

# WELCOMING REMARKS

The Center for Laser Applications (CLA) at the University of Tennessee Space Institute is pleased to present our annual report of the research projects funded by the Center and external sources for fiscal year 2013-2014.

Over the past year, The Center for Laser Applications supported the research efforts of ten UTSI Center-associated faculty who have made significant advancements in vision research, laser materials processing, chemical synthesis, single-molecule detection, nanotechnology, biotechnology, biomedical research, computational physics, plasma physics, laser-induced optical breakdown and fluid physics phenomena. Three CLA research efforts were commercialized, delivering an economic impact to the local community.

Productivity among Center faculty has been outstanding and diverse. While federal funding has been reduced and more difficult to obtain, our faculty has responded by finding direct commercial funding for research. The Tennessee Higher Education Commission (THEC) funding has proven the key to the advancement of innovation and the creation of intellectual property. THEC funds pay for the general operations of the Center and the research conducted in CLA, including the Center support staff, laboratory supplies, maintenance, travel for faculty and students to conferences, and research experiences for summer interns. Without this discretionary funding, advancement of new ideas would be limited. THEC resources allow faculty and students to pursue innovations. Capital equipment must also come from this budget. We have been fortunate to obtain a class 1000 clean room with a femtosecond nanomachining station and photolithography capability, an Optomec LENS™ machine for direct metal deposition, a modular fluorometer/phosphorimeter for fluorescence studies, a pulsed laser deposition system, and a JEOL 6320F field emission scanning electron microscope with x-ray energy dispersive analysis. With these capabilities CLA has been successful in the pursuit of new science and new sources of funding.

In spite of difficult economic times our research expenditures have begun to recover. We are enthusiastic about our opportunities for the future and proud of the past accomplishments and hope you enjoy the research summaries that follow.

*William Hofmeister*

*Director, Center for Laser Applications  
Research Professor of Materials Science and Engineering*

# CENTER FOR LASER APPLICATIONS ANNUAL REPORT 2013-2014

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## INTRODUCTION

The Center for Laser Applications (CLA) at the University of Tennessee Space Institute was established in 1984 as a state funded Center of Excellence to provide outstanding capabilities in research, education, and technology transfer in the area of laser applications. CLA began as an active multi-disciplined and collaborative research group at UTSI with expertise and significant industrial and university-based experience in phenomena related to the interactions of lasers with gases, liquids, and solids. The diverse background of the faculty and staff and the strong mission-related research programs of CLA provide a blend of applied and basic research that is unusual for universities.

## MISSION STATEMENT

The CLA mission is to advance laser applications in spectroscopy and materials synthesis. We pursue our mission in three areas:

### 1) Education

- Provide a quality education to UTSI students with emphasis on apprenticeship
- Generate opportunities for undergraduate and high school student research

### 2) Innovation

- Develop a world class reputation for research and innovation

### 3) Service

- Assist businesses in development and implementation of technology
- Increase interest in STEM areas, i.e. support science education for local students and teachers

## FOCUS AREAS

The focus of the mission-related research programs of the Center is the application of lasers and associated technology to bio/nanophotonics, materials science, laser materials interaction, energy/power and spectroscopy. These focus areas of specialization were selected to correspond to known areas of scientific and engineering challenges and to areas of development and regional and national needs.

### Bio/Nanophotonics

- Lloyd Davis - single molecule spectroscopy of biomolecules in confined spaces
- Ying-Ling Chen - vision research and modeling of human vision systems
- William Hofmeister and Lino Costa - devices for cellular chemotaxis
- Jacqueline Johnson - storage phosphor materials for mammography
- George Murray - colorimetric detection of bioactive molecules
- Christian Parigger - photo-acoustic imaging, diagnostics and applications
- Feng-Yuan Zhang - MEMS/NEMS, micro/nano fluidics

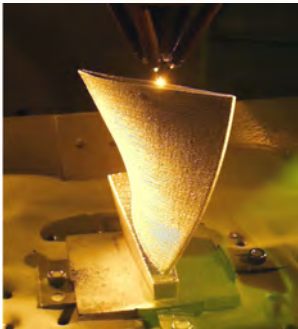
## Materials Science

- George Murray - synthesis of molecularly imprinted polymers
- William Hofmeister - solidification, direct metal deposition and femtosecond nano-structuring of materials
- Lino Costa - phase transformations, laser cladding and modeling of direct metal deposition
- Lloyd Davis - trapping and diagnostics of quantum dots
- Christian Parigger - laser-induced materials physics
- Jacqueline Johnson - development of glass imaging material

## Laser Materials Interaction

- Lino Costa - laser cladding and femtosecond laser machining
- William Hofmeister - direct metal deposition and femtosecond nanostructuring of materials
- Trevor Moeller - laser ablation dynamics and modeling of laser ablation for space propulsion
- Lloyd Davis - femtosecond fabrication of nanofluidic and wave guide devices
- Feng-Yuan Zhang - micro/nano manufacturing multifunctional materials

## Spectroscopy



Advanced Manufacturing by  
Laser Additive Fabrication

- Charles Johnson - Mössbauer spectroscopy
- Christian Parigger - ultrasensitive spectroscopy and combustion diagnostics
- Lloyd Davis - single molecule spectroscopy
- Ying-Ling Chen - combustion diagnostics
- George Murray - Raman and electrochemical spectroscopy
- Feng-Yuan Zhang - Tomography, Diode-laser absorption spectroscopy, thermography

## Non-Equilibrium Fluid Physics

- Trevor Moeller - plasma physics and combustion
- Christian Parigger - laser-plasma physics, combustion and fluid phenomena and computational modeling
- Feng-Yuan Zhang - hypersonic flow and reaction

## PERSONNEL

Dr. William Hofmeister, Research Professor of Materials Science and Engineering, was appointed Director of the Center in 2005. In 2007 Dr. Jacqueline Johnson joined CLA and secured a major grant from the National Institutes of Health for the development of materials for mammography. The National Science Foundation is also supporting this work. Her research is has attracted the attention of the community and



Dr. Murray checks the performance of molecular sequestration beads.

she received the Engineering School's Professional Development Award and a Research Fellowship from UTK. Lloyd Davis has been appointed an iBME Affiliate Professor. This past fiscal year Dr. George Murray completed the "spin off" or commercialization of his research with Raptor Detection Technologies. With the assistance of UTSI's ASSET (The Center for Advanced Scientific Support and Engineering Technology), Murray and Raptor created a small business with eight employees in incubator space at UTSI. Dr. Ying-Ling Chen's work with eye modeling and diagnostics is also being commercialized after clinical trials supported by Wang Vision Institute and NIH. Dr. Trevor Moeller continues to serve the aerospace establishment with a number of grants and task orders with Arnold Engineering Development Center.

We are happy to announce the addition of a new faculty member to the CLA team, Dr. Feng-Yuan Zhang, Associate Professor, Mechanical, Aerospace & Biomedical Engineering, who will add expertise in micro-/ nano- scale fluidics, transport, heat transfer, combustion, and energy conversion technologies to our center capabilities.

## COLLABORATIONS

A significant fraction of the research and development program of the Center is supported by state, regional, and national industries. CLA actively collaborates with the Center for Industrial Services to provide studies for Tennessee industries, and CLA has also formed long-term research partnerships with regional and national industries. Supplementing these activities are research programs sponsored by the traditional federal agencies, the National Institutes of Health, the National Science Foundation, and National Laboratories at Oak Ridge and Albuquerque, over and above numerous collaborations with national and international Universities, and the nearby Arnold Engineering Development Center. These diverse research activities, an attractive student-to-faculty ratio, and outstanding facilities, combine to offer an unusual apprenticeship experience for diligent graduate students.

# GRADUATE STUDENT SUPPORT

Over the past five years CLA supported 25 graduate students with a combination of external research funding, UTSI support, ARRA and THEC funds.

- **Aerospace Engineering**

MS: Erin Halpenney, James P. Rogers, Andrew Williams, Nehemiah Williams and Rayne Sung

- **Bio Medical Engineering**

MS: Christian Foerster and Sharon Gray

- **Materials Science**

PhD: Deepak Rajput

MS: Matthew Parrish, Russell Lee Leonard and Manh Vu

- **Mechanical Engineering**

PhD: Richard Joel Thompson

MS: Densu Aktas and Nicholas Lister

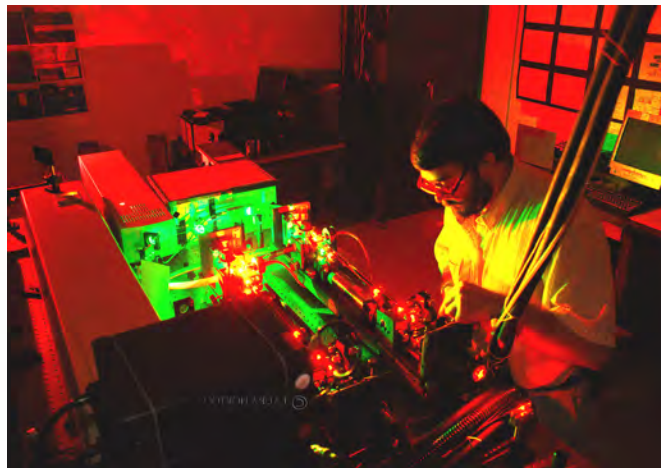
- **Physics**

PhD: William Robinson, Lei Shi, Jesse Labello, Bo Tan, James A. Germann and Jason Keith King

MS: William Ring, Alexander Woods, You Li, Justin Crawford and James Germann

# POST DOCTORAL SUPPORT

The Center supports post doctoral fellows for continuing education and research support. Currently, Dr. Brian Canfield is working in the Davis lab on single molecule spectroscopy. Mr. Robert Rhodes continues to support the nonequilibrium fluid physics research with Dr. Moeller. Dr. Abhilasha Verma worked on molecular imprinting polymers for protein sequestration. Dr. George Owens was transitioned from post doctoral status



Post Doc Brian Canfield



Post Doc Abhilasha Verma

to Raptor Detection Technologies. Past post doctoral fellows include: Dr. Paul Shen, Luna Innovations, Dr. Yelena White currently is an Assistant Professor of Physical Science for the Physics Department at East Georgia College. Dr. Zbigniew Sikorski remains active in the area of computational modeling and Dr. Xiaoxuan "Shaun" Li is a Materials Engineer at Secat, Inc. in Kentucky.

# OUTREACH AND ENRICHMENT PROGRAMS

CLA is dedicated to impacting our community in a positive way with meaningful interactions. Faculty, staff and graduate students contribute to interactions with local students and teachers. We have worked hard to develop mini-courses, summer camps, and engaging enrichment programs to offer to local teachers and all levels of students from public schools to home school programs. To date 5,333 students and 141 teachers have participated in a learning experience presented by the faculty, staff, and students in CLA. The laboratory regularly hosts adult groups such as the Coffee County Leadership Program and the Precision Machinists. In addition, the graduate students have traveled to many schools in the community for events such as Friday School at Sewanee Elementary, Fantastic Fridays at Cowan Middle School and the Science Club at Shelbyville High School.

The ASM Materials Camp engaged high school students in learning about alternative energy



strategies to performing a live play pertinent to the week's activities in the auditorium. TECH camp provided interactive, hands-on projects that facilitated career awareness and opened eyes to the excitement of scientific discovery to rising middle school students. The UTSI/CLA Computational Science camp hosted middle and high school students, as well as science and math teachers an opportunity to study computational astrophysics, meteorology, agriculture, genomics, epidemiology, pharmacokinetics, and programs using languages such as gnuplot, Perl, and NetLogo.

CLA has worked with the Tullahoma Hands On Science Center (HOSC) to provide educational experiences to alternative school students through a grant from the Payback foundation. In 2010, UTSI teamed with the HOSC to win a grant to site a Fireball Network station at UTSI with an exhibit at the HOSC. The Fireball Network tracks meteors in the night sky. In 2010 UTSI moved its summer enrichment programs for younger learners to the HOSC as summer camp programs and assists in delivering those programs at the HOSC.



Science teachers and HOSC Bill Boss

## What goes around comes around! Summer Intern Program

For the last three years CLA and UTSI have jointly funded a summer intern program, led by Dr. Jacqueline Johnson of Biomedical Engineering and CLA. The program is multifaceted in that it aims to provide a real research experience to prospective graduate students, promote diversity, educate and market. In year one the group was comprised of seven students, five females and two minorities, year two, three males and year three, three males and one female. The students range in educational level from high school to seniors in college. The interns undergo a lecture course, laboratory instruction and training in literature searches before being assigned to a research project. During the course of the summer the students write a paper, prepare a proposal, give a presentation, obtain career advice as well as participate in a full social program.



Each year feed results from a survey done verbally at the midpoint of the internship and a written survey at the end.

Summer internships have been found to be a valuable recruiting tool. Two of the students attending the first intern program are now in graduate school at UTSI and two more applied. CLA showcases its spacious laboratories, friendly faculty and staff and dedication to the involvement of students in research.



The photographs show two students hard at work in the laboratory and the 2013 interns with their supervisors at the ultimate departure bonfire.

# RESEARCH ACCOMPLISHMENTS AND FIVE YEAR BENCHMARK

Our research mission is growing. The funding provided by the Tennessee Higher Education Commission, coupled with support from the university, provided valuable leverage for sponsored research. The research awards continue to increase. This growth is possible because of the dedication of our faculty and the support of THEC and UTSI.

CLA remains active in Outreach and Business Development. The faculty are active in scientific conferences and local business meetings. Productivity among Center faculty has been outstanding during the last five year period. During fiscal years 2010 through 2014, Center faculty published 93 peer-reviewed articles, 11 books and presented at 205 regional, national, and international meetings.

## COMPARATIVE SUMMARY OF ACCOMPLISHMENTS

Benchmark Data	FY 2010-2014	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
	Cumulative					
<b>Publications</b>						
Peer-reviewed articles	93	23	15	17	18	20
Book or book chapters	11	4	5	0	0	2
<b>Presentations</b>						
International	32	8	7	9	5	3
National	173	10	28	54	41	40
<b>Research Awards</b>						
External funding received	\$5,357,149	\$1,676,546	\$2,030,691	\$278,700	\$608,143	\$763,069
THEC State Appropriations	\$4,415,214	\$965,200	\$913,468	\$858,064	\$824,380	\$854,102
Research expenditures	\$5,645,429	\$1,481,810	\$1,395,390	\$1,205,258	\$896,901	\$666,070

Despite the current funding environment, we have managed to maintain research expenditures. The decrease in funding in FY2013 is due to the commercialization of the Raptor Detection Technologies project and the shift from Raptor's research resources to the new start up. Details of current faculty research are provided in the Faculty Reports section (pp. 13-21).

# FUTURE DIRECTIONS

The University of Tennessee Space Institute's direction is changing from education and research to research and education; placing the greater emphasis on externally funded research. The Center for Laser Applications will follow that trend as well. We have built a vibrant multi-disciplinary research team broadly working in photonics, biophotonics, spectroscopy, laser materials interactions, plasma and non-equilibrium physics, fluid physics and computational modeling. These efforts will continue. Moving forward, the goal of CLA will be to involve more of the UTSI and UTK faculty and students in research using our laboratory resources. Currently, exploratory research is carried out guided by the Principals in CLA. In the future, exploratory research directions for the Center will be solicited from the faculty- at-large in the form of white paper proposals, and resources will be allocated based on this proposal process. We are confident that this plan will help serve the broader science community.

Laboratory space is one of CLA's greatest assets and in the future we will work to "broaden the tent" to make use of the facilities for more investigators. For example, we look forward to working with UT Research Foundation's ASSET program. We will also improve our flow and combustion measurement capabilities to be in line with UTSI's research in hypersonics. CLA's space and infrastructure will contribute to the success of that program.

# CLA BUDGET

## Centers of Excellence/Centers of Emphasis Actual, Proposed, and Requested Budget

	FY 2013-14 Actuals			FY 2014-15 Proposed			FY 2015-16 Requested		
	Matching	Appopr.	Total	Matching	Appopr.	Total	Matching	Appopr.	Total
Expenditures	455,965	855,855	1,311,820	421,943	843,886	1,265,829	437,621	875,242	1,312,863
<b>Salaries</b>									
Faculty	161,419	199,814	361,233	150,470	171,325	321,795	134,944	102,795	237,739
Other Professional	46,944	215,494	262,438	50,000	205,113	255,113	55,000	215,369	270,369
Clerical/ Supporting	5,625	90,100	95,725	10,000	121,400	131,400	10,500	123,828	134,328
Assistantships	42,943	46,957	89,900	11,444	22,889	34,333	12,017	24,033	36,050
<b>Total Salaries</b>	<b>256,931</b>	<b>552,365</b>	<b>809,296</b>	<b>221,914</b>	<b>520,727</b>	<b>742,641</b>	<b>212,461</b>	<b>466,025</b>	<b>678,486</b>
Longevity	67,913	135,827	203,740	67,913	135,827	203,740	71,309	142,618	213,927
Fringe Benefits	682	1,363	2,045	682	1,363	2,045	716	1,431	2,147
<b>Total Personnel</b>	<b>309,351</b>	<b>618,702</b>	<b>928,053</b>	<b>311,356</b>	<b>622,712</b>	<b>934,068</b>	<b>326,925</b>	<b>653,848</b>	<b>980,773</b>
<b>Non-Personnel</b>									
Travel	12,845	34,088	46,933	9,564	30,767	40,331	18,999	37,998	56,997
Software			0			0		2,400	2,400
Books & Journals			0			0			0
Other Supplies	9,248	32,383	41,631	12,000	26,578	38,578	13,000	30,000	43,000
Equipment	87,664	5,313	92,977	95,762	24,000	119,762	118,000	150,000	268,000
Maintenance	4,865	25,682	30,547	5,000	76,000	81,000	5,000	43,000	48,000
Scholarships		28,620	28,620		15,168	15,168		16,230	16,230
Consultants	0	0	0	0	0	0	0	0	0
Renovation	0	0	0	0	0	0	0	0	0
Professional Membership	4,260	413	4,673	4,000	1,000	5,000	4,000	1,098	5,098
<b>Media Process</b>	1,809	2,434	4,243	1,800	2,500	4,300	1,800	2,500	4,300
<b>Communication</b>	1,450	1,734	3,184	1,500	1,800	3,300	1,500	1,800	3,300
<b>Rentals</b>	258	5,172	5,430	500	5,200	5,700	500	5,200	5,700
<b>Contractual Services</b>	3,484	3,658	7,142	3,500	3,660	7,160	3,500	3,600	7,100
<b>Other Expenditures</b>									
<b>Cost Share</b>			0			0			0
<b>Total Non-Personnel</b>	<b>123,322</b>	<b>126,382</b>	<b>249,704</b>	<b>136,062</b>	<b>169,606</b>	<b>305,668</b>	<b>160,300</b>	<b>271,828</b>	<b>432,128</b>
<b>GRAND TOTAL</b>	<b>455,965</b>	<b>845,532</b>	<b>1,301,497</b>	<b>421,943</b>	<b>843,886</b>	<b>1,265,829</b>	<b>437,621</b>	<b>875,242</b>	<b>1,312,863</b>
Revenue		854,102	854,102		833,564	833,564		875,242	875,242
New State Appropriation		1,753	1,753		10,322	10,322			0
Carryover State Appropriation	455,965		455,965	421,943		421,943	437,621		437,621
New Matching Funds			0			0			0
Carryover from Previous Matching Funds	455,965	855,855	1,311,820	421,943	843,886	1,265,829	437,621	875,242	1,312,863
<b>Total Revenue</b>	<b>454,906</b>	<b>909,812</b>	<b>1,364,718</b>	<b>467,020</b>	<b>855,855</b>	<b>1,322,875</b>	<b>448,404</b>	<b>896,807</b>	<b>1,345,211</b>

# VISION SCIENCE RESEARCH

## Ying-Ling Chen

*Research Assistant Professor of Physics*

*PhD, University of Tennessee Space Institute*



The ability to provide accurate, detailed predictions of vision performance and ophthalmic diagnostics of healthy, diseased, and post-surgery eyes is needed and desired. This is an example of the convergence of physics and medicine that can have significant effects on health-care practice.

If this computational capability existed, dramatic changes can result in ocular instrument design and development, ophthalmic medical education, and ocular telemedicine. Physics and mathematical models of the eye would then be used with computational methods to simulate and accurately predict ocular characteristics and responses. Clinical trials would be performed faster and in a more cost effective manner if representative ocular responses and ocular conditions were predicted and available at their onset. Similar advances are possible in medical training if realistic diagnostic device behavior could be demonstrated for students using computed images of disease and ophthalmic conditions. Finally, opportunities in telemedicine, with expert system-based diagnostic and referral decisions, would become possible and practical.

For several years, Professor Chen's biophysics vision research in CLA has pioneered the development of numerical eye modeling and ophthalmic simulation. Professor Chen has been awarded NIH research grants to support the creation and development of realistic eye models for diseased eyes and to develop a novel adaptive photorefractive technology to detect early keratoconus disorder, which is the major cause of failure of LASIK, the popular laser surgery technique. One of her continuing efforts has focused on the development of a comprehensive customized digital eye bank with appropriate intraocular ocular scattering (IOS) features. IOS exists in both diseased and normal eyes. Although the lens may be the leading source of scatter, almost all ocular components contribute to IOS that reduces visual acuity. IOS can increase with aging, disease, medications, accidents and surgery in the eye. IOS degrades retinal vision quality and produces the glare veiling effect. Further, IOS can cause ambiguity during ophthalmic measurements and during laser surgery, reducing the accuracy, and sometimes resulting in technical errors. The mission of this research is to include the influence of IOS in ready-to-use models in order to predict these aberrations and avoid these costly errors and complications. This IOS research was proposed as a R01 type of research project to NIH and received very encouraging reviews and advises. This investigation will be revised to include clinical measurement and computational expertise and submitted in October 2014.

Professor Chen and Dr. J.W.L. Lewis have obtained three U.S. patents through The University of Tennessee Research Foundation (UTRF) for the adaptive photoscreening (APS) technology and recently an international APS patent was filed that incorporated recent research results. The purpose of this technology is to assess ocular information automatically while the examinee views a short animation in his/her natural condition. With minimum requirement of cooperation, the prototype system includes a child-friendly 3D screen that displays animations to attract the examinee's attention, to control the accommodation and visual fixation, and to interact with examinees throughout the assessment period. The current evaluation procedure includes assessments in binocular near- or far-sightedness, astigmatism, ocular motility/alignment, pupillary response, and optical opacity. Professor Chen obtained the support from the Wal-Mart Vision Center in Tullahoma, TN for clinical studies of school-age and preschool children and had acquired 160 patients participation to test the accuracy. The children's clinical studies were supported by Maturation awards of UTRF. Currently Professor Chen is developing collaborations with several research groups in the Brain Institute and Eye Institute of Vanderbilt University to investigate the APS application of detecting mental problems such as post traumatic stress disorder, dyslexia, and physical/emotional abuse through the ocular response and the hand-eye-stimulus interaction.

# MATERIALS SCIENCE RESEARCH

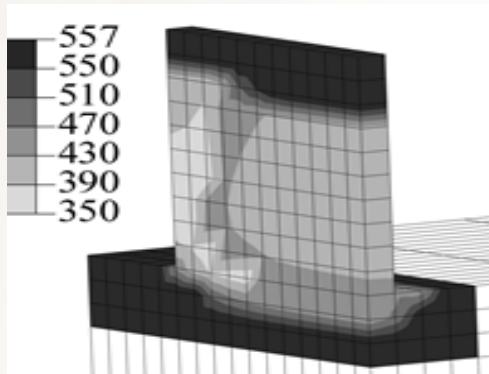


**Dr. Lino Costa**

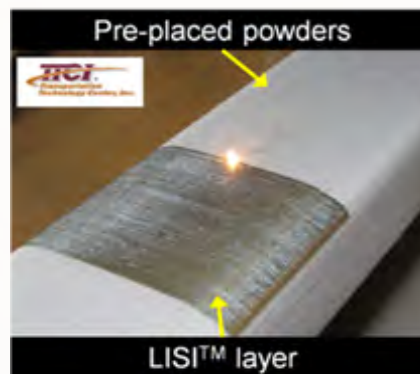
*Research Assistant Professor of Materials Science and Engineering  
PhD, Instituto Superior Tecnico, Universidade Tecnica de Lisboa*

Dr. Lino Costa joined UTSI during the fall of 2005 as a research associate and became a research assistant professor during the fall of 2010. He holds a Ph.D. degree in Materials Engineering from Instituto Superior Tecnico, in Lisbon Portugal, with a dissertation on finite element modeling of laser powder deposition of tool steels. Dr. Costa has contributed to the advancement of various laser materials processing techniques, including Laser Powder Deposition applied to Additive Manufacturing, Laser Induced Surface Improvement (LISI™) for development of wear and corrosion resistant surface coatings, and Femtosecond Laser Micromachining for fabrication of microfluidic lab-on-a-chip devices for biomedical research applications.

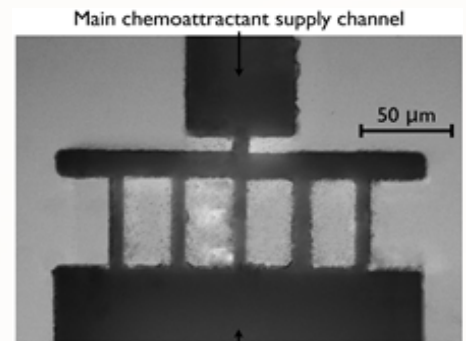
In addition, Dr. Costa continues to develop a novel nanoimprinting technique capable of populating the surface of polymer films with dense arrays of freestanding polymer nanowires. This nanoimprinting technique has been demonstrated for numerous materials including cellulose acetate, polyvinyl alcohol, polyvinyl chloride, polyethylene, polypropylene, polycaprolactone, and polyisoprene. The individual nanowires have an average



Hardness distribution (HV) of AISI 420 tool steel thin wall built using Laser Powder Deposition, calculated using a thermo-kinetic finite element model.



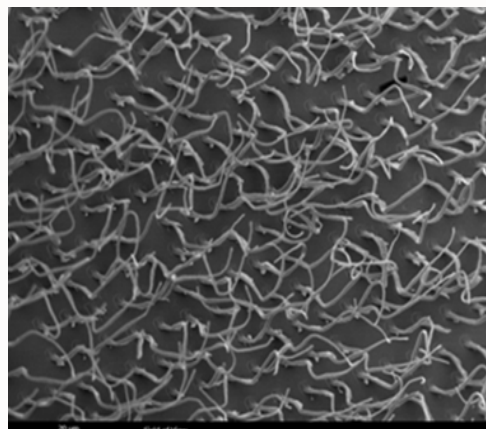
Cr-CrB2 LISI coating of a railway track section to produce a corrosion and wear resistant surface.



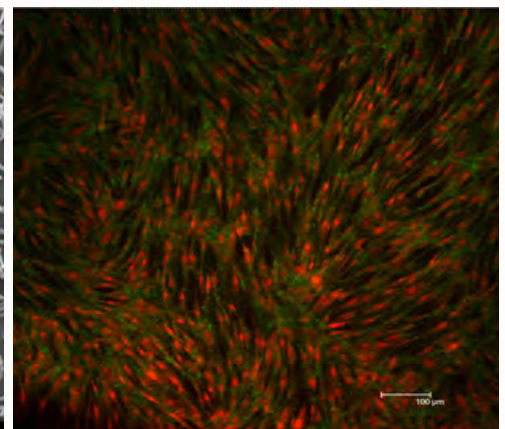
Detail of a microfluidic device used to carry out chemotaxis experiments and fabricated on a fused silica chip using femtosecond laser machining.

outer diameter of a few hundred nanometers and, depending on the material, can exhibit lengths ranging

from a few micrometers up to 75 micrometers. For a few materials, these nanowire coated polymer films have been proven effective cell culture substrates of significance to tissue regeneration applications. In addition, these nanowire structures can be loaded with nano-fillers and conformally coated with nanometer thick layers of metals and oxides to provide them with different functionalities. Arrays of metal-coated nanowires are valuable high surface area electrodes in photovoltaic and electrical energy storage applications.



Scanning electron microscope image of PVC nanowires. Scale bar: 20 μm.



Confocal microscope image of equine stem cells proliferating over PCL nanowires, by Dr. Madhu Dhar (UT Knoxville). Scale bar: 100 μm.

# ULTRASENSITIVE SPECTROSCOPY

## Lloyd M. Davis

*B. H. Goethert Professor of Physics*

*PhD, University of Auckland, New Zealand*

*Visiting Researcher at Vanderbilt University*

*Visiting Researcher at JILA, UC Boulder*

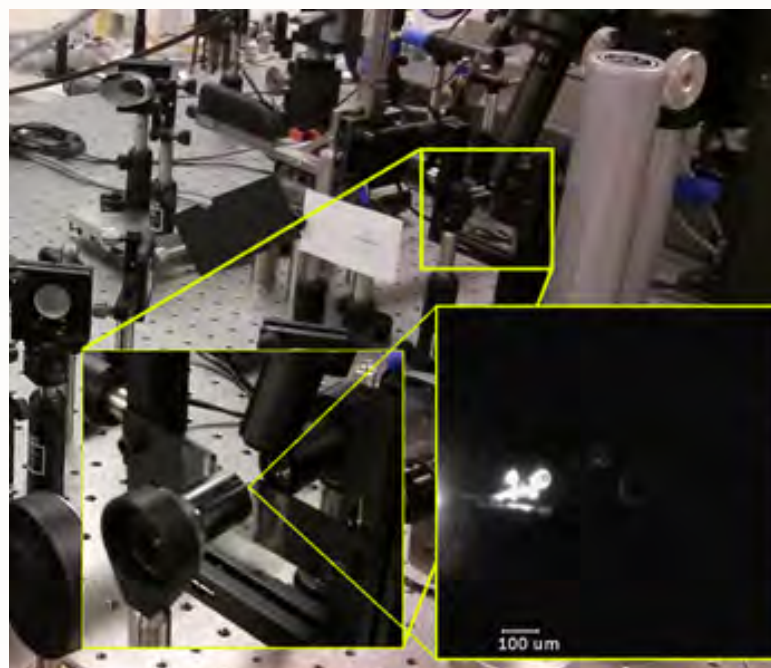
*Visiting Researcher at the Photon Factory, University of Auckland*

*User/Visiting Researcher at CNMS, Oak Ridge National Laboratory*



The research of Professor Davis and his group spans a range of activities in the areas of laser applications for chemical analysis and biotechnology. Much of this work is built on the group's earlier innovations in ultrasensitive fluorescence detection. Davis is a pioneer of experimental techniques in single-molecule fluorescence detection and spectroscopy, having co-developed the first experiments to successfully demonstrate detection of a single fluorophore in solution in the late 1980's, the first single-molecule detection in a "lab-on-a-chip" device in the 1990's, early experiments on single-molecule imaging for 3rd generation DNA sequencing in the early 2000's, and novel single-molecule detection and trapping in nano-fluidic channels around 2008-2010. In the past year, we have published the first reports on trapping of a single fluorescent nanoparticle in 3 dimensions (3-D) using a 4-electrode device and on use of a custom-built ultrasensitive confocal fluorescence microscope in which four laser foci are used as a 3-D quadrant detector for single-nanoparticle position determination and tracking. These two experiments rely on sub-diffraction imaging, in which the 3-D position of the emitter is measured more precisely than the diffraction limit of the microscope, together with real-time control of solution flow or sample position to counteract Brownian diffusion. We are conducting computational and experimental studies of single-molecule recycling in a nanochannel by alternating its motion using real-time control.

Over the past year, several external collaborations have continued, including an NSF-sponsored project with Vanderbilt University on ultrasensitive spectroscopy of nanoparticles for energy conversion applications, which grew from the 3-D trapping research. The methods for real-time control for trapping are also being applied in a project with JILA, at the UC Boulder, in which optical forces from a focused laser beam are used to sort mammalian cells in a microfluidic device as part of a process for developing new red fluorescent proteins with enhanced photostability and brightness.



Experiment for time-gated imaging of femtosecond laser nanofabrication. The lower right inset shows nanoparticles ejected from the surface during the formation of nanoholes in a fused silica substrate.

Super-resolution imaging of single proteins provides a means for nanoscale visualization of life processes inside cells, but further advances require these new improved proteins. In another collaboration with the Center for Nanophase Materials Science at Oak Ridge National Laboratory we are researching new methods for directly creating nano-channels and micro-channels using femtosecond lasers and special focusing conditions. We are also studying the fundamental processes that occur during femtosecond laser machining by time-resolved probing and imaging of the plasma. The figure shows part of an apparatus for some of these studies together with an image of the laser-induced plasma plume. This study was presented at the Annual Meeting of the American Physical Society held in March this year.



# LASER MATERIALS PROCESSING

**WILLIAM Hofmeister**

*Research Professor of Materials Science and Engineering*

*PhD, Vanderbilt University*

*Adjoint Professor of Electrical Engineering, Vanderbilt University*

*University of Canterbury Visiting Erskine Fellow, 2011*

*Fellow of ASM International*

Professor Hofmeister came to UTSI ten years ago to become Director of the Center for Laser Applications following eighteen years on the faculty of Vanderbilt University. His primary interest is in additive fabrication. Hofmeister was one of the developers of the Laser Engineered Net Shaping (LENS™) process at Sandia National Laboratories and holds a patent for a feedback control system for that process. He is working with NASA, the US Air Force and Sciaky, Inc. to develop sensors and control strategies for additive manufacture using electron beam technologies. Two patents have been awarded to NASA for his innovations in control of electron beam additive manufacture.

Currently, Professor Hofmeister is developing femtosecond laser ablation techniques for the fabrication of micro and nanofluidic devices for biological applications. He is an External Associate of the Vanderbilt Institute for Integrative Biosystems Research (VIIBRE) and holds two patents for bioreactors with members of VIIBRE. CLA has a state-of-the-art nanofabrication facility in our clean room with a femtosecond laser coupled to a microscope with four axis nanopositioning stages. CLA has built devices for the study of cell migration during chemotaxis with the Janetopolis group in Vanderbilt's Department of Biological Sciences. With Melissa Skala this collaboration was recently awarded a Discovery Grant for "Microfluidic Intravital Windows for Local Antiangiogenic Cancer Inhibition." Dr. Hofmeister's group has developed a unique 3D model for cell culture and is exploring the use of these models in several laboratories to study cancer mutagenesis, lymphocytes and tissue regeneration.

Professor Hofmeister's research in nucleation and solidification kinetics led to three space flight experiments in the 1990's to study the effects of fluid flow on nucleation using the TEMPUS facility on IML-2, MSL-1, and MSL-1R. Dr. Hofmeister was principal investigator for the TEMPUS Incandescence Measurement Instrument Project, which designed and implemented an infrared pyrometer on the existing TEMPUS flight hardware. TEMPUS experiments were conducted by "telescience" operation in low earth orbit using modeling and simulation software which Dr. Hofmeister developed for the space flight experiments.

Professor Hofmeister is active in professional societies and outreach to the local community. He has served as Board President of the Tullahoma Hands on Science Center. He frequently works with the University of Tennessee Center for Industrial Services to assist local industry such as Fischer USA, Nissan, Walker Die Casting, Ace Pump, and Jarden Zinc, with materials related problem solving.

# MÖSSBAUER SPECTROSCOPY

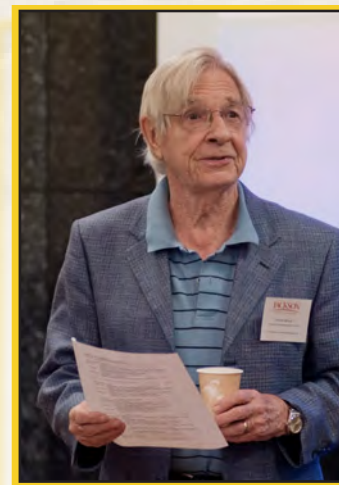
## Charles Johnson

Associate Director, UTSI

Emeritus Professor of Physics, University of Liverpool, England

M.A., Oxford University, England

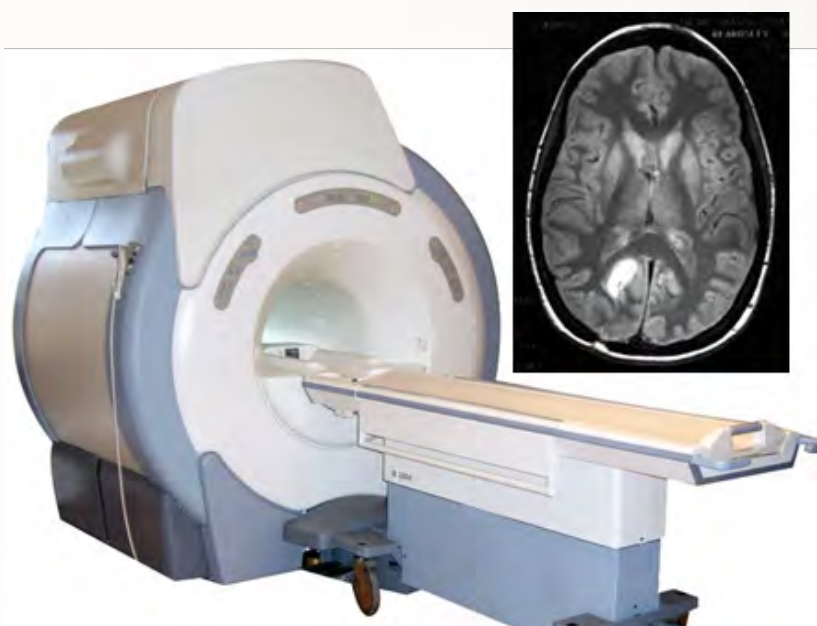
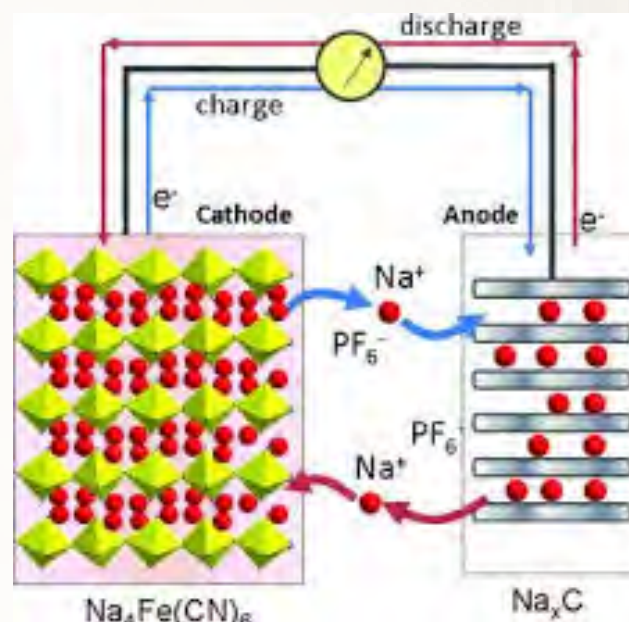
D. Phil., Oxford University, England



Dr Charles Johnson uses Mössbauer spectroscopy to study materials for applications to energy storage (batteries) and to medical imaging (Magnetic Resonance Imaging and X-ray tomography).

Measurements on battery materials are aimed at discovering new anodes for re-chargeable batteries. Lithium-ion batteries provide the same voltage as lead-acid batteries but are much lighter and convenient to use. Their disadvantages are the high cost and safety risks of lithium. Current research is on sodium-ion batteries, sodium being more abundant and stable than lithium but having similar electrochemistry. We have made  $^{121}\text{Sb}$  Mössbauer measurements on cells made at Oak Ridge containing antimony and sodium electrodes and studied the reaction with between them. On discharge,  $\text{Na}_3\text{Sb}$  is formed at the anode. On re-charging this becomes antimony again, and the cycle can be repeated.

We observed broad Mössbauer spectra of  $\text{Fe}_3\text{O}_4$  nanoparticles on cooling through the superparamagnetic blocking temperature. We have interpreted this as motional narrowing with increasing temperature. Such narrowing occurs in other spectroscopies e.g. nuclear magnetic resonance (NMR) or vibrational, where the linewidths are narrowed by motion of the nuclear spins or molecules. Borrowing the theory from NMR we deduced the relaxation times of the nanoparticles. Magnetic nanoparticles are potential contrast agents for enhancing MRI images by interacting with the protons and shortening their relaxation times. Currently this is done with gadolinium, which is the atom with the largest paramagnetic moment. But magnetic nanoparticles are much more strongly magnetic (hence they are called superparamagnets) and can produce even sharper images.





# TRANSPARENT STORAGE PHOSPHOR MATERIALS FOR DENTISTRY

Jacqueline Johnson

*Associate Professor*

*Mechanical, Aerospace and Biomedical Engineering (MABE)*

*B.Sc., University of Liverpool, England*

*Ph.D., University of Liverpool, England*

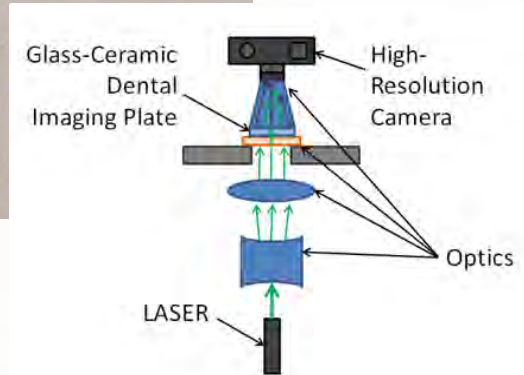
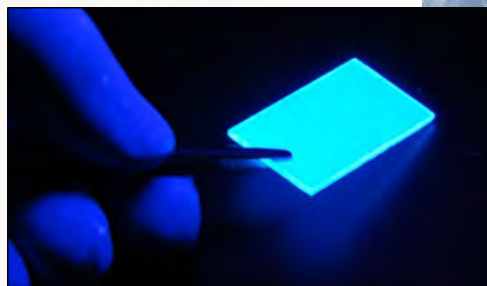
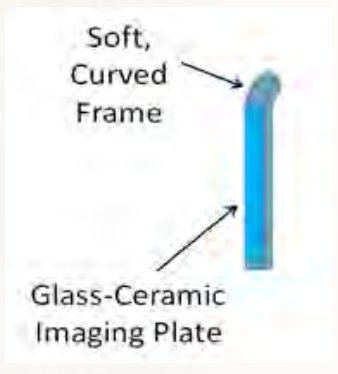
*Fellow of American Ceramic Society*

*Fellow of the Institute of Physics*

Work on ZBLAN glass ceramics progressed to the design of a commercial dental imaging system. The glass ceramic plate can replace conventional film and exceed its performance. Our plates, which can fit into existing dental envelopes, are reusable and low cost. A compatible, low-cost readout system has been designed, see illustration. A spinoff company will take the development to the next level.

Considerable performance enhancement of these glass-ceramic plates has been achieved during the last year not only for x-ray, but for  $\gamma$ -ray and neutron imaging as well. The group has also diversified beyond fluoride glasses to borate and sol gel matrices for image plates. This work is ongoing and UTSI has completed the assembly of its own scanner to read out images and test the efficiencies of the plates.

Borate matrix samples doped with Ce (III) Chloride containing no enriched isotopes gave excellent scintillation results when exposed to neutrons. One sample (not yet optimized) produced 40% the light output of GS20 (a commercial lithium glass scintillator). Eliminating enriched isotopes makes these materials relatively inexpensive. Several devices are on the horizon.



Dr. Johnson received a Research Fellowship Award from UTK and has been made Editor-in-Chief of the International Journal of Aeronautical Science & Aerospace Research (IJASAR), is on the Editorial Board for the Journal of Biomedical Technology and Research, and the Advisory Board for the Brain Tumors: Biology & Therapy Journal.

Dr. Johnson is grateful for the hard work by graduate students Lee Leonard, Jason Hah, Julie King and Research Participant, Sharon Gray as well as summer intern, Eric Gilmer.

# NONEQUILIBRIUM FLUID PHYSICS

## Trevor Moeller

*Assistant Professor*

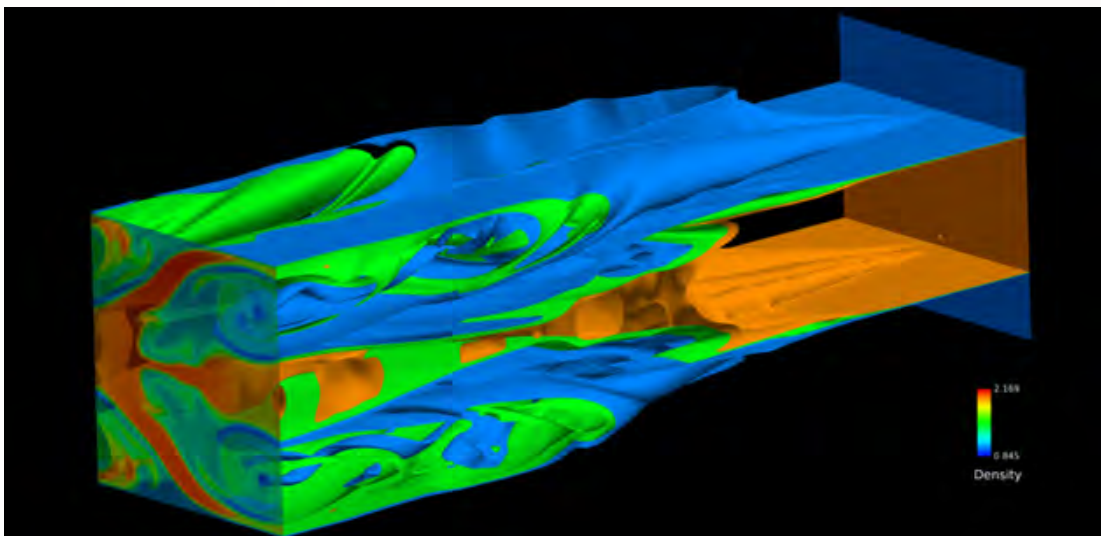
*PhD, University of Tennessee*

*UTSI Program Coordinator for Mechanical, Aerospace,  
and Biomedical Engineering (MABE)*



Dr. Trevor Moeller's research focuses primarily on high temperature gases and plasmas, including both modeling and experimentation. He has successfully completed projects involving technology development for a portable MHD generator, design and testing of a thermal storage and management system for the U.S. Air Force, and development of an ultrasensitive electric propulsion thrust stand. His current research activities for the U.S. Air Force include modeling and analysis of probes for high-temperature, high-velocity flows in rockets and gas turbine engines, precise measurement of convective heat transfer coefficients for unique probe geometries, investigations of cryodeposit contamination in cryopumped vacuum chambers, and diagnostics for space environment simulation chambers. The sensitive nature of these programs precludes the presentation of further details. Dr. Moeller also is conducting research in the development of tools for the modeling of coupled electromagnetic/fluid systems.

Key future engineering technologies such as advanced propulsion, hypersonic flight, and fusion drive Dr. Moeller's research. The accurate understanding, modeling and prediction of these technologies have motivated our new computational software and new theoretical framework. Our new software module, TEMPEST (Tennessee Electromagnetics/fluids/plasmas equation solver toolchain), facilitates accurate quantitative modeling of plasma dynamics in complex-geometry, multidimensional problems, which permits us to resolve the complete multi-species, multiscale dynamics occurring within a plasma device both efficiently and accurately. We have successfully applied this new tool to a wide range of relevant physical problems, including low-electrical-conductivity effects, magnetic field wave and diffusion behavior in the same computational domain, and magnetohydrodynamic turbulence. Currently, we are applying this approach to plasma propulsion systems and high-Mach flight and propulsion applications. We have also succeeded in applying this modeling software to capture full electrodynamic, gasdynamic devices, and low-conductivity plasma regions. Our new theoretical framework allows us to predict and understand the full multiscale dynamics within a plasma using classic analytical techniques. We are continuing to apply these new transformational tools to new problems in our drive to improve the state-of-the-art, and are pursuing new paths that will continue to extend our capabilities.



Fluid DNS simulation of a Kelvin-Helmholtz instability forming. This simulation was run with TEMPEST both with and without a magnetic field present to demonstrate suppression of small-wavelength instabilities by the magnetic field strength.

# MOLECULAR RECOGNITION



George M. Murray

*Adjunct Professor*

*Mechanical, Aerospace and Biomedical Engineering (MABE)*

*PhD, University of Tennessee*

Professor George M. Murray is an Adjunct Professor of Mechanical Aerospace and Biomedical Engineering at the University of Tennessee Space Institute. He came to UTSI in 2007 from Johns Hopkins University Applied Physics Laboratory. He specializes in chemical analysis, sensors and molecularly imprinted polymers. One of Professor Murray's areas of expertise is the preparation of specific sensors for toxic compounds. In one embodiment, the techniques of molecular imprinting and sensitized lanthanide luminescence have been combined to create the basis for a sensor that can selectively measure a specific organophosphorous compound. A complex of polymerizable sensitizing ligand europium (III) and an organophosphorous compound are copolymerized in a cross-linked polymer matrix. The polymerization mechanism used is Reversible Addition Fragmentation Transfer (RAFT) polymerization. This living radical polymerization method allows the preparation of specifically engineered block copolymer stars with nanoscale dimensions. The stars are soluble and processable imprinted materials. The stars are also end functionalized for binding to specific substrates such as glass or gold. Analogous methodologies are currently being applied to the production of sensors for the detection and determination of toxins, drugs of abuse, explosives and meat spoilage. Toxins are measured using piezo-electric transducers. Drugs are measured in an analogous manner to the nerve agents, while explosives are being detected by the production of charge-transfer complexes between the explosives molecules, (acceptor) and immobilized amines (donor). Meat spoilage sensing is obtained using luminescence from a transition metal macrocyclic complex. All of the materials are also capable of providing highly selective binding sites to other transducers, such as quartz crystal microbalance and surface plasmon resonance sensors.

Dr. Murray has published over 50 peer-reviewed papers in scientific journals as well as articles in the popular science press. He holds twenty-one U.S. patents and was named as one of the twenty-two Master Inventors of the Johns Hopkins University Applied Physics Laboratory. Dr. Murray's research interests are centered on developing methods for the sequestration and the ultra-trace determination of toxic or useful substances in real samples. The means to this goal involves the production of molecularly imprinted materials for sequestration and as specific polymer sensors. Laser spectroscopy is used for sensor transduction and verification. Laser processing is used to obtain specific form factors. Materials are also prepared for direct electronic or electrochemical transduction using electro-active polymers with imprinted polymer receptors.

# ATOMIC AND MOLECULAR LASER SPECTROSCOPY

## Christian Parigger

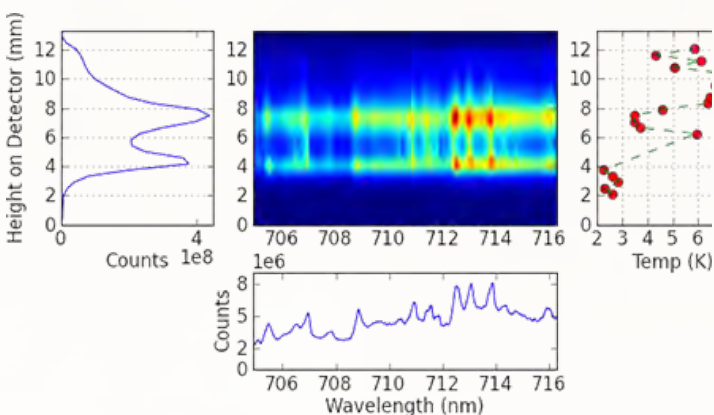
*Associate Professor of Physics and Astronomy*

*PhD, University of Otago, Dunedin, New Zealand*

*Dr. rer.nat. in Physics, University of Innsbruck, Austria*



Professor Parigger has been a member of the Center for Laser Applications (CLA) for over 27 years. The CLA celebrates its 30 year existence this year as well, along with the 50 year celebration of The University of Tennessee Space Institute (UTSI). His research contributions encompass experimental, theoretical, and computational Physics, with focus in atomic and molecular and optical (AMO) Physics. For example, fundamental and applied spectroscopy, nonlinear optics, quantum optics, ultrafast phenomena, ultrasensitive diagnostics, lasers, combustion and plasma Physics, optical diagnostics, applied optics, biomedical applications. His academic activities include service on various Masters and PhD committees both in Engineering and in Physics. He also organized as Chair the 22nd International Conference on Spectral Line Shapes (ICSLS). This conference has



Laser ablation plume above a titanium sample imaged 40 microseconds after laser-induced plasma formation using a 2 microsecond window. Note the appearance of two distinct luminescent regions in the plume. Inferences utilizing the TiO gamma band indicate markedly different temperatures for each of the two regions.

University, Arkansas State University, New Mexico State University, Denver University, University of Nebraska at Lincoln, and to National Laboratories including at Oak Ridge and at Albuquerque.

Christian Parigger's recent experimental research efforts continue to be comprised of various diagnostic works in natural science, i.e., Physics, and in applied science, i.e., Engineering. The figure illustrates results obtained with the new intensified charge coupled device (ICCD) to explore spatially and temporally resolved plasma phenomena. During the current reporting period, the students Alexander C. Woods, Michael J. Witte, David M. Surmick, and Lauren D. Swafford showed major strides towards completion of their formal post-graduate degrees. In fact, David completed his MSc requirements and will continue with his PhD at UTSI, Alexander is slated to complete all requirements for his PhD this summer and early fall, and both Lauren and Michael are well on target to complete their MSc degrees soon as well. Publications, proceedings, and presentations, including several invited presentations during the last year, amount to 77 in total as documented in the FY 2013-2014 accomplishments. Noteworthy, both Alexander Woods and David Surmick received 2014 University of Tennessee Chancellor's Honors for "extraordinary professional promise," an award that reflects extraordinary academic quality of ongoing work at the Center for Laser Applications.



# NANODYNAMICS AND HIGH-EFFICIENCY LAB FOR PROPULSION/POWER/ENERGY

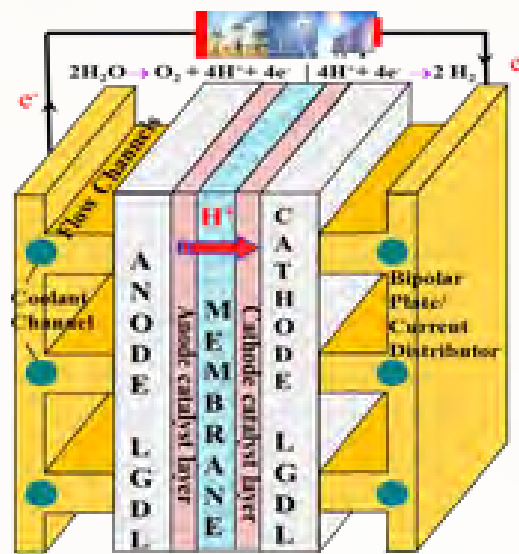
Feng-Yuan Zhang

PhD, Nagoya University

Associate Professor, Mechanical, Aerospace, and Biomedical Engineering Department

The research interests of Dr. Zhang's NanoHELP group lie in thermal-fluid sciences, nanotechnology, advanced manufacturing/3-D printing, and advanced spectroscopies and diagnostics. The goal of his NanoHELP group is to develop high-efficiency, low-cost and sustainable energy, power and propulsion devices, such as fuel cells, electrolyzers, batteries, direct combustion engines, and electric thrusters. The NanoHELP research ranges from fundamental understanding to system optimization with a strong interdisciplinary program for the study of micro/nano-scale chemical reaction, heat/mass transport, fluid mechanics, novel materials, degradation, surface/mechanical/chemical properties, multiscale manufacturing and MEMS/NEMS.

The current research projects in Dr. Zhang's NanoHELP group are partially supported by Department of Energy. As shown in Figure 1, an advanced polymer electrolyte membrane water electrolyzer (PEMWE), which is a reverse PEM fuel cell (PEMFC), has been an effective energy storage medium by producing hydrogen /oxygen from water with electricity from renewable energy sources because of its distinguished efficiency and high energy density. It has been greatly challenged for promoting higher efficiency with state-of-the-art technologies and advanced materials. The harsh environment in the PEMWE will cause material corrosion and consumption, leading to poor interfacial contacts and a reduction in its performance and efficiency. In the past year, a set of liquid/gas diffusion layers (LGDLs), made of different materials, were tested for better investigating corrosion mechanism and interfacial degradation in our group. Severe corrosions were discovered with both electrochemical



PEM electrolyzers



Stuart, Joel, and Dr. Han welcome visitors from AEDC and ORNL, and introduce their researches.

performance and electrochemical impedance measurements. Based on the discoveries, titanium was identified to be a promising material, and a matrix of Ti LGDLs with different thicknesses and a range of porosities from 30% to 80% are designed and examined for parameter optimization. The CLA nanofabrication facilities have been utilized for LGDL fabrications and surface modification. In addition, a laser/optic-based micro detection system was developed in the group to capture the dynamics of micro-scale reaction and transport through the transparent engine. A thermal infrared spectroscopy was also developed for multiscale investigation of reaction mechanism and temperature profiles.

# AWARDS, PUBLICATIONS, PROCEEDINGS, PRESENTATIONS AND PATENTS FOR FY 2013-2014

## Awards:

J. A. Johnson, Professional Development Award UTK (2013)

J. A. Johnson, Research Fellowship UTK (2014)

Alexander C. Woods, University of Tennessee Chancellor's Honors Recipient for "Extraordinary Professional Promise," April 2014.

David M. Surmick, University of Tennessee Chancellor's Honors Recipient for "Extraordinary Professional Promise," April 2014.

## Appointments:

David M. Surmick, Sandia National Laboratories Summer Internship, Albuquerque, New Mexico, May-July, 2013.

David M. Surmick, Sandia National Laboratories Summer Internship, Albuquerque, New Mexico, May-July, 2014.

Lloyd Davis, May 2014: iBME Affiliate Professor

Lloyd Davis, summer, 2014: Visiting Researcher, JILA, CU Boulder, CO.

Christian G. Parigger, International Scientific Committee Member of The Applied and Laser Spectroscopy Laboratory (ALSLAB), Pisa, Italy, May 2014.

Christian G. Parigger, Member of the Editorial Board of the Journal of Applied and Laser Spectroscopy, May 2014.

Christian G. Parigger, Journal of Physics: Conference Series, Editor: 22nd International Conference on Spectral Line Shapes, March 2014.

## Book Chapters:

Murray, G. M., "Detection and Screening of Chemicals Related to the Chemical Weapons Convention," in Encyclopaedia of Analytical Chemistry, Meyer, R. A., Ed. John Wiley: Chichester. DOI: 10.1002/9780470027318.a0403.pub2. Published 16 Sept 2013.

Robert Splinter, Christian G. Parigger, "Fluid Dynamics Phenomena in Cardiovascular Ablation with Laser Radiation," Chapter 20 in Lasers in Cardiovascular Interventions, On Topaz, Ed. (Springer, 2014) in press.

## Publications:

### Publications Peer Reviewed Journals

J. K. King, B. K. Canfield and L. M. Davis, "Three-dimensional anti-Brownian electrokinetic trapping of a single nanoparticle in solution," Applied Physics Letters **103**, 043102 (2013); DOI: 10.1063/1.4816325. [http://apl.aip.org/resource/1/applab/v103/i4/p043102\\_s1?ver=pdfcov](http://apl.aip.org/resource/1/applab/v103/i4/p043102_s1?ver=pdfcov).

L. M. Davis, J. L. Lubbeck, K. M. Dean, A. E. Palmer and R. Jimenez "Microfluidic cell sorter for use in developing red fluorescent proteins with improved photostability," Lab on a Chip **13**, 2320-2327 (2013); DOI: 10.1039/c31c50191d. <http://pubs.rsc.org/en/content/articlelanding/2013/lc/c31c50191d>.

Craig A. Brice and William H. Hofmeister, "Determination of Bulk Residual Stresses in Electron Beam Additive-

Manufactured Aluminum, Metallurgical and Materials Transactions A," November 2013, Volume 44, Issue 11, pp 5147-5153.

Spencer W Crowder, Yi Liang, Rutwik Rath, Andrew M Park, Simon Maltais Peter N Pintauro, William Hofmeister, Chee C Lim, Xintong Wang, and Hak-Joon Sung, Poly( $\epsilon$ -caprolactone)-carbon nanotube composite scaffolds for enhanced cardiac differentiation of human mesenchymal stem cells, Nanomedicine (Lond). Nov 2013; 8(11): 10.2217/nnm.12.204. doi: 10.2217/nnm.12.204.

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C. E. Johnson, M. Vu, J. A. Johnson, D.E. Brown, J. K. R. Weber, C. Paßlick and S. Schweizer, "Mössbauer spectroscopy of europium-containing glasses: Optical activator study for x-ray image plates," Hyperfine Interactions, **226**, pp 797–801 (2014). DOI 10.1007/s10751-014-1065-0.

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## Publications accepted and in press:

### Accepted Peer-reviewed Publications

Ying-Ling Chen, L. Shi, J. W. L. Lewis and M. Wang, *Infrared Retinoscopy, Ophthalmology and Visual Science, Special Issue: Optics and Technologies for Ophthalmology and Visual Science* (2014).

K. Hockemeyer, C. Janetopoulos, A. Terekhov, L. Costa, W. Hofmeister, A. Vilgelm, J. P. Wikswo, and A. Richmond, "Engineered Three-Dimensional Microfluidic Device for Interrogating Cell-Cell Interactions in the Tumor Microenvironment," *BIOMICROFLUIDICS*.

Robert Rhodes, Trevor Moeller, Abraham J. Meganathan and Ahmad D. Vakili, "Numerical Modeling of an Aspirated Total Temperature Probe," *Experimental Techniques*, No. 3, 2014.

Stuart M. Steen and Feng-Yuan Zhang: *In-situ and Ex-situ Characterizations of Electrode Interfaces in Energy Storage Electrolyzers*," *ECS Transactions*, Vol 59, 2014. (in press).

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Craig A. Zuhlke, John Bruce III, Troy P. Anderson, Dennis R. Alexander and Christian G. Parigger, "Fundamental Understanding of the Dependence of the LIBS Signal Strength on the Complex Focusing Dynamics of Femtosecond Laser Pulses either Side of Focus," *Applied Spectroscopy*, 2014 (in press).

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Christian G. Parigger, Alexander C. Woods, David M. Surmick, Lauren D. Swafford and Michael J. Witte, "Measurements of Ultra-Violet Titanium Lines in Laser-Ablation Plasma," *Spectrochimica Acta Part B: Atomic Spectroscopy*, 2014 (Accepted Pending Revision).

## Conference Proceedings:

Kathryn Hockemeyer, Tammy Sobolik, Alexander Terekhov, Melody Swartz, William Hofmeister, John Wikswo, Chris Janetopoulos, Ann Richmond, "A three-dimensional in vitro bioreactor for analysis of the tumor microenvironment: investigation of interstitial flow and the mechanism of metastasis." [abstract]. In: Proceedings of the 104th Annual Meeting of the American Association for Cancer Research; 2013 Apr 6-10; Washington, DC. Philadelphia (PA): AACR; Cancer Res 2013; 73(8 Supplement): Abstract number 2614. doi:10.1158/1538-7445.AM2013-2614.

Christian G. Parigger, Jacqueline A. Johnson, and Robert Splinter, "Optical Diagnostic and Therapy Applications of Femtosecond Laser Radiation using Lens-Axicon Focusing," Conference proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, **ISSN:** 1557-170X Pages: 374-377.

Jonathan A. Merten, Matthew Jones, Cheyenne Shepherd, Christian G. Parigger and Susan D. Allen, "Spatiotemporal Evolution of Plasma Molecular Emission Following Laser Ablation of Explosive Analogs," Proceedings of the SPIE 8710 (2013), Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XIV (2013) id. 87100S, 10 pages.

Alexander C. Woods and Christian G. Parigger, James O. Hornkohl, "LIBS: Plasma Containing Titanium as a Probe for Temperature," in Technical Program, Federation of Analytical Chemistry and Spectroscopy Societies 40th Annual Meeting (FACSS 2013), Milwaukee, Wisconsin, September 9 – October 4, 2013.

Lauren D. Swafford and Christian G. Parigger, "LIBS: Hydrogen Balmer Series Plasma Spectroscopy in Air," in Technical Program, Federation of Analytical Chemistry and Spectroscopy Societies 40th Annual Meeting (FACSS 2013), Milwaukee, Wisconsin, September 9 – October 4, 2013.

Craig Zhulke, John Bruce III, Troy P. Anderson, Dennis R. Alexander and Christian G. Parigger, "Fundamental Understanding of the Dependence of the LIBS Signal Strength on the Complex Focusing Dynamics of Femtosecond Laser Pulses Either Side of Focus," in Technical Program, Federation of Analytical Chemistry and Spectroscopy Societies 40th Annual Meeting (FACSS 2013), Milwaukee, Wisconsin, September 9 – October 4, 2013.

Michael J. Witte and Christian G. Parigger, "LIBS: Carbon Swan Plasma Emission Spectroscopy," in Technical Program, Federation of Analytical Chemistry and Spectroscopy Societies 40th Annual Meeting (FACSS 2013), Milwaukee, Wisconsin, September 9 – October 4, 2013.

David M. Surmick and Christian G. Parigger, "LIBS: Aluminum Monoxide Emission Measurements," in Technical Program, Federation of Analytical Chemistry and Spectroscopy Societies 40th Annual Meeting (FACSS 2013), Milwaukee, Wisconsin, September 9 – October 4, 2013.

Aren Haug, Brian C. Hogan, A.B. Donaldson, Christian G. Parigger and David M. Surmick, "Simulating and Modeling a Solid Propellant Rocket Plume Using an Aluminum Powder Fed Oxyacetylene Torch," Proceedings of the Western States Section of the Combustion Institute Fall 2013 Meeting, Colorado State University, Fort Collins, Colorado, October 7-8, 2013, 10 pages.

Christian G. Parigger and Alexander C. Woods, "Atomic Hydrogen and Diatomic Titanium-Monoxide Molecular Spectroscopy in Laser-induced Plasma," Proceedings of the 18th Atomic Processes in Plasmas (APIP) Conference, Auburn University, Auburn, Alabama, October 7-10, 2013, 6 pages, to be published.

Alexander C. Woods and Christian G. Parigger, "LIBS: Measurements of Laser-Induced Plasma Containing Titanium," in Technical Program, Laser-Induced Breakdown Spectroscopy in Undergraduate Research and Teaching (LIBS-URT), Juniata College, Huntingdon, Pennsylvania, November 15-16, 2013.

Christian G. Parigger and David M. Surmick, "LIBS: Measurements of Aluminum Monoxide Emission in Laser-Induced Plasma," in Technical program, Laser-Induced Breakdown Spectroscopy in Undergraduate Research and Teaching (LIBS-URT), Juniata College, Huntingdon, Pennsylvania, November 15-16, 2013.

Alexander C. Woods and Christian G. Parigger, "Micro-plasma Parameter Inferences Utilizing Titanium Spectral Transitions," in Bulletin of the American Physical Society 58 (APS, 2013), 80<sup>th</sup> Annual Meeting of the APS Southeastern Section, Bowling Green, Kentucky, November 20-23, 2013.

- Michael J. Witte and Christian G. Parigger, "C<sub>2</sub> Swan Bands Measurements Using Laser-Induced Breakdown Spectroscopy," in Bulletin of the American Physical Society 58 (APS, 2013), 80<sup>th</sup> Annual Meeting of the APS Southeastern Section, Bowling Green, Kentucky, November 20-23, 2013.
- Lauren D. Swafford and Christian G. Parigger, "Plasma Spectroscopy of Hydrogen Balmer Series in Laboratory Air," in Bulletin of the American Physical Society 58 (APS, 2013), 80<sup>th</sup> Annual Meeting of the APS Southeastern Section, Bowling Green, Kentucky, November 20-23, 2013.
- David M. Surmick and Christian G. Parigger, Aren Haug, A. B. Donaldson, Walt Gill, "Analysis of Aluminum Monoxide Emission Spectra in a Simulated Solid Rocket Propellant Flame," 80<sup>th</sup> Annual Meeting of the APS Southeastern Section, Bowling Green, Kentucky, November 20-23, 2013.
- Sultan A. Behery and Christian G. Parigger, "Measurement and Analysis of CN Violet System in Laser-Induced Plasma," in Bulletin of the American Physical Society 59 (APS, 2014), Annual APS Meeting, Denver, Colorado, March 3-7, 2014.
- Josef P. Fleischmann, Lauren D. Swafford, Michael J. Witte, David M. Surmick, Alexander C. Woods, Sultan A. Behery, Christian G. Parigger and James O. Hornkohl, "Spectroscopic Temperature and Number Density of Nitric Oxide in Laser-Induced Plasma," in Bulletin of the American Physical Society 59 (APS, 2014), Denver, Colorado, March 3-7, 2014.
- David M. Surmick and Christian G. Parigger, "Time-Resolved Aluminum Monoxide Emission Measurements in Laser-Induced Plasma," in Bulletin of the American Physical Society 59 (APS, 2014), Denver, Colorado, March 3-7, 2014.
- Lauren D. Swafford and Christian G. Parigger, "Atomic Hydrogen Measurements in Laser-Induced Plasma," in Bulletin of the American Physical Society 59 (APS, 2014), Denver, Colorado, March 3-7, 2014.
- Michael J. Witte and Christian G. Parigger, "Measurement and Analysis of Carbon Swan Emissions using Laser Induced Breakdown Spectroscopy," in Bulletin of the American Physical Society 59 (APS, 2014), Denver, Colorado, March 3-7, 2014.
- Alexander C. Woods and Christian G. Parigger, "Molecular Spectroscopy of TiO in Laser-Induced Plasma," in Bulletin of the American Physical Society 59 (APS, 2014), Denver, Colorado, March 3-7, 2014.
- James O. Hornkohl, Alexander C. Woods, Christian G. Parigger, "Diatomic Line- And Band-Structure In Laser-Induced Plasma," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 10.
- Craig Zuhlke, Dennis R. Alexander, John Bruce III, Troy Anderson and Christian G. Parigger, "Focusing Phenomena of Femtosecond Laser Radiation Interacting With Material," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 23.
- James O. Hornkohl, Josef P. Fleischmann, David M. Surmick, Michael J. Witte, Lauren D. Swafford, Alexander C. Woods and Christian G. Parigger, "Emission and Laser-Induced Fluorescence Spectroscopy of Nitric Oxide," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 53.
- Christian G. Parigger, Lauren D. Swafford, David M. Surmick, Michael J. Witte and Alexander C. Woods, "Investigation of Hydrogen Alpha Self-Absorption Effects in Laser-Induced Plasma," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 60.
- David M. Surmick and Christian G. Parigger, "Aluminium Laser-Induced Plasma Characterization," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 64.
- Lauren D. Swafford and Christian G. Parigger, "Atomic Hydrogen Balmer Series Measurements in Laser-Induced Plasma," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 69.
- Michael J. Witte and Christian G. Parigger, "Laser Induced Breakdown Spectroscopy of Graphene," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 72.
- Alexander C. Woods and Christian G. Parigger, "Atomic and Molecular Emission Lines for Plasma Characterization from Laser Ablation of Titanium," in 22<sup>nd</sup> International Conference on Spectral Line Shapes, Total Graphics Print, Tullahoma, TN, (2014), p. 73.

## Presentations - Conferences and Seminars:

J. L. King, J. A. German and L. M. Davis, "Anti-Brownian Electrokinetic Trapping of Single Nanoparticles in Solution," TN-SCORE Annual Conference, Nashville Airport Marriott, Nashville, TN, June 10-11, 2013.

Trevor M. Moeller, L. Montgomery Smith, Frank G. Collins, Jesse M. Labello, James P. Rogers, Heard S. Lowry, Dustin H. Crider, "Further results in measuring water ice buildup on optical components in cryogenic vacuum chambers," SPIE Proceedings, Vol. 8841: Current Developments in Lens and Design and Optical Engineering XIV, 88410R, September 25, 2013.

L. M. Davis, N. J. Orfield and S. Rosenthal, "Ultrasmall quantum dots as a potential source of white-light single photons," Single Photon Workshop, 2013, Oak Ridge National Laboratory, Oak Ridge, TN, October, 15-18, 2013.

K. M. Dean, L. M. Davis, J. L. Lubbeck, P. Manna, R. Jimenez and A. E. Palmer, "Multiparametric Microfluidic Flow Cytometry", at "Seeing Is Believing—Imaging the Process of Life," EMBO/EMBL Symposia, European Molecular Biology Laboratory, Heidelberg, Germany, October 3-6, 2013. (The European Molecular Biology Laboratory is Europe's flagship laboratory for basic research in molecular biology. It is supported by 20 European countries and Australia as associate member state).

R. J. Baltz, G. R. Beitel, T. M. Moeller, and M. M. May, "The AEDC/UTSI J85 Test Stands," Internal Air Force document, presented at AFRL, Dayton, OH, December, 2013.

G. M. Murray, "Imprinted Polymers for Illicit Substance Detection," Mistral Security, Bethesda, MD, December 10, 2013.

Jacqueline A. Johnson, "Nanoparticles in Medicine/Graduate Opportunities and Internships," Seminar, University of North Georgia, Dahlonega, USA (2013).

J. A. Germann, J. K. King, B. K. Canfield and L. M. Davis, "Three-dimensional tracking and trapping of single emitters in a confocal fluorescence microscope," Invited Presentation, The 17<sup>th</sup> Annual Southeast Ultrafast Conference (SEUFC), Baton Rouge, LA, January 9-10, 2014.

B. K. Canfield, T. S. Bowman, A. Terekhov, W. H. Hofmeister and L. M. Davis, "Using single femtosecond laser pulses to micromachine exceptionally high aspect ratio features," The 17<sup>th</sup> Annual Southeast Ultrafast Conference (SEUFC), Baton Rouge, LA, January 9-10, 2014.

T. S. Bowman, B. K. Canfield and L. M. Davis, "Studies of temporal dynamics of single-pulse femtosecond laser materials interactions in fused silica," The 17<sup>th</sup> Annual Southeast Ultrafast Conference (SEUFC), Baton Rouge, LA, January 9-10, 2014.

B. Wang and L. M. Davis, "Single-molecule recycling in a nanochannel," The 17<sup>th</sup> Annual Southeast Ultrafast Conference (SEUFC), Baton Rouge, LA, January 9-10, 2014.

Richard Thompson and Trevor Moeller, "An Approximate Riemann Solver for Relativistic Two-fluid Plasmadynamics," Presented at 52nd AIAA Aerospace Sciences Meeting, National Harbor MD, Paper number AIAA-2014-1192, January 13-17, 2014.

Richard Thompson, Andrew Wilson, Trevor Moeller and Chuck Merkle, "A Unified Hyperbolic Model for Coupled Fluid Dynamics and Electromagnetics in Aerospace Applications," Presented at 52nd AIAA Aerospace Sciences Meeting, National Harbor MD, Paper number AIAA-2014-1191, January 13-17, 2014.

S. M. Steen III and F.-Y. Zhang, Investigating Corrosions and Interfacial Effects of Gas Diffusion Layers in PEMWE", 2014 Electrochemical Conference on Energy and the Environment (ECEE), ECEE-0271, March 2014.

L. M. Davis, J. A. German, J. K. King, and B. K. Canfield, "Feedback-driven tracking and trapping of a single fluorescent nanoparticle in a confocal microscope," Annual Meeting of American Physical Society, Denver, CO, March 3-7, 2014.

B. K. Canfield, T. S. Bowman, A. Terekhov, L. Costa, D. Rajput, W. H. Hofmeister, and L. M. Davis, "Exceptionally high aspect ratio micromachining with single femtosecond laser pulses," Annual Meeting of American Physical Society, Denver, CO, March 3-7, 2014.

T. S. Bowman, B. K. Canfield and L. M. Davis, "Imaging and pump-probe studies of femtosecond laser ablation of fused silica," Annual Meeting of American Physical Society, Denver, CO, March 3-7, 2014.

B. Wang and L. M. Davis, "Capabilities for measuring the diffusivity of a single molecule by recycling it in a nanochannel," Annual Meeting of American Physical Society, Denver, CO, March 3-7, 2014.

G. M. Murray, "Molecular Recognition for Chemical Detection Using Molecular Imprinting," Field Forensics, Saint Petersburg, FL, April 17, 2014.

L. M. Davis, "Single-molecule fluorescence in micro-/nano-fluidic devices & femtosecond laser microfabrication," iBME, Annual Meeting, University of Tennessee Knoxville, TN, April 21-22, 2014.

S. M. Steen and F.-Y. Zhang, Optimization of Gas Diffusion Layers with High-Corrosion Resistance for PEMWE, 225<sup>th</sup> ECS meeting, The Electrochemical Society, May, 2014.

Lauren D. Swafford, David M. Surmick, Michael J. Witte, Alexander C. Woods and Christian G. Parigger, "Study of Hydrogen Balmer Series Self-Absorption in Laser-Induced Plasma," 41<sup>st</sup> Annual FACSS Meeting, Reno, Nevada (2014) Accepted for Oral and/or Poster Presentation, May 2014

David M. Surmick and Christian G. Parigger, "Spectroscopy of Laser-Induced Plasma Containing Aluminum," 41<sup>st</sup> Annual FACSS Meeting, Reno, Nevada (2014) Accepted for Oral and/or Poster Presentation, May 2014.

Alexander C. Woods, "Titanium Laser Ablation Plasma Characterization from Two-Dimensional Imaging of Atomic and Molecular Emission Lines," 41<sup>st</sup> Annual FACSS Meeting, Reno, Nevada (2014) Accepted For Oral Presentation, May 2014.

Michael J. Witte, Alexander C. Woods, David M. Surmick, Lauren D. Swafford, James O. Hornkohl and Christian G. Parigger, "Spectroscopy of Atomic and Diatomic Species Following Laser-Induced Breakdown in Air," Laser-Induced Breakdown Spectroscopy Conference, Beijing, China (2014) Submitted for Oral and/or Poster Presentation, May 2014.

D. Rajput, L. Costa, A. Terekhov, K. Lansford, W. Hofmeister, Fabrication and characterization of silica coated polymer nanowires, 22<sup>nd</sup> International Conference on Spectral Line Shapes, University of Tennessee Space Institute, Tullahoma, Tennessee, USA, June 1-6, 2014.

S. M. Steen III, F.-Y. Zhang, Energy Dispersive X-Ray and Electrochemical Impedance Spectroscopies for Performance and Corrosion Analysis of PEMWEs, 22<sup>nd</sup> International Conference on Spectral Line Shapes, University of Tennessee Space Institute, Tullahoma, Tennessee, USA, June 1-6, 2014.

Mo, Jingke (Joel), Steen, S. M., and Zhang, F.-Y., X-Ray Diffraction Studies on Material Corrosions in Renewable Energy Storage Electrolyzers, 22<sup>nd</sup> International Conference on Spectral Line Shapes, University of Tennessee Space Institute, Tullahoma, Tennessee, USA, June 1-6, 2014.

K. M. Dean, L. M. Davis, J. L. Lubbeck, P. Manna, A. E. Palmer and R. Jimenez, "Microfluidic flow cytometer for multiparameter screening of fluorophore photophysics," Conference on Lasers and Electro Optics (CLEO), San Jose, CA, June 8-13, 2014.

L. M. Davis, K. M. Dean, P. Manna, J. L. Lubbeck, A. E. Palmer and R. Jimenez, "Microfluidic cell-sorter measures fluorescence lifetime, photobleaching, and brightness for use in developing improved red fluorescent proteins," 9<sup>th</sup> International Weber Symposium on Innovative Fluorescence Methodologies in Biochemistry and Medicine, Lihue, HI, June 15-20, 2014.

R. J. Baltz, S. M. Coulter, G. R. Beitel, T. M. Moeller, and M. M. May, "Materials Testing in the AEDC/UTSI Propulsion Research Facility," NSMMS National Space and Missile Materials Symposium, Huntsville, AL, June 26, 2014.

Jacqueline Anne Johnson, "Radiation Detection: The case for glass ceramics," Seminar, Oak Ridge National Laboratory, Oak Ridge, USA, (2014).

Jacqueline Anne Johnson, "Nanoscience in Imaging," Lightning talk, Symposium, Institute of Biomedical Engineering (iBME), Knoxville, USA, (2014).

## Invited Presentations:

J. A. Johnson, L. Leonard, C. Alvarez, C. E. Johnson, S. Schweizer, R. Lubinsky, A. Petford-Long, S. Clare and T. Gorgio, "Nanoparticles in Medicine, 8th Pacific Rim International Conference on Advanced Materials and Processing," Hilton Waikoloa Village, Big Island of Hawaii, USA (2013).

Christian G. Parigger, "Laser-Induced Plasma Dynamics Measurements Using Atomic and Molecular Spectroscopy," in Euro-Mediterranean Symposium on Laser Induced Breakdown Spectroscopy (EMSLIBS 2013), Invited Speaker #O-05, Bari, Italy, September 20-24, 2013.

Christian G. Parigger, "Atomic and Diatomic Molecular Spectroscopy in Laser-Induced Plasma," in Atomic Processes in Plasmas (APIP 2013), Invited Speaker Session 6, Auburn, Alabama, October 7-10, 2013.

Christian G. Parigger, "Laser-induced Breakdown Spectroscopy and Laser-induced Plasma Research at UT Space Institute," in Laser-Induced Breakdown Spectroscopy in Undergraduate Research and Teaching (LIBS-URT), Invited Plenary Speaker, Juniata College, Huntingdon, Pennsylvania, November 15-16, 2013.

Russell Lee Leonard, Julie King, Jacqueline Johnson and Stefan Schweizer, " $\gamma$ -ray imaging enhancement using nanoscience," 38th International Conference and Expo on Advanced Ceramics and Composites Daytona Beach, USA, (2014).

## Contributed Presentations:

Dr. Susan E. Clare, Dr. Catherine Jones Murphy and Dr. Jacqueline A. Johnson, "Image Guided Surgery for Resource-limited Countries," NCI-NIBIB Point of Care Technologies for Cancer Conference, Bethesda, MD, USA, (October 2013).

J. E. King, H-Y. Hah, C. E. Johnson, J. A. Johnson, M. D. Pawet, A. J. Rondinone, K. C. Kirkbride and T. D. Giorgio, "Development of Iron Nanoparticles for Brain Cancer," (2014), Institute for Biomedical Engineering (iBME) symposium (Knoxville, USA April 2014).

H. Y. Hah, M. Cole, S. Gray, C. E. Johnson, J. A. Johnson, V. Kolesnichenko, P. Kucheryavy and G. Goloverda, "Motional narrowing in Mössbauer spectra of superparamagnetic  $\text{Fe}_3\text{O}_4$  nanoparticles," 22<sup>nd</sup> International Conference on Spectral Line Shapes, Tullahoma, TN, June 1-6, 2014.

Craig Zuhlke, Dennis R. Alexander, John Bruce III, Troy Anderson and Christian G. Parigger, "Focusing Phenomena of Femtosecond Laser Radiation Interacting With Material," Invited Oral Presentation Wed III.b, 22<sup>nd</sup> International Conference on Spectral Line Shapes, Tullahoma, TN, June 1-6, 2014.

Alexander C. Woods and Christian G. Parigger, "Emission Lines for Plasma Characterization from Laser Ablation of Titanium," Invited Oral Presentation Wed IV.c, 22<sup>nd</sup> International Conference on Spectral Line Shapes, Tullahoma, TN, June 1-6, 2014.

## Patents, Patent Applications and Disclosures:

"Adaptive Photoscreening System," Y.-L. Chen, J. W. L. Lewis, International Application no. PCT/US2012/023097, 201280013994. X, September 23, 2013.

"Nanostructures from Laser-Ablated Nanohole Templates," William Hudson Hofmeister, Alexander Yuryevich Terekhov, Jose Lino Vasconcelos Da Costa, Kathleen Stacia Lansford, Deepak Rajput, Lloyd M Davis; US Patent Application, 20130,216,779, 2013.

"Molecularly Imprinted Polymer Ion Exchange Resins," Murray, G. M. et al., Patent # 8,591,842, November 26, 2013.

"Optically Integrated Microfluidic Cytometers For High Throughput Screening of Photophysical Properties of Cells or Particles," Amy E. Palmer, Ralph Jimenez, Kevin Dean, Jennifer Lubbeck, Lloyd M. Davis, U. S. Patent Number 8,618,510,B2, Publication Date: December 31, 2013.

## Research Funded Externally

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2013-2014 Expended
<b>Davis, Lloyd</b>	Nanostructures for Enhancing Energy Efficiency, Tennessee Solar Conversion and Storage Using Outreach, Research and Education (TN-SCORE) (R02-4318034)	National Science Foundation	August 15, 2010–July 31, 2015	\$179,340	\$71,602
<b>Hofmeister, William</b>	Microfluidic Intravital Windows for Local Antiangiogenic Cancer Inhibition (R02-4411044)	Vanderbilt University	January 1, 2012–December 31, 2013	\$10,000	\$2,934
<b>Johnson, Jacqueline</b>	Advanced High-Resolution Two-Dimensional X-Ray Detector for Mammography (R02-4417020)	National Institutes of Health	February 1, 2008–July 31, 2013	\$1,768,678	0
	Study of the Evolution of Nanoparticle Crystallization and Optical Properties in Glass Ceramics (R02-4417022)	National Science Foundation	July 1, 2010–June 30, 2014	\$299,157	\$66,721
	Nanophase Glass Ceramic X-Ray Imaging Materials (R02-4417024)	National Institutes of Health/Materials Development, Inc. subcontract	October 1, 2010–September 28, 2013	\$30,000	0
	Large Area, High Resolution Storage Phosphor Detectors for High Energy (MeV) Digital Radiography (R02-4417025)	B&W Y-12 LLC	February 20, 2013–September 30, 2014	\$200,000	\$120,605
	Optical Imaging of Residual Disease with Upconverting Nanocrystals (R024417026)	National Institutes of Health/Materials Development, Inc. subcontract	September 16, 2013–August 31, 2014	\$16,000	\$12,815
	Raman Spectroscopy of Graphitic Materials (R024417027)	GrafTech	January 31, 2014–January 30, 2015	\$2,221	\$1,543
	<b>Moeller, Trevor</b>	NASA Tennessee Space Grant Consortium (R02-4320026)	Vanderbilt University	June 14, 2010–June 13, 2015	\$187,143
Cryo Deposition Research, Experimentation, and Development of Early Warning and Mitigation Technologies (R02-4348026)	Air Force/AEDC	November 21, 2008–December 31, 2014	\$294,500	\$46,106	

# Research Funded Externally

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2013-2014 Expended
<b>Moeller, Trevor</b>	Integration & Technical Support to the 12V Vertical Thrust Integration (R02-4348033)	Air Force/AEDC	September 22, 2010–September 30, 2013	\$60,000	\$34,002
	UCDS Enhancement for MDA Applications (R02-4348037)	Gloyer-Taylor Laboratories, LLC	July 1, 2012–April 30, 2014	\$300,000	\$142,590
	Design, Fabrication and Operation of Bi-Directional Reflectance Function Generator (R02-4348038)	Air Force/AEDC	January 25, 2013–June 30, 2014	\$23,000	\$19,123
	Induction Heater Technical Development Support and Structural Tests of GTL Samples (R02-4348040)	Gloyer-Taylor Laboratories, LLC	January 2, 2013–August 30, 2013	\$7,500	\$1,664
	Novel System for Cryodeposit Mitigation and Remediation (R02-4348041)	Physical Science, Inc.	March 3, 2013–December 10, 2013	\$60,000	\$51,132
	Heat Transfer Coefficient characterization for Stagnation Temperature Probe (R02-4348042)	Air Force/AEDC	April 19, 2013–June 30, 2014	\$50,000	\$33,586
	Cryotank Testing Support (R02-4348043)	Gloyer-Taylor Laboratories, LLC	September 6, 2013–September 30, 2013	\$3,866	\$3,853
	Support of Plasma Effects, Diagnostics, and Analysis in STAT (R02-4348044)	AEDC/FMF	February 24, 2014–September 30, 2015	\$55,000	\$4,304
	Radiation Uncertainty Characterization for Stagnation Probe (R02-4348045)	Air Force/AEDC	April 11, 2014–May 8, 2015	\$50,000	\$12,370
	A Cryo-Vacuum Compatible Positioning System (R02-4348046)	Square One Systems Design	June 30, 2014–June 30, 2016	\$10,000	0
	ACE Booster (R02-4348047)	Gloyer-Taylor Laboratories, LLC	June 25, 2014–December 19, 2014	\$32,000	0
<b>Zhang, Feng-Yuan</b>	Developing Novel Multifunctional Materials for High-Efficiency Electrical Energy Storage (R02-4421020)	Department of Energy	September 1, 2013 – August 31, 2016	\$300,000	\$30,686