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AIR FORCE ENGINEERING RESEARCH INITIATION GRANT PROGRAM

Grant No. AFOSR-91-0212

Administered by the Engineering Foundation of the
United Engineering Trustees, Inc.

345 East 47 Street
New York, NY 10017

Final Technical Report

(Revised July 15, 1994)

CONTENTS

- A. General
- B. Grant Recipients
- C. Abstracts and Summaries
- D. Grant-related Publications

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SECTION A: General

Grant AFOSR 91-0212 covers the Air Force Engineering Research Initiation Grant (AFERIG) program for the academic years 1991-92 and 1992-93. Twenty grants were made for 1991-92 and eight for 1992-93. The particulars of these grants (grantee, school, proposal title) may be found in Section B. Note that RI-B-91-x identify the 1991-92 grants and RI-B-92-x those for 1992-93.

Section C contains abstracts and/or summaries of the 28 grants. A copy of the full report submitted by an investigator is available to AFOSR from the Engineering Foundation through the end of FY97.

Section D contains grat-related publications.

SECTION B: Grant Recipients

1991-1992 AFERIG Recipients

1992-1993 AFERIG Recipients

1991-1992 AIR FORCE ENGINEERING RESEARCH INITIATION GRANT RECIPIENTS

RI-B-91-01

Prof. Mo-How Herman Shen Ohio State University
"Real Time Monitoring of Material Degradation of Composite Structures"

RI-B-91-02

Prof. Michael J. Readey Carnegie Mellon University
"Mechanical Properties of Alumina Ceramics Having a Duplex Microstructure"

RI-B-91-03

Prof. Anthony Petric McMaster University
"Reactive Sintering and Thermodynamic Properties of Advanced Intermetallic Compounds"

RI-B-91-04

Prof. Mansoor Alam New Mexico Inst. of Mining & Technology
"Adhesion of CVD Diamond Films to WC-3% Co Cutting Tool Material"

RI-B-91-05

Prof. David Beale Auburn University
"Control of Slider Crank Rod Vibration Using Piezoelectric Film"

RI-B-91-06

Prof. Anthony M. Waas University of Michigan
"Compressive Failure of Delaminated Laminates"

RI-B-91-07

Prof. Samuel Paolucci University of Notre Dame
"Stability of Mixed Convection Flow Arising in a Horizontal Channel Chemical Vapor Deposition Reactor"

RI-B-91-08

Prof. Alan Argento University of Michigan - Dearborn
"The Dynamic Response and Stability of a Rotating Beam Subjected to a Deflection Dependent Accelerating Surface Force with Applications to High Speed Machining"

RI-B-91-09

Prof. R. Valery Roy University of Delaware
"Stochastic Dynamic Analysis of Vibro-Impact Systems"

RI-B-91-10

Prof. James Seaba University of Missouri-Columbia
"Experimental Investigation of External Geometry Effects on Jet Diffusion Flame Stability"

RI-B-91-11

Prof. Stanley J. Reeves Auburn University
"Identification of Space-Varying Blurs in Image Restoration"

RI-B-91-12

Prof. R. Jennifer Hwu University of Utah
"Development of GaInP/GaAs and AlGaInP/GaAs Semiconductor HEMT and MIS/MISFET Structures for High-Frequency Device Applications"

RI-B-91-13

Prof. John W. Silvestro Clemson University
"The Effect of Scattering by a Near-Field Obstacle on an Aperture Antenna"

RI-B-91-14

Prof. Joseph O. Ojo Tennessee Tech. University
"Multiobjective Optimum Design of Semiconductor Power Converters"

RI-B-91-15

Prof. Bahram Nabet Drexel University
"Sensory Neural Networks for Optoelectronic Detection and Processing"

RI-B-91-16

Prof. Carmen Menoni Colorado State University
"Ultrafast Dynamics of InGaP Epitaxial Films and Multiple Quantum Wells"

RI-B-91-17

Prof. S. Hashemi-Yeganeh Arizona State University
"Theoretical & Experimental Studies of Cavity Fed Slots Excited by Narrow Wires"

RI-B-91-18

Prof. Paul A. Kohl Georgia Institute of Technology
"Low Temperature CVD Reactor for Semiconductor Passivation"

RI-B-91-19

Prof. H. Hampsch Purdue University
"Photorefractive Polymers as Electronic and Photonic Materials"

RI-B-91-20

Prof. Kevin L. Bray University of Wisconsin-Madison
"Pressure Tuning Studies of Optical Glass Device Materials"

1992-1993 AIR FORCE ENGINEERING RESEARCH INITIATION GRANT RECIPIENTS

RI-B-92-01

Prof. Tresa M. Pollock
Carnegie Mellon University
"Deformation Mechanisms and Ductility Improvement in B2 Aluminides"

RI-B-92-02

Prof. Christina L. Bloebaum
State University of NY at Buffalo
"An Intelligent Synthesis Method for Concurrent Engineering Applications"

RI-B-92-03

Prof. Steven H. Collicott
Purdue University
"An Experimental Study of the Effect of a Bow Shock on Known Free-Stream Disturbances"

RI-B-92-04

Prof. Fuh-Gwo Yuan
North Carolina State University
"Analytical and Experimental Studies of Failure in Composite Shell Structures"

RI-B-92-05

Prof. Fow-Sen Choa
University of Maryland
"Integrated Tunable Detector"

RI-B-92-06

Prof. Hong Koo Kim
University of Pittsburgh
"Semiconductor Bandgap Modulation Using Piezoelectric Thin Films"

RI-B-92-07

Prof. Daniel J. Klingenberg
University of Wisconsin
"Investigation of the Role of Structure in the Dynamic Response of Electrorheological Suspensions"

RI-B-92-08

Prof. Yozo Mikata
Old Dominion University
"Stress Field in a Continuing Fiber Composite Having an Interface with Variable Material Properties"

SECTION C: Abstracts and Summaries

The abstract for each grant is enclosed.

Where appropriate, a summary or other
technical report material is also enclosed.

PROJECT SUMMARY

AIR FORCE ENGINEERING RESEARCH INITIATION GRANT (RI - B - 91 - 01)

REAL-TIME MONITORING OF MATERIAL DEGRADATION OF COMPOSITE STRUCTURES

Submitted to

Dr. Charles V. Freiman, Director
Engineering Foundation
345 East 47th Street, New York, NY 10017

Submitted by

M.-H. Herman Shen, Assistant Professor
Department of Aeronautical and Astronautical Engineering
The Ohio State University
2036 Neil Avenue Mall, Columbus, Ohio 43210-1276

Free vibration of laminated composite beams is studied. The effect of interply delaminations on natural frequencies and mode shapes is evaluated analytically. A generalized variational principle is used to formulate the equation of motion and associated boundary conditions for the free vibration of a composite beam with a delamination of arbitrary size and location. The effect of coupling between longitudinal vibration and bending vibration is considered. This coupling effect is expected to significantly effect the calculated natural frequencies and mode shapes of the delaminated beam.

A novel methodology is developed for on-line damage identification of discrete structural (spring-mass) systems. The damage characteristic (location and severity) of the system can be first detected and then identified from the change of their dynamic response (frequencies and mode shapes) through a backward-propagation neural network. The neural network is constructed by a multilayer neural network which perform the tasks of damage location identification and damage severity determination respectively. The methodology is demonstrated on two spring-mass systems. The effectiveness and limitations of the methodology are discussed and compared to the available analytical results.

**MECHANICAL PROPERTIES OF ALUMINA CERAMICS
HAVING A
DUPLEX MICROSTRUCTURE**

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Carnegie Mellon University
Pittsburgh, PA 15213

Grant No. RI-B-91-02

ABSTRACT

This study examined the role of grain size distribution and grain shape on the strength and flaw tolerance of alumina ceramics. High-purity alumina ceramics having different grain size distributions and morphologies were fabricated. The microstructures and mechanical properties were then evaluated. The results show that the presence of coarse grains in a fine-grained matrix leads to considerable flaw tolerance. However, these materials show a decrease in the strength. The results also suggest that an elongated grain morphology leads to an increase in the fracture toughness, but only when the grain size is relatively large. Furthermore, the orientation of the elongated grains is important; crack deflection and bridging occur only when the long diameter is not normal to the propagating crack.

The results of this research also provides the basis for specifying microstructures which optimize the strength and toughness of alumina ceramics. In particular, elongated grains with a maximum length of $\sim 25 \mu\text{m}$ should yield ceramics with a relatively high strength as well as high toughness. Fabricating such microstructures will be challenging, and should stimulate further research in this area.

MECHANICAL PROPERTIES OF ALUMINA CERAMICS HAVING A DUPLEX MICROSTRUCTURE

1. OBJECTIVES

Aluminum oxide ("alumina") is the most widely used advanced ceramic to date. It is inexpensive as a raw material, easy to process, and has many desirable properties such as high strength, high-temperature stability, and excellent corrosion resistance. However, ceramics composed of alumina are brittle, limiting their use in many structural applications.

One way of toughening alumina is via composite technology, incorporating reinforcing materials such as high-strength fibers or whiskers into the microstructure. This technique has shown great promise, although processing reinforced alumina ceramics is extremely difficult and cost prohibitive for most applications. Another method of improving the toughness of alumina ceramics is to simply anneal the ceramic to coarsen the grains, since it is now well-established that toughness increases with grain size. Unfortunately, the improvement in toughness comes at the expense of strength. Thus fine-grained ceramics have a high strength but low toughness, whereas coarse-grained ceramics have high toughness but low strength.

The objective of this research was to investigate the feasibility of "tailoring" the microstructure of alumina in order to obtain both high strength and toughness in a monolithic ceramic. Specifically, our research strategy was to produce duplex microstructures consisting of isolated coarse grains in a fine-grained matrix. Furthermore, techniques common to manufacturing ceramics on an industrial scale were used to process the microstructures. We then fully characterized the microstructure, and evaluated the strength, and flaw tolerance (fracture toughness). We then analyzed our results in light of current models of toughening in monolithic, non-transforming ceramics such as alumina.

2. SUMMARY OF ACHIEVEMENTS IN FY92

In this one year program, we have concentrated on processing, microstructural characterization, and mechanical properties evaluation of alumina ceramics having different grain size distributions and grain morphologies. The program resulted in both a technical presentation as well as a technical publication (in progress). Our key results are summarized below. Further details are given in the Appendix.

2.1 Processing and Characterization of Controlled Microstructures

We have successfully fabricated dense (>98% of theoretical) microstructures of alumina consisting of different grain size distributions and grain morphologies. Specifically, as-received, high-purity alumina powders were processed to achieve fine-grained microstructures having either an equiaxed or elongated grain morphology. Duplex microstructures containing coarse and fine grains were fabricated by mixing a small amount (< 1%) of a calcium aluminum silicate glass (CAS) phase with the alumina powder. The heat-treatments were then varied to result in dense ceramics with approximately the same average grain size, but different grain size distributions. Unfortunately, distinctly bimodal structures could not be produced. However broad distributions skewed to larger grain sizes were obtained.

Grain morphologies also varied according to composition and heat-treatment. Equiaxed morphologies resulted from extremely high-purity alumina powders, whereas elongated grains resulted from less-pure starting alumina powders and those doped with the CAS glass additions. The grain size and aspect ratio distributions were obtained by analyzing several hundred grains from each specimen using a semi-automatic image analysis system.

2.2 Strength and Flaw Tolerance

In general, we observed that the strength of our materials decreased as the width of the grain size distribution increased. The strength was independent of the average grain size, and appeared to be influenced more by the size of the largest grains in the microstructure; larger grains resulted in lower strengths. Such decreased strengths could be the result of the large fraction of coarse grains present, which ostensibly act as failure origins.

The flaw tolerance was observed to increase dramatically with increasing breadth of the grain size distribution. Prior studies by other investigators (see Appendix) have shown that large average grain sizes were a necessary prerequisite for enhanced flaw tolerance. However, this study shows that it is the shape of the distribution, not only the average grain size that is the important microstructural parameter. Furthermore, it is clear from images of crack paths that elongated grains are effective grain bridging elements, provided the grain size does not become too large. Extremely coarse grains tend to fail in a transgranular fashion, and thus do not function as bridging elements.

Our results also indicate that the ideal coarse grain would be elongated in shape, with the longest dimension $\sim 25 \mu\text{m}$. This size provides for considerable crack deflection and bridging, while still facilitating intergranular fracture necessary for high toughness in these materials. Fabricating such microstructures will be challenging, and should stimulate further research in this area.

REACTIVE SINTERING AND THERMODYNAMIC PROPERTIES OF ADVANCED INTERMETALLIC COMPOUNDS

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RI-B-91-03

Intermetallic compounds and intermetallic composites appear to offer superior properties over both conventional superalloys and advanced ceramics. The problem of fabrication of intermetallic components is still the major obstacle in their implementation. The aim of this project was to investigate the thermodynamics of intermetallic compounds and the combustion synthesis and mechanical properties of ceramic/intermetallic composites containing niobium and/or titanium. Combustion synthesis (or reactive sintering) is a method of producing intermetallic compounds, ceramics or composites by reacting a compacted powder mixture of the pure elements or their oxides to form the final product.

Two types of composites reinforced by fine ceramic particulates were produced by the combustion synthesis technique. The first consisted of an aluminum alloy matrix with 15-30 wt% $\text{Al}_2\text{O}_3 + \text{TiC}$. Reacted samples were mechanically worked by hot pressing, hot isostatic pressing or hot extrusion. The tensile strength varied from 177 MPa for the 15 wt% ceramic sample to 257 MPa for the 30 wt% ceramic sample. Further work to improve these properties is continuing. The second type of composite was based on an alloy matrix of Ti-24Al-11Nb reinforced by TiB. Vickers hardness increased from 1.7 GPa for the unreinforced intermetallic to 7.4 GPa for the samples having 20 at% titanium boride phase. The microstructure of this composite consisted of TiB fibers aligned in the direction of propagation of the combustion wave. The geometry of the TiB reinforcing fibers is unique to the combustion synthesis method of processing. The fibers were less than 1 μm in diameter and up to 25 μm long which should impart excellent properties to the composite.

The thermodynamic properties of iron-niobium intermetallics were studied by the EMF method using a yttria-thoria solid electrolyte. This study was not complete at the end of the grant period and the work is continuing.

Adhesion of CVD Diamond Films to WC-3 w% Co Cutting Tool Material**Mansoor Alam**

**Department of Materials and Metallurgical Engineering
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801**

ABSTRACT

Polycrystalline diamond films were prepared by a hot filament assisted chemical vapor deposition process on WC-6 w% Co cutting tool material substrates as a function of surface preparation condition and substrate temperature during growth. The films were subsequently characterized for growth rate by SEM (after cutting the samples through their thickness), for morphology by SEM, for texture and stress by X-ray diffraction, for the amount of non-diamond carbon in the film by Raman spectroscopy and for adhesion by the tensile pull testing.

Growth rate was higher on rough surfaces as compared to polished surfaces. Presence of diamond particles embedded in the scratches on the surface cracks improved the growth rate even further. With regard to substrate temperature growth rate followed a parabolic behavior having a maximum at 1323 K. The apparent activation energy for film deposition was 70 kJ/mole. The films were dominated by ball like morphology. The typical cubic and octahedral facets were not present. Crystalline nondiamond carbon phases were not observed. Crystalline strain in the films was of the order of 0.1 percent and compared well with the thermal expansion mismatch between WC and diamond. Measured strain values did not show any correlation with either the surface preparation condition or the substrate temperature. Raman spectroscopy showed the sharp diamond band and a broad amorphous carbon band in all the films. The diamond to amorphous carbon Raman band intensity ratios varied from sample to sample but showed no correlation with processing variables. Tensile pull adhesion testing resulted in failure at the film-substrate interface, epoxy-film interface and at pin-epoxy interface. Most of the time failure was at epoxy-film interface as a result of poor epoxy-film bonding perhaps due to surface contamination. This failure mode does not give an accurate adhesion value, but only the minimum estimate of the coating adhesion which varied between 48-73 MPa. The failure modes or the failure loads did not correlate with deposition conditions or film characteristics.

This work was supported by the AFOSR under grant number RI-B-91-04 through the Engineering Foundation.

Project Title: Control of Slider-Crank Rod Vibration Using Piezoelectric Material

Grantee: David Beale, Assistant Professor
202 Ross Hall
Department of Mechanical Engineering
Auburn University, Al, 36849-5341

Grant Number: RI-B-91-05

Based on Euler-Bernoulli beam theory, the system was described by a single nonlinear ordinary differential equation with periodic coefficients. Periodic steady state solutions were found by use of Harmonic Balance Method/Fast Fourier Transform and revealed favorable agreement with Runge-Kutta numerical integration. Stability of the open loop system was examined using the monodromy matrix method and showed some interesting nonlinear phenomena such as jump, period doubling bifurcation, and amplified response. Our experiments verify the analytical findings. Nondimensional amplitude versus nondimensional crank speed was plotted to examine the effect of external force, piston mass, and crank length. In order to suppress vibration and stabilize the system, a closed loop system control scheme was designed based on a direct output feedback control law. In this study, piezoelectric ceramic elements were used as both actuator and sensor. The rod vibration was substantially suppressed at low speeds; however disturbances from the external (gas) force on the piston could not be effectively reduced at high speed due to voltage input limitations required to prevent piezo material breakdown. A study of the controlled system stability was performed, also using the monodromy matrix algorithm. Frequency-response plots were constructed by employing Harmonic Balance Method/Fast Fourier Transform to see the effects of parameter variations on the controlled system response.

Compressive Failure of Delaminated Laminates

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Graduate Research Assistant

Anthony M. Waas
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RI-B-91-06

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Sponsored by:

The Engineering Foundation
345, East 47 Street,
New York, N.Y. 10017

Summary

A mechanical model is described for the problem of buckling of unilaterally constrained, finite, rectangular plates. Due to the nature of the imposed constraint on the plate's lateral deflection, w , solving for the buckling load required the solution of a nonlinear partial differential equation in w . While the plates were modeled along the lines of classical plate theory, the nonlinearity arose from the fact that the plates were attached to nonlinear elastic foundations exhibiting a deformation sign dependent force-displacement relationship. This feature was introduced to model the unilateral constraint. The influence of different boundary conditions, material orthotropy, and transverse load distributions was investigated. For each case, the weak form of the governing differential equation was solved via the Galerkin's method. Investigations of the buckling loads of rectangular plates attached to such foundations and subjected to a uniform inplane stress field showed the validity of this approach for the cases investigated and compared to some previous exact results reported in the literature.

Stability of Mixed Convection Flow
Arising in a Horizontal Channel Chemical
Vapor Deposition Reactor

Final Report

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Notre Dame, IN 46556

August 27, 1992

1 Introduction

Fabrication of semiconductors using chemical vapor deposition (CVD) depends critically upon the uniformity of the deposition processes which in turn is strongly affected by convective and diffusive transport. A typical reactor configuration comprises of a flowing gas in a channel with deposition occurring on a heated substrate on the lower surface. If the flow and temperature fields between the two horizontal plates were fully developed, the phenomenon might be considered to be two-dimensional and the resulting deposition would be uniform. However, it is known that when the temperature difference between these plates is as large as found in CVD reactors, the fully developed flow becomes unstable, resulting in steady or unsteady vortex rolls with axes aligned with the flow, transverse to the flow, or at some other angle in between. Thus, the flow and temperature fields, and subsequently the uniformity of deposition, are completely affected by the instability which leads in general to a three-dimensional flow. These effects are important for the design and operation of CVD reactors as demands for deposition uniformity become much more stringent.

A typical horizontal channel flow reactor is shown in figure 1, and the portion near the heated substrate is illustrated in figure 2. The channel is usually a few centimeters high with an aspect ratio (width to height) of one to ten and a channel length of approximately one meter. As shown in figure 1, an entrance length is normally provided to allow for hydrodynamic development of the flow. The carrier gas is usually hydrogen or an inert gas such as helium, argon, or nitrogen. The average flow velocity U is typically a few centimeters per second.

Expansion effects caused by density changes with heating of the gas play a major role in the flow behavior and can be modelled by the ideal gas law. A heated substrate with $T_h^* \approx 1000$ to 1300 K is located in the floor of the channel, while the channel ceiling is usually maintained at the ambient temperature of $T_c^* \approx 300$ K. Because of the large temperature variation in CVD reactors (typically 300 – 1000 K) the Boussinesq approximation is not appropriate for CVD modelling. Furthermore, it is necessary to include temperature variation in the transport and thermophysical properties.

The above typical flow and temperature ranges result in the Reynolds number being typically in the range 1 – 1600 , while the Rayleigh number varies between 50 and 10^7 . Consequently, a mixed convection flow results from

the interaction between buoyancy and the imposed gas flow, and as a first approximation, the CVD reactor can be modelled by the flow between two parallel infinite plates.

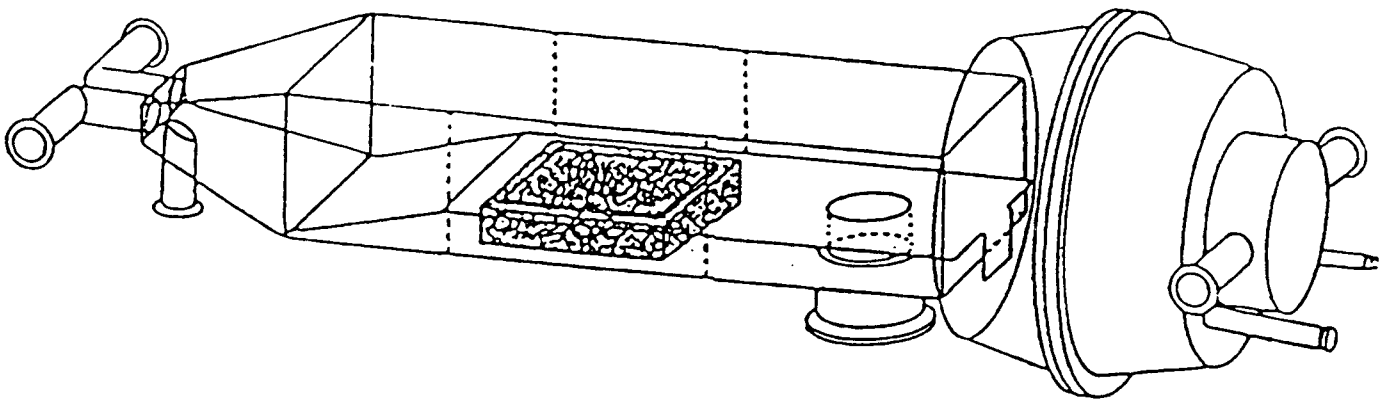


Figure 1: Horizontal channel CVD reactor.

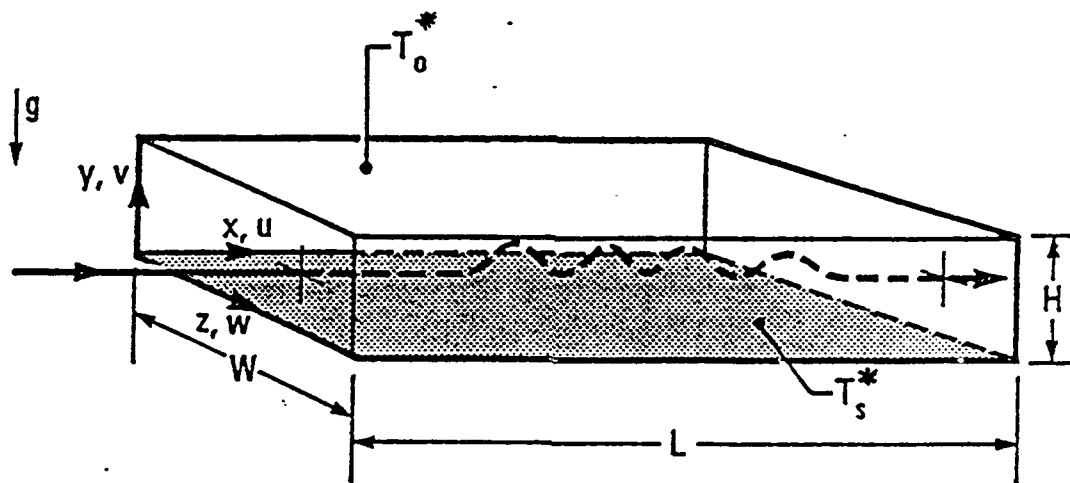


Figure 2: Horizontal channel geometry and coordinate system.

2 Outline of the Analysis

Using the transient, variable property, three-dimensional equations, applied to a horizontal channel flow, we perform a linear stability analysis of the fully developed flow which exists when the Reynolds number and the Rayleigh number are both small.

The above objective is achieved by breaking down the problem as a sequence of tasks that we now summarize in this report. Detailed descriptions of the tasks are given in the attached paper which is to be submitted for publication in a referred international journal.

- The analytical problem is defined as a system of partial differential equations in dimensionless form, and the relevant dimensionless parameters are identified. These parameters are:
 1. the Prandtl number, Pr , which characterizes the specific gas chosen;
 2. the amount of overheat, ϵ , which measures the temperature difference between the substrate and the channel ceiling;
 3. the Reynolds number, Re , which measures the flow rate of the gas; and
 4. the Rayleigh number, Ra , which measures the importance of buoyancy forces.

In this work we have chosen nitrogen as the carrier gas, thus all reported results are for $Pr = 0.7$. In addition, for the range of temperatures and pressures relevant to CVD, we have assumed that the gas behaves as calorically perfect, and the thermal conductivity and dynamic viscosity are given by Sutherland-law forms with the associated dimensionless constants $S_k = 0.5$ and $S_\mu = 0.357$.

- The basic (fully developed) flow is obtained analytically. The resulting dimensionless velocity and temperature distributions are shown in figure 3 for three values of ϵ . The basic flow is also computed numerically using an integral Chebyshev pseudo-spectral method, and the accuracy of the numerical solution is checked against the analytical solution.

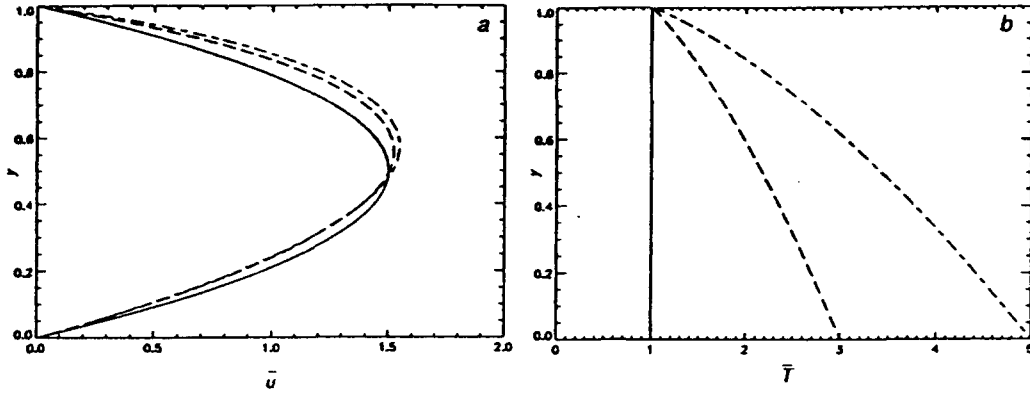


Figure 3: Longitudinal velocity and temperature profiles of the basic flow.

- The system of linear partial differential equations, which govern the growth or decay of the perturbed basic flow, is obtained by decomposing the flow into basic and disturbance components, and subsequent dropping of second order terms in perturbations.
- Using a Laplace-Fourier spectral decomposition in time and in the horizontal directions, we obtain the eigenvalue problem consisting of the generalized Orr-Sommerfeld equations.
- We then apply the same pseudo-spectral Chebyshev method in the direction normal to the channel walls to further reduced the linear stability problem to an algebraic eigenvalue problem.
- At this stage, we choose specific sets of dimensionless parameters for which stability results are obtained. These parameters are chosen so as to encompass the range of values relevant to CVD, i.e. we take three values of ϵ (2×10^{-5} , 2, 4), and 15 values of Re (in the range of 0-2000). Then for each set of such values, and for fixed values of wavenumbers in the horizontal plane, we search for the value of Ra (in the range $0-10^8$) such that the disturbance does not grow in time. This process is repeated for all wavenumbers in the range between 0 and 15. The result of this process is a marginal stability surface corresponding to the particular values of ϵ and Re . The minimum Rayleigh number over all values of wavenumbers in the marginal stability surface corresponds to

the critical value Ra_c , and the associated critical wavenumbers α_c and γ_c , and the critical longitudinal wave speed c_c .

The numerical stability results obtained using the above algorithm and procedure are summarized next.

3 Summary of the Results

Results of the analysis are used to delineate in parameter space the different flows possible. In addition, the analytical results are used to suggest appropriate choices of parameters which would lead to more uniform deposition in CVD reactors. Detailed results as well as discussions of physical modes of instabilities are given in the attached paper. Here, we only mention key points of the results which are directly relevant to CVD.

In the absence of lateral sidewalls, longitudinal rolls are found to be most unstable for arbitrary values of temperature difference between the substrate and ceiling in a channel CVD reactor, and independent of Reynolds numbers relevant to CVD. The expected lateral spacing between these rolls can be estimated from the critical wavenumber found from the analysis and displayed in table 1. This wavelength is found to be approximately twice the channel height and decreases slightly with temperature difference. However, from the table we also see that the critical Rayleigh number increases substantially with temperature difference.

Table 1: Critical values of wavenumber γ_c , and Rayleigh number Ra_c for $Pr = 0.7$ and $\epsilon \rightarrow 0$, $\epsilon = 2$, and $\epsilon = 4$.

$\epsilon \rightarrow 0$		$\epsilon = 2$		$\epsilon = 4$	
γ_c	Ra_c	γ_c	Ra_c	γ_c	Ra_c
3.117	1.70784×10^3	3.179	3.67941×10^4	3.228	2.01111×10^5

The implication of the results is that if one desires to keep film growth uniform, the geometrical and thermal design conditions in the channel reactor must be chosen in such a way as to keep the Rayleigh number below the appropriate critical value, independent of the flow rate. Failure to keep

the design Rayleigh number below critical values will result in nonuniform transverse film thickness due to the occurrence of longitudinal rolls.

Possible extensions of this work could include effects due to different Prandtl numbers, the presence of sidewalls, and the angle between gravity and the flow.

THE DYNAMIC RESPONSE AND
STABILITY OF A ROTATING BEAM
SUBJECTED TO A DEFLECTION
DEPENDENT ACCELERATING
SURFACE FORCE WITH
APPLICATIONS TO HIGH SPEED
MACHINING

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Final report submitted to the Engineering
Foundation for AFERIG Project: RI-B-91-08

September 1, 1991 - August 31, 1992

1 INTRODUCTION

The response, resonance, and dynamic stability of a rotating beam subjected to an accelerating, uniformly distributed surface force is studied in this report. Four boundary condition cases are considered: pinned-pinned, clamped-clamped, clamped-pinned, and clamped-free. (Hereafter referred to as p-p, c-c, c-p and c-f, respectively.) The beam is mechanically modeled using Timoshenko theory- which includes transverse shear deformation and rotary inertia, and by Rayleigh theory- which includes rotary inertia. Gyroscopic moments are included in the modeling; both theories then will predict a gyroscopically induced displacement component. The problem can be applied to machining processes such as turning and cylindrical grinding, in which the workpiece is represented by the beam, and the tool by the surface force. High speed processes are of particular interest because of the enhanced dynamic effects induced by high tool feed and workpiece rotational speed.

In turning processes the tool system tends to apply forces to the workpiece which vary with the workpiece deflection. The so-called deflection dependent force model is intended to capture such force variation and will be considered in this study. In addition, cases in which the loading function contains a superposed harmonic component will be treated.

In linear moving load problems in general, two types of instability are possible: simple forced resonance and parametric resonance. Simple forced resonance may occur when the beam is *forced* at a particular frequency related to the so-called characteristic exponents of the system. This resonance is the familiar resonance due to non-homogeneous terms in the differential equations. In the most general situation considered here, the forcing frequency is a function of load speed, load velocity profile, deflection dependence parameters, and the frequency of the superposed harmonic load component. Parametric resonance refers to an unstable dynamic response of the beam due to terms in the differential equations having periodic coefficients. In the present work, these terms arise due to the deflection dependent nature of the loading. Unlike forced resonance, parametric resonance occurs over a range of frequencies.

1.1 LITERATURE REVIEW

The response of non-rotating beams to moving loads has received extensive treatment. Two earlier studies are given in [1]¹ and [2] in which the focus is on wave propagation in the beam. The text by Fryba [3] contains a variety of problems involving moving loads on structures and numerous references. More recently, a simply supported, damped, Timoshenko beam has been treated in [4]. The active feedback control of simply supported, Euler-Bernoulli beams is studied in [5]. There, the beam is subjected to loads moving at constant speed; constant and harmonic magnitude loads are considered. An active scheme is developed which controls the maximum deflection.

Rotating beams subjected to moving loads have received far less treatment. In [6], modal analysis and Galerkin's method are used to treat a clamped-pinned Rayleigh beam subjected to a point force moving with constant velocity. For the same type of loading, simply supported Timoshenko and Rayleigh beams are treated in [7] by transform techniques and modal analysis, respectively. The Timoshenko beam problem treated in [7] is extended in [8] to accelerating, distributed loads. In [9], the response and dynamic stability of a simply supported Euler-Bernoulli beam are studied. The point load moves with constant speed, but is taken to be deflection dependent. The resonance of simply supported, rotating shells subjected to constant speed point loads having harmonic magnitude is treated in [10].

In general, the response of media to accelerating forces has not received extensive treatment. Some work, however, is available for an elastic half space; see, for example, [11]. Also, the response of cables to accelerating forces has received treatment [12]-[15]. Accelerating forces on non-rotating beams is described in [3] and [16]. To the author's knowledge [8] represents the only work presently available involving accelerating loads on rotating beams.

Additional works involving the dynamics of rotating and non-rotating beams are given in [17]-[24]. Some of the works on rotating beams do not include moving surface loads, however, they represent recent analytical investigations in the general area of rotating beam dynamics. Dynamic instability is studied for various rotating beam problems in [17]-[20]. In

¹Numbers in brackets denote references appearing in the BIBLIOGRAPHY section

these works the terms containing the periodic coefficients arise due to axial forcing rather than moving loads. Parametric resonance of non-rotating beams due to moving masses has been studied in [21] and [22]. To the author's knowledge, [9] represents the only study of parametric resonance due to deflection dependent moving loads. In [9] Euler-Bernoulli beam modeling is used which cannot capture the gyroscopically induced displacement component, the load speed is constant, and the load magnitude is constant (other than the deflection dependent effect). The effects of non-constant spin rate are investigated in [23] for a beam rotating about an axis parallel to its own axis; spinning shafts are included in the analysis. Also, in [24] finite elements are used to study the forced vibrations of rotating beam systems.

The governing equations in the present problem turn out to be a system of coupled, linear differential equations containing periodic nonhomogeneous terms and periodic coefficients. The regions of parametric resonance are extracted from the homogeneous version of these equations using the monodromy matrix method. The determination of the forced resonance characteristics amounts to the study of the steady state response of forced Hill equations. Some fairly general information on this topic is available in [25]-[27]. Additionally, forced and parametrically excited nonlinear systems are treated in [28]-[30] by the method of multiple scales.

Lastly, literature related specifically to high speed machining, vibrations in cutting processes, or varying machining conditions are given in [31]-[39] and will now be discussed. General reviews of high speed machining issues, problems, and expectations are given in [31]-[33]. An investigation is made in [34] of tool materials and tool failure mechanisms for high speed machining processes. In addition, strategies are deduced for developing tooling systems for high speed machining. In [35] and [36] studies are made of the effects of varying machining conditions on milling processes. Specifically, in [35] the focus is on adaptively controlled machining processes in which feedrate and spindle speed may vary. In [36] the use of variable speed cutting to suppress vibrations is studied for a face milling process. The build up of vibrations which lead to chatter in a grinding process is studied in [37]. Likewise, the role of tool geometry on chatter is investigated in [38] for a high speed turning process. The suppression of tool vibration by use of a viscoelastic damper is given in [39].

1.2 SOLUTION METHODOLOGIES

The transform solution methodology employed in [8] is ineffective for boundary conditions other than simply supported. In [3] generalized finite integral transforms are applied to the non-rotating case, however, the method requires knowledge of the beam's normal modes of vibration. These are laborious to determine in the rotating case so, in the present work, Galerkin's method is used to suppress spatial dependence in the equations of motion. The resulting time dependent equations are numerically integrated for the response of the beam.

The regions of the beam's dynamic instability due to the action of the moving load are determined using the monodromy matrix technique. This involves repeatedly integrating the homogeneous part of the governing system using specific initial conditions. The procedure is highly numerically intensive, but it permits determination of all possible regions of instability.

The forced resonance characteristics of the system are derived by modification of a state space method described in [26] involving manipulation of the forced part of the solution.

1.3 OVERVIEW OF THE REPORT

The report contains four research topics as described below.

1. (Section 2) The work in [8] is extended to additional load velocity functions and boundary conditions- in particular c-c and c-p. Also, c-f boundary conditions are considered for validation purposes. Moreover, as described in [3], non-rotating c-f beams subjected to moving loads have some structural applications.

Results are presented for the beam response using four load velocity profiles. The effects of rotational speed, load speed, and beam geometry are studied. It is found that the gyroscopically induced component of displacement is significantly effected by the varying load speed. Results reported in [5] show that beam deflections in constant speed moving load problems are controllable through the active application of forces to the beam (non-rotating). The results in the present work suggest that deflection is also controllable via the load velocity function. That is, through adjustment of the load velocity profile, the maximum deflection can be minimized and the

deformed shape of the beam can be smoothed. The gyroscopically induced displacement component is particularly effected. Such a procedure could be of use in machining processes since control of workpiece vibrations would result in improved cutting accuracy.

2. (Section 3) The transient response of rotating Timoshenko beams subjected to accelerating, deflection dependent loads is studied. The equations of motion are presented and then reduced to a system of forced Hill equations for p-p and c-c supports.

Numerical results are given for the transient response of beams for a variety of load cases. It is found that the deflection dependence tends to reduce the peak value of the beam's displacement component in the loading direction (i.e. the direct component). The gyroscopically induced component is also reduced, except for situations in which the deflection dependence is small- then the displacement is slightly increased. The effects of non-constant load speed are similar to those in the non-deflection dependent load case, further suggesting the potential for control of the beam vibration via the load velocity profile.

3. (Section 3) The resonance characteristics of the beam are studied. The combined action of load speed, deflection dependence, and superposed harmonic time dependence are considered. Conditions for which the beam may undergo a resonance are derived for the general case and two special cases. These conditions involve load speed, the frequency of the superposed time dependence, deflection dependence parameters, and the beam properties. These quantities can be related to machining parameters for various processes.

Resonance plots are presented for a variety of cases. It is found that the moving load and the superposed frequency excite the beam into large displacement in the vicinity of points predicted by the derived resonance expressions. Both the direct and gyroscopic displacement components are effected by the resonances. The forward and backward precession frequencies are involved in the resonances. Large displacements arise in the vicinity of the predicted resonance points even for a high load speed case for which the time the beam is forced is very short.

4. (Section 3) The dynamic instability of the beam due to the action of the deflection dependent moving load is studied. The instability regions in load-frequency space are determined for a typical beam geometry. Prin-

cipal regions of parametric resonance are found which emanate from both the forward and backward precession frequencies of the first mode. The region associated with the first backward precession frequency is quite wide. Combination resonance regions are found which emanate from the sum of the forward precession frequencies of two different modes. Additionally, the forward and backward precessions are found to interact to produce combination resonance regions emanating from the sum of their frequencies. The appearance of regions associated with both the forward and backward precessions, as well as those associated with combinations of the forward and backward precessions, result in a diagram having a somewhat larger percentage of unstable space than predicted by Euler-Bernoulli theory. (It is noted that Euler-Bernoulli theory predicts only one frequency for each mode.)

Lastly, the potential for applying the results to other related problems is described. (For example, harmonic axial loading as might arise due to misalignment, and slowly moving transverse loads having high frequency magnitude variation, which occur in some machining processes.)

Stochastic Dynamic Analysis of Vibro-Impact Systems

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Final Report

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2. Outline of Research

In view of the current state of knowledge in the field of vibro-impact systems, it is proposed to conduct analytical and experimental studies of vibro-impact systems in a random environment. When the degree of randomness is sufficiently high, reliable design and analysis of systems can only be achieved by adopting a probabilistic approach. Noise is inherently present in real life systems, and will cause the state of such systems to fluctuate. The interactions between the system nonlinearities and sufficiently strong external noise can give rise to noise-induced transitions, drastically modifying the dynamic behavior of the system (see Horsthemke and Lefever,⁴⁸ 1984). It seems therefore imperative to ask whether the qualitative behavior of simple vibro-impact systems can survive in a random environment. Weak external noise can be deliberately added to a dynamical system as a powerful way to scan and quantify its global behavior. In fact, in the context of chaotic responses, dynamical studies should be conducted from a probabilistic viewpoint, since the resulting motions are effectively random. Single trajectories lose their potential for characterizing the system's response in these cases; thus they should be described rather by a probability density function of the state variables. This was pointed out by Holmes²⁹ (1982). Kapitaniak⁷³ (1988) and Pfeiffer⁴⁵ (1990) introduced a small random perturbation in a chaotic system, so as to estimate through the Fokker-Planck-Kolmogorov equation the state probability density function. It is also noted that introducing small random disturbances can tell us much about the stability properties of dynamical systems.

In the first stage of research (§3), analog and digital experiments are conducted on simple idealizations of vibro-impact systems, namely:

- as a representative of systems whose impacts can be regarded as occurring instantaneously, we consider in §3.1 the motion of a single-degree-of-freedom system between a two-sided, harmonically excited rigid constraint, which is symmetrically placed relative to the equilibrium position of the system. We find large parameter regions of the system for which multiple steady-states coexist in the phase space. These steady-states may be linear (non-impacting), nonlinear (impacting) and periodic (harmonics or sub-harmonics), or nonlinear and aperiodic (chaotic). More specifically, we are interested in the effects of noise perturbations of the response which may either be impacting or

non-impacting in the absence of noise, one or the other being obtained by changing the initial conditions. We find that small noise perturbations can induce transitions from one attracting solution to the other, the rate of escape for each attractor being a function of the noise intensity. We also find that the escape trajectory out of a given basin of attraction is not arbitrary, but rather must pass through certain unstable limit sets (repellers or semi-attractors) which are located on the basin boundary.

- A more detailed study of the effects of noise perturbations is undertaken in §3.2 for a single-degree-of-freedom system with piecewise linear restoring forces, and excited by a constant-plus-harmonic forcing function. This simple model is representative of mechanical systems with backlash or clearances. By varying the forcing frequency, we find a rich array of responses whose steady-states correspond in the state space to attractors with widely differing characteristics. When several attractors coexist in the state space, weak noise perturbations can induce jumps from attractors with "weak stability" to attractors with "strong" stability. The long-term dynamical response of the system is thus reduced to those attractors with nearly equal metastability. A measure of the relative stability of an attractor to noise perturbations of a given intensity is given by the mean first-exit time taken by the trajectories to escape from the basin of attraction. It is found that mean first-exit times are scaled exponentially according to an Arrhenius-type law, when the noise intensity is varied. More specifically each attractor is characterized by an activation energy which represents the energy height to be exceeded by the system in order to escape from the basin of the attractor. Thus a global stability analysis of the system can be done by determination of the activation energy of each attractor. The transition from one attractor to another is achieved through repellers located on the common boundary of their basins. Hence the activation energy can be interpreted as the difference in energy of an attractor and an associated repeller. We also find situations of dramatic effects of weak noise perturbations even in the case of a system whose trajectories converge to a unique periodic attractor. In the absence of noise, the system behaves chaotically during some transient period before ultimately falling in a rather abrupt manner onto the attractor. The length of these chaotic transients depends on the initial conditions of the system. These transients are related to a "chaotic" repeller, or more appropriately called "semi-

attractors", that is, a set which is attracting in one direction and repelling in another. However, we observe that weak additive noise perturbations of the attractor can easily push the trajectories towards this semi-attractor, henceforth inducing wild excursions from the periodic attractor and thus causing large noise amplification. The larger the noise intensity the longer the chaotic transients. For sufficiently strong noise, the residence times of the system about the periodic attractor becomes vanishingly small and the response appears entirely chaotic, that is, the chaotic semi-attractor dominates the long-time behavior of the system.

- as a prototype of useful vibro-impact motions, we consider in §3.3 a mechanical system consisting of two rigid bodies connected by elastic springs, and in impact with a one-sided rigid barrier; here, the motion is designed to be impacting and stable. Without extensive parameter studies, we show that noise perturbations can cause transitions to non-impacting trajectories, and hence leading the breakdown of the useful impacting motions of the system.

In the second stage of research, §4, we review from the mathematics and physics literature a number of techniques of asymptotic analysis for the response of nonlinear systems perturbed by weak Gaussian white noise excitations. These techniques are based either on functional representation or singular perturbation techniques and they provide asymptotic forms of two quantities of interest: the state probability density over the basin of an attractor, and the mean exit-time of trajectories out of that basin of attraction. Both methods are based on the generalization of potential functions to non-equilibrium systems. It is shown in the first approach that a quasipotential function can be defined by minimizing an action-like functional defined over the set of all possible trajectories connecting points of the attractor to any point of its basin. Thus in this approach, the determination of a quasipotential reduces to the solution of some variational problem. In the second approach, a quasipotential function can be defined by a WKB approximation of the response probability density (solution of a Fokker-Planck-Kolmogorov equation) in the limit of small noise, and it can be shown to be governed by a Hamilton-Jacobi equation over the basin of attraction. This equation can be solved numerically by relating it to some Hamiltonian system and its corresponding canonical equations of motion. This method is also known as the "ray method" for the

asymptotic solution of diffusion equations. It can be shown that both the functional and singular perturbation (WKB approximation) approaches are in fact closely related in view of the connection of Hamilton-Jacobi theory and the Euler equations of a variational problem. The determination of the quasipotential function of a given attractor is pivotal since it defines to logarithmic accuracy the rate of escape of trajectories from the basin of an attractor in the limit of small noise. Thus an Arrhenius-type asymptotic form of the mean-exit times is generalized to case of non-equilibrium systems, and the corresponding activation energy of the attractor is shown to be the minimum difference in quasipotential between the attractor and the boundary of its basin. The determination of quasipotentials and activation energies is applied to a single-degree-of-freedom Duffing oscillator and to the vibro-impact oscillator considered in §3.2.

Finally, in §5, we define possible directions of future research in the field of nonlinear dynamical systems.

ABSTRACT

Project Title: Experimental Investigation of External Geometry Effects on Jet Diffusion Flame Stability

Submitted by: James P. Seaba, Assistant Professor, University of Missouri-Columbia

Grant No. RI-B-91-10

The external geometry effects on the lift-off of hydrocarbon jet diffusion flames were investigated. Two types of bluff body nozzles were utilized in this study, no central tube (conventional bluff body nozzles, $L/D_i = 0$) and nozzles with a central tube (length L) extending from the bluff body. The bluff-body nozzles were centered in a coflowing annulus of dry air. Four different nozzle geometries ($L/D_i = 0, 0.5, 1.0$, and 2.0) using two different bluff-body diameters ($D_i = 25.4$ mm, and 12.7 mm) at annular Reynolds numbers ranging from 800 to 5000 were studied. The nozzles were characterized at near lift-off conditions using propane, methane, and ethylene fuels. The recirculation zone created by the bluff-body was visualized using the reactive Mie scattering (RMS) technique. Stability curves of methane, propane, and ethylene using the four different nozzle geometries are presented. It was shown that external geometry has a significant effect on the lift-off process with the bluff-body nozzle $L/D_i = 0.5$ having the best overall stability. Also, the recirculation zone at the nozzle exit was determined using RMS photographs. The recirculation zone was visualized at three conditions; pure annular flow, cold jet, and combusting jet. The entrainment of the jet had the most significant effect on the recirculation zone. A comparison of recirculation zone length versus annular Reynolds number is shown in all three regimes. Numerical simulation of the recirculation zone length for pure annular flow about the bluff body nozzles showed excellent agreement with experimental results.

R1-B-91-11

Identification of Space-Varying Blurs in Image Restoration

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Final Report

for the

Air Force Engineering Research Initiation Grant

Identification of Space-Varying Blurs in Image Restoration

Final Report

The goal of the project is to restore images that have been blurred in a space-variant manner; that is, the blur characteristics vary across the image. A major obstacle to restoration of these images is identification of the point-spread function (PSF) that describes the space-variant blurring. In these cases, standard blur identification techniques are not adequate for the task. The identification of space-varying blurs is a much more complex problem. The problem is severely underconstrained, making general space-varying blur identification extremely difficult. Fortunately, for most blurs of interest, there is a great deal of structure in the PSF as a function of image coordinates. By choosing an appropriate representation for this structure, one can reduce the general blur identification problem to a much more constrained problem.

Early in the project, we committed to an iterative restoration framework for addressing the problem. Iterative restoration algorithms provide a great deal of flexibility and are conceptually simple to analyze. Since we are concerned with identifying space-varying blurs, we needed a reasonably efficient method for obtaining restorations in which the blurring is space-variant. Unfortunately, inefficiency is the major drawback of iterative methods. We investigated the development of a method for stopping the iterative procedure in space-variant restoration when the image is close to optimal deblurring. This task was pursued for two reasons:

1. A stopping rule would increase both the efficiency and the performance of iterative methods. Efficiency is increased because one can stop the procedure before convergence. Performance is increased because early termination acts as a form of regularization, making the iterative procedure robust to noise amplification.

2. The criterion used in a stopping rule can also be used to evaluate a blur identification criterion in the spatial domain at each iteration. We hoped that this would allow us to update the estimated blur at each iteration.

We achieved promising results with a stopping rule based on generalized cross-validation. At each iteration, the GCV function can be evaluated and the iteration stopped when the criterion begins to increase. Results for this are reported in

S. J. Reeves and K. M. Perry, "A practical stopping rule for iterative image restoration," in *SPIE Proceedings — Image Processing Algorithms and Techniques III*, 1992.

K. M. Perry and S. J. Reeves, "A practical stopping rule for iterative signal restoration," submitted for review to *IEEE Transactions on Signal Processing*.

K. M. Perry and S. J. Reeves, "A practical stopping rule for iterative signal restoration," submitted to the 1993 IEEE International Conference on Acoustics, Speech, and Signal Processing.

These papers and summaries are attached.

We have identified the need for a similar stopping rule in an iterative algorithm developed by Lucy and Richardson. This algorithm is nonlinear, which makes application of GCV somewhat difficult. However, we have done some promising analytical work on this problem and expect a solution to be forthcoming over the next few months.

Through our stopping rule work, we have shown that the generalized cross-validation (GCV) criterion can be estimated in the space-variant case. Previously, the GCV criterion could only be feasibly evaluated for space-invariant restoration. With this more flexible method, we can apply the GCV criterion to the evaluation of space-variant blurs.

We pursued the idea of evaluating the local PSF via GCV at each iteration to update the PSF in the iterative procedure. The idea was to evaluate the GCV criterion for a set of candidate PSF's in each region and choose the PSF with the best score. After a great deal of work on this approach, we have been unable to develop a successful method. We found that a direct comparison among PSF's cannot be made after the same number of iterations with

different PSF's. Larger PSF's tend to need more iterations than small PSF's for a direct comparison to be possible. We are continuing to work on a method that will allow us to compare PSF's in an iterative framework.

Although we have not yet solved the problem we originally proposed to address, we have made a great deal of progress on the problem. Specific accomplishments include:

1. We have developed a useful stopping rule for linear iterative image restoration and have submitted a journal paper reporting the results.
2. We have developed and examined a means of estimating the GCV criterion in an iterative context, which should be useful for blur identification.
3. We have acquired graduate fellowship funding from NASA to continue work on this and other related restoration problems.
4. We have generated a very flexible set of space-variant iterative restoration programs that will be used to continue the research on space-variant blur identification.

We feel that we are much closer to a solution of the space-variant blur identification problem than we were a year ago. We plan to continue the work that we initiated in this project to solve this problem.

**Development of GaInP/GaAs and AlGaInP/GaAs Semiconductor HEMT
and MIS/MISFET Structures for High-Frequency Device Applications**

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Grant Number: RI-B-91-12

High frequency electronic devices and circuits employing the rather novel lattice-matched heterosystems of GaInP/GaAs and AlGaInP/GaAs have been and studied in this work. The design, fabrication, and testing of device structures based on both GaInP/GaAs and AlGaInP/GaAs have been carried out. Both low- and high-frequency material, device, and circuit properties have been measured and analyzed. Negative differential resistance devices have been designed as frequency conversion circuits with gain. A new method of determination of the I-V characteristics of negative differential conductance devices has also been developed in this work. Monolithic integration of high-frequency electronic device employing GaInP/GaAs and AlGaInP/GaAs heterosystems have been studied for high-output power level.

The Air Force Engineering Research Initiation Grant allowed me to pay for the material and fabrication cost of the AlGaInP/GaAs and GaInP/GaAs device structures that were studied in this work. It also allowed me to pay for some parts required for the testing and measurements that were performed in this work. With some initial results obtained from this research supported by *the Air Force Engineering Research Initiation Grant*, both the NSF and the State of Utah (through the Center of Excellence Program) have started to support the development of high-frequency and optoelectronic device structures employing AlGaInP/GaAs and GaInP/GaAs material systems. Without the support of *the Air Force Engineering Initiation Grant*, this research would not reach the level of success I am now experiencing. I am grateful for the support of *the Air Force Engineering Research Initiation Grant*. For the coming year, I plan to develop the design of monolithic high-frequency and optoelectronic integrated circuits employing AlGaInP/GaAs and GaInP/GaAs material systems.

TABLE OF CONTENT

Introduction	2
Low-Frequency Properties	2
High-Frequency properties	9
Device Structure Design	15
Negative Differential Resistance Frequency Conversion with Gain	20
A New Method of Determination of the I-V Characteristics of	
Negative Differential Conductance Devices	29
Monolithic Diode-Grid Frequency Tripler Array Design	37
Summary	59
Publications Supported by this Grant	60

FINAL REPORT

Introduction

Advanced Air Force systems will require higher performance devices that will require high-quality heterostructure devices with enhanced capabilities. An example of this requirement is in the area of millimeter wave electronics for radar and communications systems. It is clear that complex heterostructures of various semiconductors will play an increasingly important role in advanced electronics. These structures include superlattices, multiple quantum wells, and other complex structures used in the design of high-frequency devices and circuits. Further development is also needed on possible alternative heterosystems to the commonly used AlGaAs/GaAs system.

I. Low-Frequency Properties

We have investigated the electrical properties of various $(\text{Al}_x\text{Ga}_{1-x})_y\text{InP}_{1-y}/\text{GaInP}/\text{GaAs}$ structures. In particular, capacitance versus voltage (C-V) and current versus voltage (I-V) were used to ascertain the electrical behavior of the structures and the metal contacts to these structures. This work continues in the direction established by

Casey et al. [1] on the properties of AlGaInP/GaAs metal-insulator-semiconductor (MIS) varactor structures.

1. Experimental Results

As can be seen from the raw and analyzed C-V data shown in Figs. 1 and 2, an epilayer of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ with $x=0$ (i.e., GaInP, which will be referred to as sample # 1) grown on GaAs forms a Schottky barrier to metal contacts with highly uniform parametric characteristics. The addition of Al to GaInP can produce a highly resistive epitaxial layer [1]. As an example, a set of oxygen-doped AlGaInP epilayers of identical thickness (1 μm) to that of sample # 1 were grown on N^+ GaAs which displayed a constant capacitance over the bias range of ± 30 volts. A breakdown field of approximately 5×10^5 V/cm and a resistivity of approximately 10^{13} $\Omega\text{-cm}$ were deduced from the I-V behavior of the same sample set, and, indicate the property of a dielectric insulator. The relative dielectric constant of AlGaInP was determined to be approximately 8.5 from the capacitance-voltage measurements from a group of five samples.

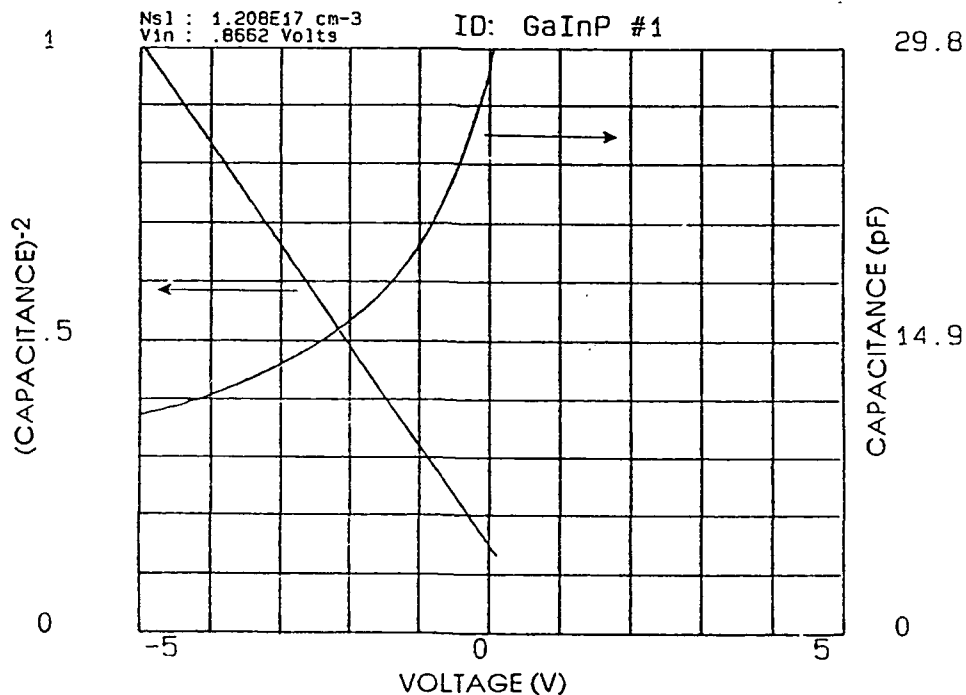


Fig. I-1 C-V curve (area 1.05×10^{-3} cm²) and $1/C^2$ versus V of GaInP sample.

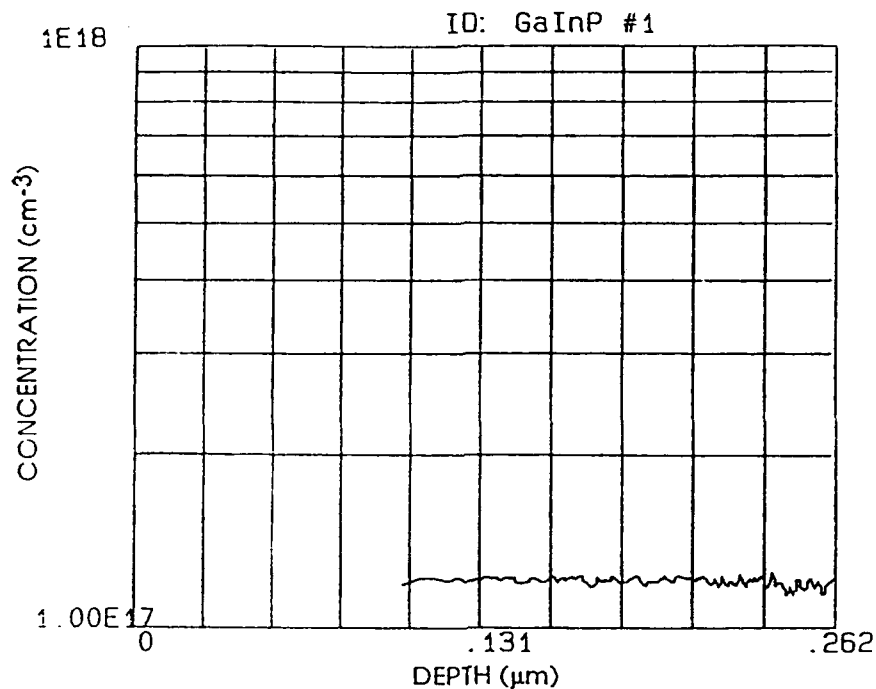


Fig. I-2 Doping profile of GaInP sample.

In this work, a multitude of AlGaInP/GaInP/GaAs samples were also investigated. Sample W375 consisted of a 0.6 μm AlGaInP layer with a multiple GaInP/AlGaInP quantum well on top of a 1 μm GaAs low-doped layer grown on a highly conductive N⁺ substrate. Samples W401, W407, and W413 consisted of a 0.1 μm AlGaInP layer, a GaInP well layer, and a 0.6 μm AlGaInP layer on top of a 1 μm GaAs low-doped layer grown on a highly conductive N⁺ substrate. The thickness of the GaInP well are 28, 84 and 270 Å for samples W401, W407, and W413, respectively. In all other respects, samples W401, W407 and W413 are identical. Large area Ohmic contacts were made to the back of the N⁺ GaAs substrate by sintering AuGe for 1 minute at approximately 430 °C. Schottky contacts to the AlGaInP epilayers were made using the conventional tri-level TiPtAu metalization scheme. Ohmic contacts to the AlGaInP layers were identical to the N⁺ GaAs back contacts and were formed during the same sintering step as that of the back Ohmic contact.

Schottky contacts to AlGaInP-containing samples W375, W401, W407, and W413 represent the general trend (that is, the larger the bandgap, the larger the Schottky barrier height) found for conventional metal Schottky contacts to GaAs-based (i.e., GaAs and AlGaAs) semiconductors. Fig. 3 shows the C-V curve of a W375 Schottky contact dot. There is considerable hysteresis between the forward and reverse direction C-V curves. This hysteresis was seen in all Schottky contact samples as further evidenced by the C-V curve (Fig. 3) of a W407 Schottky contact dot. This is a general feature observed for all the Schottky contacts to AlGaInP-containing samples which were studied (including W401 and W413). The large shift in flat-band voltage of the C-V curve of sample W407 compared to that of W375 is due, in part, to the thin GaInP layer inserted in the AlGaInP epilayer.

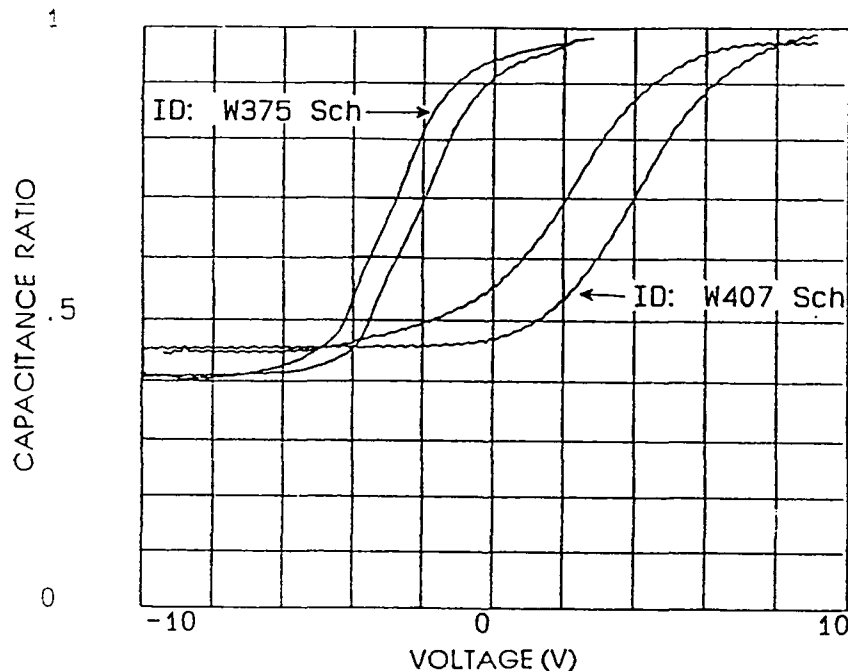


Fig. I-3 C-V curves of AlGaInP-containing samples W375 and W407 (area 1.05×10^{-3} cm²).

The trends observed for Ohmic contacts to the AlGaInP epilayers were similar for all samples investigated. The AlGaInP-containing samples to which front surface Ohmic contacts were formed, had C-V characteristics which displayed little to no hysteresis. A major drawback was the instability of these structures to withstand forward bias (accumulation) voltages of more than 1 volt. For forward biases in excess of 1 to 2 volts, large leakage currents rendered the capacitance measurements erroneous and useless for meaningful interpretation.

A dramatic difference in the I-V mechanisms was observed between the Schottky and Ohmic contacts to the AlGaInP/GaInP epitaxial layers. All the Ohmic contact AlGaInP-containing samples exhibited a combination of conduction processes that include Frenkel-Poole emission and modified Schottky emission/conduction process. These conduction processes were dependent on structure parameters of AlGaInP-containing samples.

The I-V characteristic of sample W375 is shown in Fig. 4. W375, which had a multiple AlGaInP/GaInP quantum well had modified Schottky-like behavior with $J_s = 1.18 \times 10^{-10} \text{ A/cm}^2$ and an ideality factor, n , of 10.6. The single quantum wells reported in this work (W401, W407 and W413) also displayed modified Schottky-like behavior with a monotonic increase in J_s with decreasing GaInP well width as shown in Table 1. This behavior is unlike that found in oxygen-doped AlGaInP of reference 1 in which Frenkel-Poole emission was the dominant current conduction process.

2. Summary and Conclusions

The investigation of highly insulating AlGaInP epilayers with and without GaInP wells has shown that GaInP grown on N^+ GaAs form excellent Schottky barriers with standard metalization. The addition of Al to GaInP produces a highly resistive epilayer that possesses the property of a dielectric insulator. Considerable hysteresis between the forward and reverse direction C-V curves was observed in all Schottky AlGaInP/GaInP/GaAs contact samples. However, the C-V characteristics in all Ohmic

AlGaInP/GaInP/GaAs contact samples displayed little to no hysteresis. The thin GaInP layer inserted in the AlGaInP epilayer induces a large shift in flat-band voltage of the C-V curves. The Ohmic AlGaInP/GaInP/GaAs contact samples exhibited a combination of conduction processes that include Frenkel-Poole and modified Schottky emission. The Schottky AlGaInP/GaInP/GaAs contact samples displayed modified Schottky-like behavior.

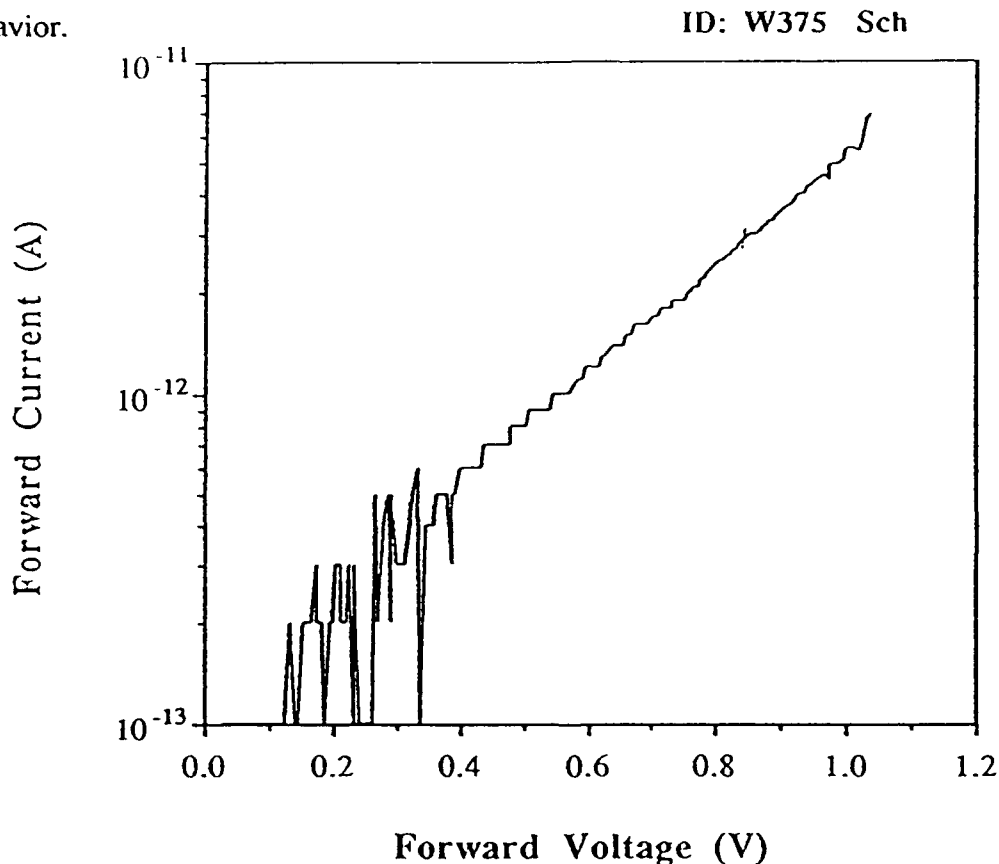


Fig. I-4 Forward I-V curve of AlGaInP-containing sample W375.

3. References

- [1] H. C. Casey, Jr., J. S. McCalmont, H. Pandharpurkar, T. Y. Wang and G. B. Stringfellow, "Current-voltage and capacitance-voltage behavior of high resistivity AlGaInP on GaAs", APL-54, No. 7, pp. 650-652, 1989.
- [2] R. J. Hwu, T. Y. Wang, L. P. Sadwick, and G. B. Stringfellow, "Electrical Properties of Schottky and Ohmic Contacts to Highly Insulating AlGaInP Structures," EDMS Proceedings, 1990.

Table I-1 I-V results of AlGaInP-containing samples W375, W401, W407, and W413.

Sample #	J_s (A/cm ²)	n	I_s (A)
W 375	1.18×10^{-10}	10.6	1.26×10^{-13}
W 401	2.44×10^{-4}	4.3	2.6×10^{-7}
W 407	4.14×10^{-11}	1.75	4.41×10^{-14}
W413	3.03×10^{-11}	3.07	3.23×10^{-14}

Air Force Engineering Research Initiation Grant RI-B-91-13

The Effect of Scattering by a Near-Field Obstacle on an Aperture Antenna

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Abstract

The goal of this project was to develop the solution techniques needed to model the interaction of an aperture antenna with a large near zone conducting scatterer. This problem is of interest to antenna designers who often must place their antenna in very complex environments and also test engineers who often must place a test object in the near zone of an antenna. The problem was analyzed using a hybrid Method of Moments/Geometrical Theory of Diffraction technique. The field in the aperture is solved for using the Method of Moments. The effect of the scatterer is included in the solution procedure by using the Geometrical Theory of Diffraction. A computer code has been developed which uses this technique to solve for the field in the aperture of the antenna and the resulting reflection coefficient. The cases of interest include scatterers that are long cylinders with circular or rectangular cross section and flat plates. The computer model has been found to be very accurate. Comparisons of the computed results with measured data show excellent agreement for the case of a circular cross section cylinder and for certain orientations of a rectangular cross section cylinder. Samples of these comparisons are included. The work presented demonstrates the effectiveness of this special implementation of the hybrid Method of Moments/Geometrical Theory of Diffraction in modeling the problem of a conducting scatterer in the near zone of an aperture antenna.

MULTIOBJECTIVE OPTIMUM DESIGN OF SEMI-CONDUCTOR POWER CONVERTERS

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ABSTRACT

The work leading to this report deals with the modeling, analysis and multi-objective optimization of resonant converters operating in both continuous-current and discontinuous-current conduction modes. Resonant converters operating in the continuous-conduction modes are modeled for predicting steady-state and dynamic performance and for design purposes. This model based on the concepts of describing function and harmonic balance techniques has been shown by experiment to accurately predict steady-state peak values, output filter components and system transfer functions up to the converter switching frequency. A small-signal model derived from this model has utility in the prediction of system dynamics and in converter closed-loop controller design. The design optimization of 100 W parallel resonant and series parallel resonant dc/dc converters operating in the discontinuous and discontinuous-conduction modes show that minimization of input peak current, minimization of converter reactive power and efficiency maximization are commensurable for a wide range of operating converter system frequency. That is, a design that minimizes the converter input current also reduces the reactive power demand and improves the converter efficiency.

Final Report

Proposal Title: Sensory Neural Networks for Optoelectronic Detection and Processing

Sponsor: Engineering Foundation through Air Force Engineering Research Initiation
Grant RI-B-91-15

Submitted by: Bahram Nabet, Ph.D.
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Date: 5/1/93

1.0 Introduction

The stated objective of the proposal "Sensory Neural Networks for Optoelectronic Detection and Processing" was to implement a class of physiologically derived neural networks in electronic hardware. Great progress was made in reaching this goal. The initial advances expanded this work to include more tasks than originally intended. Continuation of this project is now funded by the National Science Foundation through a Research Initiation Award. The PI edited one book, published one journal article, two book chapters, and several conference papers based on the results of this project. Progress in research was not at the cost of teaching excellence and the PI received teacher-of-the-year award from graduating seniors for the academic year 1991-92. These achievements were impossible without the generous support of the Engineering Foundation.

The following briefly describes our progress relative to the time plan of the proposal. Proposed tasks in the original proposal are mentioned under same heading and our progress in each category is described. Copies of relevant publications are provided as appendices to report the technical details of our work. Specifically, the enclosed book chapter "Electronic Hardware for Vision Modeling" addresses all the technical issues raised in the original proposal. The first six months of this project were described in our interim report and are also briefly reviewed and modified here.

2.0 Accomplished versus Proposed Work

2.1 Proposed work for the period 8/1/91-12/31/91

Proposed Task 1- Data acquisition board will be constructed and tested.

Accomplishments: This task has been accomplished. We have constructed and tested a data acquisition board which is connected to a Macintosh host microcomputer via a simple MODEM. The board is capable of inputting 16 lines of data in either analog current or voltage forms and extracting and storing the output. The board can also move a spatial pattern across the array. Unfortunately, recently this board has developed some problems that have been difficult to diagnose due to the fact that the undergraduate students involved in this project have graduated. This has delayed the testing of the motion detector chips that were fabricated through the MOSIS foundry service.

Our success with this board prompted a new project where a new board was designed which uses the speed and parallelism of the Macintosh II series NUBUS communication board. This new project was undertaken by a group of seniors as their senior design project. The new board was used to program the 64-pin Intel Neural Network (ETANN) chip. Intel Corp. supported this effort. The senior design group completed a prototype and upon graduation is completing the board for introduction to commercial market.

Proposed Task 2- A 16-cell fully connected network will be constructed from discrete components for ease of diagnosis and reconfiguration.

Accomplishments: This task has been completed. Analysis of the network has been completed; the results have shown good correspondence with theory. This network has been especially useful in providing scaling data, that is, expected power consumption and possible interconnectivity. The analysis of the dynamics and the implementation results, however, show that full connectivity with uniform connection strength produces a uniform behavior across the cells which is of little processing interest. The results of implementation of a network with a weight profile which decreases with distance have been very interesting and have been reported in a journal article which is attached.

Proposed Task 3- Computer simulations using spice will be started.

Accomplishments: A graduate student who was partially supported by this project, and several undergraduate students were trained on using PSPICE circuit simulation software. A relatively large library of different designs were created. Feedback and feedforward networks were simulated. Due to its feasibility, the SPICE simulation proved very useful. Results of simulation of feedback networks were reported in the enclosed journal paper, results of simulation of feedforward networks were reported were reported in two conferences.

2.2 Proposed work for the period 1/1/92-3/31/92

Proposed Task 1-16-cell network will be tested.

Accomplishments: This network was constructed and tested as mentioned above.

Proposed Task 2- Programmable synapses will be constructed and tested.

Accomplishments: Our programmable synapses are implemented by adding a second gate to a Field Effect Transistor. A SPICE file was created and several dual-gate FETs were purchased. Learning algorithms which could best be implemented within the structure of interest, given circuit constraints were studied. The designs, however, were not successful due to the very limited allowed dynamic range. We have not yet attempted to modify these designs since the stress of our work is on peripheral vision in which little or no learning is performed.

Proposed Task 3- Sensitivity tuning will be implemented

Accomplishments: This task has been accomplished. The analysis has been reported in the International Joint Conference on Neural Networks (IJCNN) in Seattle, where a theory has been presented describing the effect of variation of passive membrane conductance on light adaptation. Further work on automatic tuning of this conductance has produced circuitry that can discount the illuminant. A paper is in preparation which describes the results.

Proposed Task 4- Decision making for motion detection will be studied

exciting progress has been achieved in this area. Two motion detectors have been designed. One is a shunting detector which has evolved from our own previous work while the other is a classic motion detector proposed in 1960's. Both have been implemented so as to allow

comparison. Two papers have been submitted to conferences presenting the simulation results. A third paper is in preparation with theoretical analysis of motion detection process.

2.3 Proposed work for the period 4/1/92-6/30/92

Proposed Task 1- 16-cell network with photodetectors will be laid-out for integrated circuit fabrication.

Accomplishments While the design and simulation of a 16-cell network was accomplished as planned, we discovered that MOSIS does not support fabrication of photodetectors with large enough photocurrent to match the rest of the circuitry. We decided to fabricate our own photodetectors and connect them externally to the circuit. Fabrication of our own Metal-Semiconductor-Metal (MSM) photodetectors was only recently completed and the detectors have not been tested yet.

An alternative was also pursued which used the parasitic bipolar photodetector in CMOS. This detector is best utilized if the processing Field-Effect Transistor circuitry operates in subthreshold region of operation. We are presently working on converting our designs to subthreshold designs.

Proposed Task 2- 16-cell network with tunable sensitivity will be laid-out and simulated.

Accomplishments This circuit was designed and simulated. The result was as expected, but we observed that tuning of sensitivity interacts with edge-enhancement operation of the network. This lead to a wider study of the problem of contrast constancy which is still continuing. Preliminary results were described in the Master's thesis of a graduate student who was supported by this grant.

Proposed Task 3- A third 16-cell network with programmable connection strengths will be laid out and simulated.

Accomplishments As explained above, our programmable synapses worked but had limited dynamic range, that is, the resolution of the weights was not sufficient. This precluded simulation of a learning network. Choice, however, is the limit of programmability and we used the second gate of the FET to implement binary synapses. These binary weights were used in our motion detection circuits.

Proposed Task 4- The designs will be submitted to MOSIS for the fabrication of the chips.

Accomplishments Since the capabilities of these networks were theoretically studied and closely matched simulation results, we felt that their actual implementation is not very informative. Rather, we concentrated on studying higher level processing capabilities which could be achieved using the compiled components. A motion detector circuit was designed and submitted for fabrication that included feedback networks, binary synapses and a comparison circuit.

2.4 Proposed work for the period 7/1/92-8/31/92

Proposed Task 1- The integrated circuit chips will be tested

Accomplishments We received our motion detector circuits in September 1992. As explained above, our characterization board has not been functioning properly. While trouble-shooting the board we are also looking into commercial data acquisition instruments to test the hardware.

Proposed Task 2- Software for two-dimensional applications will be written.

Accomplishments We intended to use the small scale hardware network to act as a template for processing much larger two-dimensional images but this task has proven more difficult than expected. The first problem is accounting for boundary effects as, for example, a 4 by 4 template is moved across a 256 by 256 image. The second problem is that our test board not being fully functional did not allow inputting of information to the hardware. Presently we are studying both problems which we expect to solve during the next phase of this work.

Proposed Task 3- VLSI implementation of a much larger network will be studied.

Accomplishments We simulated a 64-cell network and now have the expertise to layout much larger networks. The research question, meanwhile, has changed from simply more cells to more complicated tasks. To this end we have designed two motion detector circuits one of which has been fabricated and awaits testing. We are studying the implementation of a neural network architecture capable of performing many more peripheral visual

processing tasks. Specifically, we are investigating the possibility of implementing a network capable of figure-ground separation.

Proposed Task 4- GaAs based integrated circuits will be studied.

Accomplishments We pursued this goal by looking into both external foundry services and developing our own fabrication capability. The former is in its initial stages. The latter has been progressing steadily. We recently fabricated our first MSM photodetectors and are planning fabrication of Metal Semiconductor FETs (MESFET). This device has logarithmic dependence of photocurrent on light intensity , property that is very suitable for our applications.

3.0 Conclusions from this Project

In this project we studied and implemented in hardware a class of biologically plausible neural networks. These networks have been used to explain a wide range of visual phenomena. The implementations had the following properties: edge enhancement, dynamic range compression, adaptation to mean intensity levels, tunability of sensitivity, and directional selectivity.

Our initial success prompted an expansion of the scope of the project to more complicated processing tasks and hence circuitry. To that end we implemented a motion detecting network that we designed and analyzed. A classic motion detection scheme was also implemented to compare and contrast both in theory and implementation with our system. We further studied how to fuse all these elements into architectures for peripheral vision with more sophisticated processing capabilities.

As expected, parts of the original proposal proved more complicated than anticipated. These were primarily extension of the network to two dimensions and incorporation of photodetectors for optical input.

The support provided by the *Engineering Foundation* for this project led to a proposal to the National Science Foundation for continuation of this work which received a Research Initiation Award. In addition, as a results of this support one journal article, two book chapters, and four conference presentations were published. The PI has also been able to complete editing a book entitled "Nonlinear Vision," published by the CRC Press in July 1992.

RI-B-91-16

RI-B-91-16

The material for RI-B-91-16 consists of the cover page from each of two articles prepared for publication.

Generation of synchronized trains of picosecond laser pulses at two wavelengths in a single cavity synchronously mode-locked dye laser

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Abstract

Synchronized trains of 5 picosecond pulses at two wavelengths were generated in a single cavity synchronously pumped dye laser containing a mixture of two dyes in a single jet and intracavity spacial masking for frequency selection. The utilization of this dual wavelength dye laser to monitor the relaxation of photoexcited carriers in multiple quantum wells was demonstrated.

Accepted for publication, Review of Scientific Instrument

Non-Resonant Tunneling in InGaP/InAlP Asymmetric Double Quantum Wells

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ABSTRACT

Non resonant tunneling rates have been measured in InGaP/InAlP asymmetric double quantum well structures for which optical phonon assisted tunneling is energetically forbidden. For an initial photoexcited carrier density of $2.4 \times 10^{11} \text{ cm}^{-2}$, tunneling times of 220, 60 and less than 9ps have been measured in samples with barrier thickness 4.5, 3.0 and 1.5nm respectively. The tunneling times were found to be strongly dependent on carrier density. The measured tunneling times and their dependence on carrier density are compatible with impurity scattering being the dominant mechanism assisting the tunneling.

Submitted for publication to Applied Physics Letters, September 1992

**THEORETICAL AND EXPERIMENTAL STUDIES OF
CAVITY-FED SLOTS EXCITED BY NARROW WIRES**

By

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**Air Force Engineering Foundation Grant RI-B-91-17
March 1, 1992 to September 29, 1992**

**prepared for
ENGINEERING FOUNDATION
345 East 47th Street
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1 PREFACE

This is the ^{second} semi-annual report for the sponsored research project entitled "Theoretical and Experimental Studies of Cavity-Fed Slots Excited by Narrow Wires," performed for the Engineering Foundation at Arizona State University. This report covers major effort and accomplishment for the period from March 1, 1992 to September 29, 1992.

The major objective of this research project is to investigate the cavity-fed slot radiators which offer some advantages in airborne applications such as conformity to non-rectangular and non-planar surfaces of airplane fuselages, while maintaining their simple construction and light weight features.

To design arrays of cavity-fed slots for a specific radiation pattern, the knowledge of the self impedance for each slot, and the mutual impedances between every pair of slots, is essential. In the first part of this report the mutual interactions between a pair of cavity-fed slots in three different arrangements are studied. They include the self impedances and the mutual impedances of the pair in side-by-side, collinear, and parallel in echelon arrangements. In the second part of the report the theoretical study of a sectoral cavity-fed slot, excited internally by a suspended narrow strip, is undertaken. The highlight of this study is the determination of the eigenvalues, eigenfunctions, and their orthogonality relations for the sectoral cavity boundary value problem, and their use in the development of the Green's functions. Computer code based on these functions has been developed to obtain the theoretical input impedance values, and they have been compared with the experimental values. Finally, a paper describing the research performed during the period September 1, 91 to February 28, 92 has been approved for the publication in IEEE Antennas and Propagation transactions.

LOW TEMPERATURE CVD REACTOR FOR SEMICONDUCTOR AND METAL PASSIVATION

Final Report
September 15, 1992

Presented to:
Engineering Foundation
Air Force Engineering Research Initiation Grant
Contract RI-B-91-18

Prepared by:
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LOW TEMPERATURE CVD REACTOR FOR SEMICONDUCTOR AND METAL PASSIVATION

1. SUMMARY:

A process has been developed to form nitrides at low temperatures on semiconductors (GaAs and Si), and transition metals (e.g. Fe, Ta). Reactive nitrogen species are generated by cracking hydrazine. The chemical vapor deposition of boron nitride has been demonstrated by the reaction of borohydride and hydrazine. A mathematical model of the reactor has been completed. The Record of Invention has been filed with the patent organization at the Georgia Institute of Technology.

Gallium nitride has been formed on GaAs by reaction of Ga with hydrazine (analogous to the growth of silicon dioxide on silicon) and expulsion of the As as a hydride. This is expected to lead to low surface state densities for the passivation of III-V compounds. The process has attracted considerable attention from IBM, and As capped samples provided by IBM will be nitrated and evaluated. Silicon nitride has been formed on Si. Capping the silicon with silicon dioxide prevented the formation of the nitride.

A survey of several transition metals has shown that nitrides can be formed by the use of hydrazine by converting the metal into the nitride or converting the metal oxide into the nitride. Iron oxide and tantalum oxide can be converted into iron nitride and tantalum nitride, respectively. Nitride-like films were formed on Fe, Cr, Mn, Ti, V, Mo, W, and Ta.

In the CVD deposition of boron nitride from the reaction of borohydride and hydrazine, the temperature at the point of mixing is critical in determining the final composition of the film. Boron nitride is intended to be used as a capping material on the semiconductor samples.

Future work will continue along the above mentioned lines of work. Although a high purity reactor has been demonstrated, the purity of the hydrazine needs to be improved in order to lower the water content. The nitride passivated semiconductor samples will be characterized for surface state density. The reactions on InP and GaSb will be investigated. The quality of the metal films and use of nitrides as a passivation layer (i.e. iron nitride) will be investigated. Finally, the temperature of the hydrazine decomposition reaction will be lowered through the use of a catalyst. Funding for these projects is being solicited.

Photorefractive Polymers as Electronic and Photonic Materials

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Grant Number RI-B-91-19

The response of amorphous polymers to an applied electric field has been investigated in the development of second order nonlinear optical (NLO) materials, but the phenomenology is poorly understood. Photorefractive polymers cannot be designed until the electric field effects are more readily understood in these materials. The first half of this work concentrated on electric field effects in polymer thin films. Later work, still in progress, has concentrated on the specific photorefractive applications. Applied electric field poling is used to align the NLO chromophores into the noncentrosymmetric orientation required to observe second harmonic generation (SHG). Contact poling requires that electrodes be in intimate contact with the polymer surfaces, with fields of up to 1 MV/cm passed across the film. The thermal and temporal stability of both the surface and bulk charges in the material following poling must be considered when developing novel photonic materials. Space charges are known to affect the magnitude and temporal stability of the second harmonic generation intensity in doped amorphous polymers. This work attempts to characterize the charge behavior of a poled, side-chain functionalized NLO polymer with later application as a photorefractive material as a function of polarity, irradiation wavelength, temperature, and electrode material using isothermal current measurements. Understanding charge effects will be important when evaluating the efficiency of poling methods for device manufacture. This will also provide information about how film processing affects the temporal stability of the chromophore orientation. This has direct bearing on the commercial utility of the polymeric NLO materials for second order NLO devices.

Abstract

R1-B-91-20

Engineering Research Initiation Grant R1-B-91-20
Pressure Tuning Studies of Optical Glass Device Materials

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The project focused on the preparation of optical glasses and the characterization of optical glasses and crystals with potential applications in the areas of fiber optics, imaging, optical computing, and energy conversion devices. Initial phases emphasized the sol-gel synthesis of rare earth and transition metal doped silicate and aluminosilicate glasses. We have successfully incorporated low concentrations of Cr^{3+} , Eu^{3+} , Tm^{3+} , Er^{3+} , Ho^{3+} , and Nd^{3+} into sol-gel silicate glasses. Continuing work is emphasizing incorporation of higher dopant concentrations and the simultaneous incorporation of multiple dopants.

Characterization studies have focused on YAG crystals doped with Cr^{3+} and Tm^{3+} . These crystals were chosen because they provide representative oxide bonding environments for transition metal and rare earth ions. An understanding of the homogeneous oxide environments in YAG will form a foundation for an understanding of the inhomogeneous, perturbed environments present in glasses.

Work on Cr^{3+} :YAG indicates 1) that the degree of distortion of Cr^{3+} sites from regular octahedral symmetry can be adequately characterized by the energy separation of the R_1 and R_2 emission lines; 2) that pressure destabilizes the Cr^{3+} 4T_2 level relative to the 2E level. This results in a decreased contribution of the 4T_2 level to the total luminescence; and 3) that increasing pressure drives the Cr^{3+} site toward a more nearly regular octahedral geometry. Work on Tm^{3+} :YAG indicates that some spectral transitions are incorrectly assigned and that heretofore unmentioned luminescence transitions may be present. Finally, work on Cr^{3+} : Tm^{3+} :YAG indicates that pressure provides us with the ability to resolve competing energy transfer processes. Specifically, at high pressure we are able to observe $^2E(\text{Cr}^{3+}) \rightarrow ^3F_2, ^3F_3(\text{Tm}^{3+})$ energy transfer in the absence of competing energy transfer from $^4T_2(\text{Cr}^{3+})$.

**Deformation Mechanisms and Ductility Improvement
in B2 Aluminides**

Final Report

for

**Air Force Research Initiation Grant
RI-B-92-01**

prepared for the

Engineering Foundation
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by

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December 1993

1.0 Summary

Intermetallic compounds have recently received a great deal of attention due to the need for high strength, low density structural materials which can serve to increase the performance and efficiency of aircraft and land-based power generation turbines, automobiles and other transportation systems. The major limitation of most intermetallics, and in particular transition metal B2 aluminides, is the lack of sufficient room temperature ductility and toughness. The mechanisms responsible for the ductility and toughness of B2 aluminides are not well understood. Many factors, including variations in stoichiometry, the presence of interstitial or substitutional elements, variations in operative slip systems and the initial density of mobile dislocations complicate efforts to isolate and examine possible rate-limiting mechanisms of deformation and fracture in these materials. The overall objective of this research was to obtain mechanistic information regarding the kinetics of deformation in the B2 aluminide NiAl, to gain insight to the rate-limiting mechanisms of deformation, and to evaluate several approaches to ductility improvement.

Transient strain rate change experiments were performed on NiAl and NiAl+0.25Fe single crystals in $\langle 100 \rangle$ "hard" orientations and $\langle 110 \rangle$ "soft" orientations over the temperature range of 77K to 873K. Similar experiments were performed on these materials after pre-straining and after application of several heat treatments which are known to improve room temperature ductility. These experiments were discussed in detail in the interim report and also in a paper attached as Appendix I. The measurements of the rate sensitivities and activation volumes for deformation indicated that the ductility of NiAl is limited by the mobility of dislocations on the operative slip systems in both the "hard" and "soft" crystal orientations. The motion of $a\langle 111 \rangle$ dislocations in hard crystals is restricted to a greater degree than the $a\langle 100 \rangle$ dislocations in soft crystals. As a result, the temperature dependence and the rate sensitivity of the flow stress of the NiAl crystals below the DBTT is largely due to the thermally-activated nature of the dislocation glide processes. Microalloying with Fe appeared to lower the resistance to the motion of $a\langle 100 \rangle$ dislocations near the DBTT in soft crystals, suggesting that microalloying may produce intrinsic changes in the deformation behavior. Conversely, pre-straining and rapid cooling following annealing did not produce changes in the activation parameters, indicating that these treatments most likely improve ductility or toughness by altering the fracture process.

To assess the influence of interstitial impurities, more recent experiments have been conducted on high purity NiAl crystals, produced by levitation zone melting. These experiments are discussed in detail in Section 3. At high concentrations, interstitial impurities may influence the flow behavior of "soft" NiAl crystals between room temperature and 600°C. However, measurements of activation parameters indicate that there is an intrinsic short-range barrier to thermally activated motion of $a\langle 100 \rangle$ dislocations in NiAl. For this reason, reductions in the impurity content are not sufficient to achieve large improvements in the room temperature ductility of NiAl single crystals.

2.0 Publications and Presentations

1. K. Kitano and T.M. Pollock, "The Kinetics of Low Temperature Deformation in NiAl Single Crystals", Structural Intermetallics, Proceedings of the First International Conference, ed. by R. Darolia, J. Lewandowski, C.T. Liu, P.L. Martin, D.B. Miracle and M.V. Nathal, TMS, Warrendale, PA, 591, (1993).
(Attached as Appendix I; selected as finalist for best paper award).
2. T.M. Pollock, "The Kinetics of Low Temperature Deformation in NiAl Single Crystals", presented at the First International Conference on Structural Intermetallics, September 1993.
3. K. Kitano, T.M. Pollock and R.D. Noebe, "The Effect of Impurity Content on Thermally Activated Deformation in NiAl Crystals", submitted to Scripta Metall. Mater.
4. T.M. Pollock, "Thermally Activated Deformation in NiAl Single Crystals", to be presented at the TMS Annual Meeting, February, 1994.

Final Report submitted to the
Engineering Foundation

***An Intelligent Synthesis Method for
Concurrent Engineering Applications***

AFERI Grant RI-B-92-02

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PROJECT SUMMARY

The objective of the proposed research was to improve upon AI-augmented strategies to increase the efficiency of the design process for large scale, complex engineering systems, such as are encountered in Concurrent Engineering (CE) applications. Complex engineering systems are characterized by inherent couplings amongst the participating design groups, which makes traditional design and optimization approaches impractical. An example of such a system is found in aircraft design, which involves the interactions of such disciplines as aerodynamics, propulsion, structures, controls, materials, performance, life-cycle costs, etc. The CE design approach requires the interaction of all engineering, production, and manufacturing groups simultaneously so as to reduce cost and bring higher quality products to market faster. In order to fully appreciate the proposed method, a description of the concurrent engineering approach and the motivation for using such an approach is presented.

Introduction

United States automotive, aerospace, computer, electronics and defense industries, among others, have been forced to respond to competitive pressures that have resulted in large losses of market share due to high product development times and excessive costs. These industries have begun to adopt the Concurrent Engineering (CE) design approach in order to create higher quality products that can be brought to market for significantly lower cost and time. In 1988, the Institute for Defense Analyses (IDA) examined the CE approach and presented recommendations to the Department of Defense concerning the advantages that can be obtained through its use. The IDA report to DoD describes CE as follows:

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost schedule, and user requirements.

The interaction of all participating engineering groups throughout the design and production cycle is truly a multidisciplinary effort that makes the traditional serial design approach shown in Fig. 1 obsolete. The dilemma facing designers using the serial approach is shown in Fig. 2, where the design freedom drops drastically while knowledge of the design increases slowly. The CE approach allows a shift in these curves, resulting in more knowledge with more design freedom.

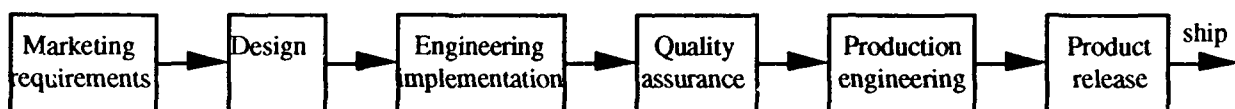


Figure 1. Traditional serial design approach

In the traditional serial environment, Dataquest estimates that "the cost of making a change increases by an order of magnitude for each phase of the design cycle". So it is obvious why designers would want to use the parallel approach embraced in CE. The IDA survey identified three initiatives essential for successful implementation of CE strategies. These include engineering process initiatives (which have to do with organizational structures and design processes), computer-based support initiatives (which involve further development of frameworks, integrated design environments, and design automation tools), and formal methods (which can loosely be categorized as the engineering techniques used to find optimal designs). This work primarily targets the development of efficient and practical formal methods based on the composition of the complex, coupled system.

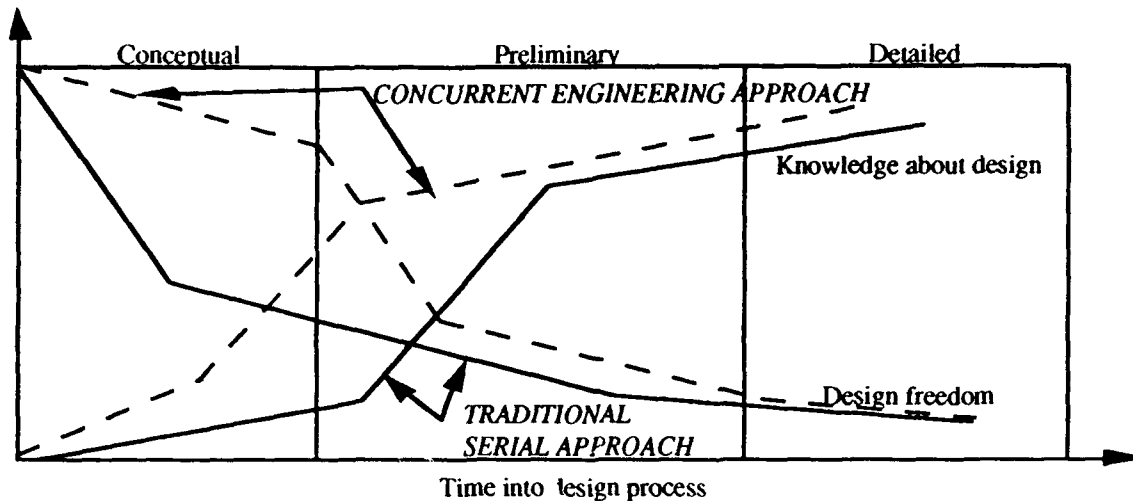


Figure 2. Trade-off between knowledge and design freedom

Any design organization setting, whether it be in the automotive, aerospace, or computer industry, is similar in that some top-down hierarchy exists. A typical organization might be divided into directorates, which are further broken into divisions, which are divided into branches, which are divided into groups, etc. While this division is necessary for practical purposes, such an organizational structure makes implementing a truly multidisciplinary design strategy (as required in CE) extremely difficult. One dilemma that makes CE difficult to practically implement is the excessive computational requirements due to the inordinate number of participating groups. The number of 'communication paths' amongst these groups (which can be considered as 'couplings') is so large that traditional formal optimization methods are often impossible to apply.

Methodology and Results

It was proposed that a decomposition method be developed that would enable the formal design of coupled problems that are encountered in application of the CE approach. The primary focus of the work was to develop a method that could accommodate the wide variety of variables (discrete and integer as well as continuous) that are encountered in CE design. Another focus involved the use of AI techniques to allow for human interface capabilities. Research efforts have demonstrated the feasibility of a decomposition method for mixed discrete/continuous problems and have shown the advantages of using Artificial Neural Networks to simulate the discrete analysis. Further avenues of research to increase method robustness and efficiency have been identified. Results and directions for further study are described in the attached papers located in Appendix A. The first (presented at the 1993 ASME Design Automation Conference) describes the results of the initial effort to develop a decomposition method which could accommodate complex systems with mixed variables. The second is an extended abstract (to be presented at the 1994 Structures, Structural Dynamics, and Materials Conference) that outlines further efforts in 1) developing a better diversification strategy to avoid local minima and 2) the training of the Artificial Neural Network used to represent the discrete analysis. The final paper will have more complete results in both these areas as research is ongoing. These two papers demonstrate that a decomposition approach can indeed be successfully used for mixed, complex engineering systems.

Student Participation/Support

Although only one Ph.D. student was directly supported by the grant for one academic year, numerous others were involved in related research. These students and their associated research projects are listed in Appendix B.

An Experimental Study of the Effect of a Bow Shock on Known Free Stream Disturbances
Engineering Foundation Air Force Engineering Initiation Grant

RI-B-92-03

Professor Steven H. Collicott

School of Aeronautics and Astronautics, Purdue University

The research effort supported by the Engineering Foundation's Air Force Engineering Research Initiation Grant is entirely new to Purdue. That is, the project is the beginning of a new effort in our labs rather than simply an acquisition of additional data in an existing experiment. In this research, non-intrusive techniques for generating and measuring point-like perturbations to a flow are developed. This technology is necessary for high-speed flow studies, especially in quiet-flow supersonic facilities. Hence the Initiation Grant has supported a portion of the initial research that beside being an important addition to the capabilities of the Purdue Aerospace Sciences Laboratory, is one of the enabling technologies for a new research program in Mach 4 boundary layer transition.

A range of experiment and instrumentation design and construction, and activities to get the fluids research underway have been completed: Rayleigh scattering verification, an examination of Rayleigh scattering near surfaces, the implications of the Rayleigh scattering results on model size, and characterization the laser-produced disturbances in the air. Additionally, extensions of the sponsored work remain in process.

Use of Rayleigh scattering as a diagnostic tool for measuring the properties of the hot spot as it traverses a bow shock is found to be impractical. This is determined in experiments inspired, but not directly supported, by this grant. The more elaborate filtered Rayleigh scattering method remains a candidate, but was not affordable under this grant.

With the proposed Rayleigh scattering technique now shown to be impractical, spot detection and growth rate measurements are performed with a second laser. A beam-deflection measurement technique is performed, and backed up by hot-wire anemometer measurements. A continuous low-power HeNe laser beam is made to pass a known distance from the point of spot generation, and is then directed onto a pin-hole aperture on a photo-multiplier tube (PMT). When a hot-spot is created, both the expanding shock wave and the expanding hot gases cause deflections of the HeNe beam, which can be detected from the output of the PMT. The growth rate of the laser-induced shock wave and hot gas or plasma is measured at a range of suitable distances. Growth rate is found to be as repeatable as the pulse-to-pulse laser energy. With this data, the spot-generation technique can be applied to wind tunnel experiments.

In summary, high-energy laser spot generation is shown to a repeatable and desirable method for creating point-like disturbances in an aerodynamic flow. This is anticipated to be especially useful in high-speed boundary layer stability and transition experiments in the modern quiet-flow supersonic tunnels. This is of critical importance because no apparatus is inserted into the flow in order to create the disturbance.

ENGINEERING FOUNDATION

Air Force Engineering Research Initiation Grant RI-B-92-04

**ANALYTICAL AND EXPERIMENTAL STUDIES OF FAILURE
IN COMPOSITE SHELL STRUCTURES**

Final Report

For the Period from September 1992 - December 1993

Prepared by

**Fuh-Gwo Yuan
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1. PROJECT SUMMARY

The primary objective of this research is to understand and then to predict the failure mechanics and mechanisms of composite shell structures using analytical and experimental approaches. The work accomplished during the period can be categorized into two aspects:

(a) A rigorous elasticity solution for composite laminated cylindrical shells subjected to bending is considered. The material of the shell is assumed to be cylindrically anisotropic. Based on the theory of cylindrically anisotropic elasticity, coupled partial differential governing equations are developed using Lekhnitskii's stress functions. Homogeneous solutions are obtained using separation of variables and polynomial forms are used for particular solutions. To illustrate the fundamental nature of the problem, an example of off-axis composite shells is presented. Complex three-dimensional stress states, large stress gradients through the thickness and strong effect of fiber orientations are reported. Detailed stress distributions of two laminated shells $[45/-45]_S$, $[45/-45]$ are examined. Experimental work has been conducted to observe the initial failure mode under monotonic bending load. Specimens made of curved laminates with stacking sequence $[45/-45]_{8S}$ has been tested. The interfacial cracking occurring near the midsurface predicted from stress analysis agrees reasonably with the experimental observation using a maximum interlaminar normal stress criterion.

(b) A circular interfacial crack in the laminated composite shells under antiplane shear is investigated. Due to the material anisotropy, Laplace equation cannot be used for governing equation like in isotropic materials. Instead, a differential equation with material constants is used for the governing equation. The problem will reduce to a Hilbert boundary value problem by combining transformation and complex variable technique. Stress distribution near the tips in terms of the local coordinate system is obtained. The strength of singularity and associated stress intensity factor K_{III} will be evaluated for various loading orientation and the degree of material anisotropy.

Final Report

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I. Summary of Our Original Proposal:

In this proposal we promised to 1. design, 2. Fabricate, and 3. characterize a multifunction optoelectronic integrated tunable detector with the capabilities of simultaneously performing the functions of a tunable optical filter, optical amplifier, frequency-shift-keying (FSK) discriminator and high speed detector. The work includes integration of an active filter with a high speed waveguide detector. Previously there are many modes inside the stop band of an active filter. The effective tuning range of this kind tunable active filter is only one half of the Fabry-Perot (FP) spacing. In this work we promise to design an active filter with accurate fabrication technique to achieve only one FP mode inside the Bragg stop band of the active filter. The full tuning range of the filter can , thus, be utilized.

II. Work We Have Done:

Since we sent out the proposal in Nov. 1991, we have actually started to work on this project. We decided to work on this problem no matter whether we can receive the grant or not.

1. The detail calculation of the design has been carried out within one month after we send out the proposal
2. The masks are designed and made 4 weeks after the theoretical calculation is finished.
3. The semiconductor laser and waveguide layers were grown in the mean time with chemical-beam-epitaxy (CBE) by the PI himself in AT&T Bell Labs., Murray Hill.
4. Due to the well controlled growth rate and uniform growth, we can accurately fabricate the device according to the calculation. The device is fabricated by the PI in AT&T during February and March 1992. The regrowth is done with metal

organic chemical vapor deposition (MOCVD) by, Ralph Logan, The PI's colleague.
 5. The laser is bound at Holmdel, AT&T Bell Labs. and DC tested around May 1992.

6. We sent a conference paper to the IEEE Summer Topical Meeting and was rated as a very good paper in that conference [1].

7. We received the grant start from Aug. 1992. Since then we have been concentrated on making 4-section high speed mounting in UMBC. It is very hard to get high speed mounting for all 4 sections. With some try-and-error we have made it possible to come out a nice design, probably for the first time in the world, to mounted the 4-section high speed device. These high speed tunable receiver are ready to put to test and system level application now.

8. We have sent out a journal paper and is accepted as well as to be published at Applied Physics Letter [2] recently to summarize what we have done. We have acknowledged Engineering Foundation for the grant support in that paper. The paper is enclosed with this report.

9. We are trying to collect the AC characteristics data of this device recently. We are also working on the system applications of this advanced device. One of my student has recently finished a system simulation on multichannel operation characteristics of this tunable detector. We sent a paper to Conference of Laser and Electro-Optics 1993 and it was accepted and presented [3].

10. This fabricated tunable detector has very fast channel switching speed, around nanosecond, which is much faster than any other wavelength tuning elements. We believe that it has strong potential to be applied to future high speed WDM optical packet switch. We hope we can receive future support to continue this research work and put this tunable receiver to real system application.

III. Budget Part:

Our budget is shown below:

Senior personal:	12,220
Material and Supplies:	9,280
Travel and Publications:	1,500
Total:	23,000

1. A detail expense report up to 7/31/93 prepared by UMBC is listed in the followed pages. We have over expended \$6,400.48 on this account at this moment due to the

accumulation of summer salaries from both last and this years. However, the over expanded part will be taken care by the EE department.

2. With the help of using AT&T facility we have saved a lot in making the devices.

3. This help us to concentrate our forces on characterization of these devices. We bought some optics, translational stages, microwave components, and mechanical mounts to achieve that purpose.

4. We went to IEEE 1992 summer topic meeting to present the integrated tunable detector paper. We also went to CLEO conference to present the second conference paper. Both are covered by the travel expenses..

IV. References:

[1]. F. S. Choa, W. T. Tsang, R. A. Logan, R. P. Gnall, T. L. Koch, C. A. Burrus, "InGaAs/InGaAsP integrated tunable detector grown by chemical beam epitaxy," IEEE Summer Topic Meeting, paper WB3, 1992.

[2]. F. S. Choa, W. T. Tsang, R. A. Logan, R. P. Gnall, T. L. Koch, C. A. Burrus, M. C. Wu, Y. K. Chen, R. Kapre, "InGaAs/InGaAsP integrated tunable detector grown by chemical beam epitaxy," to appear Appl. Phys. Lett., Sep. 27, 1993.

[3]. F. S. Choa, M. H. Shih " Multi-channel operation characteristics of a WDM integrated tunable detector" to be presented at CLEO'93, paper CWJ97, 1993.

Please find interested parties to extend this device to a WDM photonic packet switch research work. Thank you!

Final Report

Air Force Engineering Research Initiation Grant RI-B-9 96

Project Title: "Semiconductor Bandgap Modulation by Piezoelectric Thin Films"

Period: September 1, 1992 - August 31, 1993

Principal Investigator: Professor Hong Koo Kim

Technical Objective:

Investigate semiconductor bandgap modulation by pressure induced by means of a piezoelectric thin film transducer.

Accomplishments:

This research, supported by the Air Force Engineering Research Initiation Grant, has led to the successful integration of ZnO-thin-film piezoelectric transducers on a GaAs ridge-waveguide structure for a bandgap modulation experiment. The experimental results, including characterization of the fabricated devices, are briefly summarized below. Publications, presentations, and M.S. degrees produced related to this work are listed at the end of this summary.

In experimental study, we have conducted a systematic investigation to deposit high-quality zinc oxide (ZnO) films on gallium arsenide (GaAs) substrates. ZnO films have been deposited by RF-magnetron sputtering, using a ZnO compound target in Ar/O₂ ambient. Deposition parameters such as RF power, substrate-target distance, substrate temperature, gas composition, and gas pressure have been optimized to obtain highly c-axis oriented and highly resistive films. To alleviate a thermal mismatching problem between ZnO and GaAs, a thin SiO₂ buffer layer was introduced. RF magnetron sputtering was used to deposit first the SiO₂ layer (1000 Å thick), then the ZnO layer (1 μm thick) on both smooth GaAs substrates and mesa etched substrates (20 - 60 μm wide, 1 μm high). Thermal stability of the ZnO films was tested on such a buffered GaAs substrate by post-deposition annealing at 430 °C for 10 minutes, which is similar to a standard ohmic contact alloying procedure. The films, on both patterned and smooth substrates, sustained the heat treatment well, not exhibiting the crumbling typical of ZnO films deposited directly on GaAs substrates. The tendency of the patterned substrate to cause shattering of the ZnO film along mesa edges was overcome by optimizing sputter conditions. The post-deposition annealing enhanced the c-axis orientation of the ZnO films dramatically and relieved intrinsic stress significantly. These improvements are attributed to a reduction of grain boundaries and voids during the

annealing as supported by scanning electron microscopy (SEM) and X-ray diffraction. These results suggest that the ZnO/SiO₂/GaAs structure is suitable for integration of optoelectronic devices and piezoelectric transducers. If a device fabrication procedure is properly designed, these enhancements can be achieved during an ohmic contact alloying procedure, not requiring any additional process step.

Test structures for a bandgap modulation experiment were designed and fabricated. The fabrication involved monolithic integration of the ZnO pressure transducers on GaAs mesa structures. The structure has a 1- μ m-thick GaAs-epilayer mesa sandwiched laterally by the same thickness ZnO layers. Deposition of thin films usually induces a significant amount of stress as intrinsic or thermal stress. Therefore, as a preliminary work for a bandgap modulation using piezoelectric stress, we have characterized thin-film induced stress in the GaAs ridge waveguides. Stress on the cleaved facet of the waveguide was imaged with a spatially resolved and polarization-resolved photoluminescence technique. Photoreflectance measurement was also carried out on the GaAs mesa top surface in order to characterize a bandgap change caused by thin-film induced stress. The results showed that the GaAs mesa is stressed up to approximately 10^8 dyn/cm² (strain of 10^{-4} order) due to residual stress from the ZnO/SiO₂ films. This thin-film induced stress is greater than the stress that we expect from the piezoelectric stress modulation. Currently we are investigating ways to reduce the thin film stress and also to improve a breakdown field strength and stability of ZnO films.

Ferroelectric Pb(Zr,Ti)O₃ or BaTiO₃ materials show even stronger piezoelectric coefficients than ZnO. Therefore we have also investigated sputter deposition of those films on semiconductor substrates. Although these materials are generally known to be more difficult for processing than ZnO, we have deposited highly ferroelectric Pb(Zr,Ti)O₃ and BaTiO₃ films on Si or GaAs substrates using a MgO buffer layer.

In theoretical study, the electric field distribution inside the test structure was analyzed using a finite element method. The numerical analysis result shows that the electric field applied across the ZnO film does not spread to the GaAs mesa region, therefore a spectral shift in the photoreflectance measurement is expected to be purely due to a bandgap modulation by stress induced via a ZnO pressure transducer. The calculation shows that 1 nm shift of bandedge luminescence wavelength is expected with a 10 V across a 1 μ m thick ZnO film, and 15 nm shift with a PZT film. Two-dimensional finite element analysis of stress distribution is also being conducted for comparison with the polarization-resolved photoluminescence results.

Future Efforts:

So far, we have completed monolithic integration of highly c-axis oriented ZnO thin-

film transducers on a GaAs ridge structure. Our research in this area continues at an active pace. Currently, we are working for the improvement of ZnO/SiO₂ films, i.e., to reduce the thin film stress and also to improve a breakdown field strength and stability of ZnO films. The amount of bandgap change will be characterized as a function of applied voltage across the piezoelectric transducers using both the photorefectance measurement and the polarization-resolved photoluminescence measurement techniques. Finally the piezoelectric transducers will be monolithically integrated on GaAs/AlGaAs semiconductor laser structures to develop wavelength-tunable laser diodes.

Journal Papers

"ZnO Films Deposited on GaAs Substrates with a SiO₂ Thin Buffer Layer", H. K. Kim and M. Mathur, accepted for publication at *Journal of Electronic Materials*.

"Thin-Film Induced Stress in GaAs Ridge-Waveguide Structures Integrated with Sputter-Deposited ZnO Films", H. K. Kim, W. Kleemeier, Y. Li, and D. W. Langer, R. E. Sherriff, D. T. Cassidy, and D. Bruce, to be submitted to *Journal of Vacuum Science and Technology*.

Conference Presentations

"Stability of ZnO Films Deposited on GaAs Substrates with a SiO₂ Thin Buffer Layer", H. K. Kim, W. Kleemeier, and M. Mathur, presented at *Materials Research Society, Fall Meeting*, Boston, Massachusetts, December 1992.

"Structural and Electrical Properties of Pb(Zr,Ti)O₃ Films Deposited on MgO-Buffered GaAs Substrates by RF Magnetron Sputtering" N. Basit and H. K. Kim, presented at *Materials Research Society, Fall Meeting*, Boston, Massachusetts, December 1992.

"Effects of Annealing on Structural and Electrical Properties of BaTiO₃ Films Deposited on MgO-Buffered GaAs Substrates by RF-Magnetron Sputtering", P. Barrios and H. K. Kim, presented at *Materials Research Society, Fall Meeting*, Boston, Massachusetts, December 1992.

INVESTIGATION OF THE ROLE OF STRUCTURE IN THE DYNAMIC RESPONSE OF ELECTORRHEOLOGICAL SUSPENSIONS

FINAL REPORT

Air Force Engineering Research Initiation Grant RI-B-92-07

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August 17, 1993

No. of Pages: 18

No. of Figures: 14

Abstract

The dynamic response of electrorheological (ER) suspensions has received little attention relative to the effort devoted to the study of the steady shear response. We report on simulation and experimental investigations of the dynamic oscillatory response of ER suspensions, in particular focusing on the relationship between suspension structure and the rheological response. We consider the response of monodisperse and polydisperse suspensions under linear deformation, as well as the response in the nonlinear regime. Dimensional analysis of the equations of motion predict that the linear rheological response obeys a time-field strength superposition principle, which is confirmed by experiment. The response is found to exhibit a sharp dispersion that is only broadened slightly by polydispersity. Nonlinear deformation is found to significantly broaden the observed dispersion.

Stress Field in a Continuous Fiber Composite Having an Interphase with Variable Material Properties

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Abstract

Stress field in a continuous fiber composite with a variable interphase subjected to thermo-mechanical loadings is studied by using a four concentric circular cylinders model. An exact closed form solution is obtained for the stress field in the interphase in a series form using Frobenius method in a certain case. Numerical results are presented for FP fiber/Al 6061 composite with interphase, and carbon fiber/Al 6061 composite with interphase. It is found that the variableness of the thermoelastic constants in the interphase has significant effects on the stress distributions in the interphase. Therefore, this will, in turn, affect the initiation of cracks in the interphase.

SECTION D: Grant-related Publications

RI-B-91-01

M.-H. Herman Shen

Department of Aeronautical and Astronautical Engineering
The Ohio State University
328 Bolz Hall, 2036 Neil Avenue
Columbus, Ohio 43210-1276

"Structure of Damage Detection and Identification Using
Neural Network," AIAA Journal, Vol. 32, No.1, January
1994.

RI-B-91-02

Michael J. Readey

Department of Materials Science and Engineering
Carnegie Mellon University
Pittsburgh, PA 15213

1)" The Effect of Grain Size Distribution and Grain Shape on the Indentation-Strength Behavior of Alumina Ceramics", M.J.Ready, H. O'Donnell and D. Kovar, to be published in the Journal of the American Ceramic Society(in progress)

2) H. O'Donnell and M.J. Ready" The Effect of Grain Shape on the Toughness of Alumina Ceramics", presented at the 94th Annual Meeting of the American Ceramic Society, Minneapolis, MN 1992.

RI-B-91-03

Anthony Petric

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No Report of Publication

RI-B-91-04

Mansoor Alam

Department of Materials and Metallurgical Engineering
New Mexico Institute of Mining and Technology
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"Adhesion of Diamond Coatings on Tungsten Substrates,"
accepted for publication in a forthcoming special diamond
issue of the "Journal of Adhesion Science and
Technology."

RI-B-91-05

David Beale

Department of Mechanical Engineering
Auburn University
Auburn University, AL 36849-5341

1. Halbig D., Beale D., "Experimental Observations of a Flexible Slider Crank Mechanism at Very High Speed" accepted for publication in Nonlinear Dynamics.
2. Lee S.W. and Beale D.G. "Periodic Response and Stability of Flexible Rod Slider Crank Mechanism," The 1992 ASME Design Technical Conference, DE-Vol. 47, 317-325.
3. Lee S.W. and Beale D.G., "Active Control of Nonlinear Oscillations in a Flexible Rod Slider Crank Mechanism," Proceeding of the Second Conference on Recent Advances in Active Control of Sound and Vibration, Published by Technomics Publication Co. pp. 729-740, 1993.

RI-B-91-06

Anthony M. Wass

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International Journal of Solids and Structure, Vol. 31,
No. 1, pp. 75-87, 1994.

RI-B-91-07

Samuel Paolucci

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University of Notre Dame
Notre Dame, IN 46556

No Report of Publication

RI-B-91-08

Alan Argento
Department of Mechanical Engineering
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"Accelerating Load on a Rotating Rayleigh Beam," ASME
Journal of Vibration and Acoustics, Vol. 116, July, 1994.

The other two papers have been accepted for publication
in "Journal of Sound and Vibration" and are presently in
press. They are scheduled for appearance in the January,
1995 issue.

1. A Spinning Beam Subjected to a Moving Deflection
Dependent Load, Part 1: Response and Resonance.
2. A Spinning Beam Subjected to a Moving Deflection
Dependent Load, Part 2: Parametric Resonance.

RI-B-91-09

R. Valery Roy
Department of Mechanical Engineering
University of Delaware
Newark, Delaware 19716

Roy, R.V., "Noise Perturbations of a Nonlinear System with Multiple Steady States", International Journal of Non-Linear Mechanics, In Press.

Roy, R.V., and Nauman, E., "Noise Induced Effects on a Nonlinear Oscillator," Journal of Sound and Vibration, In Press.

Roy, R.V., "Noise Perturbation of Nonlinear dynamical Systems", Chapter 6, in Computational Mechanics, pp. 125-148, Computational Mechanics Publications, (Southampton, UK), Elsevier, (1993).

Roy, R.V., "Noise Perturbation of a Nonlinear System with Multiple Steady States," in Structural Safety and Reliability, Vol. 1, pp. 243-246, Balkema, Rotterdam, Netherlands.

RI-B-91-10

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No Report of Publication

RI-B-91-11

Stanley J. Reeves
Department of Electrical Engineering
Auburn University
Auburn, Alabama 36849-5201

"A Practical Stopping Rule for Iterative Image Restoration," Proceeding of 1993 IEEE Int'l Conference on Acoustics, Speech and Signal Processing.

"A Practical Stopping Rule for Iterative Image Restoration," IEEE Transaction on Signal Processing, July 1994.

RI-B-91-12

R. Jennifer Hwu
Department of Electrical Engineering
University of Utah
Salt Lake City, Utah 84112

Publications Supported by this grant:

R.J. Hwu and L.P. Sadwick, "Limitations of the Back-to-Back Barrier-Intrinsic-N+ Diode Frequency Tripler," IEEE Trans. on Electron Devices, Vol. 39, No. 8, pp. 1805-1810, 1992.

R.J. Hwu and L.P. Sadwick, "Design Criteria of the Near-Millimeter Wave Quasi-Optical Monolithic Diode-Grid Frequency-Multiplier Array," International J. Infrared and Millimeter Waves, Vol. 13 No. 8, pp.1145-1162, 1992.

Accepted for Publication:

R.J. Hwu, "Comments on "Modeling of Planar Varactor Frequency Multiplier Devices with Blocking Barriers," accepted for publication, IEEE Trans. on Microwave Theory and Techniques.

R.J. Hwu, "Recent Development of Millimeter-Wave High-Power Back-to-Back Varactor Diode Frequency Tripler," Invited Paper, Microwave Journal.

R1-B-91-13

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No Report of Publication

RI-B-91-14

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Department of Electrical Engineering
Tennessee Technological University
Cookeville, TN 38505

1. O. Ojo and I. Bhat "Simplified Analysis of Fixed Frequency Parallel Resonant DC/DC Converter with Pulse-Width Modulation," Control Archiv Fur Elektro Technik, Vol 76, No 2, 1993, pp. 139-147.

2. O. Ojo and I. Bhat "Steady-State and Dynamic Analysis of High-Order Parallel Resonant Convertors," IEE Proceedings Part B, Vol 140, No 3, May 1993, pp. 209-216.

Bahram Nabet
ECE Department
Drexel University
Philadelphia, PA 19104

- 1- B. Nabet, "Electronic Hardware for Vision Modeling," in *Nonlinear Vision: Determination of Neural Receptive Fields, Functions, and Networks*, R. B. Pinter and B. Nabet eds., 463- 474, CRC Press, Boca Raton, FL, 1992.
- 2- B. Nabet and R. B. Pinter "Multiplicative Inhibition and Volterra Series Expansion," in *Nonlinear Vision: Determination of Neural Receptive Fields, Functions, and Networks*, R. B. Pinter and B. Nabet eds., 474- 491, CRC Press, Boca Raton, FL, 1992.
- 3- B. Nabet, R. B. Darling, and R. B. Pinter, "Implementation of Front-End Processor Neural Networks," *Neural Networks*, vol 5, no. 6, pp. 891-902, 1992.
- 4- B. Nabet and L. Hojda, "Circuits for Feedforward and Feedback Multiplicative Inhibitory Networks," in *Intelligent Engineering Systems Through Artificial Neural Networks*, C.H.Dagli, S.R.T.Kumara, and Y.C.Shin eds, *Proc. Int. Conf. Artificial Neural Networks in Eng.* pp. 447-452 St. Louis, MO, Nov. 10-12, 1991.
- 5- B. Nabet and L. Hojda, " Feedforward Shunting Inhibitory Neural Networks," *IEEE Engineering in Medicine and Biology Conf.*, pp. 1446-1447, Orlando, FL, Nov., 1991.
- 6- B. Nabet and V. Shreesha, L.Loielo, S. Young, A. Levytsky, and G. Seagrave, "Implementation of Two Motion Detectors: Shunting and Reichardt," *Proc. Neural Networks for Learning, Recognition, and Control*, Wang Institute of Boston University, p. 66, May 14-16, 1992.
- 7- V.Shreesha and B. Nabet, "Modeling of a Motion Detector," in *Proceeding IASTED Int. Conf. Control and Robotics*, August 4-6, Vancouver, Canada, 1992.
- 8- B. Nabet, "Membrane Equation and Implementation of Neural Networks," *Proceedings Government Neural Networks Applications Workshop*, Dayton, OH. Vol. 1, pp. 37-41, August 24-28, 1992.

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Fort Collins, CO 80523

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