



## **Nonlinear Optics at the U.S. Army Research Laboratory's Weapons and Materials Research Directorate**

**by Anthony Valenzuela, Andrew Porwitzky, and Chase Munson**

ARL-SR-222

March 2011

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Weapons and Materials Research Directorate, ARL**

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                             |                              |                                         | Form Approved<br>OMB No. 0704-0188                          |                                                           |
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| 14. ABSTRACT<br>We provide an overview of efforts and interest in studying directed energy and ultrashort pulse lasers in the U.S. Army Research Laboratory's Weapons and Materials Research Directorate (WMRD). WMRD's interest in nonlinear optics lies primarily in target effects of filaments impacting on solid surfaces. In addition, we are keenly interested in on-going work in the theory and modeling of the basic physical understanding of propagation through atmosphere and particulates.                                                                                                                                                                                                                                                                                                                                                                                                                                                |                             |                              |                                         |                                                             |                                                           |
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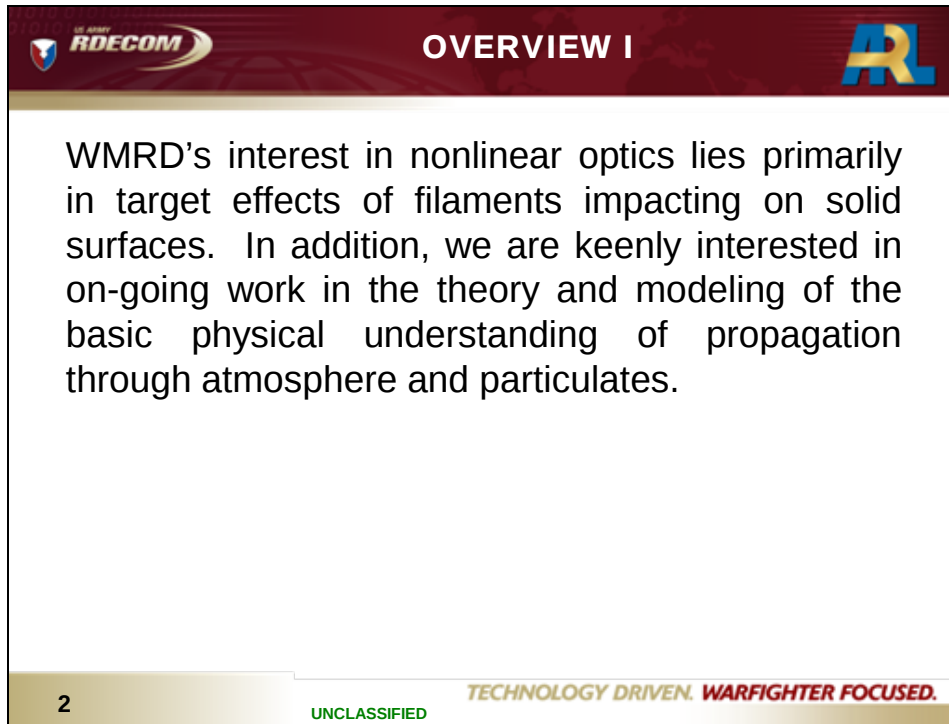
## 1. Introduction

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The following slides were presented at the Nonlinear Optics Meeting sponsored by the U.S. Air Force Office of Scientific Research (AFOSR) that was held at Albuquerque, NM, in September 2010. The purpose of the meeting was to act as both review of AFOSR sponsored nonlinear optics (NLO) works and also as a kick-off to the FY10 Multidisciplinary University Research Initiative “Propagation of Ultrashort Laser Pulses Through Transparent Media.” The slides are taken from a poster presented at the meeting to inform the U.S. Department of Defense (DOD) and related academic community about the NLO and ultrashort pulse laser efforts at the U.S. Army Research Laboratory’s Weapons and Materials Research Directorate. The goal is to encourage sharing of resources and establish collaborations that are mutually beneficial to the Army and DOD as well as prepare avenues for the translation of basic research to more applied research to meet protection and lethality needs.



Figure 1. Nonlinear optics at the U.S. Army Research Laboratory - Weapons and Materials Research Directorate.

The slide features a dark red header with the US Army RDECOM logo on the left, the title "OVERVIEW I" in the center, and a stylized "AR" logo on the right. The main content area is white with black text. The footer is a gold-colored bar containing the number "2", the word "UNCLASSIFIED", and the slogan "TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED." in red.

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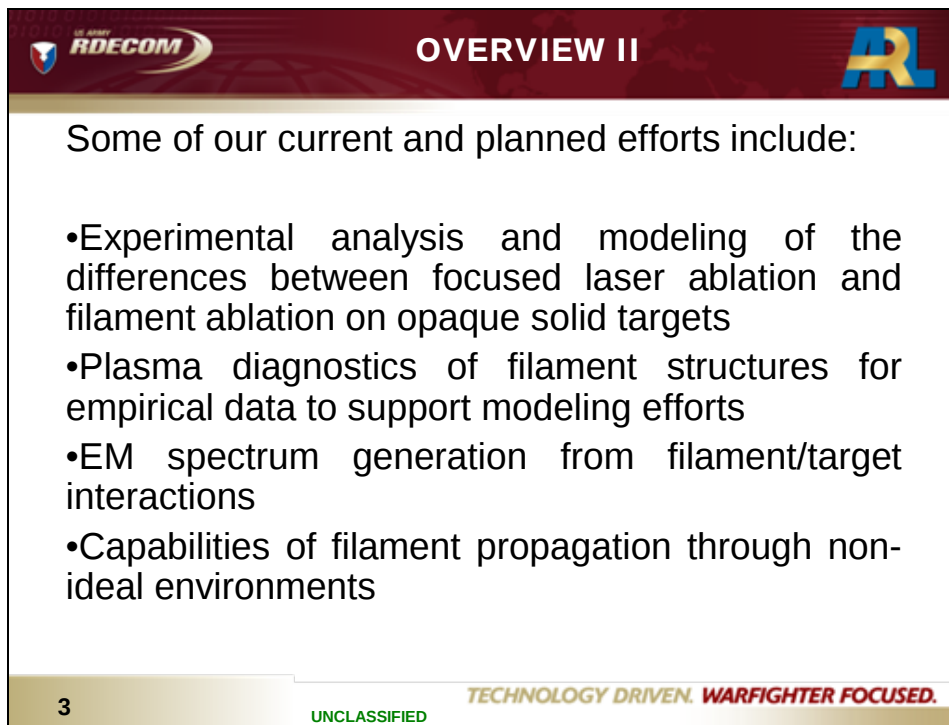
## OVERVIEW I

AR

WMRD's interest in nonlinear optics lies primarily in target effects of filaments impacting on solid surfaces. In addition, we are keenly interested in on-going work in the theory and modeling of the basic physical understanding of propagation through atmosphere and particulates.

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Figure 2. Overview I.

The slide features a dark red header with the US Army RDECOM logo on the left, the title "OVERVIEW II" in the center, and a stylized "AR" logo on the right. The main content area is white with black text, including a bulleted list. The footer is a gold-colored bar containing the number "3", the word "UNCLASSIFIED", and the slogan "TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED." in red.

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## OVERVIEW II

AR

Some of our current and planned efforts include:

- Experimental analysis and modeling of the differences between focused laser ablation and filament ablation on opaque solid targets
- Plasma diagnostics of filament structures for empirical data to support modeling efforts
- EM spectrum generation from filament/target interactions
- Capabilities of filament propagation through non-ideal environments

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Figure 3. Overview II.




## OVERVIEW III

Beyond our core mission, we are interested in advances in:

- fs laser development
- Propagation modeling
- Non-Gaussian beam dynamics
- Remote laser induced breakdown spectroscopy

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Figure 4. Overview III.




## OVERVIEW IV

Filament Effects

Opaque Media

Kevlar

Weakening

Metals

Ablation

Weakening

Detection

Plastics

Damage

Semiconductors

Damage

Transparent Media

Fused Silica

Filamentation

Obfuscation

Plastics

Obfuscation

EM Effects

EMP Generation

Electronic Disruption

Radio Interference

Waveguide

Microwaves

High Energy Lasers

Remote White Light

Guide Star

Aerosol Detection

False IR/Heat Signature

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Figure 5. Overview IV.

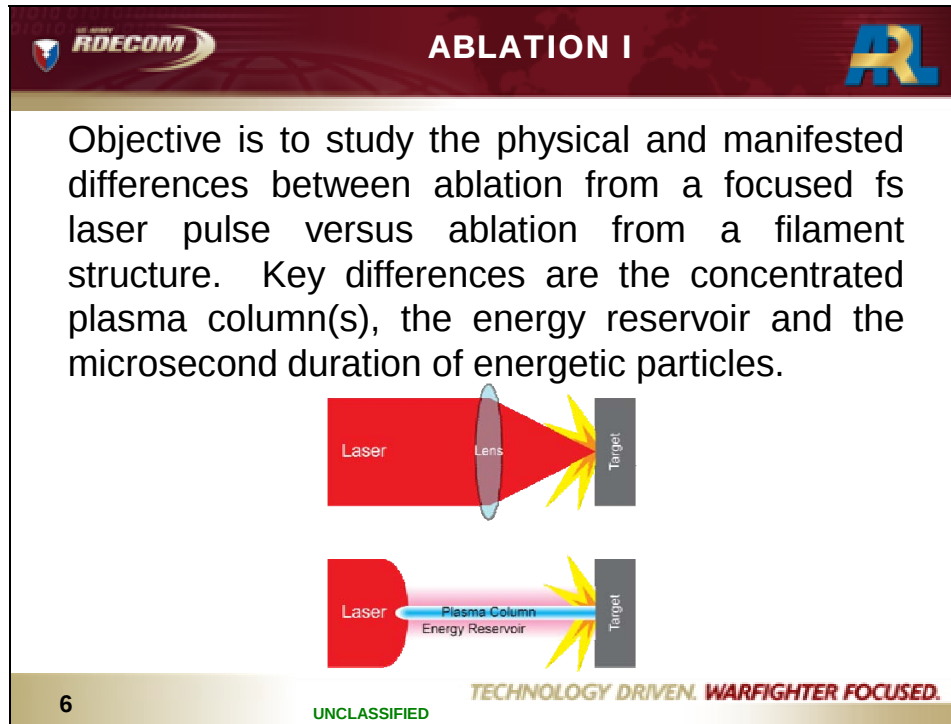


Figure 6. Ablation I.

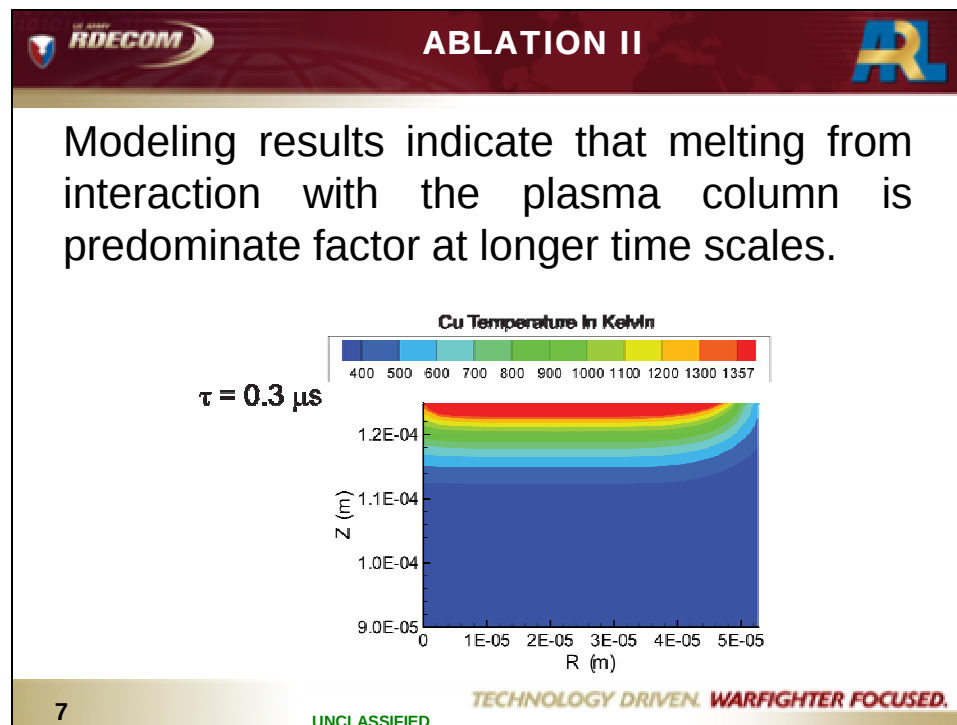
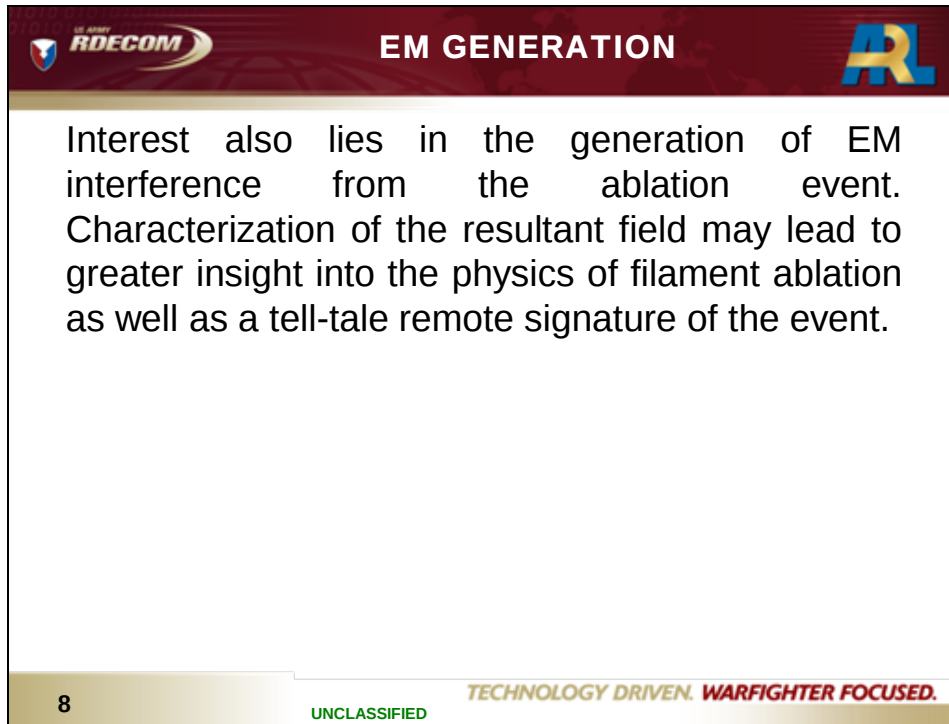


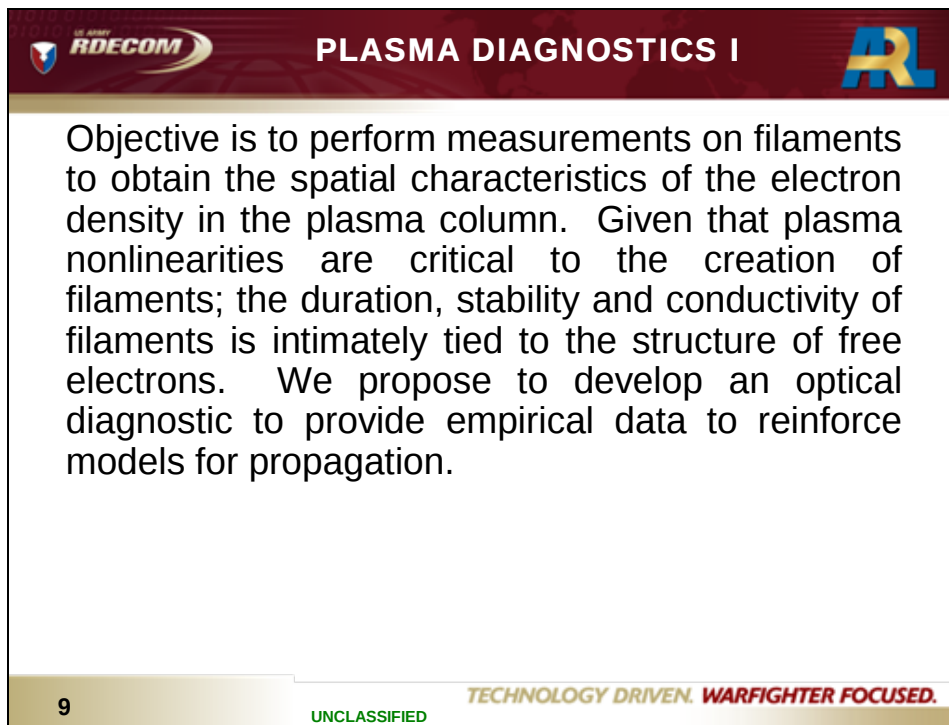
Figure 7. Ablation II.



Interest also lies in the generation of EM interference from the ablation event. Characterization of the resultant field may lead to greater insight into the physics of filament ablation as well as a tell-tale remote signature of the event.

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Figure 8. EM generation.



Objective is to perform measurements on filaments to obtain the spatial characteristics of the electron density in the plasma column. Given that plasma nonlinearities are critical to the creation of filaments; the duration, stability and conductivity of filaments is intimately tied to the structure of free electrons. We propose to develop an optical diagnostic to provide empirical data to reinforce models for propagation.

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Figure 9. Plasma diagnostics I.

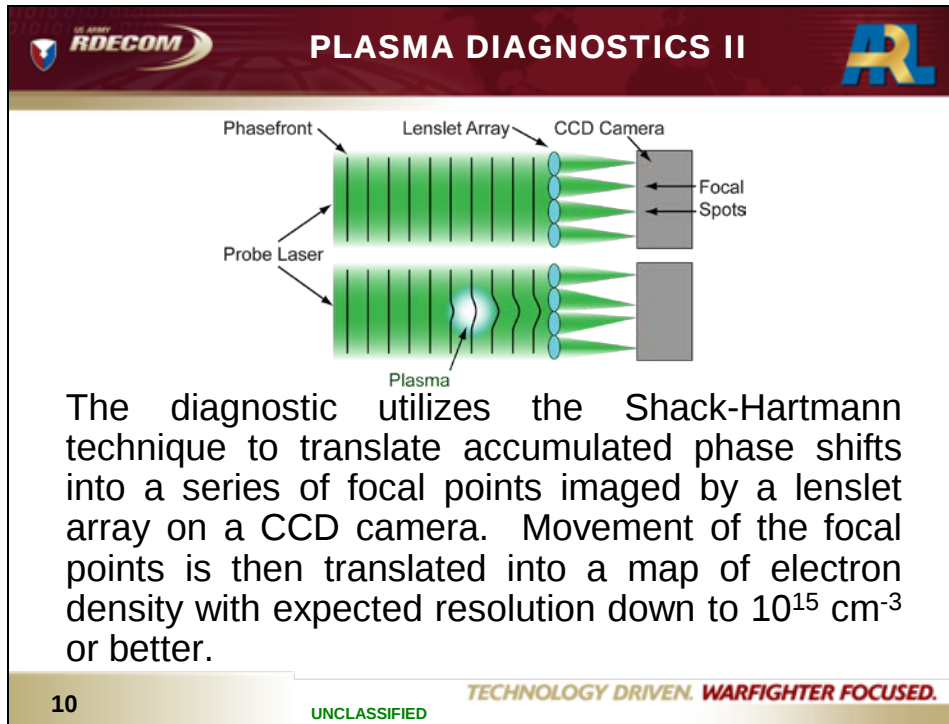


Figure 10. Plasma diagnostics II.

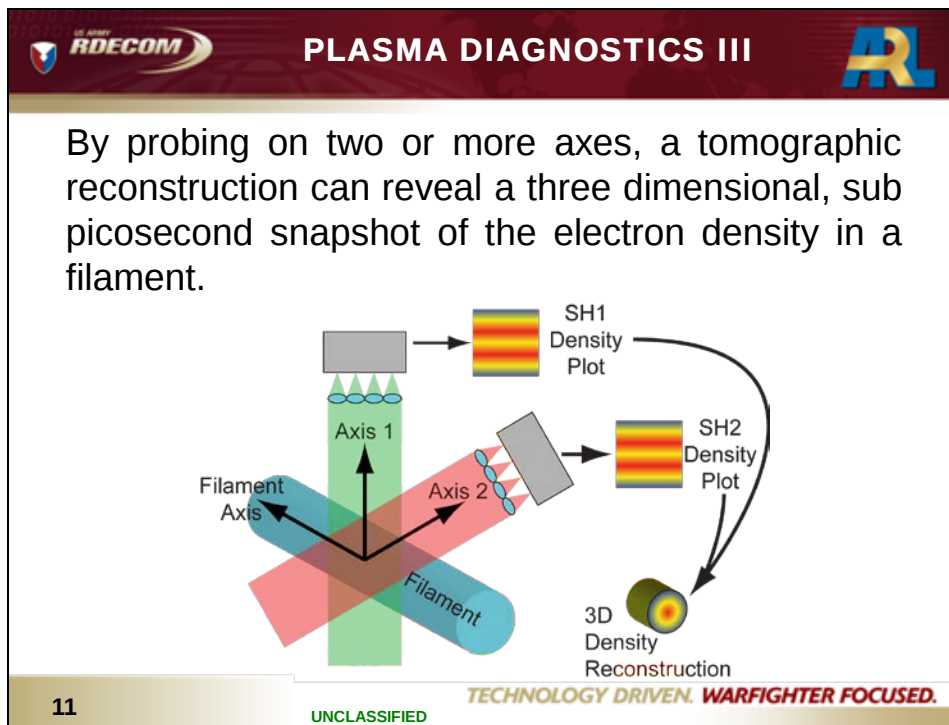
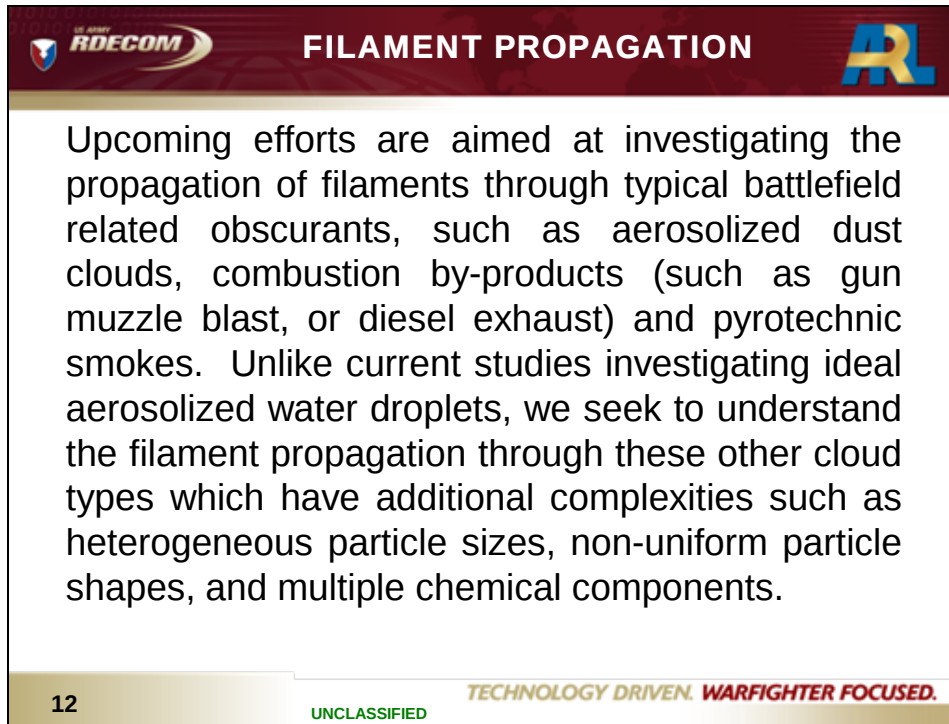


Figure 11. Plasma diagnostics III.

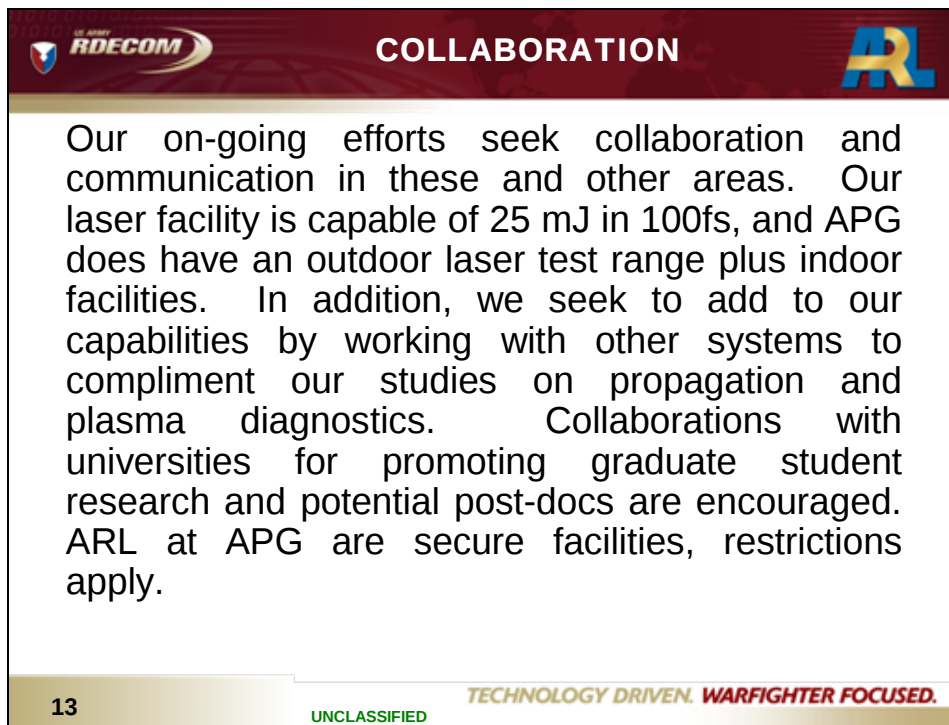


**FILAMENT PROPAGATION**

Upcoming efforts are aimed at investigating the propagation of filaments through typical battlefield related obscurants, such as aerosolized dust clouds, combustion by-products (such as gun muzzle blast, or diesel exhaust) and pyrotechnic smokes. Unlike current studies investigating ideal aerosolized water droplets, we seek to understand the filament propagation through these other cloud types which have additional complexities such as heterogeneous particle sizes, non-uniform particle shapes, and multiple chemical components.

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Figure 12. Filament propagation.



**COLLABORATION**

Our on-going efforts seek collaboration and communication in these and other areas. Our laser facility is capable of 25 mJ in 100fs, and APG does have an outdoor laser test range plus indoor facilities. In addition, we seek to add to our capabilities by working with other systems to compliment our studies on propagation and plasma diagnostics. Collaborations with universities for promoting graduate student research and potential post-docs are encouraged. ARL at APG are secure facilities, restrictions apply.

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Figure 13. Collaboration.




CONTACT INFO

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Figure 14. Contact information.




ORIGINAL POSTER



Nonlinear Optics at the US Army Research Laboratory  
Weapons & Materials Research Directorate

Anthony Valenzuela, Andrew Poratitzky, Chase Munson

### OVERVIEW

WMD's interest in nonlinear optics has primarily in target effects of filaments impacting on solid surfaces. In addition, we are seeing interest in on-going work in the theory and modeling of the basic physical understanding of propagation through atmosphere and particulates. Some of our current and planned efforts include:

- Experimental analysis and modeling of the differences between focused laser ablation and filament ablation on opaque solid targets
- Plasma diagnostics of filament structures for empirical data to support modeling efforts
- EM spectrum generation from filament/target interactions
- Capabilities of filament propagation through individual environments

Beyond our core mission, we are interested in advances in:

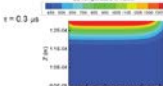
- As laser development
- Propagation modeling
- Non-Gaussian beam dynamics
- Remotely laser induced breakdown spectroscopy

### ABLATION

Objective is to study the physical and manifested differences between ablation from a focused laser pulse versus ablation from a filament structure. Key differences are the concentrated plasma column(s), the energy reservoir and the microsecond duration of energetic particles.



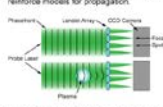
Modeling results indicate that melting from interaction with the plasma column is predominantly faster at longer time scales.



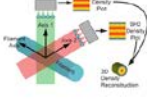
$\tau \approx 0.3 \mu s$

### PLASMA DIAGNOSTICS

Objective is to perform measurements on filaments to obtain the spatial characteristics of the electron density in the plasma column. Given that plasma nonlinearities are critical to the creation of filaments, the duration, stability and conductivity of filaments is intimately tied to the structure of free electrons. We propose to develop an optical diagnostic to provide empirical data to reinforce models for propagation.



The diagnostic utilizes the Shack-Hartmann technique to translate accumulated phase shifts into a series of focal points imaged by a sensor array on a CCD camera. Movement of the focal points is then translated into a map of electron density with expected resolution down to  $10^{-4} \text{ cm}^{-3}$  or better. By probing on two or more axes, a tomographic reconstruction can reveal a three dimensional, sub picosecond snapshot of the electron density in a filament.



### FILAMENT PROPAGATION

Ongoing efforts are aimed at investigating the propagation of filaments through typical battlefield related obscuration, such as aerosolized dust clouds, combustion by-products (such as gun muzzle blast or diesel exhaust) and pyrotechnic smokes. Unlike current studies investigating ideal aerosolized water droplets, we seek to understand the filament propagation through these other cloud types which have additional complexities such as heterogeneous particle sizes, nonuniform particle shapes, and multiple chemical components.

### COLLABORATION

Our on-going efforts seek collaboration and communication in these and other areas. Our laser facility is capable of 25 mJ in 1053 nm, and APLG does have an outdoor laser test range plus indoor facilities. In addition, we seek to add to our capabilities by working with other systems to complement our studies on propagation and plasma diagnostics. Collaborations with universities for promoting graduate student research and potential post-docs are encouraged. ARL at APG are secure facilities, restrictions apply.

### EM GENERATION

Interest also lies in the generation of EM interference from the ablation event. Characterization of the resultant field may lead to greater insight into the physics of filament ablation as well as a reliable remote signature of the event.

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Figure 15. Original poster.

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