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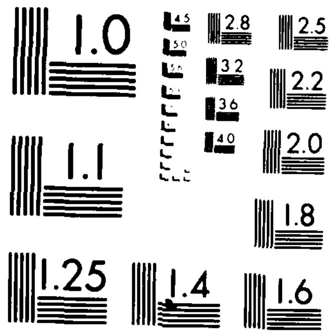

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Theoretical Studies of Experiments and Applications of Subpicosecond Photoconductivity

Annual Technical Report
September 1, 1984 to August 31, 1985

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Submitted to
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Summary Abstract

The reporting period covers the first year of a two year program whose goal is the development and use of models of femtosecond photoconductive experiments as probes of hot carrier transport in semiconductors. These experiments are being carried out in a companion effort directed by Dr. Gerard Mourou at the University of Rochester, Rochester New York. There are several main components to the modeling of such experiments. One must first model the generation of electron-hole pairs inside a semiconductor as the result of the incidence of a femtosecond optical pulse. Then one must model the processes by which the resulting current transient is developed. Lastly, the conversion of the current transient into a voltage wave transmitted down a transmission line must be understood. It is this voltage wave that is directly measured in the experiments of interest. During the first year the first two of these necessary steps were completed.

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Statement of Work

For approximately 15 years there has been interest in the possibility of constructing transistors with extremely fast switching properties by using novel features associated with charge transport in semiconductors over distances of submicron length. While there has been a large effort at theoretically analyzing these possiblities, the time and space scales are sufficiently short that meaningful experimental efforts have been precluded.

Subpicosecond optical techniques may overcome this problem. The primary goal of this program is the development and use of theoretical tools for the analysis of one key example of such optical experiments.

The experiment of interest is being performed in a companion effort headed by G. Mourou of the University of Rochester, Rochester New York. In it a laser pulse is used to activate a photoconductive transient in a gap in a microstrip line on GaAs. A second pulse then is used to electro-optically sample the voltage wave triggered in this line as a result of the photoconductive transient. Both portions of the experiment are done on a subpicosecond scale thus making it the first direct probe of subpicosecond current transients in semiconductors. It differs from the vast majority of optical experiments in that information directly pertinent to the carrier momentum is collected whereas spectroscopic techniques tend to probe only carrier energy.

There are three main steps which must be performed in the development of a model of this experiment. First, we must accurately model the processes by which the laser pulse is converted into electron-hole pairs inside the gap. Secondly we must model the ensuing transport transients and their conversion into a current transient seen at the gap terminals. Lastly, we then must model the process by which this current transient is represented as a voltage wave traveling down a microstip line as it is this wave that is sampled in electro-optic experiments of this sort. Once the models are developed they then are to be used in conjunction with actual experiments in probes of our understanding of carrier transport on the subpicosecond scale.

Status of Research

During the first portion of the first year our efforts centered on the transformation of optical pulse data into a set of electron-hole pair generation events which are distributed over the transmission line gap in both space and time. As the transport model to be used in the second step is a Monte Carlo model, we chose to use Monte Carlo techniques for this portion as well. An ensemble of incident photons is chosen which represents botn the spectral and temporal distribution of the pulse by applying the same rejection techniques commonly used to model the distribution of scattering angles in various scattering events in transport Monte Carlo studies. The location in the gap along the surface is similarly selected by using a description of the pulse shape function, most generally a Gaussian function. The penetration depth into the sample can be selected by using the photon wavelength to select an appropiate optical absorption coefficient. The penetration depth then is an exponentially distributed function with this parameter serving as the mean penetration depth. This problem is identical with the statistical distribution of free flight times between scattering events in transport studies and the same techniques were used here to solve the optical penetration problem.

Attention was then turned to the second problem. Here the difficulty is that while there has been a great deal of effort at developing good Monte Carlo models for electron transport in GaAs, holes have been neglected. They however cannot be neglected here. The development of a good hole model was the other main effort of the first year of the program. The hole model which was developed includes both light and heavy holes. The hole masses used are .45m for heavy holes and .082m for light holes[1]. The scattering processes include interband and intraband transitions through the mechanisms of acoustic phonon, optical phonon and ionized impurity scattering[2]. The drift velocity curves for holes show a peak velocity of 7×10^6 cm/s at 80 kV/cm.

The main tasks for the second year are to couple these efforts into a throrough simulation of the experiment of interest. The next step will be to couple the electron and hole transport models with Poisson's equation. This will be done by modifying existing models for GaAs MESFETs. We also will perform some simple studies of the roles of laser energy and sample temperature in determining the velocity transients. Finally, the coupling of the sample to the transmission line and solution of the resulting circuit problem must be performed. This then will allow us to directly compare the experimental measurements of the voltage wave generated in a given geometry, sample and optical pulse with those predicted by a reasonably detailed model of the internal physics of interest.

There are several main scientific questions which we hope to answer. The first is the nature and existence of velocity overshoots of carriers suddenly introduced to a high electric field in a semiconductor. All transport calculations that allow for this possibility predict it yet no unambiguous experimental observation of such an overshoot has been made. Our goal is to use these techniques in an effort at performing such an experiment.

A second important question involves the role of intervalley scattering in such experiments. The intervalley coupling coefficients are extremely important parameters and yet are difficult to either measure or compute. It may be possible to probe these processes by choosing laser energies that introduce carriers into the conduction band at the level of the satellite valley minima.

A third set of questions involve the role of carrier-carrier scattering. Optical experiments offer one vehicle of studying these interactions without the possible competing effects of increased doping density and associated ionized impurity scattering.

Publications and Presentations

No publications were produced during the first year of this program. We anticipate the production of several publications describing the above model and the various results during the second year of the program. We additionally anticipate the production of a Masters thesis during the latter portions of the second year.

Professional Personnel

Christopher Caruso is a graduate research assistant working on this program. His undergraduate degree is in Electrical Engineering from General Motors Institute, Flint MI. He presently is a graduate student in Electrical

Engineering at Arizona State University and anticipates the compl..ion of his masters degree in December 1986.

Dr. Robert O. Grondin is an assistant professor of Electrical and Computer Engineering at Arizona State University and tne principal investigator of the present effort. He received the BS, MS and Ph.D. degrees in Electrical Engineering from the University of Michigan. He was a post-doctoral fellow at Colorado State University prior to his acceptance of his present faculty position in 1983. In 1985 he was named a Presidential Young Investigator by the National Science Foundation.

Interactions

A strong interaction has developed between this effort and the companion experiemental effort at the University of Rochester. All of the personnel described above have visited the experimental site and regular communication via telephone, letter and running into each other at conferences has developed. This interaction has aided both the experimental and theoretical efforts as both groups have found it possible to vary their activities in fashions that will eventually aid in the basic scientific task of comparing theory with experiment.

Another strong interaction has developed between the investigators on this project and others who are performing investigations into transient carrier transport at Arizona State University. This has greatly aided in the development of the Monte Carlo models. There is an important result of this interaction that is not so obvious however. A relatively common transport kernel for both electrons and holes, in both III-V and silicon materials has been developed. This kernel has been successfully used in device modeling efforts. This should greatly aid the translation of any results obtained from the experiments of interest here into devices of technological interest including MESFETs, MOSFETs and HEMTs. A natural extension of these models into the modeling of hetero-bipolar devices exists but has not yet been carried out.

References

1 K. Brennan and K. Hess, Physical Review B 29, 5581 (1984)

2 C. Jacoboni and L. Reggiani, Reviews of Modern Physics, 55, 645 (1983)

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During the reporting period, the first year of a two year program, progress was made on the development of models of femtosecond photoconductive experiments as used as probes of hot carrier transport in semiconductors. In these experiments subpicosecond laser pulses are focused onto a gap in a transmission line with a semiconducting substrate. A voltage wave is then propagated down the line as a result of the photoconductive transient in the gap. During this first year we developed models for the description of the carrier photogeneration process and the ensuing photocurrent transient. Monte Carlo methods were used in both of these models.

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