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14. ABSTRACT
This project is funded to acquire a laser system to be used for study of physical and chemical properties of single aerosol particles trapped in air using the optical trapping-cavity ringdown spectroscopy (OT-CRDS) technique. The acquired laser system consists of a pumping laser that is an Nd:YAG laser from Continuum Lasers (USA) and a narrow linewidth dye laser from Radiant Dye Laser (Germany). The Nd:YAG pumped dye laser system has built-in second harmonic and third harmonic generations to create a UV laser beam down to 200 nm. Therefore, this laser

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Report Title

Final Report: Optical Trapping-Cavity Ringdown Spectroscopy System for Single Aerosol Particle Measurements

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This project is funded to acquire a laser system to be used for study of physical and chemical properties of single aerosol particles trapped in air using the optical trapping-cavity ringdown spectroscopy (OT-CRDS) technique. The acquired laser system consists of a pumping laser that is an Nd:YAG laser from Continuum Lasers (USA) and a narrow linewidth dye laser from Radiant Dye Laser (Germany). The Nd:YAG pumped dye laser system has built-in second harmonic and third harmonic generations to create a UV laser beam down to 200 nm. Therefore, this laser system has an overall wavelength tuning range of 200 nm – 700 nm. The laser repetition rate is 20 Hz. The laser pulse width is 7-12 ns. Single pulse energy, depending on an output wavelength, ranges from tens μJ to tens mJ. The laser linewidth is 0.08 cm-1 at 560 nm. The entire laser system has been purchased, received, installed, and tested. (See details in the technical report attached)

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

None

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 3.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachment

Technology Transfer

None

Project Final Report

Project funding program: DoD-DURIP (Defense University Research Instrumentation program), grant # W911NF-13-1-0297

Project type: Equipment acquisition

Project title: Optical Trapping-Cavity Ringdown Spectroscopy System for Single Aerosol Particle Measurements

Principal investigator: Chuji Wang

Program directors: Dr. Sandra I. Collier (current), Dr. Gorden W. Videen (previous)

Project mentor: Dr. Yongle Pan (ARL)

Project duration: 07/22/2013-11/21/2014, with a 3-month no-cost extension to 02/21/2015

ABSTRACT

This project is funded to acquire a laser system to be used for study of physical and chemical properties of single aerosol particles trapped in air using the optical trapping-cavity ringdown spectroscopy (OT-CRDS) technique. The acquired laser system consists of a pumping laser that is an Nd:YAG laser from Continuum Lasers (USA) and a narrow linewidth dye laser from Radiant Dye Laser (Germany). The Nd:YAG pumped dye laser system has built-in second harmonic and third harmonic generations to create a UV laser beam down to 200 nm. Therefore, this laser system has an overall wavelength tuning range of 200 nm – 700 nm. The laser repetition rate is 20 Hz. The laser pulse width is 7-12 ns. Single pulse energy, depending on an output wavelength, ranges from tens μJ to tens mJ. The laser linewidth is 0.08 cm^{-1} at 560 nm. The entire laser system has been purchased, received, installed, and tested. (See details below)

PROJECT ACTIVITIES

1. Acquisition of the equipment (proposed cost and expenditures)

Based on the quotation of the requested system (attached in the original proposal), the exact amount of $158,190 was requested and awarded in this proposal; and the fund was spent for the equipment purchase and for the system's shipment, installation, and training.

Benefiting from the end-year sales discount, approximately $11,000 was saved from the original budget ($158,190) for the laser equipment; and this saved money, with the approval from the funding program, was used to order a trapping laser source at the fixed wavelength of 1064 nm. This 1064-nm laser source, as a needed part, will be integrated into the optical trapping cavity ringdown system for the proposed project.

No costs occur to this grant for the corresponding accessories such as optical tables, other optics, lamps, controlling computers, etc. which are needed to operate the laser system, All of the corresponding accessories are either available in the PI's existing laboratories or have been purchased using the PI's overhead fund generated from other projects and returned from the university to the PI.

$5,000 were awarded collectively by the Office for Research and the Dean's Office at MSU to cover partial costs of the construction of a new laboratory (see below) that houses the proposed laser system. This university support and the support from the department by offering the new laboratory space were not originally proposed in the proposal. These additional supports from the university and the department further indicate the significance of this awarded DURIP project (the laser equipment) to the research infrastructure at MSU.

2. Project activities

<u>2.1 Construction of the new laboratory</u>

In order to support this DURIP project and maximize utility of the funded equipment, the Department of Physics and Astronomy has offered the PI a new laboratory space of approximately 450 ft^2 located in the besetment of Hilbun Hall. A new research laboratory will be constructed to house the new laser system. Study of physical and chemical properties of single aerosol particles trapped in air using the optical trapping-cavity ringdown spectroscopy (OT-CRDS) technique will be carried out in this laboratory. Fig. 1 shows a picture of the laboratory that was under construction. One 4x12 ft^2 and one 4x8 ft^2 optical tables were set up. Ventilation systems, gas tubing, water supplies, electricity, etc. had been constructed or modified prior to the setup of the proposed laser system. The package box shown in Fig. 1 contained the Nd:YAG laser that was received in March 2014.

Fig. 1. A new laboratory is under construction, where the proposed new laser system will be housed.

<u>2.2 Setup of the proposed laser system</u>

The Nd:YAG laser was first shipped and installed in the laboratory. The first on-site installation was carried out in May 2014. But the laser operation did not meet the specifications. The Nd:YAG was then shipped back to the manufacturer (CA, USA) for fixing. The second on-site installation and testing were carried out in Sept. 2014. Fig. 2 shows the on-site (in the laboratory) installation of the laser by the laser engineers from Continuum Lasers. The laser system was successfully installed and tested this time.

Fig. 2. On-site installation of the proposed Nd:YAG laser in the newly constructed laboratory.

The narrow linewidth dye laser was delivered on April 24, 2014 and the on-site installation was completed on Oct. 27, 2014. The on-site installation date was determined by availability of installation engineers from the vendor (Radiant Dye, Germany). Fig.3 shows operation of the dye laser.

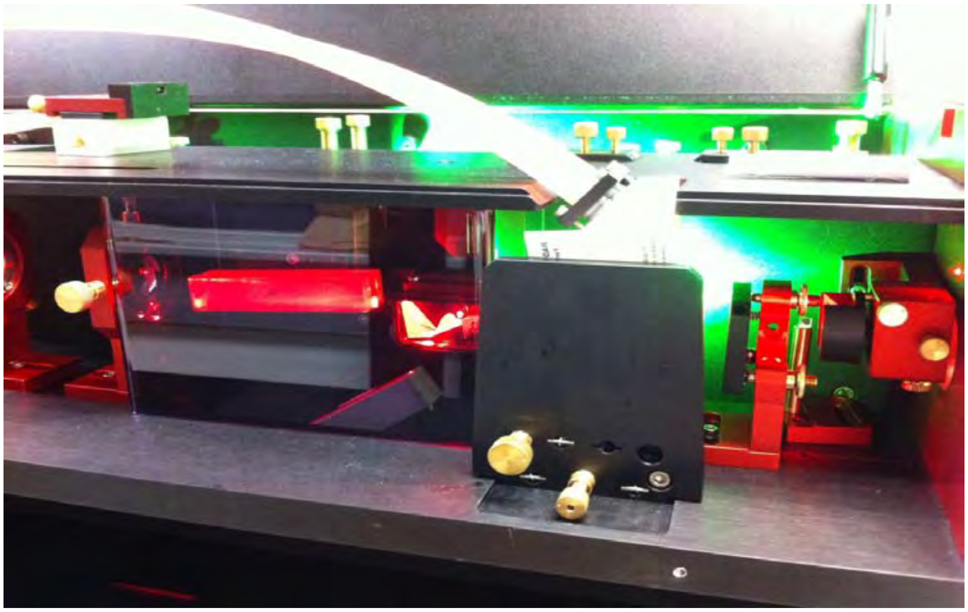


Fig. 3. Operation of the narrow linewidth (0.08 cm^{-1} at 590 nm) dye laser pumped by the Nd:YAG laser.

The leftover (~$11,000) resulting from the end-year purchase discount of the proposed equipment was used to order a compact 1064-nm laser that will be used for particle trapping. This activity was completed within the three-month period of the no-cost extension (Nov. 2014-Feb. 2015) approved by the funding program. Fig. 4 shows the operation of the near infrared 1064-nm laser. The near infrared beam spot is marked by the circle in the figure.

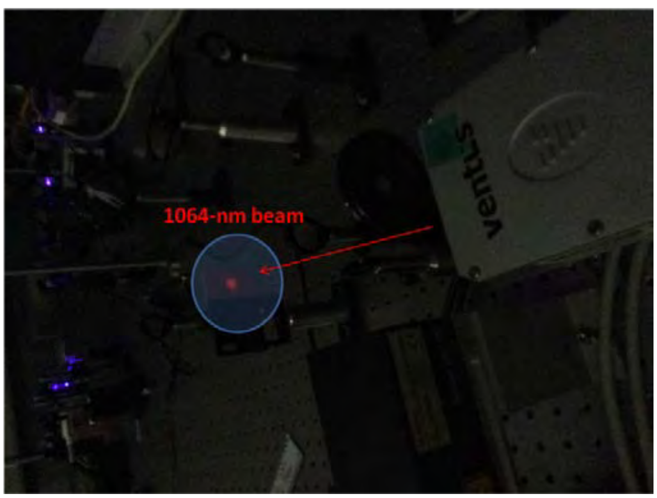
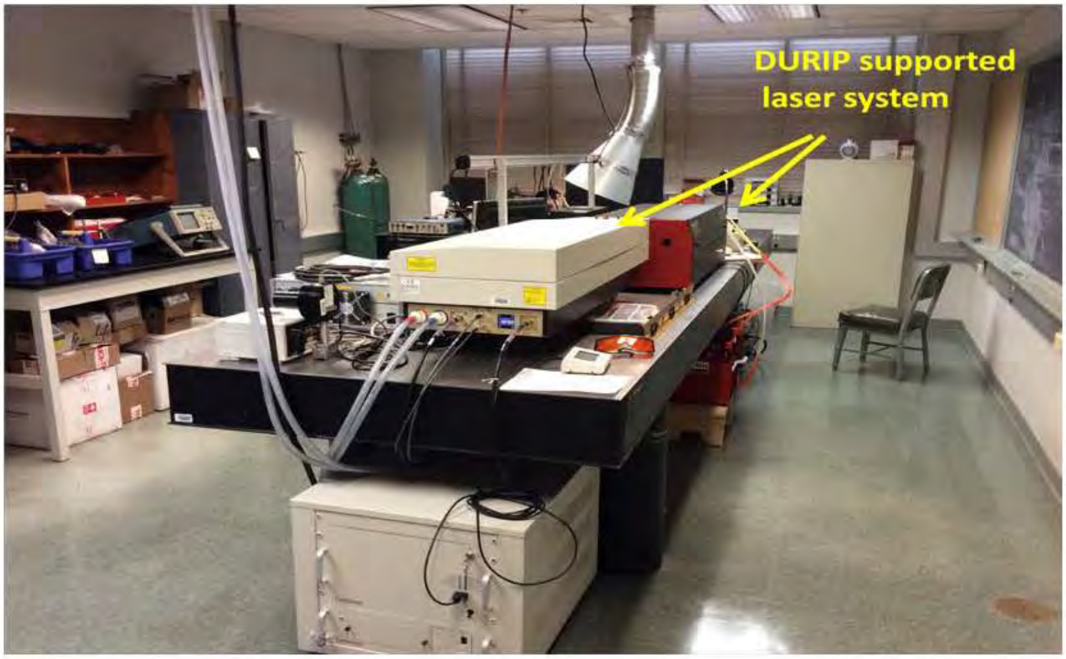


Fig. 4. Operation of the 1064-nm laser.

2.3 A new aerosol research laboratory

The proposed new laser system is fully operational and housed in the new research laboratory (R30, Hilbun Hall). Study of physical and chemical properties of single aerosol particles trapped in air using cavity ringdown spectroscopy is being carried out in this new laboratory. Fig. 4 shows a couple of pictures of the new laboratory. Currently, one PhD student, one MS student, and one undergraduate student are working in this new laboratory.



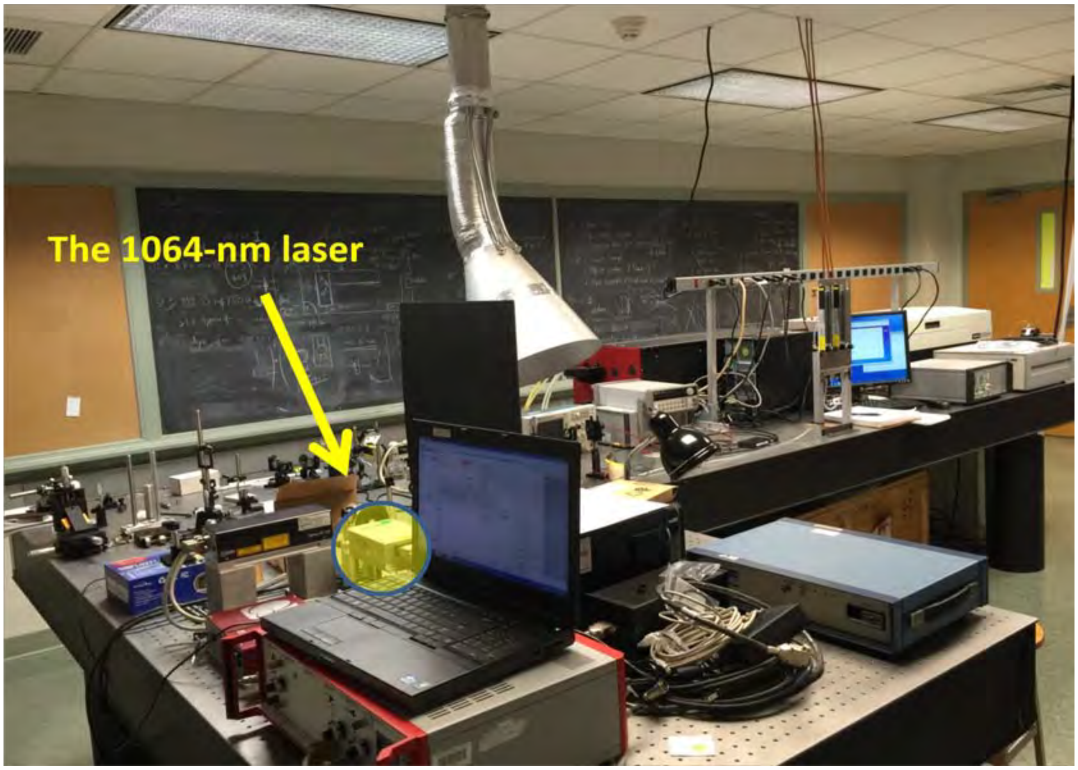


Fig. 5 The new aerosol laboratory that houses the proposed laser facility funded through this DURIP project.

3. Research activities

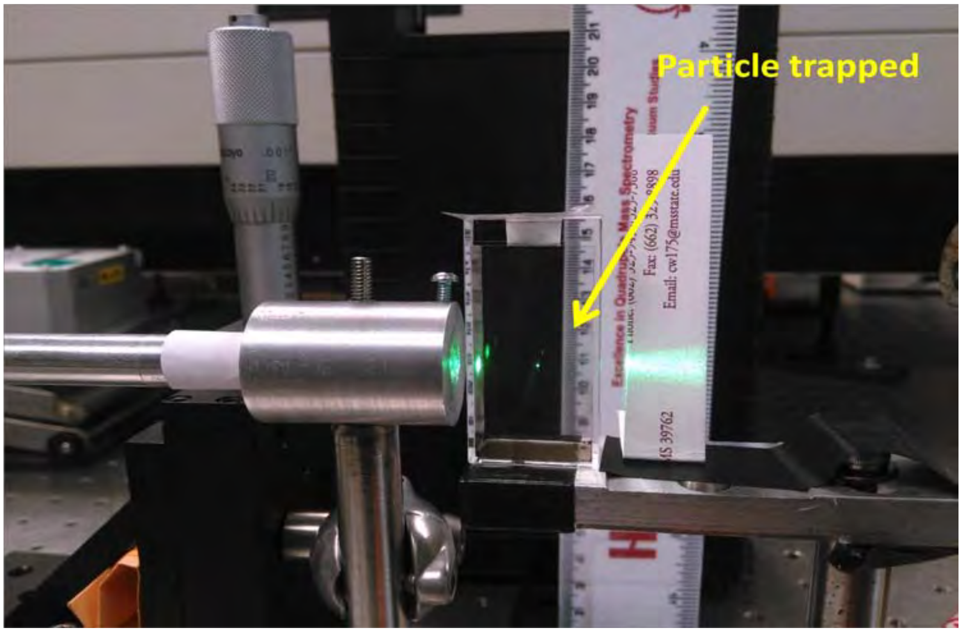
3.1 Particle trapping

This new laser system will be used to study aerosol particles using the OT-CRDS technique. The major research effort onward includes

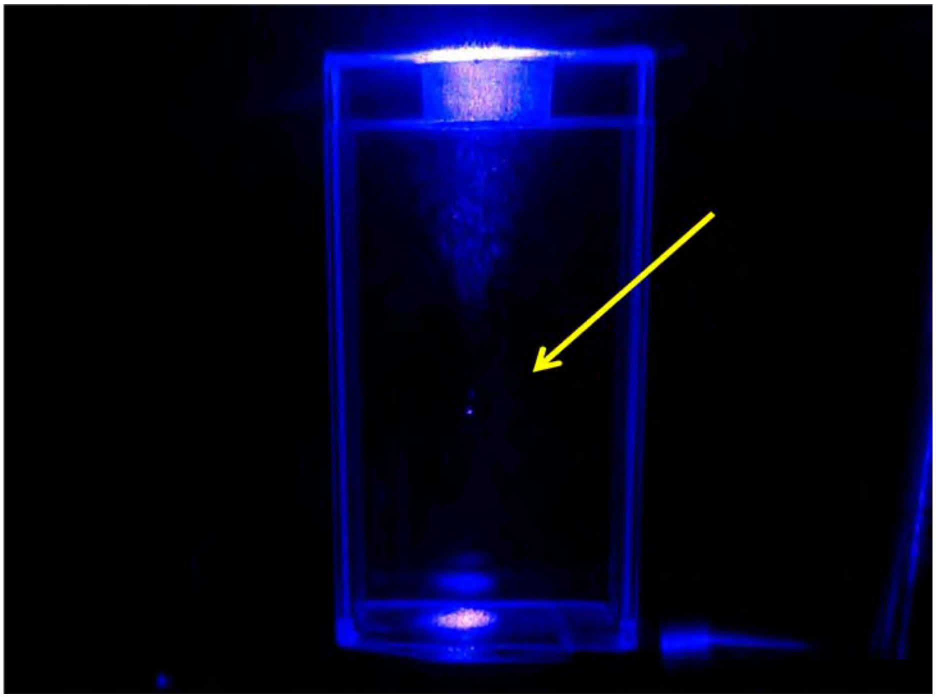
1) Single aerosol particle trapping
2) Integration of an OT-CRDS system
3) CRDS measurement of trapped particles

Upon the completion of the equipment installation (Nov. 2014), the students have been working on particle trapping using different trapping schemes and laser sources. Some interesting results have been obtained. New findings include

1) Light absorbing non-spherical bioaerosol particles (grass spores) and black carbons (multi-wall carbon nano tubes (MWCNTs), small wall carbon nano tubes (SWCNTs)) can be trapped in air by a single focused Gaussian beam. The single trapping beam can be arranged horizontally, vertically, or in any orientation.
2) Instead of using a high power laser source, power of a trapping laser can be as low as 2.5 mW at 405 nm.
3) The aforementioned particles experience a strong pushing force (along the propagation direction of the trapping laser beam). The feature of this pushing force is independent of orientation of the trapping laser beam (horizontal, vertically up, vertically down, or 45 degree up/down).

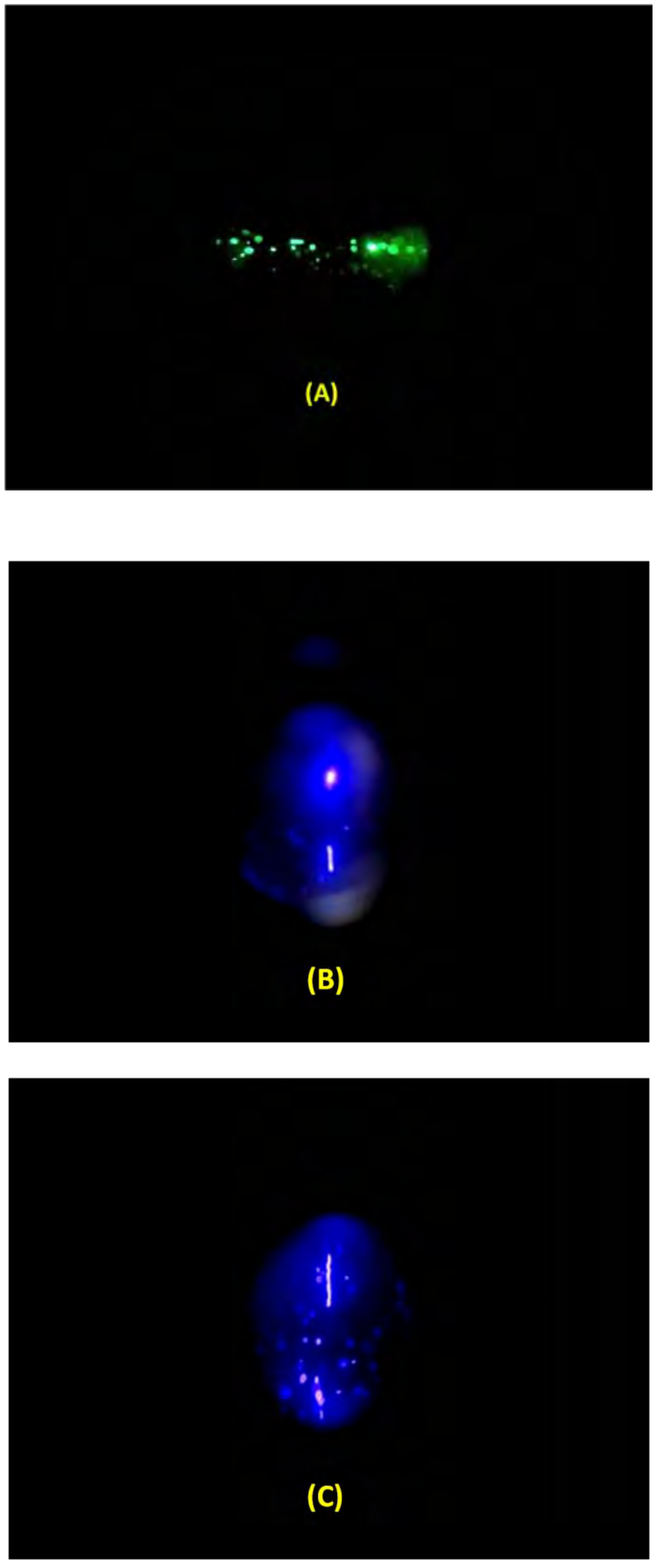


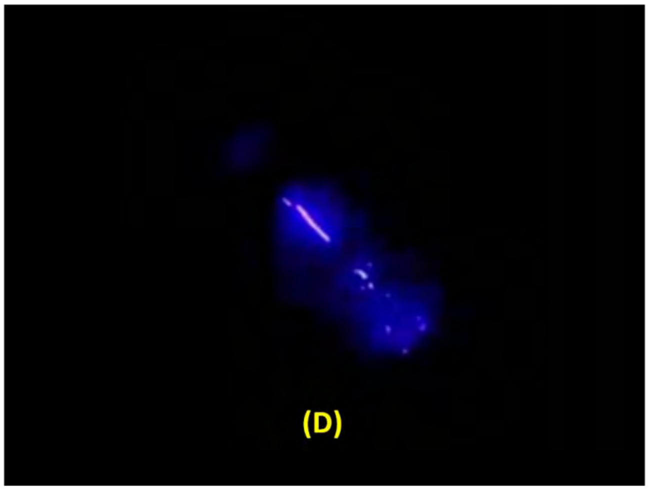
(a) Single bioaerosol particles trapped using a focused 532 nm laser (Bermuda grass smut spores, horizontal illumination at power of 4.5 mW, focus length = 10 mm, UV quartz cuvette is from Starna Cells, Inc.)



(b) Single bioaerosol particles trapped using a focused 405 nm laser (Bermuda grass smut spores, upward illumination at power of 2.0 mW, focus length = 20 mm, UV quartz cuvette is from Starna Cells, Inc.)

Fig. 6. Experimental results showing particle trapping in various situations. a) Single bioaerosol particles trapped using a focused 532 nm laser; b) single bioaerosol particles trapped using a focused 405 nm laser.





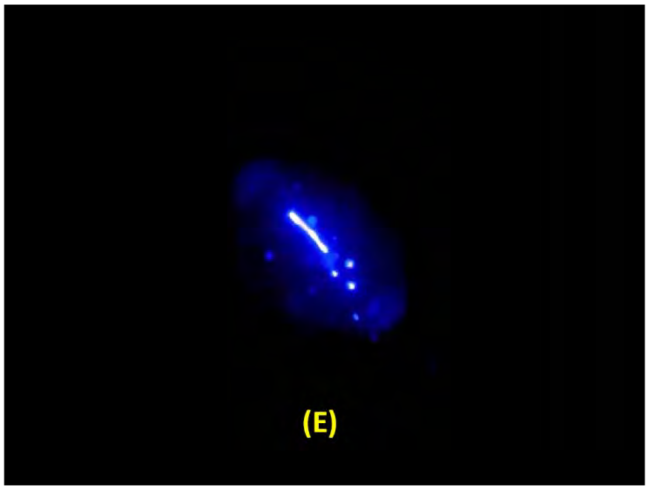


Fig. 7. Observation of the pushing force in trapping. A) Horizontal illumination (to the right) at 532 nm (Media A), B) upward illumination at 405 nm (Media B), C) downward illumination at 405 nm (Media C), D) 45 degree upward illumination at 405 nm (Media D), E) 45 degree downward illumination at 405 nm (Media E).

3.2 Integration of optical trapping into a cavity ringdown system to form OT-CRDS

Concurrent with the effort to the particle trapping, effort is being paid to the integration of the OT-CRDS system. One specially designed trapping for CRDS particle cell has been designed and quoted; and now it is being manufactured by a selected vendor. That cell will allow multiple particles to be trapped in a line, followed by CRDS characterization. Based on CRDS signal intensity and trapped particle properties, different numbers of particles will be chosen and trapped in the cell for CRDS measurement using the Nd:YAG pumped dye laser at different laser wavelengths.

3.3 Publications

No publication has been directly generated from this new laser system during this one-year funding period. The support of this project will be acknowledged in future publications generated through using the laser system.

4. Human resource development and research collaboration

- One PhD student, one MS student, and one undergraduate student are working in the funded project and these students have been trained to use the laser system.
- In addition, the new laser facility has been exposed to 4 other graduate students in the PI's research group.
- Furthermore, 10 undergraduate students (physics or engineering major) have been given a 30-min laboratory tour and the laser system has been presented to them during the tour.
- During the project period, the PI took one-year sabbatical leave in ARL, conducting aerosol research with Dr. Yongle Pan. In addition to the strong research collaboration with Dr. Pan, the PI has had direct or indirect interaction and collaboration with several other scientists in ARL. This research collaboration with ARL expects to continue.

5. Summary

A tunable, pulsed, narrow linewidth laser system has been successfully purchased with the support from this DURIP program. The laser system is operational. This laser system will have an immediate impact on the ongoing aerosol project supported by DoD through ARO, in which such a laser system is an essential part. The long-term benefit of the laser system lies in great enhancement of the research infrastructure at MSU, especially in the area of aerosol study that has ongoing collaboration between MSU and ARL.