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Advanced Electronic Technology

15 November 1971

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 August through 31 October 1971. 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 August through 31 October 1971 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

DIGITAL COMPUTERS
GROUP 23

I. INTEGRATED CIRCUIT DESIGN AND FABRICATION

A. Spin-on Sources

Attempts to use spin-on boron sources for high-frequency transistor bases were unsuccessful due to nonuniform deposition from the source. This led to undoped base areas which subsequently became emitter-collector shorts; in deeper diffused devices this sort of nonuniformity is smeared out. Boron nitride sources are now being evaluated.

Preliminary tests of spin-on phosphorous sources indicated our washed emitter processing may be satisfactory, but further tests on thinner emitters are required.

B. Oxide Reactor

Various tests of the newly purchased oxide reactor indicate that satisfactory performance is possible; however, we do not know yet whether we will be able to deposit arsenic-doped oxides.

C. Photolithography Techniques

One hundred and twenty wafers have been processed through various etching steps. Poor adhesion of the metal to the oxide has resulted in a series of experiments to determine whether the cause is inadequate precleaning or evaporator contamination such as pump oil on the oxide.

Evaluation of the photoreduction step and repeat capability of five outside vendors has shown a price range of $150 to $250 per mask (chrome), a line edge definition range of poor to good, and a line dimensional tolerance of ±15 percent in the worst case to ±5 percent in the best pattern. Delivery times ranged from three weeks to four months.

In general, the quality of the masks made outside is not superior to those made most recently by Group 83. This was demonstrated by the five mask sets for shallow devices having washed emitters made by Group 83. The mask-to-mask registration was within ±0.015 mil, maximum line width error of ±10 percent, and very good edge definition.

The six-wafer metalization fixture is complete and is being checked out. In addition, a supplementary cold trap is being designed for the vacuum system, to reduce oil back streaming into the evaporator.

D. Metalization

Experiments are in progress using a tungsten filament source to evaporate Al-Si alloy.

E. Computer Modeling of Transistor Fabrication Process

A processing model for the fabrication of transistors on silicon wafers has been developed and programmed for TX-2. The model is based on a difference-equation simulation of the one-dimensional diffusion equation during oxidation, diffusion and epitaxy processing of the silicon

wafer. Two displays are provided during the computer processing. One is a two-dimensional cross section of the silicon wafer showing the oxide, the p-regions, and the n-regions in the selected cross-sectional area of the wafer of interest. The other display is a depth profile of the net algebraic sum of the impurity concentration distribution at a selected point on the silicon wafer.

II. INTEGRATED CIRCUIT APPLICATIONS

A. Hybrid Semiconductor Memory Array

A PEW (plastic encapsulated wiring) hybrid semiconductor memory system, consisting of sixteen 64-bit high-speed bipolar semiconductor memory chips plus decoder and amplifier chips, is being developed.

The memory array has been specified in detail. Preliminary artwork for the PEW interconnection of the chips has been designed using the mask design program.

A mockup of the chip using conventional DIP integrated circuits has been built. A test pattern generator to evaluate the mockup and the PEW memory array is under construction.

Heat will be transferred from the semiconductor chips to a copper backing plate by a 0.5-mil-thick copper layer electroplated through a hole in the backing plate and the encapsulating polyester resin. Calculations indicate a semiconductor-to-backing-plate temperature difference of approximately 30°C per watt – an entirely acceptable value.

PEW semiconductor compatibility is being evaluated by measuring type 7400 TTL quad-gate chips at various points prior to, during, and after PEW processing. Other tests using drifted CV measurements on PEW-processed MOS capacitors are now being developed.

B. Photolithographic Interconnection of Plastic-Embedded Semiconductor Chips

Eight off-the-shelf Philco quad gate integrated circuit chips have been individually packaged in array form, and all but one function properly after encapsulation. Intentional variations in processing procedure were employed for evaluation purposes.

Techniques have been developed for applying electroless and electroplated metalization to the backs of encapsulated chips and arrays for the removal of heat. Several test arrays are being produced to evaluate the effectiveness of the procedure.

C. Analog-to-Digital Converter Tests

The triangular-wave "aperture-error" test was applied to a commercial A/D converter (Computer Labs VHS-630) and, for input dv/dt within the specified capability, showed a surprising shift in output DC level – up to 10 or 15 mV, or nearly half a quantization step. Inferred dynamic error has to be even larger. It is possible that the DC shift arises not from dynamic error at all, but rather from thermal drift with large signals, or some other low-frequency effect; to establish this theory, further tests are planned.

III. SEMICONDUCTOR TESTING

A. TIC Terminal

New hardware has been incorporated into the TIC terminal to control the new digital voltmeter. Programming changes were minor. The terminal was converted to the new hardware and software with very little down time.

The new hardware has provision for expansion of the test terminal and includes relay drivers and two digital-to-analog converters which will enable us to further automate transistor and wafer testing.

B. Noncontact Current Probe

Application of the integrated circuit current probe to a magnetocardiograph has been investigated. The major interference obscuring the magnetic field from the heart comes from magnetic fields at harmonics of the power-line frequency. Since the minimum bandwidth for a clinically useful cardiograph is nearly 60 Hz, a special filter had to be designed that would strongly attenuate harmonics to 60 Hz yet not reduce the quality of the cardiograph waveform. The filter operates by synchronous detection and negative feedback of the unwanted frequency. A prototype exhibits an attenuation by 100 at 60 Hz with a 3-dB bandwidth of 0.3 Hz. No critically tuned circuits are required.

The synchronous filter can also be used for the recovery of a periodic signal from noise by extracting each of the significant harmonics and adding them.

IV. MACHINE DEVELOPMENT

A. LX-1 Microprocessor

Several timing problems were discovered and rectified so that the machine now runs on a diagnostic and application program at a clock rate 12 percent faster than the nominal 40 MHz.

B. C4, A Computer for the Double Raster Display

A 32-bit general-purpose computer, called C4, to be used in the Double Raster Display System, has been designed and is nearly completed. C4 has a powerful general-purpose instruction set, plus some specialized instructions for handling raster pictures. Its computing power is roughly twice that of TX-2.

C4 accesses TX-2 core memory through the TX-2 Memory Bus Switch (C4 has no core memory of its own). It has 32 internal registers that are interconnected by a 32-bit bidirectional high-speed bus; 16 of these are scratchpad registers, while the remaining 16 are used in various specialized ways. Data in core to be manipulated must first be transferred to internal registers and then can be acted upon by three address instructions which specify two internal registers as operands and one as destination.

The basic machine instruction performs the following operation (where A, B, C are 5-bit addresses of internal registers):

$$\begin{bmatrix} \text{contents of A} \\ \overline{\text{contents of A}} \\ -(\text{contents of A}) \\ \text{A} \end{bmatrix} \begin{bmatrix} + \\ \oplus \\ \cap \\ \cup \end{bmatrix} \begin{bmatrix} \text{contents of B} \\ \overline{\text{contents of B}} \\ -(\text{contents of B}) \\ \text{B} \end{bmatrix} \rightarrow \text{contents of C}$$

where columns represent options, any of which can be chosen. For example:

$$\overline{\text{contents of A}} \quad \oplus \quad \text{contents of B} \quad \rightarrow \quad \text{contents of C} \quad .$$

This basic instruction is available in three forms:

(1) Full word,

(2) Half word, allowing independent blanking of half words of the A, B operands and left-right half-word swapping, and

(3) Single bit, where only a selected bit of the above expression is transferred into C.

Core addresses are 16-bit numbers, and instructions which reference core allow as index operands the left half and the right half of any specified internal register. Deferred addressing adds two more index operands per defer level.

A comprehensive set of shift and jump instructions is included. Individual bits of any internal register can be tested, and jumps can be made relative to the present location by using the program counter as index register.

Specialized instructions, to be used for the Double Raster Display System, include

(1) a SCALE instruction which, by combining bits, reduces the size of the pattern displayed by a factor of 2,

(2) a SHIFT/COMPARE instruction which looks for a desired (up to) 32-bit pattern among a 64-bit field, for each of 32 shift positions, and

(3) a WORD/BIT instruction which rearranges the bits of thirty-two 32-bit words so that bit n of word m becomes bit m of word n.

The SHIFT/COMPARE and WORD/BIT instructions are to be used for checking the raster picture for various characteristics (such as line widths of integrated circuit metalization masks). C4 can perform these special instructions at speeds of 10 to 100 times higher than TX-2.

An assembly language and an assembler have been designed and are operating on TX-2. Emphasis in the design of the language was placed on expressing instructions in a natural, easily understood form. Typical instructions are entered as

$$X \oplus Y \rightarrow Z$$

(where X, Y, Z are specified internal registers),

$$k \quad (U|X) \rightarrow Y$$

(where k means contents of the TX-2 address (U|V), with (U|V) = U + left half of X + right half of X),

$$(U|X) \rightarrow Y$$

(where the address (U|X) rather than its contents are loaded into Y).

Of the 36 bits in a TX-2 memory word, 32 bits are used by C4 as data and the remaining 4 bits for trapping. A TX-2 user program can set these bits and the C4 hardware will detect and interpret them. When the trap conditions are met, C4 will jump to a special program at a fixed core address, after storing the program counter and information about the cause of the trap. Possible traps are on instruction fetch, data read, data write, defer access, access to memory which is marked out of bounds, write access to memory which is marked read-only, and instruction fetch access to memory which is marked nonexecutable.

COMPUTER SYSTEMS
GROUP 28

As part of a eontinuing program to improve system efficiency and provide increased capacity, a facility for dynamically reeording various load parameters on the time-sharing system (CP/CMS) has been developed and installed. Information obtained from this performance log will be used to indieate hardware components which limit performance or software modules where improvements in strategies will provide a decrease in system overhead. Similar information, obtained from the bateh processing system (OS/360) by a new eomponent known as System Management Faeility, will also be eollected and used to improve performance of that system. Early next quarter, an IBM hardware-measuring device will be installed for a brief time to supplement and verify the output of these two software-measuring subsystems.

A major revision of the CP/CMS User's Guide has been prepared for publication using on-line editing eapabilities of the system itself. In particular, a subsystem called NSCRIPT, whieh formats edited text stored on-line, was used by a seeretary to substantially reduce eopy preparation time. In the future, even greater savings will accrue when revisions, insertions, and deletions are made by inputting only the affeeted text and relying on the system for reformatting and reprinting the updated seetion or even the entire Guide.

Beeause of the delays in getting Release 19 of OS/360 in operation, as reported earlier, a decision was made to go to a later improved version – Release 20.1. Much of the work on Release 19 was transferrable, permitting the new release to be implemented in a few weeks time. It will be put into regular Laboratory use early next quarter. A signifieant feature of the new system is improved error reeovery ineluding, where possible, instruction retry.

The Laboratory-developed general-purpose information storage and retrieval system, LISTAR, has been under continued development with an inereasing variety of applications. During the past several years, it has been tailored for an experimental comparison of manual vs on-line computer-aided indexing of medical journal articles. This work was performed for the National Library of Medicine under Contraet NLM-69-7. More reeently, LISTAR has been applied to other Laboratory programs involving on-line accessing and abstraeting of data files. The diversity of information and reports handled evidence the versatility of the system. File types inelude personnel data, seismie data, report eatalogs, and component inventories.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 August through 31 October 1971. 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 August through 15 November 1971

PUBLISHED REPORTS

Journal Articles*

JA No.			
3791	Theory of Electron-Surface-Plasmons Interactions in Tunneling, Low-Energy-Electron Diffraction, and Photoemission	K.L. Ngai E.N. Economou†	Phys. Rev. B 4, 2132 (1971)
3806	Temporal and Spatial Gain in Stimulated Light Scattering	N.M. Kroll† P.L. Kelley	Phys. Rev. A 4, 763 (1971)
3818	A High Temperature Study of Native Defects in ZnTe	F.T.J. Smith	J. Phys. Chem. Solids 32, 2201 (1971)
3838	Far-Infrared Mixing in High-Purity GaAs	B.Y. Lao M.M. Litvak	J. Appl. Phys. 42, 3357 (1971)
3840	Anomalous Properties of the Vanadium Oxides	J.B. Goodenough	Annual Review of Materials Science, Vol. 1, R.A. Huggins, Ed. (Annual Reviews Inc., Palo Alto, California, 1971), p. 101
3867	Spin-Wave Approach to Two-Magnon Raman Scattering in a Simple Antiferromagnet	R.W. Davies S.R. Chinn H.J. Zeiger	Phys. Rev. B 4, 992 (1971)
3868	The Two Components of the Crystallographic Transition in VO_2	J.B. Goodenough	J. Solid State Chem. 3, 490 (1971)
3890	Infrared Spectroscopy of CO Using a Tunable PbSSe Diode Laser	K.W. Nill F.A. Blum A.R. Calawa T.C. Harman	Appl. Phys. Letters 19, 79 (1971)
3915	The Tetragonal High-Pressure Form of $TaOPO_4$	J.M. Longo† J.W. Pierce J.A. Kafalas	Mater. Res. Bull. 6, 1157 (1971)
3916	"Mass Anomaly" in the Zeeman Effect of GaAs Donor 2p Levels	G.E. Stillman D.M. Larsen C.M. Wolfe	Phys. Rev. Letters 27, 989 (1971)
3928	Coexistence of Localized and Itinerant d Electrons	J.B. Goodenough	Mater. Res. Bull. 6, 967 (1971)

* Reprints available.

† Author not at Lincoln Laboratory.

Meeting Speeches

MS No.			
2754	Narrow-Gap Semiconductor Lasers	T.C. Harman	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 363 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2756	Shubnikov-de Haas Measurements in $Pb_{1-x}Sn_xTe$ Under Hydrostatic Pressure	J. Melngailis J.A. Kafalas T.C. Harman	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 407 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2757	Metal-Semiconductor Contacts on $Pb_{1-x}Sn_xTe$	K.W. Nill J.N. Walpole* A.R. Calawa T.C. Harman	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 383 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2763	Recent Experiments on Zero Gap Semiconductors	S.H. Groves	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 447 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2765	Electronic Properties of the Group V Semimetals	M.S. Dresselhaus	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 3 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2770	$k \cdot p$ Theory for the Conduction and Valence Bands of $Pb_{1-x}Sn_xTe$ and $Pb_{1-x}Sn_xSe$ Alloys	J.O. Dimmock	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 319 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
2780	Raman Scattering from $Hg_{1-x}Cd_xTe$	A. Mooradian T.C. Harman	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 297 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]

* Author not at Lincoln Laboratory.

MS No.			
2845	High-Resolution Magnetospectroscopy of Graphite	P. R. Schroeder* M. S. Dresselhaus A. Javan*	The Physics of Semimetals and Narrow-Gap Semiconductors, D. L. Carter and R. T. Bate, Eds. (Pergamon, New York, 1971), p. 139 [J. Phys. Chem. Solids 32, Suppl. 1 (1971)]
3141	Metallurgical and Electronic Properties of CdTe Related to Preparation of Single Crystals	A. J. Strauss	Proceedings of the International Symposium on Cadmium Telluride, Strasbourg, France, 29-30 June 1971, P. Siffert and A. Cornet, Eds. (Centre de Recherches Nucléairés, Strasbourg, 1971), p. I-1

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3775	Partial Pressures in the Cd-Te and Zn-Te Systems	R. F. Brebrick	Accepted by J. Electrochem. Soc.
3894	High Apparent Mobility in Inhomogeneous Semiconductors	C. M. Wolfe G. E. Stillman J. A. Rossi	Accepted by J. Electrochem. Soc.
3898	Persistent Photo-Dielectric Lens Effect in Cadmium Sulfide	K. B. Kanarek* C. D. Wyche A. S. Pine	Accepted by J. Appl. Phys.
3899	Exciton Bands in Antiferromagnetic Cr_2O_3	R. M. Macfarlane* J. W. Allen	Accepted by Phys. Rev.
3913A	Precision Verification of Effective Mass Theory for Shallow Donors in GaAs	G. E. Stillman D. M. Larsen C. M. Wolfe R. C. Brandt*	Accepted by Solid State Commun.
3918	Capacitance-Voltage Characteristics of Metal Barriers on p-PbTe and n-InAs: Effects of the Inversion Layer	J. N. Walpole* K. W. Nill	Accepted by J. Appl. Phys.
3920	EuTe II: Resistivity and Hall Effect	Y. Shapira* S. Foner* N. F. Oliveira, Jr.* T. B. Reed	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

JA No.

3921	EuTe III: Ultrasonic Behavior	Y. Shapira* T.B. Reed	Accepted by Phys. Rev.
3937	Fourier Expansion for Electronic Bands in Trigonal Tellurium and Selenium	G. Dresselhaus	Accepted by Phys. Rev. B
3940	Raman Scattering from Europium Chalcogenides	R.K. Ray* J.C. Tsang* M.S. Dresselhaus R.L. Aggarwal* T.B. Reed	Accepted by Phys. Letters A
3946	Aluminum Interconnections and Beam Leads on Polyimide-Coated, Copper Substrates	F.J. Bachner	Accepted by IEEE Transactions on Parts, Hybrids, and Packaging
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	Accepted by Solid State Electron.
3951	Carrier Freeze-out and Acceptor Energies in p-Type $Hg_{1-x}Cd_xTe$	C.T. Elliott* I. Melngailis T.C. Harman A.G. Foyt	Accepted by J. Phys. Chem. Solids
3953	Measurements of the Lattice Parameter of Wüstite at High Temperature	M. Hayakawa* J.B. Cohen* T.B. Reed	Accepted by J. Am. Ceram. Soc.

MS No.

2727	Theory of Antiferromagnetism and Ferrimagnetism	J.B. Goodenough	Accepted as chapter in Physics of Electronic Ceramics (Marcel Dekker, Inc., New York)
2993	Application of Heat Pipe Technology to Crystal Growth	J. Steininger T.B. Reed	Accepted by J. Crystal Growth
3018A	Phase Diagrams and Crystal Growth of Pseudobinary Alloy Semiconductors	J. Steininger A.J. Strauss	Accepted by J. Crystal Growth
3146	Infrared Detectors and Applications	J.O. Dimmock	Accepted by J. Electronic Materials
3153	Preparation and Properties of $Pb_{1-x}Cd_xS$	A.R. Calawa J.A. Mroczkowski T.C. Harman	Accepted by J. Electronic Materials
3155	The Use of Lasers in Pollution Monitoring	I. Melngailis	Accepted by IEEE Trans. Geosci. Electron.

* Author not at Lincoln Laboratory.

Meeting Speeches*

MS No.			
2917A	High Purity GaAs	C.M. Wolfe G.E. Stillman	Materials Science Seminar, University of Southern California, Los Angeles, 12 November 1971
2951B	Localized and Itinerant d Electrons in Transition-Metal Compounds	J.B. Goodenough	Chemistry Department Seminar, Brookhaven National Laboratory, Upton, New York, 30 September 1971
2951C, E	Itinerant vs Localized Electrons	J.B. Goodenough	Solid-State Student Seminar, M.I.T., 1 November 1971; Department of Physics & Astronomy Seminar, University of Florida, 11 November 1971
3090	Influence of Madelung Energy and Covalency on Structure of $A^{+}B^{5+}O_3$ Compounds	J.A. Kafalas	Fifth Materials Research Symposium on Solid State Chemistry, Gaithersburg, Maryland, 18-21 October 1971
3120	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	
3110A	Raman Spectroscopy of Solids	A. Mooradian	Esfahan Symposium on Fundamental and Applied Laser Physics, University of Esfahan, Iran, 29 August – 5 September 1971
3138B	Tunable Infrared Lasers and Their Applications	P.L. Kelley	
3110C	Raman Spectroscopy of Solids	A. Mooradian	Tenth National Meeting of Society for Applied Spectroscopy, St. Louis, 18-22 October 1971
3138	Tunable Infrared Lasers and Their Applications	P.L. Kelley	
3110D	Raman Spectroscopy of Solids	A. Mooradian	Seminar, University of Toronto, Ontario, Canada, 7 October 1971
3134A, B	Infrared Photodiodes Fabricated by Proton Bombardment	J.O. Dimmock A.G. Foyt J.P. Donnelly T.C. Harman W.T. Lindley	Seminar, Navy Electronics Laboratory Center, San Diego, 23 August 1971; Seminar, Hughes Aircraft, Malibu, 2 September 1971
3144	Materials and Processing Techniques for the Fabrication of High Quality Millimeter Wave Diodes	B.J. Clifton W.T. Lindley R.W. Chick† R.A. Cohen†	Conference on High Frequency Generation and Amplification: Devices and Applications, Cornell University, 17-19 August 1971

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

† Author not at Lincoln Laboratory.

MS No.			
3146	Infrared Detectors and Applications	J.O. Dimmock	Thirteenth Annual Conference of the Electronic Materials Committee of the Metallurgical Society of AIME, San Francisco, 29 August – 1 September 1971
3153	Preparation and Properties of $Pb_{1-x}Cd_xS$	A.R. Calawa J.A. Mroczkowski T.C. Harman	
3146A, B	Infrared Detectors and Applications	J.O. Dimmock	Seminar, Night Vision Laboratory, Ft. Belvoir, Virginia, 20 October 1971; Alloy Physics-Solid State Physics Colloquium, National Bureau of Standards, Gaithersburg, Maryland, 21 October 1971
3148	Tunable $PbS_{1-x}Se_x$ Diode Lasers in the 5 μm Region	K.W. Nill F.A. Blum A.R. Calawa T.C. Harman	Device Research Conference, University of Michigan, 28 June – 1 July 1971
3152A	Acoustical and Optical Activity in Crystals	A.S. Pine	Seminar, Purdue University, 5 November 1971
3155	The Use of Lasers in Pollution Monitoring	I. Melngailis	International Geoscience Electronics Symposium, Washington, D.C., 25-27 August 1971
3157	Single Particle Transmission in the Trigonal Faraday Geometry in Bismuth	R.A. Murphy A.L. McWhorter	U.S. – Japanese Seminar, Cornell University, 8 September 1971
3160	Optical de Haas-Shubnikov Effect	M.S. Dresselhaus	
3175	Various Aspects of Magnetic Semiconductors	J.B. Goodenough	Europhysics Conference on "Metal Insulator Transition and the Development of Narrow Energy Bands," Aussois, France, 6-11 September 1971
3192	Tunable Infrared Lasers and Their Applications	P.L. Kelley E.D. Hinkley A. Mooradian	NEREM, Boston, 3-5 November 1971

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

High-quality n-p junction photodiodes have been fabricated in p-type PbTe using Sb^+ ion implantation to form the n-type regions. At 77°K, 15-mil-square diodes have exhibited zero bias impedances as high as 15 megohms, and peak detectivities at 4.4 μm in reduced background as high as 1.5×10^{12} cmHz$^{1/2}$/W. This value appears to be limited by amplifier noise.

The surface properties and current-voltage characteristics of planar n-p InSb photodiodes fabricated by proton bombardment have been investigated in diode structures with annular guard rings formed by peripheral field plates. Low surface state densities were obtained by passivation with pyrolytic SiON, which allowed the surface potential to be controlled by the field plate. At an optimum field-plate voltage, diode leakage currents as small as 11 nA for a 13-mil-diameter device have been observed at a reverse-bias voltage of −1.0 V.

High-gain GaAs Schottky barrier avalanche photodiodes have been fabricated using Pt barriers on lightly doped n-type GaAs epitaxial layers. Guard rings were formed using proton bombardment. Small signal gains as large as 4500 were measured on $n = 2.5 \times 10^{14}$ cm^{-3} material compared with 100 to 300 observed previously on more heavily doped $n \simeq 10^{16}$ cm^{-3} material.

Coupling to GaAs acoustic surface waves was increased by more than a factor of four by sputtering a 2.5-μm ZnO film over the interdigital transducers, the radiation impedance being increased to 17 ohms. Calculations indicate that another factor-of-five improvement should be possible using this technique.

A pattern replication process utilizing soft x-rays has been developed which is capable of submicron resolution over areas of several square centimeters. By using soft x-rays instead of ultraviolet radiation, the wavelength-related diffraction problems which limit the resolution of photolithography are effectively eliminated. This technique has been demonstrated using a chrome-gold transducer pattern with 2.5-μm spacings on a 3.5-μm-thick membrane of epitaxial Si.

Far-field patterns of a 6.5-μm PbTe diode laser have been directly observed using the infrared upconversion properties of ZnS phosphor powder excited by ultraviolet light. A complex spatial-mode pattern was observed, although 80 percent of the laser power was in a single-frequency mode. This may be due to complex internal reflection of the mode.

A confocal Fabry-Perot interferometer has been used to accurately calibrate the tuning rate of current-tuned $PbS_{1-x}Se_x$ diode lasers operating near 5.2 μm. This technique provides a convenient and precise method for calibrating the tuning rate of tunable infrared laser sources.

In order to avoid off-axis and parasitic modes which occur in conventional rectangular diode laser structures, 50-μm-wide, 500-μm-long stripe geometry lasers have been fabricated in vapor-grown $Pb_{0.88}Sn_{0.12}Te$. The laser frequency spectra consisted of regularly spaced modes corresponding to the longitudinal cavity. The far-field pattern was a single lobe with beam angles of 20° in the vertical plane and 8° in the horizontal plane, corresponding to the fundamental spatial mode of the emitting region.

II. QUANTUM ELECTRONICS

Studies have continued on room temperature $In_xGa_{1-x}As$ lasers optically pumped by a Q-switched Nd:YAG laser. Above threshold the axial-mode spacing was found to be 0.9 nm, in close agreement with the theoretical value for the 150-μm cavity. Pump threshold intensities were estimated to be on the order of 10^5 W/cm^2, and conversion efficiencies up to 1 percent were observed.

Tunable laser spectroscopy has been carried out on the ν_1-band of SO_2 using a lead-tin-telluride diode laser. A value of $1151.72 \pm 0.01\ cm^{-1}$ has been found for the band center.

The Raman spectra of TeO_2 in the tetragonal D_4^4 (paratellurite) form have been obtained. All Raman active optical branches have been observed except $1A_1 + 2E$, and have been identified by their polarization selection rules. The observations indicate large polarizabilities and weak anharmonic forces, which is in agreement with the observed strong acousto-optic properties of this material.

III. MATERIALS RESEARCH

Wüstite (FeO) crystals of centimeter dimensions have been pulled from the melt in a tri-arc Czochralski furnace. Single crystals were easily grown when the melt composition was $FeO_{1.094}$, but polycrystalline boules were obtained for melt compositions of $FeO_{1.08}$ and $FeO_{1.12}$.

An oxygen meter utilizing stabilized zirconia as a solid-state electrolyte has been used to measure the oxidizing potential of several laboratory gases subjected to various treatments. Gettering with hot titanium foil or chips is found to be an effective method for reducing the oxygen content of argon and hydrogen.

In order to study the factors influencing the structure of $A^+B^{5+}O_3$ compounds, four new compounds of this type have been synthesized at high pressures and retained in metastable form at atmospheric pressure. Both $RbNbO_3$ (orthorhombic) and $RbTaO_3$ (cubic) are perovskites, but as a result of the strong Sb-O covalency $RbSbO_3$ and $TlSbO_3$ are not.

The results of a more detailed x-ray diffraction study of powdered $V_{0.95}Cr_{0.05}O_2$ are consistent with the orthorhombic structure previously assigned to this material, but do not conclusively rule out the monoclinic structure which has been established for $V_{0.976}Cr_{0.024}O_2$. Therefore, a single-crystal investigation has been undertaken to obtain an unambiguous structure determination for $V_{0.95}Cr_{0.05}O_2$.

The effect of pressure on the magnetic behavior of MnP, which is ferromagnetic at atmospheric pressure, has been studied by measuring initial permeability as a function of temperature for samples subject to fixed pressures up to 50 kbar. A transition to antiferromagnetic ordering, which probably results from pressure broadening of the Mn d-bands, appears to occur between 25 and 35 kbar.

IV. PHYSICS OF SOLIDS

During this past year, several new exploratory programs have been initiated: secondary electron emission, phosphor upconversion, and metal-insulator transitions.

The secondary electron emission program is aimed at finding and understanding materials with high secondary yields at low primary electron energies. One of the systems under investigation, $NiO:Li^+$, appears quite promising in this respect.

Two phosphor upconversion studies are under way – one concerned with the efficient conversion of laser infrared radiation (~1 μm) to the visible using rare-earth ions, and the other with optimization of the infrared stimulability of visible luminescence in ZnS. In the former program, erbium and ytterbium are being placed in hosts having the gagarinite structure; initial results, without any optimization, indicate an efficiency comparable with that of YF_3:Yb, Er, which is the most efficient infrared-to-green upconverter listed in the literature. In the latter program, several experiments have been performed on the transient as well as steady-state infrared stimulation effect in ZnS:Cu, Al under conditions of steady ultraviolet pumping. A model has been set up and the response of the system has been formulated in terms of coupled rate equations. Computer solutions are presently being carried out. In a second phase of this research, other phosphors also are being prepared and tested for infrared stimulability.

In the metal-insulator transition program, films of V_2O_3 and Ti_3O_5 have been made and are being characterized by optical and electrical measurements. A theoretical model of electronic switching near the metal-insulator transition has been formulated and is now under investigation.

High-resolution spectroscopic studies in CO and NO have continued, using current-tuned CW diode lasers. In CO, our previous measurements of the fundamental vibration-rotation absorption band taken at low gas pressures (<1 torr), with a $PbS_{0.82}Se_{0.18}$ laser, have been extended to high pressures (≲200 torr); the self-induced pressure shift in the center and the broadening of the P(9) absorption line at 4.745 μm have been obtained for the first time. In NO, a 5.255-μm $PbS_{0.62}Se_{0.38}$ laser was used for taking quantitative measurements of the Zeeman splitting and Lambda doubling of the $R(15/2)_{1/2,\,3/2}$ absorption lines and of the magnetic rotation spectrum of the $R(15/2)_{1/2}$ absorption line.

In an effort to understand the temperature dependence of light scattering from antiferromagnets, the effect of including additional graphical perturbation theory diagrams on the intensity of two-magnon Raman scattering has been examined. While neglect of these extra diagrams leads to vanishing intensity at T_N, their inclusion gives a finite value, as observed experimentally. The calculations of parallel susceptibility, perpendicular susceptibility, and staggered parallel susceptibility using graphical perturbation theory have also been formulated.

For the first time, far-infrared H_2O and HCN lasers have been used to carry out precise cyclotron resonance experiments in thin epitaxial films of $Ga_{1-x}In_xAs$ alloys, in the range $0 < x < 0.105$. Although existing theories predict a nonlinear dependence of the effective mass with concentration, an almost linear variation is observed.

Study continues of the band structure of $Pb_{1-x}Sn_xSe$ alloys, for compositions $x = 0.17$ and 0.20 (i.e., near zero gap) and carrier concentrations from 2×10^{17} to 2×10^{18} cm^{-3}. Surprisingly, the value of pressure at the resistivity minimum, which is expected to occur when the energy gap goes through zero, has been found to depend on carrier concentration and also carrier type.

V. MICROELECTRONICS

Beam-leaded substrates employing polyimide-coated copper with multilevel aluminum interconnections have been fabricated successfully, and their bonding characteristics are being evaluated.

The particle detector arrays, which require double-sided wafer processing, are being tested to determine their characteristics in beta particle bombardment. The results of these tests will determine the action taken in the next phase of the program.

Several other silicon devices or integrated circuits have reached a satisfactory level of performance and are described in the Solid State Research Report.*

The yield of masks has been improved by a concerted effort to trace the source of mask defects. Further improvements are expected when the mask-making area is modified to reduce particle contamination.

Packaging of devices for high-power applications is continuing, and improvements in thermal resistance characteristics of the E-Bird and TRAPATT devices have been significant.

Prototype hybrid limiter circuits for the LES system have been fabricated and electrical tests indicate satisfactory performance has been achieved. Several more units will be fabricated for system and environmental tests before the production units are undertaken.

The dynamic testing characteristics of the laser scanning system for integrated circuits have been explored by adding a second laser beam to change the logic states of the integrated circuit and to permit greater electrical evaluation without the usual mechanical probes. The system is particularly useful for diagnostic evaluation of the internal features of the monolithic structure.

* See Sec. V-B in the Solid State Research Report, Lincoln Laboratory, M.I.T. (1971:4) (in press)

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