

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED <b>FINAL REPORT 01 Jan 92 - 31 Dec 95</b>	
4. TITLE AND SUBTITLE <b>INTENSE XUV AND X-RAY RADIATION SOURCES</b>		5. FUNDING NUMBERS  <b>61102F 2301/BS</b>	
6. AUTHOR(S)  <b>Professor McIlrath</b>		<b>AFOSR-TR-96</b> <b>0284</b>	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  <b>Institute for Physical Science and Technology University of Maryland at College Park College Park, Maryland 20742-2431</b>			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  <b>AFOSR/NE 110 Duncan Avenue Suite B115 Bolling AFB DC 20332-0001</b>		10. SPONSORING/MONITORING AGENCY REPORT NUMBER  <b>F49620-92-J-0059</b>	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT  <b>APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED</b>		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  <b>In collaboration with Bell Laboratories, we developed a model for the ATI photoelectron spectra of argon using 200 fs pulses of UV (308nm), radiation. These spectra provide the first identification of ATI from levels which are Stark shifted by values significantly different from the free-electron ponderomotive shifts. Using this model, we were able to show the consistency of the photoelectron spectra with spectra obtained elsewhere which indicated substantial residual population of excited states following ATI ionization. We also investigated the ATI of N2 and were the first group to understand this process in detail in a diatomic molecule. At the Univ of Maryland, our work on the first ever channeling of intense laser pulses, demonstrated in the late 1993, continued with the discovery that the intense light propagates as waveguide modes (i.e., we actually observe electromagnetic propagation eigenmodes) at intensities more than 10<sup>8</sup> times beyond the destruction limit of a regular silica-based optical fibre. That is, we demonstrated control the dynamically evolving waveguide to provide single mode (near-Gaussian) or multi-mode propagation. We also showed that the guide mode structure is</b>			
14. independent of the wavelength of light propagating in it.			5
17. SECURITY CLASSIFICATION OF REPORT <b>UNCLASSIFIED</b>		18. SECURITY CLASSIFICATION OF THIS PAGE <b>UNCLASSIFIED</b>	16. PRICE CODE
19. SECURITY CLASSIFICATION OF ABSTRACT <b>UNCLASSIFIED</b>		20. LIMITATION OF ABSTRACT	

19960617 129

## Final Technical Report

AFOSR grant F49620-92-J-0059, *Intense XUV and X-ray Radiation Sources*  
For the grant period ending December 31, 1995

In collaboration with Bell Laboratories, we developed a model for the ATI photoelectron spectra of argon using 200 fs pulses of UV (308nm), radiation. These spectra provide the first identification of ATI from levels which are Stark shifted by values significantly different from the free-electron ponderomotive shifts. Using this model, we were able to show the consistency of the photoelectron spectra with spectra obtained elsewhere which indicated substantial residual population in excited states following ATI ionization. We also investigated the ATI of  $N_2$  and were the first group to understand this process in detail in a diatomic molecule.

In parallel, the high-energy (50 mJ) short pulse laser system constructed at AT&T Bell Laboratories was used in an attempt to achieve extremely short wavelength lasing along the ideas introduced in 1967 by Duguay, ie. X-ray pumping of sodium vapor to produce a transient inversion. Preliminary observations of VUV lasing were made in Xe and the postdoctoral associate at the time, David Douglas, assembled the apparatus for studies of sodium. In preparation for injection of an x-ray inverted medium with high order harmonics, his postdoctoral replacement, Dan Mittleman, investigated harmonic generation in the tight focusing limit in backfilled chambers. These studies were the first to experimentally show the effect of atomic structure on the phase matching of high order harmonics.

At the University of Maryland, our work on the first ever channeling of intense laser pulses, demonstrated in late 1993, continued with the discovery that the intense light propagates as waveguide modes (ie. we actually observe electromagnetic propagation eigenmodes) at intensities more than  $10^8$  times beyond the destruction limit of a regular silica-based optical fibre. That is, we demonstrated control the dynamically evolving waveguide to provide single mode (near-Gaussian) or multi-mode propagation. We also showed that the guide mode structure is independent of the wavelength of light propagating in it. This is a special property of a plasma waveguide. These properties are greatly fortuitous for the phase matching of highly nonperturbative nonlinear optical processes, and producing an extremely short wavelength fibre laser (ie. which doesn't need end mirrors since the waveguide determines the transverse mode structure). These experiments are currently taking place in our original lab. Our experiments have generated worldwide interest, and were most recently described in the Washington Post in September 1995.

In a new laboratory across the hall, we are nearing completion of a Ti:Sapphire laser system which will be capable of producing ultrahigh intensities (up to  $3 \times 10^{18}$  W/cm<sup>2</sup>). At  $10^{18}$  W/cm<sup>2</sup>, the electron quiver velocity is relativistic. At present, the oscillator is operating with pulsewidths  $30 \times 10^{-15}$  sec (or 30 fs), and we have amplified through the first

two stages of amplification to  $\sim 50 \text{ mJ}$  (currently giving intensities of almost  $10^{18} \text{ W/cm}^2$ , 1000 times higher than possible in our original lab). Using this new laser, we plan to construct a 1 GeV/cm electron accelerator using the waveguiding properties of our plasma channels. This will be a milestone in accelerator science.

### Patent

*A High Intensity Optical through X-ray Waveguide and its Applications*, U.S. Patent 5,394,411, issued 28 February 1995. (H.M. Milchberg and C.G. Durfee)

### 1995 Publications - University of Maryland

*Development of a Plasma Waveguide for High Intensity Laser Pulses*

C.G. Durfee III, J. Lynch, and H.M. Milchberg  
Phys. Rev. E **51**, 2368 (1995).

*Application of a Plasma Waveguide to Soft X-ray Lasers*

H.M. Milchberg, C.G. Durfee III, and J. Lynch  
J. Opt. Soc. Am. B **12**, 731 (1995).

*Mode Control in a two-pulse excited plasma waveguide*

C.G. Durfee III, T. R. Clark, and H.M. Milchberg  
J. Opt. Soc. Am. B **13**, 59 (1996).

*High Order Frequency Conversion in the Plasma Waveguide*

H.M. Milchberg, C.G. Durfee III, and T.J. McIlrath  
Phys. Rev. Lett. **75**, 2494 (1995).

*Mode-selective coupling to the plasma waveguide*

C.G. Durfee III, T. R. Clark, and H.M. Milchberg  
submitted to Phys. Rev. Lett., July 1995

### Invited Talks

1. *Optical Guiding of Ultra-intense Laser Pulses*

Physics Colloquium, American University, Washington, DC, Feb. 23, 1995 (1 hr.)

2. *Development and Applications of a plasma waveguide for high intensity laser pulses*

Applied Physics colloquium, Columbia University, New York, NY, April 14, 1995 (1 hr.)

3. *Development and Applications of a plasma waveguide for high intensity laser pulses*

Electrical engineering seminar, University of Michigan, Ann Arbor MI, April 27, 1995 (1 hr.)

4. *Channel Guided Lasers for Plasma Accelerators*

Particle Accelerator Conference PAC '95, Dallas TX, May 3, 1995. (30 min.)

5. *Applications of a plasma waveguide for intense laser pulses*

Canadian Association of Physicists 50 Anniversary Congress, Quebec City, 14 June, 1995 (30 min.)

6. *Soft X-ray Fibre Laser*

SPIE meeting on "Soft X-ray lasers and applications, San Diego, CA, 11 July 1995 (30 min.)

7. *Development and applications of a plasma waveguide for high intensity laser pulses*

Euroconference on "Generation and Application of Ultrashort X-ray pulses, Pisa, Italy, Sept. 22, 1995 (1 hr.)

8. *High intensity optical and X-ray pulse propagation in plasma waveguides*

American Physical Society Division of Plasma Physics meeting, Louisville, KY, Nov. 1995 (30 min.)