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Advanced Electronic Technology

15 August 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 May through 31 July 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

Introduction iii

DATA SYSTEMS – DIVISION 2

Introduction 1

Digital Computers – Group 23 3

I. Integrated Circuit Design and Fabrication 3

II. Integrated Circuit Applications 4

III. Semiconductor Testing 4

IV. Machine Development 5

Computer Systems – Group 28 6

SOLID STATE – DIVISION 8

Introduction 7

Division 8 Reports on Advanced Electronic Technology 9

I. Solid State Device Research 15

II. Quantum Electronics 15

III. Materials Research 16

IV. Physics of Solids 17

V. Microelectronics 17

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1971 for the Advanced Electronic Technology Program of Division 2. Separate progress reports on Graphics, Propagation Studies, Seismic Discrimination and the Education 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. Deep-Diffused Transistor Evaluation

Three deep-diffused transistors (Q1, Q2, and Q3) fabricated on a test wafer at Lincoln Laboratory have been evaluated. Q1 is a large transistor with a 4.2-mil-square emitter; Q2 has a 0.6 × 1.4-mil emitter; and Q3 has a 0.9-mil-square emitter. All devices on the wafer had a reasonable current gain, typically around 100 at 1 mA. Collector breakdown voltages were 40 V. The major problem was excess collector series resistance. These devices were made for process evaluation.

B. Shallow Emitter Experiments

Experiments have started on the fabrication of arsenic emitters. Diodes are being made for the evaluation of shallow emitter structures and metalization, with samples to be put on life test under high stress conditions as soon as they are available.

C. Photolithography Techniques

One hundred and twelve wafers have been processed through various etching steps. A satisfactory "washed emitter" technique has been developed and 18 wafers have been etched in this manner.

Comparison tests have been made on all photoresists alleged to have IC capability. Only one product is comparable with the resist now being used, and it is being tested further. Also, evaluation of the photoreduction – step and repeat capability of five outside vendors is being made. All were given identical 10X reticles and have made working plates from them. These will be checked for dimensional accuracy and imperfection counts.

A five mask set for shallow devices having washed emitters has been made and is being carefully checked for registration and dimensional accuracy.

A metalization fixture accommodating 6 wafers is being made. This apparatus will permit stationary or simple rotation of wafers normal to the source in addition to stationary, simple rotation or planetary rotation of wafers at a 38° inclination to the source.

D. Metalization

Resistivity of 1-μm thick Al films evaporated at 1000 Å/min. at 10^{-5} torr is 4.2 ± 0.2 μohm cm. (Bulk Al is 2.8 μohm cm.) For 98% Al 2% Si films the resistivity is 9.7 ± 1.3 μohm cm.

Al and AlSi films 1 μm thick, deposited on oxidized Si wafers at room temperature and annealed for 15 min. in a nitrogen gas atmosphere at progressively higher temperatures, eventually grow hillocks 0.5 to 5 μm in diameter with a density of the order of $10^5/cm^2$. The critical temperature for the hillock nucleation was 250°C for an Al film, 450°C for a 98% Al 2% Si film.

E. Transistor Geometry Test Chip

A chip has been designed with nine transistors of various geometries based on the transistor used in our standard LSI ECL gate. The basic transistor has 0.1 × 0.6-mil stripes separated by 0.1 mil and is capable of f_t performance to 5 GHz. The chip will be used for process evaluation and also for studies of the effect of geometry on device performance.

F. Space-Charge-Limited Carrier Flow in Epitaxial Collector Regions

Analysis of the epitaxial regions between the metallurgical collector-base junction and the buried collector layer, and between the buried collector layer and the top collector contact of junction transistors, shows that these regions are not ohmic at operating current densities as is normally assumed but are regions of space charge. Collector current can be carried in these regions only by a space-charge-limited flow of electrons causing excessive internal collector-voltage drops and carrier transit time delays which lower the f_t of the device.

II. INTEGRATED CIRCUIT APPLICATIONS

A. Interconnection of Plastic-Embedded Semiconductor Chips

Attempts to form array wiring of suitable thickness entirely by electroless metal deposition have not been successful. It was found that those electroless metal baths which can form deposits of sufficient thickness are corrosive to the chip metalization. Consequently, a previously successful procedure involving an initial electroless deposit followed by electroplating is being utilized.

A relatively simple photomechanical procedure for forming array wiring has been developed. A layer of selectively crosslinked polyester resin is formed with grooves where wiring is desired. The entire surface is metalized and the grooves filled with more resin. The array surface is abraded away leaving the embedded wiring. Contact between wiring layers is through vias formed in the photocrosslinked resin.

B. A Hybrid Semiconductor Memory Array

A study is being made of the feasibility of using the plastic encapsulated wiring (PEW) described above, to interconnect sixteen 64-bit integrated-circuit memory elements and several decoder circuits to form a 1024-bit memory array. Heat transfer methods, semiconductor – PEW processing compatibility, and system design are under study.

C. Analog-to-Digital Converter Tests

A new test for "aperture error" of A/D converters is being evaluated. The test is based on the shift in the measured mean or DC voltage of a randomly sampled asymmetric triangular wave as amplitude and transition times are varied.

III. SEMICONDUCTOR TESTING

A. Wafer Probe

The Electroglass 900A has been operating satisfactorily under TX-2 control. The test programs in use generate wafer maps of h_{FE}, breakdown voltages, leakage currents, forward voltage drops, and sheet resistivity. Tests of over 800 devices per wafer with up to 4 probes are routine. Single tests of this type take about 20 min. for the whole wafer in the time-sharing

mode. There have been no problems with probe contacts or prober operation. The probe points are cleaned with acetone daily. The results of the wafer map are also presented in the form of a distribution, including number of devices above or below set limits.

The prober will be modified to accept type 273 probe heads which can be adjusted more accurately and permanently. These heads will also allow a capability of 60 probes for one circuit.

B. Noncontact Integrated-Circuit Current Probe

A prototype magnetoresistive amplifier has been built to detect the signal from the noncontact current probe. The active element is a Permalloy film, whose resistance is modulated by a magnetic field. The field is produced by a coil wound on a toroidal pole piece and driven by the probe itself. It is expected that the magnetoresistive amplifier will have less flicker noise than a semiconductor amplifier and will be easier to match in impedance with the probe. The prototype amplifier exhibited a power gain of 10 dB at room temperature.

IV. MACHINE DEVELOPMENT

A. LX-1 Microprocessor

The LX-1 microprocessor has been completely checked out during this quarter. An overlapped control-memory access and scratch-memory or logical operation takes 125 nsec; an Add operation takes 150 nsec. If the next control-memory address is determined by the results of the current operation, the resultant nonoverlapped cycle is 50 nsec longer.

The Lincoln Laboratory array multiplier* is being added to LX-1. The 32-bit product will be formed and half of it transferred to a general-purpose register in 175 nsec. If the multiplier had been included in the original design, decreased interface circuit and cabling delays would easily have permitted a 150-nsec cycle.

B. META 4 I/O Controllers (TSP System)

The multichannel controller (MCC) concept for interfacing up to four cycle-stealing I/O devices to the META 4 provides a small 16-word × 16-bit IC memory for storing four control words for each of four cycle-stealing channels. It also provides a common facility for address and transfer count incrementing and other "housekeeping" activities for the channels. The devices to be connected through the MCC include the TSP System Tablets, the ARPA IMP input and output (two devices), and the LX-1 microprocessor. The LX-1 board contains not only the LX-1 control memory interface logic for the MCC device listed above, but also the LX-1 external memory interface logic for a cycle-stealing device separate from the MCC device group. With the exception of the Tablets board, which is about to be laid out, all boards are in various stages of fabrication.

C. TX-2 In-Out

In order to support speech research, an analog input-output sequence is being added to the TX-2 in-out system. This new sequence can be used for either input or output functions. The analog resolution is 12 bits with maximum sampling frequency of 40,000 samples/sec. The control of the sequence is designed for direct memory access so that it can be used under time-shared operation.

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* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 August 1970), DDC AD-712699.

COMPUTER SYSTEMS
GROUP 28

Two significant facilities have been provided to enhance reliability of the time-sharing system. The first is automatic logging of detailed input/output error information. In addition to the obvious value of such data for repairing specific failures, it is also useful as an indicator of potential troubles. The detailed record is kept on disk and printed out periodically. Concurrently, brief summary statements of I/O errors are printed out on the operator's console, allowing him to take immediate preventive or corrective action.

The second reliability enhancement is a high-speed disk-to-disk dump of all user files. Under this new procedure, two disk packs are copied each working day on a rotating schedule. The backup copies are secured at a remote location. In the event of failure or damage to the working pack, the user is sure of full recovery of his files as they existed not more than six or seven working days past. Individual magnetic-tape backup of selected user files is still available at anytime and is still recommended for those situations that warrant it.

Work on a newer release level of Operating System/360 has entered the user program testing stage. A considerable amount of time has been taken up by a variety of coding errors in the released material. In addition, the usual updating of Lincoln-provided features is required.

The general matter of system reliability and integrity has been given renewed emphasis during this quarter. Backup procedures similar to those described for time sharing have been in effect for OS/360 continually. However, all these procedures have now been re-established on a more formal basis, including an adversary mechanism to continually illuminate potential problem areas.

All the interchangeable disk packs have been replaced by less-expensive units from another vendor as a result of a competitive procurement. The cost of additional packs required by the reliability backups and the general increase in data-storage requirements have been more than offset by the savings realized.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 May through 31 July 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 May through 15 August 1971

PUBLISHED REPORTS

Journal Articles*

JA No.			
3460	Metallic Oxides	J. B. Goodenough	Chap. 4 of Progress in Solid State Chemistry, Vol. 5, H. Reiss, Ed. (Pergamon, Oxford, 1971)
3538	The Calculation of Electronic Energy Bands by the Augmented Plane Wave Method	J. O. Dimmock	Solid State Physics, Vol. 26, F. Seitz and D. Turnbull, Eds. (Academic Press, New York, 1971), p. 103
3740	Resonant Coupling of Landau Levels via LO Phonons in Polar Semiconductors and its Effects on the Landau-Level Raman Scattering from Semiconductor Plasmas	K. L. Ngai	Phys. Rev. B 3, 1303 (1971), DDC AD-723745
3741	Partial and Total Vapor Pressures over Molten Bi_2Te_3	R. F. Brebrick F. T. J. Smith	J. Electrochem. Soc. 118, 991 (1971)
3751	Composition Stability Limits for the Rocksalt-Structure Phase $(Pb_{1-y}Sn_y)_{1-x}Te$ from Lattice Parameter Measurements	R. F. Brebrick	J. Phys. Chem. Solids 32, 551 (1971)
3752A	Raman Study of the Semiconductor-Metal Transition in Ti_2O_3	A. Mooradian P. M. Raccah	Phys. Rev. B 3, 4253 (1971)
3760A	The Liquidus Line and Gibbs Free Energy of Formation of a Crystalline Compound $A_mB_n(c)$ – The Linear Temperature Approximation	R. F. Brebrick	Met. Trans. 2, 1657 (1971)
3767	Structure and Properties of the High and Low Pressure Forms of $SrIrO_3$	J. M. Longo J. A. Kafalas R. J. Arnott†	J. Solid State Chem. 3, 174 (1971)

* Reprints available.
† Author not at Lincoln Laboratory.

JA No.

3800	Interband Magnetoreflection of $Hg_{1-x}Cd_xTe$	S. H. Groves T. C. Harman C. R. Pidgeon*	Solid State Commun. 9, 451 (1971)
3816	Semiconductor-Metal Transition in Ti_2O_3	H. J. Zeiger T. A. Kaplan P. M. Raccah	Phys. Rev. Letters 26, 1328 (1971)
3842	Light Scattering from Acoustic Plasma Waves and Single-Particle Excitations in Semiconductor Magnetoplasmas	F. A. Blum R. W. Davies	Phys. Rev. B 3, 3270 (1971)
3846	Relaxation-Time Ansatz for Quantum Transport Theory: Spin Effects	R. W. Davies F. A. Blum	Phys. Rev. B 3, 3321 (1971)
3847	Carrier Concentration and Mobility in n- and p-Type ZnTe–Al	F. T. J. Smith	Solid State Commun. 9, 957 (1971)
3861	Effect of Pressure on the Crystal Structure of $CsMnCl_3$ and $RbMnCl_3$	J. M. Longo J. A. Kafalas	J. Solid State Chem. 3, 429 (1971)
3863	Raman Spectra and Lattice Dynamics of Tellurium	A. S. Pine G. Dresselhaus	Phys. Rev. B 4, 356 (1971)

Meeting Speeches

MS No.

2549	Photoresponse Properties of InSb MOS Devices	W. E. Krag R. J. Phelan, Jr. J. O. Dimmock	Proceedings of the Third Photoconductivity Conference, Stanford, August 12-15, 1969, edited by E. M. Pell (Pergamon, New York, 1971), p. 367
2551	Donor Magnetospectroscopy in High Purity Epitaxial GaAs	G. E. Stillman C. M. Wolfe J. O. Dimmock	Proceedings of the Third Photoconductivity Conference, Stanford, August 12-15, 1969, edited by E. M. Pell (Pergamon, New York, 1971), p. 265
2782	Detection and Generation of Far Infrared Radiation in High Purity Epitaxial GaAs	G. E. Stillman C. M. Wolfe J. O. Dimmock	Proc. Symposium on Submillimeter Waves, New York, 1970 (Polytechnic Press, Brooklyn, 1971), p. 345
2835	Millimeter and Far Infrared Frequency Mixing in GaAs	H. Fetterman P. E. Tannenwald C. D. Parker	Proc. Symposium on Submillimeter Waves, New York, 1970 (Polytechnic Press, Brooklyn, 1971), p. 591

* Author not at Lincoln Laboratory.

MS No.			
2863	Effects of Hydrostatic Pressure and of Jahn-Teller Distortions on the Magnetic Properties of $RbFeF_3$	J. B. Goodenough N. Menyuk K. Dwight J. A. Kafalas	J. de Physique 32 Suppl., C1, 622 (1971)
2883	Light Scattering from Plasmons in InSb	F. A. Blum A. Mooradian	Proc. Tenth International Conference on the Physics of Semiconductors, Cambridge, Massachusetts, 17-21 August 1970, p. 755
2884	Polaron Zeeman Effects in the Silver Halides	R. C. Brandt D. M. Larsen D. R. Cohn*	Proc. Tenth International Conference on the Physics of Semiconductors, Cambridge, Massachusetts, 17-21 August 1970, p. 162
2917	High Purity GaAs	C. M. Wolfe G. E. Stillman	Proc. Third International Symposium on GaAs, Aachen, Germany, 1970 (The Institute of Physics, London, 1971), p. 3
2919	GaAs Far Infrared Detectors and Emitters	G. E. Stillman C. M. Wolfe J. O. Dimmock	Proc. Third International Symposium on GaAs, Aachen, Germany, 1970 (The Institute of Physics, London, 1971), p. 212
2981A	Production Method for Aluminum Beam Leads on Ceramic Substrates	R. E. McMahon F. J. Bachner R. A. Cohen W. S. Franklin* J. D. Impey*	Proc., 1971 21st Electronic Components Conference, Washington, D. C., 10-12 May 1971, pp. 96-102
2989B	Testing Integrated Circuits with a Laser Beam	R. E. McMahon	Proc., 1971 21st Electronic Components Conference, Washington, D. C., 10-12 May 1971, pp. 412-416

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3797	Conductivity Studies in Europium Oxide	M. R. Oliver J. O. Dimmock A. L. McWhorter T. B. Reed	Accepted by Phys. Rev. B
3885	Accurate X-ray Diffraction Measurements at High Pressures: Volume Compression of TiO_x	M. D. Banus M. C. Lavine	Accepted by High Temperatures – High Pressures

* Author not at Lincoln Laboratory.

Division 8

JA No.

3908	Spin Wave Theory of Two-Magnon Raman Scattering in a Two-Dimensional Antiferromagnet	S. R. Chinn R. W. Davies H. J. Zeiger	Accepted by Phys. Rev. B
3917	Comment on the Magnetic Properties of Several Indium Thiospinels	J. B. Goodenough	Accepted by J. Solid State Chem.
3928	Coexistence of Localized and Itinerant d Electrons	J. B. Goodenough	Accepted by Mater. Res. Bull.
MS-3067	Polaron Morphologies in Vanadium Oxides	J. B. Goodenough	Accepted by Proc. Intl. Conf. on Conduction in Low Mobility Materials, Eilat, 1971

Meeting Speeches*

MS No.

2325A	Brillouin Scattering in Solids	A. S. Pine	Topics on Neutron and Light Scattering-Correlation Functions in Solids and Liquids, M.I.T. Summer School, 18 June 1971
2506C	The Preparation and Thermodynamic, Structural and Electrical Properties of TiO, VO and NbO	T. B. Reed	The Metallurgical Society Spring Meeting, Atlanta, Georgia, 17-20 May 1971
2770A	$k \cdot p$ Theory for the Conduction and Valence Bands of $Pb_{1-x}Sn_xTe$ and $Pb_{1-x}Sn_xSe$ Alloys	J. O. Dimmock	Colloquium, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland, 25 May 1971
2951A	Some Aspects of Magnetic Semiconductors	J. B. Goodenough	Summer School on Semiconductors, McGill University, 27 June – 9 July 1971
2989C	Testing Integrated Circuits with a Laser Beam	R. E. McMahon	Reliability and Testing Symposium, M.I.T., 19 May 1971
2993	Application of Heat Pipe Technology to Crystal Growth	J. Steininger T. B. Reed	ICCG-3, Marseille, France, 5-9 July 1971
3018A	Phase Diagrams and Crystal Growth of Pseudobinary Alloy Semiconductors	J. Steininger A. J. Strauss	
3089	Sealed Crucible Technique for Thermal Analysis and Crystal Growth of Volatile Compounds up to 2500°C	T. B. Reed R. E. Fahey A. J. Strauss	

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

MS No.			
3046A	Phonon Dispersion Relations in Tellurium	G. Dresselhaus A. S. Pine	Europhysics Conference on Physics of Selenium and Tellurium, Pont-à-Mousson, France, 16-19 May 1971
3075A	Brillouin Spectroscopy in Cadmium Sulfide: Acousto-electric and Anharmonic Effects and Resonance Scattering	A. S. Pine	Second International Conference on Light Scattering of Solids, Paris, 19-23 July 1971
3076	Raman Scattering in Tellurium	A. S. Pine G. Dresselhaus	
3092	Light Scattering from Acoustic Plasmons in Semiconductors in a Magnetic Field	F. A. Blum R. W. Davies	
3110	Raman Spectroscopy of Solids	A. Mooradian	Second Vavilov Conference on Nonlinear Optics, Novosibirsk, USSR, 22-25 June 1971
3110B	Laser Raman Spectroscopy and Its Application to Tunable Frequency Sources	A. Mooradian	Summer Course on Lasers and Optics for Applications, M.I.T., 27 July 1971
3121A	High Purity GaAs	I. Melngailis	Lectures, Latvian Academy of Sciences, Riga, Latvia, USSR, 10-30 June 1971
3121B	Lead-Tin Chalcogenide Lasers	I. Melngailis	
3129	Molecular and Lattice Vibrations in Solid Ammonia	A. S. Pine C. J. Glassbrenner G. Dresselhaus	International Conference on Phonons, Rennes, France, 26-28 July 1971
3141	Metallurgical and Electronic Properties of CdTe Related to Preparation of Single Crystals	A. J. Strauss	International Symposium on Cadmium Telluride, Strasbourg, France, 29-30 June 1971
3147	$Pb_{1-x}Sn_xTe$ Photovoltaic Diodes and Diode Lasers Produced by Proton Bombardment	J. P. Donnelly A. R. Calawa T. C. Harman A. G. Foyt W. T. Lindley	1971 Device Research Conference, Ann Arbor, Michigan, 28 June – 1 July 1971
3152	Acoustical and Optical Activity in Crystals	A. S. Pine G. Dresselhaus	Fermi Summer School, Varenna, Italy, 5-17 July 1971
3162	The Use of Proton Bombardment in the Fabrication of Semiconductor Devices	A. G. Foyt	Informal Seminar on Ion Implantation, Kyoto, Japan, 8-12 August 1971

Division 8

MS No.			
3166	High Field Magnetoreflection Studies in Graphite	B. L. Heflinger* M. S. Dresselhaus	Tenth Biennial Conference on Carbon, Lehigh University, 28 June – 2 July 1971
3177	Deviations from Stoichiometry in Oxides	T. B. Reed	Gordon Research Conference on Chemistry and Metallurgy of Semiconductors, Tilton, New Hampshire, 13 July 1971

* Author not at Lincoln Laboratory.

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Measurements of the wavelength dependence of the quantum efficiency of InSb n-p photodiodes fabricated by proton bombardment were made in order to determine the surface recombination velocity and the minority carrier lifetime in the n-type layer. Measured efficiencies range from 20 to 43 percent in diodes fabricated on lightly doped substrates, and from 16 to 19 percent in diodes fabricated on more heavily doped substrates, increasing somewhat with bias. The results are currently being interpreted.

Diode lasers have been fabricated from Bridgman-grown p-type PbTe and $Pb_{0.88}Sn_{0.12}Te$ using proton bombardment to produce the n-layer and n-p junction. The PbTe lasers had single-mode CW output powers at 4.2°K of up to 18μW at 6.2385μm. The $Pb_{0.88}Sn_{0.12}Te$ lasers operated CW at 4.2°K with multimode output between 10.47 and 10.56μm.

A magnetic field has been used to extend the tuning range of $PbS_{0.82}Se_{0.18}$ diode lasers in order to obtain spectra on several of the higher lying CO fundamental absorption lines. The magnetic field was first adjusted to obtain near-coincidence between the laser output and the absorption line. Small variations in diode current were then used to tune the laser mode through the absorption line.

A current tunable $PbS_{0.6}Se_{0.4}$ diode laser has been used to obtain high-resolution absorption spectra of the NO R(13/2) doublet at 5.262μm and to measure the Λ-doubling of the $^2\pi_{1/2}$ NO electronic state.

The liquidus, solidus and solvus lines of the phase diagram of $Pb_{1-x}Cd_xS$ have been determined for alloy compositions up to x = 0.6. A linear variation of the energy gap with alloy composition up to x = 0.079 was determined from electroluminescence and photovoltaic response data obtained from p-n junction diodes. Laser emission has been observed at 4.3, 3.5 and 2.5μm from diodes fabricated from x = 0, 0.015 and 0.058 alloys, respectively.

Laser emission at wavelengths near 3.45μm has been obtained from vapor-grown $Pb_{1-x}Cd_xS$ optically pumped by 0.84-μm radiation from a GaAs diode laser. Temperature-tuning of the laser wavelength has been observed between 1.7° and 44°K, and preliminary measurements of the absorption spectra of CH_4 and HCl gases have been made by temperature-tuning the laser wavelength.

II. QUANTUM ELECTRONICS

A quantum electronics effort has been established under which research on coherent sources for optical communications and tunable lasers will be carried out. A portion of the latter effort – namely, the tunable semiconductor laser program, which has been under way for several years – is reported elsewhere.*

* Solid State Research Report, Lincoln Laboratory, M.I.T. (1971:3), Sec. I (in press).

Operation of a $Ga_xIn_{1-x}As$ laser has been achieved by optically pumping just above the band edge with a Q-switched Nd:YAG laser. Laser action occurred between 210° and 300°K with outputs between 1.07 and 1.12 μm. Threshold pump powers of several watts were observed.

Spontaneous Raman scattering from electronic spin-flip excitations in n-type InSb has been studied in order to characterize the gain mechanisms in the spin-flip Raman laser. Measurements have been made of the resonant enhancement of the spin-flip scattering efficiency, the polarization selection rules, and the lineshape as a function of temperature, electron concentration and magnetic field. The results on resonant enhancement and polarization selection rules show reasonable quantitative agreement with theory, while the linewidth results can be understood qualitatively. These experimental results are especially useful in understanding the low threshold of the InSb spin-flip laser using a CO-laser pump.

A pulsed CO laser at 5.3 μm, operated by transverse electrical initiation of combustion in a mixture of CS_2 and O_2, has been used to pump an InSb spin-flip Raman laser. Second Stokes and higher-order lines were observed.

III. MATERIALS RESEARCH

The first six x-ray form factors of copper have been determined with an experimental error of about ±1 percent by measuring the absolute intensities of Bragg reflections from powder samples. Comparison of these form factors with published values obtained by an APW calculation indicates that an exchange potential given by a constant times the Slater exchange term cannot accurately predict both the experimental charge density and band energies of copper.

Measurements of electrical resistivity, sign of the Seebeck coefficient, and magnetic ordering temperature have been made on $Fe_{1-x}Cu_xCr_2S_4$ alloys. The results of S- and vacuum-annealing experiments show that these properties are influenced not only by the Fe-to-Cu ratio but also by the S-to-metal ratio.

The effects of hydrostatic pressure on the electrical properties of $Cd_{1-x}Zn_xTe$, $Cd_{1-x}Mg_xTe$, and $CdTe_{1-x}Se_x$ doped with Cl, Br, and In have been investigated in order to determine the changes produced by alloying on the energy levels of these impurities, which are non-Γ donors in CdTe. The results of similar measurements on F-doped CdS and CdSe indicate that F introduces non-Γ donor levels into these compounds.

Abrupt changes in optical reflectivity as a function of temperature, exhibiting marked hysteresis effects, have been observed in measurements on $(V_{1-x}Cr_x)_2O_3$ single crystals with $0.004 < x < 0.019$. These changes may result from the first-order metal-insulator transition which has been reported for this system.

It is proposed that in $LaRuO_3$ and $La_{0.5}Sr_{0.5}CoO_3$ the transition metal ions exist in an intermediate-spin state that is made possible by the simultaneous presence of both localized and itinerant d-electrons. The outer-d-electron configurations are, respectively, $^3T_{1g,0}\sigma^{*1}$ and $^2T_{2g,1/2}\sigma^{*0.5}$. The J = 0 ground state for the localized-electron t_{2g}^4 manifold at the Ru ions does not polarize the itinerant-d-electron σ* band in $LaRuO_3$, but the J = 1/2 ground state of the t_{2g}^5 manifold at the Co ions does polarize the σ* electron band in ferromagnetic $La_{0.5}Sr_{0.5}CoO_3$.

The monoclinic form of $TaOPO_4$ has been transformed at pressures above 25 kbars into a tetragonal form isostructural with $MoOPO_4$. Powder x-ray diffraction techniques have been used to carry out a structure refinement of tetragonal $TaOPO_4$ retained at atmospheric pressure by quenching.

IV. PHYSICS OF SOLIDS

Our previous Zeeman measurements on 2p donor states of high-purity GaAs have been repeated with much higher resolution and more accurate magnetic-field determinations. A variation with magnetic field of the Zeeman effective mass is observed; this variation can be explained by the Stark effect on the shallow donor states, which arises from the internal electric field of the ionized impurities.

Reflectivity measurements have been carried out on single crystals of SnO_2 and rutile GeO_2 in the energy range from the fundamental edges out to 11.8 eV into the ultraviolet. Unexpectedly, strong polarization effects have been observed out to 12 eV.

V. MICROELECTRONICS

Experimental operation of devices from several semiconductor programs has verified the success expected from the earlier measured electrical parameters. For example, the E-Bird program has provided diodes with stable breakdown voltages of 200 V in the electron-beam environment and with peak power capabilities in excess of 1 kW. Thermal resistance measurements indicate that values of less than 1 °C/W can be regularly obtained by paying careful attention to the bonding of the chip to the package, and by employing special techniques of attachment. However, further testing is necessary to verify the long-term stability of the thermal resistance at high power levels in the electron-beam environment.

Fabrication of the Schottky barrier gallium arsenide diodes has been continued, and minimum noise figures of 5 dB at 60 GHz have been obtained.

The double-sided processing required in the nuclear detector array has not had the anticipated difficulties, and units with good electrical parameters and modest yields are being fabricated.

The laser scanner has been modified to accommodate an additional high-power laser beam for the selected setting of digital states, but excessive losses in the optics are troublesome and will probably require some changes. A new mode of operation with the laser scanner and the integrated circuit under test is being explored in the expectation of a more versatile test mode for the integrated circuit.

The mask-making area continues to produce masks of a routine nature and high resolution, but inadequate chemical filtering and cleanliness problems of a general sort result in low yields. An investigation of glass-plate quality, process effects and the nature of defects is in progress on a limited basis.

The combined mesa-planar structure using the SIMTOP process for the mesa section is under development. A simple circuit which will test the usefulness of a mesa-planar system is nearing completion.

The beam-lead substrate program has focused on copper substrates with aluminum metalization and a polyimide dielectric. The advantages of this structure for high-frequency systems and the relative fabrication costs are being evaluated.

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