Quarterly Technical Summary

Advanced Electronic Technology

15 May 1975

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Eugene C. Raabe

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

ADVANCED ELECTRONIC TECHNOLOGY

QUARTERLY TECHNICAL SUMMARY REPORT
TO THE
AIR FORCE SYSTEMS COMMAND

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LEXINGTON MASSACHUSETTS

INTRODUCTION

This Quarterly Technical Summary covers the period 1 February through 30 April 1975. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.

CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1975 on Data Systems. Separate reports describing other work of Division 2 are issued for the following programs:

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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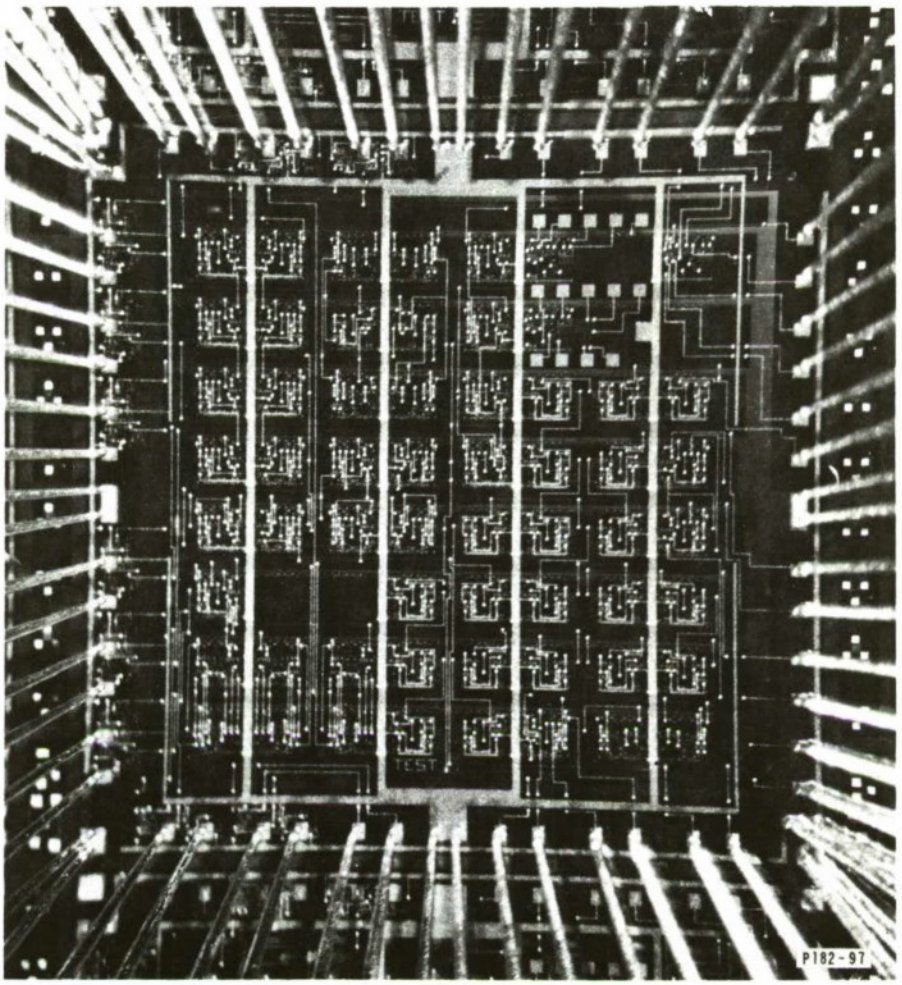

Fig. 1. ECL universal gate array wafer customized for evaluation purposes on the prober.

DIGITAL COMPUTERS
GROUP 23

I. INTRODUCTION

Advances were made in the two application areas of current interest. The three-bit quantizer was used to build a breadboard 6-bit 200-MS/sec A/D converter. The first customized wafers of the ECL universal gate array were tested with encouraging results. The universal array, which has 192 gates, is made from a standard set of diffusion masks and custom two-level metalization masks.

II. APPLICATIONS

A. Quantizers

An experimental 6-bit A/D converter using eight 3-bit quantizers operating at a low repetition rate and simulating 150-MS/sec operation was described in the last Quarterly Technical Summary. This quarter, A/D conversion of a 100-MHz sine wave at true 200 MS/sec was obtained. Total distortion is estimated to be 3 percent, some 6 dB above that of an ideal 6-bit encoder. The excess error is due to a low-order nonlinearity attributable primarily to the amplifier between the sampler and the encoder and some abrupt nonlinearities arising in the encoder which may be a consequence of signal dispersion along the transmission lines.

As reported last quarter, 30-percent yield of quantizers at wafer probe has been achieved. The yield of packaged devices after a 12-hour burn-in at room temperature is 80 percent.

Recent runs have had transistors with f_T of approximately 4 GHz at 2 mA and V_{CB} = 3 volts. Quantizers with these transistors have a regeneration time constant of about 265 psec and AC gain of 55. On 40 packaged quantizers, the rms value of offset (over 320 comparators) was 2.0 mV. Error due to the divider resistors has an rms value of about 3 percent of a quantization step.

B. ECL Universal Array

The first processed wafers of the ECL universal array have been tested. These wafers have been customized to provide gate chains for delay measurements, some circuits to test flip-flops and other logic configurations, and connections for measurement of bias voltages. Figure 1 shows one of these wafers being probed. The peripheral pads are standard for all chip configurations; the internal pads in the upper right corner are special to this evaluation chip. Because of the multiplicity of independent circuits, much test information can be obtained with less than perfect wafers. Of 192 arrays tested (6 wafers, 32 arrays each) three, all from one wafer, had all good circuits. While the yield is not acceptable, the absence of design and layout errors is gratifying. The first delay measurements give 650 psec/gate.

The second customized circuit is a 4 × 4 multiplier. The first wafers are now being tested. A multiplier control chip and a time level generator are being designed.

III. INTEGRATED CIRCUIT PROCESSING

A. Semiconductor Processing

Since spikes in the epitaxial film are a prime cause of mask damage and yield loss, wafers are inspected and rejected if they have more than five spikes. The remaining wafers are Freon plasma or chemically etched at spike locations so the spikes cannot damage masks.

A nitride reactor has been installed and other preparations are under way to provide the capability for making oxide-insulated integrated circuits. The advantages of oxide isolation for area reduction and speed increase are well known and are especially important in conjunction with the minimum area devices previously described.*

B. X-Ray Lithography

Work on x-ray lithography in silicon-device fabrication, which has now been published in a Ph. D. thesis,† has demonstrated that x-ray lithography is compatible with existing silicon-device technology.

C. Ion Implantation

Transistors with f_T's as high as 7 GHz have been made by the use of ion-implanted arsenic emitters. A paper describing this and other work on small geometry transistors has been submitted for publication.

IV. DESIGN AND TESTING

A. ECL Processing Test Devices

Three sets of test devices were designed for the ECL array wafer. They are a set of diffusion monitors comprised of sixteen resistors, a set of six transistors, and a set of metal, via, and oxide test patterns.

B. Method for Determining Delay and Other Invariants of Certain Linear Systems

The problem of characterizing a system in terms of its invariants, κ_1 (delay), κ_2 (dispersion), κ_3 (skewness),‡ κ_4 (kurtosis),§ etc. where, in general, $\kappa_n = (-1)^n [d^n \ln H(s)/ds^n]_{s=0}$ has been studied and a paper is in preparation for publication. A simple method for determining the invariants of grounded, transformerless, linear, active, RC networks with transfer functions H(s) that are regular and finite at s = 0 has been developed. For these networks, it is shown that their transfer functions can be expressed in the form

$$H(s) = H(0) \exp[\text{trace } \ln \frac{U + s\,RC}{U + s\,R'C'}]$$

and that the network invariants are simply related to the two pairs of resistance (R, R') and capacitance (C, C') matrices. A feature of the method lies in the fact that the resistance and capacitance matrices can usually be constructed by inspection of the network.

C. Testing

A symbolic debugger has been added to the TIC system to facilitate debugging testing programs.

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*Advanced Electronic Technology Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1974), DDC AD-A002877/9.

† S. E. Bernacki, "The Application of X-Ray Lithography to Microelectronic Devices," Ph. D. Thesis, Division of Engineering and Applied Physics, Harvard University, April 1975.

‡ skewness – lack of symmetry in a frequency distribution.

§ kurtosis – the peakedness or flatness of the graph of a frequency distribution.

Computer programs to measure and plot DC beta as a function of collector current and junction capacitance as a function of voltage have been implemented in the TIC language. The capacitance program has an option for obtaining doping concentration as a function of distance from the junction.

D. Mask Design

These reports have described the development of two mask design systems. One was the earliest of such systems and was the result of pioneering work in interactive graphics. The second system employs a double raster display and a special processor to obtain a very high quality scrollable display. Both systems are dependent on the TX-2 computer which is scheduled for shutdown in the near future. We have, therefore, purchased a stand-alone graphic design system with two user stations which we are just starting to use.

A principal service of the Laboratory's IBM 370/168 computer is that of time sharing under the control of the VM/370 operating system. As many as seventy users simultaneously compile programs, edit files, or process data. The ability to handle many independent users concurrently depends on the concept of virtual memory and paging. Although each program is free to address many thousands of pieces of data, for short increments of execution time only small subsets of the data need be immediately at hand. When not required, data or program code are moved out of main storage to a slower and less expensive medium such as a drum.

This swapping in and out of blocks or pages of information should be done at a speed that does not delay program execution. The data transfer rate of the swapping device represents an upper limit for this process, but the scheme for storing and retrieving pages is a major factor in paging rates short of the upper limit. The reason for this is that the necessary physical motion delay for a drum or disk to reach the beginning of a given page is likely to be several times the read or write time.

The method used to handle page storage and retrieval up to now was known as "slot sorting." It involved chaining together several outstanding page requests. The order of the chained requests was calculated to take full advantage of the drum position during a single revolution. This method was a significant improvement when installed on the old IBM 360/67 system and has been effective on the 370/168. A new method known as "multiple requesting" has now replaced it and improved paging performance by about 10 percent. It is based on the fact that the 370/168 swapping device, an IBM 2305 fixed head disk, may be addressed as eight separate logical units. This means that up to eight paging operations may be started virtually simultaneously without any sorting required. The 2305 itself monitors the rotational position of the disks for a match with one of the eight active requests. On a match, the request is processed and on completion, a search for a match against the other seven resumes. This scheme, which was installed during the quarter, has significantly reduced paging delays.

The longer a user works with the time-sharing system, the more useful programs and subroutines are accumulated. Also, the tasks attempted become more complex and the data bases larger. All this leads to an ever increasing need for on-line file storage. During the quarter, this inexorable demand led to the conversion of four of the sixteen disk drives to double capacity models. The change was invisible to users but the physical movement of data was carefully planned. Under a continuing measurements program, disk access arm motion is tracked, recorded, and plotted. Wherever long-term patterns appear, data are moved to minimize access time. This same facility also was used to plan the movement and merger of data from the smaller disks. It is now being used to plan another incremental upgrade scheduled for next quarter.

A common Laboratory problem is the preparation of large documents. Particularly during the early stages of development, a considerable amount of the author's time is lost in editing and proofreading revisions. The VM/370 time-sharing system provides both a text editor and a text formatting system called NSCRIPT. These two facilities provide users with an effective means of rapidly producing clean, edited, and formatted copy. Unchanged portions of text need

not be proofread again. All occurrences of a word or phrase may be located and changed easily and insertions require entry only of the new material. In order to make this capability more widely useful, a special NSCRIPT course was developed for secretaries with no previous computing experience. Classroom work was supplemented by considerable supervised practice on the system. Some of the first group of students are already using NSCRIPT in their work. Other classes are being planned.

SOLID STATE
DIVISION 8

INTRODUCTION

This section of the report summarizes progress during the period 1 February through 30 April 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

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Associate Head

DIVISION 8 REPORTS
ON ADVANCED ELECTRONIC TECHNOLOGY

15 February through 15 May 1975

PUBLISHED REPORTS

Journal Articles

JA No.			
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 27, 49 (1974), DDC AD-A008298
4389	The Influence of 3d Transition Metal Substitution on the Magnetic Properties of MnGaGe	J. B. Goodenough G. B. Street* K. Lee* J. C. Suits*	J. Phys. Chem. Solids 36, 451 (1975)
4402	p-n Junction $PbS_{1-x}Se_x$ Photodiodes Fabricated by Se^+ Ion Implantation	J. P. Donnelly T. C. Harman	Solid-State Electron. 18, 288 (1975)
4415	On the Wigner Distribution Function for an Oscillator	R. W. Davies K. T. R. Davies*	Ann. Phys. 89, 261 (1975)
4432	Auger Spectroscopy Studies of the Oxidation of Amorphous and Crystalline Germanium	V. E. Henrich J. C. C. Fan	J. Appl. Phys. 46, 1206 (1975)
4442	Optically Pumped Vibrational Transition Laser in OCS	H. R. Schlossberg* H. R. Fetterman	Appl. Phys. Lett. 26, 316 (1975)
4454	Optically Pumped cw InSb Lasers for NO Spectroscopy	A. S. Pine N. Menyuk	Appl. Phys. Lett. 26, 231 (1975)
4456	Light Scattering Lineshape in Opaque Materials	G. Dresselhaus A. S. Pine	Solid State Commun. 16, 1001 (1975)

Meeting Speeches

MS No.			
3778	Oxide Engineering	J. B. Goodenough	J. Solid State Chemistry 12, 148 (1975), DDC AD-A008308
3822	Surface Acoustoelectric Correlator with Surface State Memory	J. H. Cafarella A. Bers* E. Stern	1974 IEEE Ultrasonics Symposium Proceedings, Milwaukee, 11-13 November 1974, pp. 216-219

*Author not at Lincoln Laboratory.

MS No.			
3830	Tunable Infrared Lasers	K.W. Nill	Optical Engineering 13, 516 (1974), DDC AD-A008296
3883	On the Performance and Limitations of the Surface-Wave Resonator Using Grooved Reflectors	R.C.M. Li R.C. Williamson D.C. Flanders* J.A. Alusow	1974 IEEE Ultrasonics Symposium Proceedings, Milwaukee, 11-13 November 1974, pp.257-262
3890	Surface Wave Correlator – Convolver with Memory	A. Bers* J.H. Cafarella	1974 IEEE Ultrasonics Symposium Proceedings, Milwaukee, 11-13 November 1974, pp. 778-787
3891	Problems Encountered in High-Frequency Surface-Wave Devices	R.C. Williamson	1974 IEEE Ultrasonics Symposium Proceedings, Milwaukee, 11-13 November 1974, pp.321-328
3894	16-Channel Surface-Acoustic-Wave Filter Bank	V. Dolat J. Melngailis	1974 IEEE Ultrasonics Symposium Proceedings, Milwaukee, 11-13 November 1974, pp.756-759

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
4393	Unified Model of the Insulator-Metal Transition in Ti_2O_3 and the High-Temperature Transition in V_2O_3	H.J. Zeiger	Accepted by Phys. Rev. B
4473	Low-Threshold, cw $LiNdP_4O_{12}$ Laser	S.R. Chinn H.Y-P. Hong	Accepted by Appl. Phys. Lett.
4476	Efficient InSb Laser with Resonant Longitudinal Optical Pumping	N. Menyuk A.S. Pine A. Mooradian	Accepted by IEEE J. Quantum Electron.
4481	Observation of a Very Narrow Surface Resonance on Single-Crystal Aluminum	V.E. Henrich	Accepted by Surf. Sci.
4498	PbS MIS Devices for Charge-Coupled Infrared Imaging Applications	F.J. Leonberger A.L. McWhorter T.C. Harman	Accepted by Appl. Phys. Lett.
4502	Crystal Structure of $NdLiP_4O_{12}$	H.Y-P. Hong	Accepted by Mater. Res. Bull.

* Author not at Lincoln Laboratory.

JA No.

4506	Silicon and Selenium Ion Implanted GaAs Reproducibly Annealed at Temperatures up to 950°C	J. P. Donnelly W. T. Lindley C. E. Hurwitz	Accepted by Appl. Phys. Lett.
4508	Electrical Characterization of Epitaxial Layers	G. E. Stillman C. M. Wolfe	Accepted by Thin Solid Films
4509	As^+-Ion Implanted PbTe p-n Junction Photodiodes	J. P. Donnelly T. C. Harman	Accepted by Solid-State Electron.

Meeting Speeches*

MS No.

3337R	Lasers for Photochemical Applications	A. Mooradian	M.I.T. Industrial Liaison Seminar, East Brunswick, New Jersey, 24 March 1975
3812A	Nonlinear Materials: Present and Future Device Applications	A. Mooradian	M.I.T. Industrial Liaison Seminar, M.I.T., 8 April 1975
3971	Concentrated-Rare-Earth Laser Materials	S. R. Chinn J. W. Pierce H. Y-P. Hong	
3827A	Spin-Flip Raman Scattering	S. R. J. Brueck	Seminar, National Research Council, Ottawa, Canada, 25 February 1975
3935	Partially Filled Atomic Cores in Fluorides	J. B. Goodenough	American Chemical Society, Philadelphia, 10 April 1975
3936	Preparation of Sn-Doped In_2O_3 Films by RF Sputtering	F. J. Bachner J. C. C. Fan	147th Meeting, Electrochemical Society, Toronto, Canada, 11-16 May 1975
3937	Preparation and Application of Transparent Heat Mirrors for Solar-Energy Collection	J. C. C. Fan F. J. Bachner	77th Annual Meeting and Exposition, Electronics Division, American Ceramic Society, Washington, D.C., 3-8 May 1975
3949	Tunable-Laser Measurements of Atmospheric Infrared Absorption Parameters	R. S. Eng K. W. Nill	Topical Meeting, Applications of Laser Spectroscopy, Anaheim, California, 19-21 March 1975
3950	Solar-Energy Collection-Conversion	J. B. Goodenough	Seminar, Arizona State University, Tempe, 14 February 1975

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

MS No.			
3963	Narrow-Gap-Semiconductor Tunable Diode Lasers	K. W. Nill	American Physical Society Meeting, Denver, 31 March – 3 April 1975
4015	Multiphonon Absorption in Laser Windows	T. F. Deutsch	
3972	Structure and Properties of Magnetic Materials	J. B. Goodenough	American Crystallographic Association Symposium, Charlottesville, Virginia, 9-13 March 1975
3985	Planar InSb Photodiodes Fabricated by Be and Mg Ion Implantation	C. E. Hurwitz J. P. Donnelly	IRIS Detector Specialty Group Meeting, Ft. Monmouth, New Jersey, 11-13 March 1975
3986	Planar HgCdTe Quadrantal Heterodyne Arrays with GHz Response at 10.6 μm	D. L. Spears	
3987	High Sensitivity Wide Bandwidth HgCdTe Photodiodes for Heterodyne Detection in the 5 to 12 μm Region	D. L. Spears I. Melngailis T. C. Harman	
3987A	High Sensitivity Wide Bandwidth HgCdTe Photodiodes for Heterodyne Detection in the 5 to 12 μm Region	D. L. Spears	Seminar, Honeywell Radiation Center, Lexington, Massachusetts, 8 April 1975
3987B	GHz Bandwidth HgCdTe Photodiodes for Heterodyne Detection in the 4 to 12 μm Region	D. L. Spears	Seminar, Electrical Engineering and Optics, M.I.T., 17 April 1975
4052	Electrical Properties of Cadmium Sulfide	A. J. Strauss	NSF Workshop on CdS Cells, University of Delaware, Newark, 1 May 1975

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

An integrated GaAs-AlGaAs double-heterostructure laser emitting at approximately 9100 Å into a high-purity GaAs passive waveguide has been fabricated and characterized. The lowest measured room-temperature threshold current density for the lasers was 7.5 kA/cm^2, and the measured external differential quantum efficiencies of the laser-waveguide combination were about 3.5 percent.

Electrically active donor impurity concentrations above 10^{18} cm^{-3} have been achieved in GaAs by Se-ion implantation. By using pyrolytic Si_3N_4 encapsulation and a post-implantation annealing temperature of 900°C, a peak electron carrier concentration of 3.5×10^{18} cm^{-3} was measured for a sample implanted with 1×10^{14} Se ions/cm^2.

The gain profile of external cavity controlled GaAs single (SH)- and double (DH)-heterostructure lasers was measured for various active region dopants and under different device operating conditions. For SH devices, the gain profile was found to be comprised of two regions: a lower energy abnormal region which is characterized by a time delay that increases with increasing current and a higher energy portion with normal time delay behavior. For DH devices, only the normal delay was observed.

An experimental investigation of PbS metal-insulator-semiconductor (MIS) devices has led to results which suggest the feasibility of developing a monolithic two-dimensional charge-coupled imaging device in a narrow-gap semiconductor which would be operable at 77 K and have moderate sensitivity out to about 3.5 μm. A storage time of ~2.3 sec was measured, which is nearly two orders of magnitude longer than the 1/30-sec frame time for standard two-dimensional imaging.

II. QUANTUM ELECTRONICS

The GaAs-pumped CW InSb laser has been used to carry out atmospheric spectroscopy of H_2O, NO, and C_2H_4 over a 7-m path. Continuous operation in InAs and pulsed operation in GaSb and $PbS_{1-x}Se_x$ ($x = 0, 0.2, 0.4$) also have been obtained with GaAs diode laser pumping. Spectra of NH_3 in the 3-μm region were taken with the InAs laser.

Work is continuing on the evaluation of nonlinear optical materials for the middle infrared. The effects on optical attenuation of annealing $CdGeAs_2$ in a lithium atmosphere have been examined, and a study of the source of the short-wavelength infrared attenuation has been undertaken. Second harmonic generation in this material exhibits saturation effects at liquid nitrogen temperature, with a 12.8-percent external energy conversion efficiency for a 12.1-mm-long crystal. Optical surface damage measurements have been made at 10.6 μm for $CdGeAs_2$, $AgGaSe_2$, $AgGaS_2$, Tl_3AsSe_3, and Ge.

An electro-optic modulator for submillimeter radiation in $LiTaO_3$ has been developed. The index and electro-optic coefficient are enhanced by lattice contributions in this wavelength region. A 1-cm-long crystal, with a 10-kV applied field at 600 Hz, gave greater than 90-percent modulation of HCN laser radiation. Modulation up to 250 kHz was also observed, limited only by the modulation drive.

III. MATERIALS RESEARCH

Amorphous Si films deposited by RF sputtering have been converted into crystalline Si by heating with focused Nd:YAG laser radiation. Laser crystallization is potentially a technique for preparing large-grain Si films at a cost low enough to permit their use in solar cells for large-scale terrestrial applications.

The ionic conductivity of solid electrolytes has been investigated by measuring the transient current response of such materials to trains of constant-voltage pulses. Measurements of this type have shown that ion diffusion plays a significant role in the conductivity of polycrystalline materials exhibiting fast Na^+-ion transport, which are being studied for possible use as ceramic membranes in the Na-S secondary battery.

In connection with a study of the role played by surface states in the catalytic behavior of TiO_2 anodes in the photoelectrolysis of water, the surface-loss functions of titanium and vanadium oxides have been calculated from the bulk dielectric functions determined from optical data. The results are in good agreement with those obtained by electron energy-loss spectroscopy, and confirm the presence of a strong peak attributed to electron transitions between $3d^1$ states of the Ti^{3+} ion.

An electron microprobe procedure has been developed for quantitative analysis of Ga and Al in thin layers (1 to 5 μm) of $Ga_{1-x}Al_xAs$ grown on GaAs substrates by liquid-phase epitaxy. The standard used for determining both elements is a $Ga_{1-x}Al_xAs$ layer 23 μm thick whose homogeneity has been checked by microprobe measurements.

IV. MICROELECTRONICS

Bulk lifetimes in the starting materials for the fabrication of the 100 × 1 linear CCD imaging arrays and the 30 × 30 two-dimensional CCD imaging arrays used as prototypes for the TDAR program have been found to be low, leading to unacceptably high values of dark current (greater than 500 nA/cm^2) in the final devices. Adding 5% HCl during oxidation in dry O_2 has raised the bulk lifetime to as high as 2.3 msec in otherwise unprocessed wafers. Experiments are under way to determine if subsequent CCD processing can proceed without causing lowered lifetimes and the resulting high dark current.

A surface acoustic wave tapped delay line consisting of two lithium niobate crystals mounted in a single package has been delivered to the R.F. Systems Group for evaluation. The complete line has 11 taps, a maximum delay of 66 μsec, and a 3-dB bandwidth of 100 MHz. The output transducers have been raised in design center frequency from the nominal 300 MHz to compensate for the frequency dependence of propagation loss. Work on experimental short delay lines has shown that the mid-band dip in output transducer response can be reduced from 3.5 to 1.4 dB by tuning the input transducer with a series inductor and increasing the number of fingers in the output transducer from 5 to 6.

A silicon Schottky barrier diode array and a lithium niobate surface acoustic wave delay line mounted in close proximity to one another form a memory and correlator structure. In order to allow repetitive write-ins of the same signal waveform, the 5-μm platinum Schottky contacts are overlaid with 10-μm × 10-μm × 1200-Å-thick pads of high-resistivity polycrystalline silicon which have a high capacity toward the bulk silicon and allow sequential voltage pulses to add charge to the diodes without erasing the charge already stored. A coherent integration gain of 20 dB over what is achieved with a single write-in pulse has been shown.

A GaAs vapor epitaxy system has been designed and built to grow multiple layers with different doping levels on highly doped substrates for microwave and integrated optical devices. The system uses the $AsCl_3$-Ga-H_2 method in conjunction with a vertical furnace. Undoped layers have been grown with LN_2 mobilities of up to 80,000 cm^2/V sec. Sulfur doping has been used to produce layers with carrier concentration from 5×10^{14} to 3×10^{18} cm^{-3}.

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integrated circuitry	solid state devlces	quantum electronics
magnetic films	materials research	microelectronics

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This Quarterly Technical Summary covers the period 1 February through 30 April 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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