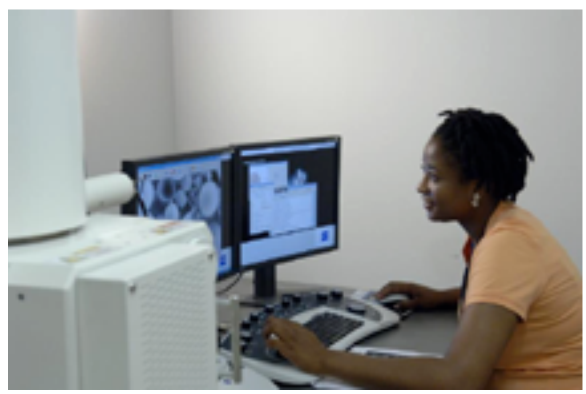
The Boston University Photonics Center

Annual Report 2005-2006



October 2006

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I. Introduction and Overview

A. Letter from the Director

This Annual Report is intended to serve as a synopsis of the Boston University Photonics Center's wide-ranging activities for the period from July 2005 through June 2006, corresponding to the University's fiscal year. It is my hope that the document is reflective of the Center's core values in innovation, entrepreneurship, and education, and that it projects our shared vision, and our dedication to excellence in this exciting field. For further information, you may visit our new website at www.bu.edu/photonics.

Though only recently appointed as Director, my involvement in Center activities dates back to the Center's formation more than ten years ago. In the early years, I worked with a team of faculty and staff colleagues to design and construct the shared laboratories that now provide every Center member extraordinary capabilities for fabrication and testing of advanced photonic devices and systems. I helped launch the business incubator by forming a company around an idea that emerged from my research laboratory. While that company failed to realize its vision of transforming the compact disc industry, it did help us form a unique vision for our program of academically engaged business acceleration. I co-developed a course in optical microsystems for telecommunications that I taught to advanced undergraduates and graduate students in the new M.S. degree program in Photonics offered through the Electrical and Computer Engineering Department. And since the Center's inception, I have contributed to its scholarly mission through my work in optical microsystem design and precision manufacturing at the Center's core Precision Engineering Research Laboratory. Recently, I had the opportunity to lead the Provost's Faculty Advisory Committee on Photonics, charged with broadening the Center's mission to better integrate academic and educational programs with its more established programs for business incubation and prototype development.

Despite these many interactions throughout the years, it is only in the past several months while serving as interim Director that I have begun to appreciate fully the complex and multifaceted nature of the Center, and the diverse, complementary activities that are carried out by the Center's faculty, staff, and students. Our programs include pioneering research with outcomes that have changed the course of the field; comprehensive development and system integration efforts that have been proven in real defense and security applications; and educational programs that are enriched by the vibrant medical, academic, and technical community that surrounds us in Boston.

I appreciate your interest in our recent progress and our future plans, and I welcome your feedback.

B. Executive Summary

By many measures, this has been a year of extraordinary change marked by substantial achievements at the Photonics Center.

Following last year's introduction of the RedOwl platform – a compact autonomous anti-sniper system featuring unprecedented performance– The Center received its largest annual grant ($9.4M) since its inception to continue to build our unique pipeline for photonics-based research and development.

In January, the Center's founding Director, Dr. Donald Fraser, announced his retirement after a decade of service. His ambitious leadership over the years focused strongly on leveraged business acceleration and defense system prototyping, and the Center's reputation in these areas grew steadily as a result. His legacy includes an exceptional collection of shared facilities housed in the landmark Photonics Center Building at 8 Saint Mary's Street in the heart of Boston University's campus. Dr. Fraser routinely challenged the Center's faculty, staff, and students to steer their scholarly work toward practical applications of light. Today, this emphasis on translating our enabling discoveries and technological breakthroughs into practical applications can be counted among our core values.

In February, Dr. Thomas Bifano was appointed as the interim Director of the Photonics Center. Dr. Bifano is a professor in the College of Engineering and served as Chair of the Manufacturing Engineering Department from 1999-2006. For a year prior to his appointment, Dr. Bifano Chaired the *Provost's Faculty Advisory Committee on Photonics (PFACP)*, a group charged by Provost David Campbell to recommend policy, action, and structural changes intended to integrate academic and educational programs more fully into the fabric of the Center. The committee was also charged with helping the Center Director articulate an expanded mission for the Center's second decade, with a goal of balancing our efforts in educational programs, faculty research, company incubation, accelerated development, and translational efforts. Other members of the committee were Irving Bigio (BME/ECE). Guilford Jones (CHEM), Theodore Moustakas (ECE) Alexander Norbash (Radiology, BUSM), Michael Ruane (ECE), Bahaa Saleh (ECE), and Selim Unlu (ECE/Physics). As interim Director, Dr. Bifano implemented many of the recommendations made by the PFACP, while broadly expanding the participation of faculty and students in shaping the Center's strategic vision.

Dr. Bifano was appointed Center Director on September 1, 2006, following seven month as the interim Director. In that transitional period, the Center's faculty, staff and students have worked collegially to transform the Center's operations, creating a cohesive hub of activity around our missions in scholarship, education, and prototyping.

Highlights of our recent activities include:

- **The Center's formal mission was updated** to add strong academic and educational focus, drawing on major PFACP recommendations. This also resulted in organizational changes, including formation of an executive advisory committee for academic programs, and a relocation of photonics-related new business venture programs to the University's centralized Office of Technology Development.

- **The Center's research and development efforts were rewarded by record setting grants** to support its fundamental research and technology development pipeline. Center faculty and staff received a total of $10.3M in new funds for the 2005-2006 year, distributed over more than 60 separate photonics-related projects. For the coming year, the Center has already received a commitment for $9.4M to support a new Army Research Laboratory (ARL) Cooperative Research Agreement,.
- **The Center expanded its support of academic scholarship,** exemplified by three initiatives: the creation of ten new graduate fellowships, the creation of a visiting professorship program; and the creation of a New Photonics Faculty Fellowships to help launch the careers of junior faculty whose research and laboratories will support our mission.
- **The Center's operations were revised to better support our faculty and students,** including reorientation of staff responsibilities, elimination of outside consultants for marketing and photonics advising, allocation of available space to academic programs, and allocation of substantial resources to building safety audits, and laboratory upgrades and repair.
- **The Center co-sponsored a National Science Foundation Research Experiences for Undergraduates (NSF-REU)** program that offered fourteen summer internships at the Center in 2006 on the subject of biophotonics (led by PI Mike Ruane).
- **The Center led development of the RedOwl sniper detection and surveillance system** that will be field-tested in September and October 2006 for the Department of Defense. Built on the enabling technology developed in the laboratories of Center faculty (Professors Hubbard and Mountain), and supported in part by a Photonics Center incubator company led by former BU students (Biomimetic Systems), this compelling project has been led by Center Deputy Director Dr. Glenn Thoren. The system has already proven to have unprecedented performance as a robot-controlled tool for identifying, illuminating, pinpointing, and imaging the source of gunshots. Other development partners include Insight Technologies and iRobot Corporation
- **The Center hosted a wide range of activities to promote community** and cohesion, and interdisciplinary collaboration. We hosted the first Center faculty meeting in ten years, formed standing committees for fellowships, academic policies, equipment support, and space management, and launched a series of social events that included a biweekly café, a summer BBQ on the BU Beach, an alley ice cream truck break, and a student-run journal club.
- **The Center's faculty and students authored more than fifty archival journal publications**, appearing in leading journals in the photonics field, were issued eight patents for original intellectual property, and presented hundreds of technical papers at leading technical symposia.

In the coming year, we have much to do. Already, we have begun to work collaboratively on infrastructural research grant proposals that can support interdisciplinary projects in areas of specialization. One such proposal, led by Center faculty member Bennett Goldberg, seeks significant new support from the National Science Foundation for doctoral graduate students working in the field of Biophotonics. This area has emerged as one of the promising themes for new collaborative work in the Center, and we expect to spend considerable effort pursuing this and other broad-based competitive grant awards this year. We are also committed to expanding the scope of our development program, anticipating the transfer of RedOwl to commercial development in the near future.

While we will continue to add improvements and functions to this compelling system, our primary focus will turn to other development projects that emerge from our R&D pipeline. More than ever, we intend to focus these development efforts on projects that have the potential to meet future defense and security needs.

The Photonics Center at a Glance

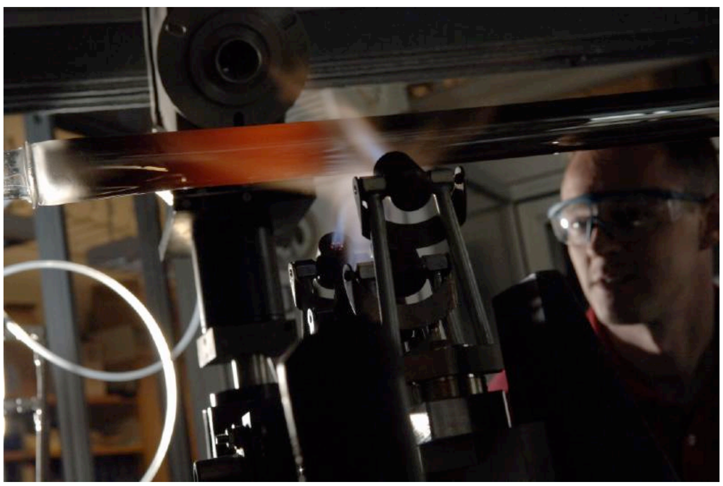
Faculty Members	29
Represented BU Departments	10
Graduate Students and Post-Docs	65
Staff Members	12
Funded R&D Projects	68
Funding for R&D (Current Year)	$10.3M
Photonics Related Courses	23
Publications in Archival Journals	53
Faculty Patents	8
Focused Research Laboratories	20
Shared Facilities	3
Photonics Center Square Footage	235,000
Laboratory Square Footage	30,000
Incubator Square Footage	23,000
Year of Building Opening	1997

C. Mission Statement

The Boston University Photonics Center will pioneer fundamental knowledge and innovative technology in the field of photonics. We aim to work on important and basic problems, to translate enabling discoveries into useful applications, and to educate future leaders in the field.

This mission is executed through:

- Basic research and scholarship in photonics
- Academic and entrepreneurial programs and initiatives for students
- Development for defense/security applications utilizing photonics
- Incubation of photonics technology companies



II. Faculty and Staff

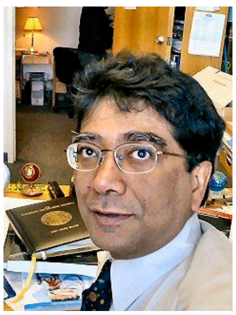
From its inception, the Center has attracted scholarly pioneers to lead our academic program in Photonics. A vibrant multi-disciplinary environment is achieved through faculty contributions from various schools and colleges within Boston University. The Center is supported by a dedicated technical and administrative staff. Working with the faculty, the staff is focused on advancing the mission of the Center in the areas of basic research in photonics, academic and entrepreneurial programs for students, development of defense applications utilizing photonics, and the incubation of photonics technology companies.

A. Photonics Center Faculty Members

Enrico Bellotti
Electrical & Computer Engineering

Thomas G. Bifano
Manufacturing Engineering/Aerospace &Mechanical Engineering

Irving Bigio
Biomedical Engineering/ Electrical &Computer Engineering



Supriya Chakrabarti
Astronomy/Electrical& Computer Engineering

Luca Dal Negro
Electrical & Computer Engineering

Shyamsunder Erramilli
Physics

Gerald Fine
Manufacturing Engineering

Rosina Georgiadis
Chemistry

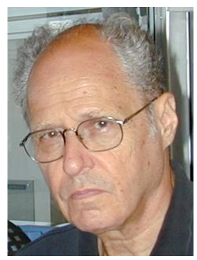
Bennett Goldberg
Physics/ Electrical& Computer Engineering/ Biomedical Engineering

Allyn Hubbard
Electrical &
Computer
Engineering

James Jackson
Astronomy

Guilford Jones
Chemistry

Michael Mendillo
Astronomy

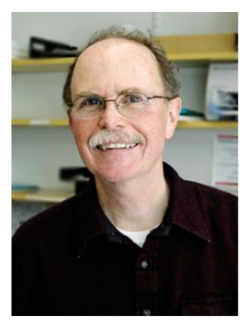


Theodore Morse
Electrical &
Computer
Engineering

Theodore
Moustakas
Electrical &
Computer
Engineering

Roberto Paiella
Electrical &
Computer
Engineering

Kenneth J Rothschild
Physics



Michael Ruane
Electrical &
Computer
Engineering

Bahaa E A Saleh
Electrical & Computer Engineering

Alexander V Sergienko
Electrical & Computer Engineering

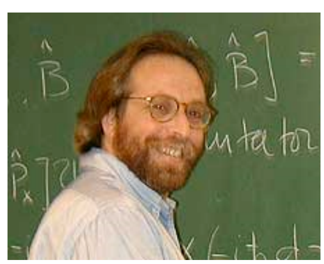
Andre Sharon
Manufacturing Engineering

Anna Swan
Electrical & Computer Engineering

Malvin C Teich
Electrical & Computer Engineering

Selim Ünlü
Electrical & Computer Engineering

Xin Zhang
Manufacturing Engineering/Aerospace& Mechanical Engineering



Lawrence Ziegler
Chemistry

Not pictured:

Barry Unger
Metropolitan College

Garland Waller
College of Communication

Gabriel Simone
BU MED

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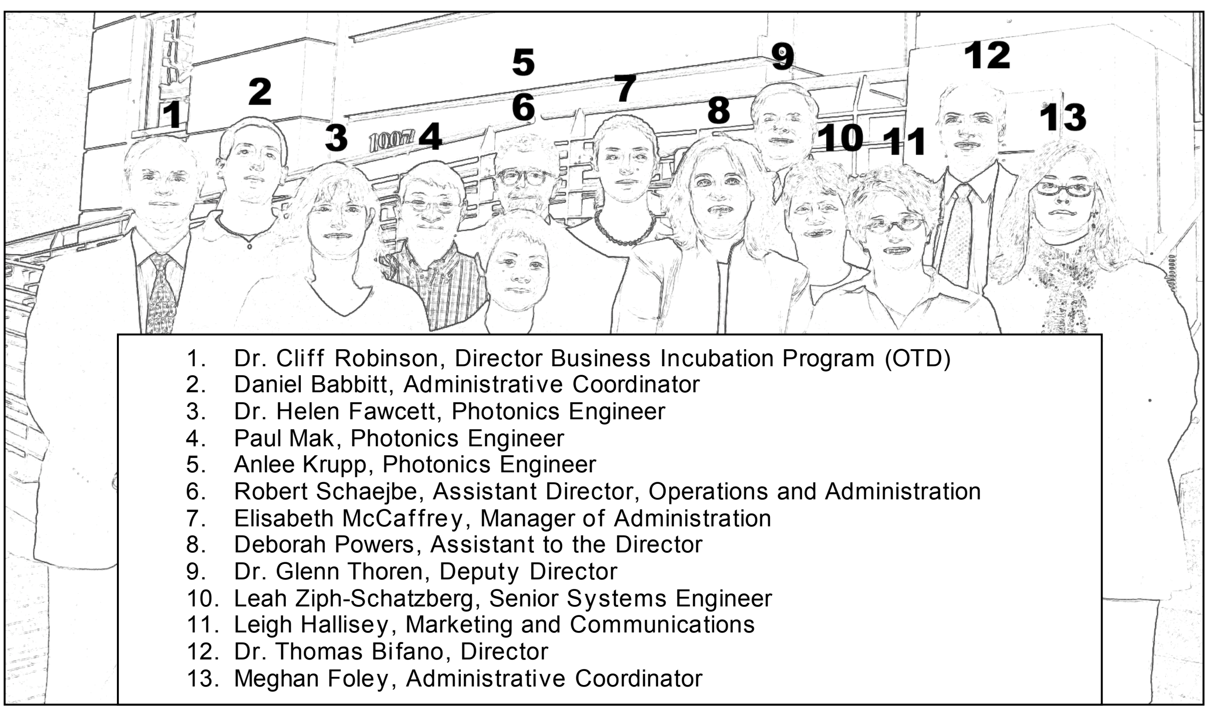
B. Photonics Center Staff



1. Dr. Cliff Robinson, Director Business Incubation Program (OTD)
2. Daniel Babbitt, Administrative Coordinator
3. Dr. Helen Fawcett, Photonics Engineer
4. Paul Mak, Photonics Engineer
5. Anlee Krupp, Photonics Engineer
6. Robert Schaejbe, Assistant Director, Operations and Administration
7. Elisabeth McCaffrey, Manager of Administration
8. Deborah Powers, Assistant to the Director
9. Dr. Glenn Thoren, Deputy Director
10. Leah Ziph-Schatzberg, Senior Systems Engineer
11. Leigh Hallisey, Marketing and Communications
12. Dr. Thomas Bifano, Director
13. Meghan Foley, Administrative Coordinator

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- **Leah Ziph-Schatzberg**
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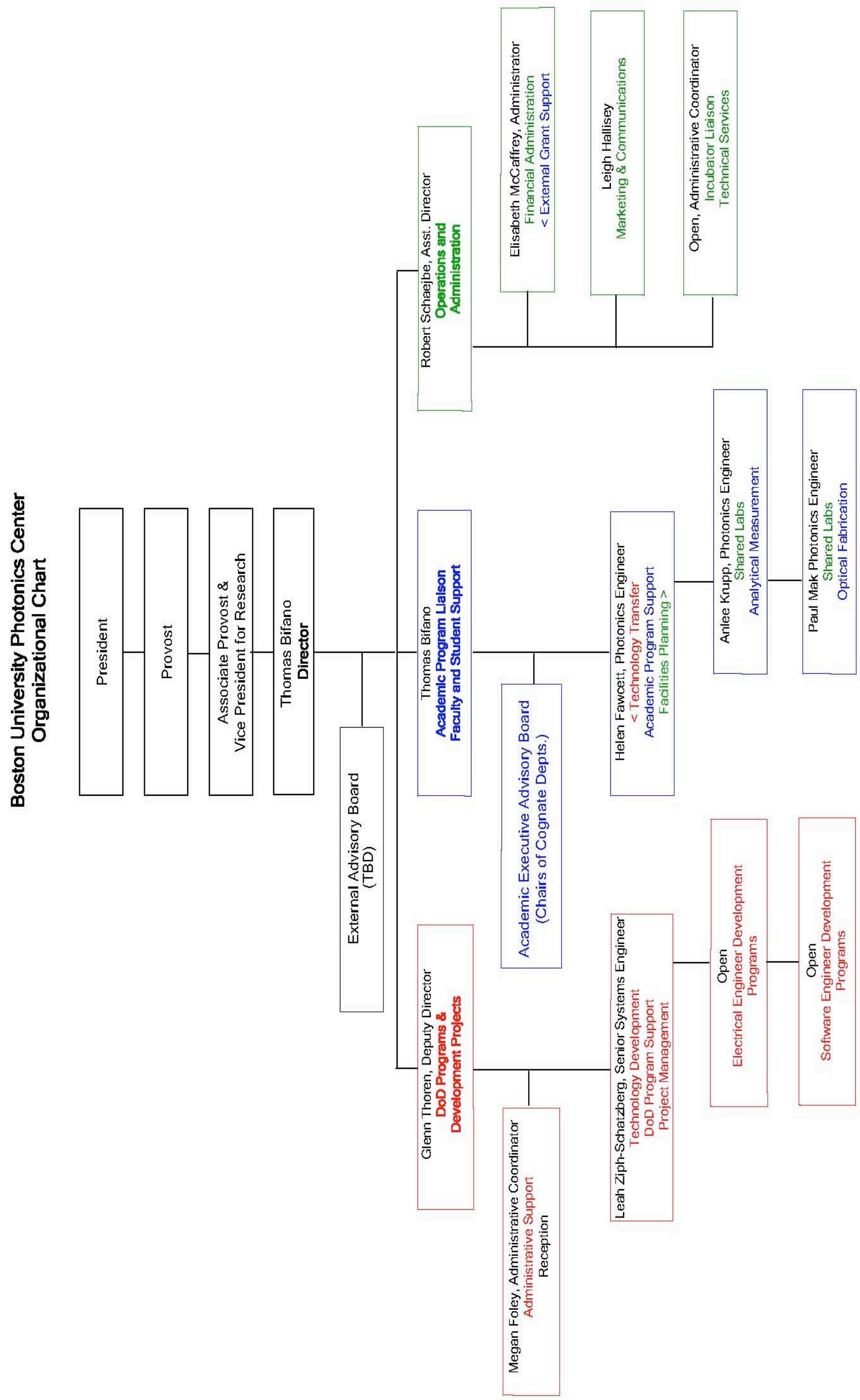
2. Organizational Chart



III. Research and Development

A. Overview

Scientific Discovery, fundamental research, and innovative development form a continuous intellectual pipeline at the Boston University Photonics Center. Our scholarly research spans the traditional disciplines of our faculty members' host academic departments: Astronomy, Biology, Chemistry, Physics, Aerospace and Mechanical Engineering, Biomedical Engineering, Electrical and Computer Engineering, and Manufacturing Engineering.

In the following pages, outcomes from our efforts in research and development for the past year are detailed. Photonics-focused grants (i.e. new funds received in the current fiscal year) are listed, as are archival journal publications.

The Photonics Center has pursued an aggressive program of technology transfer through targeted prototype development. In the past year, the highlight of that work has undoubtedly been the RedOwl acoustic-optical direction finding robotic system, summarized in this section of the annual report.

Our unique cooperative agreement with the Army Research Laboratory (ARL) offers us a way to accelerate some of our more applied research, particularly in areas that might lead toward development of prototype systems associated with our defense and security mission. This program, administered through the Center, is highlighted here through a partial summary of last year's project results.

It is difficult to capture adequately, in an annual report, the broad range of R&D activities that occur in the Photonics Center. It is equally difficult to portray the pride that our faculty have in their academic achievements and their team-based development projects. Nevertheless, these pages should convey the general sense of activity and intellectual dedication that characterizes the Center's membership.

B. Faculty Staff Research

The Center's research laboratories have pioneered breakthrough photonic devices that include blue light lasers, quantum cryptography systems, deformable mirrors that improve telescope and microscope resolution, high-speed photodetectors, and biophotonic sensors. Photonics faculty and staff receive support from industry and federal agencies including the National Science Foundation, the Department of Energy, the National Institutes of Health, and the Department of Defense. This year Photonics faculty members and students published more than 50 articles in archival journals, were issued eight patents for novel intellectual property and received more than $10.3M in external funding distributed among over 60 photonics related projects. The following table lists new funds that arrived at Boston University in the fiscal year, as reported by the Office of Sponsored Programs.

1. Externally Funded Research

Summary of Photonics Center Faculty External Research Funding

PI	Department	Project	Granting Agency	Period	Amount
Bellotti	Electrical and Computer Engineering	DURIP: Advanced Simulation Hardware for Imaging Devices and Materials (DURIP)	Department of Defense	03/01/05-04/30/06	$150,000
Bellotti	Electrical and Computer Engineering	Young Investigator Program: Single-Photon 3D Image Sensors	Department of Defense	03/15/03-04/30/06	$95,054
Bellotti	Electrical and Computer Engineering	Photonics Technology Development and Insertion/Task 18: III-Nitride Superlattice Engineering of Vertical Transport (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$58,020
Bellotti	Electrical and Computer Engineering	Numerical Simulation of Electron Beam Pumped Semiconductor UV Lasers (Subcontract via Photon Systems)	Department of Defense	04/21/05-04/28/07	$50,000
Bellotti	Electrical and Computer Engineering	CAREER: Theoretical Investigation for Single Photon Detectors for Quantum Technology – A Nano-Structure Devices Approach	National Science Foundation	05/01/05-04/30/10	$400,000
Bifano	Manufacturing Engineering	Reflective Spatial Light Modulator for High-Dynamic-Range Wavefront Control (Subcontract via Boston Micromachines Corporation)	Department of Defense	08/01/04-07/31/06	$181,313
Bifano	Manufacturing Engineering	Photonics Technology Development and Insertion/Task 27: Secure, Low-Power Data Transfer Using Modulating Retro-reflection (Photonics Center Award)	Department of Defense	05/01/05-04/30/06	$105,819
Bifano	Manufacturing Engineering	Development of a Transportable Dynamically-Compensated Scanning Laser Ophthalmoscope for Resolving Retinal Cells (Subcontract via the Schepens Eye Research Institute)	Department of Health and Human Services	09/01/04-08/31/05	$45,462
Bifano	Manufacturing Engineering	Development of a Transportable Dynamically-Compensated Scanning Laser Ophthalmoscope for Resolving Retinal Cells (Subcontract via the Schepens Eye Research Institute)	Department of Health and Human Services	09/01/03-08/31/04	$15,953

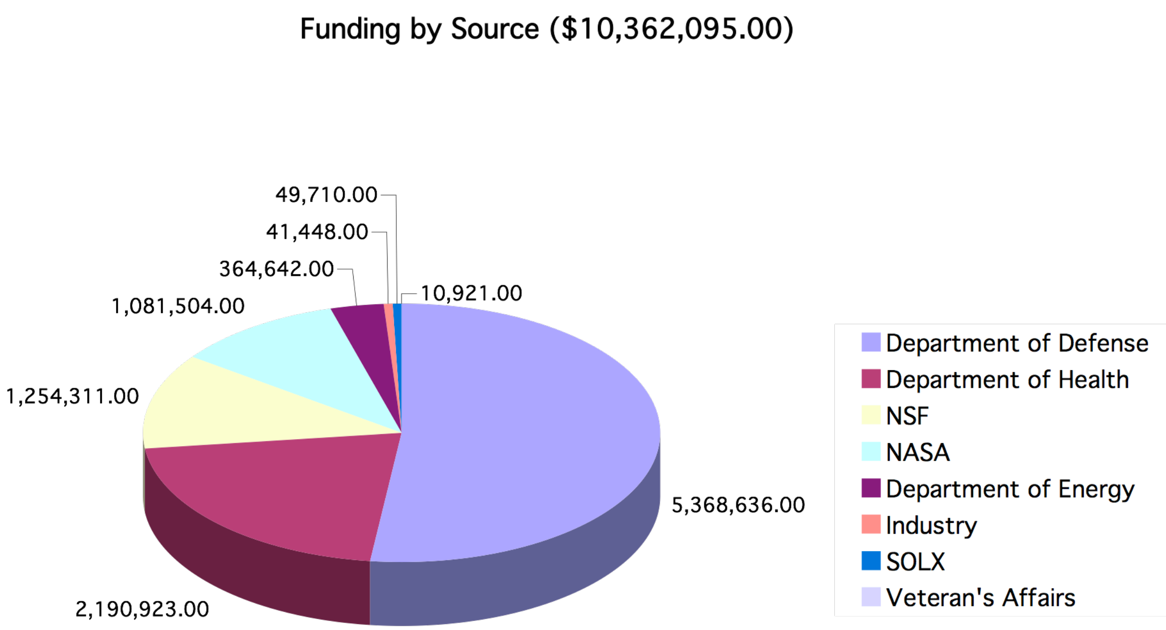
PI	Department	Project	Granting Agency	Period	Amount
Bifano	Manufacturing Engineering	Advanced Deformable MEMS Mirror Systems for the Terrestrial Planet Finder Mission (Subcontract via Jet Propulsion Laboratory)	NASA	09/17/03-02/28/06	$60,000
Bifano	Manufacturing Engineering	Advanced Deformable MEMS Mirror Systems for the Terrestrial Planet Finder Mission (Subcontract via Jet Propulsion Laboratory)	NASA	09/17/03-02/28/06	$55,000
Bifano	Manufacturing Engineering	Mfg Process Development for Gold Micro-shunts	Solx	5/1/05-12/31/05	$49,710
Bifano	Photonics	Photonics Technology Development and Insertion/Task 9: Center Operations	Department of Defense/ Army	05/01/05-10/31/06	$1,240,292
BifanoBigio	Biomedical Engineering	Optical Spectroscopy for Management of Cancer Treatment	Department of Health and Human Services	09/01/04-08/31/05	$1,146,889
Bigio	Biomedical Engineering	Optical Measurement of Fast Drug Kinetics in Tumors	Department of Health and Human Services	09/01/04-08/31/05	$311,171
Bigio	Biomedical Engineering	Graduate Student Stipend (F. Hui) Subcontract via Beth Israel Deaconess Medical Center)	Department of Veterans Affairs	09/01/04-12/31/04	$10,921
Bigio	Biomedical Engineering	Graduate Student Support (N. Kunapareddy) (Subcontract via Los Alamos National Laboratory)	Department of Energy	06/01/05-05/31/06	$31,642
Chakrabarti	Space Physics	Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE)	NASA	11/31/04-01/31/08	$545,000
Chakrabarti	Space Physics	High Throughput, High Resolution, Ultraviolet Imaging Spectrograph for Studies of Diffuse Emissions	NASA	05/01/05-04/30/06	$80,000
Desai, Goldberg	Biomedical Engineering	Photonics Technology Development and Insertion/Task 20: Integrated Biotoxin Detection System (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$94,187
Georgiadis	Chemistry	Photonics Technology Development and Insertion/Task 29: Evaluation and Optimization of Protein-Binding DNA Aptamer Sensors in Solution and Surface Environments (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$100,975

PI	Department	Project	Granting Agency	Period	Amount
Goldberg	Physics	Nanoscale Spectroscopy of Low-Dimensional Semiconductor Systems (R. Younger)(Subcontract via MIT Lincoln Laboratory)	Department of Defense	09/01/04-12/31/04	$13,154
Goldberg, Ruane, Garik, Phillips	Physics	GK-12: Project STAMP – Science Technology and Mathematics Partnershipd (additional co-pi: Donald DeRosa) (In conjunction with Science and Math Education Center)	National Science Foundation	06/01/05-05/31/06	$471,245
Goldberg, Swan, Unlu, Karl	Physics	Nanoscale Imaging of Subcellular Processes (in conjunction with Photonics Center)	Department of Health and Human Services	07/01/05-06/30/06	$348,400
Jones	Chemistry	Photonics Technology Development and Insertion/Task 4: Pathogen Detection Based on Dye Partitioning (Photonics Center Award)	Department of Defense	05/01/05-04/30/06	$88,560
Jones	Chemistry	Efficient Diode Pumped All Solid State Dye Lasers (in conjunction with Photonics Center) (Subcontract via Physical Sciences)	Department of Defense	01/01/04-04/30/05	$37,000
Jones	Chemistry	Characterization of Metal Complexes for Security Marking Applications (in conjunction with Photonics Center)	PhotoSecure, Inc.	11/01/04-10/31/05	$41,448
Mendillo	Astronomy	High Spatial Resolution Studies of the Exospheres of IO and Europa	NASA	08/01/03-07/31/06	$81,706
Mendillo	Astronomy	Cedar Post Doc: Photo-Chemistry and Neutral-Plasma Coupling at Earth and Mars	NASA	12/01/03-11/30/05	$80,298
Mohanty	Physics	Photonics Technology Development and Insertion/Task 19: UHF NEMS – GHz-Range Passive Filters and Frequency-Selective Elements (Photonics Center Award)	Department of Defense	05/01/05-04/30/06	$70,018
Morse	Electrical and Computer Engineering	Specialty Fibers fir Clinical Applications	Department of Defense	12/01/04-01/31/06	$150,000

PI	Department	Project	Granting Agency	Period	Amount
Morse	Electrical and Computer Engineering	High Temperature Fiber Optic Sensors for Space Shuttle Tiles (Subcontract via ASE Instruments, Inc.)	NASA	11/01/04-01/31/05	$22,500
Morse	Electrical and Computer Engineering	Ultra Sensitive Bio-Detection Using Whispering Gallery Spheres and Intra-Cavity Polarization Mode Beating	National Science Foundation	09/01/04-08/31/07	$60,000
Moustakas	Electrical and Computer Engineering	Cluster Ion Beam Epitaxy of III-Nitride	Department of Defense	10/01/02-12/31/05	$131,815
Moustakas	Electrical and Computer Engineering	MURI: Gas Cluster Ion Beam (GCIB) Epitaxy (Subcontract via Georgia Institute of Technology)	Department of Defense	05/01/03-05/14/06	$131,212
Moustakas	Electrical and Computer Engineering	Novel GaN HBT for Advanced T/R Modules for X-band Radar Performance Enhancement (Subcontract via Photronix, Inc.)	Department of Defense	09/27/04-09/29/06	$129,475
Moustakas	Electrical and Computer Engineering	Photonics Technology Development and Insertion/Task 6: Development of GaN Substrate by HVPE to be Used by Both BU and ARL Groups for Fabrication of UV-LEDS for Biological and Chemical Detection (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$115,000
Moustakas	Electrical and Computer Engineering	Comparative Studies of UV LEDs Emitting at 280mm Grown Along Polar and Non-Polar Direction of AIN Substrates and Templates	Department of Defense	05/01/05-08/10/06	$100,000
Moustakas	Electrical and Computer Engineering	Development of Deep UV Laser Structures onto A-plane Sapphire Substrates (Subcontract via Photon Systems, Inc.)	Department of Defense	04/21/05-04/28/07	$50,000
Moustakas	Electrical and Computer Engineering	Low-Cost Blue/UV LEDs with Very High Photon Conversion and Extraction Efficiency for White Lighting	Department of Energy	09/01/04-09/30/06	$320,000
Moustakas	Electrical and Computer Engineering	Compact Photonics Explorers Consortium – Ultraviolet Emitters and Detectors (Subcontract via Research Foundation of City University of New York)	NASA	04/01/05-12/31/05	$50,000

PI	Department	Project	Granting Agency	Period	Amount
Rothschild	Physics	FTIR Study of Signal Transduction in Sensory Rhodospins	Department of Health and Human Services	02/01/05-01/31/06	$292,250
Ruane	Electrical and Computer Engineering	Optical Sensing (J. Aldridge) (Subcontract via MIT Lincoln Laboratory)	Department of Defense	09/01/04-12/31/04	$13,154
Ruane	Electrical and Computer Engineering	Center for Subsurface Sensing and Imaging Systems (CenSSIS) – Education Program (Subcontract via Northeastern University)	National Science Foundation	09/01/04-08/31/05	$59,537
Saleh	Electrical and Computer Engineering	Center for Subsurface Sensing and Imaging Systems (CenSSIS) – Research Thrust 1-Photonics (Subcontract via Northeastern University)	National Science Foundation	09/01/04-08/31/05	$126,128
Saleh, Teich, Sergienko	Electrical and Computer Engineering	Quantum Imaging: New Methods and Applications (MURI) (Subcontract via University of Rochester	Department of Defense	05/01/05-09/30/05	$143,155
Sergienko, Saleh, Teich	Electrical and Computer Engineering	Ultrafast Quantum Optics (Amendments 7 & 8) (Subcontract via BBNT Solutions LLC)	Department of Defense	08/01/01-03/30/05	$296,084
Sergienko, Saleh, Teich	Electrical and Computer Engineering	Ultrafast Quantum Optics (Amendments 9) (Subcontract via BBNT Solutions LLC)	Department of Defense	08/01/01-06/30/05	$148,044
Sergienko, Saleh, Teich	Electrical and Computer Engineering	Ultrafast Quantum Optics (Subcontract via BBNT Solutions LLC)	Department of Defense	08/01/01-06/30/05	$112,500
Swan	Electrical and Computer Engineering	4 Schools for WIE (Subcontract via Northeastern University)	National Science Foundation	12/15/02-11/30/05	$52,921
Teich	Electrical and Computer Engineering	Free Space Quantum Key Distribution (T. Yarnell) (subcontract via MIT Lincoln Laboratory)	Department of Defense	06/01/05-08/31/05	$10,867
Teich, Saleh, Sergienko	Electrical and Computer Engineering	Free Space Quantum Key Distribution – Graduate Student Support (T. Yarnell) (subcontract via MIT Lincoln Laboratory)	Department of Defense	09/01/04-12/31/04	$14,470
Thoren	Photonics	Photonics Technology Development and Insertion/Task 22: Robot Enhanced Detection Outpost with Lasers (REDOWL)	Department of Defense/ Army	05/01/05-04/30/06	$842,009

PI	Department	Project	Granting Agency	Period	Amount
Ünlü	Electrical and Computer Engineering	Device Characterization to Support Strain-Balanced InAsSb MWIR Avalanche Photodiodes (Subcontract via Spire Corporation)	Department of Defense	10/01/04-07/29/05	$30,000
Ünlü	Electrical and Computer Engineering	Instrumentation for Optical Sub-Systems for In Vivo Cancer Imaging (Subcontract via Beth Israel Deaconess Medical Center)	Department of Health and Human Services	01/01/05-08/31/05	$20,535
Ünlü	Electrical and Computer Engineering	Instrumentation for Optical Sub-Systems for In Vivo Cancer Imaging (Subcontract via Beth Israel Deaconess Medical Center)	Department of Health and Human Services	09/01/04-12/31/04	$10,263
Ünlü,	Electrical and Computer Engineering	U.S. Turkey Workshop on Nanophotonics and Nanobiotechnology	National Science Foundation	03/01/05-02/28/06	$34,980
Ünlü, Goldberg, Ekinci, Mohanty	Electrical and Computer Engineering	NIRT: Advanced Characterization Techniques in Optics for Nanostructures (ACTION) (additional co-pi: L. Novotny)	National Science Foundation	10/01/05-09/30/06	$37,500
Zhang	Manufacturing Engineering	Photonics Technology Development and Insertion/Task 16: Uncooled Double Cantilever Microbolomeer Focal Plane Arrays with mK NETD (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$91,578
Zhang	Manufacturing Engineering	Micro-Pumped Cryogenic Two-Phase Heat Transport System (Subcontract via Foster-Miller, Inc.)	Department of Defense	12/31/04-12/30/05	$102,210
Zhang	Manufacturing Engineering	Residual Stress and Fracture of Thick PECVD Oxide Films for Power MEMS Structures and Devices	Department of Defense	10/01/04-09/30/05	$99,126
Zhang	Manufacturing Engineering	CAREER Award: Creating Nanostructured Gratings on Microstructures for Residual Strain/Stress Measurement (REU Supplement)	National Science Foundation	02/13/04-02/29/08	$12,000
Ziegler, Premasiri	Chemistry	Photonics Technology Development and Insertion/Task 17: Continued Development of a Portable SERS Microorganism Detection System (Photonics Center Award)	Department of Defense	05/01/05-10/31/06	$77,511
				Total	**$10,362,095**


Funding by Source ($10,362,095.00)
49,710.00
41,448.00
364,642.00
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1,081,504.00
1,254,311.00
5,368,636.00
2,190,923.00
Department of Defense
Department of Health
NSF
NASA
Department of Energy
Industry
SOLX
Veteran's Affairs

2. Publications and Patents

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C. Development Pipeline

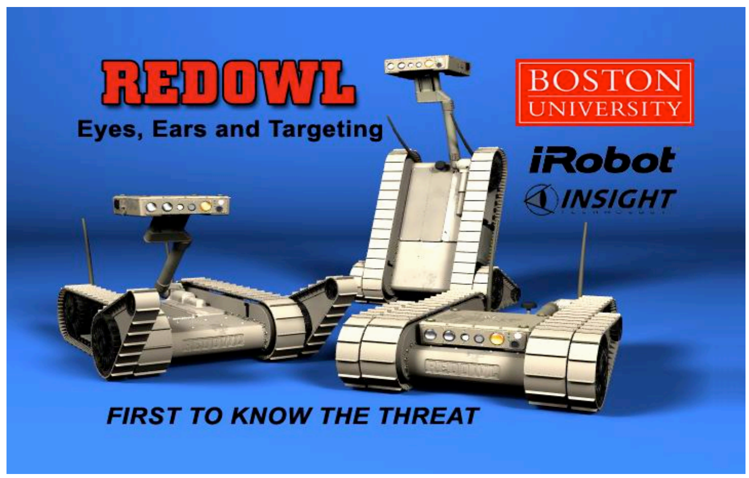
Since its inception, the Boston University Photonics Center has worked jointly with the Department of Defense to develop photonics technologies. Much of the original funding for the construction of the Center came from a grant from the Office of Naval Research. The military, through the Department of Defense, desires the most rapid access to the advanced technologies available to solve critical operational needs such as sniper detection, improvised explosive device (IED) detection and disarmament, and chemical and biological threat detection. Many potential solutions are being developed in the research efforts within Boston University. A core mission of the Photonics Center is to accelerate the development of new technology for use in defense and security applications. When the results of research are rapidly converted into useful prototype equipment and devices for these applications, the security of the nation is better protected. The proven capacity to develop promising defense technology is a critical differentiator for the Photonics Center.

1. The RedOwl Development Project

The difficult conversion of research into practical applications has been proven by the Photonics Center in the **RedOwl** sniper detection and surveillance system created through the Photonics Center's cooperative agreement with ARL. In less than 18 months a concept was converted into the most compact and capable acoustic detection and direction finding and optical surveillance system with laser illuminators on a small robot package. This was done by combining state of the art university acoustic technology and the smallest integrated and field proven military optical technology on a proven robot platform. Other prototype implementations will follow based on the combination of university research and the addition of proven capabilities supplied by selected industry partners and government laboratories. The technology prototyping pipeline will continue to be filled by the fundamental research investigations conducted by Photonics Center faculty and staff. Much of the work conducted through the cooperative agreement will be leveraged by individual investigator grants secured by the Center faculty.

RedOwl is an ongoing rapid development program led by the Boston University Photonics Center with iRobot, Insight Technology and Biomimetic Systems (a Boston University spinout company). The RedOwl is a remote, deployable sensor suite designed to provide early warning information, gunshot detection, intelligence, surveillance and targeting capabilities to military forces and government agencies. The concept for the integrated system was pioneered and led by Dr. Glenn Thoren, Deputy Director at the Photonics Center. The acoustic direction finding system was developed by Boston University's Dr. Socrates Deligeorges (now president of Biomimetic Systems, a Photonics Center incubator company) and Professors Allyn Hubbard and David Mountain at the Hearing Research Center at BU.

The RedOwl equipped PackBot has been field-tested for the Army's Rapid Equipping Force at a rifle and trapshooting range. The RedOwl robot also employs a suite of advanced optics including a thermal camera, 300X zoom daylight/infrared camera, infrared laser illuminators, a rangefinder, high intensity white driving light, and voice communication microphones and speakers, all in a package that weighs less than 5 pounds.



2. ARL Cooperative Faculty Research Awards

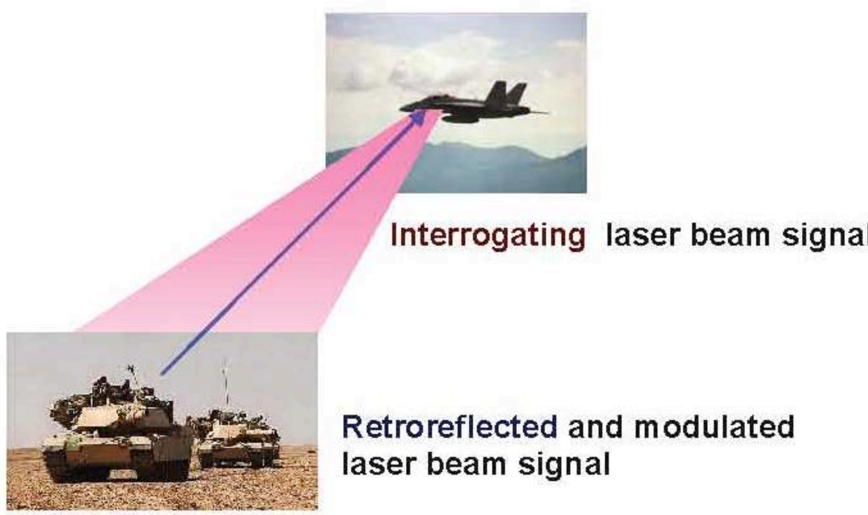
Through the ARL Cooperative Agreement Grants program, Boston University and the Army Research Laboratory have established a broad-based, effective, and productive mesh of collaborative, interdisciplinary research projects. Over the past year, Photonics Center faculty received more than $3M in funding from the Center's Army Research Lab Cooperative Agreement. The supported research spanned a wide variety of photonics disciplines, with a concentration on research applicable to solving Department of Defense issues such as chemical and biological detection and novel detectors.

(Note: The information in this section was compiled by Photonics Center Staff from faculty reports.)

Secure, low-power data transfer using modulated retro-reflection

Personnel: Thomas Bifano, Professor and Chair, Manufacturing Engineering Department
Michael Datta, Research Assistant
Wen Lu, Research Assistant
Guy Thompson, Research Assistant

Abstract: A compact, low-power device is developed to detect and modulate an incoming laser beam, and then return the modulated signal back to the location of the sender. Such a device will consist of a MEMS based electromechanical modulator combined with a passive retroreflector (e.g. a retro reflecting corner cube). The modulator serves as one of the three reflective surfaces on the retroreflector. The MEMS modulator has the characteristic that it can be made to act as a plane mirror, maximizing the amount of light that is retro reflected, or it can be made to act to act as a non-plane or non-normal mirror, reducing the amount of light that is retro reflected. One of these states requires no power to maintain, and the other uses only microwatts. The modulation frequency can be up to 250kHz with existing MEMS modulators developed at Boston University. Data to be sent from the modulated retroreflector could include voice communication, remotely sensed environmental information, or identification information (such as an "identify friend or foe" signal). A key attribute of this system is that the transmission power and pointing control required for long-distance communication are delivered by the *sending* beam (through retro reflection). That is, the strength of the sending beam determines the strength of the returned beam. Furthermore, the noise-limitations for the system are contained in the receiver co-located with the sending beam. **Almost no power is required at the retro reflecting modulator.**



Research milestones:

- Built the first generation 1550nm system consists of a source/receiver node with a 1550nm (10mW) laser, a beam-splitter, a beam expander, and a photodetector/demodulator, as shown in Figure 1.

At a distance 60m from the source/receiver is a modulated retroreflector node consisting of a corner-cube retroreflector with one facet replaced by a controllable-surface mirror.

- Designed and manufactured a new type of silicon MEMS modulator that will be mounted as one facet of a hollow retroreflector.

- The modulators were tested by driving them with 40V sinusoid (+/-20V) and measuring displacement using a high-speed laser vibrometer. The resonant frequency was measured to be >100kHz
- Developed (with help from the Fraunhofer Center for Manufacturing Innovation), a laser source/receiver for interrogation of the modulated retroreflector over long distances at 1.5μm wavelength.

Publications and Patent applications:

"MEMS modulated retroreflectors for laser communication," SPIE Symposium on Optics & Photonics, SPIE volume 5892, Free-Space Laser Communications V, 31 July through 4 August 2005 San Diego, California USA. Paper Number: 5892-12

Disclosure submitted to BU OTD: Modulated retroreflection

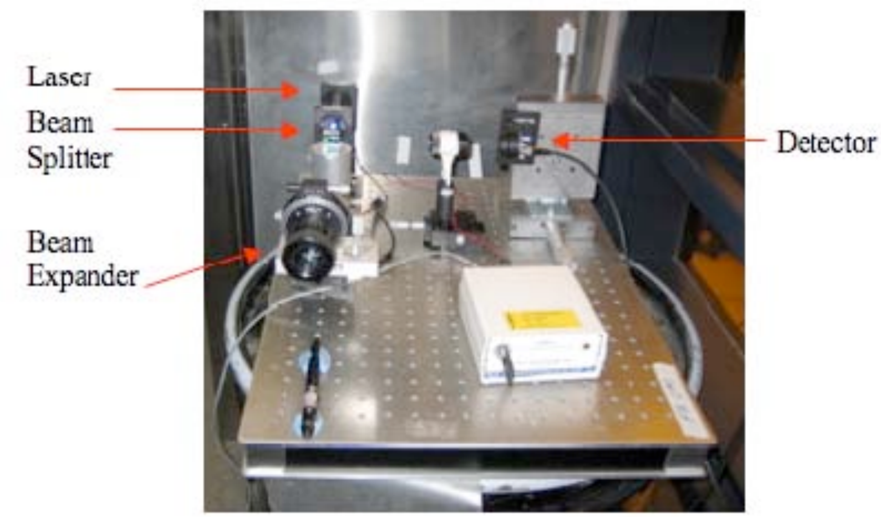


Figure 1: Source/Receiver node

Integrated Biotoxin Detection System

Personnel: **Dr. Bennett Goldberg, Professor and Chair, Physics Department**
Ayca Yalcin, Research Assistant
David Bergstein, Research Assistant

Abstract: This project utilizes our new microring resonator biosensor platform within an integrated package. For optical resonant biosensors, the goal is to create large array sensors at a reduced cost, and significantly increase stability and ruggedness. This can be accomplished with a planar optical waveguide configuration. To this end we have partnered with Little Optics, who has developed hardware for the telecommunications industry, such as the Little Optics™ Add/Drop planar optical waveguide device shown above. This device is called a microring resonator and has a very sharp resonance and has the advantage that the positioning of the parallel waveguides and the connecting evanescent wave to the series of rings are already positioned with exact tolerances.[1] Key to the operation and construction of microring resonators for biological application is the ability to custom fabricate devices and optimize their performance for sensitivity, to open windows in the top coatings to allow biomaterials to interact with the guided wave, and to design and build arrays targeted to multi-analyte detection. This development is accomplished by our industrial partner Little Optics.

The basic operation of a microring resonator as a biosensor is simple and direct. Laser light is coupled into a glass waveguide at the resonant frequency of the ring. At resonance, a large amount of the light is coupled to the output waveguide. As molecules bind to the surface of the ring, a shift in the resonant frequency occurs because of a shift in the local index, causing the output light intensity to change. Thus the action of binding biological species to the surface of the ring causes a change in the optical throughput of the device. We tested and implemented several different types of biosensor microring resonator platforms to determine the optimal combination of sensitivity, stability, immunity to noise and robustness.

Research milestones:

- Negotiated with Little Optics to receive new ring resonator chips and received new ring resonator chips from Little Optics
- Designed our own chips, received training and started fabrication at a European institution
- Designed a new flow cell and sample holder according to the new chips. These components have been tested and are currently being used to conduct the experiments.
- Investigated methods for localization of biomolecules. These bioimprinting techniques include microcontact printing with PDMS stamps and channels, electrochemical dip-pen nanolithography (e-DPN) with AFM, and microarray fabrication by photolithography.
- Tested the new ring resonator chips from Little Optics
- Achieved fiber-to-chip-to-fiber coupling with the assembled v-groove arrays
- Fabricated masters for the PDMS stamps and microchannels, which will be used to functionalize specific regions of the surface (in this case different microrings) with different molecules to demonstrate binding event to targeted analytes, and thus specificity. Used the masters to fabricate polymer stamps and channels.

[1] G. H. Vander Rhodes, B. B. Goldberg, M. S. Ünlü, S. T. Chu, and B. Little, "Measurement of Internal Spatial Modes in Microring Resonators," IEEE J. Selected Topics in Quantum Electron, 6, 1077 (2000); G. H. Vander Rhodes, B. B. Goldberg, M. S. Ünlü, S. T. Chu, W. Pan, T. Kaneko, Y. Kokobun, and B. E. Little, "Measurement of internal spatial modes and local propagation properties in optical waveguides," Appl. Phys. Lett., 75, pp. 2368-2370, (1999).

Publications:

1) “Microring Resonators for Biochemical Sensing” at the American Physical Society (APS) March Meeting 2005, session Y15: Biosensors and Hybrid Biodevices.

2) “Microring Resonators for Biochemical Sensing” at the Conference on Lasers and Electro-Optics (CLEO) 2005, session CFF: Microfluidics, Flow Cytometry, and Biosensing, May 27 in Baltimore, MD.

3) “Optical Sensing of Biomolecules Using Microring Resonators” at IEEE Journal of Selected Topics in Quantum Electronics, Jan/Feb issue.

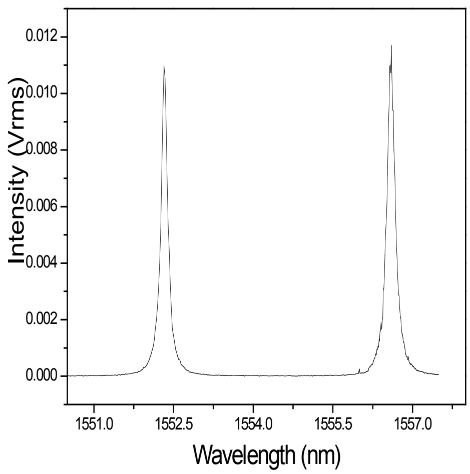


Fig. 1: *On the left*: The throughput of the microring resonators measured with the fiber array assembly. Q (~11,500) is as high as expected, however the throughput is still around -25dB. *On the right:* The fiber holder for array assembly to increase the throughput. The fiber to be placed is put in the groove on the fiber holder and placed in one of the v-grooves in the array. The holder is milled down on one side to allow for placing the second fiber without damaging the assembly of the first one.

Acoustic Direction Finder (ADF)

Personnel: Allyn Hubbard, Professor, Electrical and Computer Engineering Department
Socrates Deligeorges, Research Associate
Aleks Zosuls, Research Assistant
David Anderson, Research Assistant
Marianne Nourzad, Research Assistant
David Freedman, Research Assistant
Cassandra Browning, Research Assistant

Abstract: The group has been developing biomimetic acoustic localization systems for several applications; e.g. vehicle tracking, sniper detection system mounted on a robot (RedOwl). The main goal of this project is to apply the technology to a helmet mounted system, with out of plane microphones and a gyro mounted on the helmet. The concentration on biomimetic approaches to sound processing have been pursued in hopes that it will offer new techniques for extracting useful information from sound optimized for real world environments. The biomimetic approach has many advantages. It is capable of using small sensor spacing (between one inch and two meters) for localization. The system is multi-scale, modular, and portable. The system is also configurable for many applications and acoustic environments. The biomimetic system has high reverberation tolerance and has great potential for urban environments, in addition to providing good localization accuracy for a variety of sound sources.
The helmet based localization system uses time of arrival information processed through a biomimetic system to estimate sound source position.

Research milestones:

- Designed and built a test fixture and associated electronics for characterizing helmet with acoustic sensors.
- Characterized helmet system in a pseudo-anechoic space and generated HRFT data sets for an array of locations in free space.
- Created software models of the helmet system, developed algorithms for 3D localization, and optimized model parameters for localization task. Explored effects of sensor placement on helmet and geometry of sensor arrangement.
- Migrate model algorithms to hardware system, integrated sensor systems including tilt sensors.
- Field tested helmet system under various acoustic conditions, used acquired data to refine models and hardware.
- Demonstrated a working version of ADF/helmet system with gyro in June.
- Obtained and tested equipment and modeled performance on azimuth and elevation data collected from local gun range.
- Work out detection algorithms for mortar fire and field test at Aberdeen in March 2006.
- Started integrating new helmet algorithms in the XILINX with PowerPC embedded. Began to get the existing electronics' functionality onto a signal processing chipset.
- Prototyped helmet with tactors that buzz direction. Demonstrated performance at ARL.

Publications and Patent Applications:

1) JASA. 2006 Frank. Providence. Author: Shan Lu David C. Mountain, Allyn E. Hubbard A multicompartmental cochlear model with piezoelectric outer hair cells 151st annual meeting of the Acoustical Society of America. 2APPa4. June 2006

2) JASA2006 Earlab Providence.Socrates Deligeorges, Aleksandrs, David Mountain Allyn Hubbard, A biomimetic robotic system for localizing gunfire 151st annual meeting of the Acoustical Society of America. 2ASP1. June 2006

3) Socrates Deligeorges, Aleks Zosuls, David Mountain, David Anderson, and Allyn Hubbard Robots That Listen: Mimicking Human Hearing to Help Robots Find Snipers, http://www.acoustics.org/press/151st/lay_lang.html. Lay language paper ASA World Wide Press Room. May, 2006.

4) Socrates Deligeorges[1,2], Aleks Zosuls[1,2], David Anderson[1], Tyler Gore[2], Christian Karl[2], David Mountain[1,2], Allyn Hubbard[1,2] A Biomimetic Robotic System for Localizing Sound A Biomimetic Robotic System for Localizing Sound INTERNATIONAL CONFERENCE ON COGNITIVE AND NEURAL SYSTEMS, May, 200

5) *Marianne Nourzad[1], Christian Karl[1], Socrates Deligeorges[2] and Allyn Hubbard* Hardware implementations of a biomimetic acoustic localizing system INTERNATIONAL CONFERENCE ON COGNITIVE AND NEURAL SYSTEMS, May, 2006

6) Lu, S., Mountain, D., and Hubbard, A. A Multi-compartment Model of the Cochlea with Nonlinear Outer Hair Cell Force Generators INTERNATIONAL CONFERENCE ON COGNITIVE AND NEURAL SYSTEMS, May, 2006

May 2006-Patent application filed: Biomimetic Acoustic Detection and Localization System

Pathogen Detection Based on Dye Partitioning

Personnel: Dr. Guilford Jones, Professor of Chemistry
Dr. Pavel Landsman, Research Associate
Hui Jiang, Research Assistant

Abstract: A program of development with the goal of discrimination and optical detection of low levels of pathogenic organisms in field settings is described. A panel of absorption/fluorescence reagents has been discovered that allows rapid identification (<20 min. response time) of unusual concentrations of microorganisms in the environment and, simultaneously, their classification (e.g., the typing of bacteria). The primary targets of the panel are dormant bacterial spores, i.e., the most anticipated threat airborne bio-threat agents. For the first time, discrimination of different spore species in a potential field setting has been achieved. The panel can be implemented conveniently in a laboratory, using standard optical instrumentation (e.g., compact microplate readers) or in a portable detection device. The goal is the development of a working prototype of a field deployable mini-laboratory to be used in military or counter-terrorism missions. Other commercial (biomedical) opportunities that involve detection of non-microbial human pathogens have also been identified (e.g., pathogenic protein/amyloid aggregates associated with contagious prion disease, or Alzheimer's disease).

Research milestones:

- Light and fluorescent microscopic techniques enabling efficient characterization and quantification of dye-bacteria contacts were established
- Cyanine dye have been successfully employed in microfluidic detection of spores and in-flow discrimination of spores and vegetative bacteria
- A systematic approach toward biodetection of an "unknown pathogen" has been proposed and investigated – based on newly found dye-binding targets (specific molecular motifs) shared by all microbial pathogens
- New classes of fluorogenic probes targeting specific pathogen-related molecular hosts have been designed
- A hierarchical reagent panel (c.a. 50 dye candidates under evaluation) for instantaneous biocontamination control (bio-alert signal within 10 min.) and further classification of "unknown" biopathogens have been suggested.
- A panel of ~ 30 potent reagents of new structural design, sensitive to dormant spores and demonstrating differential response toward Bacillus forms was designed, prepared and tested vs. various Bacillus spore and outgrowing cultures
- Fast kinetic response of new reagent (THIA) was successfully used in a microfluidic flow detector to differentiate between spores and vegetative forms

Publications and Patent applications:

1) J. Wan, P. Landsman, B. Xia, P. E. Bower, V. Heinrich, G. Jones II, V. I. Vullev, "Continuous flow microfluidic devices for detection of bacterial endospores", *Proceedings of NanoBio2006 Frontiers in Biomedical Devices Conference, June 8-9, 2006, Irvine CA, USA*

2) V. I. Vullev, J. Wan, V. Heinrich, P. Landsman, P. E. Bower, B. Xia, G. Jones II, "Non-lithographic preparation of microfluidic devices", *J. Am Chem. Soc.* (2006), submitted.

3) G. Jones II; P. Landsman, "Fluorescent spectroscopic and microscopic differentiation of bacterial endospores and vegetative species with thioflavin and cyanine dyes", *Organic Letters,* in preparation

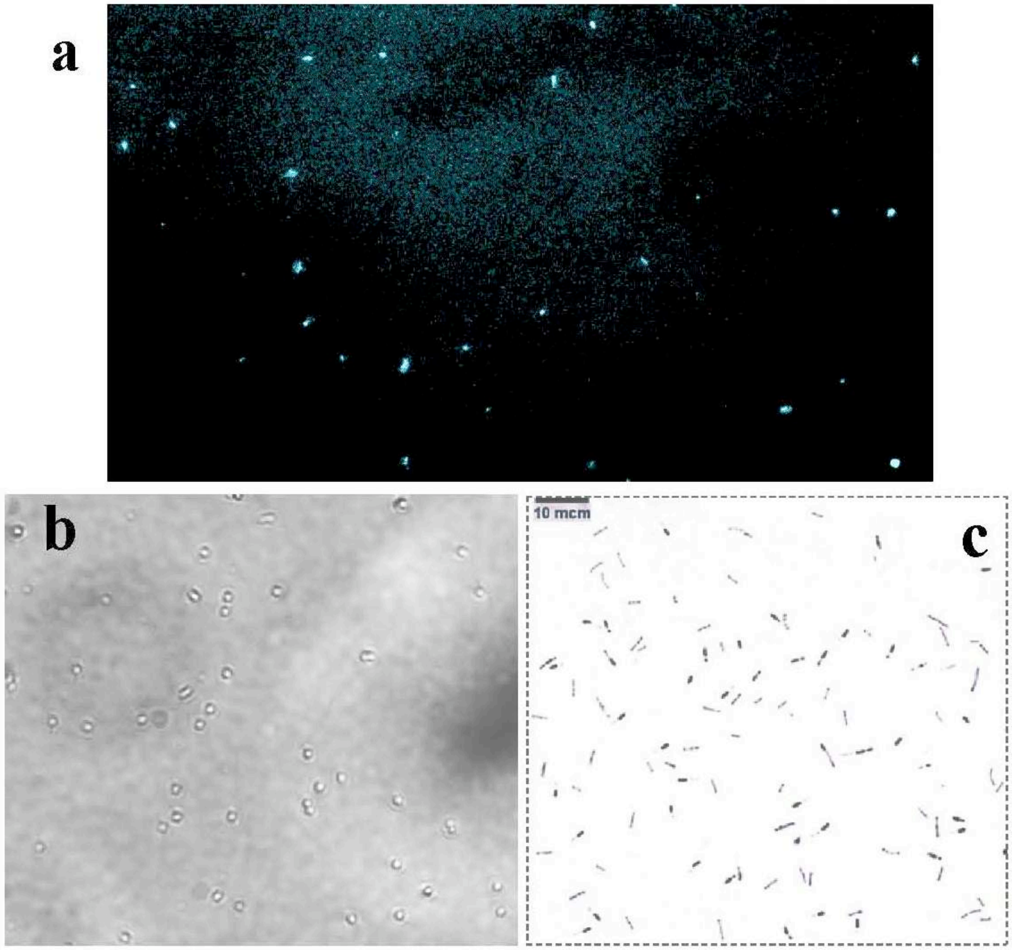


Fig. 1. Microscopic images of *Bacillus subtilis* cultures: **a –** epifluorescent image of dormant spores stained with thioflavin T; **b,c –** differential interference contrast images of dormant spores (**b**) and vegetative cells (**c**)

4) G. Jones II; P. Landsman, “Characterization of malachite green fluorescence. A multipurpose analytical system based on emission enhancement for dye-polyelectrolyte complexes.” *Organic and Biomolecular Chemistry* (2006), submitted

5) G. Jones II; P. Landsman, “Poly (methacrylic acid) enhances emission of malachite green stain extracted from Bacillus spores and enables their fluorimetric quantitation in aqueous samples”, *Journal of Photochemistry and Photobiology A: Chemistry* (2006), submitted.

Provisional patent application: “A fluorogenic detection panel for unknown pathogen in liquid suspension” – submitted

Development of GaN substrates by HVPE to be used by both the BU and the ARL groups for fabrication of UV-LEDs for biological and chemical detection.

Personnel: Dr. Theodore D. Moustakas, Photonics Center Faculty, Professor, Department of Electrical Engineering, and Department of Physics
Anirban Bhattacharyya, Research Associate
Adrian Williams Research assistant

Abstract: The overall objective of the program is to develop UV-LEDs for the detection of biological and chemical agents. Ideally such devices should be fabricated on GaN substrates, which unfortunately are not commercially available. Both our groups at Boston University as well as at ARL are developing these UV-LED structures on sapphire substrates by the molecular beam epitaxy (MBE) method. We found that the structural quality as well as the luminescence efficiency of such devices improves significantly if the sapphire substrate is first coated with a thick GaN or AlN template (quasi-substrate). In this program, continued the development of such GaN templates using the hydride vapor phase epitaxy (HVPE) method. During the current phase of the program, we developed methods for the preparation of the sapphire substrates to reveal the step structure associated with the miscut of the substrate. Such surface preparation facilitates the nucleation and growth of high quality GaN templates. Furthermore, planarization methods have been developed to form atomically smooth GaN templates prior to the epitaxial growth of the LED structures by MBE. Our laboratory is equipped with two HVPE reactors which are dedicated to this project.

Research milestones:

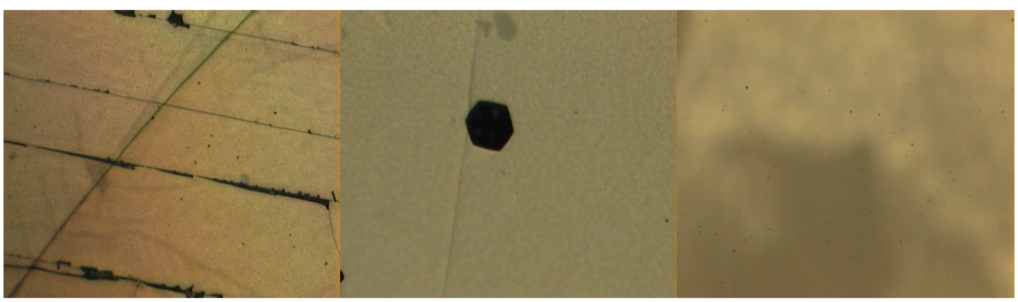
- Grew free standing GaN substrates. The horizontal HVPE reactor was redesigned to allow up to 90% conversion of the HCl to GaCl. This allowed the growth of GaN films at growth rates as high as 700µm/hr. As a result we have been able to make free standing GaN substrate with dimension one half of a 2” wafer with overall thickness 3.8mm.
- Grew a p-n junction LED on an A-plane n-GaN template by depositing 300nm of p-GaN on the top by the MBE method. This LED structure was characterized only at the wafer level and shows good rectification characteristics and electroluminescence spectrum.
- Developing an understanding of stresses in both the GaN epilayer and the sapphire substrate during growth by the HVPE method. Specifically, stresses in the film and substrate were calculated using the Stoney equation as a function of film thickness. Such analysis has yielded growth conditions that allow for the deposition of extremely thick (1mm+) crack-free GaN onto sapphire substrates. The mechanical strength of such layers has been found to be high enough to generate freestanding GaN by mechanical grinding of the substrate.
- Hall effect measurements were used to characterize the electrical properties of the GaN templates on sapphire substrates as well as freestanding GaN substrates produced by the HVPE method. Nano-indentation studies were done in collaboration with a group at Drexel University.
- Demonstrated the suitability of these GaN templates for the growth of UV LEDs, by developing such LED structures by growing the active region of the device on these substrates by the MBE method.

- Formed freestanding GaN substrates by a natural separation mechanism, effectively eliminating the need for post-growth processes such as laser liftoff, chemical etching or mechanical lapping to form freestanding GaN substrates. A number of GaN thick films were grown onto sapphire substrates by the Hydride Vapor Phase Epitaxy (HVPE) method with thickness varying from 200μm to 3.8mm using a low temperature GaN or AlN buffer as the nucleation layer. We have found that samples grown on a low temperature GaN buffer naturally delaminate from the sapphire substrate post-growth over the entire thickness range studied. Furthermore, we have observed that the thinner films have high crack densities leading to the delamination of several smaller freestanding pieces. As the GaN thickness increases, the area of the delaminated pieces also increases, ultimately leading to a 1-to-1 correlation between initial sapphire substrate area and freestanding GaN area.

Publications and Patent Applications:

1) Adrian D. Williams, T.D. Moustakas "**Planarization of GaN by the Etch-Back Method**" Mater. Res. Soc. Proc. Vol. **892,** 363 (2006).

2) Adrian Williams and T. D. Moustakas **"Formation of large-area freestanding Gallium Nitride substrates by natural stress-induced separation of GaN and sapphire"**
Journal of Crystal Growth (Submitted)



(a) **(b)** **(c)**

Figure 1 – 800μm x 1000μm optical images of surface crack density for GaN films grown to various thicknesses. (a) 200μm film suffers from dense network of cracks separated by 200-300μm. (b) 800μm film is sparsely populated with cracks separated by several mm. (c) 1300μm film is crack-free.

III-nitride quantum cascade lasers for the 3-5µm atmospheric window

Personnel: Roberto Paiella, Assistant Professor, ECE Department
Theodore Moustakas, Professor, ECE department and Physics Department
Anirban Bhattacharyya, Research associate
Kristina Driscoll, Research Assistant

Abstract: The goal of this research project is the development of quantum cascade (QC) lasers emitting in the 3-5 µm range, based on AlGaN heterostructures. QC lasers are semiconductor devices based on intersubband transitions between confined conduction-band states in coupled quantum wells. So far they have been primarily realized with InGaAs/InAlAs or GaAs/AlGaAs heterostructures, at various wavelengths spanning the mid- and far-infrared regions. Since their invention in 1994 these devices have made remarkable advances, including the demonstration of cw operation at room temperature in the 6-9 µm range, and they are now in the process of being commercialized.

However, for emission in the 3-5 µm atmospheric window the operation of QC lasers is still largely limited to cryogenic temperatures. The main limiting factor in this respect is the thermal excitation of electrons from the upper laser states into the continuum of unbound states over the barriers. This problem can be addressed using quantum wells with larger barrier heights, such as the GaN/Al(Ga)N heterostructures considered here. This goal is particularly significant since at present there is no other high-performance semiconductor laser technology fully covering this important wavelength range. Aside from QC lasers, impressive results have also been obtained with antimony-based interband lasers, however to date their longest emission wavelength at room temperature is 3.5 µm.

Research milestones:

- Measured the intersubband (ISB) absorption spectra of new samples based on GaN/AlGaN coupled quantum wells, similar to the structures to be employed in the active material of the proposed quantum-cascade (QC) laser sources.
- We have fabricated new mid-infrared light-emitting mesa structures based on a simple QC design, using a forming gas treatment to eliminate possible parallel current paths due to surface states on the etched sidewalls.

Publications:

I. Friel, K. Driscoll, E. Kulenica, M. Dutta, R. Paiella, and T.D. Moustakas, "Investigation of the Design Parameters of AlN/GaN Multiple Quantum Wells Grown by Molecular Beam Epitaxy for Intersubband Absorption," *J. Crystal Growth*, vol. 278, pp. 387-392, 2005.

Resonant Cavity Imaging Biosensor

Personnel: M. Selim Ünlü, Professor, Electrical & Computer Engineering, and Physics
David Bergstein, Research Assistant

Abstract: The essence of the project is the development of an optical label-free microarray detection technique that would enable high-throughput determination of promoter sequences. Our approach centers on the use of a structured dielectric substrate (Si-SiO_2), coated with a layer of SiO_2 , and designed for use at communications wavelengths (around 1550nm). The **resonant cavity imaging biosensor (RCIB)** detects binding between target biomolecules in solution and probe biomolecules fixed to a microarray surface. Near-IR light couples resonantly through a cavity constructed from Si/SiO_2 Bragg mirrors that contains the microarray surface. As the wavelength of the probe beam is swept, an IR camera monitors cavity transmittance at each pixel. RCIB improves on existing tag-free biosensing techniques by offering the combination of high sensitivity, high throughput, and real-time observation. The approach uses widely available communications wavelength equipment and microarray chemistry compatible SiO_2 surface and also the layered substrate is inexpensive to fabricate.

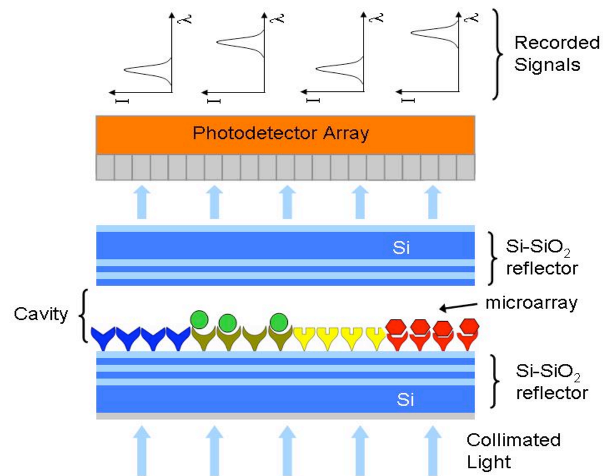


Fig. 1 The wavelength of the excitation light is swept and wavelength vs. transmission curves are recorded by a camera positioned beyond the cavity. The microarray is fabricated on one of the reflector surfaces. Binding to the surface is indicated by a local shift in the resonant response of the cavity.

SRIB: Spectral Reflectance Imaging Biosensor (SRIB), works similar to RCIB, except that the resonant signals are collected in reflection, and the cavity is simply formed within an oxide layer on a Si substrate (Figure 2). The first reflector is simply the SiO_2 – Si interface. The thin biomaterial layer patterned on the oxide surface can be considered part of the oxide layer, and so the second reflector is the air-biolayer interface. Since the reflectivity of these interfaces is not nearly that of the RCIB reflectors, the finesse is greatly reduced. Lower finesse decreases the cavity enhancement and hence the sharpness of the recorded curves

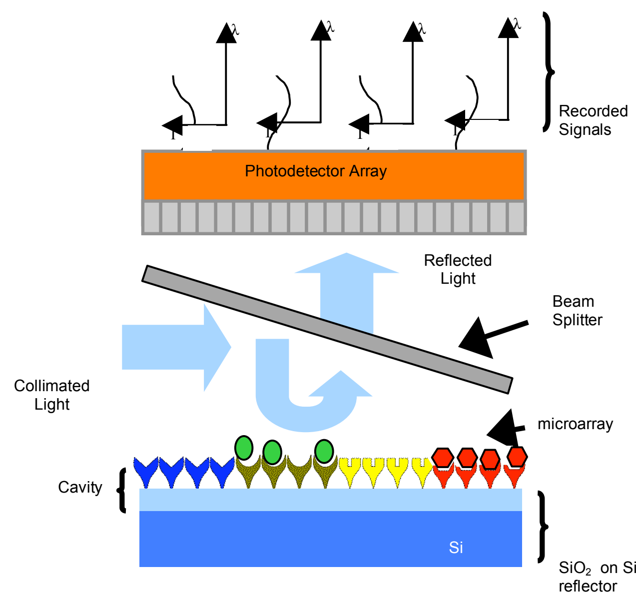


Figure 2: Working principle of SRIB

and the ability to discriminate small changes. Non-the-less, the benefit of a monolithic design is a significant one. Cavity vibrations and drift that are a problem in RCIB are completely eliminated in this design where the top noise sources become laser intensity fluctuations and camera noise. This has been confirmed by the preliminary SRIB setup that we have constructed.

Research milestones:

♠ Constructed RCIB test setup, utilizing the SOI substrates that were developed for the RCE photodetectors as reflectors in a Resonant Cavity Imaging Biosensor (RCIB) and avoiding the need for integrated photodetectors by using an external camera. The key features of these reflectors developed for the Si RCE photodetector project that enable the present biosensing application are high reflectivity, low loss, exceptional smoothness, and cost effectiveness. Obtained results with artificial array features.

♠ Constructed an SRIB system in the visible spectrum purchasing a camera and visible tunable laser. The new setup uses a New Focus tunable laser and a Q-Imaging camera with optics adapted and coated for this wavelength range. The tuning range of the laser is 768nm-785nm (18nm). A larger wavelength range with more spectral features (more of the characteristic interference curve) in the measurement would be most helpful since it would enable us to fit the curve more accurately.

♠ Preliminary noise analysis of the SRIB system has also been conducted. At a constant wavelength (not tuning) the noise of the image acquisition is limited by shot noise. The deviation per measurement is around 1% collecting 12000 photoelectrons. Camera readout and dark current noises are negligible as predicted. When 30 images (each of 4 ms of exposure) were taken and averaged per acquisition, the fluctuation drops to 0.2%, close to the predicted value.

Publications:

Presented paper “Silicon Substrates with Buried Distributed Bragg Reflectors for Biosensing” at the International Semiconductor Device Symposium Dec. 2005 in Bethesda, MD. Discusses RCIB technique and in particular the substrates that are vital to its success.

Will present a paper “Pure Silicon Integrated Fiber-Optic Receivers for Optical Multi-Gigabit Chip-to-Chip Links” at the 2006 VLSI Symposium. Demonstrates of our capability of integrating photodetection and electronic circuit functions on a single Si chip allowing for the integrated biosensors based on RCIB.

Uncooled Double Cantilever Microbolometer Focal Plane Arrays with mK NETD

Personnel: Xin Zhang, Ph.D., Fraunhofer Assistant Professor, Manufacturing Engineering Department
Biao Li, Ph.D., Project Manager, Fraunhofer Center for Manufacturing Innovation
Shusen Huang, Research Assistant

Abstract: The goal of the project is to develop uncooled, MEMS-based, double-cantilever microbolometer focal plane arrays (FPAs) for infrared (IR) imaging. The ultimate successful completion of this project will enable manufacturing of *a flat, low-cost, lightweight, high-performance double-cantilever IR imaging system reaching a noise equivalent temperature difference (NETD) in the mK range*.

The specific objectives of this year's work were twofold: (1) eliminate stress-induced curvature in free-standing bimaterial microbolometer arrays, and (2) manufacture low-cost, double-cantilever microbolometer FPAs using low-temperature micromachining techniques.

Research Milestones:

- Studied the gradient residual stress in sputtered aluminum (Al) and SiN_x films;
- Studied the stress response of both plasma-enhanced chemical vapor deposited (PECVD) SiN_x films and electron beam (Ebeam) Al films during the thermal cycling experiments;
- Designed all of the masks for single-cantilever and double-cantilever microbolometer focal plane arrays (FPAs);
- Manufactured both single-cantilever (with and without Pt/Ti pads) and double-cantilever microbolometer FPAs at MTL (Microsystems Technology Laboratory, MIT) and PHO (Photonics Center, Boston University);
- Studied the post-processing curvature modification of single-cantilever microbolometer FPAs (without Pt/Ti pads) by using Ar ion beam machining and rapid thermal annealing (RTA);
- Developed the theory to relate the gradient residual stress in a multilayered structure to the resultant bending curvature;
- Characterized the thermo-mechanical response of bimaterial SiN_x/Al microbolometer structures;
- Characterized the gradient residual stress in bimaterial SiN_x/Al microbolometer structures by using the theory developed in our previous study;
- Post-process curvature modification of double-cantilever microbolometer FPAs using thermal annealing;
- Post-process curvature modification of microbolometer structures by using continuous etching;

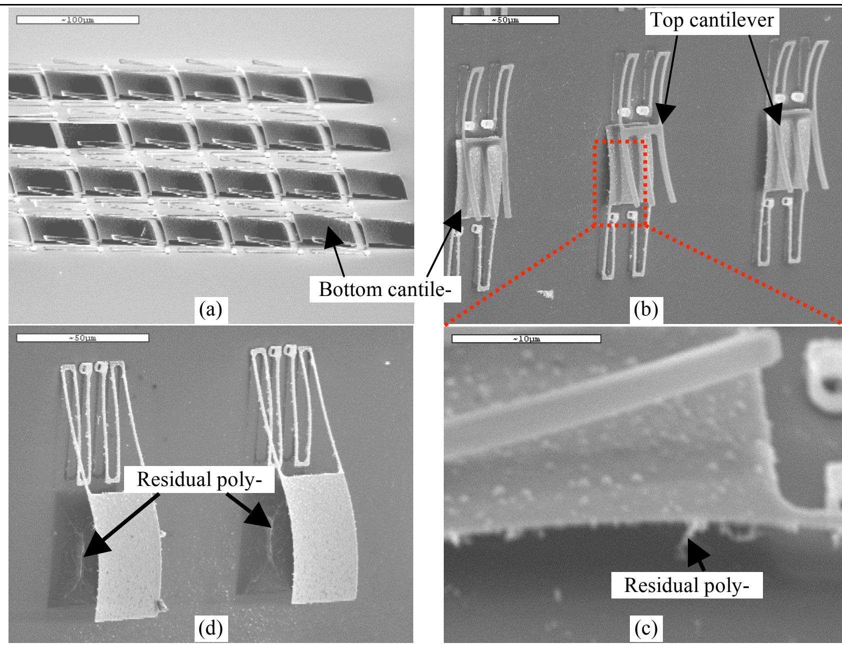


Fig. 4: *(a) and (b) The as-fabricated bottom cantilevers are bent downward to the substrate while the top ones are bent upward; (c) there is residual polyimide under the bottom cantilevers; and (d) when the bottom cantilevers are less curved after certain RTA treatments, residual polyimide can then be removed by further oxygen plasma ashing.*

Publications:

1) Shusen Huang, Biao Li, and Xin Zhang, "Elimination of stress-induced curvature in microcantilever infrared focal plane arrays," *Sensors and Actuators A: Physical*, 130-131 (2006) 331-339.
2) Shsuen Huang and Xin Zhang, "Extension of the Stoney formula for film-substrate systems with gradient stress for MEMS applications," *J. Micromech. Microeng.*, 16 (2) (2006) 382-389.
3) Shusen Huang and Xin Zhang, "Gradient residual stresses-induced elastic deformation of multilayered MEMS structures," *Sensors and Actuators A: Physical*, Accepted.

Development of a Portable SERS (Surface Enhanced Raman Scattering) Microorganism Detection System

Personnel: Dr. Lawrence Ziegler, Professor, Chemistry Department
Dr. Ranjith Premasiri, Research Associate
Jeffrey Shattuck, Research Assistant
Ishan Patel, Undergraduate student

Abstract: Our long-term goal is to develop a platform tool based on SERS microscopy employing our novel substrate for the rapid identification and detection of a broad range of category A – C priority pathogens. Ultimately, we plan to acquire spectra from single bacteria in clinical isolates within a time frame of minutes. The work during this funding period builds on our previous success with *in vitro* studies of SERS spectra of bacteria. During this current funding period further developed this technology for the identification of bacterial SERS spectra extracted from human biological fluids. In order to develop rapid, reliable diagnostic capabilities at the single cell level for these "real world" samples the performance characteristics of our SERS substrates were further developed. These include improving the concentration of SERS "hot spots", comparing the performance of Ag vs. Au clustered nanoparticles, reducing deleterious heating effects and enhancing the SERS substrate storage time. Our success with bacterial cultures was transferred to a clinical setting by spiking bacterial strains into human blood, bronchoalveolar lavage (BAL), and cerebral spinal fluid (CSF). Following human exposure to inhaled biothreats vegetative cells will be found in all these human fluids. The effects of these biological fluids on the SERS spectra of several species of bacteria; (e.g. *B. anthracis* Sterne and *E. coli*) were observed. Protocols for maximizing these signals and quantifying our results were developed. The effects of fluid exposure time, minimal concentration determinations, biological fluid substrate effects and human fluid variations were also studied.

Research milestones:

- Developed consistent methods for making both Au and Ag substrates in a repeatable manner. Increased the shelf life of the substrates.
- Developed a method to concentrate and separate bacteria from red and whole blood cells. This is achieved by a combination of centrifugation and lysis by a Na_2CO_3/Triton X-100 solution. The procedure takes only about 15 minutes and at least for the high spike doses of these initial studies resulted in recovery of ~ 30% of the bacteria spiked into the blood samples. Signals from only 10^6 bacteria per ml appear to be the limit of our current enrichment/detection procedure. For blood exposure times of up to 15 minutes, no substantial spectral changes were observed in the SERS spectra of *B. anthracis* exposed to the human blood as compared to those grown in standard culture broth.
- Demonstrated the ability of SERS to act as a sensitive detector and identifier of bacterial spores, with some limitation. The characteristic vibrational signature of CaDPA (calcium dipicolinate) is associated with all the spores that we obtained from Adam Driks (Loyola University Medical School). This signature thus only distinguishes bacillus spores from other spores and pollens.
- Developed a SERS methodology for the rapid detection and identification of *bacillus* spores. A crucial measure of the effectiveness of this approach is the sensitivity. We find that our current level of detection is < 100 spores which is better by an order of magnitude than the best previous SERS based scheme for bacterial spore detection.

- Developed and demonstrated the use of a quantitative statistical tool, PCA, for the identification and differentiation of bacteria via their SERS spectra. In our current procedure, Fourier transforms are used to reduce extraneous spectral noise and second derivatives of the observed noise-reduced SERS spectra generate “fingerprints” or “barcodes” for the data array inputs to the PCA.

Publications:

1) “Characterization of the surface enhanced Raman scattering (SERS) of bacteria”, W. R. Premasiri, D. T. Moir, M. S. Klempner, N, Krieger, G. Jones,II and L. D. Ziegler, J. Phys. Chem. B, 109, 312-320 (2005).

2) “Vibrational Fingerprinting of Bacterial Pathogens by Surface Enhanced Raman Scattering”, W. R. Premasiri, D. T. Moir and L. D. Ziegler, SPIE Vol. 5795, 2005.

3) “Vibrational Fingerprinting of Bacterial Pathogens by Surface Enhanced Raman Microscopy”, W. R. Premisiri, D. T. Moir, M. S. Klempner and L. D. Ziegler, (submitted review chapter for publication in *Applications of Surface Enhanced Raman Spectroscopy*, edited by S. Farquharson.)

4) “Surface Enhanced Raman Scattering of Microorganisms”, W. R. Premasiri, D. T. Moir, M. S. Klempner and L. D. Ziegler, invited chapter, "New Approaches in Biomedical Spectroscopy" (eds. H Kneipp and K. Kneipp).

Patents have been filed pertaining to (a) the SERS substrates and (b) the idea of a portable, Raman microscopy platform, employing these substrates, for microorganism identification and detection. Two U.S. patents were filed 12/1/05:

“Nanostructure substrate for surface enhanced Raman scattering”, W. R. Premasiri.

“Analyzer for nanostructured substrate for surface enhanced Raman scattering”, W. R. Premasiri, D. M. Moir, L. D. Ziegler.

3. Thirteen awards totaling $1.3M ARL Selected for Support in FY06 (next fiscal year)

Prof. Bellotti – Theoretical study of the optical and transport properties of III-Nitrides Quantum Wells and superlattices. $71,969. This project is part of the collaboration between Boston University and the Army Research Laboratories to develop UV-LEDs as well as novel detectors for the detection of biological and chemical agents. This theoretical work supports the design effort for these devices.

Prof. Bifano – Secure, optical data transfer using modulated retro-reflection for autonomous robot communication. $105,499. This project will develop a compact, low-power device to detect and modulate an incoming laser beam, and then return the modulated signal back to the location of the sender. This system can be adapted to the REDOWL acoustic sensing robot platform for covert communication.

Prof. Bigio – Polar Nephelometer for Rapid Measurement of the Scattering Phase Function of Particulates. $39,315. This project will build an instrument for identification of particulates (bacteria, spores or other forms) from aerosols or from aqueous suspension, as in water supply.

Prof. Dal Negro, Saleh and Teich – Fully Silicon Based Sources for Military and Biomedical Applications. $102,015. The purpose of this project is to investigate the feasibility of efficient light sources based on CMOS compatible silicon nano-materials and to evaluate their potential for stimulated emission and optical gain.

Prof. Erramilli – Nanomechanical and Gate Controlled Nanoelectrical sensors for airborne and waterborne threat detection. $72,836. The goal of this project is to develop methods for enhancing the sensitivity and specificity of nanosensors for sensing airborne and waterborne pathogens.

Prof. Jones – Rapid Fluorescence Assay for Bacterial Endospores. $96,592. The goal of this project is the delivery of a prototype of a field deployable mini-laboratory to be used in military or counter-terrorism missions.

Prof. Morse – An Ultra Sensitive Bio-Sensor. $106,635. The final goal of this project is a new sensor that can act as a general platform for ultrasensitive measurements of the change of refractive index associated with surface binding. This sensor can be used for biological as well as other measurements.

Prof. Moustakas – Development of free standing GaN substrates by HVPE method. These substrates will be used by both BU and the ARL groups for fabrication of UV-LEDs for biological and chemical detection. $150,656. This project is part of collaboration between Boston University and the Army research Laboratories to develop UV-LEDs for the detection of biological and complete infrastructure required for fabrication and characterization of this nanotubes.

Prof. Paiella and Prof. Moustakas – III-Nitride quantum cascade lasers for the 3-5 μm atmospheric window. $111,960. This project is a development of quantum cascade lasers for the 3-5 μm atmospheric window for counter measures applications (confusing heat-seeking missiles and IR detectors)

Prof. Swan – Individual Carbon Nanotubes Devices; Fabrication and Optical Characterization. $65,467. The goal of this project is to gain full understanding of carbon nanotube optical properties and pursue new applications for them. The PI will pursue industrial collaborations and complete infrastructure required for fabrication and characterization of this nanotubes.

Prof. Unlu – Development and deployment of compact integrated biosensor platforms. $162,305. The overall goal of this project is to develop and deploy compact integrated biosensor platforms based on resonant cavity imaging biosensors and microring resonator biosensors.

Prof. Zhang – Uncooled Double Cantilever Microbolometer Focal Plane Arrays with mK NETD. $99,531. This project is developing uncooled miniaturized IR detectors which will have performance comparable to state of the art cooled detectors. Therefore, IR cameras will require much less power, will be significantly smaller in size and cost significantly less than the cameras using cooled detectors.

Prof. Ziegler – Vibrational Fingerprinting of Bacterial Spores by Surface Enhanced Raman Microscopy. $116,022. This project's goal is to develop in-field analysis tools using SERS to analyze potentially lethal environmental samples containing bacterial spores and vegetative cells.

These projects are funded for a cumulative budget of **$1,300,802.**

IV. Initiatives

A. Overview

The shared vision and mutual support that forms the foundation of the Photonics Center has engendered a host of Center-based initiatives intended to accelerate and invigorate our collective activities. These initiatives are intended to catalyze new avenues of research and development while strengthening our interdisciplinary efforts. In the past year, three such initiatives were launched.

B. Photonics Center New Faculty Initiative Program

The Photonics Center has made a strategic decision to strengthen its already well-known program in biophotonics. This growth will exploit the powerful integration of "biology and light" at the Photonics Center, in collaboration with the Boston University Medical Center, to create applications and build devices in medicine, genetics, environmental science, for defense and non-defense applications. A particular emphasis will be on translational biophotonics that exploits the Center's pipeline of innovation in this field.

This highly interdisciplinary area draws on combined basic research in the physical sciences, life sciences, medical, and engineering fields focused on defense applications. The Center's specific plans include FY06 ARL Cooperative Agreement project support to assist with academic equipment and program startup costs for a new tenured or tenure-track faculty position complementary to our core intellectual and academic strengths at Boston University. These areas of strength are classified broadly to include:

- **Biophotonic imaging**, the study of optical imaging and how it is used to understand biological problems, including microscopy, subsurface probing of tissue, adaptive optics for retinal and neurobiological imaging.

- **Biomedical photonics**, the study of light-based systems for applications including detecting and treating disease, probing molecules and cells, sensing pathogens, microsurgery and wound healing. Efforts in this category will have the discriminating leverage the new BL4 (Biohazard Level 4) facility being developed with federal funding at Boston University to reinforce our position as a national leader in Biophotonics as applied to defense.

The Center's leadership in this important area of research and development will be leveraged by an unparalleled geographic concentration of biophotonics-related academic and commercial activities in the Boston area. The success of our program will depend on our ability to attract, support, and retain the field's most promising academic researchers.

To that end, the Center has established a **New Faculty Initiative Program**, comprised of three parts: support for major research equipment, support for academic research initiation, and support for collaborative research work with ARL.

Major Research Equipment Support

For FY06, we will provide funds to support major shared research instrumentation as part of the startup support for a new biophotonics faculty member hired in one of the Center's six cognate Departments (Physics, Chemistry, Aerospace and Mechanical Engineering, Electrical and Computer Systems Engineering, Manufacturing Engineering, and Biomedical Engineering). The equipment, which will be specified collaboratively by the new faculty member, the hiring Department's Chairman, and the Director of the Photonics Center, will be housed either in the Photonics Center Laboratory designated for use by the new faculty member or in one of the center's three shared laboratory facilities. In either case, the equipment must be designated in a way that allows it to be shared with other Photonics Center faculty. Moreover, the request should be for equipment that will demonstrably benefit the Photonics Center community.

Academic Research Initiation

To help accelerate the scholarly career of a new biophotonics faculty member hired by one of the Center's cognate Departments, the Center will apportion some of its ARL Cooperative Agreement Grant to support travel, laboratory development, summer research salary and graduate student stipends for the new faculty member. These discretionary resources will be allocated on the basis of the particular needs of the faculty member, and cannot reasonably be fully specified at this time. Nevertheless, a typical allocation is detailed below:

- Faculty summer salary – 3 months summer support
- Graduate Student support - one graduate student for one year
- Travel support for presentations at technical symposia, discussions with funding agencies, and visits to ARL

Collaborative ARL Research Initiation Award

Through the ARL Cooperative Agreement Grants program, Boston University and the Army Research Laboratory have established a broad-based, effective, and productive mesh of collaborative, interdisciplinary research projects. It is a strategic goal of the Center to promote the same level of collaboration in activities related to our new biophotonics initiative. To that end, a collaborative research initiation sub award will be made to the faculty member who is to be supported by the Photonics Center New Faculty Initiative Program in FY06. The award will be contingent upon submission by the faculty member of a detailed technical proposal for a research project to be conducted in collaboration with a research counterpart at ARL. Approval of the project by the Center Director and by the ARL program technical point of contact will be required before approval is granted.

The first Photonics Center New Faculty Award has been accepted by Dr. Hatice Altug, who will join the Electrical and Computer Engineering Department in January 2007 as an Assistant Professor. Hatice Altug is currently pursuing a Ph.D. in Applied Physics at Stanford University as an Intel Fellow. Her research involves design and implementation of high performance and ultra-compact nano-photonic devices and sensors including lasers and all-photonic switches and their large-scale on-chip integration for communication and bio-sensing applications. Previously, she worked on multiple quantum well electro-absorption modulators for optical interconnects, three dimensional metallic photonic crystals, microscopic theory of vortex states in superconductivity, phase transition in superconducting NbTi wires, and electron conductance quantization in metal nano-contacts. Her work on nanocavity lasers received the Best Paper and Research Excellence award in IEEE LEOS Conference in 2005. She was also awarded IEEE LEOS Fellowship. She received the first place award in the Inventors' Challenge competition of Silicon Valley with her work on micron scale all-optical switches. Her work on slow light and nano-cavity lasers has been featured on the cover of Applied Physics Letters and highlighted in several magazines. Hatice Altug is serving as the president of the Stanford OSA chapter.

C. Photonics Center PhD Research Assistantship Awards Program

The need for greater interdisciplinary research and education in photonics will require the very best students in the graduate pipeline. At the same time, we want our advanced graduate students to develop their research communication skills, and become engaged with the greater scientific society in photonics.

Therefore, we have established a new two-tiered program funding photonics graduate students in the sciences and engineering to simultaneously fill the pipeline, and also create the best possible photonics practitioners. Participating Departments in the Photonics Center community are eligible to compete for these Assistantships. Assistantship awardees are selected from a pool of nominees provided by those Departments' graduate program coordinators. Final selections are made by an appointed committee of Photonics Center faculty and staff members.

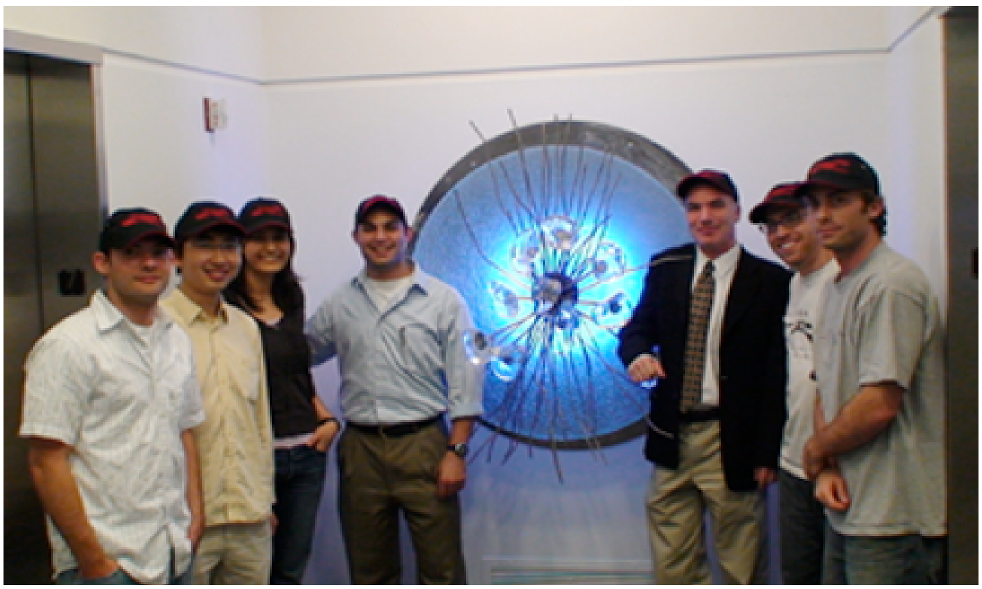
For FY06, we will provide a total of twelve academic-year doctoral assistantships in this program. In future years, we expect to provide eight full year (12 month) doctoral assistantships.

Six First-Year Graduate Research Assistantships in Photonics: The first component of our program includes six first-year Photonics Research Assistantships in FY 2006 (September 2006 - May 2007) for which the Assistants will have support for their first year (salary and tuition), will participate in Photonics Center seminars, and will be required to do a rotation through a Photonics Center laboratory during the summer following their first two semesters. (The first three months of year 2)

Six Advanced Graduate Research Assistantships in Photonics: The second component of our program includes six additional Assistantships for senior graduate students already engaged in photonics research with a Center faculty advisor. These Assistantships will sponsor one academic year of support for graduate students immersed in research laboratories and projects funded through the Photonics Center programs. These Assistants will be charged with a range of activities including: self-organizing a graduate student journal club and weekly afternoon tea; meeting with seminar speakers and distinguished visitors; attending national and international photonics meetings to present their work; assisting with workshop organization; and being ambassadors for Boston University's Photonics Center.

2006 Research Assistantship Awardees

The 2006 Photonics Center Junior Research Assistants are David Harrah from the Electrical and Computer Systems Engineering Department, Alon Singer from the Biomedical Engineering Department and Sebastian Remi from the Physics Department. Photonics Center Senior Research Assistants for 2006 are Ayca Yalcin, Nick Vamivakas and Josh Abell from the Electrical and Computer Systems Engineering Department, Kurt Schoener from BME, Logan Chieffo from the Chemistry Department, "Forest" Huang from the Manufacturing Engineering Department, and Xihua Wang from the Physics Department.



(Pictured L-R) Josh Abell; Xihua Wang; Ayca Yalcin; Kurt Schoener;
Professor Thomas Bifano, Photonics Center Director; Logan Chieffo; Nick Vamivakas

D. Photonics Center Visiting Professorship Program

The Photonics center has become well-known for its innovative work in Photonics System development. Its core faculty has established leadership positions in their field, and has earned a reputation for interdisciplinary endeavors. To promote and maintain these qualities in Center-led research, it is important that the Center creates a scholarly environment rich with new ideas, new interactions across disciplines, and continuous sharing of recently generated fundamental knowledge.

To that end, the Center has established a Visiting Professor Program, intended to attract pioneers and leading scientists and engineers for year-long residency in the Center. A Visiting Professor will be expected to interact with many of the Center's faculty and staff, and will be charged with participating broadly in its academic, educational, and translational activities.

While each Visiting Professorship will be customized to suit the particular synergies that can best be exploited by the selected recipient, it is expected that at a minimum the Visiting Professor will:

- Participate in educational activities, via short courses, topical seminars, workshops, or special topics courses taught to Photonics Center faculty and students.
- Interact with two or more of the Center's existing faculty research programs, bringing scholarly or practical expertise that is not well represented in the center's current faculty.
- Catalyze new or interdisciplinary work that will expand the Center's impact and/or contribution to the field.

For FY06, we will provide one full-time-equivalent year-long visiting professorship in this program. This might include several part-time appointments, or one full-time appointment, based on opportunity. Visiting Professorship candidates will be selected from a pool of nominees provided by Center faculty members. A courtesy appointment in one of the Center's cognate Departments is anticipated for Visiting Professors, at a level commensurate with their experience. Final selection will be made by the Center Director.

V. Education

At the core of the Photonics Center's mission is the education of future leaders in the field of photonics.

As an academic pillar for a leading large, private, urban University, Boston University's Photonics Center offers students an unparalleled educational experience. Our program gives students the opportunity to develop their research and communication skills, and to engage with world-leading scholars in photonics. The Center immerses its students in an environment that fosters collaboration, mentorship, and the unique opportunity to work with photonics companies and staff on prototype development of products through its partnership with BU's technology entrepreneurship program.

A. Selected Photonics Related Courses

Astronomy

CAS AS 441: Observational Astronomy
Astronomical techniques. Photometry, spectroscopy, photography, CCD imaging, and interferometry. Statistical methods for data reduction and analysis.

Electrical and Computer Engineering

ENG SC 560 Introduction to Photonics (Teich)
Prereq: CAS PY 313. Introduction to ray optics, wave optics, Fourier optics and holography, absorption, dispersion. Polarization, anisotropic media, and crystal optics. Guided-wave and fiber optics. Elements of photon optics. Laboratory experiments: interference; diffraction and spatial filtering; polarizers, retarders, and liquid-crystal displays; fiber-optic communication links. 4 cr.

ENG SC 563 Fiber-Optic Communication Systems (Morse)
Prereq: ENG SC 410, SC 311, SC 415, and SC 560 or consent of instructor. Introduction to fiber optics; components, concepts, and systems design techniques required for the planning, design, and installation of fiber-optic communication systems. Single- and multi-mode LED and semiconductor lasers, detectors, connectors and splicers, terminal and repeater electronics, wavelength division multiplexing optical amplifiers and solitons, and systems architecture for point-to-point and local area networks. Laboratory work on fiber and electronic measurements. 4 cr.

ENG SC 568 Optical Fiber Sensors (Morse)
Prereq: ENG SC 455. This course will cover the theory and practice of optical fiber sensors. This course will meet twice a week for two hours. In addition, there will be a three-hour laboratory each week. The focus of the course will be on laboratories involving various types of optical fiber sensors. Grades will be based on laboratory reports as well as a significant laboratory project. 4 cr.

ENG SC 569 Introduction to Subsurface Imaging (Saleh)
Prereq: Senior or graduate standing in ENG, PY, CH, MA, or CS. Introduction to subsurface imaging using electromagnetic, optical, X-ray, and acoustic waves. Transverse and axial imaging using localized probes (confocal scanning, time of flight, and interferometric techniques). Multiview tomographic imaging: computed axial tomography, diffraction tomography, diffuse optical tomography, electrical impedance tomography, and magnetic resonance imaging. Image reconstruction and inverse problems. Hyperspectral and multisensor imaging. 4 cr.

ENG SC 570 Lasers (Unlu)
Prereq: CAS PY313. Review of wave optics. Gaussian and Hermite-Gaussian optical beams. Planar-and spherical-mirror resonators. Photon streams. Absorption, spontaneous emission, and simulated emission. Laser amplification and gain saturation. Laser oscillation; pulsed lasers. Photon interactions in semiconductors. LEDs and semiconductor injection lasers. Photon detectors. Laboratory experiments: beams; divergence and collimation; electroluminescence; semiconductor injection lasers. 4 cr.

ENG SC 574 Physics of semiconductor materials (Bellotti)
Prereq: CAS PY 313 or PY 354 or equivalent. Study the fundamentals of quantum mechanics necessary to understand the properties of semiconductor materials. Study of the electrical and optical properties of materials, including crystal structure and bonding, free electron theory, band theory of solids and semiconductors. Carrier transport properties, dielectric, ferroelectric and magnetic properties. Cannot be taken for credit in addition to CAS PY 543. 4 cr.

ENG SC 575 semiconductor devices (Paiella)
Prereq: ENG SC 410, SC 455, and CAS PY 313 or PY 354, or equivalent. Fundamentals of carrier generation, transport, recombination, and storage in semiconductors. Physical principles of operation of the PN junction, metal-semiconductor contact, MOS capacitor, MOSFET (Metal Oxide Semiconductor Field Effect Transistor), JFET (Junction Field Effect Transistor) and bipolar junction transistor. Develops physical principles and models that are useful in the analysis and design of integrated circuits. 4 cr.

ENG SC 591 Photonics Lab I (Paiella)
Prereq: CAS PY313 or equivalent. Corequisite: ENG SC 560. Introduction to optical measurements. Laser safety issues. Laboratory experiments: introduction to lasers and optical alignment; interference; diffraction and Fourier optics; polarization components; fiber optics; optical communications; beam optics; longitudinal laser modes. Optical simulation software tools. 2 cr.

ENG SC 760 Advanced Topics in Photonics (Saleh)
This is an advanced special topics course in photonics; topics will vary from year to year. It will be offered in the spring term when there is no other 700-level course in the photonics area. Students who take the course on two different topics would be able to receive credit for it twice. Some of these offerings may become a permanent part of the curriculum in the future. 4 cr.

ENG SC 762 Quantum Optics (Saleh)
Prereq: ENG SC 560, or equivalent, or consent of instructor. Review of the postulates of quantum mechanics. Quantization of the electromagnetic field. Coherent, thermal, squeezed, and entangled states, and their associated photon statistics. Interaction of light with matter. Spontaneous and stimulated transitions. Theory of optical detection. Quantum theory of the laser. Interaction of light with two-level atoms, including photon echo and self-induced transparency. Quantum theory of parametric interactions. 4 cr.

ENG SC 763 Nonlinear and Ultrafast Optics (Teich)
Prereq: ENG SC 560. Tensor theory of linear anisotropic optical media. Second- and third-order nonlinear optics. Three-wave mixing and parametric interaction devices, including second-harmonic generation and parametric amplifiers and oscillators. Four-wave mixing and phase conjugation optics. Electro optics and photorefractive optics. Generation, compression, and detection of ultra short optical pulses. Femtosecond optics. Pulse propagation in dispersive linear media. Optical solitons. 4 cr.

ENG SC 764 Optical Measurement (Sergienko)
Prereq: ENG SC 560. Detailed discussion of basic principles of major optical effects such as interference, diffraction, and polarization. Analysis of practical applications of interferometry, ellipsometry, photometry, and laser spectroscopy in modern optical measurement such as characterization of industrial processes, environmental control, communication, and laboratory research. 4 cr.

ENG SC 765/BE 765 Biomedical Optics and Biophotonics (Bigio)
This course surveys the applications of optical science and engineering to a variety of biomedical problems, with emphasis on optical and photonics technologies that enable real, minimally-invasive clinical applications. The course teaches only those aspects of biology itself that are necessary to understand the purpose of the application. The first weeks introduce the optical properties of tissue, and following lectures cover a range of topics in three general areas: 1) Optical spectroscopy applied to diagnosis of cancer and other tissue diseases; 2) Photon migration and optical imaging of subsurface structures in tissue; and 3) Laser-tissue interactions and other applications of light for therapeutic purposes. In addition to formal lectures, recent publications from the literature will be selected as illustrative of various topical areas, and for each publication one student will be assigned to prepare an informal presentation (with overhead slides or PowerPoint) reviewing for the class the underlying principles of that paper and outlining the research results. Same as ENG BE 765; students may not receive credit for both. 4 cr.

ENG SC 770 Guided-wave Optoelectronics (Dal-Negro)
Discussion of physics and engineering aspects of integrated optics and optoelectronic devices. Semiconductor waveguides, lasers, and photodetectors. Layered semiconductor structures, quantum wells, and superlattices. QW detectors, emitters, and modulators. OEICs. Photonic switching. 4 cr.

ENG SC 771 Physics of Compound Semiconductor Devices (Bellotti)
Prereq: ENG SC 577 or SC 575 or CAS PY 543. Physics of present-day compound devices, and emerging devices based on quantum mechanical phenomena. MESFETs, Transferred Electron Devices, avalanche diodes, photodetectors, and light emitters. Quantum mechanical devices based on low dimensionality confinement through the formation of heterojunctions, quantum wells, and superlattices. High electron mobility transistors, resonant tunneling diodes, quantum detectors, and lasers. Materials growth and characterization are integral to the course. 4 cr.

SC 700 Nano-photonics (Dal Negro)
Fundamentals of electrodynamics, diffraction theory and optical response theory; Strongly confined fields and near-field optics: optics below the diffraction limit; Light-matter interactions in confined systems: quantum dots, wires and nanotubes, energy coupling phenomena, introductory concepts on plasmonics, photonic crystals structures; Applications to optical devices: nano-lasers, random lasers, photonic crystals LEDs, plasmon waveguides, micro-ring and ultra high Q resonators, principles of near-field optical microscopy, optical antennas and optical tweezers.

SC 700 Semiconductor quantum structures in photonic devices (Paiella)
Optical properties of semiconductors: interband optical transitions; excitons.Low-dimensional structures: quantum wells, superlattices, quantum wires, quantum dots, and their optical properties; intersubband transitions. Lasers: double-heterojunction, quantum-well, quantum-dot, and quantum-cascade lasers; high-speed laser dynamics. Electro-optical properties of bulk and low-dimensional semiconductors; electroabsorption modulators. Detectors: photoconductors and photodiodes; quantum-well infrared photodetectors.

Manufacturing Engineering

ENG MN 555 MEMS: Fabrication and Materials (Zhang)
Prereq: graduate status or consent of instructor. This course will explore the world of microelectromechanical devices and systems (MEMS). This requires an awareness of design, fabrication, and materials issues involved in MEMS. The material will be covered through a combination of lectures, case studies, and individual homework assignments. The course will cover design, fabrication technologies, material properties, structural mechanics, basic sensing and actuation principles, packaging, and MEMS markets and applications. The course will emphasize MEMS fabrication and materials. 4 cr.

ENG MN 777 Micromachined Transducers (Zhang)
Prereq: ENG MN 555 or consent of instructor. The field of microelectromechanical devices and systems (MEMS) has been growing at an exciting pace in recent years. The interdisciplinary nature of both micromachining techniques and their applications can and does lead to exciting synergies. This course will explore the world of mostly silicon-based micromachined transducers, i.e., microsensors and microactuators. This requires an awareness of material properties, fabrication technologies, basic structural mechanics, sensing and actuation principles, circuit and system issues, packaging, calibration, and testing. The material will be covered through a combination of lectures, case studies, individual homework assignments, and design projects carried out in teams. 4 cr.

B. Photonics Graduate Students (organized by Photonics Faculty Advisor)

Professor Thomas Bifano, Manufacturing Engineering

Diouf, Alioune
Kim, Duk Joon
Kim, Jin Hong
Lu, Wen
Stewart, Jason
Thompson, Guy (Raytheon)
Zhou, Yaopeng

Professor Irving Bigio , Biomedical Engineering

Anderson, Kerry Lee
Chen, Xiaoyan
Georgescu, Ramona
Gioux, Sylvain
Mulvey,
Reif, Roberto
Schoener, Kurt
Zheng, Jane

Professor David Castanon, ECE

Zhaledoust-Sani, Yashar

Professor Shyamsunder Erramilli, Physics

Amsden, Jason
Celli, Jonathan
Chen, Yu
Hou, Chang-Yu
Pinnick, Eric
Wang, Xihua

Professor Bennett Goldberg, Physics

Yalcin, Ayca

Professor Theodore Morse, ECE

Chivas, Bob
Garcia, Andrea Rosales
Wang, Eliza

Professor Theodore Moustakas, ECE

Abell, Josh
Chandresekaran, Ramya
Chen, Papo
France, Ryan
Li , Wei
Moldawer, Adam
Williams, Adrian
Xu, Tao

Professor Michael Ruane, ECE

Bergstein, David
Campbell, Bryan

Professor Anna Swan, ECE

Ayache, Maurice
Vamivakas, Nicholas
Walsh, Andy
Yin, Yan

Professor Malvin C. Teich, ECE

Bonato, Christian
Goode, Darryl
Mohan, Nishant
Nasr, Boshra
Pavlovich, Julia
Saleh, Mohammed
Yarnall, Tim

Professor Selim Unlu, ECE

Bozinovic,Nenad
Koklu,Fatih
Ozkumur,Emre
Menn,Steven
Wong,WaiYan

Professor Xin Zhang, Manufacturing Engineering

Cao, Zhiqiang (Jay)
Huang, Shusen (Forest)
Lin, I-Kuan
Qiu, Yiling
Zheng, Xiaoyu (Rayne)

Professor Lawrence Ziegler, Chemistry

Chieffo, Logan
Peng, Jay
Schneck, Jude
Shattuck, Jeff

Post-Docs	Advisor
Aamar, Ousama	Bigio, Irving
Bhattacharyya, Anirban	Moustakas, Theodore
Jaspan, Martin	Teich, Malvin
Nikiforov, Alexey	Moustakas, Theodore

VI. Facilities and Equipment

The Photonics Center's 235,000 net sq. ft. facility opened in June of 1997. Its ten floors house state-of-the-art research laboratories, laboratory support space, a business incubator, and instructional and seminar facilities specially designed for photonics research.

The building's structural steel frame is built on a reinforced concrete mat, as much as six feet deep, to minimize vibration. The basement level houses laboratories requiring low vibration and a light-free environment. Above-ground laboratories feature large windows, with a 1" airspace between the panes of glass to reduce the sound from the abutting Mass Pike.

The Center has a number of shared facilities for use by Center members and affiliated partners. In addition to these shared laboratories, the Center contains four floors (100,000 sq. ft.) of academic research laboratories and office space dedicated to its faculty researchers.

The Center's 6th Floor houses a business incubator that provides 23,000 sq. ft. of "greenhouse" space that can be flexibly configured to house up to 14 photonics start-up companies.

A. Shared Laboratory Facilities

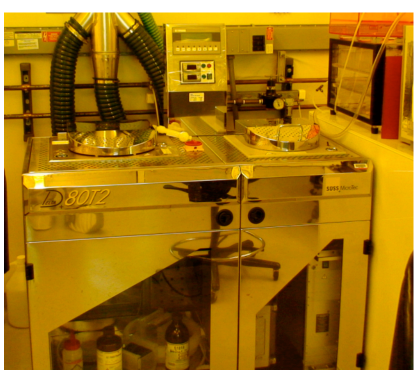
The Optoelectronic Processing Facility is a cleanroom facility that encompasses a wide range of equipment to aid in the research and processing from wafer to die level devices. The Integrated Optics Laboratory is sectioned into two main areas. A Class 100 Cleanroom for bonding and sealing processes and a laboratory space for Spectroscopy measurements and research. The Precision Measurement Laboratory encompasses analytical analysis of surfaces and materials with industry and research tools to enhance the research and scholarship of faculty and students.

The equipment in these labs is available for use by all faculty and students who are trained on the equipment or with the help of the laboratory manager. Outside industrial users of the shared labs can contact the appropriate lab manager to discuss rate schedules and training for use on the equipment of interest. Multi-usage or separate lab agreements can be put into place for companies interested in using the processing, metrology, and packaging capabilities.

Optoelectronic Processing Facility

The Optoelectronic Processing Facility, comprising 2500 sq. ft. on the 8th floor of the Boston University Photonics Center, is a multi-user facility equipped with state-of-the-art equipment for fabricating semiconductor and other optoelectronic devices. The facility includes: both class 100 and 1000 clean rooms and equipment necessary for photolithography, w et chemical processing, thin film depositions, plasma etching and cleaning, thermal oxidation, thermal annealing, electrical characterization, and device packaging.

The Class 100 Cleanroom is established as a photolithography room. Both the Headway Research photoresist spinner and Suss Microtech Delta 80 photoreisist spinner are available for use. The Headway spinner is a standard piece of photolithography equipment that provides students with hands-on experience on running a piece of equipment commonly found in industry and research labs. The Suss spinner is a relatively new technology that aids in edge uniformity. This spinner and access to Suss Microtech applications engineers provides students with training and knowledge that is outside the scope of their standard classroom learning. In the photolithography room are also Suss Microtech MJB3 and MA6 exposure tools for UV exposure of photoresist using masks that are purchased from outside vendors. The MA6 is a standard exposure tool that is found in industry and students learn first hand the capabilities of the equipment and can use this knowledge to become more experienced workers in industry or research labs.



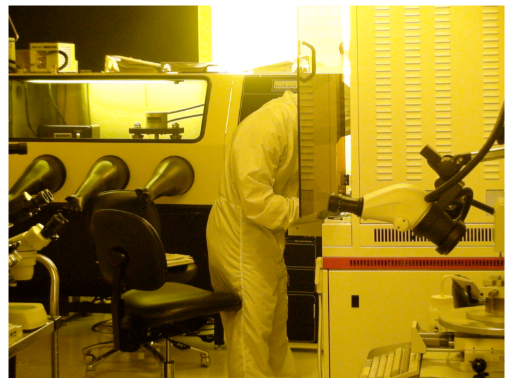
A new enhancement to research is a Heidelberg Direct Write System. Boston University will have the first system with a laser diode as an exposure source in place of the Helium Cadmium laser. This tool will not only allow students and professors to write their own photomasks (glass on chrome), but rather than spend for a costly mask to try a pattern for research, researchers can either directly write onto a wafer or a mask with the one pattern to verify their theories. Another exceptional aspect of the direct write system is the grayscale capability. Any researchers with micro-lens arrays, specific patterns for surface roughening or blazed gratings can directly write these grayscale features into the photoresist and post process as necessary. This is an exciting field that most students are not exposed to even in industry, but the ability to eliminate the need, cost, and errors from multi-layer mask designs and exposures can be explored with the grayscale capability; where in one step, the errors and costs for multiple photomasks are eliminated writing directly onto one mask and completing one processing step. Once completed with the spinning and exposures, students learn to develop their wafers and then can move on to the Class 1000 cleanroom to complete etching or deposition process steps.

In the Class 1000 cleanroom, a wide variety of options are available. With a Tencor Surface Profilometer, students learn how to measure the step height of features that they make on wafers. The capabilities and issues with stylus profilers become apparent when students can either create sharp profiles or find that the tip is too large to measure the shapes accurately. At that point, students must investigate other methods for measurement of step height and incorporate test structures in their wafers. Many processes are available for student and faculty research. A plasma asher, Reactive Ion etcher, Deep Reactive ion etcher are all available for etching features into a substrate or cleaning a substrate prior to further processing. The STS Deep Reactive Ion Etcher is an exceptional piece of equipment that few if any students are typically exposed to during their college career. It is a standard piece of equipment that even many industrial users cannot accommodate in their fabrication facilities. Thin film coatings are another area of processing in the Optoelectronic Processing Facility. Thermal Oxide Furnaces, ion assisted deposition, evaporators and sputtering systems all provide students with the capability to learn various coating processes and how to measure the films deposited after processing. Once the wafer processing is complete, a dicing saw can be used to cut the wafer into smaller die and then wirebonding, wedgebonding, or testing can be completed.

Integrated Optics Laboratory

The Integrated Optics Laboratory, comprising 400 sq. ft. Class 100 Cleanroom and 2000 sq. ft. laboratory on the 5th floor of the Boston University Photonics Center, is a multi-user facility equipped with state-of-the-art equipment for bonding, testing, and analysis of components that were processed in the Optoelectronic Processing Facility or purchased from outside vendors as part of a research project.

In the Class 100 Cleanroom, the door opens to a Miyachi Unitek Benchmark Lid Seal Machine and Projection Welding Machine for coaxial welding of TO-Can style units. The lid seal system is commonly used in the packaging industry. An environment of dry Nitrogen is infused into the gold-plated package and a welding operation fused the metal lid to the package for hermetic sealing of the unit. A Suss Microtech FC-150, flip chip bonder is the next piece of equipment that is utilized by various researchers to seal and create eutectic bonds either through thermo-compression or soldering processes. This is a precise pick and place system that uses fiducials to aid in placement accuracy. To determine if the bonding will pass MIL-Standard testing, a DAGE die shear machine will be used to die shear to failurebonded parts. A pull tester adaptor is also available to determine wire bond pull strengths and verify that they are within the specifications for the part that is bonded. An ESEC automated wire bonder is available for use, and is especially helpful if repetitive bonds are required for devices. The equipment in the Class 100 Cleanroom is equipment that is found in industry and Boston University is one of the only universities in the country to have such a unique set of equipment. The students at Boston University have the ability to learn how to use the equipment and to become more experienced workers in industry or research labs.



The second portion of the Integrated Optics Laboratory is the testing area. A newly created Spectroscopy Room allows researchers to make use of several spectroscopy tools. The Bruker FTIR along with the Hyperion allows users to try various techniques to measure absorption, reflection, transmittance, and diffuse reflectance of materials to help determine what the composition is or the light penetration. An upgrade to the terahertz region with the addition of a Silicon Bolometer puts Boston University at the forefront of technology. Very few institutions have this technology available to students and faculty. Another new purchase for the Spectroscopy room is the Varian Cary 5000 UV-VIS-NIR spectrometer. Wavelength ranges from 175 – 3300 nm and multiple accessories will make this spectrometer an essential tool to multiple users and researchers in the Photonics Center and the BU Community. Test equipment is also available in the Integrate Optics Laboratory along with multiple optical tables for positioning of fibers, lenses, and other optical components.

Precision Measurement Laboratory

The Precision Measurement Laboratory, comprising of several laboratories, provides capabilities to measure material composition as well as surface morphology. In one of the lab spaces, a JEOL SEM is available for use to view the surface of samples. An equipment upgrade to the Oxford Energy Dispersive Spectrometer (EDS) allows users to evaluate elemental composition, surface contaminants, and analyze samples in a variety of locations for surface composition uniformity. Also upgraded on the JEOL is the Gatan Cathode Luminescence (CL). The capability allows the detection of energy released in the visible spectrum from electrons in an atom returning to their original energy level after being excited by the bombardment of electrons from the e-beam in the SEM. From the spectrum, elements within the sample can be determined.

A larger extension of the PML laboratory found in the basement has a Digital Instruments (Veeco) Atomic Force Microscope (AFM) and a Multi-mode Pico force scanning probe microscope. These two instruments allow the surface profiles in three-dimensional space to be acquired and measured. The Pico-force system allows polymers and samples in solution to be analyzed as the force is monitored, not the attraction of the tip to the sample.

The Zeiss Field Emission Scanning Electron Microscope (FESEM) is a great acquisition for the university. The FESEM allows polymers and plastics to be viewed without coatings or destructive analysis. The FESEM also allows non-conductive samples to be viewed without gold coating the samples. This is a great addition to the analytical toolbox and allows viewing of devices in-situ without destroying the unit with a coating. If a functional device requires analysis, it can be placed in the SEM, analyzed and then returned for further operational research. A new addition to the Precision Measurement Laboratory is the ZYGO NewView 6300 with Dynamic MEMs capability. This instrument can be used to optically measure features on a sample, radius of curvature of lenses or slope of MEMs devices. With the dynamic MEMs capability, test stations can be set up to deflect or move MEMs devices and the entire sequence can be captured from the software. Surface roughness and flatness can also be measured on this system.

B. Incubator Facilities

Boston University has some of the finest on-campus business incubation facilities in the United States, including the Business Incubator at the Photonics Center. This 23,500 net sq. ft. facility opened in October of 2000 with the ability to flexibly house up to 14 start-up companies. The Photonics Incubator not only provides companies with the tools necessary to accelerate their growth and entry into the market, but through BU's Innovation and Entrepreneurship (I&E) group http://www.bu.edu/otd/innovation/index.html), the Incubator offers students the opportunity to work alongside entrepreneurs and technologists to gain real-world experience in their field.

Companies in the Incubator have worked with the Center's Faculty, Engineering Staff, and Graduate Students to develop technologies and products that include a laser system for the treatment of glaucoma, a PET ring for the early detection of cancer, specialty optical fiber for telecommunications, and a sequencer for decoding the human genome.

Key features of the Incubator include:

- Reconfigurable, dedicated spaces to flexibly house companies for 2-24 months
- Access to shared photonics laboratories
- Conference and meeting space
- Shared building services
- High-speed Internet access
- Parking at Charles River campus

C. Building Projects

This year, the Photonics Center completed an extensive project to enhance building safety. While this was the first such building-wide safety audit completed in recent memory, the practice will become part of our ongoing operational theme of continuous improvement. Communication between the staff, faculty and students is crucial to ensuring an environment conducive to learning and research. The Photonics Center community has joined forces with the Office of Environmental Health and Safety (OEHS) to ensure that the building is operating safely and effectively for all researchers.

Safety Walk-Through

With the help of the Office of Environmental Health and Safety, the Photonics Center Staff initiated an accompanied walk-through of the building to determine building deficiencies with regards to general laboratory safety and laser safety. Subsequently, the Photonics Center was able to purchase many items for the laboratories in accordance with OEHS and Center staff recommendations.

Some of the items that were purchased for labs occupying the Photonics Center included safety glasses, gloves, and flammables and corrosive cabinets for chemical storage. The walk through also alerted the staff to common housekeeping issues which in turn led to a staff-inspired “Laboratory Spring Cleaning Day.” This was a building-wide activity. As part of that activity, the Photonics Center hired Triumvirate Environmental to visit each lab in the Center and to retrieve and dispose of unused chemicals and chemical waste.

Below, some immediate outcomes of the safety walk-through are summarized:

- **Laser Curtain Upgrades:** OEHS and Center staff identified a number of labs with black-out curtains that were not recommended for use with the Class III and IV lasers housed in the labs. The Photonics Center purchased and installed proper laser curtains in the labs throughout the building.

- **Laser Safety Upgrades:** Other safety upgrades included purchase and delivery of protective laser goggles, electrical interconnects for laser warning signage, and lock-outs to alert occupants of the potential danger (laser light on).

- **Safety Showers and Drench Hose to Eye Wash Upgrades:** Some safety showers were found to have been improperly placed in the original laboratory build-outs. Approximately seven showers on various floors of the building were not far enough from the wall. As part of the building upgrades, the Center has begun small construction projects at each location to move those showers. Also, there were numerous laboratories that had drench hoses instead of eyewash stations. While this is not a code-violation, the OEHS requested that these be upgraded to eye washes. This upgrade is currently in process.

- **Biological Level II and Laser Lab – PHO703:** One professor's research on biological detection processes was scattered among three different laboratory spaces, creating a transport problem in the building that was deemed unsatisfactory. In addition, one of the sites occupied by this research was deemed to be interfering with another professor's lab, in which the biodetection work had been temporarily sited. The Center director, in consultation with faculty, staff, and OEHS, decided to site this work in a vacant lab, building out the space to accommodate Biohazard Level 2 research. The Center purchased a BL2 Safety Cabinet and renovated the vacant lab for this purpose.

- **Central Gas Distribution Center and Leak Detection – PHO804:** One of the labs using toxic and corrosive gases did not have adequate leak detection capability. Working with the university preferred vendor for leak detection, Apollo Safety, we were able to create a central distribution center, decrease the number of cylinders of gas from five to two, and provide leak detection at all points of use in the lab and in the gas cabinets. We were able to utilize a new, unused gas cabinet and re-use another cabinet that was up to date and compatible with the leak detection equipment. As part of this project, we were able to transfer ownership of another new gas cabinet and one of the used cabinets (no longer required with the central distribution system) to the Biomedical Engineering Dept, which put it to immediate use in new construction.

Other Upgrades of Facilities

- **Teleconferencing Upgrade:** In response to the need for live teleconferencing, the Photonics Center upgraded its capabilities to become one of the three areas on campus where teleconferencing is available. The purchase of a portable system allows the system to be taken to small conference rooms or to a larger setting.

- **Colloquium Room Media Upgrade:** The 9th floor of the Photonics Center houses a meeting room in which seminars and activities are held. In response to the recommendations of faculty and attendees of these seminars who noted poor sound and image quality, the projection and sound systems have been upgraded.

D. Equipment Projects

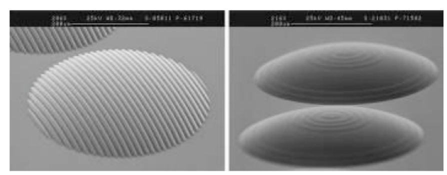
The Center was able to purchase and upgrade capital equipment critical to its research and development efforts. This year, an equipment committee was formed and an invitation to all faculty and staff members of the Photonics Center. The committee was comprised of Photonics faculty and staff and chaired by a Photonics faculty member. This committee rated equipment upgrades based on the following criteria:

- The instrument will be widely usable as a shared resource in the Photonics Center to enhance the Research and Development programs
- The instrument will provide critical leverage for attracting additional support to the Center for Research and Development
- The instrument will enhance the careers and photonics-related research of junior faculty members of the Photonics Center
- The instrument will attract additional support for Research and Development

After reviewing the recommendations of Photonics faculty and staff members, the committee used an independent ranking method to rank recommendations. Once the equipment was ranked, a proposal to the Director of the Photonics Center was compiled along with an estimate of the expense of installation of each piece of equipment. Ultimately, the Center Director selected items for purchase. Six capital purchases are described in the following pages.

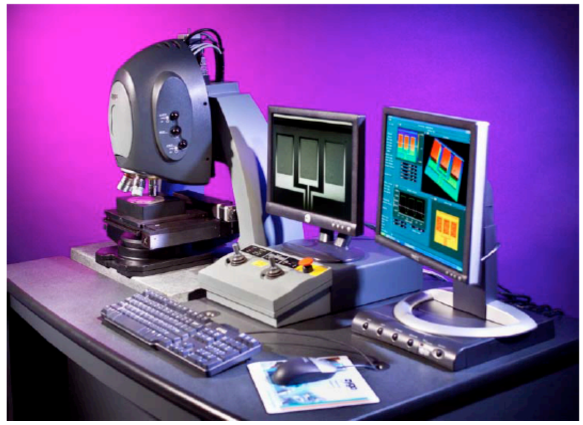
Item 1: Heidelberg DWL 66-FS

The Heidelberg direct write laser system provides capabilities within the Photonics Center's Optoelectronic Processing Facility that are not currently available in house and require expensive masks to be fabricated off-site. The proposal includes an addition to the system: grayscale technology. This will allow the direct write of micro-lenses, lens arrays, MOEMS, and other three-dimensional optical structures directly into photoresist on the final base material (silicon, gallium phosphide, glasses). The capabilities of the equipment include, direct mask design and conversion using the on-board software. The Suss photoresist spinner will be used to spin photoresist onto mask blanks, then the software will control the exposure of the mask and allow for a wet etch of the chrome from the photomask. Within a few hours, students and professors will be able to continue their research as opposed to waiting for a week for the delivery of photomasks. This direct write system is established for the next generation mask capabilities, being able to handle up to an 8" photomask, in addition, future research may require different write lenses, these items are easily interchangeable without requiring recalibration of the system. Ten minutes are required to change out the write lens for different minimal feature sizes and write times. This versatile system will allow research in multiple disciplines to utilize the same tool for a variety of technology applications.



Equipment	Price	Delivery	Accessories
DWL 66-fs Maskless Lithography Laser Writer	$270,821.41	12 - 16 weeks	Dedicated PC with mask making software and conversion capability. Ethernet connection required

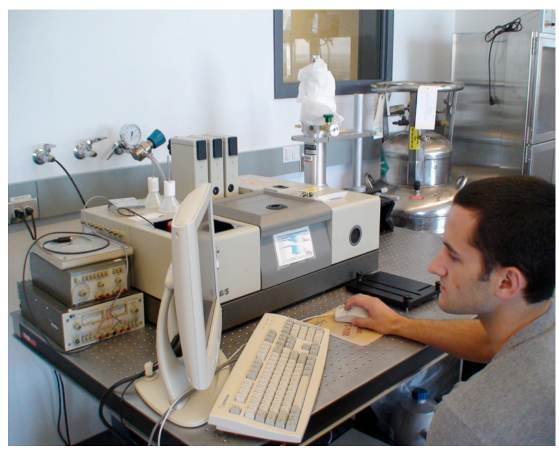
Item 2: ZYGO NewView 6300



The ZYGO optical surface profilometer is a non-contact optical probe for three dimensional surface height measurement. This tool is measuring topography, optical surface quality, and surface features. It can quantitatively identify the surface characteristics evaluate nanometer-scale changes in the surface. The dynamic MEMS option allows real-time evaluation and data recording of high speed motion. The system can be programmed to repeat the measurements in the same manner from wafer to wafer or sample to sample to eliminate any “operator” errors, and can stitch together multiply imaged zones to create a topographical mosaic. The NewView will help to enhance multi-disciplinary R&D in the Photonics Center. It is a critical addition to the shared metrology laboratory. It will be particularly useful for the emerging development research on high-speed modulators. ZYGO has offered a substantial discount considering the Photonics Center as an influential adopter.

Equipment	Delivery	Accessories
NewView 6300 3D Optical Profiler System	6 - 8 weeks	Has its own table and air table (drop shipped from TMC)

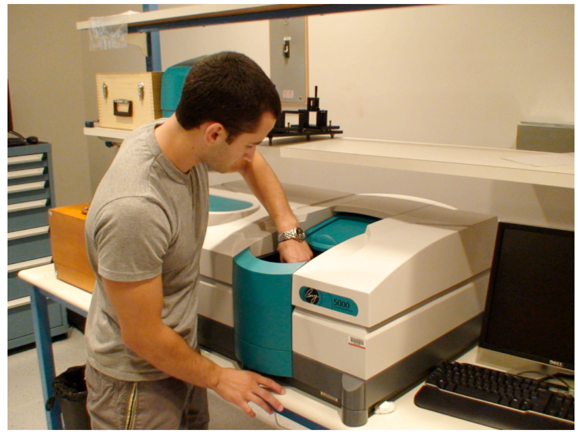
Item 3: Bruker Optics FTIR upgrade to Terahertz Spectral Range



The upgrades to the current FTIR will allow the extension of its operation to a significantly broader spectral range. The system is currently utilized by many groups at the University. The system is used to identify organic and inorganic materials, by measuring the absorption of various wavelengths by the material of interest. The addition of terahertz capability will allow spectroscopic sensing and imaging of materials such as proteins, DNA, trace gases, and medical tissue. This tool will allow the research to be enhanced in infrared optoelectronics that can be extended to tackle the “terahertz gap”. This is an emerging area of technology and the tool will become useful to more users of the Center, including those with interest in biologicals and detection of toxins or explosives.

Equipment	Price	Delivery	Accessories
FTIR Upgrades	$ 46,588.50	16 weeks	Bolometer in front 8 inches from frame. Dewar and separator for Liq He incl in quote

Item 4: Varian Cary 5000 UV-VIS-NIR Spectrophotometer



This system is a spectrometer for recording absorption spectra in the 175nm to 3300nm region. This optical measurement can be used to characterize a photoactive sample. The Model 5000 has excellent resolution (<0.05nm UV-VIS, 0.2nm NIR), large wave-length region (175 - 3300nm). In addition, a specular reflectance module will allow single bounce reflectance measurements. The instrument allows diffuse reflectance and transmission as well as hemispherical reflectance. An instrument of this type is required for routine characterization of samples of all types of biologicals, chemical, semiconductors, and optical elements, e.g. filters, beam splitters, etc. The spectrophotometer is a basic light measuring tool that is often essential for the quantitative characterization of transmissive optical components

Equipment	Price	Delivery	Accessories
Cary 5000 System	$ 58,473.00	5 weeks	Table with space for 2 x 4 ft and 110 outlet

Item 5: Bio Safety Cabinet (Qty 2)

The bio safety cabinet is rated for Biological Level 2 research. This cabinet will allow safe preparation of biological materials and is a self-contained unit. Biophotonics, and particularly biosensing, is emerging as an important R&D theme for Photonics Center faculty and staff. Thes new cabinets will permit expanded capability for those efforts.

Equipment	Price	Accessories
Bio Safety Cabinet (Price reflects purchase of two)	$ 18,850.00	Table and $125 for B&V certification included in price

Item 6: Chemical Fume Hood (Qty 2)

The Chemical Fume Hoods currently in the Optoelectronic Processing Facility were laminar flow hoods originally purchased for non-corrosive applications. As research and development needs in microsystem technology and UV sources and detectors have expanded in the laboratory and cleanroom, the use of corrosives has become important. These new chemical fume hoods will allow routine use of corrosive gases in the facility, and will replace two hoods in poor condition after a decade of constant use.

Equipment	Price	Accessories
Chemical Fume Hood (Price reflects purchase of two)	$ 22,710.00	$500 for B&V certification included in price

Other Equipment Upgrades:

Oxford EDS: The Oxford Energy Dispersive Spectrometer (EDS) required an upgrade from its Windows NT platform to prevent the software time-outs that were occurring. A new system (CPU and board) was ordered, and should be arriving in the fall.

Gatan CL: The Gatan Cathode Luminescence (CL) was upgraded in software to Windows XP. This is a three month upgrade and is scheduled to be returned sometime in the fall.

Sputtering RF matching network: A sputtering system in the 8th floor OPF was upgraded with a new matching network required to allow sputtering of multiple targets.

VII. Community Activities and Public Outreach

A. Activities Committee

As part of the effort to bring the Photonics Community together, an activities committee was established with Photonics faculty and staff members. The committee's charter was to plan events and activities that foster collegial discussion and regular interactions among the Center's community members.

The first charter of the Activities Committee was to sponsor a recurring event. A biweekly Photonics Café was proposed, to be held in the 7th floor rotunda. The café has successfully drawn the community together, and has become an important venue for Center-based collegial engagement. Future planning and execution of the event will be conducted in collaboration with the Photonics' Center Research Assistants.

The second charter of the Activities Committee was to plan a summer BBQ. The event was planned for July 19th, complete with volley ball, Photonics Center logo Frisbees, Photonics Center logo hats. Participation at the event was record breaking (nearly 150 people), and food, fun, and sun were in abundance.

B. Laboratory Spring Cleaning Day

As part of the walk through with the Office of Environmental Health and Safety, we found a significant quantity of left-over chemicals that were no longer needed in the laboratories. The Office of Environmental Health and Safety proposed that the Photonics Center offer a day to remove unwanted or unused chemicals. The Photonics Center planned a building wide chemical clean up day and hired Triumvirate Environmental to be on site for an entire day and to pack and remove the unwanted chemicals from the Center. The Photonics Center paid for the removal of all of these chemicals and at the end of the day, 750 lbs of unused chemicals were lab packed and removed by Triumvirate.

The Photonics Center enaged the participation of the Electrical and Computer Engineering (ECE) Department, and prizes were sponsored by ECE and the Office of Environmental Health and Safety. T-shirts were provided to all the participants by the Photonics Center. Working closely with the Office of Environmental Health and Safety, the Photonics Center organized the event to provide OEHS much needed information on the lab spaces at the Photonics Center, including points of contact, number of people in the labs, etc.

C. Public Relations Highlights

1. Symposium 2005

The Future of Light: The 9th Annual Executive Symposium had another sell-out year with an impressive list of industry visionaries presenting and more than 200 high-level attendees that included Army Generals, international political dignitaries, CEO's of major corporations, and faculty and administration from the BU Community. The conference also received corporate and media sponsorship from several Photonics companies and trade publications to offset our costs.

2. Other Highlights and Press Coverage

The Photonics Center at Boston University was mentioned in approximately 40 positive news stories in the press, with the majority of coverage dedicated to RedOwl, SOLX, and the LIA Project.

- The RedOwl Project was featured in major media outlets, including the Boston Globe and the Boston Herald, and the RedOwl animated video was featured on www.boston.com.

- The LIA Project, a BU spinout that uses media to engage girls and minorities in science and technology, licensed its Lia character to the National Academy of Science for its new website, www.iwaswondering.org.

- The Photonics Center's new website launched in September. Its new design will mirror the look and feel of Boston University's new website in order to achieve a unified brand identity, and will focus on faculty research, student education, and translational research. It will also have an intranet for detailed resources and information for the Photonics community.