Contract No:

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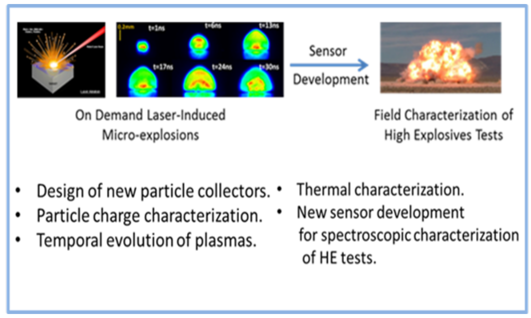
Characterization of HE Detonations Via Laser-Induced Plasmas



One objective of the Department of Energy's National Security Administration is to develop technologies that can help the United States government to detect foreign nuclear weapons development activities. The realm of high explosive (HE) experiments is one of the key areas to assess the nuclear ambitions of a country. SRNL has participated in the collection of particulates from HE experiments and characterized the material with the purpose to correlate particulate matter with HE. Since these field campaigns are expensive, on-demand simulated laboratory-scale explosion experiments are needed to further our knowledge of the chemistry and particle formation in the process. Our goal is to develop an experimental test bed in the laboratory to test measurement concepts and correlate particle formation processes with the observables from the detonation fireball. The final objective is to use this knowledge to tailor our experimental setups in future field campaigns. The test bed uses pulsed laser-induced plasmas to simulate micro-explosions, with the intent to study the temporal behavior of the fireball observed in field tests. During FY15, a plan was prepared and executed which assembled two laser ablation systems, procured materials for study, and tested a Step-Scan Fourier Transform Infrared Spectrometer (SS-FTIR). Designs for a shadowgraph system for shock wave analysis, design for a micro-particulate collector from ablated pulse were accomplished. A novel spectroscopic system was conceived and a prototype system built for acquisition of spectral/temporal characterization of a high speed event such as from a high explosive detonation. Experiments and analyses will continue into FY16.

Awards and Recognition

None

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publically published in its current form.

SRNL Legal Signature

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Signature **Date**

Characterization of High Explosives Detonations Via Laser-Induced Plasmas

Project Team: Eliel Villa-Aleman and William Spencer

Subcontractor:

Thrust Area: ST3

Project Type: Strategic

Project Start Date: October 1, 2014
Project End Date: September 30, 2016

SRNL has collected and analyzed particulates from the detonation of devices with high explosives (HE) since 2004. SRNL developed passive and electrostatic precipitator-based collectors (such as rockets) to collect particulates near and far away from the plumes created by the detonation of HE devices. The temporal formation of particulates and the correlation with radiant emissions are not well understood. Large field-scale experiments are expensive and infrequent. On-demand simulated laboratory-scale experiments are needed to further our knowledge of the chemistry and particle formation. Our goal is to develop a laboratory experimental test bed to develop new optical measurement and particle collection concepts and methodologies that can be used to correlate the particle formation process with the optical observables of the detonation fireball. Since handling small quantities of explosives in the laboratory is challenging, laser-induced plasmas can be used to simulate micro-explosions, with the intent to study the temporal behavior of the fireball observed in field tests. The temporal evolution of the plasma, generated with a Nd:YAG laser and conducted with different atmospheric conditions, will be probed with a variety of lasers including ultrafast lasers. These experiments will help design future equipment for large-scale HE tests to measure unique signatures of the device. Concurrently with laser probes, temporal and spectral emissions of the plasma and laser light scattering will be analyzed with high speed thermal and visible cameras.

FY2015 Objectives

- Set in motion the infrastructure in the laser laboratory to conduct work for the LDRD.
- Review scientific literature and identify requirements for the project.
- Procure equipment and materials.
- Design and develop an experimental laser ablation test bed to simulate HE detonations and the collection of particulates and development of diagnostic equipment.
- Develop a better understanding of plasma phenomena and characterization of transient and stable products.
- Track generated species in plasmas from atoms to molecules to particulates.

Introduction

The nuclear program status of a country can be defined, in part, by the types of tests conducted at different facilities. High explosive tests are used to explore materials' properties that will be used in nuclear device. These tests release effluents to the environment characteristic of a typical experiment.

SRNL has conducted particulate matter (PM) collection campaigns during cold hydrodynamic tests since 2004. Analysis of the particulate matter collected during the detonation can provide a traceable path to the unique construction of the device. Optical spectroscopic methods can help characterize materials from these detonations.

Laser ablation plasmas have been used for over 20 years to introduce material into a carrier gas for elemental analysis with mass spectrometry. Coating deposition is also another application for plasmas produced with lasers. Depending on the laser power density at the target, temperatures of several thousand degrees are common. Laser ablation plasmas can be used to simulate detonations with HE. It is the goal to use the laser generated plasma approach to understand potential observables in HE experiments. Significant progress was made in FY15 to create an experimental plan, assemble two experimental test beds, procure materials and equipment, repair instrumentation, design and fabricate fiber optics assemblies required to conduct highly advanced characterization experiments.

Approach

The proposed approach creates development test platforms to characterize atomic, molecular emissions and particulates formed from the laser ablation of several targets. During the course of this research, several tasks will be completed: 1) design and build a test bed for instrument development, 2) characterize "simulated explosions" using spectroscopy techniques and particle collection methodologies, and 3) correlate particulate formation with other observable phenomena like optical emission.

Test beds

Two laser ablations test bed systems will be assembled to characterize laser ablation plumes. One test bed will be used to conduct ultraviolet-visible-near-infrared experiments and the other test bed will be used to characterize the thermal/molecular emission and absorption in the infrared spectral region. Nd:YAG lasers, with energies up to 1 Joule, will be used to create an ablation plume from a target of a selected material. A stage with a set angular velocity will be used to provide new surface material for the ablation/plasma creation.

Spectral and Particulate Characterization

The spectral emission of the plasma will be characterized with an ICCD detector. Other spectroscopies such as absorption, laser induced luminescence, Raman spectroscopy will be used to study atomic, molecular and particle characterization. New technologies (picosecond laser with a fast gated imager) will be used for Raman characterization in the presence of high intensity luminescence. Picosecond and femtosecond lasers will be used as probe lasers of the plume.

New concepts in particulate collections will be evaluated to acquire temporal information during the coalescence of gaseous molecular species to particle formation. Particle collectors with deflectors for ionized particulates will be considered in this research. In these experiments, aluminum, steel, carbon and soil will be used to evaluate particle formation. Ablation of a depleted uranium metal target will be considered as a possible source of nanograms of material for reactions with aluminum. Several experiments will be conducted to explore the different aspects of plasma attributes. The particle research falls closely in the field of particle archaeology, in the sense that we would like to find how particle formation takes place in an explosion and how to identify its temporal evolution in order to improve our collections in the field.

These experiments conducted in the laboratory will help us evaluate future technologies that will be deployed in the field during HE experiments enabling SRNL to continue its presence in these campaigns.

Results/Discussion

The LDRD strategic project is a two year research & development work that will develop new technologies and methodologies to characterize the detonation of HE via laser-induced plasmas in the laboratory. Since solids, gases and ionized matter are present in any explosion/implosion, this research will concentrate in the characterization of materials that might be present in these devices. The scientific literature was reviewed to develop an experimental plan in order to identify measurable phenomena. Spectral emission from elemental and molecular species is critical in the analysis of laser plasmas. Spectral information might be obtained through fluorescence, laser-induced fluorescence, Raman spectroscopy and absorption spectroscopy. Particulates generated in a detonation have different sources which include spallation and particle growth from molecular gases. Temperature is also an important aspect of any given detonation. Shockwaves provide information on energy propagation. The requirements suggest developing a system that can simulate an explosion via laser-induced ablation of a target and characterization of light emission from the ultraviolet through the infrared region of the electromagnetic spectrum. Since spectral information is highly dependent on the temporal behavior, technologies are required to investigate the dependence of spectral on the temporal scale. The path forward for this project requires the assembling of a test bed system capable to produce "explosions on demand" and use the system to measure observables in laser ablation plasma to real world detonations. The following information captures some of the work conducted in FY15 in preparation to full scale experimentation in FY16.

1. Two laser ablation experimental setups were assembled to study laser generated plumes in the ultraviolet-visible-near infrared spectral region and in the mid to long-infrared spectral region.
   a. One laser ablation system was assembled with a step-scan Fourier transform infrared (SS-FTIR) spectrometer to monitor surface and gaseous molecular species with a temporal resolution of 50 nanoseconds. The performance of the ablation system was good but the SS-FTIR performed below expectations. The problem was identified as a bad connector within the spectrometer. The SS-FTIR will enable study of the temporal evolution of surface species and the oxidation of material followed by the generation of particulates.

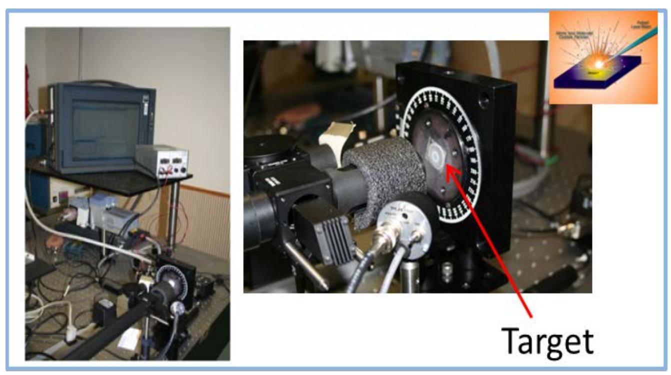

Figure 1. *Experimental laser ablation setup assembled in the laboratory for technology development.*

b. A second laser ablation experimental setup was built to study laser-induced fluorescence, particle collection and shock waves. The system performance was demonstrated with an Al target. The primary Intensified Charge Coupled Display detector (ICCD) developed timing problems and the detector with the spectrograph was sent for repairs. A more limited spectrograph was used to further demonstrate ablation and thermal emission.

Figure 2. *Experimental breadboard for temporal and spectral separation of fast phenomena.*

2. Laser ablation of aluminum and copper targets was demonstrated with both systems.
3. A picosecond gate imager was procured and will be fully operational in FY16 to study fast phenomena.
4. An ion lens kit was procured to collect particulates from laser ablation pulse. A design of the new collector is under way.
5. A new device to measure spectral information from fast phenomena was designed, built and tested in the laboratory. The concept will enable observation of the spectral evolution of an explosion or any transient phenomenon into microsecond segment intervals.

FY2015 Accomplishments

- Assembled and tested two laser ablation systems.
- Demonstrated temporal detection of light pulses with SS-FTIR.
- Developed a unique fiber optic assembly for multi-point emission characterization.
- Demonstrated the capability to measure temporally decaying spectral information.

Future Directions

- Measure the temporal IR emissivity spectra of different materials with the SS-FTIR.
- Measure Raman spectroscopy in the presence of high intensity light source with a picosecond laser coupled to a gated imager operating at 76 MHz and 250 ps.
- Build a particle collector, collect particulates and analyze with a scanning electron microscope (SEM).
- Assemble a shadowgraph system.

FY 2015 Publications/Presentations

None

References

1. None

Acronyms

HE:	High Explosives
SS-FTIR:	Step-Scan Fourier Transform Infrared Spectrometry
SEM	Scanning Electron Microscopy
Ps	Picosecond
Ns	Nanosecond

Intellectual Property

An invention disclosure on the temporal/spectral measurement of a transient phenomenon is being written.

Total Number of Post-Doctoral Researchers

None – interviews conducted in FY15, post doctoral researcher arriving Q1 – FY16.