ARI-RP-650.4

Aerosol Mass Spectrometry via Laser-Induced Incandescence Particle Vaporization

Final Report
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DOE SBIR Phase II Contract DE-FG02-07ER84890

DOE Award Number: DE-FG02-07ER84890
Recipient: Aerodyne Research, Inc.
Title: Aerosol Mass Spectrometry via Laser-Induced Incandescence Particle Vaporization
Project Director: Timothy B. Onasch
Period Covered by the Report: August 2006 to August 2009
Date of Report: 8/15/2008 – 2/15/11 (includes 6 month no-cost extension)

Purpose of Research:

The goal of this DoE Phase II project was to develop and commercialize a soot particle aerosol mass spectrometer (SP-AMS). The SP-AMS is designed to measure the mass loading, chemical composition, and size distributions of soot particles in the atmosphere. Soot particles, or refractory black carbon particles, are generated by the incomplete combustion of fuels, such as oil, coal, natural gas, biofuels, and biomass. These particles represent potential human health hazards and adversely affect visibility, air pollution, and the earth's radiation balance.

Results:

We have successfully developed and commercialized a soot particle aerosol mass spectrometer (SP-AMS) instrument to measure mass, size, and chemical information of soot particles in ambient environments. The SP-AMS instrument has been calibrated and extensively tested in the laboratory and during initial field studies. The first instrument paper describing the SP-AMS has been submitted for publication in a peer reviewed journal and there are several related papers covering initial field studies and laboratory studies that are in preparation. We have currently sold 5 SP-AMS instruments (either as complete systems or as SP modules to existing AMS instrument operators).

Potential Applications:

Our newly developed soot particle aerosol mass spectrometer (SP-AMS) represents the first real-time instrument that measure mass, chemical composition, and size distributions of soot particles under ambient conditions. This instrument should become an important tool for scientists monitoring atmospheric loadings and transportation of soot particles. This instrument should also be interest to engine companies for online, rapid feedback for reducing soot particle emissions during engine development and testing procedures. Finally, this instrument has also been shown to measure metallic nanoparticles and should be of interest to scientists in the field of nanoparticle research.

Report Contents

This report is the final report for DOE Phase II project (Contract DE-FG02-07ER84890) to develop and commercialize a soot particle aerosol mass spectrometer (SP-AMS) that utilizes a continuous wave, intra-cavity laser to vaporize elemental carbon-containing soot particles.

Final Report

This final report covers the complete phase II project. All objectives of this project have been successfully achieved: we have developed and commercialized a soot particle aerosol mass spectrometer. We have currently sold 5 SP-AMS instruments (either as complete systems or as SP modules to existing AMS instrument operators). The first instrument paper describing the SP-AMs has been submitted for publication and there are several related papers covering initial field studies and laboratory studies that are in preparation.

Task Completion Status		
Task #	**Task Action**	**Percent Complete**
1	Laser Cavity Redesign	100%
2	Laser Electronics	100%
3	Data Acquisition Software	100%
4	Laboratory Evaluation	100%
5	Field Deployment	100%

Work Plan and Performance Schedule

Performance Schedule																									
Tasks		Year 1												Year 2											
		6-Aug	6-Sep	6-Oct	6-Nov	6-Dec	6-Jan	6-Feb	6-Mar	6-Apr	6-May	6-Jun	6-Jul	6-Aug	6-Sep	6-Oct	6-Nov	6-Dec	6-Jan	6-Feb	6-Mar	6-Apr	6-May	6-Jun	6-Jul
1	Redesign of the optical and thermal couplings of the laser cavity	■	■	■	■	■	■	■	■	■	■	■	■	■											
2	Integration of laser electronics						■	■	■	■	■	■													
3	Data acquisition software development								■	■	■	■	■	■	■	■	■	■	■						
4	Laboratory characterization and instrument intercomparison	■	■	■	■												■	■	■	■	■	■	■	■	
5	Perform ambient particle measurements - Field study																							■	■

Task 1. Re-engineering of the optical and thermal couplings of the laser cavity (100% complete)

The purpose of this task was to re-engineer the intracavity Nd:YAG laser system focusing on the mechanical control of the laser alignment, the thermal management of the crystal, and optimizing the beam profile. The objectives for this redesign were (1) to remove the fragile fiber optic coupling between the pump laser and the Nd:YAG crystal, (2) to design stable, external optical adjustments for the pump laser and intracavity alignments, (3) increase intracavity laser power, (4) improve thermal management of the Nd:YAG crystal, and (5) characterize the intracavity beam and particle beam overlap region. The total redesign of the SP module is complete and the SP module is now a robust, commercially available package. Figure 1 shows the different elements of the SP module attached to a HR-AMS. Figure 2 shows the complete SP module package available for commercial sales. As noted above, we have sold 5 units (either as complete SP-HR-AMS instruments or as SP modules for existing HR-AMS instrument upgrades).

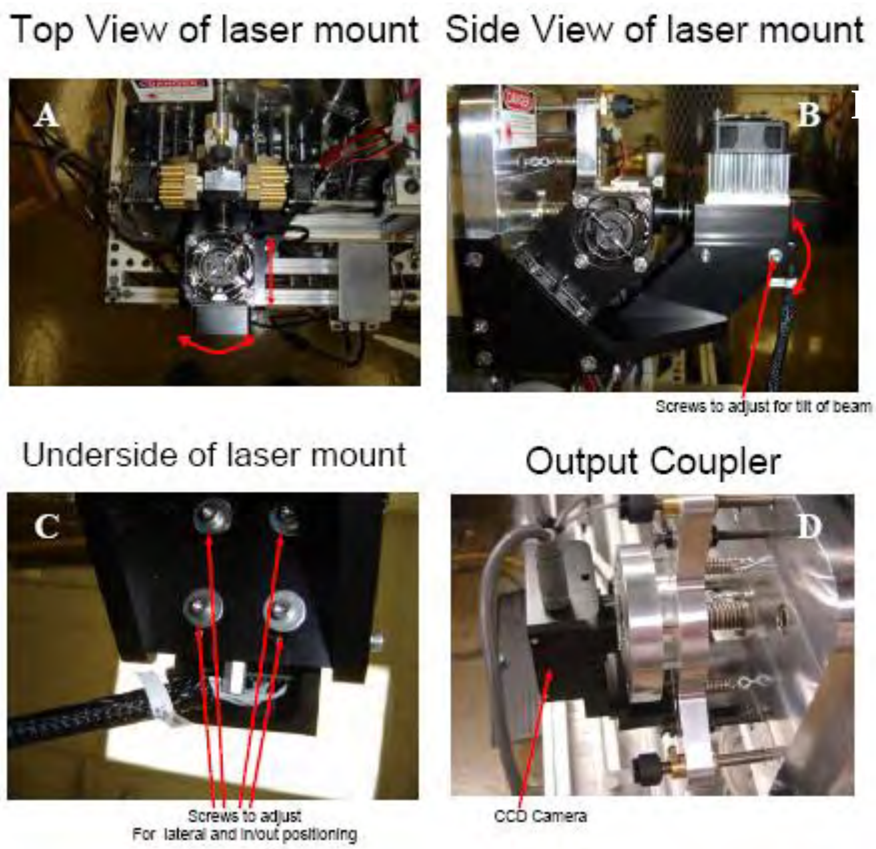

Figure 1. Pictures of the (A) laser mount from the top, (B) laser mount from the side, (C) laser mount from the bottom, and (D) output coupler with CCD camera used to image intra-cavity laser beam profile.

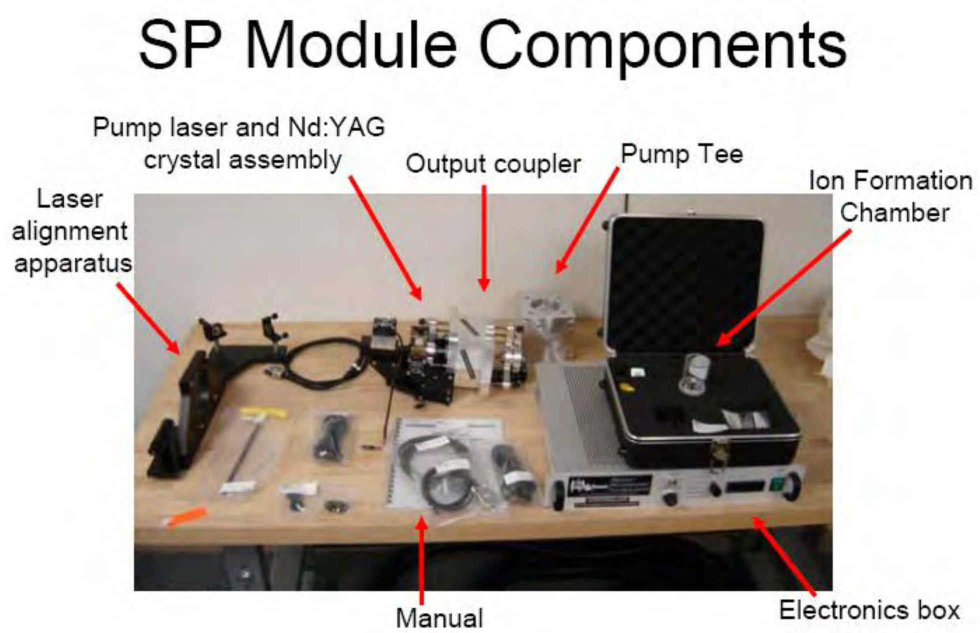

Figure 2. SP module components.

Task 2. Integration of laser electronics (100% complete)

The goal of this task was to integrate the OEM (original equipment manufacturer) laser and TEC (thermal electric cooler) control along with diagnostic electronics into a compact, efficient electronics box that can be readily powered using the current DC power supplies used by the standard AMS electronics and can be controlled via the custom data acquisition software developed for the AMS.

Figure 3. Pictures of the front and back of the finished electronics control box.

All of the associated electronics have now been integrated into a 2-U rack mountable electronics box. The 2-U height fits into the current TOF-AMS rack system. Figure 3 shows pictures of the front and back of the electronics box. The electronics box controls the laser power supply and control, thermo-electric cooler power supply and proportional-integral-derivative (PID) controller, and laser cavity power monitor into a single unit. The data acquisition software now controls turning the laser on/off, so that one can automatically cycle between different vaporizers (i.e., laser and resistively heated tungsten).

Task 3. Data acquisition software development (100% complete)

The objective of this task was to develop control and diagnostics software for the SP module. We have accomplished this goal by including in the TOF-AMS DAQ software SP module specific parameters and data identification tags set during data acquisition and used during data processing. In addition, the AMS DAQ software now controls the ON/OFF functions of the pump laser (and thus the intracavity laser).

Task 4. Laboratory characterization and instrument intercomparison (100% complete)

The SP-AMS instrument, with the final intracavity laser configuration, the consolidated electronics, and the new DAQ software, has been completely tested in the aerosol laboratories at Aerodyne Research and Boston College. The details of these tests, as well as some data obtained during related studies, are described in detail in the manuscript (Onasch et al., 2011) that has been submitted for publication in a peer-reviewed scientific journal. The results from these tests show that the SP-AMS is a sensitive refractory black carbon aerosol mass spectrometer that provides mass loadings, size distributions, and chemical information on both the refractory carbon content of particles, as well as nonrefractory coating material, when used with only the laser vaporizer. The SP-AMS can also be operated with both the laser vaporizer and the standard, resistively heated tungsten vaporizer to obtain information on total nonrefractory particulate mass, size and chemical information (same as a standard AMS) as well as on refractory black carbon particles.

Task 5. Perform ambient particle measurements - Field study (100% complete)

We have successfully deployed the SP-AMS instrument in multiple laboratory and field studies during this project, many in collaboration with other related projects: (1) summer of 2009 onboard the Aerodyne mobile laboratory in New York City measuring refractory black carbon particles at a stationary site in Queens and as a function of distance upwind and downwind from the Long Island Express way (Massoli et al., 2011); (2) summer of 2009 as part of the FLAME 3 study of biomass burning at the Montana Fire Science Laboratory funded by EPA; (3) summer of 2009 as part of a laboratory study at UTRC on flame soot funded by SERDP; (4) Fall/Winter of 2009 as part of laboratory studies at Aerodyne on metal nanoparticles funded by DoD project; (5) May 2010 during NOAA funded CalNex study on board the R/V Atlantis; (6) July 2010 as part of an EPA funded Caldecott Tunnel study; (7) September 2010 as part of a John Zink flare study in Oklahoma funded by John Zink; (8) March 2011 as part of NASA AAFEX-2 study on alternative aircraft fuels in Edwards Air Force Base in CA; (9) August 2011 as part of a ACRP funded project investigating aircraft take-off, landing, and brakes and tire emissions during landing; and (10) October 2011 as part of a MIT funded project investigating diesel engine emissions and the effects of additives in oil for poisoning diesel engine particulate filters (Cross et al., 2011). Manuscripts describing most of these studies are in preparation, with two listed below.

Cross, E. S., Sappok, A., Fortner, E. C., Hunter, J. F., Jayne, J. T., IV, W. A. B., Onasch, T. B., Wong, V. W., Worsnop, D. R. and Kroll, J. H. (2011). Real-Time Measurements of Engine-Out Trace Elements: Application of a Novel Soot Particle Aerosol Mass Spectrometer for Emissions Characterization. *Proceedings of the ASME 2011 Internal Combustion Engine Division Fall Technical Conference (ICEF2011)*.

Onasch, T. B., Trimborn, A., Fortner, E. C., Jayne, J. T., Kok, G. L., Williams, L. R., Davidovits, P. and Worsnop, D. R. (2011). Soot Particle Aerosol Mass Spectrometer: Development, Validation, and Initial Application. *Submitted to Aerosol Science and Technology*.

Massoli, P., Fortner, E., Canagaratna, M., Williams, L., Zhang, Q., Sun, Y., Schwab, J., Onasch, T., Worsnop, D., Demerjian, K. and Jayne, J. (2011). Pollution gradients and chemical characterization of particulate matter from vehicular traffic near major roadways: results from the 2009 Queens College Air Quality study in NYC. *In final preparations*.