

# Table of Contents

Introduction	1
<b>PART I</b>	<b>SOLID STATE PHYSICS, ELECTRONICS AND OPTICS</b>
<b>Section 1</b>	<b>Materials and Fabrication</b>
<b>Chapter 1</b>	<b>Heterostructures for High Performance Devices</b> ..... 7
	<i>Professor Clifton J. Fonstad, Jr.</i>
1.1	Introduction ..... 7
● 1.2	Computer Controlled Growth of Lattice-Matched InGaAlAs Heterostructures on InP ..... 7
● 1.3	Molecular Beam Epitaxy of InGaAlAs Strained-Layer Heterostructures on 111 GaAs and InP ..... 8
1.4	Monolithic Fabrication of Strain-free GaAlAs Laser Diodes on Silicon Substrates ..... 9
1.5	Integration of Vertical Cavity Surface Emitting Lasers on GaAs Integrated Circuits ..... 9
1.6	Low Temperature Growth of GaAlAs Laser Diodes ..... 10
1.7	MBE-Grown InGaAlAs/InP Long-Wavelength Laser Diodes for Narrow Linewidth Applications ..... 11
1.8	New Three-Terminal Independently Addressable Asymmetric Laser Diodes (IAADQW-LD) with Dynamic Control of Gain and Refractive Index ..... 11
● 1.9	Design and Fabrication of Distributed Feedback (DFB) InGaAlAs Laser Diodes Grown by Molecular Beam Epitaxy ..... 12
1.10	Laser Diode Modeling and Design for Narrow Linewidth Operation ..... 12
1.11	Growth and Processing of Improved InGaAlAs/InP Heterojunction Bipolar Transistors ..... 13
1.12	Microwave Characterization, Analysis, and Modeling of Emitter-Down Heterojunction Bipolar Transistors ..... 13
● 1.13	Analysis of Three-Terminal n-n-n Quantum Well Base, Tunnel-Barrier Transistors ..... 14
● 1.14	Applications of AlAs Etch-Stop Layers in InGaAlAs/InP Heterostructure Electronics and Optoelectronics ..... 14
● 1.15	Electrical Transport Studies in Directly Contacted InGaAs Quantum Wells ..... 15
1.16	Investigation of Infrared Intersubband Emission from InGaAs/AlAs/InP Quantum Well Heterostructures ..... 15
1.17	Investigation of Intersubband Relaxation Times in InGaAlAs Quantum Well Heterostructures ..... 16
1.18	Infrared Characterization of InGaAs/AlAs/InP Quantum Well Heterostructures ..... 16
1.19	Damage-Free In-Situ UHV Etching and Cleaning of III-V Heterostructures Using Molecular Beams ..... 17
1.20	Publications ..... 17
<b>Chapter 2</b>	<b>High-Frequency InAlAs/InGaAs Metal-Insulator-Doped Semiconductor Field-Effect Transistors (MIDFETs) for Telecommunications</b> ..... 19
	<i>Professor Jesús A. del Alamo</i>
● 2.1	Introduction ..... 19
● 2.2	Quantum-channel InAlAs/n <sup>+</sup> -InGaAs MIDFETs ..... 20
<b>Chapter 3</b>	<b>Novel Superconducting Tunneling Structures</b> ..... 29
	<i>Professor John M. Graybeal</i>
● 3.1	Project Description ..... 29

<b>Chapter 4</b>	<b>Chemical Beam Epitaxy of Compound Semiconductors</b> .....	<b>33</b>
	<i>Professor Leslie A. Kolodziejski</i>	
● 4.1	Facility for the Gas Source Epitaxy of Compound Semiconductors .....	33
● 4.2	Metalorganic Molecular Beam Epitaxy (MOMBE) of ZnSe .....	34
● 4.3	Photo-Assisted MOMBE of Wide Bandgap II-VI Compound Semiconductors .....	36
● 4.4	Publications .....	38
<b>Chapter 5</b>	<b>Microstructural Evolution in Thin Films of Electronic Materials</b> .....	<b>39</b>
	<i>Professor Carl V. Thompson</i>	
● 5.1	Electromigration and Microstructure .....	39
5.2	Microstructural Evolution in Polycrystalline Films .....	42
5.3	Magnetic Properties of Heteroepitaxial Thin Films .....	43
5.4	Interface Reactions in Multilayer Thin Films .....	43
5.5	Focused Ion Beam Induced Chemical Vapor Deposition .....	43
5.6	Publications .....	44
<b>Chapter 6</b>	<b>Focused Ion Beam Microfabrication</b> .....	<b>47</b>
	<i>Dr. John Melngailis</i>	
6.1	Introduction .....	47
6.2	Tunable Gunn Diodes—High Frequency Performance and Applications .....	47
6.3	Simulation of Tunable Gunn Diodes and MESFETs with Doping Gradients .....	48
6.4	Limited Lateral Straggle of Focused-Ion-Beam Implants .....	48
6.5	Focused Ion Beam Implantation of GaAs MMICs and Transistor Optimization .....	49
6.6	Ion Induced Deposition of Gold, Models and Microstructure .....	50
6.7	Focused Ion Beam Lithography for X-Ray Mask Making .....	50
6.8	Focused Ion Beams for the Repair of X-Ray Masks .....	51
6.9	Publications .....	51
<b>Section 2</b>	<b>Quantum-Effect Devices</b> .....	<b>53</b>
<b>Chapter 1</b>	<b>Statistical Mechanics of Quantum Dots</b> .....	<b>55</b>
	<i>Professor Boris L. Altshuler</i>	
● 1.1	Project Description .....	55
<b>Chapter 2</b>	<b>Single Electron Transistors</b> .....	<b>57</b>
	<i>Professor Marc A. Kastner</i>	
● 2.1	Project Description .....	57
<b>Chapter 3</b>	<b>Transport Through a Quantum Dot</b> .....	<b>61</b>
	<i>Professor Patrick A. Lee</i>	
● 3.1	Project Description .....	61
<b>Chapter 4</b>	<b>Submicron and Nanometer Structures Technology and Research</b> .....	<b>63</b>
	<i>Professor Henry I. Smith</i>	
4.1	Submicron Structures Laboratory .....	63
● 4.2	Microfabrication at Linewidths of 100 nm and Below .....	63
4.3	Improved Mask Technology for X-Ray Lithography .....	65
● 4.4	Study of Electron Transport in Si MOSFETs with Deep-Submicron Channel Lengths ...	66
● 4.5	Studies of Coulomb Charging in Ultrasmall Semiconductor Devices .....	66

4.6	Study of Quasi-One-Dimensional Wires and Superlattice Formation in GaAs/AlGaAs Modulation Doped Field-Effect Transistors .....	68
4.7	GaAs Electron Waveguide Devices Fabricated by X-Ray Lithography .....	70
● 4.8	Arrays of Field-Effect-Induced Quantum Dots .....	71
4.9	Planar-Resonant-Tunneling Field-Effect Transistors (PRESTFET) .....	72
● 4.10	Fabrication of Distributed-Feedback Lasers and Channel-Dropping Filters .....	72
● 4.11	Novel Superconducting Tunneling Structures .....	73
● 4.12	Submicrometer-Period Transmission Gratings for X-Ray and Atom-Beam Spectroscopy and Interferometry .....	74
4.13	High-Dispersion, High Efficiency Transmission Gratings for Astrophysical X-Ray Spectroscopy .....	74
4.14	Submicron-Thickness X-Ray Window Technology .....	75
4.15	Epitaxy via Surface-Energy-Driven Grain Growth .....	75
● 4.16	GaAs Epitaxy on Sawtooth-patterned Si .....	76
4.17	Publications .....	76
<b>Section 3</b>	<b>Optics and Devices</b>	<b>79</b>
<b>Chapter 1</b>	<b>Optics and Quantum Electronics .....</b>	<b>81</b>
	<i>Professor Hermann A. Haus, Professor Erich P. Ippen, Professor James G. Fujimoto, Professor Peter L. Hagelstein, Dr. Lucio H. Acioli, Dr. Santanu Basu, Dr. Guisepp Gabetta, Dr. Yuzo Hirayama, Dr. Joseph A. Izatt, Dr. Franz X. Kärtner, Dr. Antonio Mecozzi, Dr. Kazunori Naganuma</i>	
● 1.1	Additive Pulse Modelocking .....	81
● 1.2	Ultrashort Pulse Fiber Laser .....	82
1.3	Long Distance Fiber Communications .....	82
1.4	Squeezing .....	83
1.5	Integrated Optics Components .....	83
1.6	Tunable Lasers .....	84
● 1.7	Gain Dynamics in Semiconductor Amplifiers .....	85
1.8	Ultrafast Optical Kerr Effect in Active Waveguides .....	86
● 1.9	Coherent Phonons in Electronic Materials .....	86
● 1.10	Femtosecond Studies of Superconductivity .....	87
● 1.11	Femtosecond Pulse Generation in Solid State Lasers .....	88
● 1.12	Studies of Ultrafast Phenomena in Optoelectronic Materials .....	91
● 1.13	Time Domain Diagnostics of Waveguide Devices .....	95
1.14	Laser Medicine and Surgery .....	97
1.15	Overview of the EUV Laser Effort .....	100
1.16	Nd:glass Amplifier Development .....	100
1.17	Spectral Measurements of a Ni-like Mo Plasma .....	101
1.18	Progress in EUV Laser Kinetics Modeling .....	102
1.19	Laser Cavities in the Soft X-Ray Region .....	103
1.20	Boltzmann Equation Studies .....	104
1.21	Coherent Fusion Studies .....	105
<b>Chapter 2</b>	<b>Optical Propagation and Communication .....</b>	<b>109</b>
	<i>Professor Jeffrey H. Shapiro, Dr. Robert H. Rediker, Dr. Ngai C. Wong</i>	
2.1	Introduction .....	109
2.2	Squeezed States of Light .....	109
2.3	Optical Frequency Division .....	111
2.4	Laser Radar System Theory .....	112
2.5	Fiber-Coupled External-Cavity Semiconductor High Power Laser .....	114
2.6	Analog Processing of Optical Wavefronts Using Integrated Guided-Wave Optics .....	114

<b>Chapter 3</b>	<b>High-Frequency (&gt; 100 GHz) Electronic Devices</b> .....	<b>117</b>
	<i>Professor Qing Hu</i>	
3.1	Millimeter Wave and Infrared Superconducting Focal-plane Receiver Arrays .....	117
3.2	Photon-assisted Quantum Transport in Quantum Point Contacts .....	118
3.3	High-Tc Superconducting Josephson Devices .....	119
3.4	Far-infrared (THz) Lasers Using Multiple Quantum Wells .....	120
3.5	Research Facility .....	121
3.6	Publications .....	121
<b>Section 4</b>	<b>Surfaces and Interfaces</b> .....	<b>123</b>
<b>Chapter 1</b>	<b>Statistical Mechanics of Surface Systems and Quantum-Correlated Systems</b> .....	<b>125</b>
	<i>Professor A. Nihat Berker</i>	
● 1.1	Introduction .....	125
● 1.2	Renormalization-Group Approach to Electronic Systems .....	125
● 1.3	Phase Diagrams of Semiconductor Alloys .....	126
● 1.4	Quantum Spin Systems .....	126
● 1.5	Publications .....	127
<b>Chapter 2</b>	<b>Synchrotron X-Ray Studies of Surface Disorder</b> .....	<b>129</b>
	<i>Professor Robert J. Birgeneau</i>	
● 2.1	Introduction .....	129
● 2.2	Metal Surface Studies .....	129
● 2.3	Semiconductor Surface Studies .....	130
● 2.4	Publications .....	130
<b>Chapter 3</b>	<b>Chemical Reaction Dynamics at Surfaces</b> .....	<b>133</b>
	<i>Professor Sylvia T. Ceyer</i>	
● 3.1	Dynamics of the Reaction of F <sub>2</sub> with Si(100) .....	133
● 3.2	Dynamics of the Reaction of F <sub>2</sub> with Fluorinated Si(100) .....	133
3.3	New Mechanisms for Surface Processes .....	134
<b>Chapter 4</b>	<b>Semiconductor Surface Studies</b> .....	<b>137</b>
	<i>Professor John D. Joannopoulos</i>	
● 4.1	Introduction .....	137
● 4.2	Heteroepitaxial Growth .....	137
● 4.3	Molecules .....	140
● 4.4	Publications .....	142
<b>Chapter 5</b>	<b>Epitaxy and Step Structures on Semiconductor Surfaces</b> .....	<b>143</b>
	<i>Professor Simon G.J. Mochrie</i>	
● 5.1	Structure and Phase Behavior of the Si(113) Surface .....	143

<b>PART II</b>	<b>APPLIED PHYSICS</b>	
<b>Section 1</b>	<b>Atomic, Molecular and Optical Physics</b>	<b>149</b>
<b>Chapter 1</b>	<b>Quantum Optics and Photonics</b> .....	<b>151</b>
	<i>Professor Shaoul Ezekiel</i>	
1.1	Error Sources in a Fiber Optic Resonator Gyroscope .....	151
1.2	Stimulated Brillouin Fiber Laser Gyroscope .....	153
1.3	Applications of Stimulated Brillouin Fiber Lasers .....	155
1.4	First Observation of Deflection and Cooling of Three-level Atoms in Raman Resonant Standing Wave Optical Fields .....	157
1.5	Origin of the Optical Force on the Raman Dark State in Two Standing Waves .....	158
1.6	Optical Data Storage with Raman Excited Microwave Spin Echoes .....	160
<b>Chapter 2</b>	<b>Basic Atomic Physics</b> .....	<b>163</b>
	<i>Professor Daniel Kleppner, Professor David E. Pritchard</i>	
2.1	The Diamagnetic Rydberg Atom .....	163
● 2.2	Millimeter-Wave Frequency Measurement of the Rydberg Constant .....	167
● 2.3	Atom Interferometry .....	170
● 2.4	Cooling and Trapping Neutral Atoms .....	172
● 2.5	Precision Mass Spectroscopy of Ions .....	174
<b>Section 2</b>	<b>Plasma Physics</b>	<b>177</b>
<b>Chapter 1</b>	<b>Plasma Dynamics</b> .....	<b>179</b>
	<i>Professor George Bekefi, Professor Abraham Bers, Professor Bruno Coppi, Professor Miklos Porkolab, Professor Jonathan S. Wurtele, Dr. Ronald C. Englade, Dr. Stefano Migliuolo, Dr. Abhay K. Ram, Dr. Barrett Rogers, Dr. Linda E. Sugiyama</i>	
1.1	Relativistic Electron Beams .....	179
1.2	Plasma Wave Interactions—RF Heating and Current Generation .....	183
1.3	Physics of Thermonuclear Plasmas .....	190
1.4	Versator II Tokamak Research Program .....	204
<b>Section 3</b>	<b>Electromagnetics</b>	<b>209</b>
<b>Chapter 1</b>	<b>Electromagnetic Wave Theory and Applications</b> .....	<b>211</b>
	<i>Professor Jin Au Kong, Dr. Sami M. Ali, Dr. Robert T. Shin, Dr. Ying-Ching E. Yang</i>	
1.1	ILS/MLS Frequency Management Assessment .....	211
1.2	Future Aircraft Landing System: Global Positioning System (GPS) and Synthetic Vision Sensors (SVS) .....	213
● 1.3	Multilayer Media and Superconducting Electronics .....	214
1.4	Remote Sensing of Earth Terrain .....	217
1.5	SAR Image Interpretation and Simulation .....	219
<b>Section 4</b>	<b>Radio Astronomy</b>	<b>223</b>
<b>Chapter 1</b>	<b>Radio Astronomy</b> .....	<b>225</b>
	<i>Professor Bernard F. Burke, Professor David H. Staelin, Professor Jacqueline N. Hewitt, Dr. Philip W. Rosenkranz</i>	
1.1	Extragalactic Radio Source Studies .....	225
1.2	Studies of Gravitational Lenses .....	229
1.3	Radio Interferometry of Nearby dMe Stars .....	229

Table of Contents

1.4	Tiros-N Satellite Microwave Sounder .....	230
1.5	Earth Observing System: Advanced Microwave Sounding Unit .....	231
1.6	High-Resolution Passive Microwave Imaging of Atmospheric Structure .....	232
1.7	Characterization of Dolphin Whistles .....	232
1.8	Rapid Precision Net-Form Manufacturing .....	232
1.9	Conformal Experiment Design .....	232
<b>PART III</b>	<b>SYSTEMS AND SIGNALS</b>	
<b>Section 1</b>	<b>Computer-Aided Design</b>	<b>237</b>
<b>Chapter 1</b>	<b>Custom Integrated Circuits .....</b>	<b>239</b>
	<i>Professor Jonathan Allen, Professor John L. Wyatt, Jr., Professor Jacob White, Professor Srinivas Devadas</i>	
1.1	Custom Integrated Circuits .....	239
1.2	Analog VLSI Systems for Integrated Image Acquisition and Early Vision Processing .....	241
1.3	Mixed Circuit/Device Simulation .....	250
1.4	Simulation Algorithms for Clocked Analog Circuits .....	251
1.5	Numerical Simulation of Short Channel MOS Devices .....	251
1.6	Efficient Three-Dimensional Interconnect Analysis .....	252
1.7	Parallel Numerical Algorithms .....	253
1.8	Microelectromechanical Computer-Aided Design .....	254
1.9	Techniques for Logic Synthesis, Formal Verification and Testing .....	254
<b>Chapter 2</b>	<b>Computer-Aided Fabrication System Structure .....</b>	<b>261</b>
	<i>Professor Donald E. Troxel</i>	
2.1	CAFE - The MIT Computer-Aided Fabrication Environment .....	261
<b>Section 2</b>	<b>Digital Signal Processing</b>	<b>263</b>
<b>Chapter 1</b>	<b>Digital Signal Processing Research Program .....</b>	<b>265</b>
	<i>Professor Alan V. Oppenheim, Professor Arthur B. Baggeroer, Professor Gregory W. Wornell</i>	
1.1	Introduction .....	265
1.2	Oceanographic Signal Processing .....	265
1.3	Fault-Tolerant Algorithms and Architectures for Digital Signal Processing .....	267
1.4	Imaging Ice-cracks Using Diffraction Tomography .....	267
1.5	Implementation and Evaluation of a Dual-Sensor Time-Adaptive EM Algorithm for Signal Enhancement .....	268
1.6	Quantitative Comparisons of Dolphin Signature Whistles .....	268
1.7	Applications of Synchronization in Chaotic Systems .....	269
1.8	Signal Processing Applications of Chaotic Dynamical Systems .....	269
1.9	High-Resolution Direction Finding for Multidimensional Scenarios .....	270
1.10	Wavelet-Based Representation and Algorithms for Generalized Fractal Signals .....	270
1.11	Signal Processing for Ocean Acoustic Tomography .....	271
1.12	Chaotic Signaling in Binary Data Transmission and Detection .....	271
1.13	Adaptive Matched Field Processing in an Uncertain Propagation Environment .....	272
1.14	State and Parameter Estimation with Chaotic Systems .....	272
1.15	Causal Filters with Negative Group Delay .....	273
1.16	Codebook Prediction: A Nonlinear Signal Modeling Paradigm .....	274
1.17	Synthesis, Analysis, and Processing of Fractal Signals .....	274
1.18	Active Noise Cancellation .....	275

<b>Chapter 2</b>	<b>Advanced Television and Signal Processing Program .....</b>	<b>277</b>
	<i>Professor Jae S. Lim</i>	
2.1	Introduction .....	277
2.2	ATRP Facilities .....	277
2.3	Coding of the Motion-Compensated Residual for an All-Digital HDTV System .....	278
2.4	Motion-Compensated Vertico-Temporal and Spatial Interpolation .....	278
2.5	Design of a Channel-Compatible HDTV System .....	279
2.6	Multirate Systems and Structures for Image and Video .....	279
2.7	Development of a 1.5 Kbps Speech Vocoder .....	280
2.8	A New Method for Representing Speech Spectrograms .....	280
2.9	Transform Coding for High-Definition Television .....	281
2.10	A Dual Excitation Speech Model .....	281
2.11	Design of an HDTV Display System .....	282
2.12	Signal Processing for Advanced Television Systems .....	282
2.13	Relative Importance of Encoded Data Types in an All-Digital HDTV System .....	282
2.14	Transmission of HDTV Signals in a Terrestrial Broadcast Environment .....	283
2.15	Hybrid Analog/Digital Representation of Analog Signals .....	283
2.16	An Iterative Method for Designing Separable Wiener Filter .....	284
<b>Chapter 3</b>	<b>Combined Source and Channel Coding for High-Definition Television .....</b>	<b>285</b>
	<i>Professor William F. Schreiber</i>	
3.1	Project Description .....	285
<b>PART IV</b>	<b>LANGUAGE, SPEECH AND HEARING</b>	
<b>Section 1</b>	<b>Speech Communication</b>	<b>289</b>
<b>Chapter 1</b>	<b>Speech Communication .....</b>	<b>291</b>
	<i>Professor Kenneth N. Stevens, Dr. Joseph S. Perkell, Dr. Stefanie Shattuck-Hufnagel</i>	
1.1	Introduction .....	292
1.2	Studies of the Acoustics, Perception, and Modeling of Speech Sounds .....	292
1.3	Speech Synthesis .....	295
1.4	Studies of Speech Production .....	296
1.5	Speech Production Planning .....	297
1.6	Speech Research Relating to Special Populations .....	298
1.7	Models for Lexical Representation and Lexical Access .....	299
1.8	Speech Analysis and Synthesis Facilities .....	300
1.9	Publications .....	300
<b>Section 2</b>	<b>Sensory Communication</b>	<b>303</b>
<b>Chapter 1</b>	<b>Sensory Communication .....</b>	<b>305</b>
	<i>Professor Louis D. Braida, Nathaniel I. Durlach, Dr. William M. Rabinowitz, Dr. Charlotte M. Reed, Dr. Mandayam A. Srinivasan, Dr. Patrick M. Zurek</i>	
1.1	Introduction .....	305
1.2	Hearing Aid Research .....	305
1.3	Multimicrophone Hearing Aids .....	307
1.4	Cochlear Protheses .....	308
1.5	Binaural Hearing .....	309
1.6	Clinical Applications of Binaural Hearing .....	310
1.7	Tactile Communication of Speech .....	311

Table of Contents

1.8	Super Auditory Localization for Improved Human-Machine Interfaces .....	312
1.9	Research on Reduced-Capability Human Hands .....	313
1.10	Mechanistic Modeling of Primate Fingerpad .....	314
1.11	Biomechanics of Skin-Object Contact .....	316
1.12	Publications .....	317
<b>Section 3</b>	<b>Auditory Physiology</b> .....	<b>319</b>
<b>Chapter 1</b>	<b>Signal Transmission in the Auditory System</b> .....	<b>321</b>
	<i>Professor Lawrence S. Frishkopf, Professor Nelson Y.S. Kiang, Professor William T. Peake, Professor William M. Siebert, Professor Thomas F. Weiss, Dr. Bertrand Delgutte, Dr. Donald K. Eddington, Dr. Dennis M. Freeman, Dr. John J. Guinan, Jr., Dr. John J. Rosowski</i>	
1.1	Introduction .....	321
1.2	Signal Transmission in the External and Middle Ear .....	321
1.3	Basic and Clinical Studies of the Auditory System .....	322
1.4	Cochlear Mechanisms .....	323
1.5	Electrical Stimulation of the Auditory Nerve .....	325
1.6	Middle-Ear Muscle Reflex .....	326
1.7	Cochlear Efferent System .....	326
1.8	Cochlear Implants .....	327
<b>Section 4</b>	<b>Linguistics</b> .....	<b>329</b>
<b>Chapter 1</b>	<b>Linguistics</b> .....	<b>331</b>
	<i>Professor Noam Chomsky, Professor Morris Halle</i>	
1.1	Introduction .....	331
1.2	Abstracts of Doctoral Dissertations .....	331
<b>APPENDICES</b>		
<b>Appendix A</b>	<b>RLE Publications and Papers Presented</b> .....	<b>341</b>
A.1	Meeting Papers .....	341
A.2	Journal Articles .....	353
A.3	Books/Chapters in Books .....	364
A.4	RLE Publications .....	365
A.5	RLE Theses .....	366
A.6	Miscellaneous .....	368
<b>Appendix B</b>	<b>Current RLE Personnel</b> .....	<b>369</b>
<b>Appendix C</b>	<b>Milestones</b> .....	<b>375</b>
C.1	New Faculty and Staff .....	375
C.2	Retirements .....	375
C.3	Promotions .....	375
C.4	Chair Appointments .....	375
C.5	Awards and Honors .....	375
<b>Appendix D</b>	<b>RLE Research Support Index</b> .....	<b>377</b>
<b>Project Staff and Subject Index</b>		<b>381</b>