CENTER FOR ADVANCED STUDIES IN
PHOTONICS RESEARCH
(CASPR)

First Annual Report
May 31, 2003

BY
UNIVERSITY OF MARYLAND, BALTIMORE COUNTY

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NASA GODDARD SPACE FLIGHT CENTER
UNIVERSITY OF MARYLAND, BALTIMORE COUNTY

CENTER FOR ADVANCED STUDIES IN PHOTONICS RESEARCH

FIRST ANNUAL REPORT

PERIOD JUNE 1, 2002 TO MAY 31, 2003

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1. PREFACE

The University of Maryland, Baltimore County (UMBC) is pleased to submit this First Annual Report of the Center for Advanced Studies in Photonics Research (CASPR) to the NASA Goddard Space Flight Center.

CASPR was founded in June 2002, as a Center of Excellence at UMBC for conducting research over the broad spectrum of scientific and engineering subjects that are included within the subject of photonics. Initial resources were provided by NASA, with management responsibility in the Engineering Directorate of the Goddard Space Flight Center. Creation of such a Center at UMBC was motivated by the critical need for application of cutting-edge photonics technologies to enable or enhance many of the present and future Goddard missions and support operations, and by the recognition that UMBC has an outstanding capability and history in conducting successful photonics research. The University has articulated an intent to further develop CASPR into an important national resource for research and technological applications in this area:

Vision

To foster advanced research and technology development in the areas of optical communications, optical sensing and devices, and quantum optics in an effort to mutually support the needs of government, industry, and science. Through partnerships with industry and government, CASPR scientists and engineers will engage in research and development of new technologies and their use beneficial to regional economic growth. UMBC seeks to provide the university-based intellectual and performance standards required to place the Mid-Atlantic region of the United States among the foremost centers for applied photonic-related research and development in the world.

For the initial research program, eight projects were chosen, spanning subjects in Optical Communications, Optical Remote Sensing, and Quantum Optics. NASA/Goddard engineers and photonics scientists were invited to serve on CASPR program guidance and review committees, to insure maximum applicability of the research results to GSFC missions. For instance, the committee that evaluated and recommended the first set of CASPR projects included members from three Goddard divisions. The objectives and accomplishments of these projects in their first year are summarized in the following sections of this report.

Projects are decentralized and are conducted within appropriate UMBC departments and laboratories. Investigators are faculty members within those departments, and all of the graduate student researchers are working towards advanced degrees. A search for the permanent Director of CASPR is under way. The Director will have a dual
appointment, also serving as professor in one of the academic departments associated with CASPR. Currently, CASPR is administered by an Interim Administrator (part time), an Associate Administrator, and a Business Manager (part time). There are 9 professors working on CASPR projects, one Research Associate, 3 Faculty Research Assistants, and 14 Graduate Research Assistants. Their names and departmental affiliations are listed in Section 4.

During this first year, three papers have been published in peer-reviewed journals, based upon results from CASPR-funded research, and six others have been submitted for publication. In addition, nine presentations were delivered at scientific and engineering society meetings and appear in their proceedings. A list of publications is contained in Section 3.
2. PROJECT ACCOMPLISHMENTS

2.1 Signal Processing for Photonics

Personnel: Tulay Adali, Ph.D., Principle Investigator

Objective: To develop effective electrical domain (post-detection) approaches for optical communications by accounting for the physical properties of the optical transmission medium through (i) development of a new class of electronic signal processing solutions for mitigating effects of physical impairments in optical systems by accounting for the physical properties of the optical transmission medium, and (ii) studying the performance of these signal processing solutions by accurately modeling the physical phenomena using simulation techniques that have been developed.

Status: An efficient method to estimate the coefficients of a first order PMD channel has been developed and its use to reduce the PMD induced penalty using a zero-forcing equalizer has been demonstrated. The effectiveness of this equalizer has been demonstrated by simulations. The use of the channel estimates to design even more effective techniques for PMD mitigation are currently being investigated.

2.2 Terahertz and Holographic Technologies for Earth and Space Science Applications

Personnel: L. Michael Hayden, Ph.D., Principle Investigator
Megan Leahy, Graduate Research Assistant

Objective: To develop and characterize efficient, wide-band emitter-detector pairs of electro-optic polymer composites useful for the generation and detection of THz radiation. New terahertz technologies, which are useful in NASA applications, will be explored. In addition, this project will address the use of holographic wavefront correction in space telescope applications, particularly in the search for extra-solar terrestrial planets.

Status: The 30 fs amplified laser system that was partially bought with the CASPR funding has arrived and was installed in January. The new system was used to obtain THz signals from electro-optic polymer films. A prototype holographically corrected telescope was constructed and various holographic materials are being tested as to their efficiency for correcting the wavefronts of the aberrated telescope. One publication based on our THz work has been prepared so far and one conference presentation has been delivered. Two more presentations are scheduled to be presented before the summer.
2.3 Multisensor Coding for Robust Wireless Optical Communications

Personnel:  Joseph Thomas, Ph.D., Principle Investigator
            Hao Chen, Graduate Research Assistant
            Hualiang Li, Graduate Research Assistant

Objective: To exploit the potentially available spatial-diversity and spatial-multiplexing gains in wireless optical communications using multi-aperture signaling and information-theoretic concepts.

Status: Developed block-orthogonal multi-aperture signaling scheme
• Developed soft iterative receiver with nonlinear front-end for block-orthogonal and spatially-multiplexed signaling schemes
• Continuing investigations on distributed spatial-multiplexing

2.4 Tunable, Near-Infrared Detector Based on Quantum-Well Excitons

Personnel:  Terrance L. Worchesky, Ph.D., Principle Investigator
            Chen Lu, Graduate Research Assistant

Objective: To demonstrate the feasibility of a voltage-tunable, narrow-band, near-infrared detector to address the needs of NASA LIDAR efforts. The long-term goals are a 0.1-nm bandwidth detection system with a voltage-tunable range of 10 n, and the capability to develop other similar semiconductor detectors to meet NASA, DoD, and commercial requirements.

Status: Previous models for quantum-well structures have been revised to incorporate temperature-dependent effects in both the quantum-well and barriers regions. These models have been used to optimize the semiconductor layer design for cryogenic, narrow-band detector structures. A series of wafers containing these structures were fabricated using molecular beam epitaxy, and photoluminescence features with approximately 1-nm bandwidths were measured. Results of these measurements will be published in an article addressing the temperature-dependence of the semiconductor band gaps used in quantum-well systems.

Also, the low-temperature photoluminescence measurements were used to further refine the quantum-well models and to design a series of photodetector structures. Eight additional wafers have been grown that contain various quantum-well structures and incorporate ohmic contact layers. These ohmic contacts will allow an electric field to be applied to the structures to create quantum-confined Stark shifting of the electron states in the quantum-well layers. In addition, portions of these wafers will be fabricated into test structures for use in photocurrent measurements.

Based on the results of these tests the final detector design will be selected and a series of pin-photodiodes will be fabricated for testing.
2.5 High Speed All-Optical Networks

Personnel:   Gary M. Carter, Ph.D., Principle Investigator  
            Yu Sun, Graduate Research Assistant  
            Hai Xu, Graduate Research Assistant

Objective: To demonstrate the feasibility of 10 Gb/s data transmission in a variety of fiber optic environments to avoid the high “tuning” required for maximizing performance through a “cross-platform” optical networking approach.

Status: See combined status, below, for this project and the next.

2.6 Reconfigurable All-optical WDM Network

Personnel:   Yung Jui (Ray) Chen, Ph.D., Principle Investigator  
            Amit Mahajan, Graduate Research Assistant  
            Zhonghua Zhu, Graduate Research Assistant

Objective: To develop and implement an all-optical switching layer to the multiple protocol label switching (MPLS) test-bed at UMBC. This unique expanded optical networking test-bed will be used to address a variety of next-generation network (NGN) research issues and to develop new technologies and applications for NASA and other potential government and industry sponsors.

Status (for 2.5 and 2.6, combined): Infrastructure preparation has been completed for reconfigurable network experiments and for high-speed network experiments. Initial experiments have been conducted with these joint systems. The two test beds were coupled in several different configurations, using all-optical switching, via a 250 km recirculating fiber loop. At a data rate of 10 Gigabits/sec in each of 4 spectral channels signals were very clean, with bit error-rates well below 10(exp-10). Thus, the long distance test bed can be used in High Speed 10 Gigabit/sec multichannel network research experiments. Further details may be found at the CASPR website: <www.umbc.edu/caspr>.

2.7 Numerical Simulation and Analysis of Fiber Optic Compensators

Personnel:   Susan Minkoff, Ph.D., Principle Investigator

Objective: To address degradation in the quality of large quantities of data transmitted at high data rates along fiber optic lines due to effects such as polarization mode dispersion (PMD), through analysis of the performance of current compensators and the development of improved optimization algorithms.
Status:

- Significant progress has been made towards the first of our two main project goals: numerical comparison and analysis of different polarization mode dispersion compensation methods.
  - Specifically, the DOP ellipsoid and subharmonic compensation techniques have been implemented numerically into the fiber optics wave propagation computer code.
- Preliminary work has been completed to determine which compensation method works best and under what physical circumstances, and the statistical technique of importance sampling has been incorporated into the simulator in order to test rare failure events.
- A paper entitled "A comparative study of feedback controller sensitivity to all orders of PMD for a fixed DGD compensator," was presented at the 2003 Optical Fiber Communications Conference held in March 2003.

2.8 Synchronization of Distant Clocks Using Two-Photon Interferometry

Personnel: Morton H. Rubin, Ph.D., Co-Principal Investigator
Yanhua Shih, Ph.D., Co-Principal Investigator
Xuehua He, Faculty Research Assistant
Heyi Zhang, Faculty Research Assistant
Milena D'Angelo, Graduate Research Assistant

Objective: To apply well-established two-photon interferometric techniques developed at UMBC to achieve distant clock synchronization with unprecedented pico-second accuracy for future NASA space applications. The project includes both theoretical and experimental studies:
- Theoretical studies
  - Study the feasibility and possible technical difficulties;
  - Conduct analytical and numerical studies of the achievable measurement accuracy
- Experimental
  - Design the laboratory system, including the two-photon interferometer and the hardware and software interface of the system
  - Conduct experimental studies using the two-photon interferometer as required for the project
  - Conduct research on a key element of the timing registration device: the "event timer".

Status:

- Theoretical model has been developed.
- Proof-of-principle experiment has been designed.
- Major equipments have been identified and in the process of purchasing.
3. Publications and Presentations

Publications in Refereed Journals


Publications Submitted to Journals


Oral Presentations


4. **FACULTY, STUDENTS, AND STAFF**

UMBC is currently in the process of selecting and appointing the Director of CASPR. The following list represents the present cadre of CASPR personnel.

**Administrative Office**

<table>
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<tr>
<th>Name</th>
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<tr>
<td>Schiffer, Robert A.</td>
<td>Interim Administrator</td>
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<tr>
<td>Plotkin, Henry H.</td>
<td>Associate Administrator</td>
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<tr>
<td>Chapman, Gayle</td>
<td>Business Manager</td>
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**Project Faculty and Graduate Students**

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<thead>
<tr>
<th>Name</th>
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<th>Department</th>
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<tr>
<td>Adali, Tulay</td>
<td>Associate Professor</td>
<td>Computer Science and Electrical Engineering (CSEE)</td>
</tr>
<tr>
<td>Hayden, L. Michael</td>
<td>Associate Professor</td>
<td>Physics</td>
</tr>
<tr>
<td>Leahy, Megan</td>
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<tr>
<td>Thomas, Joseph</td>
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<td>CSEE</td>
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<tr>
<td>Chen, Hao</td>
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<tr>
<td>Li, Hualiang</td>
<td>Graduate Research Assistant</td>
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<tr>
<td>Worchesky, Terrance L.</td>
<td>Associate Professor</td>
<td>Physics</td>
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<td>Lu, Chen</td>
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<tr>
<td>Carter, Gary M.</td>
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<tr>
<td>Zweck, John</td>
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<td>Sun, Yu</td>
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<td>Xu, Hai</td>
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<td>Hu, Zhihang</td>
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<tr>
<td>Sinkin, Oleg</td>
<td>Graduate Research Assistant</td>
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<tr>
<td>Chen, Yung Jui (Ray)</td>
<td>Professor</td>
<td>CSEE</td>
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<tr>
<td>Chen, Wenlu</td>
<td>Faculty Research Assistant</td>
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<tr>
<td>Mahajan, Amit</td>
<td>Graduate Research Assistant</td>
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<tr>
<td>Zhu, Zhonghua</td>
<td>Graduate Research Assistant</td>
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<td>Chen, Wei</td>
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<tr>
<td>Kuscu, Mustafa</td>
<td>Graduate Research Assistant</td>
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<tr>
<td>Wang, Zhipeng</td>
<td>Graduate Research Assistant</td>
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<tr>
<td>Minkoff, Susan E.</td>
<td>Assistant Professor</td>
<td>Mathematics and Statistics</td>
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5. WORKSHOP: “FRONTIERS IN PHOTONICS RESEARCH

On January 21, 2003, UMBC conducted a workshop entitled “Frontiers in Photonics Research”. The workshop served several purposes, simultaneously:

1) It constituted the mid-term report to NASA/Goddard on status of the grant which inaugurated CASPR on June 1, 2002, illustrating the valuable projects that had been initiated.

2) It was a presentation of UMBC’s cutting-edge photonics research capabilities in Optical Communications, Optical Remote Sensing, and Quantum Optics to attendees from federal, state, local agencies, and industry. A high level of regional technological and economic potential was demonstrated, which served to justify consideration of further investment in UMBC photonics programs.

3) Outside experts generated discussion of ideas for new photonics applications, as well as the potential for forming productive collaborative research arrangements.

4) It promoted student interest and enthusiasm for pursuing careers in photonics-related disciplines.

The workshop included: two poster sessions during which each of the eight CASPR projects reported on their status; overview presentations by 3 UMBC professors describing work at the university related to Optical Remote Sensing, Fiber Optic Communications, and Quantum Optics; and presentations by 5 invited prominent representatives of industry, government, and university laboratories describing examples of cutting-edge research and challenging issues in photonics. The day concluded with a Question and Answer discussion and a tour of CASPR laboratories.

There were over 100 attendees at the workshop. The charts from some of the presentations may be viewed on the CASPR website.

6. CASPR WEBSITE

Information about CASPR may be found on the web at www.umbc.edu/caspr. It will be kept current, with news about events, grants, publications, faculty, etc.