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Quarterly Technical Summary

Advanced Electronic Technology

15 May 1972

Prepared under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period 1 February through 30 April 1972. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1972 for the Advanced Electronic Technology Program of Division 2. Separate progress reports on Graphics, Propagation Studies, Seismic Discrimination and the Educational Technology Program describe other work in the Division.

M. A. Herlin
Acting Head, Division 2

I. L. Lebow
Associate Head

DIGITAL COMPUTERS
GROUP 23

I. INTRODUCTION

The goal of Group 23's program is to achieve the capability to design and fabricate very-high-speed, large-scale integrated circuits for Laboratory systems applications. For several years, in-house work was restricted to the circuit design and mask layout parts of the activity, with semiconductor fabrication performed by a commercial contractor. Early in calendar 1971, the Laboratory initiated an in-house fabrication effort as well. A first milestone was reached during this quarter with the successful fabrication of high-speed transistors (~2 GHz). We expect that the first relatively simple integrated circuit elements will be fabricated during the next quarter.

II. INTEGRATED CIRCUIT PROCESSING

A. Transistor Fabrication

Preparations for integrated circuit processing are well advanced. Base processing with boron nitride sources permits thinner junctions with lighter doping than Philco reported. Doped oxide sources for emitters provide reproducible results without the shorting problems which previously required multiple depositions. The aluminum-silicon metalization seems to give satisfactory results. A number of runs of transistors have been made and have been found to have f_t's around 2 GHz. This design had no base insert and was in a relatively high-capacitance package, both of which tend to reduce the frequency response. Resistor and isolation diffusion experiments are being performed while work commences on the three-input gate circuit.

B. Computer Modeling

The processing model has been reprogrammed in BCPL, providing a significant reduction in the number of lines of code and a considerable improvement in readability with minor sacrifices in efficiency. This should make additions and changes to the existing programming much simpler to implement.

C. Metalization

The application of Al-Si by flash evaporation of 4% Si content wire from a series of tungsten filaments is now a routine procedure. The resulting 5000 to 7000 Å metal layer contains 1% to 2% Si, is reasonably smooth, well-adhered, and etches satisfactorily. The planetary drive wafer holding fixture is being used for improved step coverage, and pressure is approximately 3×10^{-6} torr during evaporation.

D. Photolithography Techniques

First oxide openings (base cuts) began exhibiting roughness at the bottom of the cuts, which resulted from a thin resist layer that seemed to originate at the vertical edges of the resist

during etching in buffered hydrofluoric acid. Use of a silane bonding agent has corrected the problem and improved the resist adhesion, which has permitted an overall reduction in processing time by eliminating several baking steps previously required.

III. PHOTOLITHOGRAPHIC INTERCONNECTION OF PLASTIC-EMBEDDED SEMICONDUCTOR CHIPS

A. Improved Aluminum Deposition

Improved etching of aluminum chip pads has eliminated the need for slurry abrading with alumina prior to metalization of pads of chips containing active devices. A 30-sec etch in a mixture of 90-percent orthophosphoric acid (85 percent) and 10-percent nitric acid at room temperature, followed by a 15-sec etch in pure orthophosphoric acid at 150°F, adequately prepares the aluminum to receive a deposit of immersion zinc. The zinc is a catalyst for the subsequent electroless deposition of nickel. A neutral pH boron nickel bath has been substituted for the phosphorous nickel bath previously used to avoid possible contamination of chips by sodium and potassium. The bath operates at 150°F and produces deposits of low stress and low electrical resistance. Adhesion is good as indicated by "scotch tape" pull tests.

B. Corrosion Cell Problems

Uniform plating of aluminum pads of "unprotected" chips is dependent upon chip complexity and the electrical resistance between pads and the base silicon in contact with etching and plating solutions. In the worst case, pads with low resistance to base silicon can reject plating entirely and simply erode away. These chips are best metalized after the chips have been encapsulated in plastic and the base silicon isolated from the solutions.

C. Multi-chip Memory Module

Several mock-ups of the 20-chip IC memory package have been produced to identify possible production problems. Chip-to-wiring registration is satisfactory, and ohmic contact was made to all dummy memory chips.

IV. TESTING AND MASK DESIGN

A. Photo-Encapsulated Wiring (PEW) Test Samples

Five samples of PEW single-memory chips have been delivered for evaluation and life test. One unit was bad when received due to an open on the memory chips, perhaps produced during PEW processing. The remaining units were functionally good, and were placed on power-on life test. When evaluated after several hundred hours of life test, one good unit had failed due to a high-resistance contact at the V_{ee} power pad.

A memory chip functional tester is now available, and is used to evaluate memory chips before and after encapsulation and during life test.

Memory decoder and latch circuit chips for the complete memory subsystem are now being obtained by removing them from ceramic DIP integrated circuits.

B. Masks

Several of the masks for the PEW memory subsystem have been modified to eliminate alignment errors. Also, variable density masks are being produced to compensate for aluminum reflectivity.

A mask set has been designed which produces a set of 15 high-speed isolated transistors of various geometries, plus several sheet resistance test devices. These will be used to evaluate the effect of various geometries on device yield and f_t and h_{rb}.

A mask set for evaluating two-level metalization has been produced. This will be used to evaluate processing problems and for electromigration studies.

C. Transistor Test Equipment

The automatic prober continues to be used several hours each day for testing transistor wafers; a switch box, which allows the operator to rapidly switch between various test setups and to view the transistor properties on a curve tracer, has proven very useful.

A program has been written which allows data maps for transistor wafers to be compared against test limits and produces an ink map which indicates devices not passing the test limits. This ink map is then used to control an inking program which marks bad devices on the wafer.

D. Transistor Performance Measurements

Some problems in the DC bias circuit and noise in the RF loop have necessitated an overhaul of the f_t test gear. At the same time, the opportunity was used to upgrade the operational amplifiers in the equipment.

Transistors fabricated by Group 23 have shown an f_t of 2 GHz at I_c = 4 mA and V_{cb} = 1 V.

The h_{rb} computer program has been re-entered into TX-2, thus allowing measurements to be made of r'_b and C_c. A modification to the program, which adds a correction term to r'_b and C_c resulting from the emitter to collector capacity, has also been made. Measurements will be made with both the modified and original programs for comparison.

Initial experiments have been made with capacity-vs-voltage curves on diodes in an attempt to estimate the carrier density. Initial results of density appear to be in the correct range, but distance calculations from the same measurements are in error and require further work.

COMPUTER SYSTEMS
GROUP 28

Work on the CP/CMS time-sharing system during this quarter centered around the continuing effort to improve performance by reducing system overhead and by better scheduling of users based upon the load they impose on the system. A special interface between CMS disk I/O and CP has been installed which bypasses the normal I/O channel program simulation. This facility not only reduces the overhead in simulating a virtual machine, but also reduces the number of pages locked in core during an I/O operation. Changes to the dispatcher were made to replace a fixed number of multiprogrammed tasks with a variable number based upon the working set size of a task (a number related to the number of active pages the task demands) and the total system paging activity. This type of algorithm should result in better use of the machine cycles by reducing wait time, and in better core use by eliminating conditions which cause thrashing and excessive paging overhead.

During this quarter, CMS improvements involved the file access facilities. A simplified and more flexible procedure was made available for obtaining read-only shared access to a subset of the files belonging to another account. Also, a procedure was provided to obtain read/write access to the file space of another account or to access a temporary disk in addition to the normal permanent disk. To enable programs running under CMS to access files stored under OS/360, a command is now available to copy datasets stored on an OS/360 formatted disk to a CMS file. Similarly, an OS/360 utility program is available to copy a CMS file to an OS/360 dataset. These facilities should assist in the transfer of programs and data between OS/360 batch system and the CP/CMS time-sharing system.

The OS/360 batch processing system also acquired some performance improvements during this report period. A core fragmentation problem was mitigated by forcing the memory management routines to delay allocation for the job until the interpreter releases its space and by requiring that initiators be allocated the same amount of space as the job it is about to start. A slight loss in parallel operation is more than offset by the improvement in memory continuity. Relaxation of job class limits, together with the results of system monitoring and measurement, are expected to produce more efficient multiprogramming.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 February through 30 April 1972. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS
ON ADVANCED ELECTRONIC TECHNOLOGY

15 February through 15 May 1972

PUBLISHED REPORTS

Journal Articles*

JA No.			
3892	Shubnikov-de Haas Measurements in $Pb_{1-x}Sn_xSe$	J. Melngailis T.C. Harman W.C. Kernan	Phys. Rev. B 5, 2250 (1972), DDC AD-742593
3898	Persistent Photodielectric Lens Effect in Cadmium Sulfide	K.B. Kanarek† C.D. Wyche A.S. Pine	J. Appl. Phys. 43, 586 (1972), DDC AD-742595
3919	EuTe. I. Magnetic Behavior of Insulating and Conducting Single Crystals	N.F. Oliveira, Jr.† S. Foner† Y. Shapira† T.B. Reed	Phys. Rev. B 5, 2634 (1972), DDC AD-742603
3920	EuTe. II. Resistivity and Hall Effect	Y. Shapira† S. Foner† N.F. Oliveira, Jr.† T.B. Reed	Phys. Rev. B 5, 2647 (1972), DDC AD-742606
3921	EuTe. III. Ultrasonic Behavior	Y. Shapira† T.B. Reed	Phys. Rev. B 5, 2657 (1972), DDC AD-741613
3937	Fourier Expansion for Electronic Bands in Trigonal Tellurium and Selenium	G. Dresselhaus	Phys. Rev. B 5, 1538 (1972), DDC AD-738718
3939	Study of the Optical Shubnikov-de Haas Effect	F.P. Missell† M.S. Dresselhaus	Phys. Rev. B 5, 1364 (1972), DDC AD-738719
3943A	Non-Γ Donor Levels and Kinetics of Electron Transfer in n-Type CdTe	G.W. Iseler J.A. Kafalas A.J. Strauss H.F. MacMillan† R.H. Bube†	Solid State Commun. 10, 619 (1972)
3949	$Pb_{1-x}Sn_xTe$ Photovoltaic Diodes and Diode Lasers Produced by Proton Bombardment	J.P. Donnelly A.R. Calawa T.C. Harman A.G. Foyt W.T. Lindley	Solid-State Electron. 15, 403 (1972), DDC AD-742617

* Reprints available.

† Author not at Lincoln Laboratory.

JA No.			
3953	Measurement of the Lattice Parameter of Wustite at High Temperatures	M. Hayakawa* J. B. Cohen* T. B. Reed	J. Am. Ceram. Soc. 55, 160 (1972)
3984	The Use of Lasers in Pollution Monitoring	I. Melngailis	IEEE Trans. Geosci. Electron. GE-10, 7 (1972), DDC AD-742624
3992	Preparation and Structure of a Pyrochlore and Perovskite in the $BiRhO_{3+x}$ System	J. M. Longo* P. M. Raccah* J. A. Kafalas J. W. Pierce	Mater. Res. Bull. 7, 137 (1972), DDC AD-738749
3995	p-n Junction Photodiodes in PbTe Prepared by Sb^+ Ion Implantation	J. P. Donnelly T. C. Harman A. G. Foyt W. T. Lindley	Appl. Phys. Letters 20, 279 (1972)
3996A	High Resolution Pattern Replication Using Soft X-Rays	D. L. Spears H. I. Smith	Electron. Letters 8, 102 (1972)

Meeting Speeches

MS No.			
2621	Variations of Infrared Cyclotron Resonance and the Density of States Near the Conduction Band Edge of InSb	E. J. Johnson D. H. Dickey	Electronic Density of States, L. H. Bennett, ed. (NBS Special Publication 323, 1971), p. 423
2628	On the Optical Properties and the Density of States in Arsenic	R. W. Brodersen* M. S. Dresselhaus	Electronic Density of States, L. H. Bennett, ed. (NBS Special Publication 323, 1971), p. 39
2630	Optical Properties of Aluminum	G. Dresselhaus M. S. Dresselhaus D. Beaglehole*	Electronic Density of States, L. H. Bennett, ed. (NBS Special Publication 323, 1971), p. 33
2631	Localized States in Narrow Band and Amorphous Semiconductors	D. Adler J. Feinleib	Electronic Density of States, L. H. Bennett, ed. (NBS Special Publication 323, 1971), p. 493
2727	Theory of Antiferromagnetism and Ferrimagnetism	J. B. Goodenough	Chap. 24 in Physics of Electronic Ceramics, Part B, L.L. Hench and D. B. Dove, eds. (Marcel Dekker, Inc., New York, 1972), p.777
2906	Growth of Oxide Crystals	T. B. Reed	Ferrites: Proceedings of the International Conference, July 1970, Japan, Y. Hoshino, S. Iida and M. Sugimoto, eds. (University of Tokyo Press, Tokyo, 1971), p. 289

* Author not at Lincoln Laboratory.

MS No.			
3075A	Brillouin Spectroscopy in Cadmium Sulfide: Acoustoelectric and Anharmonic Effects and Resonance Scattering	A. S. Pine	Proceedings of the Second International Conference on Light Scattering in Solids, Paris, 19-23 July 1971, M. Balkanski, ed. (Flammarion Sciences, Paris, 1971), p. 467
3076	Raman Scattering in Tellurium	A. S. Pine G. Dresselhaus	Proceedings of the Second International Conference on Light Scattering in Solids, Paris, 19-23 July 1971, M. Balkanski, ed. (Flammarion Sciences, Paris, 1971), p. 267
3129	Molecular and Lattice Vibrations in Solid Ammonia	A. S. Pine C. J. Glassbrenner G. Dresselhaus	Proceedings of the International Conference on Phonons, Rennes, France, 26-28 July 1971 (Flammarion Sciences, Paris, 1971), p. 258
3153	Preparation and Properties of $Pb_{1-x}Cd_xS$	A. R. Calawa J. A. Mroczkowski T. C. Harman	J. Electron. Mater. No. 1, 191 (1972)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3905	Structure of Orthorhombic $V_{0.95}Cr_{0.05}O_2$	J. W. Pierce J. B. Goodenough	Accepted by Phys. Rev. B
3942A	Observation of Λ-Doubling and Zeeman Splitting in the Fundamental Absorption Band of Nitric Oxide	K. W. Nill F. A. Blum A. R. Calawa T. C. Harman	Accepted by Chem. Phys. Letters
3970	Observation of Nuclear Hyperfine Splitting in the Infrared Vibration-Rotation Absorption Spectrum of the NO Molecule	F. A. Blum K. W. Nill A. R. Calawa T. C. Harman	Accepted by Chem. Phys. Letters
3974	Amplitude Renormalization Factor in Two-Magnon Raman Scattering	R. W. Davies	Accepted by Phys. Rev. B
3985	Tunable Lasers and Their Applications	H. R. Schlossberg* P. L. Kelley	Accepted by Physics Today

* Author not at Lincoln Laboratory.

JA No.			
4001	X-Ray Lithography: A New High Resolution Replication Process	D. L. Spears H. I. Smith	Accepted by Solid State Technology
4006	Tunable Laser Spectroscopy of the ν_1 Band of SO_2	E. D. Hinkley A. R. Calawa P. L. Kelley S. A. Clough*	Accepted by J. Appl. Phys.
4015	Measurement of the Gain Lineshape of a Gas Laser Using a Tunable Semiconductor Laser	F. A. Blum K. W. Nill A. R. Calawa T. C. Harman	Accepted by Appl. Phys. Letters
4028	A Laser Scanner for Integrated Circuit Testing	R. E. McMahon	Accepted by Proc. IEEE
MS-3175	Valence-Bond Approach to Magnetic Semiconductors	J. B. Goodenough	Accepted by New Developments in Semiconductors (Wolters-Noordhoff, Gronigen)

Meeting Speeches†

MS No.			
2951G	Localized vs Itinerant Electrons in Transition-Metal Monoxides	J. B. Goodenough	Colloquia in Solid State Science, Arizona State University, Tempe, Arizona, 12-14 April 1972
3043E	Semiconductor-to-Metal Transitions	J. B. Goodenough	
3356	Perovskite Polytypes	J. B. Goodenough	
2989E	A Laser Scanner for Integrated Circuit Testing	R. E. McMahon	IEEE 1972 Reliability Physics Symposium, Las Vegas, Nevada, 5-7 April 1972
3155A	The Use of Lasers in Pollution Monitoring	I. Melngailis	Third Latvian Conference on Technical Sciences, York University, Toronto, Ontario, 12-14 May 1972
3192A	Recent Developments in Tunable Infrared Lasers	A. Mooradian	Seminar, Naval Research Laboratory, Washington, D. C., 6 April 1972
3245	X-Ray Replication of Scanning Electron Microscope Generated Patterns	D. L. Spears H. I. Smith E. Stern	5th International Conference of Electron and Ion Beam Society, Houston, Texas, 7-12 May 1972

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MS No.			
3249	Resistivity of $Pb_{1-x}Sn_xSe$ vs Hydrostatic Pressure	J. Melngailis T.C. Harman J.A. Kafalas	Conference on the Physics of IV-VI Compounds and Alloys, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, 24-25 March 1972
3254	Free-Carrier Absorption in n-Type PbTe	A.J. Strauss	
3296	$PbS_{1-x}Se_x$ Tunable Lasers for High Resolution Infrared Spectroscopy	K.W. Nill F.A. Blum A.R. Calawa T.C. Harman	
3307A	PbTe Photodiodes Fabricated by Sb^+ Ion Implantation	J.P. Donnelly T.C. Harman A.G. Foyt W.T. Lindley	
3322	Control of Imperfections in Crystals of $Pb_{1-x}Sn_xTe$, $Pb_{1-x}Sn_xSe$, and $PbS_{1-x}Se_x$	T.C. Harman	
3255	Flexible, Beam-Leaded Substrates Utilizing Aluminum Interconnections and Beam Leads	F.J. Bachner	The American Ceramic Society, Inc., 74th Annual Meeting and Exposition, Washington, D.C., 6-11 May 1972
3275	Measurement of the Frequency Gain Profile of a CO Laser Using a Tunable Semiconductor Laser	F.A. Blum K.W. Nill A.R. Calawa T.C. Harman	VII International Quantum Electronics Conference, Montreal, Canada, 8-11 May 1972
3276	High Resolution Infrared Spectroscopy of NO Using a Tunable PbSSe Laser	K.W. Nill F.A. Blum A.R. Calawa T.C. Harman	
3277	Tunable Laser Spectroscopy of the ν_1 Band of SO_2	P.L. Kelley E.D. Hinkley A.R. Calawa S.A. Clough*	
3337	Tunable Semiconductor Lasers	A. Mooradian	
3362	Submillimeter Lasers Optically Pumped Off Resonance	H.R. Fetterman H.R. Schlossberg* J. Waldman C.D. Parker P.E. Tannenwald	
3286	Microscopic Theory of the Spontaneous Spin-Flip Raman Lineshape in InSb	R.W. Davies	American Physical Society Meeting, Atlantic City, New Jersey, 27-30 March 1972

* Author not at Lincoln Laboratory.

MS No.			
3287	Non-Local Pseudopotentials in Solids	G. Dresselhaus	
3288	Search for Hole Fermi Surface Anomalies in High Purity Bismuth	V. E. Henrich	
3289	Non-Γ Donor Levels in II-VI Compounds and Their Alloys	G. W. Iseler J. A. Kafalas A. J. Strauss	
3290	Why Are Donor Optical Transitions So Broad?	D. M. Larsen	
3291	Free-Carrier Absorption in n-Type CdTe	A. J. Strauss G. W. Iseler	American Physical Society Meeting, Atlantic City, New Jersey, 27-30 March 1972
3292	Magnetic-Field-Induced Resonant Raman Scattering in EuSe	J. C. Tsang* R. L. Aggarwal* M. S. Dresselhaus T. B. Reed	
3293	Linewidth of Spontaneous Spin-Flip Raman Scattering in InSb	S. R. J. Brueck F. A. Blum	
3294	Raman and Infrared Spectra of Paratellurite: TeO_2	A. S. Pine D. M. Korn T. B. Reed G. Dresselhaus	
3302A	Broad Band Laser Emission from Optically Pumped PbS_xSe_{1-x}	A. Mooradian A. J. Strauss J. A. Rossi	
3336	Optically Pumped Room Temperature GaAs Lasers	S. R. Chinn J. A. Rossi C. M. Wolfe A. Mooradian	1972 IEEE Semiconductor Laser Conference, Boston, Massachusetts, 15-17 May 1972
3338	Stripe-Geometry $Pb_{1-x}Sn_xTe$ Diode Lasers	R. W. Ralston I. Melngailis A. R. Calawa W. T. Lindley	
3307	PbTe Photodiodes Fabricated by Sb^+ Ion Implantation	J. P. Donnelly T. C. Harman A. G. Foyt W. T. Lindley	1972 IRIS Detector Specialty Group Meeting, Orlando, Florida, 15-17 March 1972

* Author not at Lincoln Laboratory.

Division 8

MS No.			
3308	InSb p-n Junction Photodiodes Fabricated by Zn^+ Ion Implantation	A. G. Foyt C. E. Hurwitz J. P. Donnelly W. T. Lindley	1972 IRIS Detector Specialty Group Meeting, Orlando, Florida, 15-17 March 1972
3309	Guarded Planar InSb n-p Photodiodes Fabricated by Proton Bombardment	C. E. Hurwitz F. J. Leonberger A. G. Foyt W. T. Lindley J. P. Donnelly	
3318	High Resolution Infrared Spectroscopy Using Tunable Semiconductor Lasers	K. W. Nill	Physics Colloquium, Ohio State University, 15 February 1972
3357	Semiconductor Lasers for Spectroscopy and Pollution Monitoring	I. Melngailis	IEEE Electron Devices Meeting, Raytheon Company, Bedford, Massachusetts, 13 April 1972
3358	Nonlinear Optics	P. L. Kelley	American Physical Society Meeting, Poughkeepsie, New York, 21-22 April 1972

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

A new soft x-ray camera, which allows a 50X faster exposure of polymethyl methacrylate, has been developed for use in x-ray lithography. By using this camera, patterns with 0.6-μm linewidths have been replicated with better than 0.2-μm resolution.

A technique has been developed which allows the fabrication of large-area masks for x-ray lithography. In this technique, 5-μm-thick windows are etched into 200-μm-thick silicon substrates which are used as frames to support the thin windows. The uniform 5-μm thickness is obtained by diffusing a heavily doped boron layer into the sample, and then etching from the reverse side with an etch that stops when the boron concentration reaches $\sim 2 \times 10^{19}/cm^3$.

Avalanche photodiodes have been made in InGaAs with Pt Schottky barriers and guard rings fabricated using proton bombardment. In reverse bias, these diodes have shown photocurrent multiplications of 200 times the low-bias response and rise times of <200 psec in response to a 1.06-μm mode-locked Nd:YAG laser.

Reliability studies have been carried out on K_a-band GaAs IMPATT diodes fabricated using plated heat sinks of copper, silver, or gold. These studies clearly indicate that plated silver heat sinks are superior to either gold or copper heat sinks. In addition, a comparison between devices made using proton-bombarded guard rings and devices made as inverted mesas showed that the proton-bombarded diodes had higher burnout resistance, with an average burnout temperature approximately 50°C higher than the inverted mesa diodes.

II. QUANTUM ELECTRONICS

Optical pumping of room-temperature GaAs lasers has been carried out using a wavelength tunable pulsed optical parametric oscillator as the pump source. The dependence of laser operation on pump wavelength and power was studied for several GaAs samples. In these preliminary studies, conversion efficiencies of nearly 5 percent were obtained for high-purity samples ($1.6 \times 10^{14}\ cm^{-3} \leq N_d + N_a \leq 1.6 \times 10^{16}\ cm^{-3}$). Si-doped samples, having higher transparency in the vicinity of the band gap than the high-purity samples, showed broadband laser emission when pumped at shorter wavelengths.

Silicon-doped GaAs double-heterostructure diodes have been fabricated. These devices have operated pulsed at room temperature. The observed lasing wavelength of 9400 Å corresponds to a transition involving a Si acceptor level which is shallower than those involved in spontaneous emission.

Studies of InAs lasers for pressure tuning in the 2.2- to 3.1-μm range have been undertaken. Pulsed operation, both with diodes and optically pumped materials, is being examined. Band-to-band laser emission is observed in high-purity optically pumped material, while band-to-acceptor laser transitions are observed from diodes. Greater heating and thus greater frequency chirping are seen in the optically pumped case. A faster, high repetition pulser is being constructed to reduce the chirp and allow higher spectral resolution.

Continuous recombination radiation has been observed at temperatures between 2° and 20°K in InSb optically pumped by a CO laser. At 5.25 μm, 10 mW of CW radiation in a single axial mode was observed and, at 5.45 μm, lower power laser radiation was seen from a conduction-band-to-Zn-acceptor transition. Pulsed operation has also been achieved in a rod of InSb optically pumped by an array of GaAs diodes. Average power outputs of about 40 mW were observed at 10°K.

Studies of the tuning characteristics of a spin-flip Raman laser have been carried out using low density ($\sim 10^{15}$ cm^{-3}) InSb. The observed tuning rate of 48 ± 2 MHz/G is three times larger than the previously observed rate for 10^{16} cm^{-3} material. At low carrier concentrations, the spontaneous linewidth should be narrower than for high concentration materials, reducing the influence of the cavity resonance condition and allowing the oscillation frequency to tune at a rate which is closer to that for spontaneous tuning (70 MHz/G). The absolute frequency of the spin-flip Raman laser was measured by the heterodyne technique, and short term frequency drifts of less than 2 MHz/sec were observed. Doppler-limited spectroscopy of NO has also been carried out with this laser.

Pressure broadening has been studied for the very narrow line in the ν_2 band of H_2O which consists of two degenerate transitions $16_{0,16} \leftarrow 15_{1,15}$ and $16_{1,16} \leftarrow 15_{0,15}$. The self-broadening coefficient of the full width was found to be 15 MHz/torr, while that for N_2 broadening was 0.6 MHz/torr. The observed ratio of 25:1 for these rates is in contrast to the 5:1 ratio reported for the 2.7-μm band.

III. MATERIALS RESEARCH

The optical absorption of n-type CdTe at room temperature has been measured between 0.9 and 12 μm for samples with carrier concentrations between 3.6×10^{16} and 1.8×10^{18} cm^{-3}. Intraband free-carrier absorption is the predominant absorption mechanism beyond 2 μm, but interband free-carrier absorption appears to be significant at shorter wavelengths.

The infrared-to-visible upconversion efficiency of $NaYF_4$:Yb,Er phosphors has been found to depend strongly on their degree of crystalline perfection. The highest efficiencies so far have been obtained for samples prepared from NaF-rich melts, which crystallize directly in the low-temperature hexagonal form rather than undergoing a cubic-to-hexagonal transformation.

The compounds $MSbO_3$ (M = Li, Na, Rb, or Ag) have been prepared in body-centered-cubic form by ion exchange between molten MNO_3 and $KSbO_3$ or $TlSbO_3$. The structures of $NaSbO_3$ and $AgSbO_3$ have been refined by analysis of x-ray diffraction data for single crystals obtained by the ion exchange technique.

The crystal structure of $CuTa_2O_6$ has been refined by x-ray diffraction analysis for a single crystal grown from a flux of excess CuO. The compound is a distorted perovskite in which each Cu atom has four coplanar nearest-neighbor anions and eight next-nearest-neighbor anions.

IV. PHYSICS OF SOLIDS

In the continuing phosphor upconversion program, several excitation sources, including a xenon arc lamp and a Nd:YAG laser, were employed to study the variation of visible emission as a function of infrared excitation in $Na_{0.8}Yb_{0.18}Er_{0.02}F_4$. In our optical system, at an

effective input intensity of 22 W/cm^2, a total radiant efficiency of over 5 percent was achieved and the efficiency was still rising at a significant rate with further increasing excitation. Since the above input intensity is well beyond what is presently available on a CW basis, it appears that saturation effects do not represent the primary limitation for this system.

The free-energy model of a metal-insulator transition, formulated earlier for Ti_2O_3, is being extended to the case of V_2O_3. A theoretical study is under way of the steady-state motion of a pulse of insulating phase injected into a film of metallic phase in the presence of an electric current.

Work in the high resolution laser spectroscopy programs continues. Zeeman tuning of several absorption lines of the paramagnetic NO gas was used to bring them into exact coincidence with fixed frequency CO laser lines and thereby obtain resolved absorption spectra of NO.

By using a $PbS_{0.82}Se_{0.18}$ diode laser operating at 4.7 μm, previous measurements on the molecule $C^{12}O^{16}$ were extended to the isotopic molecule $C^{13}O^{16}$. From a precise measurement of the spacing between absorption lines of these two molecules, the ratio of the reduced masses for the carbon isotopes was deduced and found to be in good agreement with the accepted mass spectrographic value.

The program of optically pumping molecular gas systems to produce submillimeter radiation has most recently turned to an investigation of population inversion from both the rotational and inversion-split states of NH_3. New stable transitions have been observed, identified, and used as a source for studying the linewidth of hydrogenic donor transitions in high-purity GaAs.

Samples of $Hg_{1-x}Cd_xTe$ with x = 0.22 and 0.31, cooled to below 25 °K, have been irradiated by 2.5-MeV electrons with dosages of up to $10^{15}/cm^2$. The samples were then annealed by heating for 15 minutes at progressively higher temperatures and returned to 8 °K after each step to make measurements of conductivity, Hall coefficient, photoluminescence and photovoltaic response. The results appear to be interpretable in terms of the introduction by irradiation of energy levels in the forbidden gap.

In a theoretical study of imperfections in semiconductors, a model of the effect of lattice vacancies on the electrical properties of small-gap compound semiconductors has been formulated, based on T-matrix theory. The theory is being applied in particular to cases where the gap can be made to vanish by choice of composition or the application of pressure.

V. MICROELECTRONICS

Considerable work has been required for equipment modifications and equipment procurement to implement new processes or refinements in existing processes. In particular, the thin-film laboratory has a large amount of materials processing which requires more efficient handling and scheduling to allow a continuation of short turn-around time for these tasks. Other areas of the microelectronics laboratory have also been active in equipment modifications and upgrading.

The environmental area has expanded its activity in life tests for the electron beam semiconductor (EBS) units and GaAs microwave diodes, and has continued to evaluate all prototype hybrid integrated circuits and devices produced in the microelectronics facility.

The mask-making area has delivered approximately 400 masks since the first of the year, and the workload continues at a relatively high level. The inadequate environment of the present

mask-making area continues to cause processing problems and limits the efforts to improve the throughput time.

Based on a schematic, a computer program to estimate the substrate area required for a particular circuit is nearly complete. Although the basic equation which was derived empirically has been employed for some time, the stored information on component size, substrate area, available package sizes, and I/O pin configuration allows the computer to display the available options in package shape and size.

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