AD-A131 130 ANNUAL REPORT ON ELECTRONICS RESEARCH AT THE UNIVERSITY 1/2
OF TEXAS AT AUSTIN(U) TEXAS UNIV AT AUSTIN ELECTRONICS
RESEARCH CENTER E J POWERS 15 MAY 83 F49620-82-C-0033

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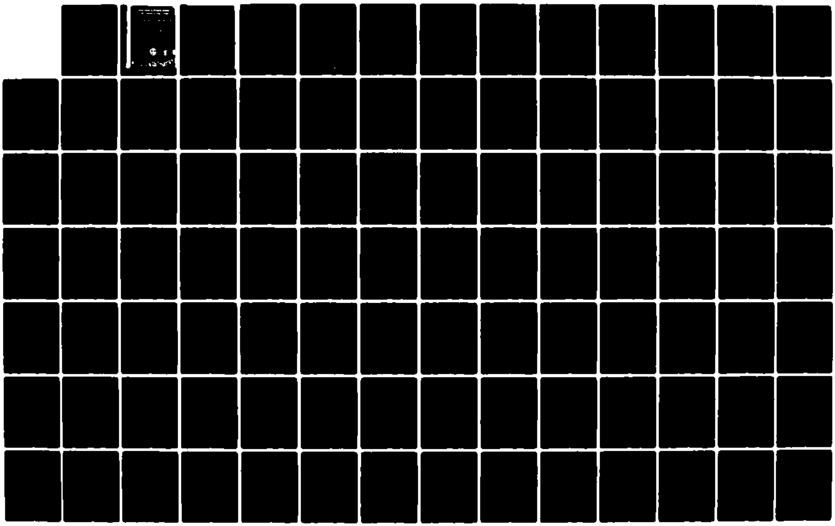

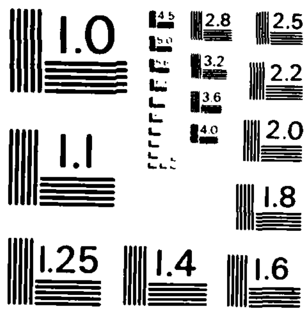

MICROCOPY RESOLUTION TEST CHART
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Annual Report on Electronics Research

at The University of Texas at Austin

For the period April 1, 1982 through March 31, 1983

JOINT SERVICES ELECTRONICS PROGRAM
Research Contract AFOSR F49620-82-C-0033

Submitted by Edward J. Powers
on Behalf of the Faculty and Staff
of the Electronics Research Center

May 15, 1983

ELECTRONICS RESEARCH CENTER

Bureau of Engineering Research
The University of Texas at Austin
Austin, Texas 78712

ABSTRACT

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear detection and estimation and (2) electronic multi-dimensional signal proccessing.

In the Solid State Electronics area recent findings in (1) interface reactions, instabilities and transport and (2) spectroscopic studies of metal/semiconductor and metal/metal oxide interfaces are described.

In the area of Quantum Electronics progress is presented for the following projects: (1) nonlinear wave phenomena, (2) structure and kinetics of excited state molecules and (3) collective effects in nonlinear optical interactions.

In the Electromagnetics area progress in guided-wave devices for the far-infrared-mm wave spectrum is summarized.

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PERSONNEL AND RESEARCH AREAS

ELECTRONICS RESEARCH CENTER

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PERSONNEL AND RESEARCH AREAS

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*Murray Wolinsky, Physics
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Hwa-Yueh Yang, EE

*Denotes persons who have contributed to JSEP projects, but who have not been paid out of JSEP funds (e.g., students on fellowships).

PERSONNEL AND RESEARCH AREAS

Advanced Degrees Awarded

Yoon-Hwa Choi, EE, M.S., May 1982, "Performance of Suboptimal Estimators or Weakly Nonlinear Estimation Problems."

Jae Young Hong, EE, Ph.D., August 1982, "Nonlinear System Transfer Functions with Applications to Nonlinear Electromagnetic Scatterers."

Taiho Koh, EE, M.S., August 1982, "Analysis of Nonsteady Signal in the Time-Frequency Plane."

Joe Mauger, EE, M.S., December 1982, "Raman Resonance Enhanced Third Harmonic Generation in CD_4."

Production Staff for This Report

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PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

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* R. L. Remke, R. M. Walser and R. W. Bene', "The Effect of Interfaces on Electronic Switching in VO_2 Thin Films," Thin Solid Films 97 129 (1982).

M. H. Kelley and M. Fink, "The Temperature Dependence of the Molecular Structure Parameters of SF_6," J. Chem. Phys. 77, pp. 1813-1817 (1982).

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* Y. Fukuoka and T. Itoh, "Analysis of Slow-Wave Phenomena in Coplanar Waveguide on a Semiconductor Substrate," Electronics Letters, vol. 18, no. 14, pp. 589-590 (July 8, 1982).

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* D. E. Grant and H. J. Kimble, "Optical Bistability for Two-Level Atoms in a Standing-Wave Cavity," Optics Letters 7 (1982).

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* T. Itoh, "Open Guiding Structures for Millimeter-Wave Integrated Circuits," Microwave Journal, vol. 25, no. 9, pp. 113-126 (September 1982).

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* J.-F. Miao and T. Itoh, "Hollow Image Guide and Overlayed Image Guide Complex," IEEE Trans. Microwave Theory and Techniques, vol. MTT-30, no. 11, pp. 1826-1831 (November 1982).

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* A. B. Buckman, "Mode Selection with a Three-Layer Dielectric Rib Waveguide," Journal of the Optical Society of America, vol. 73, no. 1, pp. 33-36 (January 1983).

* Y. Fukuoka and T. Itoh, "Slow-wave Propagation on MIS Periodic Coplanar Waveguide," Electronics Letters, vol. 19, no. 2, pp. 37-38 (January 20, 1983).

K. D. Stephan, N. Camilleri and T. Itoh, "A Quasi-Optical Polarization-Duplexed Balanced Mixer for Millimeter-wave Applications," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 2, pp. 164-170 (February 1983).

Y. C. Shih, T. Itoh and L. Q. Bui, "Computer-aided Design of Millimeter-Wave E-Plane Filters," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 2, pp. 135-142 (February 1983).

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* L. W. Frommhold, J. W. Keto and Michael H. Proffitt, "Diatom Polarizabilities from New Measurements of Collision-Induced Raman Spectra of the Noble Gases," J. Can. Phys., 59, in press.

* Yu-Jeng Chang and J. L. Erskine, "First Phase Nickel Silicide Formation and Interface Structure of Ni on Si(100)," J. Vac. Sci. Technol., in press.

* R. L. Strong, B. Firey, F. W. deWette and J. L. Erskine, J. Elect. Spect., in press.

* Y. Fukuoka, Y. C. Shih and T. Itoh, "Analysis of Slow-Wave Coplanar Waveguide for Monolithic Integrated Circuits," accepted for publication in IEEE Trans. Microwave Theory and Techniques, Vol. MTT-31.

* R. J. Mawhorter, M. Fink and B. T. Archer, "An Experimental Determination of the Vibrationally-Averaged, Temperature-Dependent Structure of CO_2," accepted in J. Chem. Phys.

* Chien-Yu Kuo and J. W. Keto, "Dissociative Recombination of Electrons in Electron Beam Excited Argon and High Densities, J. Chem. Physics, to be published February 1983.

Peter Pulay, R. Mawhorter, D. A. Kohl and M. Fink, "AB INITIO Hartree Iode Calculations of the Elastic Electron Scattering Cross Section of Sulphur Hexafluoride," submitted to J. Chem. Phys.

* R. J. Mawhorter, M. Fink, "The Vibrationally-Averaged Temperature Dependent Structure of Polyatomic Molecules II SO_2," submitted to J. Chem. Phys.

* T. D. Raymond, S. T. Walsh and J. W. Keto, "A Narrowband Dye Laser with a Large Scan Range," submitted to Applied Physics.

T. D. Raymond, N. Bowering, Chien-Yu Kuo, and J. W. Keto, "Two Photon Laser Spectroscopy of Xenon Collision Pairs," submitted to Phys. Rev.

* Yu-Jeng Chang and J. L. Erskine, "Diffusion Layer Microstructure of Ni on Si(100)," submitted to Phys. Rev. B.

D. A. Kohl, P. Pulay and M. Fink, "On the Calculations of Electron Scattering Cross Sections from Molecular Wavefunctions," submitted to Theo. Chem.

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* M. Bordelon, R. M. Walser, Y.-K. Jhee and M. F. Becker, "Effect of Pulse Repetition Frequency on The Evolution of Multipulse Laser Induced Damage of Crystalline Silicon," submitted to Applied Phys. Letts.

* Yu-Jeng Chang and J. L. Erskine, "Interface Structure of Reacted Ni Films on Si(100)," in preparation.

* M. Fink, H. J. Kimble, J. V. Hertel and G. Jamieson, "Alignment and Orientation of the Hyperfine Levels of a Laser Excited Na-Beam," in preparation.

* L. Lancaster, R. M. Walser and R. W. Bené, "Compound Formation in Annealed Sputter Deposited Thin Vanadium Films on Single Crystal Substrates," in preparation.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Technical Presentations

183rd National ACS Meeting
Las Vegas, Nevada
April 1, 1982

J. M. White, J. A. Schreifels, D. N. Belton, and B. -H. Chen, "Properties of Pt on Ti and Its Oxides."

B. E. Koel and J. M. White, "C(KVV) and O(KVV) Auger Lineshapes of Chemisorbed CO on Ni(100) Measured by XAES."

Colloquia
Indiana University
Bloomington, Indiana
April 2, 1982

M. Fink, "Electron Diffraction, A New Way to Study Force Fields."

Surface Chemistry Seminar
University of Texas
Austin, Texas
April 26, 1982

* R. M. Walser, "Picosecond Pulse Laser Damage of Crystalline Silicon."

*Funded entirely or in part by the Joint Services Electronics Program.

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DOE Workshop
BES Atomic Physics Program
Williamsburg, VA.
May 1982

J. W. Keto, "Kinetic Studies Following State Selective Laser Excitations."

1982 Offshore Technology Conference
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May 3-6, 1982

D. W. Choi, R. W. Miksad, E. J. Powers and F. J. Fischer, "Determination of Nonlinear Drift Force Quadratic Transfer Functions by Digital Cross-Bispectral Analysis."

IEEE International Conference on
Acoustics, Speech and Signal Processing
Paris, France
May 3-5, 1982

A. Mitchie and J. K. Aggarwal, "Detection of Edges Using Range Information."

W. N. Martin and J. K. Aggarwal, "Dynamic Scenes and Object Descriptions."

188th Annual Symposium of the
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Rome, Italy
May 10-12, 1982

* T. Itoh, "Open Guided Wave Structures for Millimeter-Wave Integrated Circuits."

IEEE
South Central Italy Section
May 13, 1982

T. Itoh, "Comparative Study of Millimeter-Wave Transmission Lines."

Electrical Engineering Seminar
University of Naples
May 14, 1982

T. Itoh, "Microwave Research at The University of Texas."

NATO Advanced Study Institute
on Image Sequence Processing
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Braunlage, West Germany
June 1982

J. K. Aggarwal, "Dynamic Scene Analysis."

J. K. Aggarwal, "Three-Dimensional Description of Objects."

J. K. Aggarwal, "3-D Motion Analysis."

Imperial College of Science and Technology
London, England
June 2, 1982

S. I. Marcus, "Lie Algebraic and Approximation Methods in Nonlinear Filtering."

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1982 IEEE MTT-S International Microwave Symposium
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Y. C. Shih, T. Itoh and L.Q. Bui, "Computer-Aided Design of Millimeter-Wave E-Plane Filters."

K. D. Stephan, N. Camilleri and T. Itoh, "Quasi-Optical Polarization-Duplexed Balanced Mixer."

AVS Symposium
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J. L. Erskine, "Recent Developments in Silicide Research."

Electronic Materials Conference
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*R. W. Bené, "Solid State Nucleation in Ti-Si Ultrathin Film Systems."

NATO Advanced Study Institute
on Image Sequence Processing
and Dynamic Scene Analysis
Braunlage, West Germany
July 1982

J. K. Aggarwal, "Dynamic Scene Analysis - A Panel Discussion."

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1st International Summer School on
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Calabria, Italy
July 1-7, 1982

* J. M. White, "Models for the Interaction of CO and H_2 on Transition Metal Surfaces."

Fritz-Haber-Institut der
Max-Planck-Gesellschaft
Berlin, West Germany
July 9, 1982

* J. M. White, "Coadsorption of CO and H_2 on Ni, Rh and Ru Single Crystal Surfaces."

Deutsche Forschung und
Versuchsanstalt fur
Luft-und Raumfahrt (DFLVR)
Munich, West Germany
July 9, 1982

J. K. Aggarwal, "Dynamic Scene Analysis."

Bundeskriminal Amt (BKA)
Wiesbaden, West Germany
July 16, 1982

J. K. Aggarwal, "Dynamic Scene Analysis."

NATO Adv. Study Inst.
on Cohesive Properties
of Semiconductors Under
Laser Irradiation
Cargese, Corsica
July 19-31, 1982

* R. M. Walser, "Picosecond Pulse Laser Damage of Crystalline Silicon."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Workshop on Multi-Resolution
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Leesburg, VA.
July 19-21, 1982

> L. Mahaffey, L. S. Davis and J. K. Aggarwal, "Region Correspondence in Multi-Resolution Images Taken from Dynamic Scenes."

Mexican Polytechnic Institute
Mexico City, Mexico
July 28, 1982

> * S. I. Marcus, "Nonlinear Filtering: Pathwise Solutions, Finite Dimensional Filters, and Approximations."

Argonne National Laboratory
Aug. 1982

> J. W. Keto, "Two-Photon Spectroscopy of Xenon."

Workshop on Computer Vision,
Representation and Control
Rindge, N.H.
August 1982

> J. A. Webb and J. K. Aggarwal, "Shape and Correspondence."

Department of Electrical Engineering
Texas A&M University
College Station, Texas
August 23, 1982

> J. K. Aggarwal, "Dynamic Scene Analysis."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Fourth American Physical Society
Topical Conference on High Temperature
Plasma Diagnostics
Boston, Massachusetts
August 25-27, 1982

S. J. Levinson, J. M. Beall, E. J. Powers, R. D. Bengtson and G. R. Joyce, "Estimating of $S(k,\omega)$ from Fixed Probe Pairs on the PRETEXT Tokamak."

12th European Microwave Conference
Helsinki, Finland
September 13-17, 1982

* J. -F. Miao and T. Itoh, "Hollow Image Guide for Millimeter-Wave Integrated Circuits."

* Y. C. Shih and T. Itoh, "Analysis of Printed Transmission Lines for Monolithic Integrated Circuits."

International Conference: Semiconductors in the
Vacuum UV, Applications of Synchrotron Radiation
Berlin, West Germany
September 13-15, 1982

J. L. Erskine, "Systematic Studies of Nickel Silicide Formation on Si(100) and Si(111) Surfaces," invited paper.

University of New Orleans
New Orleans, Louisiana
October 1, 1982

M. Fink,"Experimental Charge Densities of Small Molecules."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

McGill University
Department of Electrical Engineering
Montreal, Canada
October 4, 1982

J. K. Aggarwal, "Three-Dimensional Information from Image and Motion Analysis."

University of Texas
Austin, Texas
October 6, 1982

M. Fink, "Schopenhauer, Quantum Mechanics and Electron Diffraction."

RADAR '82 International Conference
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October 18-20, 1982

*J. Y. Hong and E. J. Powers, "Digital Signal Processing of Scattering Data from Nonlinear Targets."

1982 Annual Meeting of the
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October 18-20, 1982

* D. E. Grant, P. D. Drummond and H. J. Kimble, "Evolution of Hysteresis in Absorptive Bistability."

* H. J. Kimble and D. E. Grant, "Transient Response in Absorptive Optical Bistability."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Meeting of Southwest Division
of American Physical Society
Austin, Texas
November 1982

T. D. Raymond, N. Bowering, Chien-Yu Kuo and J. W. Keto, "Classical Phase Shift Analysis of Some Two Photon Absorption Profiles of Xenon."

24th Annual Meeting of the
Division of Plasma Physics
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I. INFORMATION ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE82-1 NONLINEAR DETECTION AND ESTIMATION

Principal Investigators: Professor S.I. Marcus (471-3265)
Professor J.L. Speyer (471-1356)

Graduate Students: Jessy Grizzle, Kie-Bum Eom, Taek Song, John White, and Yoon-Hwa Choi

A. OBJECTIVES AND PROGRESS: This research unit is concerned with several aspects of the statistical properties of nonlinear systems. Specifically, the design and analysis of optimal and suboptimal nonlinear estimators, the problem of detecting and identifying failure modes in fault tolerant systems, and the decentralized estimation and control of multiaccess broadcast networks have been investigated.

1. Nonlinear Estimation

The nonlinear estimation problem involves the estimation of a signal or state process $x=\{x_t\}$ which cannot be observed directly. Information concerning x is obtained from observations of a related process $y=\{y_t\}$ (the observation process). The objective is the computation, for each t, of least squares estimates of functions of the signal x_t given the observation history $\{y_s, 0\leq s\leq t\}$ -- i.e., the computation of conditional expectations of the form $E[\phi(x_t)|y_s, 0\leq s\leq t]$, or perhaps even the computation of the entire conditional distribution of x_t given the observation history. These state estimates are generated by passing the measurements through a nonlinear system. Optimal state estimators have been derived for very general classes of nonlinear systems, but these are in general infinite dimensional. That is, it is usually not possible to recursively generate the conditional mean of the system state given the past observations. The basic objective here is the design, analysis, and implementation of high-performance optimal and suboptimal estimators which operate recursively in real time. There are few known cases aside from the linear (Kalman) filtering problem in which the conditional mean (the minimum variance estimate) of the system state given the past observations can be computed recursively in real time with a filter of fixed finite dimension. However, in [1] we have proved that for certain classes of discrete-time and continuous-time systems, described either by a finite Volterra series or by certain types of state-affine realizations, the minimum variance estimator is recursive and of fixed finite dimension.

Beneš [2] has recently given an explicit solution for the conditional density for a class of nonlinear filtering problems with nonlinear state equations and linear observations. In [3] we have extended his results and our results of [1] in the following way. In [1] we found finite dimensional filters for the conditional moments for problems involving linear systems feeding forward into nonlinear systems; in [3], we have studied problems in which systems of Benes type feed forward into nonlinear systems of the type considered in [1]. We have derived recursive filtering equations for the conditional moments of the Benes' problem and used these to derive new finite dimensional optimal filters for the class of nonlinear systems described above.

By means of an algebraic approach to nonlinear estimation, we have in [4] shown that for some problems, including a linear system with cubic observations of the state plus white noise, no nontrivial statistics of the form $E[\phi(x_t)\ y_s, 0\leq s\leq t]$ can be computed exactly with recursive finite dimensional filters; this is the first such result in the literature. However, these results do not address the issue of non-exact but high-performance suboptimal filters; this issue is addressed in [5] and [6]. In these papers, we have considered linear estimation problems with small nonlinear perturbations. A typical such system is of the form

$$\begin{aligned} dx_t &= ax_t dt+dw_t, \\ dz_t^{\varepsilon} &= [x_t+\varepsilon h(x_t)]dt+dv_t, \end{aligned} \tag{1}$$

where h is a polynomial function. In general, such problems do not possess finite dimensional filters for the conditional statistics, and approximate filters are sought. The approach is to expand the unnormalized conditional density $\rho(t,x)$ in powers of ε

$$\rho^{\varepsilon}(t,x) = \rho_0(t,x) + \varepsilon\rho_1(t,x) + \varepsilon^2\rho_2(t,x) + \dots . \tag{2}$$

In order for this expansion to result in a useful suboptimal filter, we first showed that the error

$$\rho^{\varepsilon}(t,x) - \sum_{i=0}^{n} \varepsilon^i \rho_i(t,x)$$

is of the order of ε^{n+1} for ε small; i.e., (2) is a true asymptotic expansion. Then the same result was shown to be true for approximations of the normalized conditional density and conditional means.

Even if (2) is an asymptotic expansion, it is not of much use in nonlinear estimation unless each term in (2) can be computed with a finite dimensional recursive filter. It is in this phase of the investigation that Lie algebraic methods are useful, because they can provide guidance into the computation of such filters. In [5] and [6], it is shown that the individual terms in (2), and hence the conditional mean, can indeed be computed with finite dimensional filters. The mean-square errors of the resulting filters in the case of the zero-th and first order approximations were compared via Monte-Carlo simulation to the extended Kalman filter (EKF) and the Bobrovsky-Zakai lower bound [6],[10]. The behavior found in all the simulations was the following: the zero-th order filter performs worse than the EKF, but the first order filter performs better than the EKF (which is the most widely used suboptimal filter).

A different approach to nonlinear estimation problems has been pursued in [7]; the problems in this paper have the property that in spherical coordinates the measurements are linear and Gaussian but the state dynamics are nonlinear, whereas in rectangular coordinates the state dynamics are linear and the observations are nonlinear. In the noiseless case a nonlinear transformation produces in rectangular coordinates a pseudo-linear measurement consisting of a matrix function of the original measurements multiplying the state vector. In this case, a linear observer structure has been developed through the minimization of an integral quadratic form. The resulting observer, called the pseudo-measurement observer (PMO), is shown to have the property that the estimation errors converge to zero. The PMO performance has been compared to that of the EKF used as an observer. It is shown via simulation that the EKF performance degrades and even diverges with large initial state estimation error, whereas the PMO is guaranteed to be globally stable. In a noisy environment, the structures of the observers are retained, and the observers become filters. The resulting filters are the PMF and the usual EKF; in addition, a new filter, the modified gain extended Kalman filter (MGEKF) is formulated. A simulation study in the noisy environment shows the PMF is biased while the MGEKF shows excellent filtering performance under various conditions. The EKF still shows erratic behavior except for the case where initial errors are small. The bias of the PMF for the system with both process noise and measurement noise is analyzed and upper and lower bounds for the bias and actual covariance are obtained.

In related work, a survey of recent methods in nonlinear estimation was presented in [8]; emphasis was placed on the use of the unnormalized version of the conditional density.

The research in this area is continuing and has been complemented by Grant AFOSR-79-0025 from the Air Force Office of Scientific Research and Grant ECS-8022033 from the National Science Foundation.

2. Fault Detection and Identification

An essential aspect in the design of fault tolerant digital flight control systems is the design of failure detection and redundancy management systems. Design considerations are concerned with the trade-off between the cost of hardware redundancy and the complexity and robustness of the software for analytic redundancy. In analytic redundancy dissimilar instruments are combined through analytic relations to achieve redundancy. Since these relations contain system parameters, additional uncertainty may be introduced beyond that present in the sensors. The processing of the outputs of these relations to produce adequate fault detection and isolation performances may require complex decision and estimation software. A decision rule, the Shiryayev sequential probability ratio test (SPRT), is used in [9] to detect failures between similar instruments, as well as between dissimilar instruments through analytic redundancy. Unlike the Wald SPRT, which tests for the presence of failure or no failure in the entire data sequence, the Shiryayev SPRT detects the occurrence of a fault in the data sequence in minimum time if certain conditions are met. The performance of the Shiryayev SPRT in detecting a failure between two rate gyros as compared to standard fixed interval schemes is presented, as is the performance for a single accelerometer failure using translational kinematic equations to form a parity relation for analytic redundancy.

The research in this area is continuing and is complemented by a grant from General Dynamics, Fort Worth Division.

3. Decentralized Estimation and Control of Multiaccess Broadcast Networks

Our earlier methodology for decentralized stochastic control problems [11] is applied in [12] to multiaccess broadcast communication problems. The objective of multiaccess broadcast communication is the efficient sharing of a single communication medium among many users, while giving each access to the full bandwidth of the channel. In the so-called Aloha-type schemes, a terminal sends a new message immediately upon receipt; if two terminals send simultaneously, a "collision" occurs, and each terminal retransmits after a random delay. When terminals are able to gather some information about the state of the network, feedback control policies (centralized, decentralized, or adaptive) may be implemented to improve performance. A number of such control schemes have been proposed in the literature. On the other hand, this problem fits precisely into the decentralized control framework discussed in [11]. In [12] we have applied the optimal decentralized control policies derived in [11] to problems of this type. It is shown that the optimal policy is nonrandomized, stationary, and extreme. Optional policies can be calculated via the policy iteration algorithm, and the complexity of the algorithm is reduced by using equivalence relations on the state space. For many-user systems, the computations are infeasible, so a class of suboptimal policies (conjectured to be optimal) is proposed and shown to perform well. We compared the results with those of previously proposed algorithms. Tradeoffs between the information available to each terminal and the value of the performance index were examined in detail.

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THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE82-2 ELECTRONIC MULTI-DIMENSIONAL SIGNAL PROCESSING

Principal Investigator: Professor J. K. Aggarwal (471-1369)

Graduate Students: S. Park and T. Leou

A. PROGRESS: The broad objective of the research unit is to develop new and efficient techniques for the processing of multi-dimensional signals. The current research focuses on the analysis, synthesis and implementation of linear time-variant (LTV) digital filters in both time and frequency domains. Significant progress has been achieved in the analysis, synthesis and implementation of LTV digital filters, as described in the following.

As reported earlier in [1], we have developed a framework for the analysis and synthesis of time-variant one-dimensional digital filters, and investigated the interrelationships among the three characterizations of linear time-variant digital filters; namely the impulse response, the generalized transfer function and the time-variant difference equation. Also as documented in [2], we have proposed an efficient technique to determine the generalized frequency characteristics of LTV digital filters from the short-time Fourier transform properties. The developed technique allows spectral modification properties of the filter to vary with the changing frequency content of the desired sequence. The overall advantage is that the resultant bandwidth of the LTV digital filter is much narrower than that of a linear time-invariant digital filter.

Complementing the above results, we have recently published the paper [3] where problems associated with the synthesis and implementation of recursive time-variant filters are investigated. In this work, we describe two techniques to approximate a given impulse response as a degenerate sequence that is realizable as a recursive difference equation. Both techniques use a least-squares error criterion to minimize the difference between the given and the approximated impulse responses. Numerical examples illustrating and comparing results of these techniques are also included in [3]. In addition we present several recursive structures for the implementation of both causal and non-causal degenerate impulse responses.

The above publications [1,2,3] present a comprehensive set of results for time-variant digital filters. In particular, they present fundamental results on the nature of time-variant digital filters; they discuss the properties of the responses in terms of short-time Fourier transform; and they document implementation procedures and structures for the filters.

In addition, we have investigated the implementation of one-dimensional (1D) linear time-variant digital filter as two-dimensional (2D) linear time-invariant (LTI) digital filter. These results have been accepted for publication in Circuits and Systems [4]. We have shown in this paper that by mapping 1D input/output sequences into 2D sequences, we may approximately implement the 1D LTV filter as 2D LTI filter. The advantages and disadvantages of this implementation technique are also discussed.

Continuing our work on the frequency domain, the filter performance and computation requirements of the technique are compared with those of conventional time domain criterion. Our result demonstrates that the frequency domain technique is efficient in computation time but yields suboptimal filter, as presented in [5].

The above work is being continued. In particular, we are investigating the recursive realization of rational generalized transfer function as linear time-variant difference equation. The purpose is to derive a system of overdetermined set of linear equations relating coefficients of the transfer function and the difference equation. Hopefuly, the minimax solution of the overdetermined system by numerical method will yield a solution to provide an approximate realization. Several other interesting avenues of research are being pursued as outlined in the renewal proposal for period April 1, 1983-March 31, 1986. In the past year, the following presentations were made [5,6,7,8].

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II. SOLID STATE ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE82-1 INTERFACE REACTIONS, INSTABILITIES AND TRANSPORT

Principal Investigators: Professor M.F. Becker (471-3628)
Professor R.W. Bene' (471-1225)
Professor A.B. Buckman (471-4893)
Professor R.M. Walser (471-5733)

Graduate Students: Mark Bordelon, E. Ehsani, Y.K. Jhee, Y.H. Ku, Segeun Park, J. Wiedner and H.Y. Yang

A. SCIENTIFIC OBJECTIVES: One principal objective of this research unit is to understand and model the instabilities and interactions which develop at interfaces. In the long range we wish to do this at microscopic level and with the generality necessary to allow us to design interface systems with specific structures and electronic properties useful in advanced microelectronics and other emerging technologies. We have made significant progress in the last few years in our limited objective of understanding the nucleation of structures in binary thin film systems and one of our specific objectives in the next proposal period is to extend these results to ternary systems. The basic increase in complexity in these systems is that of the generalization of the supply of the elements in the reaction process. We plan to achieve this objective using two types of systems; 1) Si substrate with controlled series/parallel deposition of 2 different transition metals and 2) single metal deposition upon compound semiconductor substrates. Another objective is to increase our understanding of the binary systems to a greater level. Generally this will involve a more microscopic understanding as well as the fit of individual systems into the overall scheme.

Another objective of this unit is to increase our microscopic understanding of ordering processes at phase transitions in solids beyond that provided by strictly thermodynamic perspectives. The long range goal of these studies would, for example, suggest how radiation and particle beams can be intelligently used to beneficially modify electronic material properties or to synthesize desirable metastable phases. Most of the JSEP sponsored research to date has been to develop and apply picosecond laser reaction kinetic techniques for inducing and monitoring non-equilibrium structural transformations in solids. We initially applied these techniques to the study of martensitic shear transformations and successfully demonstrated the ability to induce and monitor nonequilibrium phases in vanadium dioxide [1].

The current thrust of this research is to study the mechanism of laser induced damage in solids. Emphasis will be on semiconductors (mainly silicon) and metal surfaces. Our viewpoint is that laser damage is a first order phase transition; and when it is induced by picosecond laser pulses, it is non-equilibrium in nature. Experimental techniques which probe the state of the target materials just below the picosecond laser pulse damage threshold will be used to determine the characteristics of the precursors to the phase transition. Study of exoemitted charges in addition to conventional morphology and statistical studies will be employed to determine the nature of the first detectible phase after damage is nucleated.

B. PROGRESS: Over the past year we have continued our study of the systematics of first nucleation in binary systems. In particular we have studied the Ti-Si system in detail; partly because this is one of the end phases in our recently begun investigations into the systematics of ternary phase formation.

In particular, it is part of the study of Ti-Co-Si and Ti-Ni-Si systems. The Ti-Si system is interesting in its own right technologically, because it is a possible metallization for new gates and interconnects and scientifically because it has been recently reported that the TiSi phase is nucleated prior to the predicted $TiSi_2$ phase. We have studied this system using transmission election diffraction (TED) as well as bright field TEM X-ray diffraction, resistivity and Auger spectroscopy and find that the phase found prior to the equilibrium $TiSi_2$ phase is a nonequilibrium phase founded by ordering of the interstitial diffusion of Ti into the Si substrate. This work has been reported at the Electronic Materials Conference in Ft. Collins (1982) and published in the Journal of Electronic Materials [2].

Some initial TED results on the Ti-Co-Si system indicates that for certain preparation conditions this nonequilibrium superstructure phase may be suppressed and that $CoTi_2$ may precede either Co_2Si or $TiSi_2$ formation. More measurements are needed to map out the nucleation path with changes in sample preparation conditions including supply of the transition metals.

In related work, we have extended our modeling considerations to metal-metal thin film systems. We have found that the overwhelming majority of binary systems satisfy a metal-metal rule (Rule MM) which states that first nucleation in metal-metal thin film reactions is the phase immediately adjacent to the low temperature eutectic in the binary phase diagram. This rule, in conjunction with our previous rule for metal-covalent semiconductor systems (Rule MC), indicates quite clearly the barrier to nucleation encountered in metallic glass forming regions near deep eutectics of metal-covalent semiconductor systems. This leads to "phase skipping" in these systems. This work has been recently published in Applied Physics Letters [3].

We have begun studying the ternary systematics of metals deposited on compound semiconductors with a review of work on metals deposited on GaAs. Generally this work can be characterized as inconclusive or ambiguous as far as first phase identification for first phase nucleation is concerned [4,5,6,7]. The reason is probably because relatively thick films were studied using techniques which are not particularly sensitive for phase identification in the ultrathin film regime. We have thus began a TED study of thin films of metals deposited on GaAs substrates. Our work to date has concentrated on determining the best etchants to use in the prethinning and jet thinning techniques and a determination of the best system (metal) to begin the study. At present the etchants have been determined by trial and error and we have started measurements on the Pd:GaAs system. We are not ready to report the results yet, however.

Finally, we have begun making measurements of stress of ultrathin films of metals deposited on Si substrates. These measurements are just beginning, but using the laser technique we have initially seen that very thin Co films on Si are highly compressive prior to nucleation of Co_2Si. Thicker films of Co_2Si and other silicides are known to be tensile on Si substrates. At least one of the newer theories [8] on glass or noncrystalline alloy formation relies critically on stress build up due to topological constraints and it would be very useful to see if we can observe any systematics of stress build up in the prenucleation regime.

This information, in conjunction with the noise fluctuation work being pursued with NSF support, could be very useful in determining the microscopic structural changes along the reaction path.

During the past year we have also conducted detailed experimental studies of picosecond laser induced damage as a non-equilibrium phase transition and proposed a new damage mechanism. This model, which includes energy transfer by resonant surface plasmons on small charge density droplets, is corroborated by our existing experimental data. Experimental data has been taken which demonstrates the nucleation and growth aspects of the laser damage process [10,11].

The motivation for this work has its origin in several facts. First, the picosecond time domain results in several simplifications due to the elimination of transport during the pulse duration. Near band-gap excitation of 1.06μm limits the heating of the sample by fast phonon decay of hot electrons. Silicon, a covalent material, was chosen for the absence of polar optical coupling mechanisms and the absence of an electron collision time sufficiently short to allow avalanche ionization. Finally, experience gained in the excitation of VO_2 through a non-equilibrium, semiconducting-metallic phase transition in the first such study [1] led to a conceptual framework for these types of experiments.

We have performed an experimental demonstration of the heterogeneous nature of the nucleation and growth of laser damage in crystalline silicon. The samples of single crystal silicon were prepared from low resistivity <100> and <111> wafers with high resistivity 1.5 or 2.5μm epitaxial layers. To obtain the very thin samples used in some experiments, the wafers were masked and electrochemically etched, exposing about 0.5cm^2 of epitaxial membrane [9,10].

The damage nucleation and growth was studied by monitoring the transmission of the irradiated region at 633nm while multiple pulse damage was initiated at a prf of 5Hz. The laser pulses were supplied by a passively mode-locked 1.06μm Nd:YAG laser. Single pulses were selected with an average FWHM duration of 38psec.

The sample transmission could then be related to a percent of the spot area transformed to the final state of damage. The results of this measurement showed an incubation period, a sigmoidal shape, and have been fit to the Avrami equation for the behavior of nucleation and growth. These results strongly suggested that this damage process is a (micro) heterogeneously nucleated first order phase transformation process. This in turn suggested that a morphological study of the nucleation process would be beneficial.

A systematic study of the morphology of laser damage of silicon has been conducted. The multiple pulse damage threshold represents the point of closest approach to the phase transition where the morphology of nucleation may be studied. This method avoids the catastropic damage characteristics of single pulse damage which tends to destroy evidence of its early formation stages.

An automatic translation stage was constructed for the sample which would count laser pulses and give a sequence of irradiations at increasing powers of 2 or single pulses. A high resolution SEM study showed the development of the coherent damage morphology with increasing numbers of pulses. The nucleation of the damage appears first as oval pits with their long axis orthogonal to the optical electric field. Subsequently and simultaneously formed pits are regularly spaced along single rows. Parallel rows of pits finally form into grating structure. Clearly the first phase of the damage process self-consistently selects pit formation at a specified distance from another pit, orthogonal to the optical field. The second phase of damage is the formation of regular spaced rows of pits (grooves). The grooves are spaced by the free space wavelength, suggesting that they are formed by the constructive interference of a scattered surface wave. This second process is consistent with the damage observed to propagate from pre-existing linear structures such as scratches oriented normal to the optical field.

All of the damage we observed in these experiments was at the front surface. Even the optically thin 1.5μm thick films damaged first at the front surface. Near threshold, only front surface damage was observed. Since our silicon samples were extremely thin compared to the absorption length, this observation indicates that the damage could not have been initiated by the optical electric field, which by simple Fresnel arguments, is a maximum on the exit surface.

Silicon, with a band gap of 1.11ev at 300K, has a linear absorption constant of only $10cm^{-1}$ for 1.06μm (1.17ev) laser pulses. At intensities approaching the multi-pulse damage threshold, our experimentally measured transmission data indicates the presence of an additional two photon absorption. Assuming that an indirect two photon process dominates, we obtained a two photon absorption constant β=52cm/GW by fitting the data.

Using this absorption process for 38 psec 1.06μm pulses at an intensity of $1GW/cm^2$ only 10^{18} to 10^{19} charge pairs are produced per cm^3. In addition, the computed temperature rise during the pulse is less than one degree K. Although free carrier absorption was omitted from these calculations, it is not expected to increase the refractive index or temperature jump significantly.

These extrapolated values of ΔT and Δn are much too small to initiate catastrophic damage which is, of course, the basic scientific enigma found in nearly all studies of laser damage in nearly-transparent media. Note that electronic avalanche ionization is not a highly probable process at the high excitation frequency of the Nd:YAG laser and, is ruled out by our observation of entrance face damage in thin samples.

To circumvent these difficulties we have proposed a new laser damage mechanism suggested by the morphological studies of the early damage nucleation regime [12,13]. This work suggests that, despite the apparent absence of avalanching, locally high absorption in some highly excited, small, charge density "embryos" is the precursor to damage. Furthermore, the consistent observation of coherently interfering "embryos" indicates that these are of intrinsic or homogeneous origin and not due to the presence of highly absorbing extrinsic heterogeneities.

We are led to suggest that an electronic spinodal separation occurs near the damage threshold when the average excited charge density approaches $\sim 10^{19}/cm^3$. Inside the spinodal the electron and hole excitations are subject to spontaneous clustering under the influence of some unknown driving force.

The proposed damage mechanism involves the resonant absorption of incident photons by the collective electronic oscillations (surface plasmons) of embryo regions having near-critical radii and excited charge density approaching that of the liquid. This model is consistent with the evidence of cooperative interaction between damage sites. The direction and separation of the sites are those expected of a coherent, dipolar radiative interaction between resonant surface plasmons on adjacent sites just prior to liquid phase nucleation. Subsequent resonant absorption, in the presence of Auger or other fast decay processes, will rapidly heat the site to a liquid vapor instability and cause pit formation.

While normally incident light will not couple to the planar surface plasmons of a solid, it will couple efficiently to any charge density droplets that form. The coupling will be resonant for a droplet size and charge density such that $\omega_{sp}=\omega_0$. Damage will nucleate at the lowest intensity for which coherent radiative coupling occurs between the resonant surface plasmons of two or more droplets.

A small, compared to lambda, spherical charge droplet will support a number of surface plasmon modes. Our calculations show that the lowest mode will be resonant in energy with the laser photons as a density of $n=2x10^{22}$ cm^{-3}. From the classical theory of radiating dipoles, we have computed the in phase and quadrature components of the radiated field in a direction orthogonal to the optical field. The minimum spacing for which the radiative fields will constructively interfere is at a separation of $1.2\lambda_{Si}$ or about 375nm. This interaction distance compares favorably with the 350-380nm values obtained from our SEM experiments.

The proposed mechanism should result in a large increase in the laser energy deposited micro-heterogeneously at the surface near the damage threshold. It is not clear, however, how the material will relax such an intense, fast, local electronic excitation.

In summary our studies of the isointensity laser damage kinetics of crystalline silicon, while still continuing, have led to the following conclusions:

(1) Multiple picosecond pulse laser damage of silicon is a first order phase transformation which may be accessed by laser induced charge density jumps at intensities near to those required for homogeneous melting.

(2) Multiple pulse damage transformation kinetics indicate that large area damage is a micro-heterogeneously nucleated process. This data suggests that a relevant phase diagram for silicon contains a metastable region in which charge density clusters can be elevated to or beyond the liquid phase.

(3) The identification of a new, and possible widespread, laser damage mechanism, in which energy transfer is by resonant surface plasmons on small charge density clusters.

C. FOLLOW-UP STATEMENT: All of the work involving the study of reaction paths at metal-semiconductor interfaces described in the preceding section is continuing under the new 3 year JSEP contract.

The research involving the use of picosecond laser techniques to both excite and study non-equilibrium phase transitions in solids will, however, be split between Research Units SSE83-1 and QE83-1 in the next 3 year program. SSE83-1 is the continuation of the present unit and the laser kinetic research in this unit will be focused on (1) exploring the use of laser kinetic techniques to probe the non-equilibrium phase diagram of semiconductors and (2) monitoring the recrystallization reaction kinetics of glassy and amorphous semiconductors.

Since the experimental techniques developed in the past 3 years appear to be especially productive in shedding new light on the difficult problem of understanding laser-induced damage in solids we will, in Research Unit QE83-1, expand these techniques and apply them to the study of laser-induced damage in a wider variety of materials to include metals and insulators.

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THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE82-2 SPECTROSCOPIC STUDIES OF METAL/SEMICONDUCTOR AND METAL/METAL OXIDE INTERFACES

Principal Investigators: Professor J.L. Erskine (471-1464)
Professor J.M. White (471-3949)

Graduate Students: Y. Chang, S. Shi, H. Peebles, P. Blass and K. Thrush

A. OBJECTIVES: The scientific objective of this research unit is to investigate atomic and molecular level properties associated with selected solid surfaces and solid state interfaces. The work is divided into three related subareas: 1) metal/semiconductor interfaces, 2) metal and semiconductor surface/adsorbate systems, 3) metal/metal and metal/metal oxide systems.

Research on metal/semiconductor interfaces is focused on understanding the electronic structure and composition of silicide structures which form when metal atoms deposited on a semiconductor surface react to form an interface. Particular emphasis is being directed towards understanding structural, metallurgical and electronic properties of the silicide interfaces which affect selective growth processes and electrical characteristics, namely the Schottky barrier height. This work utilizes Auger electron spectroscopy (AES), to characterize near surface composition, low energy electron diffraction (LEED) to determine geometrical structure, angle resolved photoelectron emission spectroscopy (ARPS) to study electronic properties of the constituent atoms, x-ray photoelectron spectroscopy (XPS) to study the chemical state of silicon and the deposited metal, and transmission electron diffraction (TED) to study interface crystal structure and composition.

Research on surface/adsorbate systems is primarily oriented towards supporting our work on metal/semiconductor interfaces and on metal/metal oxide interfaces. In preparing any solid state interface, impurity atoms and molecules are incorporated from the background of atomic and molecular species in the vacuum chamber. These impurities can chemisorb at surfaces where interfaces are being formed and can influence the growth kinetics, electronic properties, and crystal structure of the interface. Our research includes investigations of the structure and composition of selected adsorbates on semiconductor, metal and metal oxide surfaces with emphasis on materials used in interface systems being investigated under metal/semiconductor and metal/metal oxide headings. Several state-of-the-art experimental techniques are available to accomplish this work. These include the capability to obtain the vibrational spectra of atoms and molecules at surfaces using high resolution electron energy loss spectroscopy (EELS). These capabilities provide an opportunity to obtain detailed structural information related to species adsorbed at solid surfaces.

Research on metal/metal oxide interfaces is focused on the development of depth profiling and analysis methods of studying the top most atomic layers that form when a clean metal is exposed to oxygen. This work utilizes electron spectroscopy, particularly XPS, to obtain substrate core level intensities. Of great interest are satellite intensities of core levels which reflect changes in the metal/metal oxide interactions.

B. PROGRESS: We have made significant progress in several subareas indicated in Section A which summarizes our objectives. This section outlines scientific progress in these subareas and describes current efforts to improve the instrumentation required for our research.

1. Metal Semiconductor Interface

Our last progress summary reported that we had successfully produced high quality epitaxial films of NiSi on Si(111) and Si(100) substrates and had obtained the first detailed description of the electronic structure using angle resolved photoemission [1]. Our results were useful in checking several recent calculations [1-3].

We have recently studied the low coverage interaction of Ni atoms with Si(100) surfaces and have discovered that it is possible to form a diffusion layer of Ni atoms in the Si lattice with novel properties [4]. We believe that the diffusion layer is characterized by Ni atoms in interstitial voids of the Si lattice, and that these Ni interstitial defects can account for selective growth processes based on a model proposed by Tu [5]. The diffusion layer is not depleated by prolonged annealing, and the stoichiometry of the layer is $NiSi_2$.

Our work on the diffusion layer and bulk electronic properties has provided the basis for careful studies of interface formation and growth. We have obtained a detailed picture of the room temperature growth of silicide-Ni contacts at Si surfaces using Auger and photoemission spectroscopy, and by measuring work function changes [6].

Interface formation studies were extended to higher temperatures and these experiments have yielded what appears to be an important discovery. All interfaces we have studied to date show evidence of having an ordered Si-rich stoichiometric phase at the interface. We believe that this ordered phase is the diffusion layer phase which we discussed previously [4]. Our UPS studies have established that a Si rich silicide is always present during the initial phase of interface formation. This phase can be identified along with the stoichiometric phases which nucleate and grow by selective growth at various temperatures (Ni_2Si at 200 C and NiSi at 430 C). Transmission electron diffraction (TED) shows that the silicon rich phase is ordered and corresponds to an fcc superlattice of Ni atoms. This result has important implications [7]. First, it provides a basis for accounting for the constant Schottky barrier height in Ni silicide interfaces independent of the silicide phase which forms the "metal" contact. Second, it suggests that either the interface phase can bypass selective growth to form $NiSi_2$ or that the diffusion layer (which has the same stoichiometry but different crystal structure) forms. If the actual structure is the diffusion layer structure as we have suggested, then this result can account for selective growth.

2. Metal/Metal Reactions

The addition of small (submonolayer) amounts of potassium (K) on metal substrates has generally been characterized with a decrease in binding energies of core and valence electrons of the substrate and an increase in such energies for K due to electron donation by the alkali to the conductor. We have completed preliminary studies on the effect of variable amounts of K dosed onto the surface of single crystal Si using AES and XPS. XPS results indicate no shift in the core electron levels of K and Si as a function of K doseage, but AES shows an increase in the binding energy (or decrease in relaxation) for the Si valence orbitals. At greater K coverages, probably corresponding to multilayer formation, Si energies cease to change while K evinces an increase in valence binding energies. This, with the unexpected ability of Si to support multilayers of K, suggest future spectroscopic work to probe further the physical properties of this system as well as to explore changes in Si surface chemistry with K adaptions.

We have also continued work involving Ag deposition on Rh(100) with particular emphasis on the growth of epitaxial layers and the coadsorption of CO and H_2 on this system. Parts of this work are being published in a feature article in the Journal of Physical Chemistry [10].

3. New Instrumentation

We have received information from the National Science Foundation (Division of Materials Research) that our synchrotron radiation beam line will be funded. This project will provide support to establish two beam lines at the Aladdin storage ring facility in Stoughton, Wisconsin. The beam lines will consist of a 6-meter torroidial grating monochromator (photon energy 10-200 eV) and an extended range grasshopper monochromator (photon range 20 eV - 1500 eV). This instrumentation will increase tremendously the range of material science research we are able to conduct through our JSEP center.

Local high resolution x-ray photoelectron spectroscopy facilities are needed to conduct some of our planned experiments. We have recently had visitors from Leybold-Heraeus (Dr. Martin Wilmers) who came to Austin to discuss application of the capabilities we have developed in electron optics to help design a high resolution multichannel detection x-ray photoelectron spectrometer. DoD instrument program funding would make it possible to pursue this state-of-the-art instrument.

C. CURRENT RESEARCH: The overall scientific objective of our current and planned research program remains unchanged. We are working toward establishing accurate interface models for selected metal silicon interfaces. In addition, our work is aimed at understanding nucleation and growth mechanisms, transport phenomena and reaction kinetics which lead to interface structures and which also have bearing on the stability and electrical characteristics of the interfaces.

Based on our recent results on nickel silicide-silicon interfaces we plan to pursue several new directions. One of our first priorities is to investigate the evolution of the Ni silicide interface using high resolution valence band XPS. The reaction layer which is formed when Ni interacts with Si to form a silicide is approximately equal to the escape depth of electrons (about 12 Å) for photon energies we have available in our lab (resonance lamp sources 16-48 eV). The escape depth for electrons at 1400 eV is considerably larger, and will permit the actual interface to be probed. Valence band XPS results when compared with corresponding UPS studies will yield important information related to the interface composition and electronic properties which is not available by other techniques.

We are also planning to correlate Schottky barrier heights measured on our own samples with the structural, compositional and electronic properties we are obtaining for these interfaces. The barrier height may be deduced from core level photoemission data, and may also be measured directly from threshold photoconductivity measurements. Our recent work indicates that the barrier height in Ni silicides is closely related to the interface structure and stoichiometry. If we can obtain relationships between the structural and compositional properties of the interfaces and the barrier height, it may be possible to make progress towards a general description of barrier heights in reactive metal contacts.

We have not succeeded in forming truly thin epitaxial silicide layers, however there is now some evidence that this is possible [8]. We are continuing our efforts to produce interfaces having an ordered silicide overlayer thin enough (10 Å) to permit study of the electronic structure of the interface by UPS. We would like to search for interface electronic states, and also use UPS and XPS to investigate impurity migration and interface stability under annealing and other perturbations.

Future plans include work of a similar nature on other silicide systems. we are currently examining the prospects of studying Co and W silicides and are looking at some of the silicides which have already been studied fairly thoroughly such as Pt and Pd. Some ordered phases of these silicides have been reported to occur by selective growth [9] and there is a possibility that ordered structures exist at the interface as we have shown in the case of Ni on Si(100).

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III. QUANTUM ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE82-1 NONLINEAR WAVE PHENOMENA

Principal Investigators: Professor M.F. Becker (471-3628)
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A. PROGRESS: This research unit is concerned with analytical and experimental studies of nonlinear wave interactions in physical systems. The work may be subdivided into two areas: (1) the development of digital time series analysis techniques useful in analyzing and interpreting fluctuation data generated by nonlinear interactions in various media, and (2) nonlinear optics in the infrared spectral region in molecular gases.

1. Nonlinear Wave Interactions: The objective of this work is to develop digital time series analysis techniques that enable one to properly analyze and accurately interpret experimental fluctuation data associated with nonlinear and/or nonstationary wave phenomena in a variety of media. One of the principal characteristics of any nonlinear system is the introduction of new frequency components, e.g., harmonics and intermodulation products. The "efficiency" with which these new spectral components are generated is given by an interaction or coupling coefficient. In the case of nonlinear systems where one can define an "input" and "output", the "efficiency" with which the new spectral components are generated is described by nonlinear transfer functions. For quadratically nonlinear interactions, the coupling coefficients or transfer functions are two-dimensional functions of frequency. For cubic interactions, the corresponding coupling coefficients or transfer functions are three dimensional functions of frequency. This clearly suggests that higher-order (i.e., multi-dimensional functions of frequency) spectral densities must be utilized to appropriately analyze and interpret fluctuation data associated with nonlinear physical systems. For quadratically and cubically nonlinear systems, the bispectrum $B(\omega_1, \omega_2)$ and the trispectrum $T(\omega_1,\omega_2,\omega_3)$ are the appropriate spectral densities, respectively. During the past year our research efforts have focused on the following topics summarized in subsequent paragraphs.

a. Nonlinear System Modelling in the Frequency Domain. Following the successful development of modelling a nonlinear system in terms of a hierarchy of continuous orthogonalized Volterra-like transfer functions [1,2] we have focused on the following topics. First, a discrete version of the orthogonalized Volterra series model has been developed since the continuous model provides a conceptual framework but the actual computation of such transfer functions will be carried out on a digital computer. Second, the sensitivity of the digital approach to both weak and strong external noise has been investigated in a preliminary fashion.

As discussed in our previous work [1], our modelling has been based on the "black box" approach where the nonlinear system is modelled in terms of a parallel combination of such black boxes, with each box being characterized by an appropriate linear or nonlinear transfer function. This approach is particularly appropriate when one has only the input and output time series data to work with, but no, or very incomplete, knowledge of the nonlinear system equations. Of particular importance is the fact that the nonlinear transfer functions may be determined directly from the input-output data by computing the higher-order cross spectra, (e.g., cross bispectrum, cross trispectrum, etc.) [1].

To apply these concepts to digitized input-output data we developed a discrete orthogonalized Volterra series model which incorporates new definitions of the relevant higher-order spectra and which takes into account the effects of finite record length. Based on this discrete model we have implemented a computer algorithm to estimate the nonlinear transfer functions directly from the raw digitized input output data [2,3]. This algorithm has been applied in studies of the nonlinear response of moored vessels to random ocean waves [4,5] and electromagnetic wave scattering from nonlinear metallic targets [6]. This latter work is JSEP supported and will be described further in subsequent paragraphs.

It is well known that nonlinear electrical phenomena are associated with metallic joints in man-made objects. Experimentally it is observed that the I-V characteristics of such metal junctions exhibit an asymmetrical nonlinearity with third order predominating. This property is utilized by harmonic radar to achieve selective detection of metal targets, especially when concealed by natural clutter. Specifically harmonic radar detects metal targets by sensing only the third harmonic frequency component in the backscattered field. If this signal component is contaminated due to natural, intentional or inadvertent interference, the performance of this type of radar may be severely degraded.

Recently, we proposed a conceptual model which enables one to systematically characterize a nonlinear target in terms of a hierarchy of linear, quadratic, cubic, etc. radar cross sections [7]. The harmonic radar turns out to be a special case of this model. With the aid of high-order spectral density functions, these nonlinear cross sections can be digitally computed from the transmitted and scattered signals [6].

Our most recent work has been concerned with investigating how one can detect the third-order characteristics of a metallic target, when the strength of the third harmonic frequency component is far below that of the external noise or intentional jamming signal. The key idea of our approach lies in the fact that the digital third-order cross trispectrum used to detect the third harmonic is primarily sensitive to the phase coherence between the transmitted fundamental and relatively weak backscattered third harmonic, rather than on the amplitude of the third harmonic. On the basis of a computer simulation we have demonstrated the feasibility of using digital cross trispectrum analysis to detect weak (S/N ratio$\approx$-20db) third harmonic signals. These initial results will be described in a forthcoming conference paper [8].

b. Applications of the Local Wavenumber Spectrum in the Study of Turbulence. Many theories modelling turbulent fields in solids, liquids, gases, and plasmas, model the turbulent field $\phi(x,t)$ as a superposition of approximately linear modes. Due to nonlinear interactions between the modes, energy is redistributed in wavenumber and frequency space. In the steady state, the fluctuations arrive at a characteristic spectral density $S(k,\omega)$. Recently we developed a method for estimating $S(k,\omega)$ (formerly denoted by $P(k,\omega)$) of a turbulent fluctuation using fixed pairs of probes. The quantity we actually estimate, called the local wavenumber spectrum $S(K,\omega)$, is a good estimate of the conventional spectrum if the fluctuation is a superposition of oscillatory plane waves with slowly varying amplitudes and wavenumbers:

$$\phi(x,t) = \int d\omega\, a(\omega)\, e^{i(k(\omega)x-\omega t)} \tag{1}$$

with

$$\left| \frac{1}{a(\omega)} \frac{d^n a(\omega)}{dx^n} \right| = (\ell_a^{(n)}(\omega))^{-1} << k^n(\omega) \tag{2}$$

$$\left| \frac{1}{k(\omega)} \frac{d^n k(\omega)}{dx^n} \right| = (\ell_k^{(n)}(\omega))^{-1} << k^n(\omega) \tag{3}$$

For $n=1$, the last two conditions simply mean that the length scales $\ell_a^{(1)}(\omega)$ and $\ell_k^{(1)}(\omega)$ of wave amplitude and wavenumber variation are much longer than the wavelength $\lambda=2\pi/k$. The idea that the wave amplitudes $a(\omega)$ and the wavenumbers $k(\omega)$ may be slowly varying functions of space is in the same spirit as the WKB approximation method used in the solution of differential equations with slowly varying coefficients; henceforth, we refer to Eqs. (2) and (3) as the WKB assumptions.

An important question in the study of turbulence is whether or not expansions of the form of Eq. (1) are in fact valid. Estimates of the spectral density $S(k,\omega)$ in plasmas using laser or microwave scattering techniques have revealed that fluctuations with a given wavenumber k are broadly distributed in frequency space; in fact, the width $\sigma_\omega(k)$ of the distribution is of the same order as the mean frequency $\bar{\omega}(k)$. Intuitively, this would seem to indicate that the plane wave expansion of the form of Eq. (1), involving modes which at any given time and place have a well defined dispersion relation $k(\omega)$, no longer makes sense. The coherence time $\tau_c = \sigma_\omega^{-1}(k)$ is on the same order as the mean period of oscillation $\bar{T}=2\pi/\bar{\omega}(k)$, which would seem to imply a violation of the WKB assumptions. We have found, on the other hand, that short correlation times (or in the spatial dimension, coherence lengths ℓ_c short compared to a wavelength) do not necessarily imply a violation of the WKB assumptions. The spectral broadening and concommittant reduction in coherence times or lengths can be a result of slow, random variations in the dispersion characteristics of the turbulent medium which are still consistent with the WKB assumptions.

One way of testing the WKB assumptions is to compare the local and conventional wavenumber and frequency spectra. If the length scales $\ell_k^{(n)}(\omega)$ and $\ell_a^{(n)}(\omega)$ are short compared to a wavelength, $S(k,\omega)$ will tend to have a larger spectral width $\sigma_k(\omega)$ than $S_\ell(K,\omega)$. In [9], we demonstrate using two probe data, that it is possible to estimate the spectral widths $\sigma_k(\omega)$ and $\sigma_K(\omega)$ of both conventional and local wavenumber spectra. The two estimates agree quite well for turbulence observed in an RF-discharge [9] and in the edge turbulence in the pre-text tokamak [10]. The difference in the spectral widths $\sigma_k(\omega)$ and $\sigma_K(\omega)$ is sensitive to the 1st order derivative in Eq. (2); if $\ell_a^{(1)}(\omega)$ is small compared to a wavelength, $\sigma_k(\omega)$ will be large compared to $\sigma_K(\omega)$. In ref. [11] the comparison of higher order moments, in order to test Eqs. (2) and (3) to higher order, is discussed. More recently, using a four probe arrangement, we have tested Eq. (2) to 4th order and Eq. (3) to 2nd order by making direct estimates of the length scales $\ell_a^{(n)}(\omega)$ and $\ell_k^{(n)}(\omega)$. The WKB assumptions appear to be well satisfied, despite the fact that the large spectral widths we observe might suggest otherwise. These results and the significance of the WKB approximation in turbulence will be discussed in a forthcoming publication.

2. Nonlinear Optics: The objective of the research program in nonlinear optics has been to study new types of resonant optical nonlinearities in molecules at infrared wavelengths. This research has employed third harmonic generation (THG), multi-photon absorption, and degenerate four-wave mixing (DFWM) to measure the nonlinear properties of two classes of molecules; those with a single two-photon resonance and those that are approximately triply resonant at one, two, and three photon energies. When these techniques are used with a

step-tunable CO_2 laser, the spectral dependence of the nonlinear susceptibility, its magnitude, and the influence of limiting processes can be measured. This has been the final year of work on this project and the work consisted of concluding and writing up the study of THG in CD_4 gas. This case emphasizes a two-photon resonance which is unusually sharp and strong.

Progress in Nonlinear Optics has been in four general areas over the last several years: multi-photon absorption and THG in SF_6 [12,13], three wave parametric interactions in dispersive media [14], DFWM in SF_6 [15], and THG in CD_4 [16,17,18]. The first three areas have been concluded and covered in previous annual reports. The fourth area was concluded this year and is covered in the three publications noted above. The major conclusions of this fourth area will be summarized here along with their interpretation.

It is known that the Raman susceptibility and the THG susceptibility are closely related. The molecule CD_4 was selected because of its strong, narrow Raman line at 4.7 microns. This is two-photon resonant with CO_2 laser photons in the 9.4 micron band. The THG conversion of CD_4 was measured and found to be as large as CO at room temperature. When the gas temperature was lowered to 193K at a constant gas density, the THG conversion efficiency of CD_4 increased fivefold. The increase is due to two predicted effects. First, the absorption of the fundamental laser wavelength is reduced substantially. The room temperature absorption was due to highly excited rotational states which were depopulated as the temperature was lowered. The second contributing effect is that the two-photon resonant states are of low rotational energy, and their population increased as the temperature was lowered.

At pressures below 300 torr and at a temperature of 193K, the THG conversion efficiency was substantially larger than CO (a standard at this wavelength). However, the conversion efficiency of CD_4 failed to increase with increasing pressure above 300 torr. We believe this is due to residual absorption at the fundamental wavelength which remains even at 193K. In conclusion, the THG susceptibility was found to be high as predicted from the Raman susceptibility, but THG conversion efficiency was found to be limited by residual absorption at 9.4 microns.

3. Follow-up Statement: This unit will not appear in future Annual Reports. The work on nonlinear wave interactions will be continued as Research Unit IE83-3 "Digital Time Series Analysis with Applications to Nonlinear Wave Phenomena." The work in nonlinear optics has been concluded and will not continue in subsequent proposals. Future work in a related area concerns the effect of nonlinear and other quantum processes in solids on the laser induced damage of these materials.

This latter work will be described in future Annual Reports under Research Unit QE83-1 "Quantum Effects in Laser Induced Damage."

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THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE82-2 STRUCTURE AND KINETICS OF EXCITED STATE MOLECULES

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A. RESEARCH OBJECTIVES: The experiments to be proposed emphasize structural and dynamical studies of molecular systems using non-linear interactions with electromagnetic radiation for detection or state selective excitation. The scientific objectives are (1) contributions to the knowledge of the basic process of non-linear interaction of matter with light, (2) development of non-linear techniques as dynamical probes, (3) structural studies of excited states of molecules and ions previously unavailable for study, (4) studies of energy transfer processes in both collisional and collision-free environments. These objectives will be pursued under three research efforts: non-linear scattering of electromagnetic radiation, inelastic and superelastic scattering of electrons from excited states produced selectively by laser excitation, and dynamical studies of excited molecules produced by multiphoton excitation.

Collisional Pairs of Atoms or molecules are capable of absorbing and scattering light in ways that go beyond the familiar absorption and scattering by non-interacting atoms (molecules). Collisional pairs ("diatoms") acquire "collision-induced" properties, such as an electric dipole moment (if dissimilar pairs are considered) of a gas or gas mixture. These interact with electro-magnetic radiation in linear and other ways and give rise to second and higher-order virial dielectric properties of the real gases. In recent years, ab initio calculations of the collision-induced properties at all levels of sophistication have appeared. It is the goal of our work to provide new, often the first, measurements of collision-induced quantities for a direct comparison with the fundamental theory, and thus to obtain an understanding of the interactions of light with real gases at the molecular level.

Superelastic Scattering

The extensive studies of the molecular properties of many systems in the electronic ground state have led to the vast capabilities of today's chemical industry. As our knowledge grows, more efficient ways are found to produce compounds and to control reaction paths during the formation of products. Due to the availability of a large variety of lasers which produce high energy photons at an ever diminishing cost, a second thrust in the production of exotic compounds can be predicted for the near future. Critical for this progress is a good understanding of molecules in an excited electronic, vibrational and rotational state. It is in this transient mode where the crucial reactions will take place. As an example how ground and excited state properties are different, consider the rare gases. In the ground state they are exceedingly inert, while the excitation of an outer electron generates an alkali like system with its core and valance electron and subsequent strong reactivity.

The bulk of the new data on excited species comes from absorption and fluorescence spectroscopy. The know-how accumulated so far has already lead to some new chemical processes not otherwise possible. But as in the discharge of laser tubes, the excited molecules have several avenues to distribute the excitation energy internally. These escape channels have been known for a long time and are identified as radiationless transitions. The problem with molecules undergoing such a transition is that they often change the symmetry of their state and become inaccessible to studies in the fluorescence spectrum due to the restrictions imposed by the selection rules.

Our scientific objective is to take advantage of low energy electron scattering to probe the excited molecules. Electrons interact with the target much more strongly than photons, breaking selection rules in the scattering process and increasing the sensitivity of the detection to optical resonance extinction coefficients. The scattered electrons can be grouped into three categories: the elastic scattered electrons (analogous to Rayleigh scattering for photons), the inelastic scattered electrons (analogous to the Stokes photons), and the superelastic scattered electrons (analogous to the anti-Stokes photons). It is the last group of electrons which we intend to use as a diagnostic tool. The basic principal of this method had been demonstrated on laser excited Na [1] and Ba [2], and with the extension of this method to molecules a new sensitive and very versatile tool will become available for the new and promising field of laser chemistry.

Energy Transfer Reactions are being studied at high densities. This research has involved two areas: 1. reactions of excited atoms and molecules following state-selective multiphoton excitation of atoms and molecules, and 2. ion-molecule reactions at high densities. The former experiments are simil:. in spirit to those done at synchrotrons using resonance absorption except two-photon transitions offer the advantages: 1) greater choice of final states, 2) better time resolution, 3) better energy resolution, 4) the absorption length on resonance is significantly longer, and 5) higher energies can be reached when pumping through windows. This research program using non-linear photoexcitation was initiated by JSEP support in the past three year contract, is now producing exciting data, and has attracted support from the Department of Energy.

In previous units studying molecular reactions, we were motivated to understand the chemistry of excimer lasers; and in those studies found that at high densities many reactions are termolecular. At high pressures molecules react fundamentally differently than at low pressures; yet research studying reactions at pressures near or above atmosphere is relatively new. In research studying ion-molecule reactions at high pressures [3,4,5,6], we are greatly hampered by the lack of a probe which can even distinguish the ion type. For unambiguous studies it is necessary first to develop a selective probe applicable in high pressure discharges.

The probes for such studies must have high sensitivity, and good spectral and temporal resolution. Temporal resolution is required so that the decay rates can be used to measure reaction rates. We are interested in reactions such as association, recombination, and charge transfer. Nonlinear optical probes based on coherent Raman scattering used in conjunction with high power pulsed lasers potentially meet all these criteria. Two techniques currently under consideration are coherent antistokes resonant Raman spectroscopy and gain modulated Raman spectroscopy. The spectral and temporal characteristics of these techniques are governed by the characteristics of the lasers employed. A continuing goal of this research unit is to demonstrate experimentally that such probes have the necessary sensitivity. When successful, these experiments will represent the first Raman spectra of molecular ions and will greatly aid in the understanding of polyatomic molecules and high pressure discharges.

Polyatomic ions of interest include Xe_3^+, Ar_3^+ and Xe_nCl^+ which are relevant to excimer lasers. Other molecular ions for which there exists a need for experimental analysis include those formed in atmospheric discharges; H_3^+, N_3^+, N_4^+, O_3^+ and O_4^+ all fall into this category. The results from such studies will be applicable to the problem of particle beam transport in the atmosphere. Of particular fundamental interest is H which is the simplest nonlinear polyatomic molecule. Data gathered on it may be compared directly to ab initio calculations.

B. Progress: Our electron diffraction work with high energy electrons has continued with extensive data compilation on molecules at elevated temperatures [7,8,9,10]. Also, our studies on the theoretical background of the diffraction work have lead to several new results [11,12]. Since this research is now supported by the NSF, the JSEP funding is shifted toward the development of the most accurate low energy electron diffraction unit currently in operation in the world.

We have continued to build up the superelastic scattering unit from three aspects: the laser excitation source, the electron beam, and the gas jet. As for the laser, a linear dye laser was modified to incorporate a Michelson interferometer [13]. This leads to two advantages: first, the laser runs single mode with the same output power and therefore multifold spectral density, and second, one arm in the spectrometer contains a beam waist, which is excellently positioned to allow intracavity photon frequency doubling.

The peripheral equipment was extended by Hansch-type wavemeter [14] and a 75 MHz etalon which is used as a marker generator to keep track of the frequency as it is tuned through the rotational-vibrational spectrum. As for the gas jet, we are making progress but several problems still remain. Our quadrupole spectrometer is in place and working and in Fig. 1 a well resolved spectrum of NO_2 and its fragmentation products is reproduced. The problems lie with the peaks not seen in the mass spectrum. According to the thermodynamics of the reactions

$$2NO_2 \rightleftharpoons N_2O_4$$

we should have a strong N_2O_4 peak in our spectrum, given the conditions under which the nozzle system is run [15]. Since the optical quenching cross sections are in general very large, the N_2O_4 can act as a perturber in our jet and must be taken into account in the interpretation of the scattering data. Most NO_2 studies suffer under this handicap, and it might provide a simple explanation for the often contradictory results in the literature in regard to NO_2. We hope that the appearance potential of the fragments will give use more insight.

The scattering apparatus itself is finished and ready to take data [16]. Not only will we be able to measure the total energy spectrum at every scattering angle between 1-150°, but we have the ability to measure the cross sections better than 0.1% on a relative scale. This will lead to very sensitive comparisons with theory, particularly in the elastic channel. These data will then tell us much more about charge cloud polarization [17], exchange effects [18], intramolecular multiple scattering [19], and spin contributions [20]. The inelastic data, when maintained at that high accuracy, will show the correlation effects in the Comption profiles from the individualized subshells of the target molecules. Finally, when the laser is introduced into the scattering process, the dynamics of intramolecular relaxation can be studied.

In a previous report [21] we reviewed our work on collision-induced laser light scattering, a relatively weak two-photon progress arising from the polarizability change induced by molecular interactions [22-24]. Since that report was written we have expanded the scope of our work, in cooperation with Dr. G. Birnbaum at the National Bureau of Standards, Washington, D.C., by considering the dipole moments induced in non-polar gases by molecular collisions [25]. Induced dipoles interact with radiation, usually by absorption in the infrared. Two mechanisms are known that induce dipoles. The overlap-induced dipole arises from electronic rearrangement of the collisional complex if dissimilar molecules interact [26,27], e.g. He and H_2. The multipole-induced dipole, on the other hand, relies on polarization of a molecule in the electric multipole field of another molecule nearby [28], e.g. the electric field of H_2 polarizing a collisional partner in the vicinity. The infrared absorption spectra of induced dipoles feature broad continua of characteristic shapes. Multipole-induced dipole spectra usually show broad structures at the rotational/vibrational frequencies of the monomers. All essential features of the infrared spectra induced by binary collisions can be computed from an adiabatic theory [29], provided two functions describing the molecular interactions are known: the interaction potential, V(R), and the induced dipole moment, M(R). We were able to show that, conversely, potential and dipole function are rather critically defined over a certain range of separations by accurate measurements of induced spectra, preferably at a variety of temperatures. The spectral profiles with their gentle change of slope and curvature with wavenumber apparently contain significantly more information than was hitherto utilized. The new device employed in our analysis of the measurements is an adiabatic line shape computer program, presumably the only one presently available for such work. The systems studied are selected for their astrophysical interest [26-28, 30-32] (H_2, He, Ch_4, etc); but rare gas mixtures (He-Ar, Ne-Ar, Ar-Kr) were also considered [33] for critical comparisons with the fundamental theory, which predicts these functions V(R), M(R), for many systems, with varying degrees of accuracy. In general, a satisfying, very close agreement with the ab initio theory is observed except in Ne-Ar, where the ab initio dipole moment was shown to be in error [34]. Empirical induced dipole functions [29,33], and for the first time a potential function [30,34], presumably improvements over the ones computed from first principles, could be obtained for several molecular systems which allow a most reliable computation of the absorption spectra even at temperatures that are different from those of the measurements, an important consideration particularly in the physics of planetary atmospheres. New insights are obtained concerning the role of dimers, i.e. diatomic molecules bound together by the weak van der Waals forces, which affect the optical properties of the dense systems more than commonly expected, particularly if heavy systems (e.g. those involving species other than hydrogen or helium) are considered. Surprisingly, dimers affect the optical properties of dense gases even at temperatures of 300K and higher in several important cases [28,32].

Progress: Energy Transfer Reactions: Initial experiments studying reactions of excited species have begun with studies of collisions of xenon $5p^5 6p$ following two-photon laser excitation. Excitation spectra have been measured from 76,000 to 82,000 cm while observing laser induced fluorescence (LIF) from the lowest bound xenon excimer (radiation at 172 nm) and atomic transitions in the infrared. We illustrate the two-photon pumping process in Fig. 2. At pressures above 50 Torr excimers are rapidly produced by association of $5p^5 6s$ states which are radiation trapped. All states excited to $5p^5 6p$, whether they radiate or are collisionally deactivated to $5p^5 6s$, produce fluorescence at 172 nm.

With laser excitation, a large flux of photons reaches the photodetector. The flux produced is large enough that the response time of the photomultiplier makes single photon counting techniques impossible, but small enough to make usual analogue techniques impractical. We have developed a detection scheme based on digitizing the charge at the photodetector for the first 100 nsec following excitation. This charge is divided by the mean charge for a single photon event and added to individual photons counted at later times. This enables the detection of up to 900 photons per laser pulse. This signal is limited by the linearity of the photomultiplier. We have found the precision of this detection system to be limited by Poisson statistics for signals from 10-2 to 900 photons per laser pulse. Our noise levels are limited by scattered light to levels of 5x10 photons per laser pulse.

We have measured the laser induced fluorescence near 828 nm produced by excitation of 6p[1/2] at various pressures. Similarly we have observed fluorescence of 6p[3/2] near 823 nm and 6p[5/2] near 905nm. In Table 1 we list both the calculated two photon transition rates for these states in the dipole-dipole approximation for several intermediate states and the measured transition rates. The experimental cross sections have been measured using laser induced fluorescence both in the infrared and in the vacuum u.v. In the infrared, the optical detector system is absolutely calibrated using an NBS traceable standard lamp. In the vacuum u.v. we do not have standard lamps available, hence we have measured the two photon coefficients relative to the known Rayleigh scattering cross section, $d\sigma/d = 6\times10^{-26}$ cm^2 for the scattering geometry, polarizations, and laser frequencies of our experiment.

The absolute measured rates are in reasonable agreement with theory when errors are taken into account. We observe ratios of two photon coefficients in Table 1 of 8:4:1 for 6p[1/2] : 6p[5/2] : 6p[3/2] . The accuracy of these relative rates is 10%. These ratios are in significant disagreement with ratios of 2.5:2:1 when using a single intermediate state. We note in Table 1 that there is a significant contribution to theoretical transition rates from 5d[3/2], and 7s[3/2], intermediate states; hence a single intermediate state model gives only an order of magnitude estimate and a sum over intermediate states is required for accurate calculations.

Table 1. Two-Photon Coefficients

The calculated values are given for specific intermediate states.

α for given $\|i>$, ($cm^4/J2$)				Experiment
$\|e>$	$6s[3/2]_1$	$5d[3/2]_1$	$7s[3/2]_1$	
$6p[1/2]_0$	100	73	12	43
$6p[3/2]_2$	43	7.7	19	4.5
$6p[5/2]_2$	92	4.2	17	22.4

Precision excitation spectra of $6p[1/2]_0$, $6p[3/2]_2$ and $6p[5/2]_2$ have been measured over a broad pressure range. These data demonstrate a significant advantage of multiphoton spectroscopy for lineshape studies-- since the absorption length is large, data are accurate both in the line core and line wings. In Fig. 3 we show an example of high resolution data obtained in the line core. Szudy and Baylis [36] have derived a unified pressure broadening model applicable in both the line core and line wing. This model predicts a simple asymmetric Lorentzian for the line shape when a single interaction potential is assumed. The model predicts the pressure dependence of the shifts, widths, and asymmetry are related to the strength and order m of the interaction potential, Cm/R^m. The measured shifts, widths, and asymmetry [35] are in agreement with the model for pressures of 1 to 1000 Torr when the single potential C_5/R^5 is used for J=2 states and when C_6/R^5 is used for J=0 states.

We have also obtained precise spectra in the far line wings. Various lineshape theories have been applied to the analysis of these data. The quasistatic theory and the unified statistical theory by Szudy and Baylis have been used to analyze the linewing in order to extract numerical potentials for internucleation separations from 3.7 A to 10.0 A. As described, the long range interaction potential is obtained from measurements of the line core at low pressures. The two potentials were smoothly joined to generate an analytical representation of the potential over the full range of internuclear separations. Calculations using this potential in the Anderson-Talman theory [37,38] were compared with the data over the full line profile. A comparison of the calculations and data are shown in Fig. 4.

In addition to determining the interaction potentials for states of $5p^5 6p$ we have begun reaction studies. While exciting on resonance, we have measured the branching fractions for product states. With experiments now in progress measuring the time dependence of fluorescence from these states, we will determine collision cross sections for fine structure changing collisions on a state-to-state basis.

Experiments to obtain coherent Raman scattering were begun during the past year. To date these experiments have been in the building stage and significant progress has been made. Two N_2 pumped dye lasers have been constructed which provide 50 kw peak power with bandwidth less than 1 GHz. These lasers will be used to probe the N_2 laser discharge. Because of the time delay in producing the dye laser beams a long-pulse (10 nsec) N_2 laser was constructed. Initial experiments have obtained gain modulated Raman spectra of CCl_4. More sensitive electronics for monitoring the gain or absorption of the probe laser are being constructed. When the electronics are complete, tests will be made on low pressures of air prior to attempts to observe signals from the N_2 discharge. For studies using CARS, we have designed an unique prism monochromator (93% transmission with 20 cm^{-1} bandpass) for extracting the colinear CARS beam from the pump lasers. This device is being constructed in the machine shop. The prism monochromator, combined with the sensitive technique for photon counting described earlier will provide a sensitivity significantly better than current state of the art.

C. FOLLOW-UP STATEMENT

Our research supported by the JSEP program has gained such momentum that additional federal funding could be secured. The electron diffraction work is now sponsored by the NSF, and the high gas density reaction kinetics studies are financed by the DoE. This provided the ideal moment to reorganize our groups QE82-2 and QE2-3. The diatom work is close to completion, it has been summarized in last years significant accomplishments. Therefore, we formed two new groups for the next trianium: QE83-2 and QE83-3, emphasizing the new ideas we plan to pursue in the coming years. Hopefully, this project will again lead to significant results to attract new federal support.

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Fig. 1 Mass Spectrum of NO_2 and $N_2)_4$ (-30°C)

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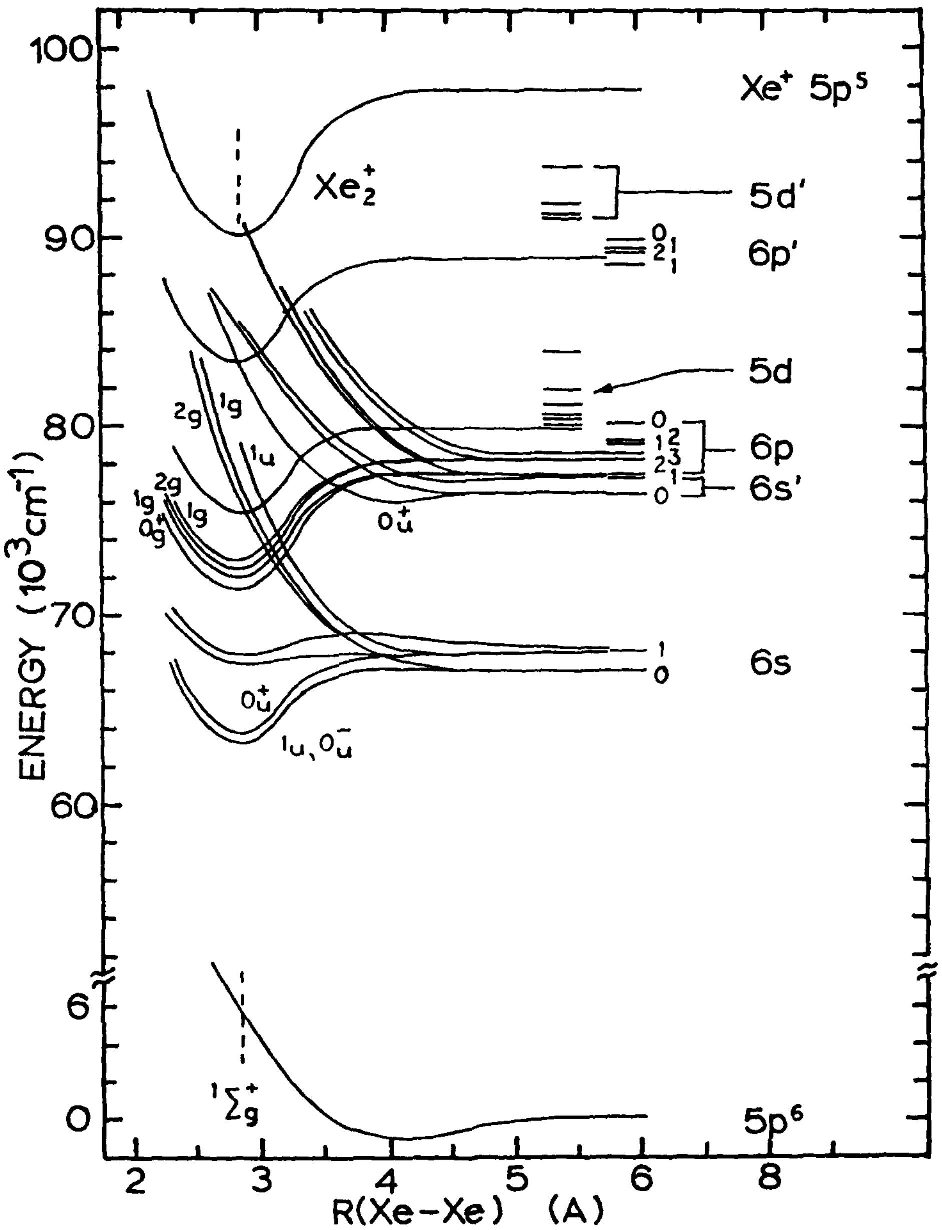

Fig. 2 The states of the 6p manifold are excited via two photon absorption. The molecular curves drawn are based on the estimates by Mulliken.

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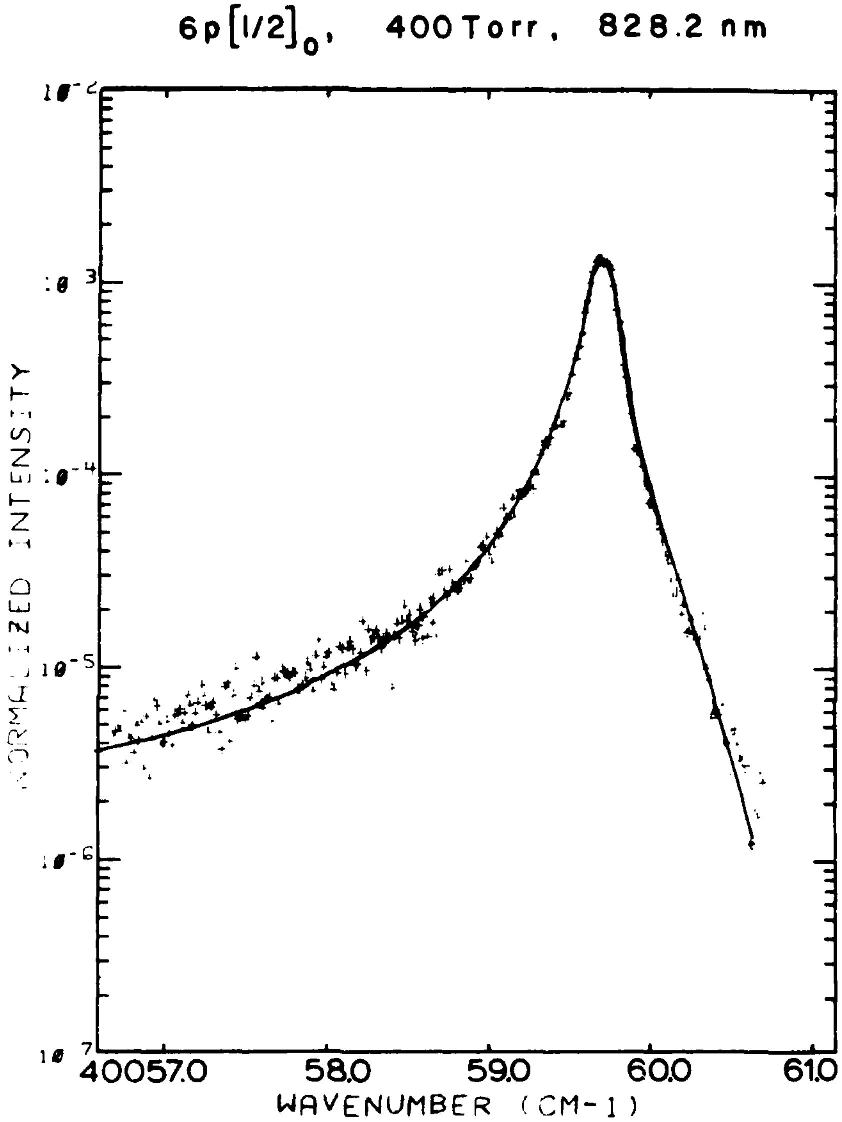

Fig. 3 The narrowband laser was used to obtain this absorption spectra of $6p[1/2]_0$ at 400 Torr. The transition of this state to the lower lying $6s[3/2]_1$ state (8282 Å) was used as the fluorescence monitor. The solid curve is the least squares fit of an asymmetric Lorentzian to the data.

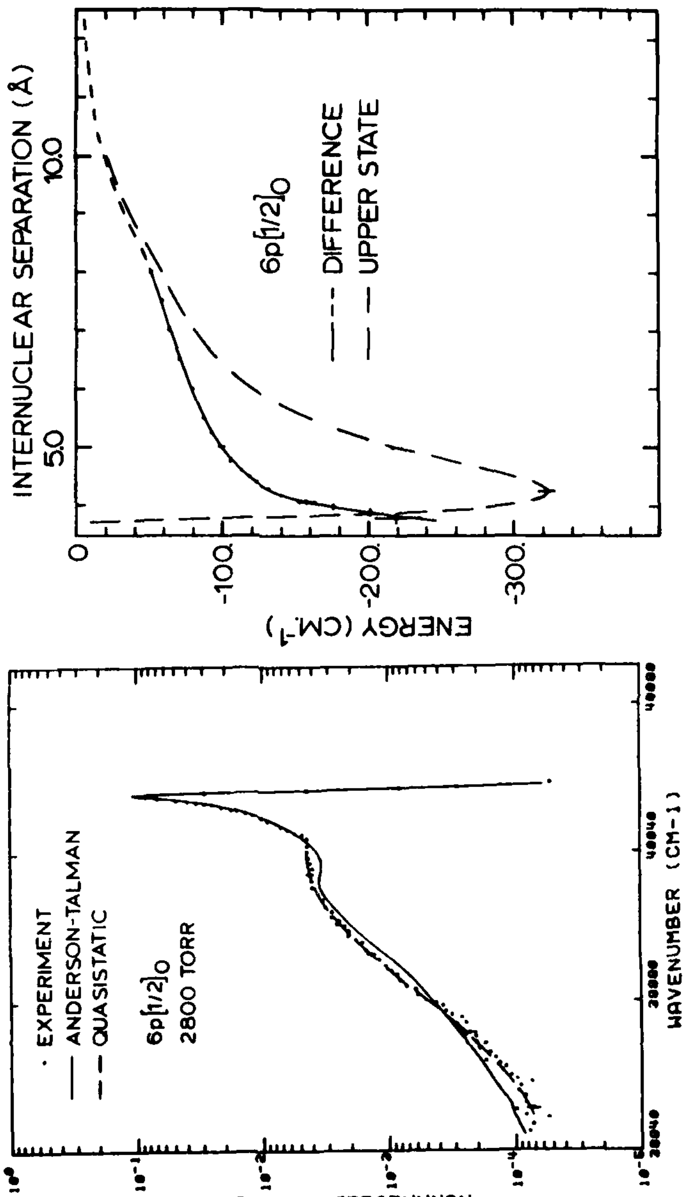

Fig. 4 Experimentally measured and calculated line shapes for xe $6p[1/2]_0$. At left are experimentally measured points compared with the calculated line shapes, while on the right we show the potentials used in the calculation.

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE82-3 COLLECTIVE EFFECTS IN NONLINEAR OPTICAL INTERACTIONS

Principal Investigators: Professor H.J. Kimble (471-1668)
Dr. A. T. Rosenberger

Graduate Students: David Grant, Luis Orozco, Murray Wolinsky, L.A. Wu

A. RESEARCH OBJECTIVES: The objective of this research unit is to investigate the behavior of nonlinear optical systems that are strongly coupled. The dynamics of such systems are not explicable in a simple way based upon perturbative analyses. Rather, the coupling is such that one must deal with the combined system as a new dynamical entity, as for example in the interaction of gas phase atoms and resonant electromagnetic radiation discussed below. In general our efforts are devoted to the study of physical systems that are on the one hand amenable to detailed microscopic analysis while on the other hand experimentally realizable. The intent is to investigate both the range of dynamical behavior exhibited and as well the possible role played by quantum fluctuations in the atom-field coupling.

Within this general context we have initiated over the past three years with the support of JSEP a project to study optical bistability. In our experiments an atomic beam passes through the intracavity field of a high finesse interferometer. As the intensity of the laser incident upon the optical cavity is varied we record the transmitted laser power and intracavity fluorescent intensity. For zero intracavity atomic density, the input-output characteristic is a straight line. As the atomic beam density increases the transmission function develops a region of differential (ac) gain. Beyond some critical point a hysteresis cycle emerges in the input-output curve. The onset and growth of the hysteresis cycle can be characterized by a parameter C known as the atomic cooperativity parameter. C is defined as the ratio of intracavity atomic loss [illegible] to the linear loss of the cavity π/F, with F equal to the cavity finesse. (C is analogous to the pump parameter of laser theory, which is defined as the ratio of atomic gain to cavity loss and which describes the onset of laser action).

By conducting experiments in the system described above, we are making an investigation of optical bistability free from certain "complicating" features such as inhomogeneous broadening, optical pumping, or other nonradiative relaxation mechanisms. The theoretical descriptions for such a system of "two-level" atoms are numerous and predict a wide range of phenomena which are of relevance to the study of cooperative interactions in atomic and molecular physics, to the study of the fluctuation and relaxation processes for nonlinear systems driven far from thermal equilibrium, and to potential applications in optical signal processing. However in spite of the rather advanced state of development of the theory, almost no experimental information is available. The intent of our research is to address experimentally several questions that until now have been treated only theoretically for bistability in the "simple" arrangement of two-level atoms inside an optical resonator.

B. PROGRESS: In the last Annual Report (1981-1982) we discussed our preliminary measurements of optical bistability [1]. Those measurements still represent the first and only systematic study of the onset and growth of hysteresis in absorptive bistability. Over the past year we have extended this work to analyze in detail the role of each of the following in optical bistability: (1) Inhomogeneous (Doppler) broadening - Experiments have been carried out both with and without appreciable inhomogeneous broadening. (2) Cavity-mode structure - Experiments have been performed in both Fabry-Perot (standing wave) and ring (travelling wave) geometries to investigate the importance of variations in the longitudinal and transverse structure of the intracavity field. (3) Transient response - Our experiments in an all optical system have systematically explored the dependence of switching time on the size of the switching increment in the vicinity of the hysteresis cycle [1-4]. In addition to the experimental program, a collaborative effort has been ongoing with Dr. P.D. Drummond of the University of Rochester to analyze our data in the light of current theories of optical bistability. In this section we will deal with each aspect (1)-(3) of the research program.

As has been discussed by many authors [5-7], the behavior of many nonlinear optical systems is analogous to that of systems that undergo equilibrium phase transitions. Of course the optical systems, such as those in optical bistability, are driven far from thermal equilibrium by some pumping mechanism. Nonetheless formal associations between the variables of a thermodynamic process and those of an optical process can be made. This has been done in the case of optical bistability [8-9]. In the language of equilibrium phase transitions, one is then interested in examining the bistable system for the "critical" onset of bistability and for the characteristics of the system above and below this critical point. In optical bistability the values of the critical atomic cooperativity parameter C_0 and of the actual switching powers depend upon the resonator structure and on the detailed nature of the intracavity nonlinearity. The intracavity media in most bistable systems that have been studied in the past are sufficiently complex in their own right that it has not been in general possible to make detailed comparisons between theory and experiment. Our experiment is unique in that the intracavity medium behaves to a good approximation as a simple "two-level" atom [10] with a single nondegenerate ground state and single nondegenerate excited state (in this regard, see also the work of reference [11]). We are then able to investigate not only the dependence on geometric factors or susceptibility but as well the higher order processes in optical bistability.

Inhomogeneous broadening has a large effect on the characteristics observed in optical bistability. Even in the cases where a homogeneously broadened system has been obtained by collisional broadening or phonon processes, actual observations are far removed from the fundamental radiative relaxation mechanism. In our experiments we have studied optical bistability both without appreciable broadening of any kind other than purely radiative relaxation and with inhomogeneous (Doppler) broadening amounting to three times the natural linewidth. As predicted [12,13,16] we see marked changes in both the values of the critical cooperativity parameter and of the incident switching intensities. With inhomogeneous broadening the critical density for observing optical bistability increases two-fold in a fixed finesse cavity, while the incident switching intensities are raised by 50% relative to their expected values for bistability in the Doppler free case. The theoretical analysis of the experiments carried out by Dr. Drummond has demonstrated the need to analyze the broadening mechanism as not simply inhomogeneous but rather as due to the moving atoms in our atomic beams. The motion of the atoms through the standing-wave pattern of the intracavity field tends to "wash out" the maxima in the pattern and hence to increase the incident power required for switching [1,3,16].

Our experiments have also investigated the role of Gaussian beams in optical bistability. The radial distribution of intensities of an incident laser beam and of the intracavity field greatly alters the response of a bistable system as compared to the results obtained from a plane-wave analysis [14,15,17]. Critical values of the cooperativity parameter C and of switching intensities are increased several fold. As well the rate of growth of hysteresis with increasing intracavity atomic density is drastically reduced [3]. Stated somewhat differently, a fixed intracavity nonlinearity and range of incident laser power that would be sufficient to observe optical bistability in the plane-wave theory would be insufficient for bistability in our experiments. Overall we have obtained good agreement with the Gaussian beam theory of our experiments, but some remaining discrepancies are being investigated.

In order to eliminate the effects of standing waves and inhomogeneous broadening, we have recently made major alterations in our apparatus. For the first time in this field we are now studying optical bistability in a ring resonator with an intracavity medium that is nearly free of inhomogeneous broadening. We have constructed a new interferometer that operates in a ring or travelling wave configuration. Such an interferometer and intracavity medium represent a bistable system in which not only the deterministic effects in optical bistability but as well as many of the dynamical processes can be studied. With this arrangement we hope to record certain of the higher order correlation functions in optical bistability. For example, measurements of average incident and transmitted intensities can be understood from a knowledge of the (static) nonlinear susceptibility of the intracavity medium. On the other hand, the spectral density of the fluorescent or transmitted light involves quantum and other fluctuations of the resonator-atomic system.

We also plan to search for the occurrence of "self-pulsing" instabilities in optical bistability [19,20]. Parts of the steady-state hysteresis cycle that were thought to be stable are in fact predicted to be unstable against small perturbations. The nature of the new "stable" states that evolve is one in which continuous-wave incident light is converted by the (passive) bistable device to time-dependent, oscillatory transmitted light. The instability (transition from continuous-wave output to oscillatory output) arises from the strong coupling of atomic and cavity dynamics so that neither atoms nor cavity can be thought of as slightly perturbed by the presence of the other. While the observation of such instabilities would be of scientific interest, it would also be of possible significance for the use of bistable devices as elements in optical signal processing. Recent numerical simulations of the Maxwell-Bloch equations indicate the possibility of observing these instabilities in our experiment [21].

Our preliminary work with the ring cavity and nearly Doppler-free system have been directed toward a comparison with the usual steady-state theories of optical bistability [4]. As in the standing wave cavity we have recorded the onset and growth of the hysteresis cycle as a function of atomic cooperativity. Values of both incident and transmitted intensities have been measured. A detailed comparison of our data with theory is in progress, but in general terms our results agree with the standard steady-state theories in the mean-field limit in the region around the critical onset of bistability. However for $C>40$, corresponding to a well-developed hysteresis cycle, we have observed features in the input-output characteristics that are greatly different from the usual theories of optical bistability. In particular, the hysteresis cycle appears to be gradually truncated as C increases from 40 to 50. Unexplained structure develops in the hysteresis cycle not only in the region between the turning points but also for incident intensities well above the upper turning point.

We are currently exploring several possible causes for this behavior. They are as follows: (1) Existence of dynamical instabilities on the upper branch of the hysteresis cycle can cause premature precipitation to the lower branch [19,20]. (2) The mean-field theory might not be applicable to our experiments at high values of C due to the large intracavity absorption and resulting longitudinal and transverse variation of the intracavity field. (3) Switching between the fundamental and higher order transverse modes of the interferometer might occur due to its mode-degenerate (confocal) nature. (4) The approximation of an intracavity medium composed of two-level atoms might break down at the high intensities within the cavity. These intensities are 10^3-10^4 times the saturation intensity of the medium and are comparable to or greater than the hyperfine spacings of the atomic levels. Both additional experiments and numerical investigations are underway in an attempt to explain the behavior that we have observed.

In a separate set of measurements in the standing-wave cavity with a Doppler-broadened intracavity medium we have investigated transient response in absorptive bistability [2]. In these measurements the bistable system is subjected to an input that turns on from zero to some final value in a time that is short compared to cavity or atomic relaxation times. The evolution in time of the output of the cavity is recorded as the transmitted field builds from zero to a final steady-state value. The time taken by the output to reach steady-state is determined for various amplitudes of the input pulse to the cavity. For switching from zero to a final value large compared to the turning points of the hysteresis cycle, the output of the cavity evolves as if there were no intracavity medium. However as the switching increment above the upper turning point of the hysteresis cycle diminishes, the time taken for the output to reach steady state increases rapidly. More than a ten fold increase in switching time has been observed for switching within a few percent of the upper turning point. This phenomenon has been predicted theoretically [23] and seen in a hybrid device [24] previously. However, our measurement is one of only two direct observations of "critical slowing down" in all optical bistable systems [2,25]. The slowing of response to changes in driving field can be related to a change in the dynamical behavior of the system based upon the thermodynamic analogies discussed earlier. Such slowing down would have to be considered in any device application.

C. FOLLOW-UP STATEMENT: The work that has been outlined in the previous section is to be continued, and the research program is outlined in the most recent JSEP proposal. Principle funding for the research will however be shifted. The program in optical bistability that was begun three years ago under the sponsorship of the JSEP has attracted funding from the National Science Foundation and from the Venture Research Unit of British Petroleum, Int. While JSEP support will continue to be acknowledged in future publications from the work, several new projects have been discussed in the 1983-86 JSEP proposal and are being developed. The general area of the project is still that of cooperative or collective effects in nonlinear optical systems.

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IV. ELECTROMAGNETICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
ELECTROMAGNETICS

Research Unit EM82-1 GUIDED-WAVE DEVICES FOR THE FAR-INFRARED -MM WAVE SPECTRUM

Principal Investigators: Professor A.B. Buckman (471-4893)
Professor T. Itoh (471-1072)

Graduate Students: Yoshiro Fukuoka and Lingtao Wang

A. SCIENTIFIC OBJECTIVES: This work has as its overall objective the identification, analysis and, finally, the prototype demonstration of useful semiconductor waveguide devices for production and control of radiation in the frequency range from ten to a few hundred gigahertz. This part of the spectrum is uniquely suited to a number of DoD needs, but its exploitation will require a mix of designs, some using concepts first developed in interated optics, and others adapting microwave techniques. This research will focus on use of the Gunn and IMPATT mechanisms for radiation sources and on use of carrier injection and the field effect for electronic active guided wave devices such as modulators, active filters and beam deflectors. For the most part, the device concepts to be studied are compatible with planar waveguide integrated circuit technology.

B. PROGRESS:

(a) Gain Devices

In the area of distributed gain devices, two additional works have been initiated in addition to development of Gunn devices.

(a.1) Distributed Gunn Devices

This work is the continuation of the previous effort in realizing distributed Gunn devices made of a subcritically doped GaAs layer. Based on the theoretical study on characteristics of distributed gain mechanism [1], we built several test devices during the previous period. Although we found that gain mechanism certainly exists, the overall gain was still too small to compensate the insertion loss of the structure.

During the present period, we continued fabrication using several GaAs wafers. To date the best performance was obtained in one of the devices. As shown in Fig. 1, we need one more dB to generate a device gain in this device. Assuming that a substantial insertion loss comes from the series resistance in coplanar electrodes, we are fabricating another device with thick electrodes by the plating technique at Hughes Aircraft Company.

(a.2) Distributed IMPATT Devices

A new effort in characterizing distributed IMPATT devices of either single-drift or double-drift types has been initiated. Since IMPATT structures require PN junctions, precise control with fabrication process is needed if a distributed structure is considered. Due to recent advances in MBE technology, this problem is now solved. From points of view of gain and frequency limit, the IMPATT is more attractive than Gunn. In our analysis program the effects of several semiconductor layers, lossy electrodes and transverse size can be incorporated.

(a.3) Distributed Heterostructure

A recent prediction of negative differential gain based on the real-space transfer mechanism [2] can be used for distributed gain devices. As a first step, we analyzed a structure consisting of several alternating layers of GaAs and GaAℓAs. The former is using a negative conductivity and the latter positive conductivity. This is a model to study the minimum requirement on the negative conductivity in order to generate a net gain out of this distributed device. The numerical results have been obtained.

A more realistic approach has also been initiated in which we obtain a distributed impedance (per unit length) obtained from the calculation of negative differential gain in the lumped device model. Our effort is concentrated in obtaining a circuit model from the device theory [2]. Once this impedance information is available, we can model a distributed structure as a transmission line with this impedance distributed through the line. The propagation constant and the characteristic impedance then provide gain information.

(b) <u>Control Devices</u>

(b.1) Schottky Coplanar Waveguide

It is known experimentally that there exist slow waves in a coplanar or microstrip transmission line created on a lossy semiconductor substrate if one of the electrodes is Schottky contacted. The size of the depletion layer beneath the Schottky contact can be controlled by a DC bias, resulting in electronic control of the phase delay of the slow wave (variable distributed phase shifter). In the previous period, two algorithms were developed to analyze these slow wave phenomena [3,4].

One of the problems associated with the Schottky slow wave structure is its inherent loss. During this period, we have made an attempt to reduce this loss by using a periodically doped semiconductor substrate. A calculation of such a periodic Schottky coplanar waveguide clearly indicates a substantial reduction of the attenuation constant. However, an even more interesting feature of this periodic structure with an appropriate doping level is that at higher frequencies, the slow-wave ratio is improved which decreases in a uniform line as the frequency is increased (Fig. 2). These two phenomena, namely reduced attenuation and enhanced slow-wave factor at higher frequencies, make this structure more attractive [5]. An experimental study has recently been conducted using graphite powder that simulates doped semiconductor. The results confirm validity of our theoretical procedure that resulted in the prediction [6].

(b.2) Polarization and Mode Control

It has been theoretically shown that a dielectric waveguide structure may be constructed to discriminate a particular mode out of several modes with identical and orthogonal polarizations [7,8]. This structure is all dielectric, all isotropic and promises to greatly relax the constraints of extinction ratio versus insertion loss trade-off which limit the usefulness of other mode filters. During this period, this concept was tested using a dielectric waveguide structure designed for 60 GHz operations. The experimental results indicate basic soundness of the theoretical prediction.

C. FUTURE DIRECTIONS:

(1) In the area of distributed Gunn devices, we first wait for the results of a new thick-electrode device presently being fabricated. Depending on the results, new geometries will be studied such as the rib structure. The majority of the work will be transformed to an existing ARO contract.

(2) The distributed IMPATT work initiated toward the end of this contract period requires several more weeks' investigation before we find out a preferred approach.

(3) Heterostructure Devices

This work is considered very important and is well correlated with other JSEP units. In the coming year, we will concentrate on analysis of this structure under JSEP support.

(4) Studies on Schottky contact planar waveguides will be investigated in two important areas. The first is the discontinuity at the junction between planar waveguides such as the one appearing in a periodic structure. The second is an experimental study of periodically doped Schottky coplanar waveguides. Two possible fabrication techniques seem to be available. One is to create periodic mesa in the substrate and another is periodic ion planting. we evaluate these two techniques more carefully before selecting the preferred approach.

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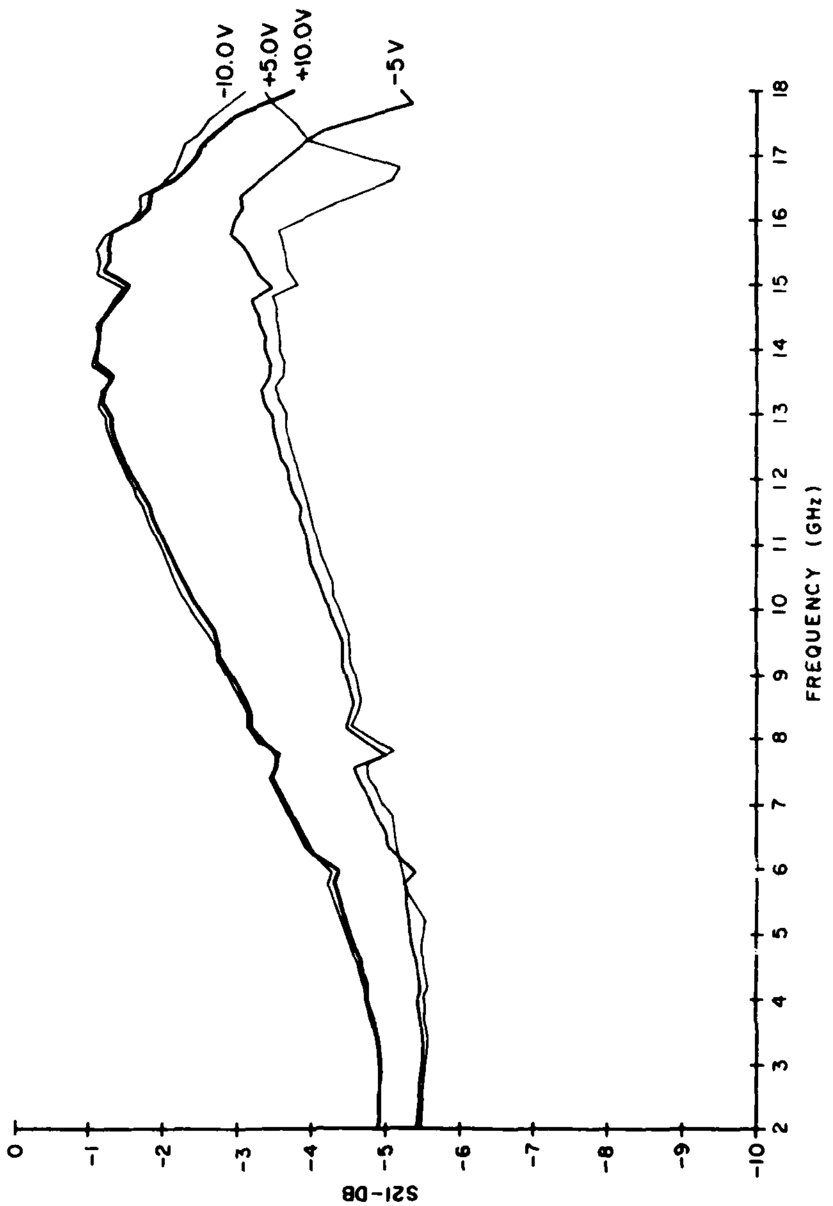

Fig. 1 Transfer characteristic of a distributed Gunn device $n = 3 \times 10^{14}$ cm^{-3}, Device length 5000 μm.

RESEARCH GRANTS AND CONTRACTS

RESEARCH GRANTS

FEDERAL FUNDS

Armament Laboratory, Eglin Air Force Base, "Investigation of Information Enhancement, Estimation and Guidance Algorithms for Homing Missile Guidance," Professors Jason L. Speyer and David G. Hull, Co-Principal Investigators, October 1, 1981-September 30, 1984.

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National Science Foundation, MEA 78-00719, "Experiments on Nonlinear Interactions During the Transition to Turbulence," Professors R. W. Miksad and E. J. Powers, Co-Principipal Investigators, November 1, 1978-October 31, 1982.

National Science Foundation, MEA-82-11205, "Experiments on Spectral Energy Redistribution due to Nonlinear Interactions and Phase and Amplitude Modulations during Transition to Turbulence," Professors R. W. Miksad and E. J. Powers, Co-Principal Investigators, February 15, 1983-July 31, 1984.

RESEARCH GRANTS

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National Science Foundation, CHE 80-07940, "Experimental Determinations of Charge Densities by Electron Diffraction," Professor M. Fink, Principal Investigator, July 1, 1980-June 30, 1983.

National Science Foundation, ECS-8022033, "Lie Algebraic Methods in Nonlinear Estimation," Professor S. I. Marcus, Principal Investigator, March 15, 1981-August 31, 1983.

National Science Foundation, DMR 7923629, "Experimental Studies of Intrinsic Surface Electronics Properties," Professor J. L. Erskine, Principal Investigator, July 1, 1982 -June 30, 1983.

National Science Foundation, ECS 8 802-1511, "Computational Models for Processing Sequences of Bioengineering Images," Professor J. K. Aggarwal, Principal Investigator, May 1, 1981-October 31, 1983.

Office of Naval Research, "Structure and Reactivity in Catalytic Systems Involving Metal Oxides and Electrode Surfaces," Professor J. M. White, Principal Investigator, August 1, 1982 - July 31, 1983.

Office of Naval Research, Contract N00014-79-C-0553, "Studies of Non-Reciprocal Effects in Planar Submillimeter to Optical Waveguiding Structures," Professor T. Itoh, Principal Investigator, June 1, 1980-August 31, 1983.

U.S. Air Force Armament Technology Laboratory, F08635-81-K-0101, "Measurements of Aerodynamic Transfer Functions Utilizing Novel Digital Time Series Analysis Techniques," Professors Edward J. Powers and Ronald O. Stearman, Co-Principal Investigators, June 19, 1981-November 19, 1982.

U.S. Air Force Office of Scientific Research AFOSR 79-0025, "Optimal and Suboptimal Estimation for Nonlinear Stochastic Systems," Professor S. I. Marcus, Principal Investigator, December 1, 1978 -November 30, 1983.

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U.S. Air Force Office of Scientific Research AFOSR 80-0154, "High Resolution Electron Energy Loss Studies of Chemisorbtion Species of Aluminum and Titanium," Professors J. L. Erskine and J. M. White, Principal Investigators, April 1, 1982 - March 31, 1983.

U. S. Air Force Office of Scientific Research, F49620-83-K-0013, "Automatic Recognition and Tracking of Objects," Professor J. K. Aggarwal, Principal Investigator, December 1, 1982 - November 30, 1983.

U.S. Air Force Office of Scientific Research, 82-0064, "Automatic Recognition and Tracking of Objects," Professor J. K. Aggarwal, Principal Investigator, December 1, 1981 -November 30, 1982.

U.S. Army Research Office, DAAG29-81-K-0053, "Interface Structures for Millimeter-Wave Circuits," Professor T. Itoh, Principal Investigator, March 1, 1981 -February 29, 1984.

U.S. Army Research Office, DAAG29-81-K-0053, "Interface Structures for Millimeter-Wave Circuits," (additional funding), Professor T. Itoh, Principal Investigator, March 1, 1981 -February 29, 1984.

OTHER THAN FEDERAL FUNDS

General Dynamics Corporation, Fort Worth Division, "Development of Synthesis Techniques for Fault Tolerant Digital Flight Control Systems," Professor Jason Speyer, Principal Investigator, March 1 -December 31, 1982.

Petroleum Research Fund, "The Interaction of Vibrationally Excited Ammonia and Methanol with Well-Characterized Surfaces," Professor J. M. White, Principal Investigator, September 1, 1982 - August 31, 1983.

Texas Atomic Energy Research Foundation, "Analysis and Interpretation of Plasma Fluctuation Data Utilizing Digital Time Series Analysis," Professor E. J. Powers, Principal Investigator, May 1, 1976-April 30, 1983.

Texas Instruments, "Millimeter-Wave Transmission Lines Study," Professor T. Itoh, Principal Investigator, June 1, 1976 -December 31, 1982.

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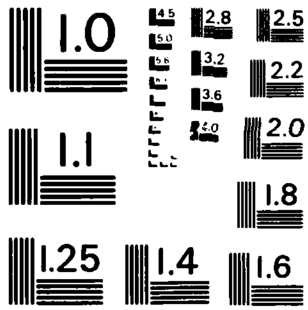

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University of Texas Research Instrumentation Grant, Professor R. M. Walser, Principal Investigator, January 18, 1982 -August 1, 1982.

U.T. Research Institute, "Investigations of Optical Bistability," H. J. Kimble, Principal Investigator, November 19, 1981 -November 18, 1982.

U.T. Research Institute, "Investigations of Optical Bistability," H. J. Kimble, Principal Investigator, February 1, 1982 -January 31, 1983.

Venture Research Unit of British Petroleum, Int., "Nonequilibrium Phase Transitions in Optical Systems," Professor H. J. Kimble, Principal Investigator, February 1, 1983 - January 31, 1986.

Robert A. Welch Foundation, F-788, "Coherent Raman Spectroscopy of Molecular Ions," Professor J. W. Keto, Principal Investigator, June 1, 1980 -May 31, 1983.

Robert A. Welch Foundation, "Interactions of Reactive Species with Surfaces," Professor J. M. White, Principal Investigator, June 1, 1982 - May 31, 1983.

Robert A. Welch Foundation, F534, "Electron Scattering from Alkali Halide Vapors," Professor M. Fink, Principal Investigator, June 1, 1980 -May 31, 1985.

Robert A. Welch Foundation, F-720, Experimental Studies of Metal Surface Absorbates," Professor J. L.Erskine, Principal Investigator, June 1, 1981 -May 31, 1983.

Robert A. Welch Foundation, F-789, "Momentum Redistribution by Resonant Radiation," Professor H. J. Kimble, Principal Investigator, June 1, 1980 -May 31, 1983.

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J.K. Aggarwal attended and participated in the NATO-Advanced Study Institute in Braunlage, West Germany, June 1982.

Edward J. Powers visited Dr. Jim Smith of the Office of Naval Research and Dr. Sevick of the David Taylor Model Basin, Washington, D.C., to discuss research possibilities on June 30, 1982.

July 1-2, 1982, Edward J. Powers met with Dr. William Von Winkle and colleagues of the Naval Underwater Systems Center, New London, Connecticut to discuss research possibilities.

On July 13, 1982, Dr. Donald Ball, Director of Chemical and Atmospheric Sciences AFOSR visited with Dr. James Erskine in his lab.

September 9-10, 1982, Dr. Erskine attended an ONR contractors meeting being held at the University of Texas at Austin and then later met with ONR representatives.

T. Itoh visited Dr. H. Jacobs of Army ERADCOM at Fort Monmouth on September 10, 1982, to answer questions on distributed gain and control devices as well as dielectric waveguides.

T. Itoh was on an Advisory Panel for Graduate Fellowship Program of the Army Research Office on November 8-9, 1982.

On December 1-3, 1982, Dr. James Erskine participated in an AFOSR molecular dynamics seminar at the Air Force Academy, Colorado Springs, Colorado.

Professor R.M. Walser visited DARPA in Arlington, Virginia on January 11, 1983 to consult with Dr. Robert Stovall on magnetic thin films.

Professor R.M. Walser visited NRL in Washington, D.C. on January 10, 1983 to consult with Drs. Bruce Faraday, Carmen Carasella, Gary Prinz and others on the subject of magnetic thin films. He also presented a seminar on "Thin Film Magnetodielectrics."

On January 17 and 22, 1983, T. Itoh met Dr. C. Krowne of the Naval Research Laboratory on the occasion of IEEE Committee Meetings in Boston and Houston and discussed the future directions of slow-wave and other monolithic transmission line problems conducted at the University of Texas and at the Naval Research Laboratory.

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

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin. In the area of Information Electronics progress is reported for projects involving (1) nonlinear detection and estimation and (2) electronic multi-dimensional signal processing.

In the Solid State Electronics area recent findings in (1) interface reactions, instabilities and transport and (2) spectroscopic studies of metal/semiconductor and metal/metal oxide inter-

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In the area of Quantum Electronics progress is presented for the following projects: (1) nonlinear wave phenomena, (2) structure and kinetics of excited state molecules, and (3) collective effects in nonlinear optical interactions.

In the Electromagnetics area progress in guided-wave devices for the far infrared-mm device spectrum is summarized.