Optics and Photonics Research for Montana Economic Development - MREDI Project
Quarter 1 Report - November 6, 2015
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Publicity for Optics MREDI project
The start of this MREDI project and related national-level recognition of MSU's role in establishing and sustaining the Montana optics and photonics economic sector generated a significant amount of publicity during this quarter. Many of these stories are related to an event that illustrates the significance of the role of MSU in economic development. The University Economic Development Association (UEDA) selected the MSU Optical Technology Center (OpTeC) as the recipient of their Award of Excellence in the "Talent Development" area. A brief summary follows:

7/16/15 Bozeman Chronicle story prior to MREDI announcement (mentions strength of Montana Optics and Photonics industry): http://www.bozemandailychronicle.com/news/montana_state_university/montana-gears-up-to-award-million-for-research/article_6ab5b7d4-c571-56e2-ac5a-24f0c8942625.html

8/18/15 MSU News Story: http://www.montana.edu/news/15681/montana-state-university-awarded-research-funding-to-spur-state-s-economy

8/18/15 Montana Associated Technology Roundtable (MATR) announcement of MREDI project: http://www.matr.net/article-67447.html

8/18/15 NBC Montana news story about MREDI announcement: http://www.nbcmontana.com/news/state-money-pours-in-for-montana-research-projects/34786468

8/19/15 Flathead Beacon news story about MREDI: http://flatheadbeacon.com/2015/08/19/research-grants-announced-for-montana-montana-state/

8/19/15 KSL news story about MREDI: http://www.ksl.com/?nid=157&sid=36038111&title=research-grants-announced-for-montana-montana-state

8/25/15 Photonics.com online news story about MREDI precision agriculture: http://www.photonics.com/Article.aspx?AID=57661

9/16/15 Bozeman Chronicle story about Montana optics and photonics industry: http://www.bozemandailychronicle.com/news/economy/optics-research-industry-blossom-in-bozeman/article_249ce589-75a7-5796-a2e7-e6b238fbd155.html

MSU-produced video about Optics and Photonics MREDI project: https://www.youtube.com/watch?v=wA0DbkzwSK4

10/7/15 University Economic Development Association (UEDA) announces Award of Excellence to MSU's Optical Technology Center: http://us4.campaign-archive2.com/?u=148d8087193215a0c78e516a8&id=91bbd79ccf&e=26435fb1aa

10/7/15 University Economic Development Association (UEDA) archive of MSU's Optical Technology Center nomination and award summary:
http://universityeda.org/value-to-members/best-practice-sharing/awards-of-excellence/2015-awards-of-excellence/awards-of-excellence-2015-finalists/optical-technology-center-optec/

10/11/15 Montana Associated Technology Roundtable (MATR) announcement of MSU's OpTeC economic development award:
http://www.matr.net/article-68218.html

10/12/15 MSU News story about OpTeC economic development award:
http://www.montana.edu/news/15787/msu-s-optical-technology-center-wins-economic-development-award

10/12/15 KBZK news story about OpTeC economic development award:
http://www.kbzk.com/story/30242996/msus-optical-technology-center-wins-economic-development-award

10/12/15 Bozeman Daily Camera news story about OpTeC economic development award:
http://www.bozemandailychronicle.com/news/economy/msu-optical-technology-center-wins-economic-development-award/article_e510556f-5d1a-5ada-b401-dacab453ddad.html

10/12/15 NBC Montana news story about OpTeC economic development award:
http://www.nbcmontana.com/news/msu-tech-center-receives-top-award/35826252

Subproject 1: Ultra-compact spectral imagers for precision agriculture and mapping of wildfires and natural resources (Joseph Shaw, joseph.shaw@montana.edu with NWB Sensors, Inc.). Development of ultra-compact imaging systems for weed mapping in precision agriculture, UAV mapping of wildfires, and a wide variety of ground-based and airborne remote sensing. The sensor systems will be commercialized through NWB Sensors, Inc. and tested for precision agriculture at Montana farms in Fairfield, MT and Sidney, MT with Meridian Flying Services from Sidney, MT.

Milestones

a) September 30, 2015: Initial agricultural data collection completed
b) December 31, 2015: Initial weed maps complete
c) June 30, 2016: Prepare a refined imaging system and application-specific algorithm
d) December 31, 2016: Complete results of summer 2016 harvest experiment
e) June 30, 2017: Finish imaging system and algorithms and transfer to private partner

Accomplishments to date

- Milestone "a" was completed on schedule and we are on schedule to meet the rest.
- Two prototype spectral imagers with near infrared (NIR), red, and green channels were constructed and operated alongside two commercial GoPro cameras with standard red, green, and blue (RGB) channels.
- Imagers were operated with GPS systems in three combines during grain harvest in Fairfield, Montana, during August 2015.

- More than 450,000 images were collected over 9 days, covering an estimated 700 acres of barley and 80 acres of wheat.
- These data are being used as a training set to test weed detection algorithms.
- Manual classification of nearly 100 scenes with a variety of conditions has been done to create a training data set that will be used to create a robust weed detection algorithm. In these scenes, regions have been manually selected and put into 4 categories: clean crop, weeds, harvested crop (stubble), other obstructions (ditches, pivot tracts, etc).

Initial results show that a simple Normalized Difference Vegetation Index (NDVI) algorithm is insufficient for reliable weed detection in the variable conditions experienced in the field. For example, the imaged scenes included barley and weeds, but also included green non-ripe barley, lodged barley, bare stubble, closed dirt ditches, pivot wheel tracks, animals, and combinations of these objects at one time. Furthermore, these occurred under a variety of lighting conditions including direct sunlight, overcast skies, broken clouds, dusk, dusty air, and artificial headlights (nighttime). Because of this wide variety of scenes a multi-dimensional analysis is being conducted using a variety of color ratios (including NDVI), scene brightness, color vectors, and other parameters.

Manual classification of nearly 100 scenes under a variety of conditions has been performed to create a training data set that will be used to create a robust weed detection algorithm. In these scenes, regions have been manually selected and put into 4 categories: clean crop, weeds, harvested crop (stubble), and other obstructions (ditches, pivot tracts, etc). These expert-classified data sets are now being used to develop a robust classifier to identify weeds within the scene.

Figures 1-3 are photographs from the August 2015 barley harvest at Nugent Farms in Fairfield, Montana. Figure 1 shows a prototype spectral imaging system mounted in the cab of a combine. Figure 2 is a wide-angle image of the combine seen from the front (the prototype spectral imager is in the cab, but is not noticeable in this image). Figure 3 is another photograph of the combine during harvest.

Figure 1. Photograph of a prototype spectral imager mounted in the cab of a combine during the August 2015 barley harvest at Nugent Farms in Fairfield, Montana (photo by Paul Nugent).

Figure 2. Wide-angle image of the combine during barley harvest at Nugent Farms in Fairfield, Montana (photo by Paul Nugent).

Figure 3. Photograph illustrating weeds embedded in grain during August 2015 harvest.

Expenditures to date

Salaries $19,710.21, Benefits $3916.56, Operations $3483.96, total Expenditures $27,110.73

Subproject 2: High-performance, real-time image processing for hyperspectral imaging (Ross Snider, rksnider@ece.montana.edu with Resonon, Inc.). Design a high-speed hyperspectral waterfall sorting system to fuse object edge information with hyperspectral data to sort agricultural products quickly and efficiently using Resonon's Hyperspectral Imagers and remove rejected items via airjets. The goal is to perform the data fusion, accept/reject decision, and removal all in real-time using FPGA technology.

Milestones

a) February 1, 2016: Determination of center of mass of each food item in image/line scan
b) September 1, 2016: Determine trajectory of food item for precise timing removal
c) February 1, 2017: Integrate hyperspectral data within food item edge boundaries
d) June 31, 2017: Use hyperspectral data within food item edges to classify food item as accept/reject
e) June 31, 2017: Time air jets to remove rejected food items
f) June 31, 2017: Final report emphasizing commercial products and potential

Activities to date

- We have a senior design group starting to work on the line scan camera imaging.
- Identified high speed line scan Camera (8K pixels, 80 kHz line scan rate, monochromatic, CameraLink interface). Have quote ($3,280) that includes CameraLink cables, Power supply, and 50-mm line sensor macro lens (f mount). The line scan camera data will be processed by an Altera Arria V FPGA development board with a CameraLink interface.
- Looking into a conveyor belt test bed system. Resonon is checking with a supplier they are familiar with. The conveyor belt test bed will have objects falling off the end of the conveyor belt to be sorted in free-fall. An ideal setup, which would be a recirculating conveyor belt system, looks like it will be too expensive. We may end up just getting a basic system.
- Looking into purchasing FESTO MHJ fast-switching valves (0.8 ms on time, 0.4 ms off time) for air jet array. Looking at setting up an array of air jets to eject unwanted items.

Projected next quarter activities

- Physically integrate line scan camera to Arria V FPGA board.
- Start on VHDL component interface to capture data in FPGA fabric.
- Start on VHDL component interface to initialize Line scan camera.
- Purchase conveyor belt test bed.
- Purchase air jet components and start work on air jet subsystem.

Expenditures to date (there will be significantly higher expenditures after camera purchase)
Salaries $183.00, Benefits $7.04, Operations $7,164.31, total Expenditures $7,354.35

Subproject 3: Remote Sensing Algorithms for Precision Agriculture (Rick Lawrence with Resonon, Inc.) Develop and apply a methodology using hyperspectral imagery for determining optimal narrow spectral band combinations for identifying targeted invasive weeds in specific crops.

Activities to date

- We are in the process of conducting an extensive review of methods for selecting optimal hyperspectral band pass ranges for targeted differentiation of invasive species in specified crops.
- We have hired Samuel Tittle as an undergraduate research assistant. He will be completing his BS in Geospatial and Environmental Analysis in December 2015, at which time he will start his graduate program on this project on a Graduate Research Assistant.

Expenditures to date
Salaries $334.38, Benefits $13.01, Operations $0, total expenditures $347.39.

Subproject 4: Machine Vision Algorithms for Precision Agriculture (Neda Nategh with Resonon and NWB Sensors, Inc.) Develop machine vision algorithms for weed detection and food sorting using spectral imaging data.

Milestones

a) Nov. 31, 2015 Formalize strategy for machine vision research in collaboration with spectral imaging team.
b) May 31, 2016 Initial machine vision algorithms developed.

c) Sep. 30, 2016 Initial testing of machine vision algorithms complete.
d) May 31, 2017 Final testing and development complete.
e) June 30, 2017 Final report completed.

Activities to date

- First-quarter activity was recruiting student to work on project.

Expenditures to date

No expenditures to date while student is recruited and spectral imaging team prepares to provide sample data to work with.

Subproject 5: Microcavity sensors for hyperspectral imaging (Zeb Barber with Advanced Microcavity Sensors LLC). Advance MSU/Advanced Microcavity Sensors LLC (AMS) technology on microcavtity hyperspectral imaging sensors toward commercial applications in agriculture and engineering tests to determine feasibility of mounting sensor technology on UAV; secondary objective solving MT problems in agriculture and biomedical (skin cancer). The primary objective focused on MREDI goal #2: creating private sector jobs.

Milestones

a) June 1, 2016: Investigate non-circular symmetric micro-cavity mirrors for transverse mode manipulation
b) September 1, 2016: Evaluate Microcavity Hyperspectral Imaging prototype system for early crop disease/weed detection
c) December 30, 2016: Determine engineering specifications for use of Hyperspectral Sensor on UAV
d) June 30, 2017: Submit final report specifying technical accomplishments and outlining commercial potential.

Activities to date

- MSU Spectrum Lab received subcontract from Spectral Molecular Imaging Inc. of Beverly Hills, CA on a Phase I Air Force Small Business Technology Transfer (STTR) contract. This STTR provides funds for the investigation and development of the microcavity spectral imaging technology for Defense department needs in biomedical applications. This sub-contract provides $77,682 to MSU Spectrum Lab for a 9 month effort, with potential to receive a minimum of $250,000 in Phase II funds.
- Advanced Microcavity Sensors (AMS) research contract with the Montana Board of Commercialization and Technology (MBRCT) was finalized and funds were transferred to AMS. This project also provided a sub-contract to MSU Spectrum Lab in the amount of $59,482.00. The AF STTR project above also represents matching funds for the MBRCT effort.
- Dr. Russell Barbour, due to the MBRCT funding at AMS, has dropped to 0.5 FTE at MSU Spectrum Lab and will be transitioning to full time at AMS over the coming year.
- Dr. David Atherton a recent PhD graduate from the University of Nevada-Reno and MSU Physics alum was hired in June 2015 based in part on the potential for the MREDI funding on this project. Dr. Atherton is providing the bulk of the effort on the STTR the MBRCT and this effort for MSU Spectrum Lab.

Expenditures to date
Salaries $7,090.41, Benefits $2,323.85, Operation $198.20, total Expenditures **$9,618.46**

Subproject 6: Hyperspectral imaging for monitoring cell growth (Ed Dratz, dratz@chemistry.montana.edu with Resonon, Inc.). Design a hyperspectral imaging system for monitoring the metabolic state of live cells in culture. Applications to stem cells for understanding disease mechanisms in individuals, drug testing in cells from individuals, potentially optimize personal nutrition, and solve montanan's health problems.

Milestones

a) February 1, 2016: Complete design and testing of proof of principle prototype hyperspectral imager with improved cost/benefit, prototype interface for cell hyperspectral analysis, and development of stem cell labeling
b) May 1, 2016: Integrate the prototype systems for advanced analysis of stem cell metabolism with hardware and software control. Test for evaluation of optimization of selected nutrients
c) October 1, 2016: Refine and improve software and operating conditions of real time hardware and software for variations of metabolic state for culture optimization
d) February 1, 2017: Enhance user interface to control system and software to control and optimize nutrient composition; evaluate possible changes in microscope system for improved performance
e) June 30, 2017: Proof of principle for feedback control of nutrient optimization with nutrient dosing control system. Investigate biochemical individuality in pilot experiment
f) June 30, 2017: Submit grant proposals to leverage additional support. Final report to MUS that summarizes accomplishments and commercial potential

Activities to date

- Progress toward Milestone a) … Considerable progress has been made in the Dratz lab (PI) on preparing optogenetic probes of oxidation/reduction state of human adult stem cells in culture. A graduate student in the Dratz lab is devoting full effort to preparing the optogenetic probes and is being assisted by two postdoctoral in the Reijo Pera lab and a Research Assistant Professor in the Singel lab, all in the Chemistry and Biochemistry Department. An advanced undergraduate Electrical and Computer Engineering (ECE) Design Team in the Snider lab in ECE has been designing the microscope stage controller system. The stage requirements have been put out for bid and two responsive bids are being evaluated with purchase planning early in the next quarter. A graduate student in the Snider lab is devoting full effort to the high speed hyperspectral imaging analysis software and will be working on this crucial aspect of this project into the next year.
- Prof Dratz and Prof. Snider have had four phone conferences with scientists and administrators from the EMD Millipore Corporation, supported by many email communications, to gain access to the software codes to control the Onyx CellAsic microfluidic cell culture control and observation system. The desired software code access has been granted by EMD Millipore administrators and software engineers and an Onyx CellAsic system will be ordered at the start of the second quarter.
- The Resonon Inc work to date has been to move an upright microscope test system from the Dratz Lab to Resonon's facility for initial testing of the excitation laser system for hyperspectral

imaging. Preliminary concepts have been formulated for coupling laser beams to the telescope system. Additional work is needed to test the concept and begin development.

Expenditures to date
Salaries $10,322.96, Benefits $1,111.68, Operations $5,334.45, total expenditures $16,769.09

The personnel include two graduate students devoting full effort to the project, two advanced undergraduates on an ECE Design Team and one half month of faculty time in summer.

Subproject 7: Translational research to commercialize micro-mirror technology (Arrasmith at Revibro Optics). Translate MSU-developed deformable mirror technology to a commercially sustainable product.

Milestones

a) Refine production to achieve a repeatable fabrication process. This milestone will involve a redesign of fabrication masks, purchase of new wafer bonding equipment, and refinement of wafer bonding process (June 30, 2016).
b) Obtain funding from another source. Revibro will pursue funding through commercial sales and commercial R&D efforts (June 2016), and through SBIR/STTR or similar government funding (June 2017).
c) Create 2 full time Montana jobs: One job will be created immediately to sustain the founder of Revibro (August 2015); Technical and/or sales and marketing hire (December 2015).

Activities to date

- Finalized subaward from MSU.
- Revibro Optics has begun investigation into commercial wafer bonding solutions. We are currently working with OAI to develop a semi-custom bonding machine to fit our needs and budget.
- Revibro Optics attended the SBIR road show on August 18, 2015 and started discussions with several government agency reps about upcoming SBIRs. As submission deadlines approach, Revibro Optics will monitor solicitations and submit proposals for valuable SBIR topics.
- Revibro Optics engaged two MSU students from the BMGT 475R class. As part of their class work in this “Management Experience” class, the students are working pro bono as consultants for Revibro Optics. Their efforts are helping with marketing materials, as well as market research and customer engagement. The experience to date has been very valuable and will continue to help Revibro Optics find and engage customers through the end of the year.
- We have been working on marketing materials for the upcoming Photonics West trade show in February, 2016. This is an important event to secure commercial interest for Revibro Optics’ deformable mirrors. We expect several product sales to result from this trade show.
- Chris Arrasmith, founder of Revibro Optics, is employed full time thanks to the MREDI project. In the coming year, Chris will be searching for another hire to help with sales and marketing or the deformable mirror products.

Total Expenditures
Personnel $5156.25

Subproject 8: Active waveguides and integrated optical circuits (Rufus Cone, cone@physics.montana.edu, collaborating with Babbitt, Nakagawa, Barber, Himmer, Avci, and Thiel with S2 Corp., AdvR, FLIR/Scientific Materials, and Montana Instruments). Integrate Montana products, expertise, and capabilities to improve marketability, performance, and enable additional products: Build interdisciplinary connections among MUS and Montana optics industries to integrate (a) optical crystals by FLIR/Scientific Materials Corp. (SMC); (b) waveguide photonic components of AdvR, Inc.; (c) Montana Instruments (MI) cryogenic systems; and (d) S2 Corp. (S2C) signal processing devices.

Milestones

a) Fall 2015: Fabrication of rare earth doped optical waveguide suitable for optical signal processing applications
b) Summer 2016: Integration of an optical waveguide into a cryostat
c) Spring 2017: Demonstration of SSH processing in a cryogenic waveguide
d) June 2017: Final report summarizing technical results and emphasizing commercial potential.

Activities to date

Discussion

During this first reporting period, we initiated a number of parallel efforts with the Montana companies S2 Corp., FLIR / Scientific Materials Corp., AdvR Inc., and Montana Instruments to enable these companies to enter markets where light beams are used to take over tasks normally carried out with electronics. The optical or "photonic" devices can actually do things beyond the performance of modern electronics. Our work develops new capabilities at MSU and is directly targeted to enable Montana participation in international markets that use light "guided" through crystals. These integrated photonic "waveguide" devices have many more functionalities than the more familiar optical fibers and are the essential next generation of product applications. The word "integrated" here implies subminiaturized packaging of the type familiar from modern electronics. Indeed, we are making "circuits for light."
Our vision is to employ special rare-earth-activated crystals produced by Scientific Materials-FLIR with the waveguide design and the miniature packaging capabilities of AdvR, all integrated with Montana Instruments low temperature systems to enable photonic signal processing systems produced by S2 Corp., leading to new products for each company. With this goal, we are rapidly developing the infrastructure and expertise required to extend the current photonic technologies of MSU and Montana businesses into the optical waveguide field, establishing new and powerful class-leading capabilities in subminiaturized integrated photonic circuits to MSU's research arsenal and Montana companies' product lines.

This project involves broad interdisciplinary collaborations between six different research groups at MSU from several departments and centers, providing unique synergy that establishes a long-term program of sustainable collaboration in this field, with short-term development focused on immediate return for Montana businesses and current research programs at MSU. The initial efforts of these groups are focused into several key areas:

- Rare-earth-activated crystal and waveguide development by the ***Cone-Thiel group***
- Photonic circuit information processing theory and demonstrations by ***MSU Spectrum Lab***
- Testing of Montana Instruments cryostat stability and optical integration by the ***Babbitt group***
- Waveguide fabrication and lithography evaluation by the ***Montana Microfabrication Facility***
- Computational modeling of waveguide design and performance by the ***Nakagawa group***
- Analysis of waveguide structure by the MSU ***Imaging and Chemical Analysis Laboratory***

A high-level outline of the overall project plan is presented in Figure 4 showing how current activities tie into our key milestones and project outcomes. All activities are on schedule to successfully meet our project goals.

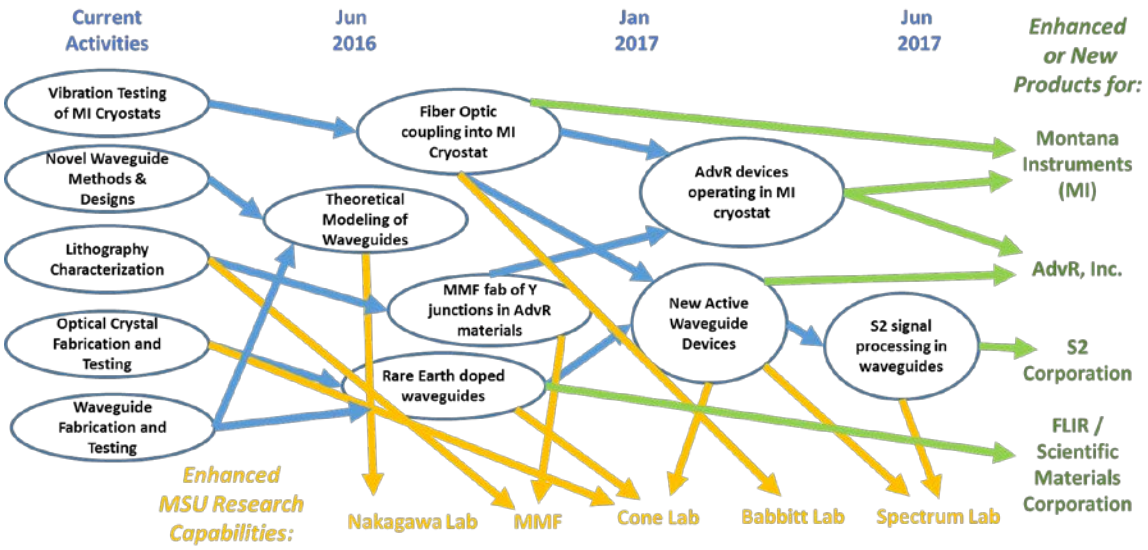

Figure 4. Approximate timeline of key project milestones showing interconnections and outcomes.

A number of important results have already been achieved during this first reporting period, as outlined below.

- MSU physics' collaboration with Montana Instruments was initiated and progress is going well. The latest model of Montana Instrument's closed cycle optical cryostat was installed in one of the Physics' optics labs (Prof. Babbitt's Lab). The installation included training for two graduate students and one undergraduate student on the maintenance and operation of the state-of-the-art cryostat. The set-up of the optics, electronics, and computer control is complete and initial testing has begun. The process of setting up the optical system for conducting optical coherence testing of the cryostat also afforded the students extensive training on laser systems, optical components, and other lab test equipment.
- Continued discussions and planning for joint development efforts were carried out with all companies: FLIR / Scientific Materials Corp., S2 Corp., Montana Instruments, and AdvR Inc.
- Supplies and hardware required for rare-earth-activated waveguide synthesis were purchased and assembled. The process of purchasing the Montana Instruments cryostat required for this effort was initiated.
- Rare-earth-doped planar waveguides were fabricated in $LiNbO_3$ crystals and the indiffusion process for putting Erbium rare-earth ions into $LiNbO_3$ crystal was demonstrated.
- We successfully demonstrated a simple method for rapid fabrication of basic channel waveguides with micron resolution using metal film deposition methods. Furthermore, a new approach for employing evanescently coupled silicon waveguides was developed that may allow well-established silicon photonics to be applied to current rare-earth-activated crystal technologies.
- Advanced spectroscopic characterization using spectral hole burning and optical coherent transient measurements was carried out on Thulium-indiffused $LiNbO_3$ wafers for study of photonic signal

processing properties, verifying that the crystal properties meet the requirements for S2 signal processing, as done at S2 Corporation.

- MSU Spectrum Lab has begun setting up a test bed system for photon echo and spectrum analysis and to study interferometric measurement techniques in Tm:$LiNbO_3$ materials
- Efforts have begun to acquire the necessary new theoretical modeling tools and software to build up a numerical modeling capability for micro/nano scale optical waveguides and devices involving purchase of new computer modeling and analysis software.
- Two undergraduate students working on this project successfully submitted directly related research proposals to the MSU Undergraduate Scholars Program, and they have received awards in support of their studies. These student efforts will directly contribute to this project's goals.
- A seminar series for students involved in the MREDI project, as well as other students, is being hosted by Spectrum Lab (offered as a class this fall through the Physics Department). In the seminar, the students are learning about the physics of optical coherent transient phenomena, including those used in the coherence testing of Montana Instrument's cryostat; the physics of the spectral holeburning crystals produced by Scientific Materials; the physics involved in the spectral holeburning based spectrum analyzer produced by S2 Corporation; and the physics of various optical components and laser systems, including those produced by AdvR and Bridger Photonics.

Progress on Economic Objectives

- The collaborative process of installation and set-up of the Montana Instruments cryostat for testing in Babbitt lab at MSU afforded the opportunity for Montana Instruments to film a marketing video of one of their units in action in an optics lab.
- Work was carried out with Scientific Materials Corp. to evaluate and improve a new line of optical laser crystals that will allow them to enter a solid-state laser market and successfully compete with the current established suppliers. Measurements and analysis carried out in the Cone lab at MSU provided quantitative analysis of industry-standardized material performance and provided guidance for additional material improvement requirements used by Scientific Materials Corp. in their continued product development.
- Based on discussions with AdvR and Scientific Materials, a fabrication system was designed and is in the process of being implemented to produce very thin single crystal wafers required to enable products at both companies. At AdvR, these crystal wafers will be used to build a new type of optical waveguide that allows improved nonlinear optical applications. At Scientific Materials, these crystal wafers will allow them to enter the market of thin radiation scintillator detectors—a product currently only offered by a competitor in Czechoslovakia.
- A presentation on fundamental properties and ultimate capabilities of rare-earth-activated materials was presented by Charles Thiel at S2 Corp. in August for visiting federal IARPA visitors and funding managers, answering critical questions about scalability of S2 Corp systems required to receive next stage funding.
- Measurements and analysis were carried out to improve materials supplied to S2 Corp for signal processing by reducing optical heating and providing multiplexing signal capacity enhancements.
- Industry collaborators BAE systems (Nashua, NH) and S2 Corp. are in negotiation with the Office of Naval Research (ONR) for a ~$11.9 Million ONR Discovery and Innovation project that will be supported and directly benefit from our MREDI waveguide development efforts. This project at S2 Corp will include a $767,000 three year subcontract for MSU Spectrum Lab (PI: Barber) and is expected to add several new Montana jobs at both S2 Corp and MSU.

- A subcontract to MSU Spectrum Lab (PI: Barber) from S2 Corp. that is supported by our MREDI efforts was increased in duration (+4 months) and budget (+$60k) for continued work on the project entitled "Efficient Photonic Computational Engine for Selection and Filtering."
- A research proposal related to our MREDI efforts was submitted to the Montana Space Grant Consortium on "Nanoscale Poling and Structuring in Nonlinear Optical Materials" for $50k (PI: Himmer and Co-PI: Nakagawa).

As work continues on our MREDI efforts to develop waveguide technologies for Montana Industry and MSU, a number of research professionals and student researchers have joined the project. In the case of most of the research professionals, support by MREDI funding has allowed them to remain in Montana. In one case, a lucrative job offer to work on lighting system development was turned down to remain in Montana and work with MSU and local industry on this MREDI effort. At MSU, non-faculty personnel working on this effort so far include Charles Thiel (Senior Research Scientist, Spectrum Lab and Physics Department), Tia Sharpe (Research Engineer, Spectrum Lab), Krishna Rupavatharam (Senior Research Scientist, Spectrum Lab), Jacob Braunberger (Ph.D. Student, Physics), Aaron Marsh (Ph.D. Student, Physics), Philip Woodburn (Ph.D. Student, Materials Science), Rose Ahlefeldt (Postdoctoral Fullbright Scholar), Brett Wilkins (Undergraduate Student, Physics), and Kaitlin Poole (Undergraduate ROTC Student, Physics). In addition to these academic positions, additional funding from outside of Montana that is critically supported by our MREDI effort is expected in the near term at S2 Corp. where several new jobs are expected to be added over the next year.

Expenditures to date
Salaries $6,903.61, Benefits $1,087.77, Operations $7,622.19, total Expenditures $15,613.57

Additionally, the process of purchasing the required Montana Instruments cryostat for $120,000 to be used in this work has been initiated.

Subproject 9: Optical Parametric Oscillator for Tunable Lasers (Kevin Repasky, repasky@ece.montana.edu, with AdvR, Inc.). Investigate optical parametric oscillator performance in support of characterizing large aperture periodically poled non-linear optical crystals and in support of continued development of large area methane detection.

Milestones

a) December 2016: Model optical parametric oscillator performance using SNLO modeling tools
b) June 30, 2017: Demonstrate singly resonant optical parametric oscillator pumped at 1064 nm and seeded at 1650 nm
c) June 30, 2017: Final report including scientific merit and commercial products or potential

Activities to date

- Purchased camera for characterizing infrared laser beam ($5000)
- Purchased 2 infrared diode lasers ($2000)
- Purchased diode laser mount ($500)
- Hired 1 graduate student at beginning of Fall semester

Expenditures to date
Salaries $1780.00, Benefits $9.43, Operations $4745.00, total expenditures $6534.43

Subproject 10: Nonlinear Optical Detection of Surface Contaminants (Rob Walker, rawalker@chemistry.montana.edu, with Altos Photonics). Develop a new method for detecting organic contaminants that accumulate on the surface of water based on nonlinear vibrational overtone spectroscopy (NVOS).

Milestones

a) December 2015: Demonstrate feasibility of using new spectroscopic method for surface detection of adsorbed species
b) June 2016: Submit SBIR application with Altos to develop detection and monitoring instrument based on NVOS
c) December 2016: Successful application of NVOS to environmentally relevant systems including contaminants on water surfaces and solid substrates
d) June 2017: Final report summarizing technical accomplishments and commercial potential.

Activities to date

This project's goal is to develop new surface-specific, optical methods capable of detecting adsorbed molecules. Specifically, our efforts are focused on exploiting the advantages of nonlinear optical spectroscopy to create a simple, sensitive technique that can identify the presence of organic contaminants at water/air and solid/liquid interfaces. Our ultimate objective is to use discoveries from our seminal studies to guide the development of portable devices capable of being used for field measurements.

During the first several months of this project, we have made progress on several fronts. We have purchased equipment and designed and built an assembly for our planned studies. This equipment includes a near-infrared photomultiplier tube (PMT) and related optics to direct near-infrared light onto the sample. The PMT is not a common one and had a lead time for delivery of 12 weeks. The unit is scheduled to ship on Nov 12. We have also begun preparing model samples for the initial, proof-of-principle studies. We fully expect to meet our first milestone of demonstrating feasibility of using this new spectroscopic method for surface detection of adsorbed species by the end of December, 2015.

The MREDI-award has provided partial support for 2 graduate students working on this project in the form of stipend, benefits, and tuition. Starting in the Spring '16 semester, a graduate student will be supported full-time as a Graduate Research Assistant.

Expenditures to date

Salaries $4,731.48, Benefits $643.22, Operations $1913.99, total Expenditures $7,288.69
Spending will increase considerably in the next 3 months as more resources are dedicated to supporting personnel.