. Gordon, A. Zigler, and T. M. Antonsen, Jr.,, ""GeV acceleration in tapered plasma channels"", Physics of Plasmas, p. 2364, vol. 9, (2002). Published

J. Fan, E. Parra, K. Y. Kim, I. Alexeev, H. M. Milchberg, J. Cooley, and T. M. Antonsen,, "
"Resonant self-trapping of high intensity Bessel beams in
underdense plasmas"", Physical Review E, p. 056408, vol. E65, (2002). Published

J. Cooley, T. Antonsen, H. Milchberg, J. Fan, E. Parra , L. Margolin, L. Pyatnitskii,, ""Parametric Instability in the Formation of Plasma Waveguides"", Physical Review Letters, p. , vol. , ( ). Submitted

JZ Wu and TM Antonsen, "Laser pulse splitting and trapping in tenuous gases", PHYS PLASMAS

, p. 2254, vol. 10, (2003). Published

I. Alexeev, TM Antonsen KY. Kim and HM Milchberg, "Self-focusing of intense laser pulses in a clustered gas", Phys Rev. lett., p. 103402, vol. 90, (2003). Published

Books or Other One-time Publications

Web/Internet Site

URL(s):

Description:

Other Specific Products

Contributions

Contributions within Discipline:

1. The simulation code WAKE is now used by anumber of research groups to simulate short intense laser pulse propagation in gasses and plasmas.

Contributions to Other Disciplines:

The quasi-static algorithm developed for the laser propagation code WAKE has also been employed in codes developed by the PI for the simulation of high power electron beam driven microwave sources. These codes are being used by the US Vacuum Electronic industry to design sources for radar, communistions and particle accelerators.

Contributions to Human Resource Development:

Material from our research has already been incorporated the graduate introductory course on plasma physics (PHYS761) which was taught by the PI in the Fall of 2002, and will be taught by the PI in the Fall of 2004. In addition the PI taught an honors undergraduate course on electromagnetic wave propagation (ENEE381H) in the spring of 2003, and used examples from his research to motivate students to learn the subject. That course had the highest student evaluation scores in the college of Engineering for that semester.

Contributions to Resources for Research and Education:

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Contributions Beyond Science and Engineering:

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Categories for which nothing is reported:

Organizational Partners

Any Book

Any Product