UMBC URCAD 2009 -- Wednesday, April 22

Undergraduate Research – The Start of a Career

Dr. Anthony M. Johnson, Director*

Center for Advanced Studies in Photonics Research (**CASPR**)

Professor of Physics

Professor of Computer Science & Electrical Engineering

University of Maryland, Baltimore County (**UMBC**)

2002 President of the Optical Society of America (OSA)

Editor-in-Chief, *Optics Letters* (95-01)

NSF ERC MIRTHE Deputy Director & Materials Research Thrust Leader

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* Before January 1, 1995
  Distinguished Member of Technical Staff
  Photonic Circuits Research Department, AT&T Bell Laboratories (now Alcatel-Lucent)

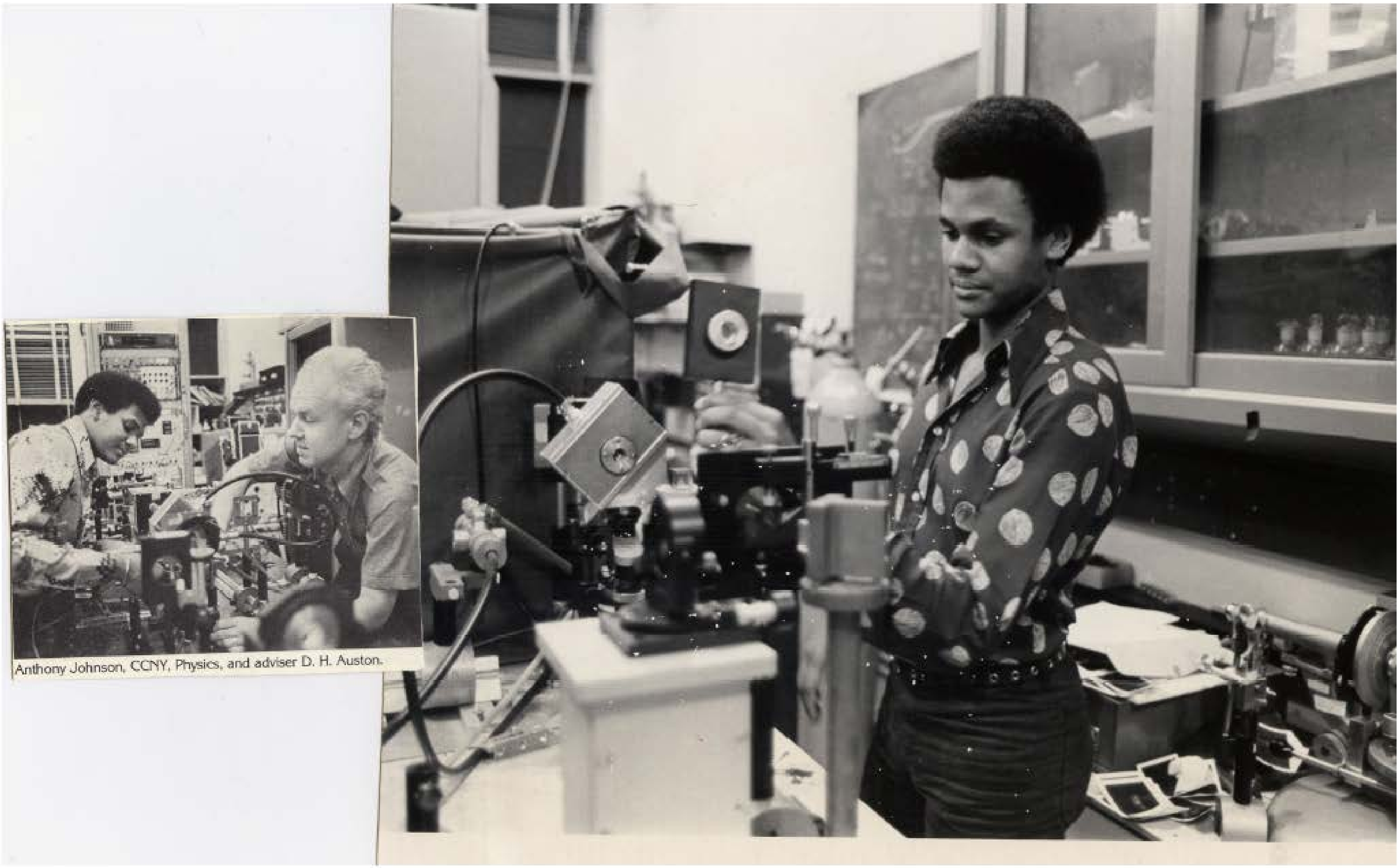
CASPR

CENTER FOR ADVANCED STUDIES IN PHOTONICS RESEARCH

UMBC

AN HONORS UNIVERSITY IN MARYLAND

1974 Bell Labs Summer Research Program, Murray Hill, NJ



David H. Auston – Lasers and Picosecond Optoelectronics – currently President, Kavli Institute

Robert C. Dynes – Low Temperature Physics and Superconductivity – Past President of UC

MICROWAVE SWITCHING
BY
PICOSECOND PHOTOCONDUCTIVITY

THESIS

Submitted in Partial Fulfillment
of the requirements for the
degree of

BACHELOR OF SCIENCE (Physics)

at the

POLYTECHNIC INSTITUTE OF NEW YORK

by

Anthony M. Johnson

June 1975

Approved:

May 16 1975

H. J. Juretschke

Head of Department
and Thesis Advisor

Copy No. 4

First scientific award:

Sigma Xi Undergraduate Research Award for Bachelor's Thesis (1975)

AN ABSTRACT

MICROWAVE SWITCHING
BY
PICOSECOND PHOTOCONDUCTIVITY

by

Anthony M. Johnson
Advisor: Hellmut J. Juretschke
Co-Advisor: Dave H. Auston

Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science (Physics)

June 1975

Bulk photoconductivity produced by the absorption of picosecond optical pulses in silicon transmission line structures has been used to switch and gate microwave signals. The technique permits the generation of microwave and millimeter wave pulses as short as a single cycle, and requires only a few microjoules of optical energy. The switching speed is essentially limited only by the duration of the optical pulses. The basic features of the device are illustrated with switching experiments at 1 GHz and 10 GHz, and the results are discussed with reference to the physical properties of the high density plasma responsible for the switching.

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IEEE Journal of Quantum Electronics, vol. QE-11, pp. 283-287, June 1975

Microwave Switching by Picosecond Photoconductivity

A. M. JOHNSON AND D. H. AUSTON

Abstract—**Bulk photoconductivity produced by the absorption of picosecond optical pulses in silicon transmission-line structures has been used to switch and gate microwave signals. The technique permits the generation of microwave and millimeter-wave pulses as short as a single cycle, and requires only a few microjoules of optical energy. The basic features of the device are illustrated with switching experiments at 1 GHz and 10 GHz, and the results are discussed with reference to the physical properties of the high-density plasma responsible for the switching.**

I. Introduction

In many cases, both for experimental purposes and for applications, it is desirable to have a capability for generating very short bursts of microwave and millimeter-wave signals of relatively high power. The current state of the art, however, is limited to switching speeds of approximately 1 ns [1]. Furthermore, at these speeds, the semiconductor p-i-n diodes which are used for this purpose are limited to powers of a few tens of watts. In this paper, we describe a simple optical technique for switching microwave signals which offers a significant improvement of both speed and power handling.

Although bulk semiconductor plasmas have received considerable attention as microwave switching devices [2], the use of high-density, optically generated plasmas has not been given serious consideration. Aside from the obvious speed capability, picosecond optical pulses have the additional advantage of enabling the generation of extremely high-density plasmas without damaging the material. Longer optical pulses are less efficient since they tend to produce more heating, and consequently are more likely to cause damage. It has recently been demonstrated [3] that plasma densities in excess of 10^{20} cm^{-3} can be readily generated by the absorption of single-picosecond optical pulses in semiconductors. Plasmas such as these are highly degenerate and have quasi-metallic properties. Their high conductivities make them ideal for bulk switching applications. The research reported in this paper is an extension of related work [4] in which switching and gating of dc signals was achieved with solid-state plasmas produced by picosecond pulses.

Manuscript received December 9, 1974.
A. M. Johnson was with Bell Laboratories, Murray Hill, N.J. 07974. He is now at the Polytechnic Institute of New York, Brooklyn, N.Y. 11201.
D. H. Auston is with Bell Laboratories, Murray Hill, N.J. 07974.

II. Optoelectronic Microwave Switching

An example of a microwave switch which utilizes the photoconductivity produced by picosecond optical pulses is illustrated in Fig. 1. It consists of a 50-Ω microstrip transmission-line [5] structure fabricated on a high-resistivity silicon substrate. The microstrip line consists of a uniform aluminum ground plane on the bottom and a narrow strip for an upper conductor in which there is a gap. Input and output microwave signals are coupled to the silicon chip by 3-mm coaxial-to-microstrip launchers. In a typical application, one side of the device would be connected to a microwave-signal source and the other to a load or test instrument. The switching action is produced by two optical pulses; one in the green region of the spectrum at $\lambda = 0.53$ μm, which is used to turn on the switch, and the other in the infrared at $\lambda = 1.06$ μm, which turns it off. The absorption constant at $\lambda = 0.53$ μm in silicon is 8×10^3 cm^{-1}, and consequently the effect of absorbing a green pulse in the microstrip gap is to produce a thin surface

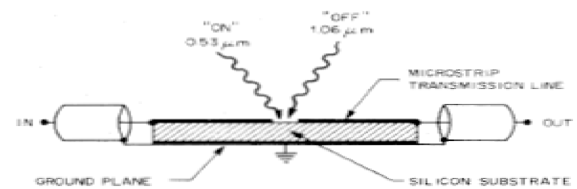
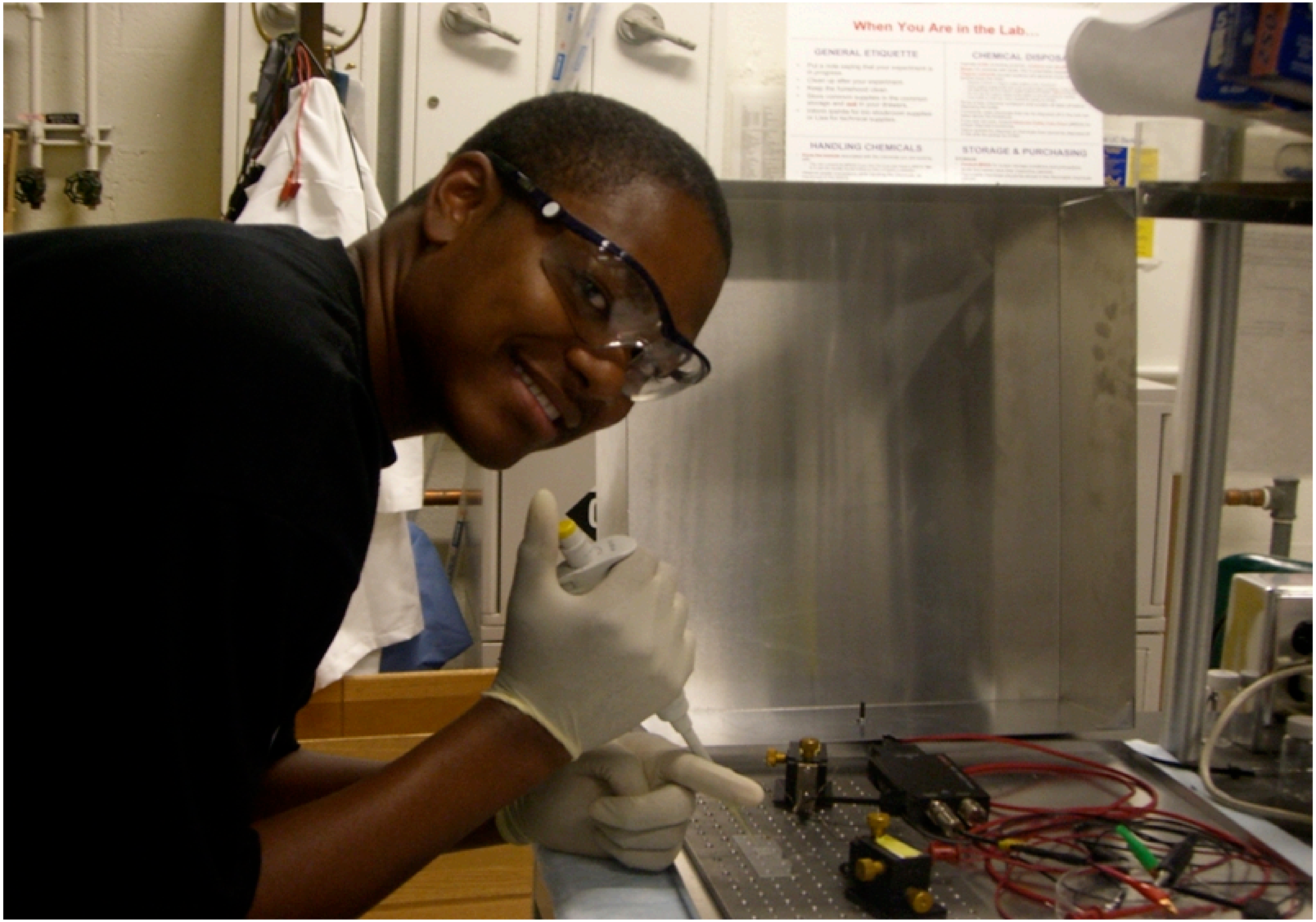


Fig. 1. An optoelectronic switch. The transmission of the switch is turned on by a surface layer of photoconductivity produced by the green pulse, and is turned off by volume photoconductivity produced by the infrared pulse, which shorts the device.

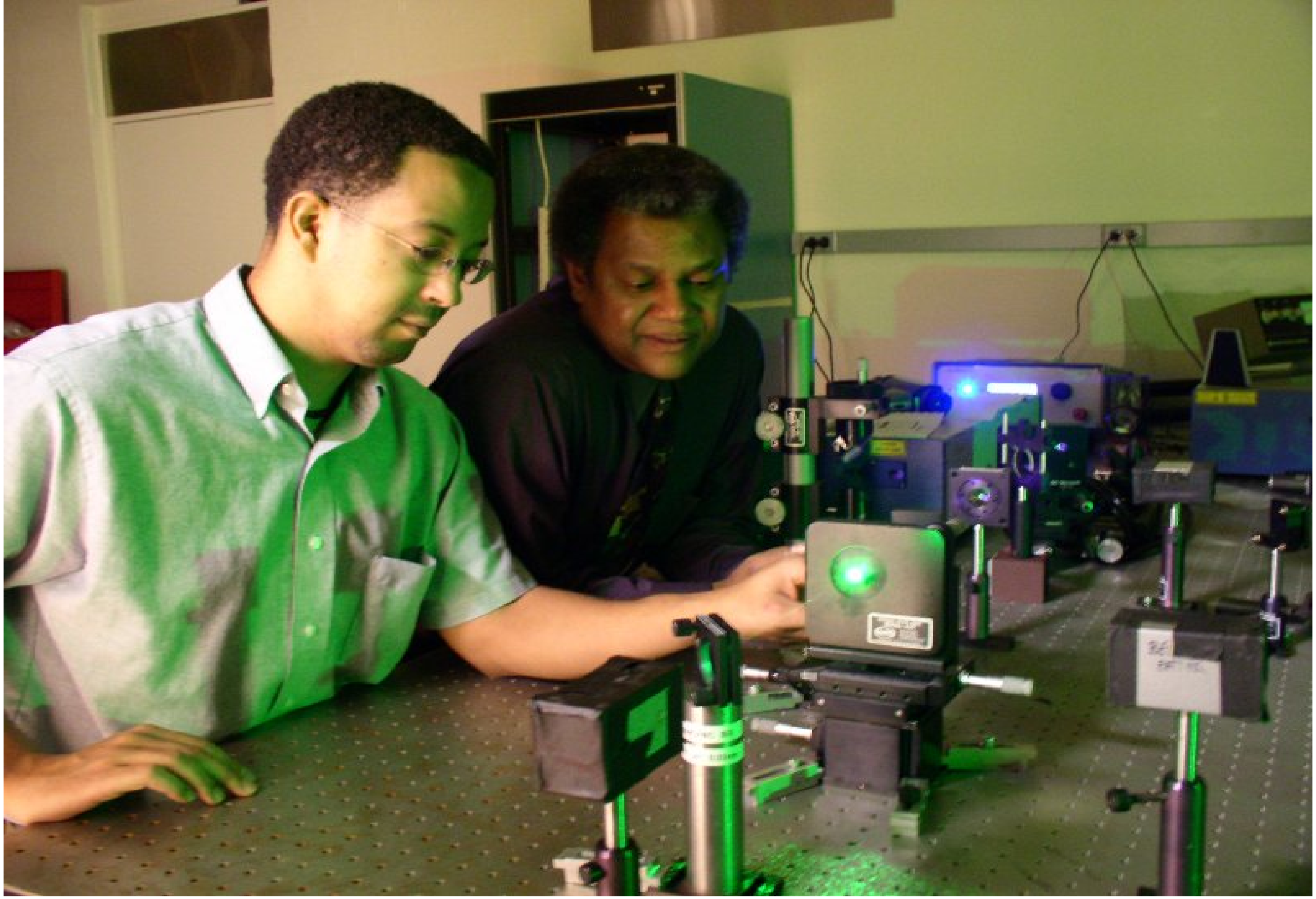
Brandon Johnson, BS Mechanical Engineering, Dec. 2008, Meyerhoff Scholar, M16

Will attend graduate school at Stanford University on a Full Fellowship in Fall 2009



Summer 2006 Research Experience, UC Berkeley, Nanoengineering Lab of Dr. Arun Majumdar

Project: "An Exploration in Nanoengineering: Ion and Heat Transport in Nanostructures"



Robinson Kuis, Undergraduate Ronald E. McNair Scholar at NJIT – undergraduate research in modelocked lasers and nonlinear optics

Rob joined my group to pursue a PhD in Applied Physics at NJIT

Rob moved to UMBC to help build the CASPR Ultrafast Optics & Optoelectronics Lab

Rob will complete his PhD in Applied Physics at UMBC by December 2009 the latest!!

Rob will be 1 of the 10-15 Latino-Americans in the US receiving a PhD in Physics in 2009

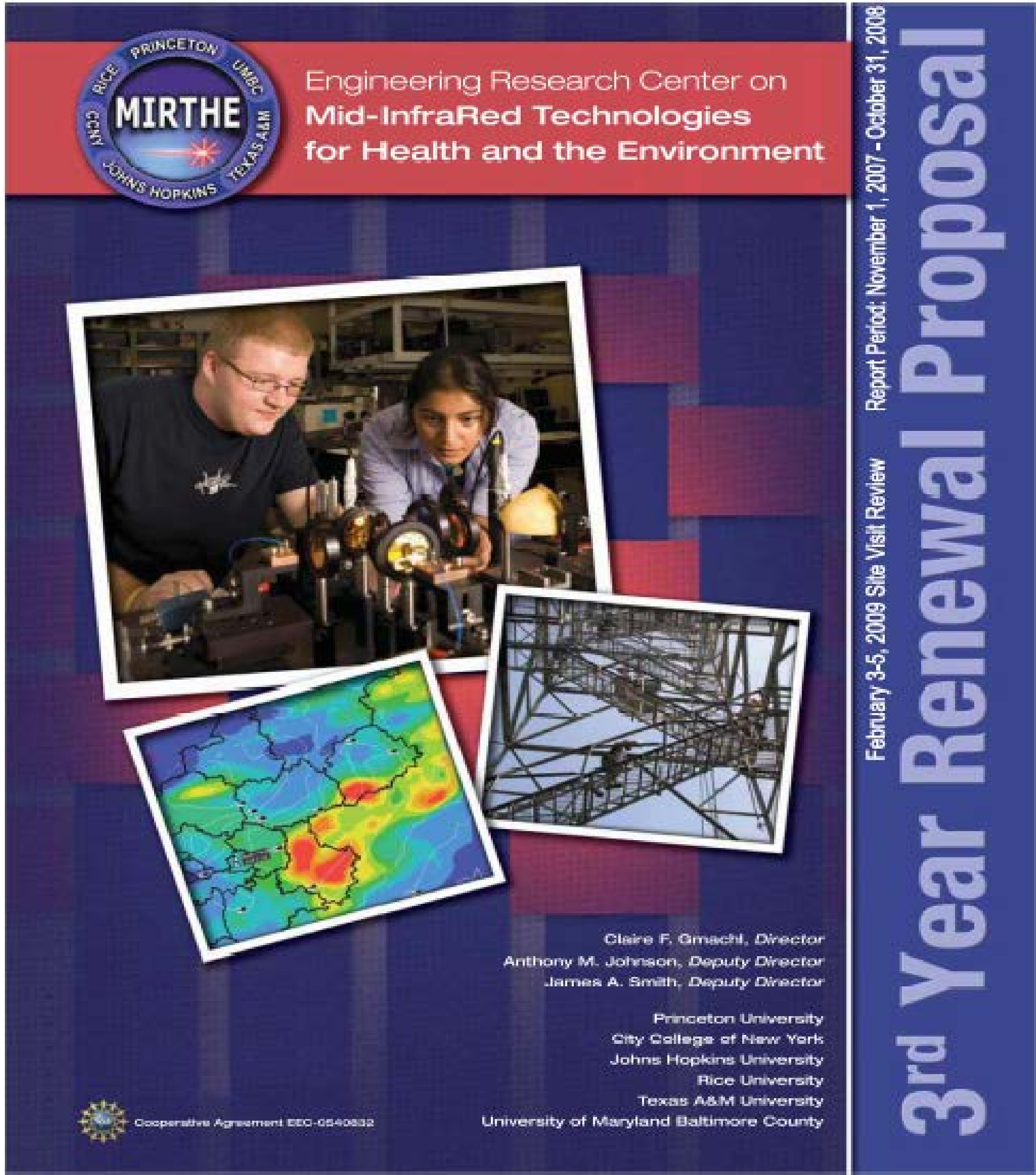
Bryan Bruce, Senior, CSEE

Meyerhoff Scholar, M17

Undergraduate Research at CASPR Lab, Fall & Spring Semesters ('07 – present) with NSF MIRTHE support – ultrafast optical phenomena in semiconductors, Raman spectroscopy and testing of quantum cascade lasers

Bryan will graduate with a BS in May 2009 and will attend UMCP for graduate school

Photo → Bryan performing measurements on quantum cascade lasers during the NSF MIRTHE REU Program @ Princeton during Summer '08 in MIRTHE Director Claire Gmachl's lab



Time-Resolved Reflectivity Measurements to Characterize Novel Semiconductor Materials

Benjamin Ecker[1], Robinson Kuis[1, 2], Dr. Anthony Johnson[1, 2, 3], UMBC

Motivation

•Problem:

One of the main goals of MIRTHE is to develop high quality but low cost trace gas sensing devices for health and environmental measurements which make use of Quantum Cascade Lasers (QCLs). The performance of the sensors depends upon the characteristics and quality of the semiconductor layers which make up the QCLs. Layers grown from new materials, different techniques, and varying compositions demand characterization.

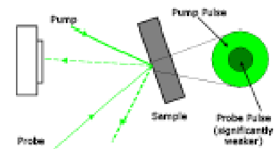
•Solution:

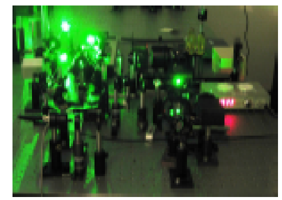
A measure of the quality of the semiconducting material is the lifetime of optically generated carriers excited by short pulses of light. Typically, a short lifetime corresponds to a poor quality sample; the photo-excited carriers become trapped rapidly by defects in the sample. While a long carrier lifetime usually corresponds to a high quality sample. These lifetimes can be as short as several picoseconds (ps).

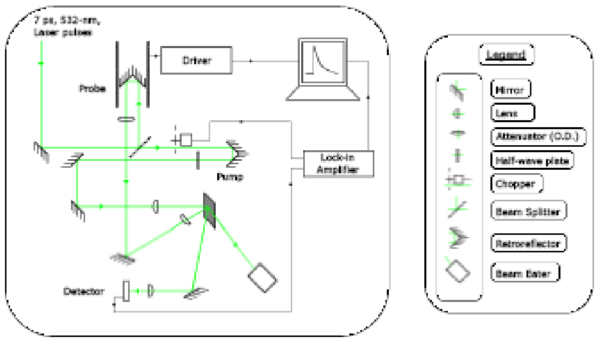
A time-resolved reflectivity measurement is one method to determine the lifetime of the photo-generated carriers. The carriers contribute to a small change in the refractive index and the reflectivity of the material. To perform a time-resolved reflectivity measurement, the pump-probe technique can be used to map out the small change in reflectivity, and thus determine the lifetime of the carriers and the quality of the semiconducting layer.

Theory Behind Pump-Probe Technique

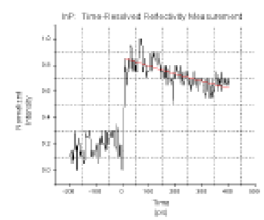
- The pump pulse generates optically excited carriers in the sample.
- A small change in the refractive index and reflectivity of the semiconducting layer occurs with a significant carrier density created by the pump pulse.
- As the electron-hole pairs recombine or become trapped by defects in the sample, the photo-generated carrier density decreases resulting in a decrease in the change in the refractive index and reflectivity of the sample.
- The probe pulse after traveling through a variable time delay arrives at the sample, spatially overlapped with pump pulse.
- Depending upon the delay, a varying amount of the probe is reflected.
- By mapping out the delay and the amount reflected, it is possible to determine the lifetime of the carriers, and the overall quality of the semiconducting sample.







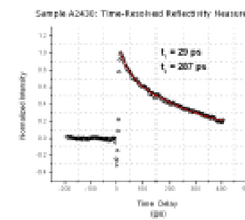
Experimental Data

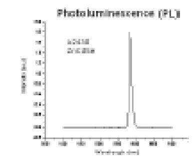


Pump Power: 100 mW
Probe Power: 3.5 mW

*Used to check validity of setup
*Expected to have exceeding long lifetime
*InP is a typical substrate used to grow QCLs layers on

Fitted InP Lifetime: 1263 ps





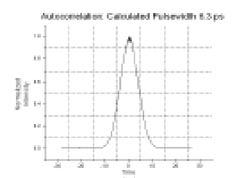
Fitted Sample A2430 Lifetime: T1 = 29 ps
T2 = 287 ps

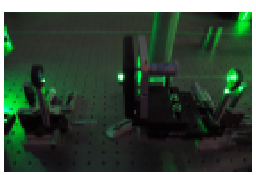
*Sample A2430 ZnCdSe
*Expected to have long lifetime
*Expected to be high quality sample due to narrow PL peak
*Sample grown from Molecular beam epitaxy (MBE)
*Sample could be used as a Quantum Well in a QCL

Sample Grown by Maria C. Tamargo's Group at City College of New York

Source

- Nd:Vandate laser at wavelength 1064-nm
- SESAM (semiconductor saturable absorber modelocking) modelocked laser with nominal pulsewidth at 7 ps and a repetition rate of 76 MHz





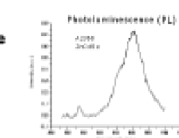
- The infrared wavelength of the laser was frequency-doubled to a visible wavelength of 532-nm (green) using a nonlinear optical crystal of potassium titanyl phosphate (KTP)

- Thanks to MIRTHE for financially supporting this research
- Thanks to the NSF who supports MIRTHE who support this research
- MANY, MANY, MANY THANKS to all those at CASPR for all their guidance, encouragement, and help with just about everything

Conclusions

The time-resolved reflectivity measurements produced good data. Measurements on Sample A2430 confirm that the sample is indeed of high quality and that it could make a very good II-VI semiconducting layer in a Quantum Cascade Laser.

**Future time-resolved reflectivity measurements will be performed on sample A2360 which is expected to be a poor quality sample because of a broad PL peak. It should produce carriers with an exceeding short lifetime.



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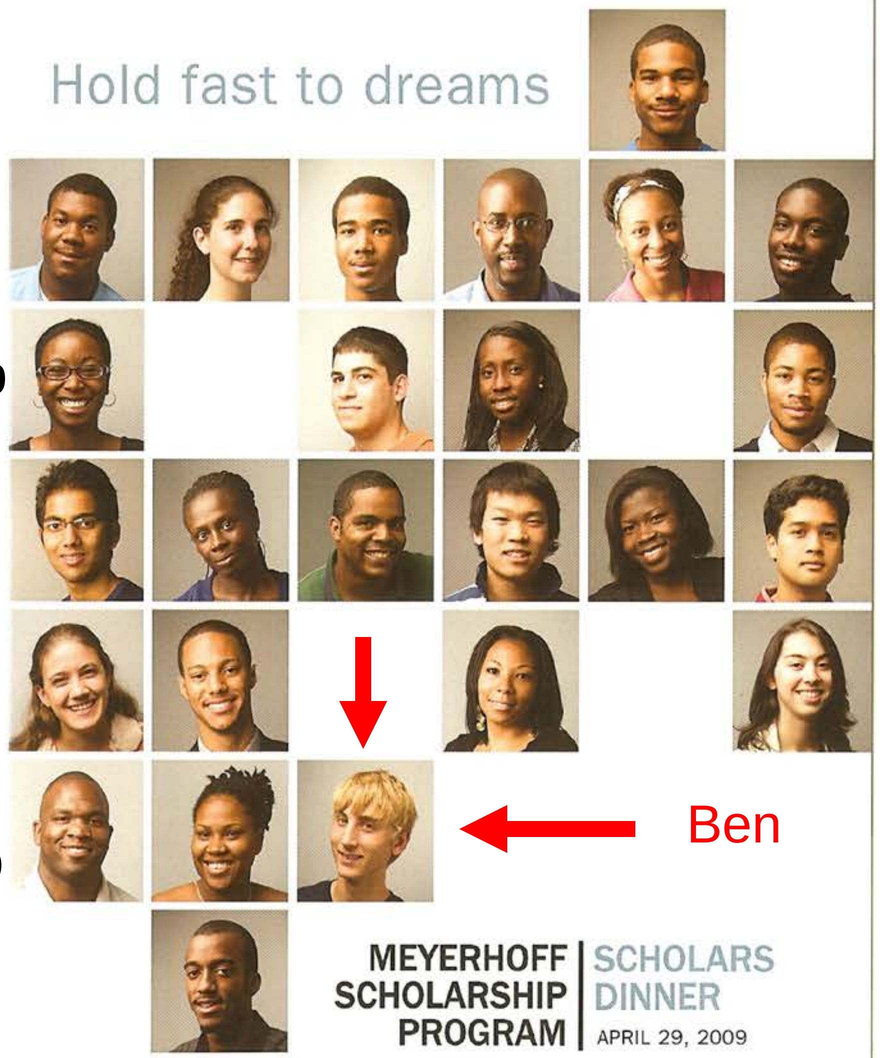
[3] Department of Computer Science and Electrical Engineering, University of Maryland Baltimore County, Baltimore, MD 21250, United States of America

Benjamin Ecker, Sophomore, Physics

Meyerhoff Scholar, M19

Undergraduate Research Summer '09 at CASPR in the NSF MIRTHE REU Program @ UMBC -- "Time-Resolved Reflectivity Measurements to Characterize Novel Semiconductor Materials"

Ben will participate in the Summer Undergraduate Research Fellowship (SURF) Program at NIST in Gaithersburg, MD during Summer '09



MD middle school students visit the CASPR Ultrafast Optics & Optoelectronics Lab as part of the UMBC ESTEEM (Enhancing Science & Technology Education & Exploration Mentoring) summer camp program during the Summer '05 – the OSA (Optical Society of America) sent a staffer to record the event and prepare an article for Optics & Photonics News (OPN)

OPN October 2005

OSA Past President Brings Lasers to Summer Camp

Patricia Daukantas

Anthony M. Johnson explains laser safety to middle school students in the ESTEEM program.

On one of the hottest afternoons of July, 25 middle school students witnessed some cool applications of laser technology. OSA 2002 president Anthony M. Johnson hosted the students for a couple of hours at his laser laboratory at the University of Maryland, Baltimore County (UMBC).

The middle schoolers, who live in Anne Arundel and Baltimore counties in Maryland, spent four weeks in a UMBC summer camp that is part of a program called ESTEEM (Enhancing Science and Technology Education and Exploration Mentoring). The camp, under the auspices of UMBC's Center for Women and Information Technology and Shriver Center, aims to stimulate girls' interest in technology careers; however, boys are welcome to attend as well, and several of this year's campers were boys.

The campers began their day learning about a fundamental aspect of the science of light: solar energy. In their morning session, they built small plastic toy cars powered by solar panels.

Campers use night-vision scopes to view infrared light.

In the afternoon, Johnson, who serves as director of UMBC's Center for Advanced Studies in Photonics Research (CASPR), told the youngsters that he became interested in lasers many years ago, thanks to a summer internship he did at Bell Laboratories—the site of many early innovations in the field.

He played for the campers an introductory OSA video, "Lasers as a Tool," which explains how the devices work and showcases numerous applications in the home, laboratory, factory and hospital. Apart from a few "ewwwws" when the camera zoomed in on surgical procedures, the students watched the video without squirming.

Johnson discussed how lasers are used in dentistry and ophthalmology as well as CD-ROM drives. He also explained that his own interests lie in the field of ultra-high-speed photonics, a topic that fits into UMBC's physics and electrical engineering departments, where he holds joint appointments.

The lasers in his lab, he said, give off pulses that are a million times shorter than a billionth of a second, and some that are even a thousand times shorter than that. "You can only do measurements that fast with light, because no electronics can do that," he told the students. His explanation of the lasers' intense speed increased the impact of his exhibition of his picosecond and femtosecond lasers.

Those lasers are included in a laboratory that Johnson calls the "million dollar

The Ultrafast Optics and Optoelectronics Group (Feb. ’08)

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