Undergraduate Research – The Start of a Career

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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
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June 1975

Approved:
May 16, 1975

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AN ABSTRACT

MICROWAVE SWITCHING
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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.
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.

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-\(\Omega\) 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 \(\lambda = 0.53\) \(\mu\)m, which is used to turn on the switch, and the other in the infrared at \(\lambda = 1.06\) \(\mu\)m, which turns it off. The absorption constant at \(\lambda = 0.53\) \(\mu\)m in silicon is \(18 \times 10^4\) 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 a volume photoconductivity produced by the infrared pulse, which shorts the device.](image)
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
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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 Ecker¹, Robinson Kuis¹,², Dr. Anthony Johnson¹,²,³, 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.
- The electron-hole pairs recombine or become trapped by defects in the sample, the photogenerated 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.

Source

- Nd:Vanade laser at wavelength 1064-nm
- SESAM (semiconductor saturable absorber modelocking) modeled 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 Ti:Li semiconducting layer in a Quantum Cascade Laser.

Experimental Data

- Pump Power: 100 mW
- Probe Power: 3.5 mW

- *Used to check validity of setup
- *Expected to have an exceedingly long lifetime
- *It is a typical substrate used to grow QCL layers on
- *Sample A2430 InCdSe
- *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 A2430 Lifetime: T₁ = 29 ps
T₂ = 297 ps

Sample Grown by Marla C. Tamargo’s Group at City College of New York

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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).