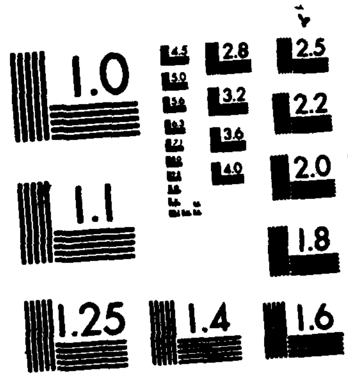
AD-A181 213 APPLICATIONS OF SUBPICOSECOND SPECTROSCOPY(U) ROCHESTER 1/1
UNIV N Y LAB FOR LASER ENERGETICS G MOUROU 19 MAY 87
AFOSR-TR-87-0747 AFOSR-84-0318

UNCLASSIFIED F/G 7/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DTIC FILE COPY (2)

SECURITY CLASSIFICATION OF THIS PAGE

AD-A181 213

DTIC ELECTE JUN 1 1987 S D

REPORT DOCUMENTATION

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRIC
2a. SECURITY CLASSIFICATION AU	3. DISTRIBU... OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRA... SCHEDULE	
4. PERFORMING ORGANIZATION ... NUMBER(S) D	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 87-0747
6a. NAME OF PERFORMING ORGANIZATION University of Rochester Laboratory for Laser Energetics 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code) 575 Elmwood Ave. Rochester, NY 14620	7b. ADDRESS (City, State and ZIP Code) Bld 410 Bolling AFB, D.C. 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR 8b. OFFICE SYMBOL (If applicable) NE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-84-0318
8c. ADDRESS (City, State and ZIP Code) Bld 410 Bolling AFB, D. C. 20332	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2305	C1	

11. TITLE (Include Security Classification)
Applications of Subpicosecond Spectroscopy

12. PERSONAL AUTHOR(S)
Prof. Gerard Mourou

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Annual	FROM SEP 85 TO SEP 86	19 MAY 1987	09

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The electro-optic sampling technique has been used to mreasure the response of a permeable base transistor (PBT) fabricated at Lincoln Laboratory. The rise time was measured to be 5 ps, the fastest room temperature rise time reported to that time. The collaboration with Arizona State U continued. Two different laser systems were used to measure the rise time of the photo-current through a GaAs photoconductive switch. The measurement technique has been deomonstrated and a comprehensive study is now underway.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	unclass

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Dr. Gerald Witt	202-767-4931	NE

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

AFOSR-TR- 87-0747

Annual Technical Report
APPLICATIONS IN SUBPICOSECOND SPECTROSCOPY
AFOSR Contract #84-0318
For Period Ending September 1986

The goal of this project was to apply the electro-optic sampling (EOS) technique to the study of subpicosecond electron/hole transport in III-V semiconductors by looking at the time resolved photocurrent in semiconductors. The technique, developed at the Laboratory for Laser Energetics (LLE) has measured electrical transients as short as several hundred femtoseconds with submillivolt sensitivity. Electro-optic sampling is being used to measure the transient response of gallium arsenide permeable base transistors (PBTs) and to study the behavior of gallium arsenide photoconductive switches under a range of experimental conditions. This technique has also been demonstrated in the low temperature regime using a new fully cryogenic sampler.

(A) Device measurements

PBTs are among a class of recently-developed gallium arsenide-based transistors which have switching speeds approaching 10 ps and beyond (others include high electron mobility transistors and heterojunction bipolar transistors). These switching speeds are determined intrinsically by the transit time of electrons through the gate channel and extrinsically by parasitic circuit elements. Measurement of the transient response, coupled with frequency-domain measurements and detailed modeling of the device, will yield information about the picosecond electron transport in these devices. Conventional characterization techniques, such as the sampling oscilloscope, cannot resolve picosecond speeds. Ring oscillator measurements, in which a large number of these devices are strung together in a ring and the accumulated switching delay is measured, yield only data averaged over all of the devices. The EOS technique is well suited for measuring the picosecond response of discrete devices. Previously it has been used to measure the response of MESFET's (25 ps) and TEGFET's (17 ps).

The PBT, developed at MIT's Lincoln Laboratory, is a vertical device with a geometry similar to a vacuum tube triode. Here, however, the metallic grating has a submicrometer periodicity and is completely imbedded in gallium arsenide. As a result of the small dimensions and high electron mobility in gallium arsenide, high-speed operation is expected. S-parameter measurements have indicated a maximum frequency of oscillation of more than 200 GHz. The measured step response, using the EOS technique, is shown in Fig. 1. The rise time is approximately 5 ps. This measurement represents, to the best of our knowledge, the fastest rise time for any room-temperature three-terminal device.

Most devices of this type are expected to exhibit enhanced speed and gain at low temperatures; therefore it is important to extend the EOS technique into the cryogenic regime. A cryogenic GaAs/$LiTaO_3$ sampler with Pb-alloy superconducting coplanar transmission lines has been developed and tested. When immersed in superfluid helium ($T < 2.18$ K) conduction losses were eliminated and the response improved to 360 fs. The sampler has been used to measure the response of a Josephson junction to a stepped voltage pulse and to study picosecond pulse propagation in superconducting transmission lines.

(B) Subpicosecond transport in gallium arsenide

Electrons in gallium arsenide under high-field conditions are predicted to exhibit a transient velocity that may be as high as twenty times their long-term equilibrium velocity. This effect, known as velocity overshoot, has been of great interest to device physicists because the speed of most devices is inherently limited by the transient time of electrons in the device. There has been no direct experimental evidence of the effect to date because it occurs on such a short (~ 0.2 ps) time scale at room temperature (at low temperature the effect is enhanced and the maximum velocity occurs after several picoseconds).

In a gallium arsenide photoconductive switch electrons and holes photogenerated with a laser pulse drift due to an applied electric field, and induce a current in the external circuit. When a short (< 0.1 ps) laser pulse is used and the EOS technique is applied, the photocurrent is observed to have a very fast (~ 0.4 ps) rise time and a long (~ 100 ps) decay. The decay is simply the recombination lifetime of the photogenerated carriers; the rise time is a function of the laser pulsewidth, the geometric size of the optical probe pulse and sampler electrodes, and the transient velocities of the carriers. Changes in the rise time as a function of excitation wavelength, applied bias, and temperature can be correlated with changes in the drift velocity of the carriers.

We have studied the rise time of the photocurrent using two different laser systems. In the first system, a colliding-pulse mode-locked (CPM) laser delivers ~ 60 fs pulses at $\lambda = 620$ nm at a rate of 100 MHz to generate and probe the photocurrent. At this wavelength electrons are generated well up into the conduction band and the velocity overshoot effect is expected to be small. Figure 2 shows the photocurrent rise at two different applied biases; a small shift of ~ 100 fs is observed, demonstrating that very small changes may be resolved using this technique. Although small line changes can be measured the electron transport cannot be inferred at this point. More work has to be done to obtain good ohmic contact on a GaAs material which is semi-insulating.

Velocity overshoot is expected to occur under high-field conditions when the electrons have been generated very close to the band-edge ($\lambda \sim 850$ nm). In order to study the photocurrent rise time at longer excitation wavelengths, a white light continuum laser source has been developed. A dye laser similar to the CPM generates < 100 fs pulses that are amplified by the frequency-doubled output of a Nd:YAG regenerative amplifier. After amplification there is sufficient energy in the laser pulses to generate a white light continuum when focussed into a water cell. Different wavelengths may then be selected using interference filters to excite the photoconductive switch. The switch response under overshoot conditions ($\lambda \sim 850$ nm, $E_{bias} \geq 10$ kV/cm) is currently being compared with the response under conditions when no overshoot is expected ($\lambda = 620$, 750 nm, $E \leq 5$ kV/cm). Figure 3 shows the time resolved photoconductivity induced in GaAs with 850 nm light obtained with the kilohertz amplified system. A more systematic study of the rise time as a function of the field and excitation wavelength and temperature can now be undertaken.

PUBLICATIONS

"Picosecond Characterization of Ultrafast Phenomena. New Devices and New Techniques," D.R. Dykaar, *et al.*, Ultrafast Phenomena V 1986, Springer-Verlag.

"Ultrafast Optics Applied to Modern Device Research," G. Mourou, K. Meyer, J. Whitaker, and M. Pessot, to be published in Picosecond Electronics and Optoelectronics, Lake Tahoe Conference I.

"Subpicosecond Electro-Optic Sampling: Principles and Applications," J.A. Valdmanis and G. Mourou, IEEE J. Quant. Elec. QE-22(1), 69-78 (1986).

"Electro-Optic Sampling: Testing Picosecond Electronics. Part 1. Principles and Embodiments," Laser Focus, 84-96 (1986).

"Electro-Optic Sampling: Testing Picosecond Electronics. Part 2. Applications, Laser Focus, 96-106 (1986).

PARTICIPATING PROFESSIONALS

The experiments required tunable short pulses around 850 nm so photocarriers could be generated in GaAs without excessive kinetic energy as well as technique to look at electrical signals with a few hundred femtosecond resolution.

A large number of people, graduate students essentially, have been involved either in the source development or electro-optic sampling improvement. The people involved in this research have been:

Professors: G. Mourou and T. Castner (University of Rochester); R. Grondin (University of Arizona)

Graduate Students: D. R. Dykaar, T. Norris, K. Meyer, and M. Pessot (University of Rochester)

INTERACTION AND COUPLING ACTIVITIES

The work done at Rochester could only be done with the excellent assistance of the group of Professor R. Grondin at the University of Arizona,Tempe for the Monte Carlo simulation.

The Rochester group is constantly interacting with other laboratories working on the inception and development of ultrafast components and circuits. It is trying to promote the techniques based on ultrafast optics in high speed electronics. For instance it interacted extensively with groups such as MIT Lincoln Lab for the characterization of the permeable base transistors and resonant tunneling diode. Also with Gremens at Princeton, Thomson CSF in France, and Texas Instruments for the characterization of TEGFET and resonant tunneling diodes.

The group activity is reflected by the large number of invited presentations it has given during 1986.

• WOCSEMMAD - San Francisco, CA	February 10
• University of California at Berkeley	February 19
• DARPA EHF Review-San Diego, CA	February 20
• University of Illinois at Urbana	March 13
• Hypress Incorporated-Elmsford, NY	March 14
• Texas Instruments	March 20
• CLEO-San Francisco, CA	June 9
• Ultrafast Phenomena-Snowmass, CA	June 16
• High Speed Electronics-Stockholm	August 7
• Los Alamos National Laboratory-Los Alamos, NM	September 15
• Optical Society of America Ultrashort Pulse Symposium-Seattle, WA	October 19
• Electron Device Activities in Western New York Conference-Rochester, NY	October 22
• Solid State Division Seminar, Oak Ridge National Lab-Oak Ridge, TN	October 30
• Materials Research Society, Symposium on Interfaces, Superlattices and Thin Films-Boston, MA	December 2
• University of Michigan	December 15

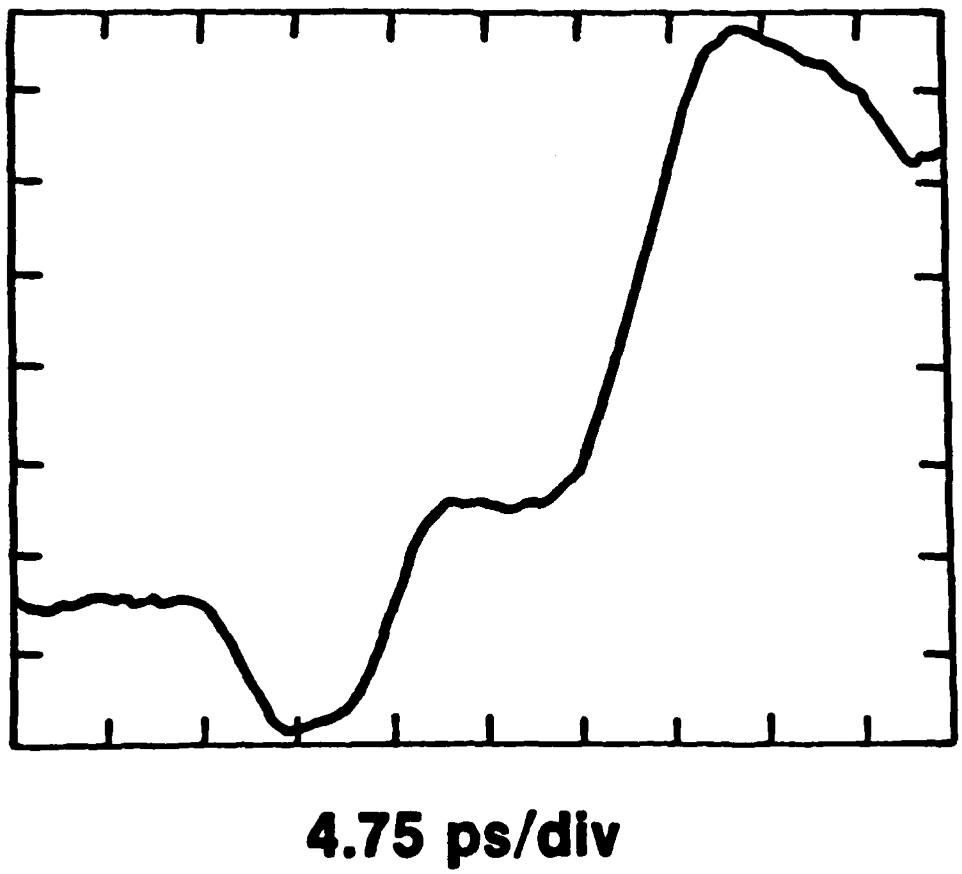


Fig. 1 Measured step response of the Permeable Base Transistor ($\tau_r \sim 5$ ps)

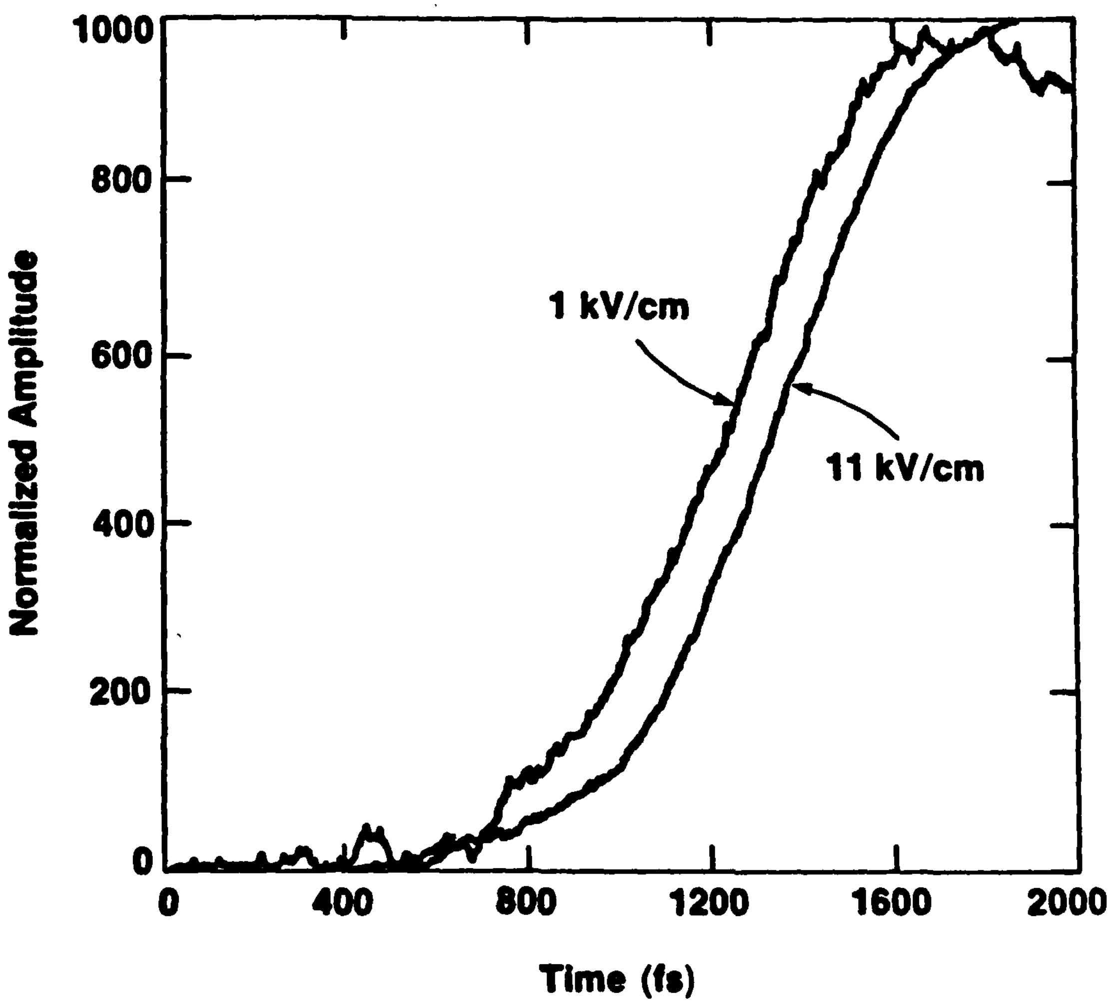
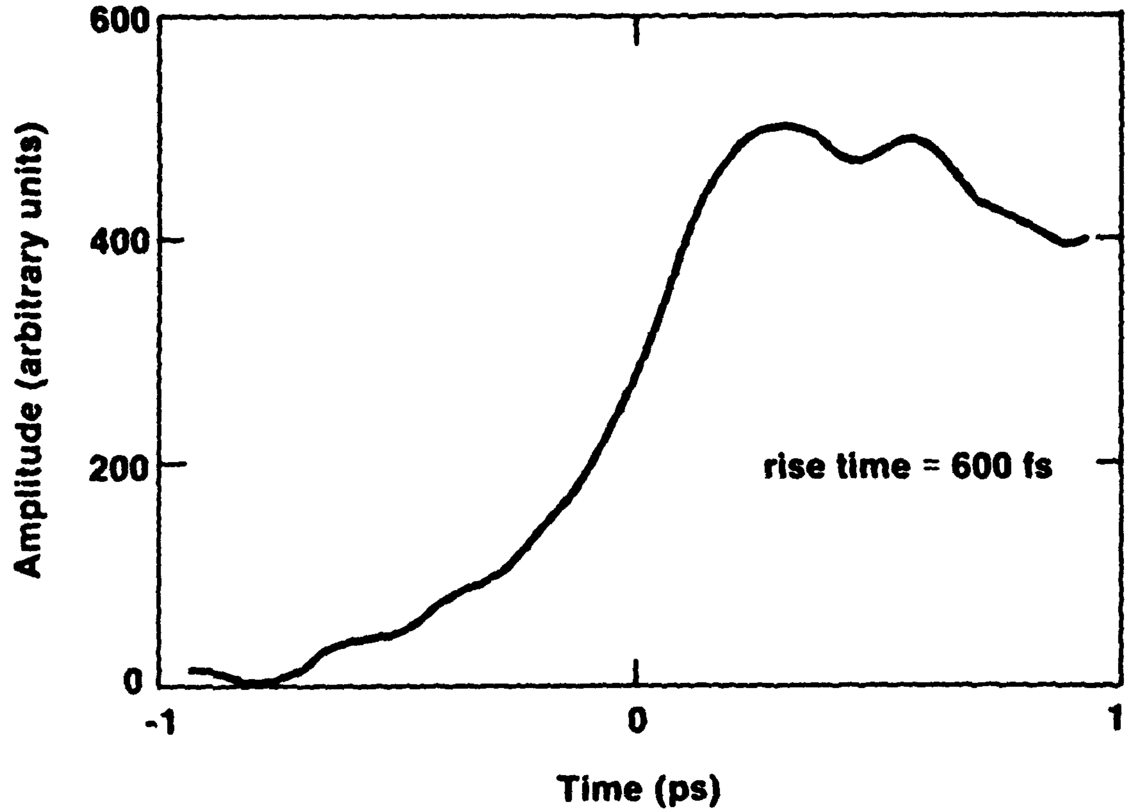


Fig. 2 Comparison of the GaAs switch response, excited by λ = 620 nm light, under high and low field conditions

Transient Response of GaAs Switch Excited with $\lambda = 850$ nm

UR LLE



END
7-87
DTIC