Center for Optical Sensors and Spectroscopies (COSS)

Alabama EPSCoR RII

http://www.coss.phy.uab.edu/
What is the Purpose of the COSS?

The objective of the COSS is to utilize optical sensor technology used for detecting environmental contaminants and to improve these techniques using recently developed revolutionary laser and spectroscopic technologies.

- One application will be Counter-Terrorism related applications such as the detection of chemical warfare agents and their precursors, explosive agents, and biological warfare agents.
- Another application is to assist in emergency response to protect human health after natural disasters through the rapid detection of organic and inorganic toxicants.
- A final application is for biological related research.

MISSION: the mission of the COSS is to promote optical sensing and spectroscopy research on environmental, biomedical, and national security issues through collaborative use of resources and expertise among the member universities, government and industrial laboratories, and improve sensor techniques using recently developed revolutionary laser and spectroscopic technologies.
Alabama EPSCoR RII

"Enhancing Alabama's Research Capacity in NanoBio Science and Sensors"

Strategic Plan

first year Research and Education Program of COSS:

- Perform nanoscale research on biological and nanoscale materials using the unique (only one in the USA) Raman/AFM/NSOM System
- Research directed toward the long-term development of electrically pumped mid-IR lasers for ultra-portable trace gas detection systems
- Development of doped “smart nanoparticles” for image guided interventions
- Development of “Optical Nose” system for trace gas detection and analyses
- Development of environmental challenge samples for testing and characterization by COSS Spectroscopy instrumentation
- Develop NLO materials for sensor protection (SP) in the blue spectral region
- Investigation of mid-IR frequency comb development for ultra-fast spectroscopy
- Improve Pipeline for Nano-Bio and Sensor Research through COSS
- Develop Educational Process for COSS Science in Motion Experiment
- Dissemination of COSS Results

Center for Optical Sensors and Spectroscopies

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Perform nanoscale research on biological and nano materials using the unique Raman/AFM/NSOM System:

COSS. 1. Set up nanoscale RAMAN/AFM/NSOM System.

During last quarter nanoscale Raman/AFM/NSOM system installation (only one in the USA) was partially complete. This system combines four different platforms (confocal fluorescence, Raman, AFM, and NSOM) in one instrument allowing simultaneous studying of samples of interest using all four platforms in wide spectral range from UV to near-IR with unprecedented spatial resolution down to several nanometers. This system is unique, with the only analog located in Max Planck Institute, Leipzig Germany.
**Development of "Optical Nose" System for trace gas detection and analysis:**

**COSS.3. Design and test mid-IR light sources for "Optical Nose" system**

One of the key components of the "Optical Nose" system is Tm-fiber pumped Q-switched Ho\(^{3+}\):YAG laser (2.1\( \mu \text{m} \)). Recently, with the use of Cr:ZnSe saturable absorbers developed at UAB/COSS, an effective passive Q-Switching of the Ho:YAG laser cavity was demonstrated.

- Output energy up to 3 mJ,
- Repetition rate 100-1500 Hz
- Efficiency with respect to free-running operation 75%
- Slope efficiency 38%

Developed technology allows simplification of the "Optical Nose" basic pump source. In addition, COSS researches designed optical system combining developed single frequency tunable (2-3\( \mu \text{m} \)) laser with a multipass optical cell (total pass 240 m) for preliminary testing of organic molecules. After this testing optical system will be combined with Nonlinear Optical Parametric Generator based on ZGP crystal pumped by Ho:YAG laser with tunability over 2.1-10\( \mu \text{m} \) spectral range.

[Graph showing CW and Passive QS output energy vs input power]

[Image of laser setup]
Research directed toward the long-term development of electrically pumped mid-IR lasers for ultra-portable trace gas detection systems:

COSS.8. Study transition metal doped bulk, thin film and QD II-VI structures for electrically pumped, tunable mid-IR light sources.

UAB/COSS developed methods of fabrication of new co-doped semiconductor materials for mid-IR electroluminescence devices based on Cr:Me:ZnSe/ZnS crystals.

In this fall we studied of the Cr$^{2+}$ compensation mechanisms in the crystals co-doped with donor and acceptor impurities. Optical and electrical characterization of Cr:ZnSe crystals with Ag, Cu, Al, In, and Zn co-dopants were studied to optimize Cr$^{2+}$ mid-IR electroluminescence.

The best results were obtained with p-conductive Ag:Cr:ZnSe samples featuring a low 600 $\Omega \cdot$ cm resistivity. First mid-IR electroluminescence in presumable p-type Ag:Cr:ZnSe was demonstrated, which could prove valuable for developing laser diodes that function in this spectral region.

(A) Electroluminescence of Ag:Cr:ZnSe crystal, (B) Electrical excitation pulse profile. Peak Voltage: 100V
Development of doped “smart nanoparticles” for image guided interventions:

COSS.11. Study doped "smart nanoparticles" for image guided interventions

The UAB/COSS researches start development of multifunctional fluorescent and upconverting ZrO2/Au-core targeted nanoparticles for Image-Guided laser-based photo-thermal therapy. The proposed multifunctional nanoscale system will combine the following innovative features:

- Gold nanorods with tunable surface plasmons band in Near-IR spectral range as a contrast agent for efficient absorption of energy delivered by laser radiation,
- Gold nanorods will be coated with ZrO2 which has a high melting point and is non-toxic as well as gold,
- Inert and biocompatible ZrO2 surface will provide simple chemistry for their bio-conjugation with biomolecules for targeted delivery,
- Doping of the ZrO2 coating layer with combination of rare-earth (RE) ions will enable fluorescence imaging of malignant cells, as well as guiding and monitoring of photo-thermal therapy. Combined together, the innovative features of multifunctional nanocomposite system will enable imaging, localization, and thermal therapy with positive feedback for effective cancer treatment. We envision this technology could be employed intraoperatively to eradicate remaining tumor cells after standard surgical resection to minimized the tumor burden.

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A new class of NLO materials for sensor protection in the blue region based on oligothiophenes:

COSS.8. NLO materials for sensor protection in the blue spectral region

UAB/COSS developed a new class of NLO materials for sensor protections in the blue region based on phosphine-substituted oligothiophenes.

Optical and materials properties can be tuned by varying X, R\(^{(1)}\), R\(^{(2)}\) and n.
New optical sensing elements:

COSS.5. Development of environmental challenge samples for testing and characterization by COSS spectroscopy instrumentation

UAB/COSS developed a new types of optical sensing elements that combine a binding site for an analyte with a metal center as a spectroscopic probe.

\[
\begin{align*}
&M \quad O O O O O C P C P O O C C O \\ + \quad M X & \quad \leftrightarrow \\
&\quad O O O O O C P C P O O C C O \\
&\quad M \quad O O O O O C P C P O O C C O \\
\end{align*}
\]

\[ MX = LiBPh_4, NaI; n = 0, 1; R_2 = \]

Titration of \( n = 0 \) with \( LiBPh_4 \) (K = 2.7 mM\(^{-1}\))

Titanation of \( n = 1 \) with NaI (K = 0.27 mM\(^{-1}\))

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http://www.coss.phy.uab.edu/
Dissemination of COSS Results:
COSS.29. Publish 10 papers or book chapters per year

For the first quarter COSS published:

2. I.S. Moskalev, V.V. Fedorov, V.P. Gapontsev, D.V. Gapontsev; N.S. Platonov; S.B. Mirov , "Highly efficient, narrow-linewidth, and single-frequency actively and passively Q-switched fiber-bulk hybrid Er:YAG lasers operating at 1645 nm", *Optics Express*, Vol. 16 Issue 24, pp.19427-19433 (2008)

Nine other papers and chapters (two of them are invited papers) are accepted for publication in peer-reviewed journals and books.
Conference Presentations 10/08-02/09

San Jose, California, USA, January 2009

**SPIE Photonics West** plays key role for photonics community.
- world’s largest biomedical optics event
- forum for basic laser device research and laser materials
- micro- and nanofabrication conferences
- optoelectronic technologies

**SPIE Photonics West 2009** brought together 1,100 exhibitors and 17,903 conferences participants

- Changsu Kim, Jeremy M. Peppers, Dmitri V. Martyshkin, Vladimir V. Fedorov, Sergey B. Mirov, The Univ. of Alabama at Birmingham “Chromium-doped ZnSe and ZnS gain media for optically and electrically pumped mid-IR lasers” [7193-110]

Advanced Solid-State Photonics (ASSP), Denver, Colorado February 2009

**Advanced Solid-State Photonics** Topical Meeting remains the world's premier forum for discussing new developments in laser and nonlinear optical materials and devices.

- Igor S. Moskalev, Vladimir V. Fedorov, Sergey B. Mirov, Patrick A. Berry, Kenneth L. Schepler; Univ. of Alabama at Birmingham, USA, AFRL, AFRL/RYJW, USA. “12 Watt CW Polycrystalline Cr2+:ZnSe Laser Pumped by Tm Fiber Laser” [WB30]

Water Environment Federation Technical Exposition and Conference, Chicago, IL, October 2008


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SRMACS 2009 The Southeastern Regional Meeting of the American Chemical Society, the largest professional society in the world, held in Nashville, TN in November of 2008 was the largest Southeastern Regional Meeting and had symposia and technical sessions in all areas of Chemistry.

- Samantha D. Hastings, Samuel B. Owens Jr., Gary M. Gray, The Univ. of Alabama at Birmingham
  “Asymmetric Hydroformylation of Styrene Using Tartaric-Acid Derived Bis(phosphite) Ligands” .......... [64880]

- Jason L. Freeman, Gary M. Gray, The Univ. of Alabama at Birmingham “Non-Linear Optical Properties of Phosphonite-Substituted Bithiophene Derivatives”...........[63984]

- Qun Zhao, Gary M. Gray, Jianwei Wang, Christopher M. Lawson The Univ. of Alabama at Birmingham
  “Synthesis and Characterization of Phosphine-Substituted Bithiophenes as Nonlinear Absorbers in the Blue Region”...........[63900]

- Makeba B. Murphy-Jolly, Samuel B. Owens Jr., Gary M. Gray, Christopher M. Lawson The Univ. of Alabama
  at Birmingham “Synthesis and Characterization of Phosphite-Substituted Schiff Base Ligands for NON-Linear Optical (NLO) Applications”...........[63668]

- Abha A. Kaisare, Samuel B. Owens Jr., Gary M. Gray The Univ. of Alabama at Birmingham “Styrene Hydroformylation : Improved Catalytic Efficiency by Adding Alkali Metal Salt and Controlling Ligand to Rh Molar Ratio of Rh(I) Complexes of (2,2-C₈H₁₂O₂)POCH₃”...........[63615]

- Justin T. Sheff and Gary Gray ay The Univ. of Alabama at Birmingham “Cation Binding by Metallacrown Ethers Containing Bis-Phosphite Polyether Ligands”...........invited paper [63553]

Center for Optical Sensors and Spectroscopies http://www.coss.phy.uab.edu/
COSS Sustainability:

COSS.30. Submit at least one non-EPSCoR COSS related proposal per year

Proposals submitted (first quarter):

• S. Mirov – PI, “New class of broadly tunable, mid-infrared, electrically pumped solid state lasers”, NSF

• D. Martyshkin – PI, “Diabetes Research and Training Center Pilot & Feasibility Program”, UAB

  This project plans to study capabilities of Raman/AFM/NSOM system to resolve important questions in islet biology regarding to the insulin granules and vesicles trafficking dynamics during glucose stimulated biphasic insulin release.

• R. Pitt – PI, “Sorption and Ion Exchange Media for the Treatment of Critical Environmental Pollutants”, The Boeing Company

  This recently funded project is investigating numerous bioretention soil amendments that can be used to further treat a wide range of heavy metal, organic, and radiological contaminants present at low concentrations in the environment.
Progress towards Self-Sustainability

Industrial Collaborators

Center for Optical Sensors and Spectroscopies

http://www.coss.phy.uab.edu/
1.2 Identify and implement projects involving multiple centers

COSS center in collaboration with Alabama A&M University is studying content of liposomal membranes and lipid vesicles for drug delivery application using Raman Microscopy.

[Image: Center for Optical Sensors and Spectroscopies]

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### COSS future activities

According to the Strategic Plan, the COSS program will include following research activities for the next quarter:

- **COSS will be focused on the improvement of the fabrication technology of the TM doped binary and ternary II-VI semiconductors.** The major goal of these research will be development new laser materials for direct tunable lasing over 2-5 μm spectral range.
- **COSS will continue to develop new high power and high energy mid-IR laser system for spectroscopic, biological and medical applications.**
- **COSS will start characterization of the spectroscopic system based on developed tunable mid-IR lasers and multi-pass optical cell.**
- **COSS will continue collaboration with other centers and institutions on the characterization of the organic and nanocomposite materials using unique MicroRaman-Atomic Force-Near Field Microscopy System.**
- **COSS will continue research on PAH sources to the environment, including their control, and instrumentation needs for their efficient characterization.**
- **COSS will continue research on optical and electrical characterizations of the TM doped semiconductor material for developing new type of the solid-state lasers with electrical excitation.**