ADVANCED ELECTRONIC TECHNOLOGY

QUARTERLY TECHNICAL SUMMARY REPORT
TO THE
AIR FORCE SYSTEMS COMMAND

1 MAY – 31 JULY 1980

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INTRODUCTION

This Quarterly Technical Summary covers the period 1 May through 31 July 1980. 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 May through 31 July 1980 on Data Systems. Separate reports describing other work of Division 2 are issued for the following programs:

- Seismic Discrimination
- Distributed Sensor Networks
- Network Speech Systems Technology
- Digital Voice Processing
- JTIDS Speech Processing
- Packet Speech Systems Technology
- Radar Signal Processing Technology
- Restructurable VLSI Technology
- Multi-Dimensional Signal Processing

DARPA/NMRO
DARPA/IPTO
OSD-DCA
AF/ESD
AF/ESD
DARPA/IPTO
ARMY/BMDATC
DARPA/IPTO
AF/RADC

A.J. McLaughlin
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I. INTRODUCTION

Connecting vias for Restructurable VLSI have been formed using both a commercial laser zapper and a CW argon laser. Mask sets for a CMOS gate array and scaled NMOS devices have been laid out. Photoresist sensitive polyimide has been used successfully as a resist, and 100-Å oxy-nitride films have been fabricated by nitridation of thermally grown silicon dioxide.

II. MNOS MEMORY

A. 64-kbit Memory Arrays

Processing of 64K memory array wafers was accelerated in order to produce a collection of good chips for full functional evaluation with the new computer-controlled MNOS memory exerciser. Problems which were identified and solved in the memory chip process related to anomalously high epi doping, poor nitride storage, and poor contact cut etching. The primary yield detractor now on 64K chips is believed to be photolithographic defects. The use of our new DSW wafer stepper should substantially improve this situation when it is finally operational.

Avalanche breakdown in deep depletion in the Si substrate of MNOS memory capacitors is used as a threshold to provide a write inhibit on half-selected bits in crosspoint capacitor arrays. Experimental measurements on these arrays on SOS using Ne-damaged Si isolation between Si digit lines indicates that the avalanche threshold does inhibit writing on half-selected bits for write times of 10 μsec or less. However, with longer write times thermal generation of minority carriers at the damaged Si isolation sidewall reduces the inhibit voltage across the deeply depleted MNOS capacitor substrate, which results in an increased write disturb on half-selected tabs.

A viable process was developed for using positive photoresist as a neon implant mask in the damaged Si isolation process used in the memory. This involved lowering the resist postbake temperature and using mechanical wafer heatsinking during the Ne implant step to prevent resist flow. Using a positive resist mask simplifies and improves the reliability of the damaged Si isolation process.

B. On-Chip MNOS Memory Sense Amplifier

An on-chip charge-transfer sense amplifier has been designed for the MNOS capacitor memory. It is large (14 transistors with total gate width of about 750 μm) and complicated (nine clocks, several with multiple levels and controlled transition times). Simulations with the SPICE2 circuit-analysis program show that, for bit capacitance on the order of 30 fF and bitline capacitance up to 4 pF, a memory array will operate with a 5-μsec cycle time. The ratio of signal-to-random-noise is on the order of 60 dB.

C. Array Testing

A margin checking box has been added to the sense amplifier output comparator which allows variation and digital display of the sense threshold. Programs are being written to display bad-bit maps and histograms for various worst-case storage patterns including the effect of read disturb and long-time storage decay.
III. RESTRUCTURABLE VLSI

A. Bulk CMOS Test Chip

Design of masks for a bulk CMOS test chip which is oxide isolated with self-aligned polysilicon gates and single-level metal has been completed. Its fabrication requires 9 masks.

The test chip includes a gate-array with 240 CMOS transistor pairs which are grouped into 6 columns of 20 cells, each cell being two CMOS transistor pairs. Each cell can be configured into two inverters, a 2-input NAND gate, a 2-input NOR gate, or a transfer gate. Flip-flops, latches, exclusive-OR gates, AND-NOR gates, OR-NAND gates, larger NAND gates or NOR gates, and dynamic storage elements can be obtained by interconnecting adjacent cells. Thirty-six in-out cells are provided which can be customized to output pad drivers or input pad buffers. Inverting or noninverting input pads have protective diodes and resistors. The gate-array is customized by changing only the metal mask.

For the first fabrication, the gate-array has been customized to contain a 31-stage ring oscillator with fan-out of 1, and a 27-stage ring oscillator with fan-out of 3. These will provide data for estimating typical stage delays.

The gate-array by itself is 125 × 125 mils (3.175 × 3.175 mm), and has 40 in-out and power pads. It will mount in a 40-lead chip-carrier package. The circuitry is designed using λ = 2.5 μm design rules. Polysilicon gates are 5 μm (2λ) wide, for instance. Many of the design conventions are based on those used in Mead and Conway, * and by XEROX-PARC for MPC designs.

B. Scaled NMOS

A new NMOS reticle set contains many small test devices and six ring oscillators of various channel lengths. It will be used to develop a short-channel process using thin, thermally grown nitride or oxynitride as the gate dielectric.

C. Laser-Formed Vias

A technique has been developed which uses a laser to form connecting vias selectively between two levels of aluminum wiring on a silicon wafer. The same laser can be used to "zap," or remove, metal thus providing a capability of either adding or deleting connections. These techniques can be used to provide the defect avoidance and user customization for large-area Restructurable VLSI.

Other workers have reported use of a dye laser, multiple pulses, and a post-laser thermal anneal to make connections between metal and silicon through a thin thermal oxide and between metal layers through a deposited oxide. The present work uses a commercial I.C. mask trimmer employing a pulsed laser. Single pulses provide low-resistivity connections with no thermal annealing required. The insulating layer between the two aluminum layers is formed by sputtering 3000 to 6000 A of amorphous silicon.

Chains containing forty 0.25- × 0.25-mil vias between first- and second-level metal were successfully connected with resistances of less than 0.3 ohm per via. Unprogrammed sites exhibit a highly nonlinear resistance, characteristic of the amorphous silicon, with currents in the...
nanoamp range at 10 V. Current-carrying capacity in excess of 500 mA was achieved on a number of via chains before blowout.

IV. SILICON PROCESSING

A. Thermal Nitridation

$\text{SiO}_2$ layers 100 to 140 Å thick have been converted to a silicon oxynitride by reacting the film with $\text{NH}_3$ and $\text{N}_2$ at approximately 1200°C. The resulting nitrogen composition of the film is dependent on the initial $\text{SiO}_2$ thickness, the nitridation time, and the nitridation temperature. Breakdown fields of 8 to 12 MV/cm have been achieved with leakage current of $<10^{-4}$ A/cm$^2$ at 5 MV/cm. The films are resistant to oxidation at 1000°C in dry O$_2$ and to etching in buffered HF (7:1). Capacitors fabricated with Al electrodes on a 157 Å oxynitride film on silicon were irradiated to 1 Mrad (Si) with 1.5-MeV electrons. Flatband shifts of $-0.3$ V were observed for capacitors biased at 5 V. This shift is believed to be due to sodium or some other mobile positive-ion contamination in the film.

B. Bipolar Processing

The diagnostic technique of deleting various process steps has identified the epitaxial growth process to be the single most important contributor to bipolar transistor emitter-collector leakage. This result appears valid regardless of whether polysilicon is simultaneously deposited (as in the poly-ox process) or not (as in damaged silicon isolation). Moreover, additional data generated in damaged silicon isolation experiments which use extremely thin epi (<1 μm) indicate that leakage increases with decreasing epitaxial thickness. This condition may be the limiting factor in the damaged silicon isolation technique where the epi thickness needs to be thin enough for neon near-penetration.

A defect decoration etching technique recently described in the literature has been adopted to investigate backside damage gettering effectiveness. Experiments have verified that the usual methods of backside damage such as ion implantation or mechanical scoring do indeed reduce the etch pit density of the front surface. However, abrading the back sides with a glass-bead blasting apparatus does not reduce the density. Apparently, glass-bead impact does not produce the right kind of crystallographic damage necessary for gettering, as does damage produced by sharp points being scored across the surface.

C. Photosensitive Polyimide

Photosensitive polyimide having exposure times comparable to positive photoresist has been evaluated. It is capable of defining 2-μm features and smaller, seems to produce a uniform surface, and exhibits the high-temperature characteristics expected of polyimide. Work with reactive ion etching of metal-masked polyimide has clearly demonstrated excellent anisotropic etching in material as thick as 30 μm. Slot widths smaller than 0.2 μm have been made in 1.5-μm-thick material, and it appears that depth-to-width ratios of 20:1 or greater are possible.

V. TESTING AND INSTRUMENTATION: MOS CAPACITANCE TEST SYSTEM

As part of a continual upgrading of the TIC MOS capacitor test system, a digital storage oscilloscope has been added to the Zerbst lifetime measurement. This technique uses the measurement of the capacitance of a device which is pulsed into deep depletion and allowed to recover to the inversion state as a basis for the calculation of bulk and surface lifetime values. The previous technique required a series of pulsed measurements in which the capacitance was sampled at successively longer delays. The repeated pulsing of the MOS device tended to modify the charge density and thus compromise the measurement. The use of the digital storage scope allows the storage of a single capacitance-vs-time waveform. This information can be retrieved from the oscilloscope memory by the TIC computer and processed as required to obtain values for the lifetime. Further improvements are expected when a higher-resolution plug-in unit is obtained for the oscilloscope.
The Amdahl 470V/7 central processor, installed toward the end of the previous quarter, is effectively providing Laboratory users with about twice the throughput of the system it replaced. Because of its compatibility, user software has required no changes at all and system software has required only minor changes to reflect physical differences such as configuration and error recording. Tuning of the system for efficient operation has also been related principally to the differences in configuration.

The net result is that the VM time-sharing system on the 470V/7, by both subjective and objective measures, is considerably more responsive and productive. Typical VS batch processing run times have been reduced to half their previous duration.

Notwithstanding this improved performance, average daily central processor use under VM time sharing has steadily moved back up toward the 90-percent level. Furthermore, a full second- and third-shift of batch processing often leaves a backlog of work before switching over to first-shift VM operations. This rapid growth in demand, together with future load projections, has led to the initiation of a study of alternatives for providing computing capacity beyond the planned field upgrade of the 470V/7 to a V/8. It is now likely that the upgrade itself will have to be advanced to FY 81 to handle these growing requirements.

In addition to continuing assignments to provide basic systems services and capabilities, members of Group 28 are involved in broadly based Laboratory efforts aimed at increasing staff productivity through the application of computer technology. One such effort is in the area of publications, which is defined to include various forms of printed text, lecture displays, and simple block drawings.

During this quarter, a Micom word processor has been installed to explore potential benefits of communications between different systems and the capability for producing simple block drawings. In another area, a software working group has been established to investigate and promote the use of modern software engineering techniques for Laboratory programming activities.
INTRODUCTION

This section of the report summarizes progress during the period 1 May through 31 July 1980. The Solid State Research Report for the same period describes the work of Division 8 in more detail. Funding is primarily provided by the Air Force, with additional support provided by the Army, DARPA, Navy, NASA, NSF, and DOE.

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Head, Division 8

I. Melngailis
Associate Head
# DIVISION 8 REPORTS ON ADVANCED ELECTRONIC TECHNOLOGY

15 May through 15 August 1980

## PUBLISHED REPORTS

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<td>4947</td>
<td>Solid Electrolytes Containing Both Mobile and Immobile Alkali Ions</td>
<td>H. Y-P. Hong</td>
<td>J. Power Sources</td>
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<td>137 (1980)</td>
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**Meeting Speeches**

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### Journal Articles

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<td>5115</td>
<td>Surface Passivation Techniques for InP and InGaAsP p-n Junction Structures</td>
<td>V. Diadiuk, C. A. Armiento, S. H. Groves, C. R. Hurwitz</td>
<td>IEEE Electron. Devices Lett.</td>
<td>Accepted</td>
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<td>5119</td>
<td>The CLEFT Process, A Technique for Producing Epitaxial Films on Reusable Substrates</td>
<td>R. W. McClelland, C. O. Bozler, J. C. C. Fan</td>
<td>Appl. Phys. Lett.</td>
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5135 High Performance Quasi-
Optical GaAs Monolithic
Mixer at 110 GHz
H. J. Clifton
G. D. Alley
R. A. Murphy
J. H. Mroczkowski
Accepted by IEEE Trans.
Electron Devices

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4530D High-Resolution Molecular
Spectroscopy Using a Tunable
Difference-Frequency Laser
System
A. S. Pine
High Resolution Infrared
Applications and Develop-
ments Symp., Gaithersburg,
Maryland, 23-25 June 1980

4967B Graphoepitaxy
D. C. Flanders
Greater New York Chapter
American Vacuum Society,
RCA Laboratories, Princeton,
New Jersey, 4 June 1980

5127A Recent Advances in High Effi-
ciency, Low Cost GaAs Solar
Cells
J. C. C. Fan
G. W. Turner
R. P. Gale
C. O. Bozler
1980 Gordon Research Con-
ference on Crystal Growth,
Plymouth, New Hampshire,
14-18 July 1980

5130A Laser Processing of
Semiconductors
J. C. C. Fan
H. J. Zeiger
R. P. Gale
R. L. Chapman
Seminar, Digital Equipment
Corporation, Hudson,
Massachusetts, 11-12 June
1980

5157A Solid-Phase Crystallization
Produced by Laser Scanning of
Amorphous Ge Films: The Role
of Latent Heat in Crystallization
Front Dynamics
H. J. Zeiger
J. C. C. Fan
R. P. Gale
R. L. Chapman

5204A Low Loss GaAs Optical Wave-
guides Formed by Lateral
Epitaxial Growth over Oxide
F. J. Leonberger
C. O. Bozler
R. W. McClelland
I. Melngailis

5325 Analog Memory in MNOS De-
vice: Model and Experiments
R. S. Withers
R. W. Ralston
E. Stern

5334 Low Leakage, High Gain
GaInAsP/InP Avalanche
Photodetectors
V. Diadiuk
S. I. Groves
C. E. Hurwitz

5335 Intracavity-Loss-Modulated
GaInAsP Diode Lasers
D. Z. Tsang
J. N. Walpole
S. I. Groves
J. J. Hsieh
J. P. Donnelly

5346 Direct Writing of Micrometer-
Sized, Highly Doped Regions on
Semiconductors by UV-Laser
Photodeposition
D. J. Ehrlich
R. M. Osgood, Jr.
T. F. Deutsch

*Titles of Meeting Speeches are listed for information only. No copies are available for distribution.
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<tr>
<td>5219A</td>
<td>Integrated Optics and Optoelectronic Switches for Signal Processing</td>
<td>F.J. Leonberger</td>
<td>Workshop on High-Speed Optical and Electronic Devices, Dedham, Massachusetts, 21 June 1980</td>
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<td>5232</td>
<td>High-Power Output and Tuning Properties of the UV Solid-State Ce:YLF Laser</td>
<td>D.J. Ehrlich, P.F. Moulton, R.M. Osgood, Jr.</td>
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<td>5236</td>
<td>Laser-Induced Photochemical Reactions for Electronic-Device Fabrication</td>
<td>D.J. Ehrlich, R.M. Osgood, Jr., T.F. Deutsch</td>
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<td>Temperature-Dependent Spectral Study of the XeBr Excimer Bands via Two-Photon Optical Pumping</td>
<td>D.J. Ehrlich, R.M. Osgood, Jr.</td>
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<td>C.W. Patterson, R.S. McDowell, P.F. Moulton, A. Mooradian</td>
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<td>W.T. Lindley</td>
<td>Electro '80, Boston, 12-15 May 1980</td>
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<td>A. Chu</td>
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<td>5243</td>
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<td>H.I. Smith, D.C. Flanders</td>
<td>9th Intl. Conf. on Electron and Ion Beam Science and Technology, St. Louis, Missouri, 11-16 May 1980</td>
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<td>5264</td>
<td>Recent Advances in Tunable Lasers</td>
<td>A. Mooradian</td>
<td>Intl. Conf. on Lasers, Peking, China, 19-22 May 1980; Seminar, Raytheon Co., Waltham, Massachusetts, 11 June 1980</td>
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<td>Vapor-Phase Epitaxy of InP and GaInAsP</td>
<td>P. Vohl</td>
<td>NATO-sponsored Workshop on InP, Harwichport, Massachusetts, 17-19 June 1980</td>
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<td>5285</td>
<td>Synthesis and Crystal Growth of InP</td>
<td>G. W. Iseler</td>
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<td>Liquid-Phase Epitaxial Growth of InP and InGaAsP Alloys</td>
<td>S. H. Groves, M. C. Plonko</td>
<td>Solar Energy Research Institute - Program Review Talk, Washington, DC, 10-12 June 1980</td>
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<td>M. W. Geis, D. C. Flanders, D. J. Silvermanith, D. A. Antoniadis, H. L. Smith</td>
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<td>5278C</td>
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<td>Collisional Narrowing of HF Fundamental Band Spectral Lines by Neon and Argon</td>
<td>A. S. Pine</td>
<td>35th Annual Symposium on Molecular Spectroscopy, Ohio State University, Columbus, 16-20 June 1980</td>
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<td>5420</td>
<td>Surface Diffusion in MBE Growth of GaAs</td>
<td>A. R. Calawa</td>
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<td>Properties of W-GaAs Schottky Barriers After High Temperature Anneal</td>
<td>K. R. Nichols, C. O. Rozyer</td>
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<td>Growth-Temperature Dependence of LPE GaInAsP InP Lattice Mismatch</td>
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<td>D. K. Killinger, N. Menyak</td>
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I. SOLID STATE DEVICE RESEARCH

Improved versions of inverted-mesa n'-InP/n-InGaAsP/n'-InP/p-InP avalanche photodiode structures have been fabricated and characterized. Uniform avalanche gains of 700, dark current densities of $3 \times 10^{-6}$ A/cm$^2$ at a multiplication (M) of 10, and an excess noise factor of 3 (also at M = 10) have been achieved in diodes with wavelength cutoff at 1.25 \mu m.

A theoretical analysis shows that, under general conditions in broad-area InGaAsP/InP double-heterostructure lasers, an appreciable amount of reabsorption of the spontaneous photons can occur which results in a lowering of the laser threshold current density. Based on these calculations, improved results can be expected if the free-carrier absorption in the InP and the transmission loss through the laser sidewalls are minimized and the absorption in the active layer is enhanced.

P-type HgCdTe photoconductors, which can be operated by thermoelectric cooling, have been investigated for use above 77 K as photo-mixers in tactical CO$_2$-laser systems. The devices (100 \mu m square) have shown heterodyne sensitivities at 18 MHz of $5 \times 10^{-20}$ W/Hz at 77 K and $1.8 \times 10^{-19}$ W/Hz at 195 K, with bandwidths of 140 and 30 MHz, respectively. Bandwidths in excess of 100 MHz at 195 K were achieved with sensitivities of about $4 \times 10^{-19}$ W/Hz.

II. QUANTUM ELECTRONICS

The first observations of tunable Q-switched operation in Ni:MgF$_2$ and Cu:MgF$_2$ lasers have been made. In addition, the first mode-locked Ni:MgF$_2$ laser has been demonstrated and has produced pulses of approximately 100 pscc duration.

An analysis of mechanisms giving rise to the nonlinear optical response of semiconductors has been developed. Resonance enhancement effects are identified, and the application to bistability in integrated optical devices is discussed.

A number of modifications made on the quasi-optical radiometer has resulted in an improvement in the system noise temperature to 2900 K. The radiometer was used in the detection of CO in the molecular cloud Orion at 601 GHz, marking the first successful submillimeter heterodyne radio astronomy experiment using an optically pumped far-IR laser local oscillator.

III. MATERIALS RESEARCH

A growth procedure has been developed for using the liquid-encapsulated Czochralski technique to obtain a high yield of InP single crystals capable of providing substrates for research on optoelectronic devices. By establishing a suitable temperature gradient at the growth interface, this procedure minimizes the probability of twinning but does not result in excessive dislocation densities.

In connection with the liquid-phase-epitaxial growth of GaInAsP/InP heterostructures for optoelectronic devices, the phase diagram for growth of GaInAsP layers lattice-matched to (100) and (111)B InP substrates has been established over the temperature range from 570° to 650°C for the entire composition range from InP to the limiting ternary alloy, Ga$_{0.47}$In$_0.53$As. For a given growth temperature and Ga concentration in the liquid phase, the Ga distribution coefficient is always higher for (100) growth than for (111)B growth, but the difference decreases with increasing temperature.
The feasibility of using the trichloride method of vapor-phase-epitaxial growth to obtain GaInAsP-InP heterostructures has been demonstrated by growing lattice-matched GaInAsP layers on (100) InP substrates. Further development of this method, which uses PCl₃ and AsCl₃ as the sources of the Group V elements, would be required to achieve the degree of alloy composition control desired for device applications.

Heteroepitaxial Ge₁₋ₓSiₓ alloy films of good crystal quality have been obtained by transient heating of Ge-coated Si single-crystal samples with a graphite strip-heater. On the basis of initial experiments on the chemical vapor deposition of GaAs layers on these alloy films, there appear to be no serious obstacles to the fabrication of high-efficiency, low-cost GaAs solar cells utilizing the GaAs-Ge₁₋ₓSiₓ/Si structure.

Liquidus isotherms for temperatures from 425⁰C to 600⁰C and solidus lines for CdTe mole fractions between 0 and 0.7 have been determined for the Te-rich corner of the Hg-Cd-Te system. From the data, it is clear that a very wide range of Hg₁₋ₓCdₓTe compositions can be grown at temperatures of 425⁰C to 600⁰C by liquid-phase-epitaxial techniques.

IV. MICROELECTRONICS

A simple technique has been developed for exposing large-area, low-distortion, periodic structures. The technique, called spatial-period-division, employs near-field diffraction from periodic and quasi-periodic parent masks to produce intensity patterns with spatial periods finer than the parent mask. Spatial-period-division used in conjunction with soft x-ray lithography should be especially attractive for exposing structures with periods below 100 nm.

Two schemes have been implemented for fixed-pattern-noise cancellation in a SAW/CCD time-integrating correlator. One method uses a second CCD chip to store the fixed-pattern noise for subsequent subtraction from the SAW/CCD output, and the other uses an A/D converter and a computer for digital post-processing of the correlator output. The dynamic range of the device has been improved to 40 dB from 20 dB.

A GaAs integrated mixer consisting of a slot coupler, a coplanar transmission line, a surface-oriented Schottky-barrier diode, and an RF bypass capacitor all monolithically integrated on the GaAs surface has been fabricated for operation at 110 GHz. The monolithic mixer module mounted in the end of a waveguide horn has an unloaded double-sideband mixer noise temperature of 49 K and a conversion loss of 3.8 dB.

Lateral overgrowth of single-crystal Si over an SO₂ bar structure on a single-crystal silicon substrate has been achieved by epitaxial growth using the reduction of SiCl₄ in a hydrogen gas environment. 1 μm to 4 μm of lateral overgrowth has been observed for thin (0.04 μm) SO₂ bars on (100)-oriented silicon wafers. The amount of overgrowth is dependent on the orientation of the silicon substrate and the thickness of the SO₂ layer.

A. ANALOG DEVICE TECHNOLOGY

A theoretical model has been developed which explains an earlier experimental demonstration of analog nonvolatile memory in metal-oxide-oxide-semiconductor (MOS) capacitors. Experiments have successfully extended such analog memory behavior to devices produced by a process compatible with charge-coupled-device (CCD) technology. These results indicate the feasibility of an integrated MNOS/CCD analog memory, and work to fabricate such a memory is now under way.
LiNbO$_3$ surface-acoustic-wave edge-bonded transducers have been fabricated on ST quartz and (001)-cut GaAs substrates. Efficient transduction has been demonstrated in the vicinity of 100 MHz with fractional bandwidths of 50 and 91 percent for the quartz and GaAs substrates, respectively. Conversion loss as low as 4 dB has been measured for quartz. A model which accurately predicts this transducer performance has been devised.

Recent experiments have demonstrated the feasibility of using an acoustoelectric coherent integrator for programmable processing of burst waveforms of the type employed in Doppler radar systems. The device output, as a function of Doppler-shifted input, produced the expected Doppler ambiguity functions for 3-μsec gated-CW subpulses in bursts of 2, 4, 8, 16, and 32 subpulses.
This Quarterly Technical Summary covers the period 1 May through 31 July 1980. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.