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Quarterly Technical Summary

General Research

15 May 1970

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 February through 30 April 1970. It consolidates the reports of Division 2 (Data Systems), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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DATA SYSTEMS DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1970 for the General Research Program of Division 2. Separate progress reports on Graphics, Seismic Discrimination and the Educational Technology Program describe other work in the Division.

M. A. Herlin
Acting Head, Division 2

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1970

PUBLISHED REPORTS

<u>Journals Articles*</u>			
JA No.			
3519	Detection of Conjugate Photo-electrons at Millstone Hill	J. V. Evans I. J. Gastman*	J. Geophys. Res. <u>75</u> , 807-815 (1970)
3595	OH Radio Emission Associated with Infrared Stars	W. J. Wilson† A. H. Barrett† J. M. Moran	Astrophys. J. <u>160</u> , 545-572 (1970)
3694	Very Long Baseline Interferometer Studies of H ₂ O Sources	M. L. Meeks J. M. Moran B. F. Burke† D. C. Papa† G. D. Papadopolous† P. R. Schwartz† S. H. Knowles† W. T. Sullivan†	Astrophys. J. Letters <u>160</u> , L63-L68 (1970)

* * * * *

UNPUBLISHED REPORTS

<u>Journal Articles</u>			
JA No.			
3630	Detection and Estimation Practices in Radio and Radar Astronomy	T. Hagfors J. M. Moran	Accepted by Proc. IEEE
3635	Millstone Hill Thomson Scatter Results for 1965	J. V. Evans	Accepted by Planet. Space Sci.
3637	Midlatitude Ionospheric Temperatures During Three Magnetic Storms Occurring in 1965	J. V. Evans	Accepted by J. Geophys. Res.
3685	The Conductivity of a Weakly Ionized Plasma as Related to Particle Diffusion in μ Space	T. Hagfors	Accepted by Phys. Fluids
3695	F Region Heating Observed During the Main Phase of Magnetic Storms	J. V. Evans	Accepted by J. Geophys. Res.

* Reprints available.

† Author not at Lincoln Laboratory.

Division 2

		<u>Meeting Speeches*</u>	
MS No.			
2537	Radar Studies of Planetary Surfaces	J. V. Evans	Brown University, Providence, 4 March 1970; NASA Goddard Space Flight Center, Greenbelt, Maryland, 3 April 1970; Case Western Reserve University, 28 April 1970
2793	Spectral Line Interferometric Data Processing Techniques and Their Application to the Study of OH Sources	J. M. Moran	VLBI Symposium, Charlottesville, Virginia, 13-15 April 1970
2767	Very Long Baseline Interferometry with Large Effective Bandwidth for Phase-Delay Measurement	A. E. E. Rogers	
2768	Interferometric Observations of Artificial Radio Sources	C. A. Knight [†] T. A. Clark [†] H. F. Hinteregger [†] R. Preston [†] A. E. E. Rogers I. I. Shapiro A. Whitney [†]	
2793A	Very Long Baseline Interferometer Studies of H ₂ O Sources	J. M. Moran	
2812	Vertical Drift of Ionization in the Upper F Region	J. V. Evans L. A. Carpenter	URSI Meeting, Washington, D. C., 16-17 April 1970
2813	Incoherent Scatter Observations of F Region Storm Effects	J. V. Evans	
2854	A Theory of Incoherent Scattering from a Partly Ionized Gas Where Ion-Neutral Collisions Are a Dominant Influence	T. Hagfors	
2814	Radar Determination of the Topography, Reflectivity, and Surface Roughness of Mars	A. E. E. Rogers M. E. Ash I. I. Shapiro G. H. Pettengill [†]	
2855	Preliminary Results of Geodetic and Astrometric Measurements Made Through Radio Interferometry	H. F. Hinteregger [†] B. F. Burke [†] C. A. Knight [†] D. Robertson [†] I. I. Shapiro A. R. Whitney [†] J. C. Carter J. M. Moran	AGU Meeting, Washington, D. C., 20 April 1970

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

[†] Author not at Lincoln Laboratory.

SURVEILLANCE TECHNIQUES

GROUP 21

I. SUMMARY

Group 21 is responsible for the operation and maintenance of the Millstone Radar and the Haystack Research facilities of Lincoln Laboratory's Millstone Hill Field Station. At Haystack the emphasis is on planetary and lunar radar and on radiometric techniques, whereas at Millstone ionospheric and radar propagation studies related to precision tracking techniques are conducted for the Advanced Ballistic Missile Defense Agency, U.S. Army (ABMDA).

Ranging observations for refining the fourth test of general relativity emphasized observations centered around the superior conjunction of Mercury on 23 March. Observations of the moon were made with the Haystack-Westford (Hayford) radar interferometer in experiments, with partial NASA support, to determine whether measurements of lunar topography can be made with useful accuracy. Initial results look quite promising.

Under the extended radio astronomy observing schedule made possible by a grant to the Northeast Radio Observatory Corporation from the National Science Foundation, a number of new programs have been initiated. They are listed, together with the name of the principal investigator and his institution, in Sec. III-C. The goal of 80 hours per week of observing time for visiting academic scientists is being closely approached.

The performance of the Haystack pointing servo has been substantially improved by the completion of a new hydraulic servo installation incorporating solid state electronics. Planning and major procurements for this important addition were done before resources became scarce, but the completion has been long delayed because of the increasing austerity.

II. SPACE SURVEILLANCE TECHNIQUES

Tropospheric and ionospheric propagation effects which can impair the performance of a precision tracking radar are being investigated to aid in the development and evaluation of BMD radars, as fully reported in the semiannual reports to ABMDA. Both refraction and clutter effects are being studied. In addition to the observation of auroral backscatter and ionospheric scintillation effects, a VHF/UHF phase coherent beacon experiment has been implemented to measure total electron content along the transmission path from a suitably instrumented satellite. By correlating these observations with those taken simultaneously at a site operated by the General Electric Company in Schenectady, the height and extent of ionospheric irregularities can be determined. Thomson scatter observations of the ionosphere have been extended to probe the features associated with traveling ionospheric disturbances (TID) and auroral storms.

The replacement assembly of a frequency selective subreflector, which is necessary to implement simultaneous, two-frequency monopulse angle tracking measurements, is scheduled for delivery in May. The first model failed during high-power operation at Millstone, causing a delay of some months in this phase of the measurements.

Division 2

Considerable progress has been made in computer software. Millstone's unique program for providing real-time predictions and antenna steering, based on an orbit-fit to current observations, has been successfully adapted to passive operation on UHF angle and Doppler data alone. The program was previously operational only at L-band, where angles, range, and an instantaneous Doppler estimate are obtained from active skin tracking.

A number of interesting passive tracks including satisfactory Doppler data have been recorded for playback and further study. Doppler bias estimates have been derived by fitting orbits to observations from several consecutive passes of each satellite, and good agreement has been obtained with values expected on the basis of the known beacon-frequency offsets from the nominal (400 MHz).

It has not proved possible to obtain repeatable antenna angle calibrations with the present position encoders, so that specification of models for angle-bias corrections and monopulse calibration must await completion of the new encoder system now under development. Although qualitatively it can certainly be said that amplitude scintillations are observed with regularity to the north and are rarely seen to the south, a quantitative estimate of accompanying tracking perturbations cannot yet be made with confidence.

III. HAYSTACK RESEARCH PROGRAM

A. Planetary Radar Studies

1. Mars

The NASA Viking project (a spacecraft mission to Mars) engineers are currently examining the radar measurements of the planet Mars (see the last quarterly technical summary) in their efforts to fix certain engineering design parameters which depend on the Martian atmospheric pressure derived from radar-measured topography and spacecraft radio occultations.

Some estimates have been made of the improved accuracy which will be possible in the radar measurements planned for the 1971 Mars opposition. Data processing hardware just completed at Haystack should permit the code baud length to be decreased from 60 to 6 μ sec which, together with a better (≈ 4.5 db with respect to the 1969 opposition) signal-to-noise ratio owing to Mars close proximity in 1971 (0.38 a. u. at opposition), should allow the topography to be measured to 0.1 km. The geometry of the 1971 opposition will allow topographic measurements in the region 12° to 25° south of the Martian equator.

2. Venus and Mercury

Ranging observations of the two inner planets continued for the Fourth Test of Relativity experiment. The Venus operations served to provide refined data over this portion of the orbit. The emphasis, however, was on observations centered on the superior conjunction of Mercury. The results of this intensive work were most discouraging. The low signal-to-noise ratios that were observed, together with an intermittent computer problem, made the results subject to considerable doubt, though every effort will be made to utilize whatever information they contain.

B. Radar Studies of the Moon

1. Backscatter Mapping

Mapping is complete, as is most of the work of assembling hemisphere-wide maps from the individually measured ZAC areas. The final report to NASA is being prepared.

2. NASA Consulting

We have continued to serve as consultants to the NASA Manned Spacecraft Center in the selection of landing sites for future Apollo missions. S. H. Zisk has attended two meetings of the Group for Lunar Exploration Planning, in February and April, where he contributed radar information about small-scale surface roughness at the proposed sites and assisted in the selection of the latest site list.

A detailed study of the radar data at the proposed and alternate Apollo sites has been completed at the request of the Mapping Sciences Division of NASA/MSC. This material will appear as part of a review volume on the scientific gains that are hoped for from future moon missions.

The report of the Apollo Dust Obscuration Committee has been published (see the last quarterly technical summary). S. H. Zisk was a member of this ad hoc group.

3. Topography Feasibility Experiments

Work has begun on feasibility experiments which will attempt to measure precisely the moon's topography, using the Haystack radar and the Haystack-Westford interferometric receiver. Preliminary observations were conducted during two weeks in March, with much of the time since then devoted to analyzing the data.

It now appears that the phase stability will be good enough to produce the hoped-for 0.5- to 1-km resolution in three dimensions, but (as expected) it also appears that an improvement in signal strength will be necessary to observe ZAC areas farther than 30° from the mean sub-earth point. Work is proceeding on a coded-pulse capability for the radar that will provide an effective 15-db increase in transmitted power. This work should be finished by the time of the next scheduled observations in June.

Partial funding for this work is provided by the NASA/Manned Spacecraft Center, Houston, under Contract NAS 9-7830.

C. Radio Astronomy

We have continued the regular monitoring programs at 7.8 and 15.5 GHz on the time-varying quasars and peculiar galaxies and, at 22.2 GHz, on the intense water-vapor sources. Both these efforts have been described in previous issues of this quarterly technical summary. New experiments initiated this quarter together with their chief investigator and his institution are listed, in order of increasing radio frequency, as follows:

- (1) A search for emission for a form of heavy water (the isotopic species H_2O^{18} rather than the more abundant species H_2O^{16}) at 5.8 GHz (C. A. Gottlieb, Harvard College Observatory). Initial evaluation of the data gives a negative result for the search thus far.

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- (2) A survey of recombination lines at 7.9GHz with the maser receiver in the Planetary Radar Box (E. J. Chaisson, Harvard College Observatory). This survey includes searches for recombination lines in gaseous envelope around the highly ionized regions in galactic nebulae.
- (3) Use of the 22-GHz radiometer for observations of the sun during the near-total eclipse of the sun on 7 March 1970 (M. Simon, State University of New York at Stony Brook). These observations were made to search for solar limb brightening and to measure the angular size of active regions on the solar disk. Evidence of limb brightening was found and the angular widths of several active regions were determined to be less than one minute of arc.
- (4) A search for new sources of 22-GHz water-vapor emission has discovered three new sources coinciding in position with infrared stars (A. H. Barrett, M.I.T.).
- (5) A study of the earth's atmosphere, the stratosphere and mesosphere, by radiometric techniques (D. H. Staelin, M.I.T.). At 22 GHz, we have made regular observations of the sun at low angles to measure the absorption of radiation by water vapor in the stratosphere. At 101 GHz, the Haystack spectrometer system was used with a small horn antenna to measure ozone (O_3) in the mesosphere.

We consider radiometric observations of the stratosphere and mesosphere to be an important new technique for remote monitoring of H_2O and O_3 concentrations as a function of time. With the prospect of a large volume of air traffic in the lower stratosphere within the next decade, it will be necessary to monitor these constituents from the point of view of pollution and possible climate modification.

Study of the spatial structure of interstellar water vapor radio sources is continuing with the use of very long baseline interferometers. In January 1970 the 85-foot antenna of the Naval Research Laboratory was used with the Haystack antenna to permit observations with an interferometer of length 667 kilometers or 50×10^6 wavelengths. Data from these observations were studied during this quarter. The sources W49, Orion and VY Canis Majoris were unresolved, implying that their angular size is less than 0.003 second of arc. The various spectral features in W49 were found to be spatially separated by about 1 second of arc. The spatial structure of the H_2O sources seems to be very similar to that found in OH sources. However, the size of individual H_2O features is smaller than the size found in OH sources. The emission in both cases is thought to be due to a maser mechanism.

IV. HAYSTACK ENGINEERING

A. Antenna System

This period saw, finally, the completion of a major upgrading of the antenna pointing system. Design and procurement of major components were accomplished some time ago when more support was available.

New hydraulic servos now serve both elevation and azimuth axes, while the original vacuum tube electronics have been replaced with state-of-the-art solid state systems based upon commercially packaged operational amplifiers. Both velocity feedback and rate integration are incorporated, affording stable operation and tracking errors at sidereal rates which appear to be determined by the least significant bit on the 19-bit position encoders ($\pm \approx 5$ arc sec).

Evaluation of the actual performance obtained in observing celestial objects has begun.

B. Planetary Radar System

Radar observations were supported with VA-949AM klystrons S/N 13 and S/N 1. A new unit, S/N 18, met with an accident at the Varian plant and required re-processing. This, in turn, was followed by a second, catastrophic accident immediately following the successful testing of the reprocessed unit. Work was immediately begun on S/N 20, and it suffered a collector failure while in the process of evaluation. Although Varian will eventually make good on these failures, the current tube situation is grim, and continuing use of aging S/N 1 limits power to less than 300kw.

C. Radiometric Systems

The radiometers in the Planetary Radar Box (PR Box) continued to support extensive spectral line radiometric observations at X- and K-bands as well as continuum work at X-band. Preliminary work has extended the capabilities of the PR Box radiometers. The installation of an X-band parametric amplifier for extending frequency coverage beyond that available with the radar maser system is already in progress in support of a planned search for excited OH at 8135 MHz. System temperatures of 180° with nitrogen cooling and 120° with helium cooling should be achieved.

Systems incorporated in the Radiometer Box (R Box) supported continuum and/or spectral line work at frequencies of 5.6, 6.03, 7.8, 10, 15.5, 22.2, 23.7 and 35 GHz.

The 5.6- and 6.03-GHz work used a room temperature parametric amplifier provided by Harvard. Haystack's old 4.5- to 5.5-GHz Clavin feed was retuned as required and, though not optimum for the task, yielded overall antenna efficiencies of about 35 percent.*

A new 100-delay digital autocorrelator has been under construction for some months, and finally became operational in late February. It can analyze bandwidths up to 25 MHz with typical resolution of 1/40 of the selected bandwidth.

* Equivalent in aperture to an 85-foot dish with 70-percent efficiency but with the finer beam resulting from the 120-foot diameter.

DIGITAL COMPUTERS GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Computer-Controlled Wafer Probe

The Electroglas Model 900A prober has been operating under TX-2 program control. Complete X- and Y-positional control based on an absolute coordinate system keyed to the reference chip has been demonstrated. Wafer maps have been generated and the program can return the probe to recheck only the good chips (or only the bad chips if the case warrants). Repeated probing of a 3-bit parity wafer (perhaps 30 times so far) has produced little serious damage. Probe bounce delay and power supply sequencing are included in the program. Some problems still exist with regard to proper contact pressures, but these are being resolved. Both adjustable probes and a fixed probe card have been used in initial tests. The chips have 3×3 -mil pads on 6-mil centers. A 52-point fixed probe will be used in tests on adder arrays.

B. High-Speed Multiplier

The first L-100 two-bit gated adder integrated circuits, produced by Philco-Ford Microelectronics for our high-speed multiplier, have been tested and have showed excellent performance. Carry delay per bit and sum delay were both somewhat smaller than the design values of 1 and 4 nsec, respectively. A 17×17 -bit multiplier using these circuits has been designed and will be tested as soon as we receive a sufficient number of circuits from Philco. This multiplier will generate 34-bit products in approximately 50 nsec.

C. Interconnection of Integrated Circuits

Four-point probe resistance measurements of chemically deposited metals on passivated via-test chips indicate interface resistance values of 10 milliohms or less per via for metallization consisting of zinc, nickel, and gold over chip aluminum. Two groups of sixteen chips, totaling 128 vias per group, were batch processed with 100-percent yield of low-resistance interfaces.

Present efforts at array assembly include the use of premetalized, passivated test chips as described, as well as unpassivated and unmetalized chips. For the latter, procedures have been developed for simultaneously sensitizing and metalizing chip aluminum and plastic encapsulant without injury to chip metalization.

A problem with array construction is poor adhesion of the plastic dielectric layer to the chip surface, which results in delamination of the dielectric layer with increased temperature. Efforts at solving this problem continue to center around the use of silane coupling agents.

II. MAGNETIC FILM ENGINEERING

A. Specifications for LCM II

The prototype memory now being developed will have a capacity of one million bytes in a single module. It will be fabricated from a matrix of 32,768-word lines and 320-digit lines where as many digit lines are used as required to give 32 bytes of 8 or 9 bits each plus parity. The memory is formed from two half-stacks each containing 16 word substrates and 4 digit substrates. A word substrate has 1152 (1024 + spares) lines 1-mil wide on 2-mil centers; each digit requires two lines so each digit substrate has 160 (plus spares) 6-mil lines on 10-mil centers. The physical dimensions of the stack are approximately $44 \times 12 \times 6$ inches.

Word access is accomplished through a diode matrix with diode chips bonded directly to the word substrate. For electrical and packaging reasons the matrix is subdivided into four 64×128 matrices. A complete digit channel (sense amplifier, buffer, and digit driver) is provided for each digit line.

The memory will be designed to operate with a 0.7- μ sec read-rewrite cycle time. The 500-megabits/sec data rate makes the memory a well-matched backup store for the high-speed semiconductor main memory, while the access time of only 0.3 μ sec matches that of the many smaller main memories.

The data buffer will be organized as 32 bytes of eight or nine data bits each plus parity bits as required, up to one parity bit per byte. For a data bus 4 bytes wide (e.g., TX-2) the buffer would be arranged as eight words, and any one or all eight could be transferred to or from the memory at 75-nsec intervals during the appropriate time in the memory cycle.

Very-high-speed bursts of read-or-write-only cycles are possible. Sixty-four long words (2048 bytes with block limits memory determined) could be transferred to or from the memory at a rate of 32 bytes, each 200nsec. This rate requires a bus width of at least 16 bytes.

B. Word Lines

Two dozen word substrates have been scribed with 1.3-mil-wide lines on 2-mil centers and "Mann Machine" generated pad pattern negatives. Line-to-pad alignment and scribing quality were very good. Also, a set of 24 "dummy" word substrates consisting of 70-mil-wide lines on 75-mil centers have been made for inclusion in the LCM II prototype stack. Poor adhesion of the metal layers has resulted in lifting of the lines on a number of these substrates.

C. Word Decoding Matrix

Experiments are continuing with diode interconnection using copper bus lines on "kapton" which are electrically-mechanically attached to each diode with conductive epoxy. The previous problem with this method was short circuiting of the diode due to the epoxy's touching the un-passivated sides of the chip. We now have diodes with passivated sides which should eliminate this problem.

D. Digit Lines

Eight digit substrates, 2.2 inches wide by 52 inches long have been scribed on the large scribing machine. The mechanism works well, but poor adhesion and bumps in the copper

surface have caused the lines to peel or be of uneven width. In an attempt to eliminate these problems, lamination of copper foil directly to glass substrates is being tried.

E. Magnetic Film Plating

A clean bath has been set up to plate copper for digit lines. Bright, adherent, very low stress copper is being plated, but whether this plating is adequately free of pin holes and inclusions has not yet been determined. Permalloy-like platings of adequate anisotropy for closure have also been plated.

F. Optical Testing of Magnetic Films

The drive coils and optical structure of the optical B-H loop for 52-inch substrates have been fabricated, and the rest of the mechanical parts are under construction. The electrical design is complete, and the signal amplifier has been built and operates well. An option for converting the loop to an inductive sense system with a strip line drive has been investigated and looks feasible if it proves to be necessary.

G. NDRO Experiments

Wide margins on the word current for NDRO operation are conceptually possible, using flat films in a closed easy-axis configuration in which the digit line is a hairpin. Because easy-axis skew is likely to be the same on the closely spaced legs of the digit lines under any word line, word-current disturbing will result in a null signal from the film directly under the word line. Regions written on either side of the word line by the coincidence of digit and fringing word fields will be read out nondestructively. Experimental results confirmed that a 2:1 range of word currents gave a signal which was of constant amplitude and one-sixth the DRO output. Word line centers of 8 mils appear feasible.

H. "Transformerless" Sense System

A new sense-amplifier digit-line configuration has been devised which provides the necessary sense and digit-drive isolation. Two digit-line hairpins, one in each half-stack, are connected in series to a differential-amplifier input stage. Digit drive is applied to the lines in parallel through a diode or resistor coupling circuit; the digit-drive voltage then appears at the amplifier terminals in common mode. This circuit, being direct coupled, has no input-stage energy-storage elements to slow recovery from residual digit transient. It does have an inherently poor rejection for any common-mode voltage appearing on one of the digit lines, but this can be improved with a two-winding common-mode choke. The advantage over the 4-transistor circuit described in the last quarterly technical summary is its greater simplicity in semiconductor elements, which makes it more amenable to realization with commercially available monolithic devices or even discrete components.

The "transformerless" sense system has been used with a switched amplifier to achieve rapid digit recovery. An MOS switch between the direct-coupled input stage and the first coupling capacitors is opened during the digit transient to prevent capacitor charging. Cycle times of less than $0.4\mu\text{sec}$ have been achieved with LCM I (15-inch) digit lines.

III. COMPUTER SYSTEMS

A. ARDS Terminal

A Computer Displays, Incorporated, ARDS remote keyboard-display terminal was connected to the Lincoln Laboratory IBM 360/67 time-shared computer. The IBM 360 is equipped with a modified 2701 Teletype Adapter Type II operating at 1200 bauds/sec. A data set adapter was developed which allows a half-duplex Bell System 202C10 Data Set to be connected to the 2701. This data set adapter along with certain modifications to the ARDS terminal and the supporting software controls the direction of transmission of the data sets.

The ARDS terminal has been used in the Laboratory and has been taken to the National Medical Library in Washington, D.C. to demonstrate remote usage of information retrieval programs implemented on our 360 system. User satisfaction is greatly increased by the high-speed transmission of data to the ARDS storage display.

The data set adapter and ARDS modifications will allow the ARDS terminal to be easily connected to a number of other computers through their teletype interfaces.

B. ARPA Network

Work is in progress on the connection between TX-2 and the ARPA network. The connection will feature full-duplex (simultaneous bi-directional) buffered data transfer between TX-2 and the local IMP. The sequence switch for the new input-output sequence pair on TX-2 has been designed, wired and statically checked out. The plug-in units for the sequence switch have been built and tested. The design of the input-output control box is nearly complete, and wiring has begun. A partial order for logic cards has been placed.

C. TX-2 Display

The new character generator for the TX-2 display system has been installed and is performing well. This character uses the hybrid circuits of the TX-2 conic display generator for the stroke generation and a read-only memory for the character repertory. It has two writing speeds. A slower speed of approximately $300\mu\text{sec}$ and a higher speed of $20\mu\text{sec/character}$. These two speeds match the characteristics of the two types of display units, storage CRTs and refresh CRTs. As a result, the overall display efficiency is improved. At the same time, superior characters are obtained.

PSYCHOLOGY GROUP 25

I. DESIGNS FOR MAN-MACHINE INTERACTION ON COMPUTERS

A. Reckoner/Mediator on IBM 360/67

The Mediator system is now fully operational on the IBM 360/67. The current library of programs, which constitute the Reckoner facility, works smoothly for the numerical solution of array arithmetic and matrix algebra problems. The programs are documented in an abbreviated User Guide, in a more extensive User Manual and in a detailed set of external specifications. There is also a guide for programmers which shows how to write new programs in Fortran for the current library or for starting a library in a new problem area. Arrangements have been made for rapid access to a time-sharing account for novice Reckoner users. A graphics terminal and a supporting graph-plotting routine are available for inspecting data. In short, all conditions have been met for introduction of the facility to Lincoln staff. So a field test of the Reckoner/Mediator concept has begun.

B. Monitoring Performance of TX-2 Executive

The mechanism for gathering statistics on memory management by the Apex executive proved to be inadequate. As a consequence, during the past quarter the Data Collection Device was modified by Group 23 to provide external control. Specifically, it allows system designers to start or stop the collection process without disturbing the users.

The data collection software which monitors allocation of memory is now completely debugged. The data sent to the collection device by these routines have been expanded and refined. Certain changes have been made to answer new questions posed by the prior results. Several experiments are planned in which performance data will be gathered over a range of values of key system parameters. Optimum settings and system sensitivity to the parameters will be inferred from the results. A report describing the memory management algorithms in Apex is in draft form. It will include data from the planned experiments.

C. Human Factors in On-Line Computation

This report concerns our recent experiments on problem-solving behavior on the Lincoln Reckoner, a facility for manipulating arrays of numerical data. The tasks in the experiment elicited the kind of behavior typical of an engineer or scientist working on-line with the computer. Outputs occurred on the typewriter, oscilloscope display screen, and the high-speed Xerox printer. Controlled delays were interposed between the command for an output and its occurrence. The findings suggest that the variability of the delay had a negligible influence, but the average delay, which the user could predict, had a marked effect. More specifically, as the average delay was increased, outputs were commanded at a lower rate. The subjects were quite sophisticated and managed to solve problems with fewer requests for output by adopting

a variety of tactics. Another result was that the average time to solve a problem was not strongly affected by delay because relatively little of the time was taken up by output commands. It therefore appears that longer delays in computer responses, which imply reduced system cost, might become more acceptable if facilities are developed to enhance the users' ability to adapt. A technical report describing this work is in preparation.

II. EDUCATIONAL METHODS

A sizable portion of the group effort during this quarter has been in the Educational Technology program and will be reported separately.

COMPUTER SYSTEMS GROUP 28

An extensive survey of the present and future needs of the Computer facility has been conducted. While confirming the continuing need for both a time-sharing and batch-processing capability, the study indicated that the level of use has declined well below the capacity of the current configuration. For this reason, a recommendation was made to cut back on the amount of equipment installed to a point that will still handle the current level of work with some inconvenience to users. Therefore, one of the duplex central processing units and its associated input-output channels will be discontinued during the summer. The remaining CPU will operate with the full one-million bytes of main memory, all the presently installed secondary storage, and a substantial amount of the other peripheral equipment. This configuration will make it necessary to shorten the time-sharing schedule. However, that will be compensated by the fact that it will be possible to accommodate about 50 percent more users concurrently. Similarly, the batch-processing operation cannot begin until time sharing is shut down in the early evening, but it, too, is compensated by the fact that a new version of the system will produce about 25 percent more work than the current system.

This new batch-processing system is IBM's OS/360-MVT-HASP. A major feature of it will be the ability to run two or more user programs concurrently in the larger memory. A first step in this work, a smaller version of the Fortran compiler is being prepared for testing. Additional features will include a smaller linkage editor, spooling of the SC-4060 display output to disk, a considerably faster assembler, and a revised accounting program. Since batch processing will not operate during the day on the new hardware configuration, a considerable amount of work has been done to implement versions of OS that will run under the time-sharing system. Also, a number of changes have been made to the LLMPs program to provide better support for data collection activities.

During the quarter, several new features have been added to improve the performance of the CP-67 time-sharing system. One of these is the dynamic allocation of page space on the swapping drums. In previous versions of the system, an area of the drum large enough to accommodate a user's entire virtual memory was set aside as he logged on. Since only about half this space is normally used, there was a great waste of expensive high speed storage and users logging on after the drums were "filled" would be required to page to the much slower disks. By allocating space dynamically as required, it is almost a certainty that every user will have his most active pages on the drum.

A new algorithm for selecting pages to be swapped out of memory has also been completed. The scheme, generally referred to as "Least Recently Used" (LRU), keeps a recent history of accesses to each page in core. Whenever space is required for a new page, this history is referenced to find a page which has been inactive for the longest period of time. This then becomes the area selected to be swapped out, making room for a new page. The object of LRU is to reduce the probability that any page swapped out to the drum will be needed very soon again. When

such a condition occurs and two programs vie with each other for page space, the system is said to be "thrashing." A related feature added to CP is the facility for designating certain pages which may not be considered for swapping and are thus "locked" into main memory. Currently, six pages of the CMS nucleus are shared by all users without any of the delay or overhead caused by normal page swapping.

At times during this quarter, CP/CMS was run with four core boxes providing a total of one million bytes of main storage. With this increased amount of memory, there have been peaks of 45 simultaneous users. More measurements must now be made to determine the effect on performance of: (a) the new paging algorithm, (b) dynamic page space allocation, (c) shared systems, and (d) increased main storage.

The CMS file system has been modified to support a full 2314 disk (203 cylinders, 24 million bytes) as private or shared storage. This capability may be used for large data base applications. In addition, a CMS facility for writing on a second disk has been provided. It is intended that users would have access to a temporary disk (T-disk) in addition to a private disk (P-disk). The T-disk would thus serve as a second read/write area for CMS files. A previous facility for dynamically linking the P-disk of one user as a read-only disk of another user and the use of this disk to provide access to shared files has been simplified. By issuing the SHARE command, a user may now link to all the files of another user or to a subset.

The Fortran debugging system (FDS) described in the last quarterly report is now operational and is being used to help debug Fortran programs.

OPTICS DIVISION 5

INTRODUCTION

This section summarizes the General Research efforts of Division 5 for the period 1 February through 30 April 1970. A complete presentation of the Optics effort may be found in the quarterly Optics Research Report and in the Semiannual Technical Summary and Quarterly Letter Reports to the Advanced Research Projects Agency.

R. H. Kingston
Head, Division 5

R. H. Rediker
Associate Head

DIVISION 5 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1970

UNPUBLISHED REPORTS

Journal Article*

JA No.			
3634	High-Resolution Infrared Spectroscopy with a Tunable Diode Laser	E. D. Hinkley	Accepted by Appl. Phys. Letters for May 1970
MS-2719	Laser Technology	R. H. Kingston	Proceedings: Technology Forecast for 1980 (31 October 1969)

Meeting Speech†

MS No.			
2867	Design of Stable CO ₂ Lasers and Their Applications	C. Freed	NBS Colloquium, Boulder, Colorado U.S. Department of Commerce 6 April 1970

* Reprints available.

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

OPTICAL MEASUREMENTS GROUP 52

We have measured the resonances arising from the standing-wave saturation effect (an effect responsible for the Lamb dip) in individual P- and R-branch transitions of the 10.6- μ band in a room temperature sample of pure CO₂ gas at pressures as low as 0.005 torr (corresponding to an absorption coefficient of about 1.5×10^{-6} /cm), and a total absorption path of 3 cm. In the preliminary experiments half-widths as low as 200 kHz have been observed, with the limiting low pressure widths due to power broadening. By utilizing these standing-wave resonances we have locked CO₂ lasers to the center of any oscillating P- or R-transition.

We have obtained data at pressures from 0.05 to 0.8 torr, for laser output powers of 10^{-3} to 1.0 W at a number of transitions. These data were then analyzed to obtain the dependence of linewidth on pressure and power.

We determined the pressure broadening as 3.75 MHz/torr for the half-width. The pressure shift was also measured.

Frequency response measurements of Pb_{0.80}Sn_{0.20}Te photovoltaic detectors at 77 k have been extended by heterodyne experiments involving a stable CO₂ laser and a tunable Pb_{0.88}Sn_{0.12}Te diode laser. The detectors show reduced response for frequencies above 60 MHz; however, beat frequencies of over 500 MHz were detectable.

High-resolution spectroscopic data were obtained near the Q-branch of ethylene (C₂H₄) near 10.6 μ m, using tunable Pb_{0.88}Sn_{0.12}Te diode lasers. As expected, the absorption spectrum is more complex than that of ammonia, but simpler than that of sulfur hexafluoride, previously obtained by this technique. Measurements of the Doppler linewidth agree with the theoretical prediction.

ENGINEERING DIVISION 7

INTRODUCTION

The Engineering Division is involved in all Laboratory programs which produce hardware. Its support of the General Research program appears in the design and fabrication of devices used in Solid State research, in the modification and upgrading of facilities at Haystack Hill, and in the development of mechanical and optical components for teaching machines. In this report, two important improvements in the Haystack radio telescope are discussed.

J. F. Hutzenlaub
Head, Division 7

ENGINEERING DIVISION 7

I. HAYSTACK

A. Helium Refrigerator

A helium refrigerator is being fabricated for a maser dewar system. The maser is to be cooled by liquid helium (4.2°K), and the refrigerator is to supply sufficient refrigeration to offset all radiation and conduction losses. This will enable indefinite operation of the maser with a single fill of liquid helium. Should the refrigerator fail, it will have the redundancy of operating on batch filling.

The expansion engines have been assembled, and during the next quarter their mounts will be used to locate and align the engine mountings and gas connections inside the heat exchanger mandrel. Although the finned tubes for the heat exchangers have been completed, the heat exchanger headers are only about 80 percent completed.

The next steps will be the completion of the headers and the welding of the engine mounts and gas connections. The completed parts of the heat exchanger mandrel will be welded together, after which the finned tube can be wound on the mandrel. The outer shell of the heat exchanger will then be fitted and welded in place.

B. New Hydraulic Drive

Installation of a new and much improved hydraulic drive for the Haystack elevation axis was completed during this quarter. Satisfactory performance similar to that of the azimuth axis* was obtained. Increasing the linear range of the analog error signal in both axes produced improved performance when shifting from one target to another. A report giving a detailed description of the new servomechanisms and their performance is being prepared.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1970), DDC AD-704573.

SOLID STATE DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 February through 30 April 1970. 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 GENERAL RESEARCH

15 February through 15 May 1970

PUBLISHED REPORTS

<u>Journal Articles*</u>			
JA No.			
3281	Crystallographic and Magnetic Properties of Perovskite and Perovskite-Related Compounds	J. B. Goodenough J. M. Longo	<u>Landolt-Bornstein Tables</u> , Group III, 4, Part A (Springer, Berlin, 1970), p. 126
3412A	Experimental Comparison of Hartree-Fock and Slater Exchange Potentials in Aluminum from the Charge Density Point of View	P. M. Raceah V. E. Henrich	Intl. J. Quant. Chem. <u>IIIS</u> , 797 (1970)
3498	Polarons Bound in a Coulomb Potential. I. Ground State	D. M. Larsen	Phys. Rev. <u>187</u> , 1147 (1969)
3501	Evidence for a Native Donor in ZnSe from High Temperature Electrical Measurements	F. T. J. Smith	Solid State Commun. <u>7</u> , 1757 (1969)
3517	Resonant Raman Scattering from LO Phonons in Polar Semiconductors	D. C. Hamilton	Phys. Rev. <u>188</u> , 1221 (1969)
3521	Ionized Impurity Density in n-type GaAs	C. M. Wolfe G. E. Stillman J. O. Dimmock	J. Appl. Phys. <u>41</u> , 504 (1970)
3524	Inelastic Light Scattering from Semiconductor Plasmas in a Magnetic Field	F. A. Blum	Phys. Rev. B, <u>1</u> , 1125 (1970)
3528	Linear Wave-Vector Shifts in the Raman Spectrum of α -Quartz and Infrared Optical Activity	A. S. Pine G. Dresselhaus	Phys. Rev. <u>188</u> , 1489 (1969)
3577	Reinterpretation of $^4A_2 \rightarrow ^2E$ Exciton Spectra in $YCrO_3$	J. W. Allen	Solid State Commun. <u>8</u> , 53 (1970)
3580	Electrically Active Point Defects in Cadmium Telluride	F. T. J. Smith	Met. Trans. <u>1</u> , 617 (1970)
3591	Comparison of Theoretical and Experimental Charge Densities for C, Si, Ge, and ZnSe	P. M. Raceah R. N. Euwema† D. J. Stukel† T. C. Collins†	Phys. Rev. B, <u>1</u> , 756 (1970)

* Reprints available.

† Author not at Lincoln Laboratory.

Division 8

JA No.

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|------|--|--|--|
| 3606 | High Temperature Electrical Properties of CdSe: Evidence for a Native Donor | F.T.J. Smith | Solid State Commun. <u>8</u> , 263 (1970) |
| 3625 | Report on the Symposium on Magnetic Semiconductors held in Yorktown Heights, New York, November 1969 | J.O. Dimmock | Appl. Optics <u>9</u> , 438 (1970) |
| 3650 | Pressure-Induced Pyrochlore to Perovskite Transformations in the $\text{Sr}_{1-x}\text{Pb}_x\text{RuO}_3$ System | J.A. Kafalas
J.M. Longo | Mat. Res. Bull. <u>5</u> , 193 (1970) |
| 3660 | Pressure Dependence of the Electrical Resistivity of EuO | M.R. Oliver
J.A. Kafalas
J.O. Dimmock
T.B. Reed | Phys. Rev. Letters <u>24</u> , 1064 (1970) |

MS No.

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|-------|--|---|--|
| 2387A | Some Applications of the Thermal Single Determinant Approximation | T.A. Kaplan
P.N. Argyles | Intl. J. Quant. Chem. <u>IIIS</u> , 851 (1970) |
| 2466 | The Role of Oxygen Pressure in the Control and Measurement of Composition in 3d Metal Oxides | T.B. Reed | <u>The Chemistry of Extended Defects in Non-Metallic Solids</u> (North-Holland, Amsterdam, 1970) |
| 2506 | Structural, Electrical and Magnetic Properties of Vacancy Stabilized Cubic 'TiO' and 'VO' | M.D. Banus
T.B. Reed | |
| 2515 | Evidence for a Continuous Sequence of Structures in the Bi-Te System | R.F. Brebrick | |
| 2662 | Two-Magnon Raman Scattering in KNiF_3 | S.R. Chinn
H.J. Zeiger
J.R. O'Connor | J. Appl. Phys. <u>41</u> , 894 (1970) |
| 2663 | Multiplet Structure in the Reflectance Spectra of Europium Chalcogenides | J.O. Dimmock
J. Hanus*
J. Feinleib | J. Appl. Phys. <u>41</u> , 1088 (1970) |
| 2666 | Magnetic and Optical Properties of the High- and Low-Pressure Forms of CsCoF_3 | J.M. Longo
J.A. Kafalas
J.R. O'Connor
J.B. Goodenough | J. Appl. Phys. <u>41</u> , 935 (1970) |
| 2668 | Magnetic Ordering Effects in the Reflectance of EuO, EuS, EuSe and EuTe | W.J. Scouler
J. Feinleib
J.O. Dimmock
T.B. Reed
C.R. Pidgeon* | J. Appl. Phys. <u>41</u> , 1085 (1970) |

* Author not at Lincoln Laboratory.

MS No.

2670	Theory of Localized vs. Band Magnetic Semiconductors	T. A. Kaplan R. A. Bari	J. Appl. Phys. <u>41</u> , 875 (1970)
2677	Onset of Magnetism in Vanadium Oxides: ^{51}V NMR Studies of VO	W.W. Warren, Jr.* A.C. Gossard* M.D. Banus	J. Appl. Phys. <u>41</u> , 881 (1970)
2679	Specific Heat of EuO	A.J. Henderson* G.R. Brown* T.B. Reed H. Meyer*	J. Appl. Phys. <u>41</u> , 946 (1970)
2847	Lectures on Magnetism	N. Menyuk	Proceedings Winter School in Solid State Chemistry, Indian Institute of Technology, Kanpur, India, 26 November – 12 December 1969

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UNPUBLISHED REPORTS

Journal Articles

JA No.

3603A	Simple Model Potential Approach to the X-Ray Form Factor in Aluminum	P. Ascarelli* P.M. Raccah	Accepted by Phys. Letters
3618	Phase Diagram of the Zinc-Cadmium-Tellurium Ternary System	J. Steininger A.J. Strauss R.F. Brebrick	Accepted by J. Electrochem. Soc.
3626	Simple, Versatile Techniques for Qualitative and Quantitative Evaluation of Spark Source Mass Spectrographic Plates	E.B. Owens	Accepted by Rev. Sci. Instr.
3633	Electron Mobility in High-Purity GaAs	C.M. Wolfe G.E. Stillman W.T. Lindley	Accepted by J. Appl. Phys.
3645	Report on the Symposium on Magnetic Semiconductors, IBM Research Center, Yorktown Heights, New York	J.B. Goodenough	Accepted by Phys. Today
3646	Quantitative Analysis of Ternary and Quaternary Semiconducting Alloys with the Electron Microprobe	M.C. Finn	Accepted by Anal. Chem.

* Author not at Lincoln Laboratory.

Division 8

JA No.

3648	N-P Junction Photodetectors in InSb Fabricated by Proton Bombardment	A.G. Foyt W.T. Lindley J.P. Donnelly	Accepted by Appl. Phys. Letters
3651A	Anomalous Absorption of Micro-waves by Interstellar H ₂ CO	M.M. Litvak	Accepted by Astrophys. J. (Letters)
3657	X-Ray Diffraction at High Pressures	M.D. Banus	Accepted by High Temperatures - High Pressures
3663	Crystal Structure of Hexagonal RbNiF ₃ (6H)	R.J. Arnott* J.M. Longo	Accepted by J. Solid State Chem.
3672	Laser Emission from Metal-Semiconductor Contacts on PbTe and Pb _{0.8} Sn _{0.2} Te	K.W. Nill J.N. Walpole* A.R. Calawa T.C. Harman	Accepted by Appl. Phys. Letters
3681	Ultrasonic Attenuation Near the Spin-Alignment Transition of EuTe	Y. Shapira* T.B. Reed	Accepted by Phys. Letters
3684	Growth of EuO, EuS, EuSe and EuTe Single Crystals	T.B. Reed R.E. Fahey	Accepted by J. Cryst. Growth
3686	Polarized Maser Emission from Interstellar OH and H ₂ O	M.M. Litvak	Accepted by Phys. Rev.
3691	Phase Transitions in Perovskite-Like Compounds of the Rare Earths	S. Geller* P.M. Raccach	Accepted by Phys. Rev.
3701	Analysis of Frozen Aqueous Solutions by Spark Source Mass Spectroscopy	E.B. Owens	Accepted by Anal. Letters

MS No.

2754	Narrow Gap Semiconductor Lasers	T. C. Harman	Accepted by J. Phys. Chem. Solids
2770	k·p Theory for the Conduction and Valence Bands of Pb _{1-x} Sn _x Te and Pb _{1-x} Sn _x Se	J. O. Dimmock	Accepted by J. Phys. Chem. Solids
2780	Raman Scattering from Hg _x Cd _{1-x} Te	A. Mooradian T. C. Harman	Accepted by J. Phys. Chem. Solids

Meeting Speeches

MS No.

2420G	Recent Advances in Laser Spectroscopy	A. Mooradian	Physics Department Seminar, M.I.T., 8 April 1970
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* Author not at Lincoln Laboratory.

MS No.

2496B-C	Pitfalls, Detours and Shortcuts on the Road to Single Crystal Growth	T. B. Reed	Regional Meeting of Electrochemical Society, Inc., New York, New York, 11 March 1970 Materials Seminar, Northwestern University, Evanston, Illinois, 7 April 1970
2598A	Theory and Practice of Vapor Phase Crystal Growth	T. B. Reed	Materials Seminar, Case Western Reserve University, Cleveland, Ohio, 3 April 1970
2667A	A Gridded Thick Film Metalization Structure Employed in Multichip Circuit Fabrication	H. H. Pichler	NEPCON '70 West, 10-12 February 1970
2670A	Localized vs. Band Magnetic Semiconductors	T. A. Kaplan	Solid State Physics Seminar, General Electric Research and Development Center, Schenectady, New York, 12 March 1970
2702	Rigid and Nonrigid Beam Lead Substrates	R. E. McMahon F. J. Bachner R. A. Cohen	1970 IEEE International Solid State Circuits Conference, Digest of Technical Papers, 18-20 February 1970
2720A	Spectroscopy of Shallow Donor Levels in GaAs Extrinsic Photodetectors	G. E. Stillman	Department of Physics Seminar, University of Illinois, 5 May 1970
2754	Narrow Gap Semiconductor Lasers	T. C. Harman	Conference on Physics of Semimetals and Narrow Gap Semiconductors, Dallas, Texas, 20-21 March 1970
2757	Metal-Semiconductor Contacts on $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$	K. W. Nill J. N. Walpole* A. R. Calawa T. C. Harman	
2760	High-Resolution Magnetospectroscopy of Graphite	P. R. Schroeder* M. S. Dresselhaus A. Javan	
2763	Recent Experiments on Zero-Gap Semiconductors	S. H. Groves	
2765	Electronic Properties of the Group V Semimetals	M. S. Dresselhaus	
2770	k · p Theory for the Conduction and Valence Bands of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ and $\text{Pb}_{1-x}\text{Sn}_x\text{Se}$ Alloys	J. O. Dimmock	
2780	Raman Scattering from $\text{Hg}_x\text{Cd}_{1-x}\text{Te}$	A. Mooradian T. C. Harman	
2754A	Narrow Gap Semiconductors	T. C. Harman	Materials Science Seminar, Purdue University, 12 May 1970

* Author not at Lincoln Laboratory.

Division 8

MS No.

2740A	Magnetospectroscopy of Shallow Donors in CdTe	D. R. Cohn* B. Lax* D.M. Larsen
2756	Shubnikov-deHaas Measurements in $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ Under Hydrostatic Pressure	J. Melngailis J. A. Kafalas T.C. Harman
2776	Green's Function Theory of Strong Coupling Phonon Sideband Absorption	J. W. Allen
2777	Fermi Surface and Optical Properties of Potassium	G. Dresselhaus A.R. Wilson C. Y. Young
2784	Absolute X-ray Form Factor of Nickel	V.E. Henrich P.M. Racciah
2785	Light Scattering from Drifted Carriers in n-GaAs	A. Mooradian A.G. Foyt
2789	Electrical Conductivity in the Hubbard Model	D. Adler* R.A. Bari R. V. Lange*
2790	Energy Gap Minimum in $\text{ZnTe}_{1-x}\text{Se}_x$ Alloys	G. W. Iseler
2791	Energy Gap Minimum in $\text{CdTe}_{1-x}\text{Se}_x$ Alloys	A. J. Strauss
2792	Quasi Particle Approach to the Optical Properties of Simple Metals	C. Y. Young
2795	Electron Spin Waves in Nonmagnetic Semiconductors	F. A. Blum
2796	The $2s(T_2)$ Level of Bi Donors in Si Observed by Optical Absorption	W.E. Krag W. H. Kleiner
2798	Raman Spectrum of Ti_2O_3	P.M. Racciah A. Mooradian
2801	The Infrared Properties of Arsenic	R. W. Brodersen M. S. Dresselhaus
2802	Theory of Surface Plasmon Excitation in Electron Tunneling, Low Energy Diffraction and in Photoemission	K. L. Ngai E. N. Economou* M. H. Cohen*

American Physical Society,
Dallas, Texas, 23-26 March 1970

* Author not at Lincoln Laboratory.

MS No.			
2803	Optical, Magnetic, and Ultra-sonic Studies of Antiferromagnetic EuTe with Magnetic Fields up to 260 kG	C.R. Pidgeon* S. Foner* Y. Shapira* J. Feinleib T.B. Reed	American Physical Society, Dallas, Texas, 23-26 March 1970
2804	Band Theory of Optical Activity	A.S. Pine G. Dresselhaus	
2822	Exciton-Magnon Transitions in Cr_2O_3	R.M. Macfarlane* J.W. Allen S. Sugano*	
2850	Comparison of Experimental Charge Densities with Band Calculation Predictions	P.M. Raccach	
2762	Anomalous Properties of the Vanadium Oxides	J.B. Goodenough	Purdue University, Lafayette, Indiana, 7 April 1970
2764	Composition Stability Limits of $(\text{Pb}_{1-y}\text{Sn}_y)_{1-x}\text{Te}_x$ from Lattice Parameters	R. F. Brebrick	Electrochemical Society, Los Angeles, California, 15 May 1970
2775	Spin Waves in Plasma-Like Metals	A. R. Wilson	Physics Seminar, University of Alberta, Alberta, Canada, 6 February 1970
2782	Detection and Generation of Far Infrared Radiation in High Purity Epitaxial GaAs	G. E. Stillman C.M. Wolfe J. O. Dimmock	International Symposium on Sub-millimeter Waves, Polytechnic Institute of Brooklyn, New York, 31 March - 2 April 1970
2835	Millimeter and Far Infrared Frequency Mixing in GaAs	H. Fetterman P. E. Tannenwald C. D. Parker	
2802A	Surface Plasmon Excitations and Their Role in LEED	E. N. Economou* K. L. Ngai	Fourth LEED Theory Seminar, National Bureau of Standards, Gaithersburg, Maryland, 1 May 1970
2839	Optical Properties and Electronic Structure of the Magnetic Semiconductors, EuO, EuS, EuSe and EuTe	W. J. Scouler	Seminar, University of Virginia, Charlottesville, Virginia, 20 February 1970
2866	The Thermal Single-Determinant Approximation - A New Generalization of Hartree-Fock Theory	T. A. Kaplan	Physics Seminar, Michigan State University, East Lansing, Michigan, 2 April 1970
2894	Behavior and Misbehavior of d Electrons in Some Vanadium Oxides	J. B. Goodenough	Materials Science Center Seminar, The Pennsylvania State University, University Park, Pennsylvania, 15 May 1970

* Author not at Lincoln Laboratory.

SOLID STATE DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Three high purity epitaxial GaAs samples have been evaluated as far infrared detectors under different background conditions. Spectral response measurements at 4.2° and 1.93°K indicate that the long wavelength response from 200 to 350 μ is due primarily to a combined photo-thermal excitation process. The conductivity and thus the performance characteristics of the detectors consequently depend critically on both the detector temperature and background radiation. The best long wavelength response was observed at 4.2°K in reduced background.

Long wavelength laser emission at 28 μ has been observed from Schottky barrier diodes fabricated by evaporating Pb contacts on Bridgman-grown $\text{Pb}_{0.715}\text{Sn}_{0.285}\text{Te}$. The material used was $4.5 \times 10^{17} \text{ cm}^{-3}$ p-type and was obtained as part of a study of the preparation and characterization of metal saturated $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ as a function of isothermal annealing temperatures.

N-p junction photovoltaic detectors have been fabricated in p-type $\text{Hg}_{0.5}\text{Cd}_{0.5}\text{Te}$, using proton bombardment to create the n-type region. The photovoltaic response of these diode peaks at 1.8 μ with a quantum efficiency of 15 percent. The 300°K detectivity at the peak is $2 \times 10^{10} \text{ cmHz}^{1/2}/\text{W}$.

A vidicon type television camera tube has been constructed employing an array of reverse-biased GaAs Schottky barrier photodiodes to form the image sensing target. This target has many advantages over a conventional photoconductive vidicon target, and its simplicity of fabrication and stability make it an attractive alternative to the silicon p-n photodiode array target.

A new technique has been developed for the fabrication of semiconductor devices utilizing a thin semiconductor layer. The advantage of this is that different parts of the devices can be fabricated on both sides of the layer in close proximity to each other, adding an additional dimension to the fabrication technology. The technique has been used to fabricate GaAs Schottky barrier field effect transistors in which the source and drain ohmic contacts separated by 5 μ are on one side of a 0.5- μ -thick layer of GaAs and the 5- μ -long Schottky barrier gate is on the opposite side positioned over the source-drain gap. This structure and others utilizing this technique should result in improved high frequency performance of many semiconductor devices.

Acousto-electric amplification coefficients have been measured at room temperature over the frequency range from 1.23 to 3.75 GHz in $5 \times 10^{14} \text{ cm}^{-3}$ n-type GaAs using Brillouin scattering. Good agreement with theory is observed for the absolute value of the gain coefficient over this range and for the frequency of maximum gain.

II. MATERIALS RESEARCH

A new seed rod, cooled by means of a heat pipe, has been used for pulling crystals in the tri-arc Czochralski furnace. Use of the heat pipe, a device in which extremely efficient heat transfer is accomplished by the evaporation and condensation of a volatile liquid, eliminates the disadvantages encountered with a water-cooled seed rod.

Single crystals of CdO with dimensions up to about $8 \times 8 \times 3$ mm have been grown from the vapor phase at about 1050°C by an open tube method in which a stream of helium saturated with cadmium vapor is mixed with an oxygen stream inside a cylindrical liner made of high purity Al_2O_3 .

Charts of the standard free energy of formation (ΔG_f°) as a function of temperature have been constructed for binary selenides and tellurides on the basis of published thermodynamic data. No charts of this type have previously been available for these compounds.

The effects of deviations from stoichiometry on the lattice parameter and electrical resistivity of EuO have been confirmed by measurements on europium-saturated and oxygen-saturated single crystals. A marked increase in the optical transmission of EuS and EuSe single crystals grown from europium-rich solutions has been achieved by annealing the crystals in sealed tungsten crucibles.

Optical transmission measurements on $\text{ZnTe}_{1-x}\text{Se}_x$ single crystals have confirmed the existence of an energy gap minimum in this alloy system. Similar measurements demonstrate a strongly nonlinear dependence of energy gap on composition in the $\text{ZnTe}_{1-x}\text{S}_x$ alloys, although no minimum can be observed because the mutual solubility of ZnTe and ZnS is too low.

Optical transmission measurements on $\text{CdTe}_{1-x}\text{Se}_x$ single crystals have established the existence of an energy gap minimum in this alloy system. The data indicate that the energy gap for a given composition is about 0.03 eV higher for samples with the hexagonal wurtzite structure than for those with the cubic zincblende structure.

An energy level scheme which takes account of the role of cation vacancies has been proposed for NiO. This scheme accounts for the optical and electrical properties of both undoped and Li-doped NiO.

The polaron morphology in vanadium spinels has been investigated by analyzing the observed variation in Seebeck coefficient with composition in the systems $\text{Mg}[\text{B}_x^{2+}\text{V}_{2-x}]\text{O}_4$ where B = Mg or Ni. The results indicate that with decreasing V-V separation (R), the polarons change from V^{4+} cations to V_2 -cluster and V_4 -cluster polarons, and finally to itinerant electrons, in a narrow range $2.99 > R > 2.94 \text{ \AA}$.

Integrated intensity data obtained in x-ray diffraction measurements on powdered samples have been used to carry out a structure refinement for the hexagonal (6H) form of RbNiF_3 . The results are generally in agreement with published values, but there are significant discrepancies in the positions of the fluorine atoms.

The effect of high pressure on the crystal structure of CsMnCl_3 , RbMnCl_3 , and RbFeCl_3 has been determined by means of x-ray diffraction measurements. For each compound, the proportion of hexagonal close packing decreases with increasing pressure, and the ultimate high pressure form has the perovskite structure, which is entirely cubic close-packed.

The volume compression of TiO_x for samples with x between 0.83 and 1.25 has been investigated by means of x-ray diffraction studies made with diamond-anvil high pressure units. For pressures up to 140 kbars, the measured values of $-V/V_0 \Delta P$ are between 2.3×10^{-4} and $4.0 \times 10^{-4} \text{ kbar}^{-1}$.

III. PHYSICS OF SOLIDS

The quasi-particle approach to the optical properties of simple metals has now been applied to the calculation of the optical properties of potassium. Using nonlocal pseudo-potentials and the experimental Fermi surface, both the photon energy threshold for interband absorption and the magnitude of the absorption have been calculated.

Work on Ti_2O_3 continues. In an attempt to describe the nature of the insulator-metal transition a model, based on the competition between elastic and electronic free energies of the system as a function of temperature, is being investigated. Although this model is capable of giving a reasonable description of the change in c/a ratio with temperature, it predicts a very pronounced "mode softening" in the vicinity of the transition which is inconsistent with our Raman scattering data.

A mechanism for the description of a metal to semiconductor transition with increasing temperature has been found. The result is based on a comparison of the free energy for localized (Wannier) versus band (Bloch) states for a half-filled band Hubbard Hamiltonian.

The phonon pinning spectrum of an electron bound to an impurity in a semiconductor, as affected by the presence of the impurity, is under study. A preliminary calculation indicates pinning due to interaction with local or resonant modes, as well as pinning due to lattice modes.

A band theory of optical activity, which arises from terms in the dielectric constant linear in q , has been developed. The general results, when reduced to a simple four-band model, give a value for the ratio of rotary power parallel and perpendicular to the c -axis which is close to our previously measured ratio in α -quartz.

Work on the magnetic semiconductor EuO has now been extended to studies of magnetic properties in the vicinity of the Curie temperature. Measurements have been analyzed to determine the magnetic critical indices.

In other magnetic work the study of two-magnon Raman scattering in KNiF_3 has been extended to samples doped with Mn^{2+} impurities. In addition to the intrinsic two-magnon excitation previously observed in pure samples, a new, relatively narrow line has been observed, with an intensity that is dependent on the Mn^{2+} concentration. The line is tentatively identified as a resonant two-magnon state associated with an Mn^{2+} impurity. The Raman spectrum of the antiferromagnet CsMnF_3 has been observed using the 4880-Å radiation from an argon laser. In addition to the active phonon modes, a mode has been observed whose shape, position, temperature dependence and polarization indicate that it arises from the excitation of two magnons.

Theoretical work on light scattering from acoustic plasma waves and single electron excitations in magnetoplasmas continues. A model calculation, involving only scattering due to density fluctuations and ignoring spin-orbit coupling, has been carried out to illustrate some of the general features of magnetoplasma quasi-elastic scattering.

In another phase of the laser program, heterodyne experiments with both millimeter and infrared sources have been performed in high purity, epitaxial GaAs. The millimeter waves produce avalanche breakdown, and mixing via hot electrons is observed. At laser frequencies the DC bias level determines whether detection proceeds via a similar hot electron mechanism or through photothermal ionization of shallow donor states. The time constant associated with the latter process is significantly faster than that of hot carrier relaxation.

Two nonlinear effects on the polarization and linewidth of an intense broadband maser signal have been calculated with application to the interstellar masers. One is the competition between

opposite circularly polarized Zeeman modes by means of parametric down-conversion involving an electron cyclotron idler wave. The second is the saturation broadening in a two-level system due to a broadband signal having Gaussian statistics.

IV. MICROELECTRONICS

The Microelectronics Group, which is now part of the Solid State Division, has a dual charter of service and research in integrated electronics. Service tasks have provided an opportunity to apply new processes and techniques that have been developed as part of the research program on integrated circuits. Typically at any one time there are about 20 active programs ranging from special semiconductor devices to large hybrid integrated assemblies. In addition, about five or six research programs are in progress as long range support for Lincoln Laboratory programs.

The present programs in research and development include the following:

- (1) Rigid and nonrigid forms of beam lead substrates have been fabricated with gold and more recently with aluminum metallization for the beams and air gap crossovers. Some work remains to be done to improve yield and cost reduction of the fabrication and assembly of the substrates, but the basic techniques are developed for several forms of substrates, including an automated version.
- (2) Aluminum beam lead silicon chips have been developed as a complementary assembly method to the beam lead substrates. Air gap crossovers using aluminum metallization on the silicon chips also look promising as a means of providing an additional and high yield interconnection method at the chip level.
- (3) A silicon dioxide passivation method for mesa semiconductor devices has been developed which has several advantages over present passivation methods. Actual devices have been fabricated using this technique with excellent results.
- (4) A development effort on Impatt and Trapatt microwave devices with special geometries has been pursued during the past year. New packaging and die attachment techniques are being investigated to reduce the thermal coefficient and improve the efficiency.
- (5) A laser scanner for mask inspection and semiconductor chip evaluation has been built and tested. Improvements in the scanning mechanism are under way which will allow faster scanning. Metallization faults, mask misalignment, diffusion faults and oxide problems and device gain characteristics can be examined with the scanner.

Other programs that are more applications oriented and include some research or development are listed below.

- (1) A strip or an array of 64 silicon photodiodes spaced 6 mils on centers has been developed for a satellite stabilization system. Two approaches have been taken: one method employs 4 strips of 64 diodes assembled very accurately in a single package, and a second method employs a redundancy and discretionary wiring to allow the fabrication of the four diode arrays on a single silicon wafer.
- (2) Special diodes with very shallow junctions (0.5μ) have been fabricated for use in high power applications with an electron beam as the input control. These devices hopefully will compete favorably with magnetrons and traveling-wave tubes in power and frequency. Present results indicate an oxide charging problem and lower power capabilities than anticipated.
- (3) A multi-element particle detector using a silicon array is under development in cooperation with Dr. Kosta M. Tsipis (Laboratory for Nuclear Science, M.I.T.).

Other programs of a service nature that require moderate development are:

- (1) Surface wave transducer program
 - (a) Fine line masks
 - (b) Semiconductor amplifier substrates
- (2) Microwave thin film assemblies
- (3) Mixer diodes employing 5- μ Schottky barrier devices.

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This Quarterly Technical Summary covers the period from 1 February through 30 April 1970. It consolidates the reports of Division 2 (Data Systems), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems
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