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Model Undergraduate Integrated Optics Laboratory

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Michael D. Lemmon
Dept. of Electrical Eng.
University of Notre Dame
Notre Dame, IN 46556 USA

Biswajit Das
Dept of Electrical Eng.
West Virginia University
Morgantown, WV 26506

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Contents

1 Summary

During the period from August 1992 to September 1995, the department of electrical engineering at the University of Notre Dame developed and implemented an undergraduate laboratory in integrated optics. The lab was targeted for graduating seniors who would be entering the optical communications market. The development of this lab was sponsored under NSF grant DUE-92-51621 as part of the National Science Foundation's Leadership in Laboratory Development (ILI/ILD) program. The principal accomplishment of this sponsored work was the development of a low-cost undergraduate integrated optics lab which could be easily duplicated in other universities attempting to start an optics program. In 1994, a similar lab program was started at West Virginia University (WVU) when the project's principal investigator (Dr. B. Das) moved to WVU.

The work supported by this grant resulted in 2 conference publications [3] [4], 1 technical report [2], 1 MS thesis [1], and the development of an integrated optics curriculum at the University of Notre Dame and West Viriginia University.

Grant funds were used to equip the integrated optics laboratory at Notre Dame, provide partial financial support for graduate students working on the project, and for domestic travel to conferences where the results of this project were reported.

The individual who participated in the research of the present grant include: Dr. B. Das (West Virginia University), Dr. M.D. Lemmon (University of Notre Dame), Dr. David Naylor (University of Illinois, Chicago), and Dr. L. A. Hornak (West Virginia University) ; graduate students William LaMonaca, Gavin Fredericks, Anthony Mesa, and Jieming Xi; and undergraduate student Danielle Walker.

2 Impact on Engineering Education

This project had three fundamental tasks. These tasks were the development of an undergraduate lecture course in photonics, the development of an undergraduate lab supporting the lecture course, and the dissemination of the project results to other universities. The following subsections briefly describe the tasks, summarize the results, and discuss their impact on engineering education.

2.1 Lecture Course Development:

Prior to 1992, there was no optics curriculum at the University of Notre Dame's department of electrical engineering. This was perceived to be a great deficiency in the department's program given the current prominence of optical technologies in the communications industry. The objective of this task was to develop an optics curriculum at the undergraduate level which would prepare graduating seniors for careers in optical communication. The course was designed to integrate the department's traditional strengths in system science and electronic materials research.

The result of this task was the introduction (1993) of a senior level course in photonics. The success of this class prompted the department to hire additional faculty (Dr. D. Hall, 1994) whose areas of expertise lay in integrated optics. These additional faculty have helped expand the optics program at Notre Dame. The current curriculum now includes an undergraduate and graduate level course in photonics and integrated optics.

2.2 Undergraduate Lab Development

This is the major task of this project. The objective was to develop a senior-level lab in optical waveguide devices which would support the lecture component of the optics curriculum. The principal concerns in lab development were as follows;

- The lab should be inexpensive (under $ 50,000) to start and maintain. In this way, smaller universities would have a model for the development of their own photonic programs.
- Lab development should take into account the limited lab skills of average undergraduate (senior) students.
- Lab development should complement the developed lecture courses in photonics.

Work in this area was carried out primarily by Dr. B. Das (West Virginia University) and Dr. M. D. Lemmon (University of Notre Dame). Fabrication of some specialized lab components was carried out by Dr. Naylor (Univ. of Illinois, Chicago) and Dr. L. A. Hornak (West Virginia University). Components of the proposed lab were first implemented by graduate students and later by undergraduate students. The results and experiences of these students were then used to develop the lab which was first implemented in the spring of 1994 at the University of Notre Dame.

Description of ILI Laboratory

The integrated optics laboratory consisted of the following two facilities:

- **Integrated Optical Device Fabrication Facility:** This facility was developed in an existing micro-electronics laboratory which was partially used for an undergraduate IC fabrication course. The facility makes use of existing equipment as well as some additional equipment acquired through the grant and has the capabilities for wafer cleaning, ion exchange, photolithography, aluminum evaporation and etching.

- **Device Characterization Facility:** This facility was developed from an existing optical signal processing laboratory in the department of electrical engineering. The lab allows the characterization of simple passive optical waveguide devices such as directional couplers.

Students used the facilities to perform 4 different laboratory experiments in which students fabricated and characterized an optical waveguide device known as an optical power divider. These lab experiments are briefly enumerated below.

1. *Index of Refraction Measurement*

   In this lab exercise the students experimentally determined the index of refraction for a glass slide (standard microscope slide) by carefully measuring the material's Brewster angle. This glass slide was used as a substrate for implementing polymer waveguides in later experiments.

2. *Fabrication of Polymer Slab Waveguides*

   The students fabricated polymer waveguides on the previously characterized glass slides using positive photoresist. The thicknesses of the waveguides were determined by the photorsist spin speeds which were ascertained by the students from the manufacturer supplied data sheets. Waveguide thickness was varied to highlight the dependence of modal characteristics on a slab waveguide thickness.

3. *Modal Characterization of Polymer Slab Waveguides*

   The students characterized the waveguides fabricated in lab exercise 2 by experimentally detemrining their depths, indices of refraction, and the effective indices of the guided modes. The propagation constants for the modes in the waveguides were determined by measuring the coupling angles for the modes by maximizing the brightness of the m-lines of the wavegudes. The waveguide depth and the effective index of the modes were determined from the propagation constants and the data were compared with the theoretical predictions.

4. *Fabrication of Integrated Optical Devices*

   The students designed and fabricated a plymer Y waveguide structure using an oxidized silicon wafer as substrate. Silicon V-grooves were used for interfacing optical fibers for coupling light in and out of the device. The students were provided with oxidized silicon wafers with prefabricated V-grooves and the photolithography mask. The students performed photoresist deposition, mask alignment and exposure, and photoresist development with special attention to alignment of device to the V-grooves. This lab exericise taught students the technological standard regarding interfacing of IO device and optical fiber and the degree of tolerances necessary in such systems

Detailed descriptions of the lab experiments and facilities will be found in the attached appendices. The appendices contain the lab handouts used in class, copy of [3], and a copy of the M.S. thesis which evaluated the different technologies that could be used in the lab.

2.3 Dissemination of Results

The results of this project are being disseminated to other universities. The project curriculum originally developed at the University of Notre Dame has been adopted by West Virgina University's department of electrical engineering. Broader dissemination of the project has also been carried out by the presentation of conference papers [3] [4].

3 Personnel

The following individual participated in the project:

1. *Dr. B. Das, prinicpal investigator.* He received 1.5 months of summer support (1993)
2. *M.D. Lemmon, co-principal investigator.* He received 1 month of summer support (1993)
3. *Dr. David Naylor*, University of Chicago, Illinois. Not directly supported financially, but provided technical assistance and advise concerning fabrication of V-groove couplers.
4. *Dr. L. A. Hornak*, University of West Virgina. Not directly supported financially, but provided technical assistance in fabrication of V-groove couplers and polymer waveguide devices.
5. *Mr. Jieming Xi*, graduate student. He received 1 year of support in 1993 while working to complete his M.S. in electrical engineering from the University of Notre Dame under the direction of Dr. B. Das.
6. *Mr. William LaMonaca* , graduate student. No finanical support from this grant, but his work in 1993-1994 while completing his M.S. in electrical engineering from the University of Notre Dame under the direction of Dr. M.D. Lemmon dealt directly with the fabrication issues of concern in this project.
7. *Mr. W. Gavin Fredericks*, graduate student. No finanical support from this grant, but he assisted in developing V-groove fabrication techniques while completing his M.S. in electrical engineering from the University of Notre Dame under the direction of Dr. B. Das.
8. *Ms. Danielle Walker*, undergraduate student. No finanical support from this grant, but assisted in lab development as part of an undergraduate research program (1994).

4 Activities Related to Grant

1. The course on fiber and integrated optics was taught for the first time in Spring 1993 by B. Das and M. D. Lemmon to 15 senior undergraduate and first year graduate students at the University of Notre Dame.
2. In Spring 1994, W. LaMonaca completed his Master's thesis working on development of the integrated optics laboratory. The results from this thesis identified polymer technologies as the most feasible technology upon which to base an undergraduate integrated optics lab.

3. Spring 1994, collaboaration developed with Dr. Naylor at UC Chicago regarding fabrication of V-groove structures.
4. Integrated Optics Laboratory was offered for the first time to 6 undergraduate students in spring 1994 at the University of Notre Dame.
5. Summer 1994, Dr. B. Das moves to West Virginia University to continue project development at WVU.
6. Fall 1995, Dr. D. Hall (University of Notre Dame) expands optics program at University of Notre Dame.
7. Fall 1995, Dr. B. Das collaborates with Dr. L.A. Hornak at WVU in developing V-grooves and passive optical power dividers. This work was to develop a similar curriculum to that offered at Notre Dame at WVU.
8. Fall 1995, Presentation of ASEE/DELOS paper [4]
9. Fall 1995, Presentation of SPIE paper [3]

5 List of Accomplishments

This project produced 2 conference publications and led to the development of an integrated optics curriculum at two different universities (University of Notre Dame and University of West Virginia). 3 students who directly contributed to the project graduated with their M.S. degrees and 1 undergraduate student assistant graduated. The project also produced 1 technical report summarizing the experiences of the PI and Co-PI on this project.

References

[1] W. LaMonaca, *Design and Fabrication of Low Cost Polymer Directional Couplers*, MSEE Thesis, (advisor: Dr. M.D. Lemmon), University of Notre Dame, 1994.

[2] M.D. Lemmon and B. Das, *Undergraduate Laboratory in Waveguide Photonics*, Technical Report of the ISIS Group, Dept. of Electrical Engineering, University of Notre Dame, ISIS-96-002, 1996.

[3] B. Das, L.A. Hornak, and M.D. Lemmon, "A Model Undergraduate Integrated Optics Laboratory", in *Proceedings SPIE International Conference on Education in Optics*, San Diego, California, Vol. 2525, pp. 136-147, July 9-10, 1995.

[4] B. Das and M.D. Lemmon, "A Model Undergraduate Integrated Optics Laboratory", 1995 Annual ASEE Conference, June 25-28, 1995, Anaheim, CA. (*this paper was selected for broader exposure at the conference by the ASEE/DELOS division*).

Appendix A

Laboratory Handouts

Appendix B

B. Das, L.A. Hornak, and M.D. Lemmon
"A Model Undergraduate Integrated Optics Laboratory"
in *Proceedings SPIE International Conference on Education in Optics*
San Diego, California,
Vol. 2525, pp. 136-147, July 9-10, 1995.

Appendix C

W. LaMonaca
Design and Fabrication of Low Cost Polymer Directional Couplers,
MSEE Thesis, (advisor: Dr. M. D. Lemmon)
University of Notre Dame, 1994.