



Imaging Under Extreme Conditions

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CALIFORNIA INSTITUTE OF TECHNOLOGY

07/28/2015
Final Report

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REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 22-07-2015		2. REPORT TYPE Final		3. DATES COVERED (From - To) May 2011 - May 2015	
4. TITLE AND SUBTITLE Imaging Under Extreme Conditions				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER FA9550-11-1-0055	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Zewail, Ahmed, H., Dr.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of Technology (Caltech) 1200 East California Blvd. M/C 127-72 Pasadena, CA 91125				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research 875 North Randolph Street Suite 325, Room 3112 Arlington, VA 22203				10. SPONSOR/MONITOR'S ACRONYM(S) AFOSR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution Statement A: Approved for Public Release.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The study of materials and their surfaces under extreme conditions is fundamental to their functions and to control of properties. In order to visualize the changes in the structure, we have advanced ultrafast electron microscopy (and diffraction) to a new level. The electron pulses typically have an energy of 30 keV for diffraction and 100-200 keV for microscopy, corresponding to speeds of 33-70% of the speed of light. The atomic-scale resolution is achieved with a time resolution of femtoseconds, as reported in the publications; attosecond resolution has also been described therein. Such attosecond electron pulses are significantly shorter than those achievable with extreme UV light sources near 25 nm (~50 eV) and have the potential for applications in the visualization of ultrafast electron dynamics.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 2	19a. NAME OF RESPONSIBLE PERSON Dr. Ahmed H. Zewail
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) 626-395-6536

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From: Professor Ahmed Zewail, Caltech

Contract/Grant Title: Imaging Under Extreme Conditions
Contract/Grant #: FA9550-11-1-0055
Reporting Period: 15 May 2011 to 14 May 2015

Annual Accomplishments:

The study of materials and their surfaces under extreme conditions is fundamental to their functions and to control of properties. In order to visualize the changes in the structure, we have advanced ultrafast electron microscopy (and diffraction) to a new level. The electron pulses typically have an energy of 30 keV for diffraction and 100-200 keV for microscopy, corresponding to speeds of 33-70% of the speed of light. The atomic-scale resolution is achieved with a time resolution of femtoseconds, as reported in the publications; attosecond resolution has also been described therein. Such attosecond electron pulses are significantly shorter than those achievable with extreme UV light sources near 25 nm (~50 eV) and have the potential for applications in the visualization of ultrafast electron dynamics.

A number of variant techniques of 4D Ultrafast Electron Microscopy (UEM) imaging have been reported including 4D tomography, sub-particle imaging, electron energy-loss spectroscopy, and photon-induced near-field microscopy, the PINEM effect. Publications of research at Caltech were reported in *Science*, *Nature*, *JACS*, *JPC*, *ChemPhysChem*, *PNAS*, *Nano Lett.*, and *Angewandte Chemie*.

The applications of 4D UEM (and diffraction) are numerous, and we have successfully reported, using direct imaging, the atomic-scale of molecular nanocrystals, the phase transition in metal-insulator transitions, the embryonic crystallization following extreme melting, the discovery of nanogating in quasi-1D materials, and the nature of interface electric fields for free nanoparticles and nanoparticles on surfaces. We also reported on the theoretical foundation for the phenomena, and research continues in these new directions. Recent highlights are published as overviews and reviews in *Science* (Review), *Accounts of Chemical Research* (Review), *Scientific American*, and in a book.

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- 1) A. Yurtsever and A. H. Zewail, "Kikuchi Ultrafast Nanodiffraction in Four-Dimensional Electron Microscopy," *Proc. Natl. Acad. Sci. U.S.A.* **108**, 3152 (2011).
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- 6) O. F. Mohammed, D.-S. Yang, S. K. Pal, and A. H. Zewail, "4D Scanning Ultrafast Electron Microscopy: Visualization of Materials Surface Dynamics," *J. Am. Chem. Soc.* **133**, 7708 (2011).
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- 9) S. Schafer, W. Liang, and A. H. Zewail, "Structural Dynamics of Surfaces by Ultrafast Electron Crystallography: Experimental and Multiple Scattering Theory," *J. Chem. Phys.* **135**, 214201 (2011).
- 10) S. T. Park and A. H. Zewail, "Enhancing Image Contrast and Slicing Electron Pulses in 4D Near Field Electron Microscopy," *Chem. Phys. Lett.* **521**, 1 (2012).
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- 6) A. H. Zewail, "4D Visualization of Matter," Imperial College Press, London (2014).

Changes in Research Objectives, if any: None.

Change in AFOSR Program Manager, if any: None.

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The full title of the funded effort.

Imaging Under Extreme Conditions.

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AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-11-1-0055

Principal Investigator Name

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Professor Ahmed H. Zewail

Program Manager

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Dr. Michael Berman

Reporting Period Start Date

05/15/2011

Reporting Period End Date

05/14/2015

Abstract

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- 6) A. H. Zewail, "4D Visualization of Matter," Imperial College Press, London (2014).

Changes in research objectives (if any):

None.

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None.

Extensions granted or milestones slipped, if any:

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Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

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