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Quarterly Technical Summary

Advanced Electronic  
Technology

15 February 1975

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**Lincoln Laboratory**

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS



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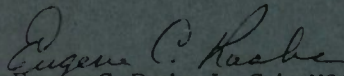
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ADVANCED ELECTRONIC TECHNOLOGY

QUARTERLY TECHNICAL SUMMARY REPORT  
TO THE  
AIR FORCE SYSTEMS COMMAND

1 NOVEMBER 1974 - 31 JANUARY 1975

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## INTRODUCTION

This Quarterly Technical Summary covers the period 1 November 1974 through 31 January 1975. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.

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DATA SYSTEMS  
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 November 1974 through 31 January 1975 on Data Systems. Work in the following programs in Division 2 is described elsewhere.

Seismic Discrimination	ARPA
Educational Technology	AF, NSF Bureau of Mines
Speech Evaluation	OSD - DCA
Digital Voice Terminal	ESD
Packet Speech	ARPA
Airborne Command and Control	ARPA
Incoherent Scatter	NSF
Radar Propagation Studies	BMDATC
Radar Signal Processing Technology	BMDATC

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## DIGITAL COMPUTERS GROUP 23

### I. INTRODUCTION

Dramatic yield improvements were achieved this quarter in fabrication of 3-bit quantizers for wideband analog-to-digital conversion. Experiments indicate that this device may be usable to 200 MS/s. Layout of an ECL universal array which has the equivalent of 192 three-input gates has been completed and mask production started. Exploratory logic design has verified the advantages of the ECL two-level design.

### II. APPLICATIONS

#### A. Quantizers

The most recent five quantizer runs had a 30-percent yield at wafer probe. The 350 devices will be packaged and tested for high-frequency performance.

An experimental 6-bit A/D converter has been built for evaluation of quantizers. From input to output the converter is comprised of: (1) a conventional diode-bridge track-and-hold circuit, (2) a Tektronix P6201 active probe which drives the 50-ohm signal input line of, (3) eight 3-bit quantizers, (4) MECL III translation and latch circuitry, and (5) a low-speed digital-to-analog circuit. At a low repetition rate the track-and-hold circuit is pulsed twice with a pulse spacing appropriate to the simulated quantizing rate (e. g., 6.7 nsec for 150 MS/s) and the quantizers are latched on either the first or second sample of the pair, again with the appropriate pulse spacings. The sweep circuitry of a sampling oscilloscope is used to sweep the set of timing pulses across a sine-wave input. The reconstituted signal from the D/A is visually compared with the input signal on a sampling oscilloscope.

With quantizers from the above cited runs, a 75-MHz sine wave has been sampled at 150 MS/s at quantization levels of 15 mV. There is monotonicity between input and output and slight distortion in the reconstituted output. At 100 MHz and 200 MS/s there are a few bad output codes and some distortion. These results with a conventional track-and-hold circuit and a rudimentary system indicate the potential of this quantizer for use in wideband A/D converters.

#### B. ECL Universal Array

The layout of the ECL array has been thoroughly checked and tapes submitted for mask generation. A 15-mil-wide strip containing six test transistors has been added along one side of the 237- × 238-mil chip. A two-inch wafer will hold 32 arrays plus some test device chips. The first two customized devices will be an evaluation chip and a 4 × 4 reclocked multiplier. Several new cells were designed this quarter and the Digital Voice Terminal partitioned to yield three new custom parts.

### III. INTEGRATED CIRCUIT PROCESSING

#### A. Semiconductor Processing

The 30-percent yield of quantizers at wafer probe was achieved by reducing the number of shorts as described in the previous quarterly technical summary and by rigorous in-process inspection of wafers. Spikes in the epitaxial film were determined to be the cause of much mask

damage and resultant low yields. Wafers with spikes are now rejected by visual inspection and work is proceeding to reduce spike incidence.

A new and improved etchant for AlSiCu films was described in a recent quarterly technical summary.\* Since it does not etch Al, we have attempted to use AlCu films for second-level metal but were unsuccessful because of poor adhesion of AlCu to the Rotox insulating film. A rinse has been developed which completely removes residual deposits after etching of AlSiCu with the new etchant without degradation of resist, metal or oxide. The use of Freon plasma as the last cleaning step immediately prior to top-level metallization has been shown to produce consistently low metal-to-metal contact resistance before sintering. After sintering, the layer-to-layer via resistance is essentially the bulk resistance.

#### B. X-Ray Lithography

Two effects of soft x-ray irradiation on silicon MOS structures have been observed. One is the creation of fixed charge in the oxide near the Si-SiO<sub>2</sub> interface and the other is the creation of voltage-dependent surface states in the silicon near the Si-SiO<sub>2</sub> interface. Both charge distributions can be annealed out with a 10-minute anneal at 455°C. X-ray lithography has been used exclusively in the fabrication of arrays of MOS capacitors and insulated-gate field effect transistors. These devices, after annealing, exhibit electrical behavior identical to that of devices fabricated with conventional photolithography.

### IV. ANALYSIS AND TESTING

#### A. Measurement of $r'_b$

The term  $r'_b/r_e \omega_T$  in the equation for delay of an ECL gate<sup>†</sup> is especially significant at larger collector current. Since our measure value,  $r'_{b \text{ meas}}$ , does not adequately predict delay time, an analysis has been made of the test method. A transistor-model equivalent circuit is used that approximates the distributed base resistance and the internal collector-to-base capacitance by three non-equivalent, lumped, RC, L-sections. In the analysis it is assumed that both the external emitter-to-base and collector-to-base capacitances of the model can be tuned out by shorted quarter-wave tuning stubs. The substrate is assumed to be shorted to the collector and a collector-to-emitter capacitance is assumed to be present. The results of the analysis show that the capacitance measured by the  $r'_b$  test equipment is exactly the total internal collector-to-base capacitance independent of all other capacitances associated with the transistor model equivalent circuit, such as substrate capacitance, collector-to-emitter capacitance, etc. The analytical expression for  $r'_{b \text{ meas}}$  gives the same  $r'_b$  vs  $I_C$  characteristics as is measured and is believed to be a correct representation of the measurement. The analysis shows that  $r'_{b \text{ meas}}$  is not the desired sum of base resistances associated with the three lumped RC, L-sections which is required to compute gate delay times. Fortunately, the  $r'_b$  calculated from device dimensions has been shown to give a calculated delay quite close to measured delay.

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\* "The new etchant is Phosphoric acid with small amounts of Ceric Ammonium Nitrate, (NH<sub>4</sub>)Ce(NO<sub>3</sub>)<sub>6</sub>, and Hydrofluoric acid." Advanced Electronic Technology Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 August 1974), p. 3, DDC AD-787882/0.

† Advanced Electronic Technology Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1973), p. 4, DDC AD-774451/9.

## B. Wafer and Device Testing

A plotting software package is now operational in the TIC system which permits foreground or background plotting on the Versatec printer-plotter.

The transistor testing programs are being converted from the TX-2 system to the TIC system.

Hardware has been built and programs written for functional testing of customized ECL universal arrays. Due to the standardization of input-output geometry and characteristics, it should be quite easy to test new array designs.

COMPUTER SYSTEMS  
GROUP 28

With the close of the quarter, the IBM 370/168 completed its first year of service as a replacement for the overburdened 360/67. Although the pattern of operation is the same as it was under the old system, time sharing (VM/370) during the working day and batch processing (VS2-1) at night, users are experiencing a dramatic improvement in access and turnaround time.

This expected benefit has significantly increased the productivity of both programmers and end users. It has also established new standards of performance that begin to tax the facilities of the system. This is reflected by the work of the quarter, which continues to include the addition of user features but increasingly concerns itself with performance considerations.

Graphic output from data provided by the recently reimplemented VM performance measurement routines shows a definite increase in the percent of total central processing unit (CPU) time and the portion of that time devoted to the user or problem state. The percentage of CPU time used for supervisor or overhead activities declined slightly to just over thirty percent, while problem-state time frequently exceeded fifty percent. The resulting total time, which often approached ninety percent toward the end of the quarter, indicates not only greater use of the system, but the need for more work in the area of system configuration design and performance improvement.

One part of the VM system which has received such performance improvement attention is that of access to user information stored on disks. This kind of information, varying considerably in total size, is stored in blocks of 800 bytes "chained" together by an index of pointers. However, individual blocks are not necessarily physically contiguous on the disk. For this reason, user data are retrieved one block at a time with each reference incurring the relatively high access overhead of disk storage even in those cases where the blocks are physically sequential. During the quarter, a modification was made to read in two consecutive blocks each time a user called for data. The second block is held in a system buffer until the user makes another request for data. If the next request is for the second block, it is immediately moved to the user's buffer and the overhead of another disk read is saved. If the request is not for the prefetched second block, a normal read of the desired data takes place. Appropriate controls are also provided to invalidate, if necessary, the prefetched block during a write operation. The effectiveness of the scheme needs more evaluation and refinement, but early results indicate a badly needed ten-percent performance improvement in disk channel operations.

A new version (Release 1.7) of the batch processing system (VS2) has been installed. Several Lincoln modifications were added to make it operate more efficiently when it is under the control of the VM time-sharing system during the working day. Also, changes were made to permit selective use of a smaller type font for printed output. The new type uses a more compact page size which is easier to handle and store and nearly twenty-five percent less expensive.

A program is now in progress to review and replace data communications equipment within the Laboratory with more cost effective devices. In some cases, interactive user terminals are being replaced by faster and less expensive units. In other cases, the replacement unit

(such as an alphagraphic terminal) is somewhat more expensive but offers significant performance advantages for the application. Because most of the terminals are located within the Laboratory, direct wire connections to the central computer are gradually replacing expensive telephone switching equipment. For those few users who require the flexibility of switched connections for contact with other systems, a small data phone system will be retained.

SOLID STATE  
DIVISION 8

INTRODUCTION

This section of the report summarizes progress during the period 1 November 1974 through 31 January 1975 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.

A. L. McWhorter  
Head, Division 8

DIVISION 8 REPORTS  
ON ADVANCED ELECTRONIC TECHNOLOGY

15 November 1974 through 15 February 1975

PUBLISHED REPORTS

Journal Articles

<u>JA No.</u>			
4272	Electronic Structure of Transition Metals. III. d-Band Resonance and Regge-Pole Theory	A. O. E. Animalu	Phys. Rev. B <u>10</u> , 4964 (1974)
4310	Comparison of Optical to Injection Excitation in GaAs Heterostructure Lasers	J. A. Rossi S. R. Chinn J. J. Hsieh M. C. Finn	J. Appl. Phys. <u>45</u> , 5383 (1974)
4358	Heterodyne Measurements of $^{12}\text{C}^{16}\text{O}$ Laser Frequencies and Improved Dunham Coefficients	H. Kildal R. S. Eng A. H. M. Ross*	J. Mol. Spectrosc. <u>53</u> , 479 (1974)
4373	Thickness and Surface Morphology of GaAs LPE Layers Grown by Supercooling, Step-Cooling, Equilibrium-Cooling, and Two-Phase Solution Techniques	J. J. Hsieh	J. Cryst. Growth <u>27</u> , 49 (1974)
4376	Flashlight-Size External Cavity Semiconductor Laser with Narrow-Linewidth Tunable Output	H. Heckscher J. A. Rossi	Appl. Opt. <u>14</u> , 94 (1975)
4399	Graphite Landau Levels in the Presence of Trigonal Warping	G. Dresselhaus	Phys. Rev. B <u>10</u> , 3602 (1974), DDC AD-A006314
4400	Horizontal Unseeded Vapor Growth of IV-VI Compounds and Alloys	T. C. Harman J. P. McVittie	J. Electron. Mater. <u>3</u> , 843 (1974), DDC AD-A006315
4404	Doppler-Limited Molecular Spectroscopy by Difference-Frequency Mixing	A. S. Pine	J. Opt. Soc. Am. <u>64</u> , 1683 (1974)
4416	Band Structure of $\text{CdGeAs}_2$ Near $\vec{k} = 0$	H. Kildal	Phys. Rev. B <u>10</u> , 5082 (1974)
4418	Doppler-Limited Spectra of the $\nu_3$ Vibration of $^{12}\text{CH}_4$ and $^{13}\text{CH}_4$	A. S. Pine	J. Mol. Spectrosc. <u>54</u> , 132 (1975)

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\* Author not at Lincoln Laboratory.

JA No.

- |      |  |  |  |
|------|--|--|--|
| 4422 | Submillimeter Heterodyne Detection and Harmonic Mixing Using Schottky Diodes   | H. R. Fetterman<br>B. J. Clifton<br>P. E. Tannenwald<br>C. D. Parker<br>H. Penfield* | IEEE Trans. Microwave Theory Tech. <u>MTT-22</u> , 1013 (1974) |
| 4424 | Electroabsorption Avalanche Photodiodes  | G. E. Stillman<br>C. M. Wolfe<br>J. A. Rossi<br>J. P. Donnelly                       | Appl. Phys. Lett. <u>25</u> , 671 (1974)                       |
| 4427 | Submillimeter-Wave Optically-Pumped Molecular Lasers   | H. R. Fetterman<br>H. R. Schlossberg*  | Microwave J. <u>17</u> , 35 (1974)                             |
| 4429 | Effects of Cesium on Secondary-Electron Emission from MgO/Au Cermets   | V. E. Henrich<br>J. C. C. Fan  | J. Appl. Phys. <u>45</u> , 5484 (1974)                         |
| 4431 | Transparent Heat-Mirror Films of TiO <sub>2</sub> /Ag/TiO <sub>2</sub> for Solar Energy Collection and Radiation Insulation  | J. C. C. Fan<br>F. J. Bachner<br>G. H. Foley<br>P. M. Zavracky                       | Appl. Phys. Lett. <u>25</u> , 693 (1974)                       |
| 4437 | Double Heterostructure Pb <sub>1-x</sub> Sn <sub>x</sub> Te Waveguides at 10.6 μm  | R. W. Ralston<br>J. N. Walpole<br>T. C. Harman<br>I. Melngailis                      | Appl. Phys. Lett. <u>26</u> , 64 (1975)                        |
| 4438 | Crystal Structure and Fluorescence Lifetime of NdAl <sub>3</sub> (BO <sub>3</sub> ) <sub>4</sub> , a Promising Laser Material  | H. Y-P. Hong<br>K. Dwight  | Mater. Res. Bull. <u>9</u> , 1661 (1974)                       |
| 4447 | High Resolution Q-Branch Spectrum of CO <sub>2</sub> at 618 cm <sup>-1</sup>   | J. P. Aldridge*<br>R. F. Holland*<br>H. Flicker*<br>K. W. Nill<br>T. C. Harman       | J. Mol. Spectrosc. <u>54</u> , 328 (1975)                      |
| 4449 | Heterodyne Measurements of <sup>12</sup> C <sup>18</sup> O, <sup>13</sup> C <sup>16</sup> O, and <sup>13</sup> C <sup>18</sup> O Laser Frequencies; Mass Dependence of Dunham Coefficients | A. H. M. Ross*<br>R. S. Eng<br>H. Kildal   | Opt. Commun. <u>12</u> , 433 (1974)                            |

Meeting SpeechesMS No.

- |       |  |   |   |
|-------|--|---|---|
| 3651A | Reliability of Silicon and GaAs K <sub>A</sub> -Band IMPATT Diodes     | P. Staecker<br>W. T. Lindley<br>R. A. Murphy<br>J. P. Donnelly    | In <u>12th Annual Proceedings, Reliability Physics Symposium</u> (IEEE, New York, 1974), p. 293                       |
| 3750  | Performance and Reliability of K <sub>A</sub> -Band GaAs IMPATT Diodes | R. A. Murphy<br>W. T. Lindley<br>D. F. Peterson<br>P. W. Staecker | In <u>1974 IEEE S-MTT International Microwave Symposium Digest of Technical Papers</u> (IEEE, New York, 1974), p. 315 |

\* Author not at Lincoln Laboratory.

MS No.

3778	Oxide Engineering	J. B. Goodenough	J. Solid State Chemistry <u>12</u> , 148 (1975)
3804	Performance of Automobiles Using 5-30% Methanol in Gasoline	T. B. Reed R. M. Lerner E. D. Hinkley R. E. Fahey	1974 Proc. 9th Intersociety Energy Conversion Engineer- ing Conf., San Francisco, 26-30 August 1974
3827	Spin-Flip Raman Scattering	S. R. J. Brueck	<u>Proceedings of the 12th International Conference on the Physics of Semiconduc- tors, 15-19 July 1974, Stuttgart, Germany</u> , M. H. Pilkahn, Ed. (B. G. Teubner, Stuttgart, 1974), p. 780

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## UNPUBLISHED REPORTS

Journal ArticlesJA No.

4432	Auger Spectroscopy Studies of the Oxidation of Amorphous and Crystalline Germanium	V. E. Henrich J. C. C. Fan	Accepted by J. Appl. Phys.
4442	Optically Pumped Vibrational Transition Laser in OCS	H. R. Schlossberg* H. R. Fetterman	Accepted by Appl. Phys. Lett.
4452	Planar InSb Photodiodes Fab- ricated by Be and Mg Ion Implantation	C. E. Hurwitz J. P. Donnelly	Accepted by Solid-State Electron.
4454	Optically Pumped CW InSb Lasers for NO Spectroscopy	A. S. Pine N. Menyuk	Accepted by Appl. Phys: Lett.
4456	Light Scattering Lineshape in Opaque Materials	G. Dresselhaus A. S. Pine	Accepted by Solid State Commun.
4459	Screening in Compensated Semiconductors	D. M. Larsen	Accepted by Phys. Rev.

Meeting Speeches<sup>†</sup>MS No.

3337P	High Resolution Tunable Infrared Lasers	A. Mooradian	Laser-Induced Chemistry Meeting, University of California, San Diego, 18-19 December 1974
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\* Author not at Lincoln Laboratory.

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

MS No.

3337Q	Photochemical Applications of Lasers	A. Mooradian	IAP Seminar, M.I.T., 14 January 1975
3337S	High Resolution Tunable Infrared Lasers	A. Mooradian	EPA Symp. on Long Path Techniques as Applied to Detection of Ambient Air Pollution, National Environmental Research Center, Research Triangle Park, North Carolina, 4-5 February 1975
3884	$Pb_{1-x}Sn_x$ Te Epitaxial Heterostructure Lasers and Waveguides	J. N. Walpole R. W. Ralston A. R. Calawa T. C. Harman J. P. McVittie	Fourth IEEE Int. Semiconductor Laser Conf., Atlanta, 18-20 November 1974
3889	The Gain Profile and Time Delay Effects in External Cavity Controlled GaAs Lasers	J. A. Rossi J. J. Hsieh H. Heckscher	
3917	Applications of Transparent Heat Mirrors and Conductors in Solar-Energy Collection	J. C. C. Fan	Boston Chapter IEEE, Electron Devices Group, RCA, Burlington, Massachusetts, 18 December 1974
3927	III-V Compound Laser Diodes: Past, Present and Future	J. A. Rossi	Meeting of Southeastern Michigan Section IEEE, Ann Arbor, 22 January 1975
3930	Fermi Energy at the Solid-Liquid Interface	D. I. Tchernev	Seminar, Electrical Engineering Dept., Tufts University, 14 November 1974
3943	Integrated Optics	S. R. Chinn	IEEE Electron Devices Group Meeting, Microwave Associates, Burlington, Massachusetts, 22 January 1975
3958	Alkali-Ion Transport in Skeleton Structures	J. B. Goodenough H. Y-P. Hong J. A. Kafalas K. Dwight	First Annual ARPA Meeting on Batteries, Arlington, Virginia, 7 January 1975
3966	New Perspectives on Solar Energy	J. B. Goodenough	Seminar, Magnet Laboratory, M.I.T., 13 January 1975
3984	Solar Energy Cooling with Zeolites	D. I. Tchernev	NSF Workshop on Solar Heating and Cooling, New York City, 21-23 November 1974

SOLID STATE  
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Planar quadrantal arrays of photovoltaic HgCdTe detectors have been fabricated for azimuth and elevation tracking in the ARPA/STO CO<sub>2</sub> laser radar system. ZnS was used as a diffusion mask for an indium-mercury diffusion into p-type material with a 19-percent CdTe alloy composition. These photodiode arrays have shown quantum efficiencies over 50 percent, with a uniformity of better than 4 percent.

Electrically active donor impurity concentrations greater than  $10^{18}$  cm<sup>-3</sup> have been achieved in GaAs by Si-ion implantation. By using a pyrolytic Si<sub>3</sub>N<sub>4</sub> encapsulating technique and a post-implantation annealing temperature of 900°C, a peak electron carrier concentration of  $8 \times 10^{18}$  cm<sup>-3</sup> was measured for a sample implanted with  $1 \times 10^{15}$  Si ions/cm<sup>2</sup>.

The measured sheet electron carrier concentration for Se-ion-implanted GaAs has been increased by a factor of five over previously reported values. The Se-ion-implantation dose was  $1 \times 10^{14}$  cm<sup>-2</sup>; the specimen implantation temperature was 500°C, and the Si<sub>3</sub>N<sub>4</sub> encapsulated samples were annealed at 900°C after implantation.

The average power output from external-cavity-operated large-optical-cavity (LOC) GaAs laser diodes has been increased from about 10 μW to the 1- to 10-mW range. As anticipated from earlier data on external-cavity-operated devices, all the diodes' power was radiated into a line 0.62 Å wide which was tunable over a range of approximately 50 Å.

GaAs varactor diodes are being fabricated for use in K<sub>a</sub>-band parametric amplifiers which are to be employed as the first stage in ground-station receivers for the LES-8/9 satellites. These diodes have zero-bias cutoff frequencies in excess of 600 GHz, which should be adequate to meet the system requirements.

II. QUANTUM ELECTRONICS

The threshold and efficiency of a transversely excited, CW, NdP<sub>5</sub>O<sub>14</sub> laser have been measured with 0.58-μm excitation. For a similar configuration, diode-pumped thresholds are calculated to be 4 to 8.5 mW at 0.80 μm, depending on pump bandwidth.

Indium antimonide has been operated continuously as a recombination radiation laser having a single-ended output power of 10 mW when pumped longitudinally with 160 mW of CO laser radiation. About three-orders-of-magnitude greater efficiency was found for longitudinal pumping compared with transverse pumping. Wedge tuning and magnetic-field dependence of the threshold were studied.

For the nonlinear material CdGeAs<sub>2</sub>, the efficiency of second harmonic generation has been improved by operation at liquid nitrogen temperature, where carrier concentration is reduced. The change in phasematching angle with temperature has been observed and compared with the measured change in birefringence. Type I phasematching for difference-frequency generation has been measured in CdGeAs<sub>2</sub> and AgGaSe<sub>2</sub> at room temperature in the 12- to 17-μm region.

Spontaneous spin-flip linewidths in InSb have been measured at high magnetic fields. The results, which are in good qualitative agreement with theory, complete the linewidth studies over the range of carrier concentrations and magnetic fields that are expected to be used in a high-energy pulsed spin-flip laser.

High-energy, narrow-linewidth spin-flip-laser operation has been observed in the 11- to 12- $\mu\text{m}$  range in InSb. At 11.7  $\mu\text{m}$  the maximum single-ended output was 0.6 mJ, while at 12.1  $\mu\text{m}$  the single-ended output was of the order of 0.3 mJ. The linewidth was measured to be less than  $0.07\text{ cm}^{-1}$  at the 0.5-mJ output level. Temporal characteristics of the output, as well as magnetic-field tuning properties, were studied.

### III. MATERIALS RESEARCH

External quantum efficiencies up to 80 to 85 percent, corresponding to internal quantum efficiencies close to 100 percent, have been achieved for the decomposition of water in optimized photoelectrolytic cells with  $\text{TiO}_2$  anodes. These high efficiencies show photoelectrolysis to be a very promising method for the direct conversion of solar energy to chemical energy in the form of gaseous hydrogen.

The electronic structure of  $\text{TiO}_2$  and  $\text{Ti}_2\text{O}_3$  surfaces is being investigated by electron energy-loss spectroscopy in an attempt to elucidate the catalytic behavior of  $\text{TiO}_2$  anodes in photoelectrolysis. It is proposed that a triplet of energy-loss peaks observed in the spectra of both compounds is due to transitions from the ground state of the  $\text{O}^{2-}$  ion to the lowest d-level of Ti, and a strong peak observed only for  $\text{Ti}_2\text{O}_3$  is attributed to electron transitions between  $3d^1$  states of the  $\text{Ti}^{3+}$  ion.

Films of Sn-doped  $\text{In}_2\text{O}_3$  with potential applications in the collection and conversion of solar energy have been deposited by RF sputtering on substrates heated by electron bombardment. The electrical conductivity, visible transmission, and infrared reflectivity of these films all increase with increasing substrate temperature, reaching values of about  $5 \times 10^3 (\text{ohm-cm})^{-1}$ , 90 percent, and 95 percent (at 10  $\mu\text{m}$ ), respectively, for a substrate temperature of about  $650^\circ\text{C}$ .

A reflectometer has been constructed for making absolute measurements of specular reflectance at true normal incidence. This instrument, which also can be used for transmittance measurements, was developed in order to obtain accurate optical data for use in the design and evaluation of transparent heat mirrors for thermal insulation and solar collection.

Dilatometer measurements on oriented single crystals of  $\text{AgGaSe}_2$ , an efficient nonlinear material used for frequency doubling and mixing in the infrared, have shown that the thermal expansion coefficients parallel and perpendicular to the c-axis are negative and positive, respectively. The negative coefficient explains why single crystals grown from the melt by the Bridgman method are always cracked unless the growth axis is within about  $20^\circ$  of the c-axis.

Single-crystal x-ray diffraction analysis has been used to determine the crystal structure of  $\text{NdLiP}_4\text{O}_{12}$ , a compound in which we have demonstrated low-threshold, efficient, room-temperature CW laser action. As in other high-Nd-concentration laser materials, including  $\text{NdP}_5\text{O}_{14}$ , concentration quenching of  $\text{Nd}^{+3}$  fluorescence is greatly reduced in this structure because neighboring  $\text{Nd}^{+3}$  ions do not share common  $\text{O}^{2-}$  ions.

### IV. MICROELECTRONICS

Several VERS-11 sensors (Visible Earth Radiation Sensors) have been delivered for use in the LES-8/9 satellite project. The final sensor design consisted of four 8-element photodiode arrays mounted on a 2- $\times$ 2-inch alumina substrate using conducting epoxy. The substrate was then mounted into an aluminum plate using a vacuum outgassed epoxy, and connection to the external circuitry was made with connectors mounted in the reverse side of the plates. The finished sensors have performed as expected and have passed the qualification tests required for use on the satellites.

Two significant changes have been made in the fabrication procedure for the silicon charge-coupled device (CCD) imaging arrays to be used in the Telescope Detection and Ranging (TDAR) program. The first change was a final high-temperature anneal of the silicon in  $H_2$ , rather than in  $N_2$ , which resulted in lowering the fast interface state density from  $2 \times 10^{11}$  to  $2 \times 10^{10} \text{ cm}^{-2} \text{ eV}^{-1}$ . The second change involved the deposition of the gate-level polysilicon layers in  $N_2$  rather than  $H_2$ , and at a lower temperature (650 to 750°C) rather than 1000°C. The resulting grain size,  $\sim 1 \mu\text{m}$ , is satisfactory for the present device. Measurements of charge transfer efficiency on a 100-element linear CCD fabricated as above with a n-type buried channel have shown inefficiency values as low as  $2 \times 10^{-4}$  per transfer at 1 MHz.

A silicon Schottky barrier diode array has been made for use with a lithium niobate surface acoustic wave (SAW) device to form a memory and correlator structure. The silicon structure, which is  $100 \times 800 \times 9$  mils thick, has an array of 0.2-mil-diameter PtSi Schottky barrier diodes on 0.5-mil centers on the active surface, in close proximity to the lithium niobate. The initial device has shown very promising performance, with a storage time of 10 msec for a write time of 50 nsec.

A SAW tapped delay line is currently being designed and fabricated for use in the Re-entry Systems Program. The complete line will have 11 output taps of varying delays, with a maximum delay of 66  $\mu\text{sec}$  and a 3-dB bandwidth of 100 MHz. An initial prototype line of smaller delay (7.5  $\mu\text{sec}$ ) has been made and evaluated. The line does operate as expected, except for a larger-than-expected minimum in the response at center frequency. The transducers are currently being modified to minimize this response dip.

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