Imaging Under Extreme Conditions

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CALIFORNIA INSTITUTE OF TECHNOLOGY

07/28/2015
Final Report

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**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.

**SUBJECT TERMS**

- Imaging Under Extreme Conditions
- Extreme Conditions
- Electron Microscopy
- Attosecond Pulses
- Ultrafast Dynamics
- Femtosecond Resolution
INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

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4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

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5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

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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.

Archival Publications (published) during reporting period:


Some Recent Reviews & Books:


**Changes in Research Objectives, if any:** None.

**Change in AFOSR Program Manager, if any:** None.

**Extensions granted or milestones slipped, if any:** None.
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### Primary Contact Phone Number

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### Organization / Institution name

California Institute of Technology (Caltech)

### Grant/Contract Title

The full title of the funded effort.

Imaging Under Extreme Conditions.

### Grant/Contract Number

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

FA9550-11-1-0055

### Principal Investigator Name

The full name of the principal investigator on the grant or contract.

Professor Ahmed H. Zewail

### Program Manager

The AFOSR Program Manager currently assigned to the award

Dr. Michael Berman

### Reporting Period Start Date

05/15/2011

### Reporting Period End Date

05/14/2015

### 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.

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AFOSR LRIR Number

LRIR Title
Reporting Period
Laboratory Task Manager
Program Officer
Research Objectives
Technical Summary
Funding Summary by Cost Category (by FY, $K)

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