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# Quarterly Technical Summary

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## Advanced Electronic Technology

15 May 1973

Issued 28 June 1973

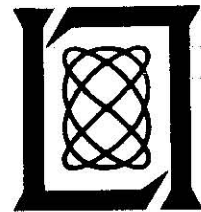
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# Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS



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## INTRODUCTION

This Quarterly Technical Summary covers the period 1 February through 30 April 1973. It consolidates the reports of Division 2 (Data Systems), Division 4 (Air Traffic Control), and Division 8 (Solid State) on the Advanced Electronic Technology Program.

Accepted for the Air Force  
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DATA SYSTEMS  
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1973 on Data Systems. Separate reports on Speech Understanding, Seismic Discrimination, Educational Technology, Radar Measurements, FAA Interactive Graphics and ATC Surveillance and Communication describe the work of Division 2 on these programs.

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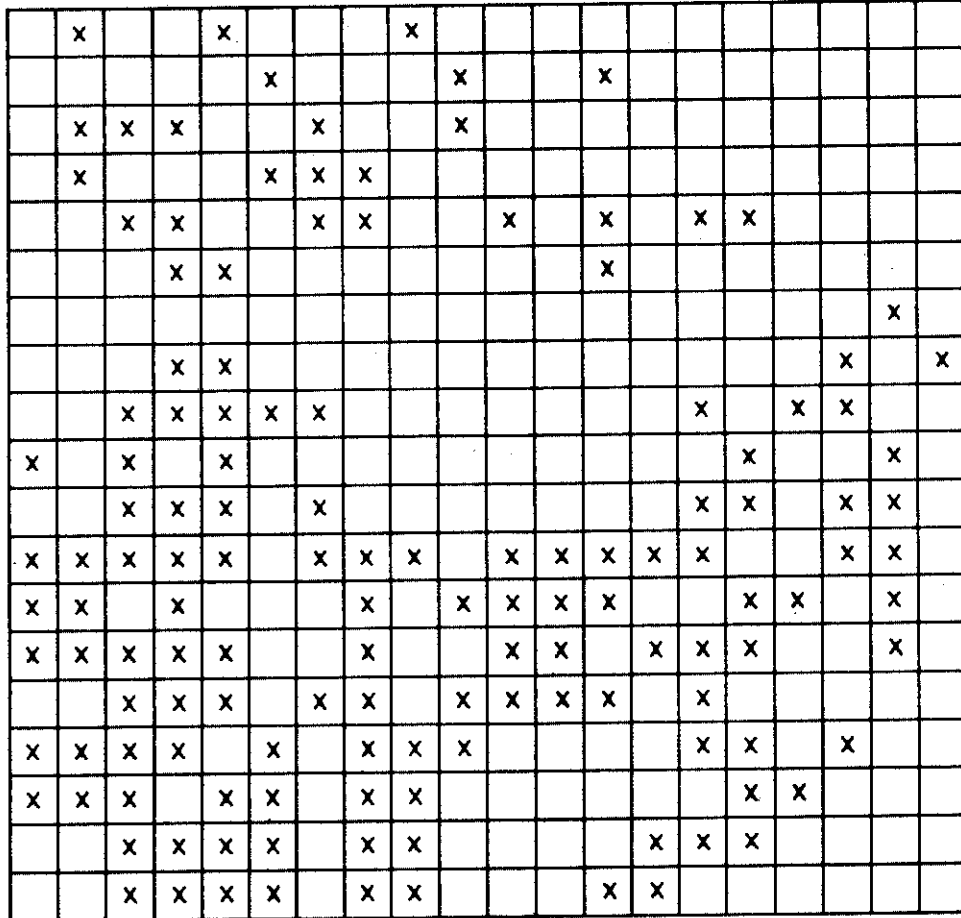


Fig. 1. Yield map of 2-bit adder wafer with 36-percent yield. Positions of 137 good circuits in array of 380 are indicated by X.

# DIGITAL COMPUTERS

## GROUP 23

### I. INTRODUCTION

During this quarter, the first wafers for a comparator designed for use in high-speed A/D converters were processed. A 20-chip memory array was built using photolithographic interconnection of plastic-embedded chips and the double-raster display system was connected to TX-2.

### II. INTEGRATED CIRCUIT PROCESSING

#### A. Integrated Circuit Fabrication

The first three wafers of comparator circuits (see Sec. V-A) have been processed and functionally tested. The transistors, which have 2.5- $\mu\text{m}$  emitter widths, were designed for an  $f_T$  of 2 GHz. Yields at wafer function test for the three wafers were 0, 13 and 23 percent but transistor collector breakdown voltage is below specification. The mean static input-offset voltage of working devices on the second wafer was 5 and 3 mV for the two comparators on each chip. These relatively low offsets indicate good emitter geometry control. Parameter and AC tests are in progress.

Our photolithography techniques have now been developed so that these wafers were processed with no errors that would have required resist stripping and recoating. The processing cycle for one run was three weeks. Since marginal resist adhesion to metal (aluminum-silicon) continues to be the weakest link in the process, a resist evaluation study is in progress.

The yield of functionally good 2-bit adder circuits at wafer probe test on seven wafers from three runs was 17 percent, ranging from 0 to 36 percent. Figure 1 shows the map of good circuits on a wafer with 36-percent yield. These circuits have a chip size of 50  $\times$  55 mils. The yield map indicates the feasibility of our making more-complicated circuits on larger chips.

#### B. Dielectric Isolation

Since significant improvements in speed and size will follow from dielectric isolation of our circuits, several isolation methods are being investigated. Some success is being achieved in growing heavily arsenic-doped epitaxial layers for buried collectors. This will enable the production of thinner buried collectors of better crystalline quality than we can make reliably with spin-on sources, and will ease the problem of making certain types of dielectric isolation.

#### C. Metalization

Molybdenum films with resistivity of 6 to 7  $\mu\text{ohm-cm}$  have been evaporated onto silicon with an electron-beam gun in a vacuum of  $3 \times 10^{-6}$  torr. The substrate temperature must be held near 475°C since molybdenum will alloy with silicon at 525°C, and below 425°C the resistivity is much higher. This film resistivity is near the molybdenum bulk resistivity of 5.6  $\mu\text{ohm-cm}$  and twice the 3- $\mu\text{ohm-cm}$  resistivity of a typical aluminum film. Several two-level molybdenum test chips have been packaged and are being life tested, in comparison with aluminum, for electromigration and other failure modes.

#### D. Electron-Beam Pattern Definition

A wafer of transistors with 0.5- to 2- $\mu\text{m}$  emitter linewidths has been fabricated while maintaining the integrity of alignment benchmarks. The wafer had a DC parameter yield of 40 percent but was not tested for  $f_T$  due to the high resistance of the nonepitaxial collector. Transistors now being fabricated on epitaxial wafers will be tested for high-frequency behavior.

### III. PHOTOLITHOGRAPHIC INTERCONNECTION OF PLASTIC-EMBEDDED SEMICONDUCTOR CHIPS

#### A. Memory Arrays

A 20-chip, 1024-bit memory array has been constructed and is completely functional. The hybrid array, shown in Fig. 2, is made from sixteen Intel 3101A 64-bit memory chips, two decoder, and two latch chips. The passivated chips are cast on 0.250-inch centers in a polyester

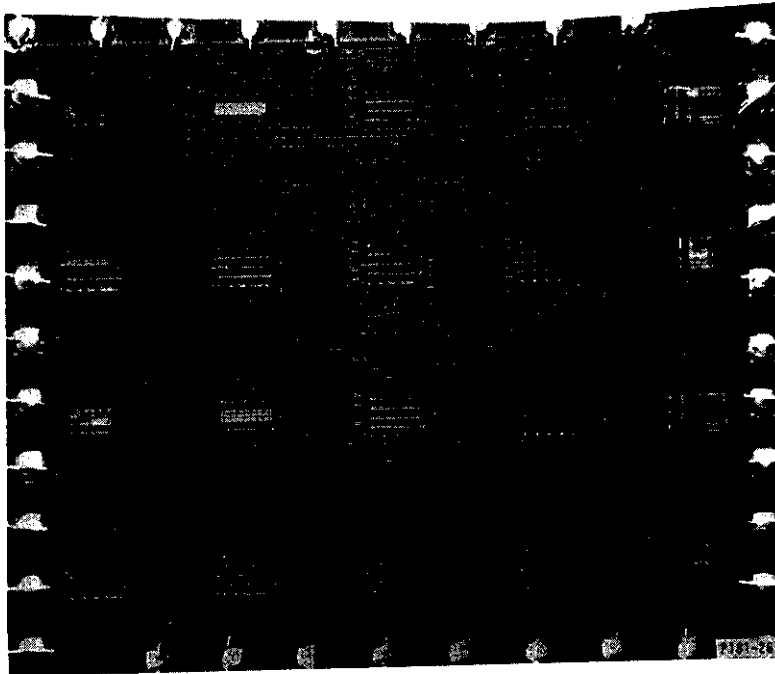


Fig. 2. A 20-chip memory array cast in polyester resin and interconnected with three layers of nickel selectively deposited in grooves in photopolymerized polyester resin.

resin. A metal heat sink is plated directly to the backs of the chips through photoformed openings in the resin. Access to chip metalization is through 0.003-inch-square via holes in a 0.001-inch-thick photoformed polyester layer, and 0.002-inch-thick nickel is selectively deposited in grooves in photopolymerized polyester resin to form the interconnections. There are three interconnecting layers. Power and ground lines are 0.050 inch wide and the signal lines 0.010 inch wide. The technology reliably permits formation of 0.005-inch-wide conductors. The entire array is  $1\frac{1}{4}$  by  $1\frac{1}{2}$  inches in size. Memory access time is 50 nsec and the array dissipates 7.5 W.



## B. Process Improvements

An improved technique has been developed for controlling resin-layer thickness during chip-array construction. A gravity-controlled, time-pressure (weights) method for squeezing liquid resin to a predetermined thickness on a leveled substrate is being used with good repeatability.

## C. Batch Packaging

A number of prototype multiple packages were molded with etched lead frames and dummy silicon strips and then separated into individual units. Work is progressing on the next step of interconnection of leads across the dice using photosensitive polyester and electroless plating techniques.

# IV. TESTING

## A. Evaluation of 16-Transistor Test Groups

Two significant results have been obtained from further testing of the wafers with transistors of various geometries. Addition of a second collector contact has had a more significant effect on both  $f_T$  and current capability than any other geometry variation. Adding a second base stripe to a 0.1-mil-wide emitter did not improve its current-handling capability. However, when the emitter was widened to 0.4 mil, the current capability doubled. Simple calculations show the dominant factors limiting  $f_T$  in these transistors are base transit time and collector charging time.

## B. Test Facility

A Data General Nova 1230 computer with 24,000 words of memory and two moving-head discs has been purchased for control of the wafer test facility. The TX-2 test programs are being rewritten in Fortran to operate with the Nova Real Time Disc Operating System. Design of a hardware interface to the tester has begun.

# V. APPLICATIONS AND DESIGN AIDS

## A. High-Speed Comparator

The CP1 is a latched voltage comparator intended for use in high-speed analog-to-digital converters. It consists of an input emitter-follower pair, a differential amplifier, and a flip-flop. Computer simulations predict that with 2-GHz transistors, the circuit should settle to within 5 mV of an input step in about 1 nsec, have a turn-on regenerative time constant of less than 0.3 nsec, and be usable with unlatch pulses 1 nsec wide. With a power dissipation of 60 mW per circuit, it should be feasible to integrate eight on a chip. The initial implementation is two circuits with different output stages on a chip.

## B. C-Circuit and Arbiter

The masks for the consensus circuit have been laid out and the mask design for the IC-tunnel-diode arbiter is near completion.

## C. Double-Raster Display System

The double-raster display is now operational with the C4 and TX-2 computers. The display generates a high-resolution flicker-free picture by drawing all horizontal lines during a horizontal

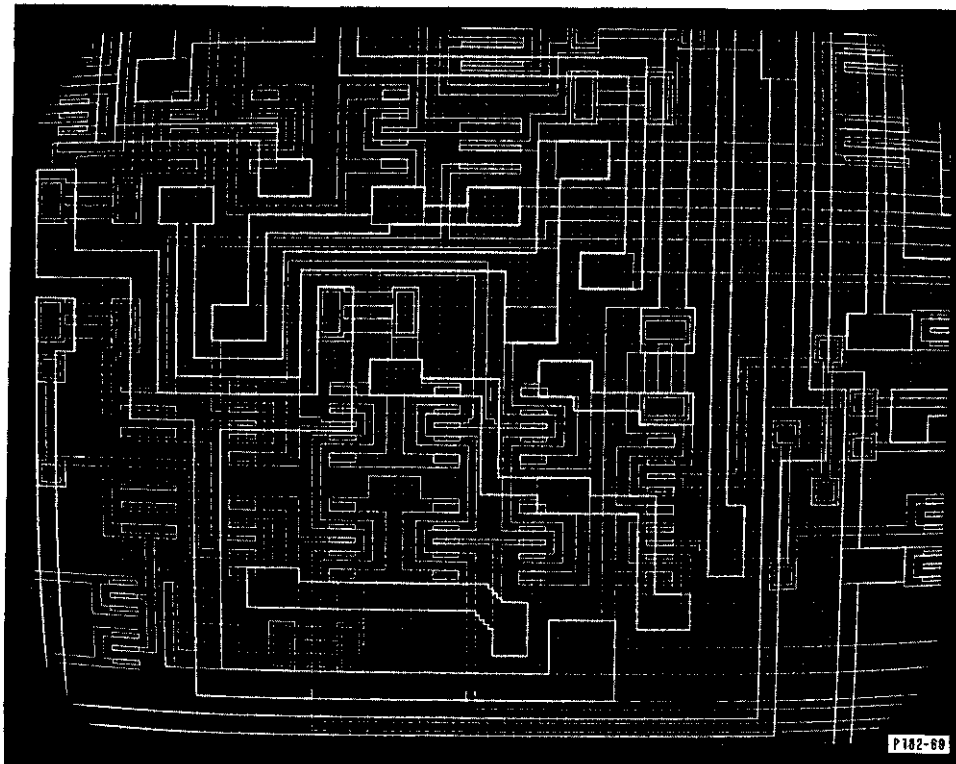


Fig. 3. IC layout on Double Raster Display. All lines are drawn on or halfway between grid lines. Two "levels" are shown at different intensity.

raster scan period, and all vertical lines during a vertical raster scan period. Figure 3 is a photograph of the 8- x 10-inch CRT screen showing a portion of the 2-bit adder circuit layout. A set of user-level programs is now available which allows a limited number of commands for the manipulation of line segments. A section of an integrated circuit mask was manually entered using these commands. Scrolling operations, which require moving data files off and on the TX-2 drum, are now working and enable the creation and inspection of arbitrarily large pictures. Routines are being written for moving and copying of components. Overall system performance is expected to demonstrate significant advantages over existing integrated circuit mask design systems.

## DIGITAL PROCESSORS GROUP 24

### I. CURRENT PROGRAM

The Lincoln Laboratory speech processor program is pursuing the goal of specifying appropriate vocoder hardware configurations for defense communication applications. Part of our efforts to date has been directed toward fully digitized versions of analog vocoders previously constructed at Lincoln Laboratory for use at 2400, 4800 and 9600 bits per second (bps). These vocoders had acceptable voice quality and the digitized versions are expected to be compact and low priced. Another part of our efforts has been directed toward analysis, simulation and implementation of Linear Predictive Coding (LPC) vocoders.

A digital filter channel vocoder has been designed and a simulation on the FDP is now being debugged. This simulation will aid in the detailed design decisions for register and coefficient lengths. The vocoder design is a digital equivalent of a 16-channel vocoder operating at ~2400 or 4800 bps, with a time waveform pitch extractor. It is estimated that under 400 dual-in-line logic packages could implement this vocoder at under 50 W of necessary power.

A simulation study of the LPC vocoder is continuing. At the present time, a complete analysis and synthesis simulation exists on the FDP with both Atal and Markel analysis schemes implemented. It is possible to code several parameters including direct form filter coefficients, reflection coefficients, area functions, and roots of the filter polynomial. Several coding studies are under way, with particular emphasis on coding roots. These roots are effectively speech formants and should be insensitive to coding and quantization noises.

### II. NEW AREAS

In addition to the work described above, new efforts are beginning in pitch detection research and in the development of an evaluation facility. The extraction of pitch information from the speech signal as part of both channel and LPC vocoders remains an important issue. Past channel vocoders designed at Lincoln Laboratory have used so-called "time domain" techniques for deriving this period measurement. This approach has been successful in reducing errors associated with such signals and has helped to improve the quality of naturalness of the synthetic output speech. The cost and complexity of such pitch extractors must be reduced by careful study of the signal-processing requirements in the light of present logic development in the low-speed MOS area. Presently, a time domain pitch extractor designed and constructed for a recent vocoder equipment has been simulated on the FDP and is used in several vocoder simulations including an LPC mode. Other pitch extractors will be investigated in both simulation and implementation studies. The problem of pitch extraction on telephone speech (with low frequencies absent) is an ongoing one that needs renewed study.

Work is beginning on the implementation of real-time simulation programs of channel and LPC vocoders as well as a real-time simulation system. The system will facilitate comparison of real-time vocoder simulations in conversational mode use.

COMPUTER SYSTEMS  
GROUP 28

A new version of the CMS time-sharing system has been generated, and is being used on an experimental basis. This version, 3.1, is more compatible with the batch (OS/360) operating system, and shows positive indications of higher levels of system performance.

In the Graphics area, some significant enhancements have been made to the software for the 4060 microfilm plotter. The new subroutines provide the capability to plot using a polar coordinate system directly. The ability to generate 3-dimensional plots on a CRT terminal as well as the 4060 microfilm plotter is provided on the time-sharing system now. Additionally, some of the new subroutines give the user the ability to generate bar graphs.

The integrity of CP/67 has been enhanced by providing a capability to recover from memory data failures. Machine check processing has been modified to allow the time-sharing system to continue operation in a degraded mode, should a storage data check occur in a user area. The particular page in main memory is removed from user space, and marked permanently unavailable. This technique will provide much greater reliability to time-sharing operations.

System performance for CP/67 for the first quarter of 1973 showed a significant improvement. By the addition of one memory module in the fourth quarter of 1972, the time-sharing system has been able to increase from 47 to 53 the average number of users served. The time spent in user program execution was raised from an average of 58 to 63 percent, guaranteeing the same level of system responsiveness to the additional six users being served. System wait time was reduced from an average of 8 to 3 percent.

The major effort on the batch processing system (OS/360) has consisted in the application of programming fixes to various components of the system, in particular, the Fortran compilers and the data set utility IEHMOVE. Effort was also spent in generating graphic reports for more-useful interpretation of system performance data. These reports were helpful in the design of system improvements which are currently being implemented. These improvements are intended to ease the external operation of the system rather than increase significantly the performance level which is registering approximately 90-percent CPU utilization for the regular and controlled system combined. The improvements consist of new HASP operator commands to facilitate job scheduling based on estimated run time, and/or class and changes to the HASP dispatcher to recognize and schedule priority jobs, backlog jobs, CPU bound and I/O bound jobs.

AIR TRAFFIC CONTROL  
DIVISION 4

INTRODUCTION

The Air Traffic Control Division at Lincoln Laboratory is engaged in studies and development programs for the Federal Aviation Administration and the Transportation Systems Center of the Department of Transportation. These activities are described in other reports. In addition, three small tasks being conducted for the Air Force are reported herein: (1) studies of microwave landing systems in support of the NATO Industrial Advisory Group (NIAG), (2) the construction of a computer-driven airborne display for the SEEK BUS program, and (3) studies of the TPN-19 system for the Terminal Control Program Office at ESD.

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AIR TRAFFIC CONTROL  
DIVISION 4

The following three tasks are being carried out with Air Force support.

#### I. APPROACH AND LANDING SYSTEMS

Effort in support of Lincoln Laboratory's participation as a U.S. technical representative to the NATO Industrial Advisory Group (NIAG) Subgroup 1 (SG-1) has been continuing. Subgroup 1 is in the process of assessing several alternative concepts for a NATO approach and landing system for the post-1975 period.

Some of the concepts under active consideration are part of the U.S. MLS program; however, several "ground derived" systems\* under quite active consideration are not part of the program.

A key area in this assessment is the effects of coherent interference (multipath). The results of a coherent interference (multipath) simulation by the Electronics Research Laboratory (ELAB) of the Norwegian Institute of Technology became available during this report period. Preliminary examination of these ELAB results suggests that

- (a) There was no major difference in multipath performance between the more-promising air- and ground-derived systems at the model airports, given similar apertures and antenna locations.
- (b) Scattering from stationary aircraft near the approach end of the runway is a major source of error for the more-promising systems.

A detailed examination of several of the scattering models used in the ELAB study is being undertaken to better define the technical validity of the results.

#### II. AIRBORNE GRAPHICAL DISPLAY

Assembly has been completed of all major components of the experimental airborne graphic display equipment which will be used with the SEEK BUS data link. The hardware is currently being tested in the Laboratory. During the next quarter, it will be interfaced with the SEEK BUS equipment and a complete system check will be performed involving all the hardware and software.

Plans are being formulated for installation and flight testing of the display in an aircraft equipped with the SEEK BUS data terminal. Both tactical and air traffic control applications of the display will be demonstrated and evaluated. Flight tests during FY 74 are contingent upon the availability of aircraft and surveillance facilities.

#### III. TPN-19 (GCA) STUDIES

In continuing support of the ESD Terminal Control Program Office, the Laboratory has taken part in a review by ESD of the effectiveness of the TPN-19 system. In particular, several alternatives to the PAR have been examined with a view to both lower cost and improved performance in heavy rain. Two promising candidates appear to be (a) an interferometer based on the ATRBS beacons, and (b) the addition of digital Doppler processing to a modified TPN-19 PAR. Work on these tasks is continuing.

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\* These are systems which perform direction finding on a signal emitted by an aircraft and then transmit its coordinates to the aircraft via a digital data link.

SOLID STATE  
DIVISION 8

INTRODUCTION

This section of the report summarizes progress during the period 1 February through 30 April 1973 on Solid State Research projects funded primarily by the Air Force. The Solid State Research Report for the same period describes this work of Division 8 in more detail.

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DIVISION 8 REPORTS  
ON ADVANCED ELECTRONIC TECHNOLOGY

15 February through 15 May 1973

PUBLISHED REPORTS

Journal Articles\*

<u>JA No.</u>			
4048	Efficient Optically Pumped InP and In <sub>x</sub> Ga <sub>1-x</sub> As Lasers	J. A. Rossi S. R. Chinn	J. Appl. Phys. <u>43</u> , 4806 (1972), DDC AD-758940
4064	Optically Pumped Room-Temperature GaAs Lasers	S. R. Chinn J. A. Rossi C. M. Wolfe A. Mooradian	IEEE J. Quantum Electron. <u>QE-9</u> , 294 (1973), DDC AD-758950
4070	Optical Properties of Graphite	L. G. Johnson G. Dresselhaus	Phys. Rev. B <u>7</u> , 2275 (1973)
4081	Electric-Field-Induced Transient Spin-Flip Raman Laser Pulses in InSb	A. Mooradian S. R. J. Brueck E. J. Johnson J. A. Rossi	Appl. Phys. Letters <u>21</u> , 482 (1972), DDC AD-753311
4087	PbS Photodiodes Fabricated by Sb <sup>+</sup> Ion Implantation	J. P. Donnelly T. C. Harman A. G. Foyt W. T. Lindley	Solid-State Electron. <u>16</u> , 529 (1973)
4106	Identification of Donor Species in High-Purity GaAs Using Optically Pumped Submillimeter Lasers	H. R. Fetterman J. Waldman C. M. Wolfe G. E. Stillman C. D. Parker	Appl. Phys. Letters <u>21</u> , 434 (1972), DDC AD-753310
4115	Anomalously High "Mobility" in GaAs	C. M. Wolfe G. E. Stillman D. L. Spears D. E. Hill† F. V. Williams†	J. Appl. Phys. <u>44</u> , 732 (1973), DDC AD-759090
4118	Effect of Surface States on the Amphoteric Behavior of Sn in Vapor Epitaxial GaAs	C. M. Wolfe G. E. Stillman	Solid State Commun. <u>12</u> , 283 (1973)
4130	Fast, Accurate Secondary-Electron Yield Measurements at Low Primary Energies	V. E. Henrich	Rev. Sci. Instr. <u>44</u> , 456 (1973)

\* Reprints available.

† Author not at Lincoln Laboratory.



JA No.

- |      |   |   |   |
|------|---|---|---|
| 4159 | Surface Mobility Measurement<br>Using Acoustic Surface Waves  | A. Bers*<br>J. H. Cafarella*<br>B. E. Burke | Appl. Phys. Letters <u>22</u> , 399<br>(1973) |
| 4171 | Interpretation of the Transport<br>Properties of $\text{Ln}_2\text{NiO}_4$ and<br>$\text{Ln}_2\text{CuO}_4$ Compounds | J. B. Goodenough                            | Mater. Res. Bull. <u>8</u> , 423<br>(1973)    |

Meeting SpeechesMS No.

- |       |  |   |   |
|-------|--|---|---|
| 3167  | Polaron Energy Levels in<br>Magnetic and Coulomb Fields                                  | D. M. Larsen  | In <u>Polarons in Ionic Crystals<br/>and Polar Semiconductors</u> ,<br>J. T. Devreese, Ed. (North-<br>Holland, Amsterdam, 1972),<br>pp. 237-287   |
| 3175  | Valence Bond Approach to<br>Magnetic Semiconductors                                      | J. B. Goodenough  | Chapter in <u>New Develop-<br/>ments in Semiconductors</u> ,<br>P. R. Wallace, R. Harris<br>and M. J. Zuckermann, Eds.<br>(Noordhoff International<br>Publishing, Leyden, 1973),<br>pp. 107-174 |
| 3222A | Magneto-Optical Transitions<br>and Fermi Surface in Arsenic                              | R. W. Brodersen<br>G. Dresselhaus<br>M. S. Dresselhaus          | <u>Proceedings of 11th Conference<br/>on the Physics of Semiconduc-<br/>tors</u> (Polish Scientific Pub-<br>lishers, Warsaw, 1972),<br>Vol. 1, p. 341   |
| 3254  | Free-Carrier Absorption in<br>n-Type PbTe  | A. J. Strauss   | J. Nonmetals <u>1</u> , 133 (1973)  |
| 3302A | Broad-Band Laser Emission<br>from Optically Pumped<br>$\text{PbS}_{1-x}\text{Se}_x$      | A. Mooradian<br>A. J. Strauss<br>J. A. Rossi                    | IEEE J. Quantum Electron.<br><u>QE-9</u> , 347 (1973),<br>DDC AD-759091   |
| 3307  | PbTe Photodiodes Fabricated<br>by $\text{Sb}^+$ Ion Implantation                         | J. P. Donnelly<br>T. C. Harman<br>A. G. Foyt<br>W. T. Lindley   | J. Nonmetals <u>1</u> , 123 (1973)  |
| 3338  | Stripe-Geometry $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$<br>Diode Lasers                    | R. W. Ralston<br>I. Melngailis<br>A. R. Calawa<br>W. T. Lindley | IEEE J. Quantum Electron.<br><u>QE-9</u> , 350 (1973),<br>DDC AD-759093   |
| 3367  | Pseudobinary Phase Diagram<br>and Existence Regions for<br>$\text{PbS}_{1-x}\text{Se}_x$ | A. J. Strauss<br>T. C. Harman                                   | J. Electron. Mater. <u>2</u> , 71<br>(1973)   |

\* Author not at Lincoln Laboratory.

MS No.

3369A	Proton-Guarded GaAs IMPATT Diodes	R. A. Murphy W. T. Lindley D. F. Peterson A. G. Foyt C. M. Wolfe C. E. Hurwitz J. P. Donnelly	In <u>Gallium Arsenide and Related Compounds</u> (The Institute of Physics, London, 1973), pp. 224-230
3392	Schottky Barrier GaAs EBS Amplifier	W. T. Lindley W. E. Krag C. M. Wolfe R. J. Sasiela R. A. Murphy C. E. Hurwitz D. F. Kostishack A. J. Yakutis A. G. Foyt	In <u>Gallium Arsenide and Related Compounds</u> (The Institute of Physics, London, 1973), pp. 295-300
3421	Pressure Variation of the Curie Temperature and Spontaneous Magnetization in $Fe_2P$ and $Fe_2P_{0.9}As_{0.1}$	J. B. Goodenough J. A. Kafalas K. Dwight N. Menyuk A. Catalano*	<u>AIP Conference Proceedings No. 10, Magnetism and Magnetic Materials 1972</u> , C. D. Graham, Jr. and J. J. Rhyne, Eds. (American Institute of Physics, New York, 1973), Sec. 42, p. 1355
3462	Programmable Switch-er-oo Chain	R. H. Baker* R. E. McMahon	1973 IEEE International Solid State Circuits Conference Digest of Technical Papers, Vol. XVI, pp. 88-89, Philadelphia, Pennsylvania, 14-16 February 1973

\* \* \* \* \*

UNPUBLISHED REPORTS

Journal Articles

JA No.

4061	Inhomogeneous Line Broadening in Donor Magneto-Optical Spectra	D. M. Larsen	Accepted by Phys. Rev. B
4119	Electron Radiation Damage and Annealing of $Hg_{1-x}Cd_xTe$ at Low Temperatures	J. Melngailis J. L. Ryan T. C. Harman	Accepted by J. Appl. Phys.
4120A	Structures and a Two-Band Model of the System $V_{1-x}Cr_xO_2$	J. B. Goodenough H. Y-P. Hong	Accepted by Phys. Rev. B
4122	Lineshape of the Doppler-Limited Infrared Magnetic Rotation Spectrum of Nitric Oxide	F. A. Blum K. W. Nill A. J. Strauss	Accepted by J. Chem. Phys.

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\* Author not at Lincoln Laboratory.

JA No.

- |      |  |   |   |
|------|--|---|---|
| 4124 | Near Resonance Spontaneous Spin-Flip Light Scattering in InSb  | S. R. Brueck<br>A. Mooradian<br>F. A. Blum                                | Accepted by Phys. Rev. B  |
| 4143 | High Power Output in Pb <sub>1-x</sub> Sn <sub>x</sub> Te Diode Lasers with Improved Mirror Quality  | J. N. Walpole<br>A. R. Calawa<br>R. W. Ralston<br>T. C. Harman            | Accepted by Appl. Phys. Letters   |
| 4148 | Backward Stimulated Light Scattering and the Limiting Diameters of Self-Focused Light Beams  | P. L. Kelley<br>T.K. Gustafson*   | Accepted by Phys. Rev. A  |
| 4151 | Pressure-Tuned GaAs Diode Laser Absorption Spectroscopy of Xenon Hyperfine Structure   | A. S. Pine<br>C. J. Glassbrenner<br>J. A. Kafalas                         | Accepted by IEEE J. Quantum Electron.   |
| 4157 | Tunable Laser Measurements of Water Vapor Transitions in the Vicinity of 5 $\mu$ m   | R. S. Eng<br>P. L. Kelley<br>A. Mooradian<br>A. R. Calawa<br>T. C. Harman | Accepted by Chem. Phys. Letters   |
| 4165 | Magnetic Moment  | J. B. Goodenough  | Accepted by <u>Encyclopedia of Chemistry</u> (Utet/Sansoni Edizioni Scientifiche, Firenze)                        |
| 4168 | Infrared Reflectivity of Paratellurite, TeO <sub>2</sub>   | D. M. Korn<br>A. S. Pine<br>G. Dresselhaus<br>T. B. Reed                  | Accepted by Phys. Rev. B  |
| 4169 | Field Dependent Central Cell Correction in Germanium in a Magnetic Field   | N. Lee*<br>D. M. Larsen<br>B. Lax*  | Accepted by J. Phys. Chem. Solids   |
| 4173 | Apparent Mobility Enhancement in Inhomogeneous Crystals  | C. M. Wolfe<br>G. E. Stillman   | Accepted as Chapter in <u>Semiconductors and Semimetals</u> , Vol. 11, A. C. Beer, Ed. (Academic Press, New York) |
| 4175 | High-Efficiency Secondary-Electron Emission from Sputtered MgO-Au Cermets  | V. E. Henrich<br>J. C. C. Fan   | Accepted by Appl. Phys. Letters   |
| 4181 | Tunable CW Pb <sub>0.98</sub> Cd <sub>0.02</sub> S Diode Lasers Emitting at 3.5 $\mu$ m: Applications to Ultrahigh-Resolution Spectroscopy | K. W. Nill<br>A. J. Strauss<br>F. A. Blum                                 | Accepted by Appl. Phys. Letters   |
| 4182 | High Power, Narrow Linewidth Operation of GaAs Diode Lasers  | J. A. Rossi<br>S. R. Chinn<br>H. Heckscher                                | Accepted by Appl. Phys. Letters   |

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\* Author not at Lincoln Laboratory.

JA No.

4203	Narrow Gap Semiconductors	T. C. Harman I. Melngailis	Accepted as Chapter in <u>Applied Solid State Science</u> , R. Wolfe, Ed. (Academic Press, New York)
MS-3249	Resistivity of $Pb_{1-x}Sn_xSe$ vs Hydrostatic Pressure	J. Melngailis T. C. Harman J. A. Kafalas	Accepted by J. Nonmetals

Meeting Speeches\*MS No.

2917B, C	Impurity Behavior in High-Purity GaAs	C. M. Wolfe	Seminar, Sperry Rand, Gainesville, Florida, 26 April 1973; Seminar, Electrical Engineering Department, University of Florida, Gainesville, 27 April 1973
3142E	Spontaneous and Stimulated Spin-Flip Scattering in InSb	S. R. J. Brueck	Seminar, Aerospace Corporation, El Segundo, California, 23 March 1973
3138D	Tunable Semiconductor Lasers and Their Applications	P. L. Kelley	Seminar, Bell Telephone Laboratories, Holmdel, New Jersey, 16 February 1973
3138E	Tunable Infrared Lasers and Their Applications	P. L. Kelley	Seminar, Harvard University, 7 March 1973
3452C	I. Acoustical and Infrared Rotary Effects in Helical Lattices; II. Pressure-Tuned Diode Laser Spectroscopy	A. S. Pine	Material Sciences Colloquium, M.I.T., 16 February 1973
3348E	Infrared Spectroscopy Using Tunable Semiconductor Lasers	K. W. Nill	American Physical Society, New England Section, Hartford, Connecticut, 14 April 1973
3348F	Tunable Laser Infrared Spectroscopy Using Semiconductor Diode Lasers	K. W. Nill	Material Sciences Colloquium, M.I.T., 11 May 1973
3348G	High Resolution Infrared Spectroscopy with Tunable Semiconductor Lasers	K. W. Nill	Physics Seminar, National Bureau of Standards, Boulder, Colorado, 2 May 1973
3337E, F	Tunable Semiconductor Lasers and Their Applications	A. Mooradian	Seminar, University of Illinois, Urbana, 8 March 1973; Physics Colloquium, Brown University, Providence, Rhode Island, 30 April 1973

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

<u>MS No.</u>			
3428A	Tunable Semiconductor Diode Lasers for High Resolution Infrared Spectroscopy	F. A. Blum	Opto-electronics Symposium, M.I.T., 1 March 1973
3428B	High Resolution Infrared Spectroscopy Using Tunable Semiconductor Diode Lasers	F. A. Blum	Seminar, Physical Sciences Laboratory, Texas Instruments Inc., Dallas, 22 February 1973
3454	Structural Studies in the System $KF-YF_3$	J. W. Pierce H. Y-P. Hong	Tenth Rare Earth Research Conference, Arizona State University, Tempe, 30 April - 3 May 1973
3468	Preparation and Structure of $RbMgF_3$ , $RbMgF_4$ , $TlMgF_3$ , and $Tl_2MgF_4$	J. A. Kafalas	Solid State Chemistry Symposium, 165th Meeting of American Chemical Society, Dallas, Texas, 8-13 April 1973
3471	Preparation and Structure of $RbSbO_3$ , $RbNbO_3$ , and $RbTaO_3$	J. W. Pierce J. A. Kafalas H. Y-P. Hong	
3474A	Free Energy Model of the High Temperature Metal-Insulator Transition in $Ti_2O_3$ and $V_2O_3$	H. J. Zeiger	American Physical Society Meeting, San Diego, 19-22 March 1973
3483	Model Potential and Phonon Spectra of Ten Transition Metals	A. O. E. Animalu	
3489	Frequency Control of a Spin-Flip Laser	S. R. J. Brueck	
3490	Role of Bulk and Surface Plasmons in the Emission of Slow Secondary Electrons	V. E. Henrich	
3491	Infrared Stimulation of Photoluminescence in ZnTe	G. W. Iseler J. W. Allen	
3492	Kinetic and Spectroscopic Properties of Infrared Stimulated Photoluminescence in ZnTe:O	J. W. Allen	
3493	Calculation of the Optical Dielectric Constant for Te	G. Dresselhaus	
3494	Lineshape Studies of Shallow Residual Donors in High-Purity n-Type GaAs	D. M. Korn D. M. Larsen C. M. Wolfe G. E. Stillman	
3495	Transition to Metallic Conduction in Compensated Semiconductors	D. M. Larsen	
3496	Impurity Doping of Pb- and Te-Saturated PbTe	A. J. Strauss	

<u>MS No.</u>			
3504	Optical Studies of $(V_{1-x}Cr_x)_2O_3$	J. C. C. Fan W. Paul* P. M. Racciah*	} American Physical Society Meeting, San Diego, 19-22 March 1973
3505	Evaluation of Optical Constants	J. C. C. Fan P. M. Racciah*	
3497	Development and Use of Optically Pumped Submillimeter Lasers	H. R. Fetterman	Physics Seminar, Yale University, 10 January 1973
3503	Recent Developments in Tunable Laser Technology	A. Mooradian	Industrial Liaison Seminar, M.I.T., 1 March 1973
3509	Phosphors for Solid-State Infrared-to-Visible Image Conversion	J. W. Allen G. W. Iseler	2nd Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, 26-27 March 1973
3516	Field Plate Guarded InSb Photodiode Arrays	C. E. Hurwitz A. G. Foyt W. T. Lindley	} Meeting of IRIS Specialty Group on Infrared Detectors, Washington, D.C., 13-15 March 1973
3521	High Quantum Efficiency HgCdTe Photodiodes at 10.6 $\mu\text{m}$	D. L. Spears T. C. Harman I. Melngailis	
3522	$\text{In}_x\text{Ga}_{1-x}\text{As}$ Schottky Barrier Avalanche Photodiodes for 1.06 $\mu\text{m}$	G. E. Stillman C. M. Wolfe A. G. Foyt W. T. Lindley	
3536A	Tunable Laser Measurements of Water Vapor Transitions in the Vicinity of 5 $\mu\text{m}$	R. S. Eng	} Meeting on Absorption of Infrared Laser Radiation in the Atmosphere, MITRE Corporation, Bedford, Massachusetts, 4-5 April 1973
3540	Introduction to Meeting on Absorption of Infrared Laser Radiation in the Atmosphere	P. L. Kelley	
3554	Pulsed Lead-Salt Diode Lasers for Atmospheric Absorption Spectroscopy	E. J. Johnson	Seminar, GTE Laboratories, Waltham, Massachusetts, 6 April 1973

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\* Author not at Lincoln Laboratory.

SOLID STATE  
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

CW output power up to 240 mW and single-mode power up to 52 mW have been observed in stripe-geometry PbS diode lasers operated near liquid helium temperature. This output power, which represents an increase by more than an order-of-magnitude over previously observed power levels in lead-chalcogenide lasers, has been achieved through a number of significant developments in the technology of these lasers, including: the use of higher-quality material than was previously available, the formation of diffused stripe-junctions using photolithographic techniques, and improved procedures for the formation of low-resistance contacts. The measured output power corresponds to an overall external quantum efficiency of 16 percent and an incremental external quantum efficiency of 22 percent. An incremental internal quantum efficiency of 44 percent and an internal loss coefficient of  $15 \text{ cm}^{-1}$  have been deduced by reflection-coating one of the laser end-faces.

HgCdTe photodiodes designed for high-speed heterodyne applications at  $10.6 \mu\text{m}$  have been fabricated by Hg-diffusion into p-type crystals with an alloy composition of about 19 percent CdTe. A 3-dB roll-off frequency in excess of 800 MHz has been measured for these diodes by heterodyning a tunable PbSnTe diode laser with a fixed-frequency  $\text{CO}_2$  laser. The high-frequency quantum efficiency was typically 40 percent, and local-oscillator-noise-limited operation was observed at 400 MHz with about 1 mW of  $\text{CO}_2$  laser power. Heterodyne signals have been observed at frequencies up to 20 GHz by beating a standard  $\text{CO}_2$  laser with an isotope  $\text{CO}_2$  laser.

II. QUANTUM ELECTRONICS

Room-temperature GaAs lasers operated in an external grating controlled cavity have given high output power (3 W) in a narrow emission line (0.04 nm). The lasers are wavelength tunable over an 18-nm range. The devices were fabricated from single heterostructure  $\text{Al}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$  material, with one cleaved face suitably antireflection-coated for external cavity operation.

Fluorescence studies of neodymium metaphosphate ( $\text{NdP}_3\text{O}_9$ ) have been carried out. An energy level structure for  $^4\text{F}_{3/2}$ ,  $^4\text{I}_{11/2}$ , and  $^4\text{I}_{9/2}$  manifolds is proposed. For the sample studied, the decay time of the 890-nm fluorescence is found to be  $14 \pm 3 \mu\text{sec}$ .

Studies have been made of the linear and nonlinear optical properties of the chalcopyrite structure materials  $\text{CdGeAs}_2$  and  $\text{AgGaSe}_2$ . Minimum absorption constants are found which are smaller than previously reported values. Measurements of the index of refraction as a function of wavelength have been made, and damage studies have been carried out on  $\text{AgGaSe}_2$ . CW sum frequency mixing has been observed with output at  $3.55 \mu\text{m}$  (sum of CO and  $\text{CO}_2$  laser frequencies) as well as difference frequency mixing between 12.2 and  $13 \mu\text{m}$  (differences between CO and  $\text{CO}_2$  laser frequencies).

Measurements have been made of the oxygen broadening coefficients of several water-vapor transitions in the  $5\text{-}\mu\text{m}$  region. Variations in the ratio of nitrogen-to-oxygen broadening coefficients have been found which range from 1.1 to 1.8. A positive pressure shift has been observed in air for the  $6_{3,4} \leftarrow 5_{0,5}$  transition at  $1946.35 \text{ cm}^{-1}$ . A detailed study has been made of the low-pressure Doppler-broadened profile of this line.

### III. MATERIALS RESEARCH

The Bridgman method is being used to grow improved single crystals of  $\text{CdGeAs}_2$  and  $\text{AgGaSe}_2$ , two promising materials for nonlinear optical applications in the infrared. The best  $\text{CdGeAs}_2$  crystal prepared so far contains a region of about  $200 \text{ mm}^3$  suitable for nonlinear experiments, compared with a volume of  $4 \text{ mm}^3$  reported in the literature.

The microstructure and electrical resistivity of sputtered  $\text{MgO-Au}$  cermet films have been investigated as functions of the substrate temperature during deposition. Films deposited at substrate temperatures of  $100^\circ\text{C}$  or less have low sheet resistivities, probably because they contain numerous  $\text{Au}$  filaments about  $1 \mu\text{m}$  long.

The crystal structure of  $\text{NdP}_3\text{O}_9$  has been determined by analysis of intensity data obtained in x-ray diffraction measurements on a flux-grown single crystal. The structure, which is orthorhombic, consists of chains of corner-shared  $\text{PO}_4$  tetrahedra and zig-zag chains of edge-shared  $\text{NdO}_8$  octahedra, both running along the c-axis.

### IV. PHYSICS OF SOLIDS

Investigation of the kinetics of the highly efficient blue upconverting phosphor  $\text{NaY}_{0.797}\text{Yb}_{0.20}\text{Tm}_{0.003}\text{F}_4$  has been essentially completed. The rate equations which were set up have been solved numerically and give good agreement with the experimental time dependence of the emission at  $1.84$  and  $0.81 \mu\text{m}$ ; the results at  $0.475 \mu\text{m}$ , however, give a poor fit at long times (large populations) due to saturation effects.

In another phase of the phosphor program, polaron effects are being studied theoretically in the  $\text{ZnTe:O}$  system which has high optical quantum efficiencies and interesting infrared stimulation properties. The polaron model being examined considers an electron trapped to a square well potential and coupled to LO phonons as well.

Detailed differential sputtering studies were carried out on secondary-electron-emitting films of  $\text{MgO-Au}$  cermets, by using Auger spectroscopy to monitor the surface composition of the films during argon-ion bombardment. The bombardment produced a stable  $\text{MgO}$ -rich surface layer which gave higher yields and lower crossover voltages from thick films, without charging, than would have been possible if the surface had retained the bulk composition.

By using lasers and a Fourier interferometer, high-resolution far-infrared magneto-optic studies of hydrogenic shallow donors in very high-purity epitaxial n-type  $\text{GaAs}$  have revealed a doublet structure which is of comparable magnitude (at the same average magnetic-field value) to that observed for cyclotron resonance. The splittings have been identified as arising from differences between spin-up and spin-down energies due to the nonparabolicity of the bands. In both cases, an  $H^2$  magnetic-field variation is found for the splitting, although the magnitude of the splitting does not agree (by a factor-of-3) with spin-split cyclotron-resonance calculations using the 6-band Kane model.

### V. MICROELECTRONICS

As a means of extending the upper-temperature operating range, the EBS diodes have been fabricated with a molybdenum-gold metalization in place of the previous aluminum-gold system. The diode-processing and fabrication results with the  $\text{Mo-Au}$  metalization have been very satisfactory, and operational tests of the diodes are under way.

Preliminary work has started on the materials and masks for the advanced  $2.1\text{-GHz}$  EBS diodes.



An automatic system for measuring the density and thickness of the epitaxial layers for EBS diodes and other semiconductor devices has been designed, tested, and put into operation.

Prototype charge-coupled devices have been fabricated for use in a satellite earth horizon sensor, and the initial testing for charge transfer efficiency, leakage, and I/O characteristics is currently in progress.

The balance of the equipment required for our  $K_a$ -band GaAs diode packaging facility was received, installed, and put into operation. Careful control of our procedures has enabled us to package these diodes with a minimum of shift in their characteristics, which are monitored and individually documented throughout the process. Approximately sixty of these packaged diodes have been furnished to the LES-8/9 project for preliminary testing. These diodes are to be characterized and evaluated to select those suitable for stress- and life-testing at various levels of junction temperature.

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