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# Quarterly Technical Summary.

## Advanced Electronic Technology

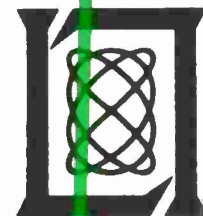
15 February 1971

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

### Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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# Quarterly Technical Summary

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## Advanced Electronic Technology

15 February 1971

Issued 7 April 1971

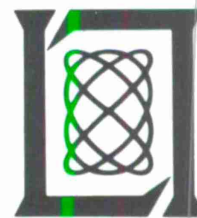
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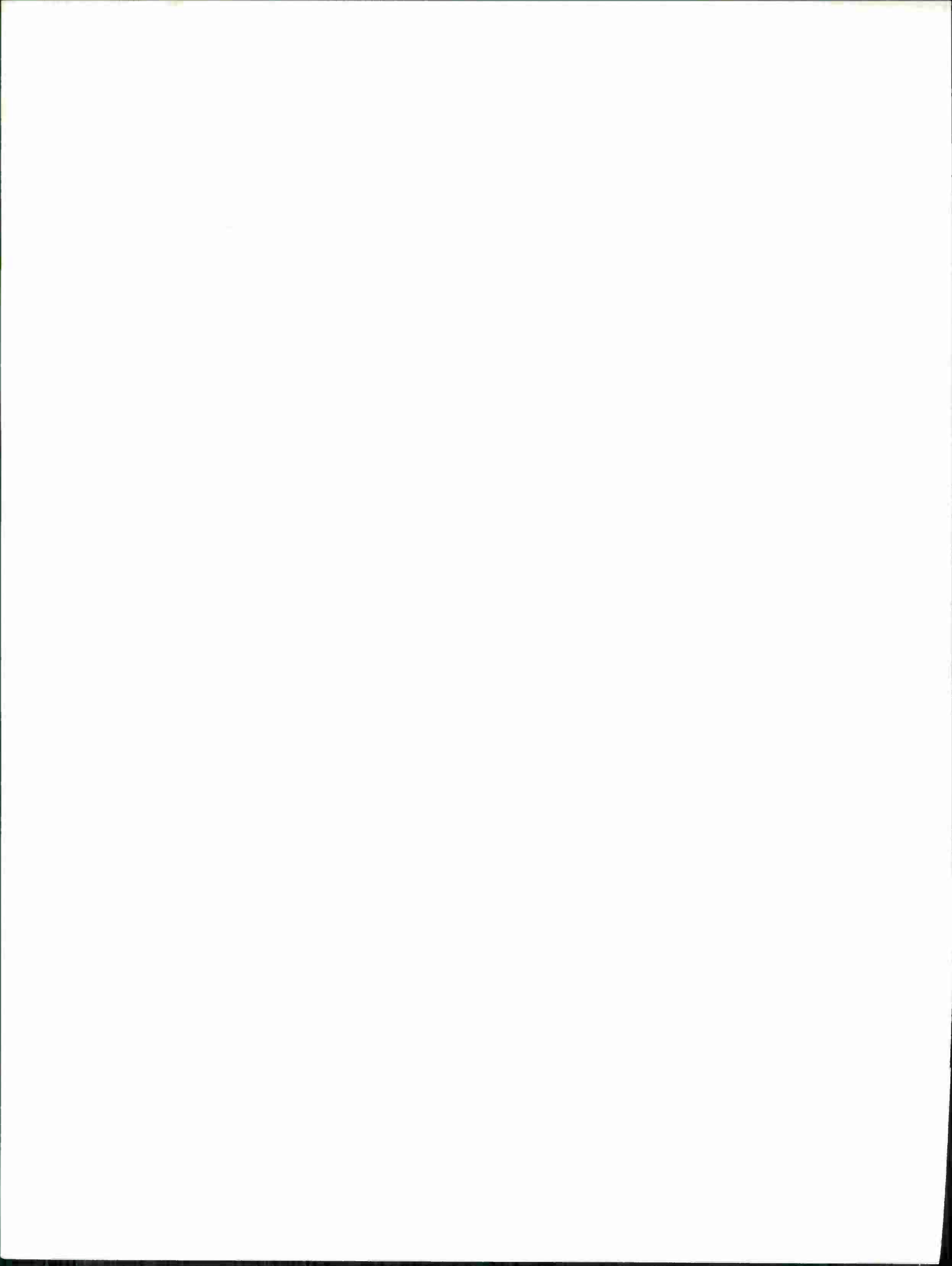
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## INTRODUCTION

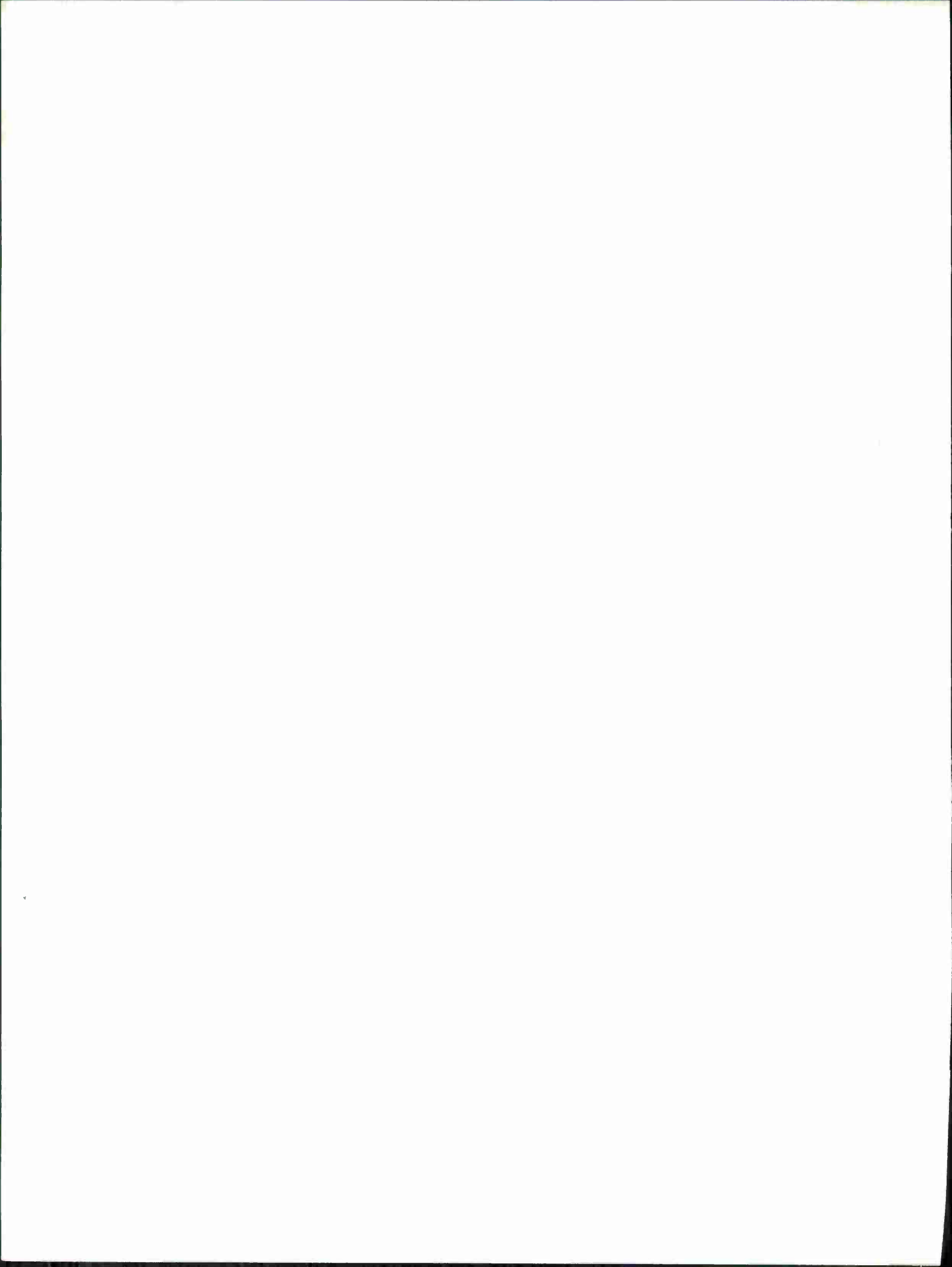
This Quarterly Technical Summary covers the period from 1 November 1970 through 31 January 1971. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.

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



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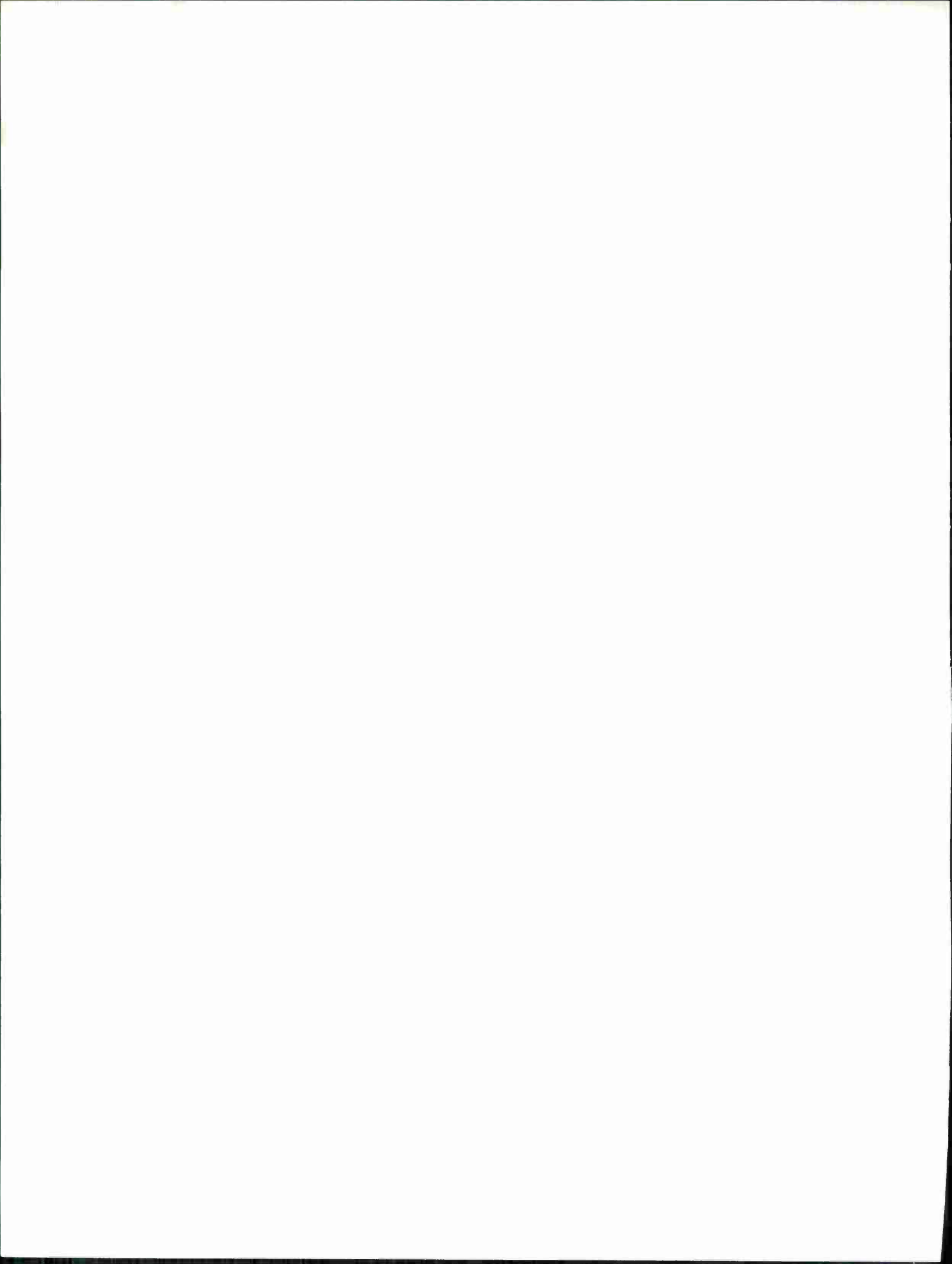


## DATA SYSTEMS DIVISION 2

### INTRODUCTION

This section of the report reviews progress during the period 1 November 1970 through 31 January 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 DEVELOPMENT

A number of experiments were performed to determine proper techniques and parameters for etching 0.1 mil cuts in 10,000 Å thick oxide on silicon wafers. Concurrently, a four mask test pattern was produced that includes 3 transistors, 1 diode and 3 resistors with some 0.2 mil geometry areas. Also, several fixtures and a rudimentary mask aligner were built.

Base level cuts were etched in 15 wafers prior to diffusion by Group 87. Additional etching experiments are being done on aluminum in preparation for producing conductors in the metallization layer.

Test equipment is being prepared for measurement of junction depth, resistivity, surface charge and other parameters of the silicon wafers. Investigations of available epitaxial reactors indicated that for the present, purchasing epitaxial services will be more cost-effective than purchasing a reactor.

Experiments are in progress to evaporate the alloy 98% Al 2% Si required for metallization on shallow junction devices by two processes. These are fractionation from a 67% Si 33% Al alloy and flash evaporation of 98% Al 2% Si pellets or wire.

### II. PHOTOLITHOGRAPHIC INTERCONNECTION OF PLASTIC-IMBEDDED SEMICONDUCTOR CHIPS

Via-chip arrays (connections only) have withstood in excess of 5000 hours of continuous 150°C temperature and over 5000 hours and 3000 cycles from 25°C to 150°C.

Results of four-probe DC resistance tests of aluminum-to-electroless nickel interfaces agree with results obtained from similar AC measurements with no polarity sensitivity detected.

Corrosion currents, which occur during the electroless metallization of pads on integrated-circuit chips, can interfere with nickel deposition on selected pads. One remedy is to mask all exposed silicon before metallizing the aluminum pads. Tests of active devices packaged with this process showed that, while the devices functioned, leakage currents were high and the devices deteriorated rapidly under high-temperature reverse-bias conditions. However, no attempt had been made to decontaminate these devices by prolonged rinsing prior to encapsulation.

Electroless nickel is found superior to electroplated copper for array wiring because of its superior "throwing power" into small vias. Alternatively, photoexposure techniques are now available which make it possible to deposit nickel only where desired.

### III. SEMICONDUCTOR TESTING

#### A. Non-Contact Integrated-Circuit Current Probe

The first non-contact magnetoresistive current probe was fabricated on a type IIa diamond heat sink. The active region is a 50 μm by 59 μm rectangle made by scribing with a diamond tool a film of vacuum-evaporated Permalloy about 600 Å thick. Measurements taken with the diamond mounted on a massive metal heat sink indicate that the diamond does have the published thermal

## Division 2

conductivity of about  $20 \text{ watt}^\circ\text{C}^{-1} \text{ cm}^{-1}$  (about 4 times that of copper) at room temperature. A current of 300 mA was passed through the active rectangle with a temperature rise of  $14^\circ\text{C}$ .

An amplifier for the probe was built, using several multi-emitterstripe transistors in parallel to match the 10-ohm source impedance of the probe. It has a random noise voltage at the input of 80 nV rms in the 2 kHz - 10 kHz band, equivalent to a noise figure of 4 dB. (A current of 1 mA in the integrated circuit will produce a signal of about 100  $\mu\text{V}$  in the probe.)

### B. Test Equipment Modifications

The  $f_t$  (gain-bandwidth product) equipment was modified to allow measurements under forward-biased collector conditions. Test results show that CDI (collector diffused isolation) transistors exhibit peak  $f_t$ 's of 2.5 GHz at  $-0.5 \text{ V}$  collector to base compared to 1.5 GHz for conventional transistors. This is related to the very excellent  $f_t$  performance of the CDI units at high currents. This type of transistor can make an excellent driver with no increase in size required.

Modifications to the programs and the programmable power supplies greatly improved the performance of the TIC transistor test programs.

### C. Plastic-Coated Transistor Life

High temperature reverse bias measurements were made on experimental transistors molded into polyester resin. The tests were unsatisfactory but not significant because of the limited number of devices available and the lack of control devices.

To remedy the situation, tests will be made on chip versions of the 2N2222 and of the PD7400, a quad 2-input nand gate. Normally packaged devices will be available for both types. Molded chips will be evaluated after each process step. Initial life testing will be under reverse bias at  $150^\circ\text{C}$ . An MOS test device will also be evaluated to check for changes in the oxide during the plasticising process.

## IV. MAGNETIC FILM ENGINEERING

### 10-Megabit Memory Feasibility Study

A final report on the feasibility study of the 10-megabit memory module was written and will be published in the next quarter. A summary paper will also be presented at the next Intermag Conference.

Magnetic Film processing facilities are being converted to provide metallization and photolithography for LSI.

## V. COMPUTER APPLICATIONS

### A. Test Computer

The general-purpose functional-test interface unit for the SEL810A test computer has been built and debugged. It is being used to functionally test several plug-in-units for the LX-1 computer.

### B. Transistor Test Terminal

New units being designed for transistor testing are: transistor bias control unit, Digital voltmeter control, and Digital-to-Analog Converters.

### C. Graph Theory and IC Layout

A new planarity-testing algorithm has been developed as a result of research in graph theory. Two significant advantages over currently used planarity tests are:

- (1) The algorithm requires less computation and less storage;
- (2) When applied to the layout of integrated circuits, the algorithm can be modified in a natural and efficient way to take into account both the physical configuration of devices and dimensional constraints.

The second advantage is particularly valuable in any practical application. The test has been applied (by hand) to an 80-gate circuit with good results.

PSYCHOLOGY  
GROUP 25

I. RECKONER/MEDIATOR

Development of the Reckoner/Mediator facility on the IBM 360/67 time shared computer has been completed. Assistance to users of the Reckoner will continue to be provided.

II. OTHER WORK

Work by the group on the design and use of a new learning machine is reported separately in the Quarterly Technical Summary of the Educational Technology Program.

Work on computer graphics is reported in the Quarterly Letter Report to the Advanced Research Projects Agency.

## COMPUTER SYSTEMS GROUP 28

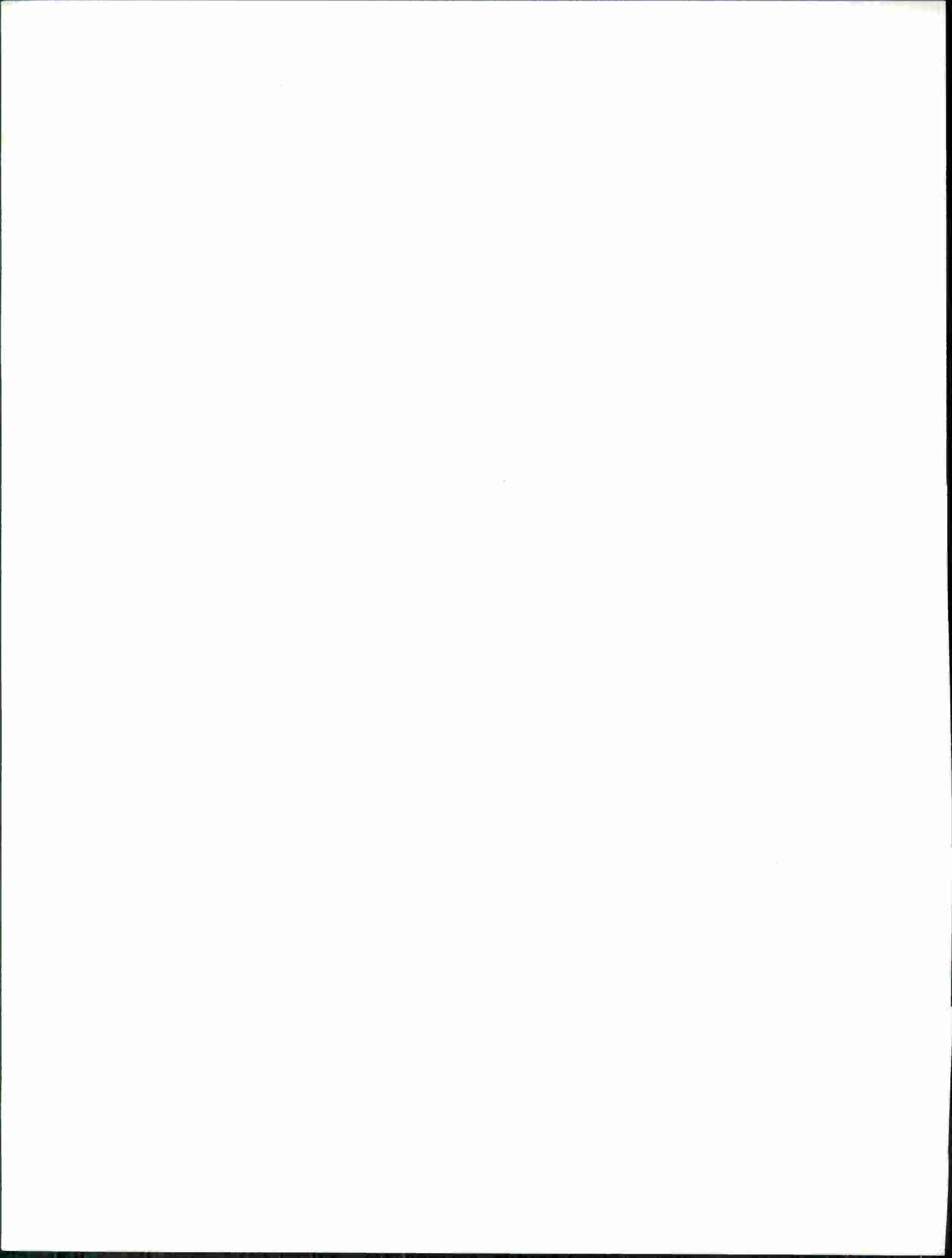
During the quarter there were two additional minor reductions in equipment. The first of these was the IBM 2250 Graphics Display subsystem. The use of CRT-like output devices in an interactive computing system is still considered an important requirement for the Laboratory. However, many less expensive and more versatile systems are becoming available in the commercial market. In particular, much of the less sophisticated work of this type is now being performed on a storage tube display.

The second equipment reduction was the release of one of the three high-speed swapping drums. This was made possible by dynamic allocation of page space in the time sharing system and reorganization of the non-core resident portions of the batch processing system.

Work is continuing on the hardware and software interfacing of the computer to the ARPA network. Additional functional changes in the time sharing system include the ability for users to read and punch paper tape, a performance improvement resulting from a modification of the dispatcher, and reduction of downtime attributable to an automatic restart following transient system malfunction.

The ability for terminal users to initiate batch processing was advanced by two particular activities. The first of these is provision for the use of special tapes on "Express" runs under the time sharing system. The second facility, which is still in the development stage, will permit time sharing users to set up jobs during the day for operation under the OS/360 Batch Processing System at night. One of the important features of this facility will be a program to assist in the generation of the necessary job control statements which are a frequent and annoying source of errors.

As the Laboratory gains experience in the use of the new multiprogramming version of IBM's OS/360 Batch Processing System (MVT-HASP), further refinements in the definition of job classes and operating limits are being developed. The problem in this area is to provide a user with all the flexibility he needs to do his job and, at the same time, protect him from himself by limiting the execution of endless loops and the expensive and inefficient allocation of hardware which he does not require.



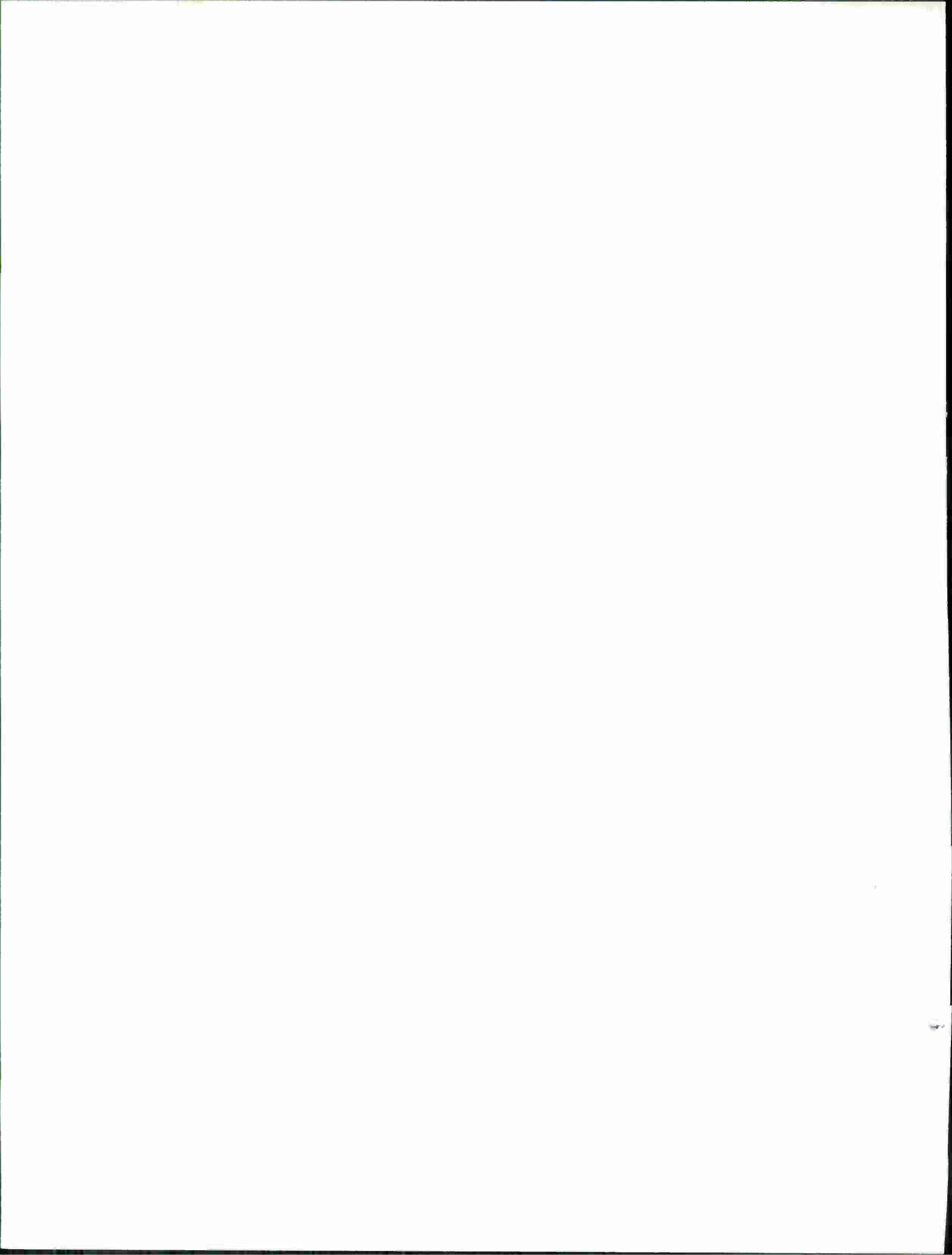
# SOLID STATE DIVISION 8

## INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1970 through 31 January 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 November 1970 through 15 February 1971

## PUBLISHED REPORTS

### Journal Articles\*

<u>JA No.</u>			
3611	Magnetic Susceptibility of Europium Trifluoride	S. Kern <sup>†</sup> P. M. Racciah A. Tveten <sup>†</sup>	J. Phys. Chem. Solids <u>31</u> , 2639 (1970)
3631	Electrical Conductivity in Narrow Energy Bands	R. A. Bari D. Adler <sup>†</sup> R. V. Lange <sup>†</sup>	Phys. Rev. B <u>2</u> , 2898 (1970)
3659A	Direct Observation of Acoustical Activity in $\alpha$ Quartz	A. S. Pine	Phys. Rev. B <u>2</u> , 2049 (1970)
3661	Collective Oscillations in a Simple Metal. I. Spin Waves	A. R. Wilson D. R. Fredkin <sup>†</sup>	Phys. Rev. B <u>2</u> , 4656 (1970)
3664	Magnetoreflexion Studies in Bismuth	M. Maltz <sup>†</sup> M. S. Dresselhaus	Phys. Rev. B <u>2</u> , 2877 (1970)
3682	Narrow-Band Expansions in the Hubbard Model: A Comment	R. A. Bari	Phys. Rev. B <u>2</u> , 2260 (1970)
3725	Harmonic Generation in Cold Nonuniform Plasma in a Magnetic Field	F. A. Blum	Phys. Fluids <u>14</u> , 196 (1971)
3727	Linewidths of a Gaussian Broadband Signal in a Saturated Two-Level System	M. M. Litvak	Phys. Rev. A <u>2</u> , 2107 (1970)
3730	Si <sub>3</sub> N <sub>4</sub> -Masked Thermally Oxidized Post-Diffused Mesa Process (SIMTOP)	R. A. Cohen R. W. Mountain	IEEE Trans. Electron Devices, <u>ED-18</u> , 54, (1971)
3737	Study of the Spin-Reordering Transition in Cr <sub>5</sub> S <sub>6</sub>	K. Dwight N. Menyuk J. A. Kafalas	Phys. Rev. B <u>2</u> , 3630 (1970)

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\* Reprints available.

<sup>†</sup> Author not at Lincoln Laboratory.

Division 8

JA No.

- |      |                                                                                                                 |                                                               |                                            |
|------|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|--------------------------------------------|
| 3738 | Effects of Hydrostatic Pressure and of Jahn-Teller Distortions on the Magnetic Properties of RbFeF <sub>3</sub> | J. B. Goodenough<br>N. Menyuk<br>K. Dwight<br>J. A. Kafalas   | Phys. Rev. B <u>2</u> , 4640 (1970)        |
| 3765 | Raman Scattering in CsMnF <sub>3</sub>                                                                          | S. R. Chinn                                                   | Phys. Rev. B <u>3</u> , 121 (1971)         |
| 3772 | Polaron Zeeman Effect of Shallow Donors in CdTe                                                                 | D. R. Cohn*<br>D. M. Larsen<br>B. Lax*                        | Solid State Commun. <u>8</u> , 1707 (1970) |
| 3773 | Even-Parity Levels of Donors in Si                                                                              | W. H. Kleiner<br>W. E. Krag                                   | Phys. Rev. Letters <u>25</u> , 1490 (1970) |
| 3777 | Perturbation Theory for the Bound Polaron                                                                       | D. M. Larsen                                                  | J. Phys. C <u>3</u> , L185 (1970)          |
| 3787 | Polarization Modulated Magnetorelectance in EuSe and EuTe                                                       | C. R. Pidgeon*<br>J. Feinleib*<br>T. B. Reed                  | Solid State Commun. <u>8</u> , 1711 (1970) |
| 3789 | Identification of Exciton-Neutral Donor Complexes in the Photoluminescence of High Purity GaAs                  | J. A. Rossi<br>C. M. Wolfe<br>G. E. Stillman<br>J. O. Dimmock | Solid State Commun. <u>8</u> , 2021 (1970) |
| 3796 | Acceptor Luminescence in High-Purity n-Type GaAs                                                                | J. A. Rossi<br>C. M. Wolfe<br>J. O. Dimmock                   | Phys. Rev. Letters <u>25</u> , 1614 (1970) |
| 3799 | Continuous Stimulated Spin-Flip Raman Scattering in InSb                                                        | A. Mooradian<br>S. R. J. Brueck<br>F. A. Blum                 | Appl. Phys. Letters <u>17</u> , 481 (1970) |
| 3814 | Absence of Hartree-Fock Behavior in Hubbard's Simple Decoupling Solution of Correlated Narrow-Energy-Band-Model | R. A. Bari<br>T. A. Kaplan                                    | Phys. Letters A <u>33A</u> , 400 (1970)    |

MS No.

- |      |                                              |              |                                                                                                                                           |
|------|----------------------------------------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| 2847 | Magnetism                                    | N. Menyuk    | <u>Modern Aspects of Solid State Chemistry</u> , C. N. R. Rao, Ed. (Plenum Publishing Corporation, New York, New York, 1970), pp. 159-217 |
| 2877 | Magneto-Optics of Polarons in Semiconductors | D. M. Larsen | Proceedings Tenth International Conference on the Physics of Semiconductors, USAEC CONF-700801 (1970), p. 145                             |

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\* Author not at Lincoln Laboratory.

<u>MS No.</u>			
2882	Electron and Phonon Dispersion Relations in Tellurium	G. Dresselhaus M. S. Dresselhaus	<u>Ibid.</u> , 338
2886	Interaction of Bound Electrons with Local and Resonant Modes in Semiconductors	R. W. Davies H. J. Zeiger	<u>Ibid.</u> , p. 256
2888	Role of the Crystal C/A Ratio in $Ti_2O_3$ and $V_2O_3$	J. B. Goodenough	<u>Ibid.</u> , p. 304
2892	Variational Approach to the Metal-Semiconductor Transition	T. A. Kaplan R. A. Bari	<u>Ibid.</u> , p. 301
2893	A Raman Study of the Semiconductor-Metal Transition in $Ti_2O_3$	A. Mooradian P. M. Racciah	<u>Ibid.</u> , p. 310
2907	Light Scattering from Hot Electrons in Semiconductors	A. Mooradian A. L. McWhorter	<u>Ibid.</u> , p. 380
2915	Acoustoelectric Instabilities in n-GaAs	D. L. Spears	<u>Proceedings National Electronics Conference</u> , Vol. XXVI (NEC, Inc., Oak Brook, Illinois, 1970) p. 342

\* \* \* \* \*

## UNPUBLISHED REPORTS

Journal Articles

<u>JA No.</u>			
3741	Partial and Total Vapor Pressures Over Molten $Bi_2Te_3$	R. F. Brebrick F. T. J. Smith	Accepted by J. <u>Electrochem. Soc.</u>
3747	Electron Spin Waves in Non-magnetic Conductors: Self-Consistent Field Theory	F. A. Blum	Accepted by <u>Phys. Rev. B</u>
3758	Critical Magnetic Properties and Exchange Interactions in EuO	N. Menyuk K. Dwight T. B. Reed	Accepted by <u>Phys. Rev. B</u>
3760A	The Liquidus Line and Gibbs Free Energy of Formation of a Crystalline Compound $A_mB_n(c)$ . I. The Linear Temperature Approximation	R. F. Brebrick	Accepted by <u>Met. Trans.</u>

Division 8

JA No.

3785	A Rapid Scanning Microscope for Light Probing and Infrared Mapping	R. J. Phelan* N. L. DeMeo, Jr.	Accepted by Appl. Optics
3800	Interband Magnetoreflexion of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$	S. H. Groves T. C. Harman C. R. Pidgeon*	Accepted by Solid State Commun.
3804	Effects of Short Range Interactions on Electron Charge Ordering and Lattice Distortions in the Localized State	R. A. Bari	Accepted by Phys. Rev.
3813	N-P Junction Photovoltaic Detectors in PbTe Produced by Proton Bombardment	J. P. Donnelly T. C. Harman A. G. Foyt	Accepted by Appl. Phys. Letters
3818	A High Temperature Study of Native Defects in ZnTe	F. T. J. Smith	Accepted by J. Phys. Chem. Solids
3826	Raman Spectroscopy of Solids	A. Mooradian	Accepted by <u>Laser Handbook</u> , F. T. Arecchi, Ed. (North-Holland Publishing Co., Amsterdam)
3831	Anomalously High "Mobility" in Semiconductors	C. M. Wolfe G. E. Stillman	Accepted by Appl. Phys. Letters
3840	Anomalous Properties of the Vanadium Oxides	J. B. Goodenough	Accepted by <u>Annual Review of Materials Science</u> , Vol. 1 (Annual Reviews, Inc., Palo Alto)
3842	Light Scattering from Acoustic Plasma Waves and Single-Particle Excitations in Semiconductor Magnetoplasmas	F. A. Blum R. W. Davies	Accepted by Phys. Rev. B
3846	A Relaxation-Time Ansatz for Quantum Transport Theory: Spin Effects	R. W. Davies F. A. Blum	Accepted by Phys. Rev. B
3850	Efficient, Single Mode, CW, Tunable Spin-Flip Raman Laser	S. R. J. Brueck A. Mooradian	Accepted by Appl. Phys. Letters
3854	Testing Integrated Circuits With a Laser Beam	R. E. McMahon	Accepted by Electronics
3861	Effect of Pressure on the Crystal Structure of $\text{CsMnCl}_3$ and $\text{RbMnCl}_3$	J. M. Longo J. A. Kafalas	Accepted by J. Solid State Chem.

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\* Author not at Lincoln Laboratory.

<u>MS No.</u>			
2863	Effects of Hydrostatic Pressure and of Jahn-Teller Distortions on the Magnetic Properties of $\text{RbFeF}_3$	J. B. Goodenough N. Menyuk K. Dwight J. A. Kafalas	Accepted by <u>J. de Physique</u>
2961	Effect of Pressure on the Magnetic Properties of $\text{Ca}_{1-x}\text{Sr}_x\text{MnO}_3$	J. A. Kafalas N. Menyuk K. Dwight J. M. Longo	Accepted by <u>J. Appl. Phys.</u>
2966	High Pressure $\text{RbFeCl}_3$ - A Transparent Ferrimagnet	J. M. Longo J. A. Kafalas N. Menyuk K. Dwight	Accepted by <u>J. Appl. Phys.</u>
2992	Varied Roles of the Outer d Electrons	J. B. Goodenough	Accepted by <u>Proceedings of the Robert A. Welch Foundation Conferences on Chemical Research XIV. Solid State Chemistry</u> , Houston, Texas, 9-11 November 1970

Meeting Speeches \*

<u>MS No.</u>			
2302A, 2302B	Raman Scattering from Plasmons, Phonons, and Impurities in Semiconductors	G. B. Wright	Seminar, Texas Christian University, 4 January 1971; Colorado State University, 21 January 1971
2899A	Polaron Self-Energy Effects in the Phonon-Assisted Cyclotron Resonance in InSb	E. J. Johnson	Seminar, Naval Research Laboratory, Washington, D. C., 9 December 1970
2915	Acoustoelectric Instabilities in n-GaAs	D. L. Spears	National Electronics Conf., Chicago, Illinois, 7-9 December 1970
2959	Magnetic Properties of Europium: Pressure and Impurity Effects	N. Menyuk K. Dwight J. A. Kafalas	} Sixteenth Annual Conference on Magnetism and Magnetic Materials, Miami Beach, Florida, 16-20 November 1970
2961	Effect of Pressure on the Magnetic Properties of $\text{Ca}_{1-x}\text{Sr}_x\text{MnO}_3$	J. A. Kafalas N. Menyuk K. Dwight J. M. Longo	
2966	High Pressure $\text{RbFeCl}_3$ - A Transparent Ferrimagnet	J. M. Longo J. A. Kafalas N. Menyuk K. Dwight	
2970	Canted to Paramagnetic Phase Transition in EuTe	N. F. Oliveira, Jr.† S. Foner† Y. Shapira† T. B. Reed	

\* Titles of meeting speeches are listed for information only. No copies are available for distribution.

† Author not at Lincoln Laboratory.

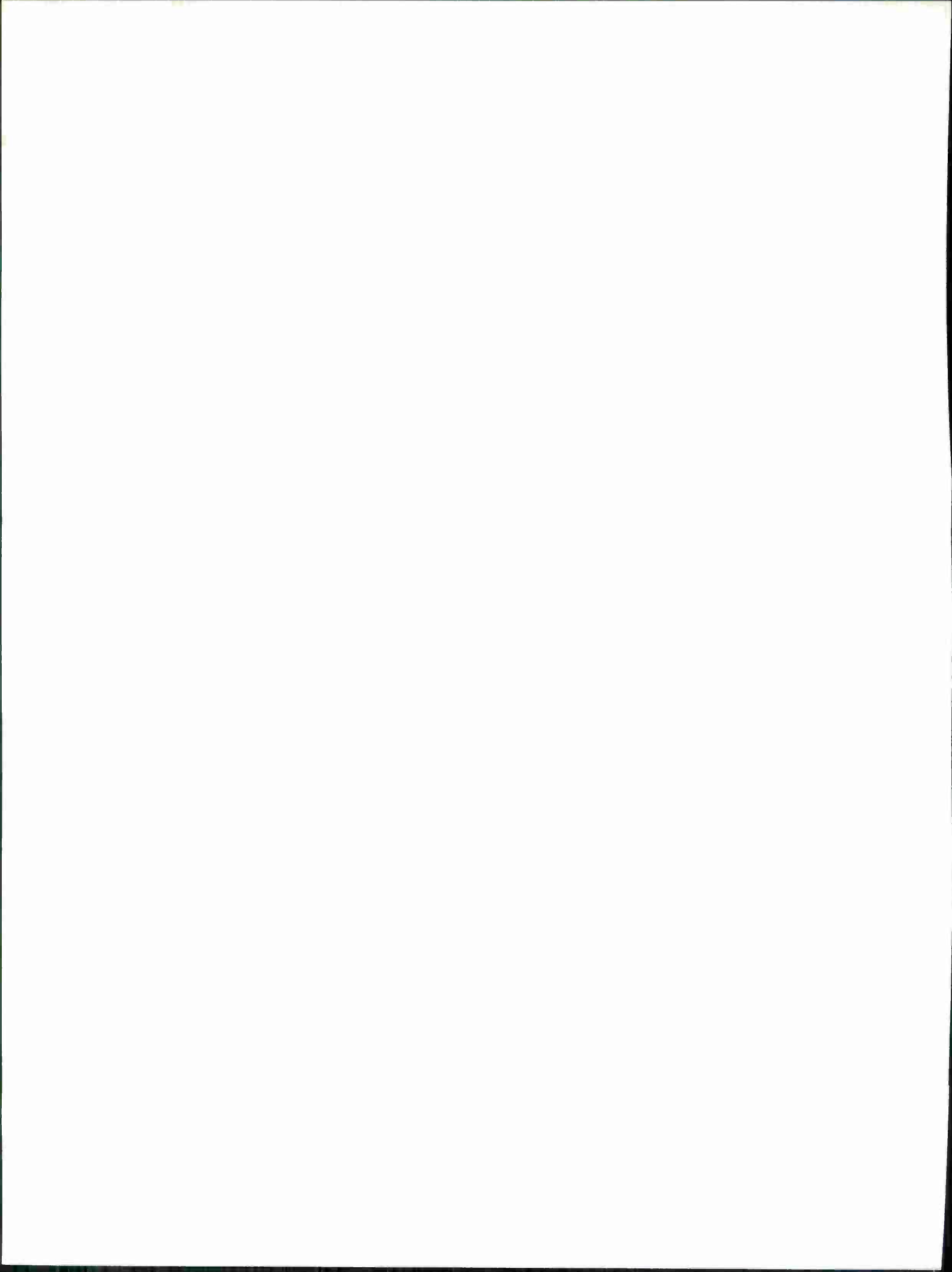
Division 8

MS No.

2965B	Experiments on Bound Polarons in the Silver Halides	R. C. Brandt	Seminar, University of Utah, 23 November 1970
2986	The Self-Induced Thermal Lens Effect and Related Phenomena in the Atmospheric Propagation of Laser Beams	P. L. Kelley	Ninth Aerospace Sciences Meeting, New York City, 25-27 January 1971
2991	Polaron Magneto-Optics	D. M. Larsen	Greater Washington Solid State Physics Colloquium (GWSSPC), 11 February 1971
2992A	Varied Roles of Outer d Electrons	J. B. Goodenough	Seminar, Catalysis & Surface Material Science Group, Esso Research & Engineering Co., Linden, New Jersey, 11 December 1970
2997	Lattice Effects in the Localized States	R. A. Bari	American Physical Society Meeting, New York, New York, 1-4 February 1971
3009	The Role of the Ambient Gas in Material Preparation and Crystal Growth	T. B. Reed	AIME, Boston Section, Cambridge, Massachusetts, 1 February 1971
3010	Polarization and Linewidth Properties of Broadband Masers	M. M. Litvak	Optics and Infrared Seminar, M. I. T., 2 December 1970
3011	Lattice Effects in Raman Scattering from Semiconductor Plasmas	K. L. Ngai	Physics Seminar, Naval Research Laboratory, Washington, D. C., 16 December 1970
3013	Two Center Excitations in $\text{Cr}_2\text{O}_3$ and $\text{CoF}_2$	J. W. Allen	Seminar, Bell Telephone Laboratories, Murray Hill, New Jersey, 9 December 1970
3018	Phase Diagrams and Crystal Growth of Compound and Alloy Semiconductors	J. M. Steininger	Seminars: CNRS, Bellevue, France; LEP, Limeil-Brévannes, France; University of Bordeaux, Talence, France; CENG-LEPI, Grenoble, France; Thomson-CSF Research Center, Orsay, France; 1-28 January 1971
3043, 3043A	Semiconductor-to-Metal Transitions	J. B. Goodenough	Colloquium, Department of Chemistry, Northeastern University, 18 January 1971; Seminar, Electrical Engineering and Chemistry Departments, University of Texas at Austin, 22 January 1971

MS No.

3061A	Multielectron Field Emission	K. L. Ngai	Physics Colloquium, University of Virginia, 3 February 1971
3064	Tunable, CW Infrared Lasers and Their Applications	A. Mooradian	Physics Seminar, National Bureau of Standards, Boulder, Colorado, 14 January 1971
3064A	High Power Tunable CW Infrared Lasers and Their Applications	A. Mooradian	Physics Seminar, Ford Motor Research Laboratories, Dearborn, Michigan, 15 January 1971
3083	Donor Central Cell Corrections in GaAs	D. M. Larsen	Physics Colloquium, Naval Research Laboratory, 11 February 1971
3091	Optical Properties of the Alkalis Using the KKR-Z Method	C-Y. Young	Physics Seminar, City University of New York, 16 February 1971



# SOLID STATE DIVISION 8

## I. SOLID STATE DEVICE RESEARCH

Proton bombardment has been used to fabricate n-p junction photovoltaic detectors from p-type PbTe and  $\text{Pb}_{0.88}\text{Sn}_{0.12}\text{Te}$ . Peak detectivities at  $5\mu\text{m}$  as high as  $3.4 \times 10^{11} \text{ cm Hz}^{1/2}/\text{W}$  in reduced background have been observed in PbTe diodes at  $77^\circ\text{K}$  with quantum efficiencies of 36 percent. Peak detectivities of the  $\text{Pb}_{0.88}\text{Sn}_{0.12}\text{Te}$  diodes at  $10.2\mu\text{m}$  were as high as  $1.2 \times 10^{12} \text{ cm Hz}^{1/2}/\text{W}$  in reduced background at  $15^\circ\text{K}$  with quantum efficiencies of 37 percent.

$\text{Pb}_{0.93}\text{Sn}_{0.07}\text{Te}$  diode lasers which at  $4.2^\circ\text{K}$  emit continuous  $8.6\mu\text{m}$ -radiation have been fabricated for high resolution spectroscopy of pollutant gases. Continuous-wave output powers up to  $40\mu\text{W}$  and pulsed powers up to  $10\text{mW}$  have been obtained. The diodes were fabricated through an extension of the vapor growth technique used for  $10.6\mu\text{m}$ - $\text{Pb}_{0.88}\text{Sn}_{0.12}\text{Te}$  diode lasers by employing thallium doping.

$\text{Pb}_{1-x}\text{Sn}_x\text{Te}$  laser crystals grown by the horizontal closed tube vapor transport process have been obtained with well-defined facets and surface areas up to  $1\text{cm}^2$ . The vapor transport in this process is greatly enhanced over that of the vertical growth procedure by convection currents of the  $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$  vapor in the tube.

Photoluminescence studies of epitaxial GaAs in a magnetic field have shown that two acceptor levels are present in high purity material and that two free-electron neutral-acceptor and two donor-acceptor pair bands are observed at low temperatures.

A simple model has been developed which demonstrates that an anomalously high apparent Hall mobility can be obtained in semiconductors containing inhomogeneities. Experimental verification of the model has been obtained by introducing high conductivity regions into epitaxial GaAs which have produced as much as a three to five fold increase in apparent mobility. These results cast some doubt on the use of high mobility values alone as an indication of material quality unless the homogeneity can be established.

Efficient, single mode, CW, tunable spin-flip Raman laser emission has been observed in InSb using a CO laser as a pump. External conversion efficiencies in excess of 50 percent and pump thresholds below  $50\text{mW}$  have been observed with the incident pump and Raman beams collinear.

## II. MATERIALS RESEARCH

A method has been developed for making melting point measurements by means of thermal analysis on volatile compounds at temperatures up to about  $2500^\circ\text{C}$ . This method, which utilizes welded metal crucibles to contain the samples, has been used to determine the melting points of EuO, EuS, EuSe, EuTe and several other refractory compounds.

The effect of hydrostatic pressure on the Néel temperature and ferromagnetic moment of  $\text{Ca}_{1-x}\text{Sr}_x\text{MnO}_3$  has been measured for samples with  $x = 0, 0.15, 0.25$  and  $0.50$ . The results indicate that orthorhombic distortion decreases with pressure as well as with  $x$  and that variation of the Mn-O-Mn angle influences  $T_N$  less than variation in chemistry.

Two distinguishable mechanisms have been identified in the monoclinic-to-tetragonal transition in  $\text{VO}_2$ : an antiferroelectric-to-paraelectric transition at a temperature  $T_t$  and a change from homopolar to metallic V-V bonding at a temperature  $T'_t$ . In pure  $\text{VO}_2$  at atmospheric pressure, the two transitions occur at the same temperature (340°K), but a  $T'_t < T_t$  may be induced by hydrostatic pressure or atomic substitutions. In the intermediate temperature range the structure is orthorhombic.

The optical absorption of n-type PbTe with carrier concentrations between  $9 \times 10^{16}$  and  $5 \times 10^{18} \text{ cm}^{-3}$  has been measured at room temperature between 6 and 15  $\mu\text{m}$ . For most of the samples, the dependence of the absorption coefficient on wavelength and carrier concentration indicates that at room temperature free carrier absorption is the dominant absorption mechanism in this wavelength range.

### III. PHYSICS OF SOLIDS

The magnetic field dependence of the Hall coefficient and resistivity has been measured for p-type samples of  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ , in which the energy gap was opened up from negative and very small positive values to approximately 0.06 eV by the application of hydrostatic pressure. The concentrations of electrons, heavy holes and light holes, as a function of pressure, are obtained; comparison with band model calculations yields a number of parameters including the pressure coefficient of the energy gap.

Study of the ultrasonic attenuation for bismuth in a magnetic field has been continued. Giant quantum oscillations associated with nonextremal orbits of the electrons have been unambiguously observed for the first time.

A many-body formulation of the field emission problem has been obtained, which can account for the high energy tail observed in the emission current of some materials. On the other hand, anomalies appear in the spectrum of tungsten, which seem to be due to the transient hole potential introduced when an electron tunnels out of the metal. This requires some additional modification of the theory.

A one band model has been constructed to describe nonmetallic behavior in several limits. The limiting cases are insulating behavior due to strong correlations, band splitting accompanied by lattice distortion and localization of small polarons at high temperatures.

Work has been initiated on an evaluation of broadband pyromagnetic detectors of the type reported by Caruthers and Walser. Simply by carefully designing the magnetic circuit and including leakage flux, we have obtained greater than an order of magnitude increase in responsivity over previous results.

Paramagnetic resonance of ferrous fluorosilicate has been extended to the submillimeter region by means of HCN and DCN lasers. The new results explain the apparent discrepancy between microwave EPR and other magnetic measurements.

Our recent studies have shown that the first few terms in the high-temperature expansion for the magnetic susceptibility provide the most reliable tool for analyzing experimental susceptibility data in terms of exchange interactions. The expressions for the first five terms, previously given for a single interaction, have now been generalized to an arbitrary number of Heisenberg exchange interactions.

A qualitative explanation has been obtained for the transverse to longitudinal spin flip transition at  $T = 122^\circ\text{K}$ , and the first order nature of the antiferromagnetic transition at  $312^\circ\text{K}$  observed

in chromium metal. These transitions occur in an extension of the Fedders-Martin model of itinerant spin density wave antiferromagnetism when the contribution of the magnetic induction to the free energy is included in the theory.

A spin wave diagrammatic approach has been developed for the temperature dependence of the line shape for two magnon Raman scattering in a simple antiferromagnet. A good description of the temperature dependence of the peak position is obtained, but in order to explain the line width, a large damping, much larger than a crude estimate yields, must be assumed for zone boundary magnons.

Study of the optical Raman scattering in  $\text{FeF}_2$  has continued with emphasis on identifying the previously reported intense line at  $1090 \text{ cm}^{-1}$  which seemed to be related to magnetic ordering. No obvious magnetic field effects for the configuration  $H \parallel c$  were observed for fields up to 88 kG; further studies will be attempted with a larger bore magnet which will permit examination with a  $90^\circ$  scattering geometry. Similar results were found for another sample obtained from a different source, indicating that impurity effects are probably not an important factor in the observed scattering.

A weak resonant enhancement of the Brillouin scattering cross section, less than one would predict on the basis of a theory by Loudon but greater than that expected from a simple dielectric constant approximation, is observed as the fundamental absorption edge of CdS is thermally tuned through the incident radiation at  $5145 \text{ \AA}$ . For the first time the spectral resolution is sufficient to observe an absorption-induced spread in optical wavevector resulting in line broadening. The absorption calculated from these observations is in satisfactory agreement with published transmission measurements on thin platelets.

#### IV. MICROELECTRONICS

The service-oriented programs have progressed rather well during this period and notable progress has been made in several major programs.

The program to explore the relationship of material properties to performance characteristics of the gallium arsenide millimeter wave diodes has provided considerable data and a number of high performance diodes.

Large numbers of silicon wafers are being processed for oxidations and diffusions in support of the LSI program.

Several other programs involving semiconductor processing such as surface wave amplifiers, photodiode arrays, read-only memory structures, a particle detector array and TRAPATT microwave diodes have either advanced to the prototype stage or are at the point where final devices or components are being delivered.

The air gap crossover techniques and related beam lead substrate methods are currently being applied to several service programs with excellent results.

The second generation laser scanner for integrated circuit testing is nearly complete and preliminary tests indicate greater system sensitivity has been achieved with a greater over-all reliability. New integrated circuit structures such as silicon on sapphire have been tested and evaluated with the new laser system, and further tests are under way to explore the effects of a higher power laser.

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