Implementation of photonics program at the undergraduate level

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ABSTRACT

In response to widespread applications of photonics and increasing needs of industry for qualified personnel, a B.S. program in Photonics was implemented in the fall of 1989 at the State University of New York (SUNY) Institute of Technology, Utica, New York. The curriculum was developed recognizing the strong interdependence of photonics and electronics. It was also made flexible so that the students could move to other areas of science and engineering. This article describes the program and reviews the current applications of photonics which affect the program curriculum. It is expected that the graduates from this program will be better equipped to find suitable jobs and function more effectively in industry.

1. INTRODUCTION

Photonics is a relatively new term in technology, formed by analogy with electronics and reflects the growing tie between optics and electronics forged by the increasing role that semiconductor materials and devices play in optical systems.[1] The field of photonics includes large numbers of optically related technologies such as lasers, fiber-optics, electro-optics, quantum electronics, acousto-optics, integrated optics, non-linear optics, opto-electronics, optical data storage and others.

It was the development of semiconductor laser/detector systems and low loss fibers which initiated the age of photonics and led to wide ranging commercial and military applications. Recently there has been a breakthrough in the development and fabrication of non-linear optical materials and devices and it is only a matter of time before optics will be used for switching, multiplexing and computing at the speed of light. The use of Erbium doped optical amplifiers, which is already a practical reality, is going to revolutionize long-distance optical communications from video distribution to broadband networking. Progress in photonic sensors, lasers and imaging are finding applications in aerospace, photodynamic therapy, medical imaging, fiber optic endoscope and laser treatment in invasive surgery.

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The field of photonics is diverse and extensive. Trends indicate that photonics applications will enhance or displace many existing electronic and mechanical technologies. However photonics and electronics are complementary technologies and promising results can be obtained by combining the best of two worlds. The major success, in the near future will be in applications where photonics interface easily with electronics and can draw advantages from the large and well established electronics base. The current world market for photonic equipment is estimated to be well over $10 billion and expanding annually at a rate of 20 to 40 percent. The use of fibers and guided wave optics in communication alone is over $2 billion industry. Over 28 million laser diodes and detectors are used annually in applications like fiber-optic telecommunication, optical data recording, laser printers, video disks and others.[2,3]

The most serious challenge facing photonics is the shortage of suitably trained graduates especially at the B.S. level. Photonics engineers[3] are required to develop wide ranging products and to work at the interface between electronics and photonics.

The need for trained graduates in the current industrial base is large and with growing photonics industrial base, the prospects for employments are bright.

The need for starting a new program in photonics can thus be summarized as due to:

The need of industry for more qualified personnel in photonics related areas.

The rapid growth of photonics applications in our information-based society.

Need for an upper division program because more community colleges are starting photonic related programs.

2. APPLICATIONS

In order to implement a new program in photonics, it was important to understand the emergence of such a technology and study its applications so that the curriculum could respond to the needs. Photonics has already been used successfully in applications like fiber optic communications, video conferencing, compact disks, laser printers, synthetic aperture radar processors, signal correlators, spectrum analyzers, antenna beamforming, sensors, displays and many others. Those receiving the greatest attention currently are:[4]

Optical telecommunications
Optical computing and signal processing
Photonic sensors
Optical storage and display

2.1 Optical telecommunications

Fiber optics communication is firmly established for long-distance telecommunications because of the large bandwith, the greater distance between repeaters, and the freedom from electrical interference. It is predicted that by early in the next century, essentially all telecommunication signals (voice, data and video) both long-distance and exchange loop will be carried by optical fibers.[5]

With the success of the fiber optic transmission, there has been much discussion on how optical circuits could be directly switched without the need to first converting the signal into electrical form. This can be achieved by photonic switching which is rapidly becoming an area of key interest. Recently, optically controlled switching devices have been developed which have switching potential at rates in the range of 1 Tera Hertz. In addition, photonic switching fabrics are expected to foster entirely new network architectures.[6]

It is an accepted fact that the fiber will reach the doorstep of millions of Americans by the mid 1990's. Services may include multi-national television, frame-shifted broadcast, viewer interactive television, single frame video, and demographically tailored programming and advertising.[7]

2.2 Optical computing and signal processing

The distinction between optical signal processing and optical computing is arbitrary and sometimes either method is applicable to solving a given problem. Optical computing[8] includes not only the current attempts to realize digital optical computers based on logic gates, but also the older field of analog optical computers have become a major research topic in recent years. The goal is to create an optical computer that will be comparable to an electronic digital computer, but better in some significant way such as the speed and processing power. Optical computing and data processing offers a number of advantages over electronic technology such as the capability of parallel processing for massive data, the interconnect capability without crosstalk, high fan-in/fan-out, increase in speed, high spectral parallelism and ease of spatial integration.

Due to the lack of interaction between photons, switching operations associated with computing have been traditionally difficult using optics. However, switching and optical bistability can be achieved via interaction in non-linear optical materials. In the world's first[9] digital optical processor demonstrated by AT&T in 1990, the switching is handled by S-SEED, optical switches based on Multiple Quantum Well confined stark effect p-i-n structure fabricated by molecular beam epitaxy technology.

Optical computers will not replace the existing computers in the near future, but will impact in the field of supercomputers. Specific optical devices are, however, already being used as parts of general purpose computers for the functions of interconnection and mass storage.

2.3 Photonic sensors

There are two classes of photonic sensors, namely fiber optic sensors and focal plan arrays.[4]

2.3.1 Fiber optic sensors

Most of these sensors directly probe physical phenomena and can detect virtually any stimulus more accurately with greater sensitivity than conventional sensors over a wider dynamic range. These sensors can be used to measure temperature, pressure, magnetism, acidity, pollution, and flow of liquids and gases. Fiber optic gyros, hydrophones and magnetometers are among the high performance type sensors which are spatially versatile, and have no moving parts in the case of gyros.[10]

Another important application of fiber optic sensors is in medical probes where they are revolutionizing imaging, diagnosis and therapy. Optical fibers can be inserted through natural openings of the human body or through a small incision. Physicians can perform surgery inside the human body by directing a beam of laser light, avoiding the need for invasive procedures where the healthy tissues must be cut through to reach the site of the disease.[11]

2.3.2 Focal plane arrays

This class of photonic sensors detect visible or infrared radiation using charge-injection and charge-coupled devices. They have been used in ecological monitoring, miniature video cameras, and strategic and tactical military applications. Focal plane arrays are also finding uses in passive optical radars such as infrared search and track equipment for satellite imaging and potentially for autonomous equipment control.[4]

2.4 Optical storage and display

In the growing information society magnetic storage will not be able to provide the capacity, the speed of access, and the low cost media to cope with large amounts of data. Optical storage media offer higher density storage by a factor of 500 and thus, potentially lower cost. It has relative immunity to dust and is removable.

There are three types of optical storage systems, namely Read Only devices, Write-Once Read-Many (WORM) and Multiple Read and Write System. The first two are used mainly for storage of large quantities of information while the third one is rewriteable and is available now in the form of magneto-optical disks of layered media. The advantages of this non-contact laser optical system will likely lead to its eventually replacing conventional magnetic recording.

Displays are inherently optoelectronic devices, as they convert electronic information into text or image for viewing. Photonic display uses a light beam to write on a photoconductive media, such as laser beams on a liquid crystal cell. These displays have been demonstrated in specialized applications but are not likely to replace electronic display technologies in the near future.[12] Photonics is being used in a new type of "interactive display" where the orientation of a viewer's eye ball will determine the display cursor position finding applications as in variable resolution displays.

3. PROGRAM IMPLEMENTATION

These applications show a strong interdependence of photonics and electronics. As a result, the center of focus in educational institutions for training in optics is shifting from physics departments to electrical engineering departments.[3] Based on this perspective a B.S. program in photonics was implemented at the SUNY Institute of Technology in the fall of 1989, being the first[13] in the United States to treat photonics as an independent discipline. While developing the curriculum, we sought the input from local industries, notably the Photonics Center at Griffiss Air Force Base, Rome, New York.

The SUNY Institute of Technology is one of four specialized colleges in the 64-campus system of the State University of New York. Established in 1966, the college is an upper division institution, enrolling only graduate and undergraduate transfer students.

The photonics program accepts students from two-year community colleges having an associate degree, or those who have completed a minimum of 56 college credit hours. Students from two-year engineering science/math and other parallel programs, including photonics, lasers and electro-optics, can complete their B.S. requirements in four semesters (two years) of full-time study. Students who transfer from non-parallel programs such as electrical engineering technology may need to take some additional courses. To earn a B.S. degree, a student must complete a minimum of 124 hours and transfer credits usually fulfill half the degree requirements. The minimum requirements of 124 credit hours might be increased to 130 credit hours as the program develops.

The curriculum emphasizes the design and applications of devices and systems for optical signal processing, optical computing and optical communications. However, the avenues for practice of photonics continue to proliferate and extend to all areas of engineering and technology in society. The rapid changes in technologies and their scientific bases and the diversity of applications require a broad educational background for learning new and specialized information.

To accomplish these objectives the photonics program as shown in the appendix, provides a strong scientific and mathematical base through a sequence of courses (38 credit hours) in mathematics, physics, optics, and chemistry/material science. Students also take courses in electronic devices, electrical communications and computer programming (12 credit hours). Additional courses such as digital electronics, VLSI design, digital image processing and computer vision, digital filters, thin film technology, vacuum technology, thermodynamics, quantum mechanics, electromagnetic waves and artificial intelligence can be chosen to fit in the open electives and restricted technical electives (24 credit hours).

The photonics core courses (16 credit hours) namely electro-optic devices, systems and measurement, fiber optics, fourier optics, lasers and applications make extensive use of labs and computers both as tools for problem solving and simulation of optical devices, systems and techniques. Laboratory experience is a very important component of our program as it combines the basic theory of modelling and fundamental laws of photonics. In addition, a senior project is offered for students who want to go further into exploration of new areas, such as problem-solving, and design and test for design verification.

High level courses (8 to 12 credit hours) through technical electives are provided so that students will have the potential to grow as technology advances. To date three such courses, optical communications, introduction to optical computing and integrated optics, have been offered. We expect to introduce more elective courses as the program develops. The photonic students need a minimum of two elective courses to graduate.

Oral and written language skills are improved through courses in English, technical and oral communication, writing and liberal arts courses. A broader social perspective is added through courses in humanities, social and behavioral sciences.

To achieve coherence in the program, a structure of prerequisites has been built into the course offerings. Academic advisors insure that the electives picked by their students are suitable logical groupings and form an appropriate fit with their academic and career objectives. Academic advisers also ensure the proper transfer of credits from the student's previous colleges and prepares their program of study for the upper division college requirements.

4. CONCLUSION

Prospects for photonics-related industries are bright. Suitably qualified personnel will be needed to build operational systems, establish a healthy photonics industrial base, and educate decision makers and users about the importance of photonics technology.

The B.S. program implemented at the SUNY Institute of Technology has already graduated its first class and expects to supply more trained personnel. Due to the flexible curriculum, graduates from this program can be employed not only in the area of photonics, but also in other areas of science and engineering.

The program discussed in this paper is for the upper division colleges but it can easily be applied to the last two years of four-year programs in the United States (the first two years are usually spent covering liberal arts, science and mathematics requirements toward the B.S. degree). It is hoped that more colleges and universities will introduce similar programs at the undergraduate level. This is vital to provide the qualified personnel who will be needed in this growing technology. Photonics applications will have a major impact on the information-based society of the future.

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6. APPENDIX

B.S. Degree Requirements

To earn a Bachelor of Science (B.S.) degree in photonics, a student must complete a minimum of 124 credit hours and fulfill the following requirements:

(Transfer credits usually fulfill half the degree requirements)

1. Arts and Sciences - 62 credits

A. Liberal Arts - 24 credits

	Minimum Credits
Oral Communications	3
Written Communications (including an upper division writing course)	6
Humanities* (Art/History/Music/Literature/Philosophy/Foreign Language)	6
Behavioral Science (PSY/SOC/ANT)	3
Social Science (ECO/POS/GOG/SSC)	3
Electives	3
Total Credits	24

*Written communications and technical writing courses do not fulfill this requirement.

B. Mathematics and Science - 38 credits

General Physics	6
Chemistry/Material Science	4
Geometrical Optics	4
Physical Optics	4
Mathematics (Calculus I, II, Differential Equations)	12
Electives from Math and Science	balance
Total Credits	38

2. Technical Coursework - 30 credits

Introduction to Photonics	3
Electro-optical Devices, Systems and Measurement (with lab)	4
Fiber Optics (with lab)	4
Lasers and Applications (with lab)	4
Fourier Optics	3
Senior (400) Level Electives	8
Restricted Technical Electives	balance
Total Credits	30

3. **Interdisciplinary Coursework - 12 credits**

Computer Programming Language	3
Electives - Electrical and Computer Science	9
Total Credits	12

4. **Open Electives** Balance of 124

TOTAL CREDITS **124**

Restricted Technical, Senior Level Electives and Open Electives

Integrated Optics
Introduction to Optical Computing
Optical Communication
Special Topics in Photonics
Digital Image Processing and Computer Vision
Senior Project Thesis
Data and Computer Communication Technology
Digital Filters
Communication Transmission Techniques
Digital Electronics
VLSI Design
Quantum Mechanics
Thermodynamics
Electromagnetic Waves
Thin Film Technology
Artificial Intelligence

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