Quarterly Technical Summary

Advanced Electronic Technology

15 November 1980

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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

[Signature]
Raymond L. Loiselle, Lt. Col., USAF
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LINCOLN LABORATORY

ADVANCED ELECTRONIC TECHNOLOGY

QUARTERLY TECHNICAL SUMMARY REPORT
TO THE
AIR FORCE SYSTEMS COMMAND

AUGUST – 31 OCTOBER 1980

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LEXINGTON MASSACHUSETTS
INTRODUCTION

This Quarterly Technical Summary covers the period 1 August through 31 October 1980. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.
DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 August through 31 October 1980 on Data Systems. Separate reports describing other work of Division 2 are issued for the following programs.

Seismic Discrimination: DARPA/NMRO
Distributed Sensor Networks: DARPA/IPTO
Network Speech Systems Technology: OSD-DCA
Digital Voice Processing: AF/ESD
Digital Voice Interoperability Program: AF/ESD
Packet Speech Systems Technology: DARPA/IPTO
Radar Signal Processing Technology: ARMY/BMDATC
Restructurable VLSI: DARPA/IPTO
Multi-Dimensional Signal Processing: AF/RADC

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I. INTRODUCTION

The first run of CMOS test chips has been processed successfully; extensive testing is under way in order to characterize the process. MNOS 64K-bit memory arrays with yields in the 95 to 98% range have been fabricated and tested.

II. MNOS MEMORY

Several 64K memory chips were produced on which 95 to 98% of the memory array was operational. The computer-controlled memory tester was debugged, and programs written to evaluate the best chips. Write times of 3 μs were used, and the 8-μs read access time at the wafer probe was limited by the off-chip decoding circuits and sense amplifier. Retention measurements on entire memory arrays revealed a fast initial stored-charge loss up to 1 s followed by a much slower charge decay rate up to at least several days. An extrapolated flatband voltage ($V_{FB}$) window of 2.5 V is obtained after one month storage. A standard deviation of 0.3 V about the mean $V_{FB}$ was measured indicating good uniformity of stored charge. Deep depletion is used to inhibit partial writing on half-selected cells during writing. The most frequent half-select condition was examined and found to produce at most a 0.5-V shift in the stored $V_{FB}$ after 1 hr of continuous disturbing. This disturb is small, but could be further reduced by a slight increase in epitaxial Si thickness or slight reduction in nitride thickness. Read disturbing was performed for 1 hr. No disturb was observed, as expected, since the read operation is performed with relatively small voltages in deep depletion. Since our memory approach emphasizes very high density rather than nonvolatility, refresh cycles are permitted but only at such a rate that power consumption would never become a problem. A 4-hr chip refresh cycle is therefore acceptable and is consistent with retention and write and read disturb data taken to date. Measurements are under way to more fully characterize the 64K memory chips, and results will be documented in a final report.

III. ADVANCED CIRCUIT DESIGN AND SIMULATION

A. Bulk CMOS Test Chip

The many test devices on the first run of CMOS chips have been wafer probed and most perform as predicted. Shift registers, gate chains, and flipflops have been operated successfully. Most defects relate to lithography problems which should be easy to remedy.

B. Scaled NMOS

The first run of scaled NMOS test chips is in process again now that the direct-step-on wafer machine is becoming available for routine use.

C. Thermal Nitride

Thin (100 Å) oxide films nitrided in ammonia at high temperatures have been shown to have a sandwich structure with high nitride compositions on the outside and at the silicon interface and
almost pure oxide in the center. Experiments are in progress to characterize the formation rates of the nitride layers. The interface electrical properties are functions of the degree of nitridation of the interface, and it has been shown that sintering the aluminum gates causes a positive shift of the flatband voltage, even to the point of generating negative interface charge; it is hoped this process can be tuned to adjust the interface properties.

IV. RESTRUCTURABLE VLSI TECHNOLOGY

A. Laser-Formed Vias

We continue to explore the programming technique for RVLSI which uses laser-formed interconnections between two levels of isolated but overlapping metal lines.

Our previous work employed a commercial IC mask trimmer with a Nd-YAG laser as the light source. Using 100-ns-long pulses, with peak power in the 2.2-kW range, successful connections were made with a single pulse impinging on a multilayered sandwich structure (1 μm of base thermal oxide, followed by a first-level metal (0.5 μm aluminum alloy), a second-level insulating layer (0.2 to 1.0 μm of amorphous Si or CVD SiO₂), and topped by a second-level metal (0.3 μm of aluminum)). Contact resistances of less than 3 ohms were obtained for all connections produced above a threshold laser power level. By using base oxides greater than 5000 Å, diode contacts to the substrate at high laser power levels were successfully eliminated. Unfortunately, SEI photographs of all via connections showed the contact hole surrounded by a web of filaments produced by the explosive nature of this short-pulse process.

The presence of this splattered material led us to investigate a lower peak power level (5 to 10 W) with a longer pulse (5 ms) using a mechanically shuttered CW argon laser. Electrically, these contacts behaved similarly to those generated by the Nd-YAG laser. However, the SEM pictures showed no filaments, with only a smooth ring-shaped wall surrounding the contact crater, an indication of a less violent reaction.

The fact that both procedures produced useful contacts suggests the wide range of processes which can operate to yield laser connections. Current work is concentrated on the splatter-free argon-pulse system.

B. X-Y Positioning Table

A wafer positioning table for laser restructuring has been designed and built. The table uses DC stepping motors to travel over the complete area in steps of 3 μm in both the X and Y directions. A controller is being designed to automate the process.

C. Restructurable VLSI Test Circuit

Design has been started to provide a preliminary demonstration of laser-programmed links in a large-area restructurable VLSI circuit. This circuit will be built on the gate array included on the bulk CMOS test wafer now being processed. The CMOS gate arrays will be customized to form multiple copies of a basic cell. Laser-programmed vias and interconnect metal will be routed in a regular pattern over the wafer in the areas around the gate array now occupied by

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test devices and circuits. After the gate arrays have been individually tested, 16 good arrays will be interconnected on the wafer by laser programming to form a complete subsystem. This feasibility test will be a precursor for the DARPA-sponsored spread-spectrum integrator chip.

V. SEMICONDUCTOR PROCESSING

A. Lithography

The direct-step-on wafer projection printer is being integrated gradually into the photolithography processing. While good line width resolution has been obtained, machine stability and level-to-level misalignment have presented difficulties.

B. Polyimide as an Ion Implant Mask

Polyimide is being investigated as an ion implant mask and shows the same stopping power as positive photoresist without thermal deformation even at ten times the ion current possible with photoresist. If the polyimide can be conveniently stripped after implant, the previously demonstrated capability of etching 0.2-μm slots in 1.5-μm-thick layers will make it a very high resolution masking material for VLSI.

VI. DEVICE THEORY, TEST, AND MODELING

A. CMOS Design Rule Checks

The problem of geometrical design rule checks becomes more difficult as the chip size increases. For our CMOS process, there are 52 rule checks which must be performed on thousands of devices whose component parts are found on nine different mask levels. Manual scanning under such conditions is impractical. Consequently, a computer program has been written which employs the Mask Design Rule Checking, MIDRC, system to check our CMOS layouts. The program must first determine which mask provides the definitive boundary for each device, e.g., N-regions, P-regions, N-inserts, P-inserts, N-transistors, P-transistors, etc. The output of the test program, written on magnetic tape, consists of plots of each of the individual device categories and a plot for each type of design-rule violation. Some P-island and poly spacing errors were found on the first mask set design. The program requires about 20 min. of CPU time on the Amdahl 470/V7 to check the CMOS mask set. Since the number of design-rule errors on a real mask set is likely to be small, it was necessary to design a test mask set to debug the checker. This set is a 50-element CMOS array which contains one rule violation in each cell. Both the test array and the rule checking program are being improved as we gain experience with the system.

B. Process Reporter Program

PROREP is a program to report the status of wafer runs, tracking them through the various fabrication steps. An initial version is now operational on the AMDAHL machine, under VM.

Using the DEFINE command, a user enters into the system a wafer-run definition which consists of global information and the process steps. Global information includes wafer ID, status, priority, technology, date, and comment. Process step definitions for each step include the

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process name, status, date, and comment. When a wafer-run process step is completed, the wafer definition is updated to reflect this change. The program produces run location sheets similar to those now being produced manually and also on-line information previously not available. A password scheme is employed to limit write access to the files.

C. Photodepopulation Spectroscopy of MNOS Diodes

Photodepopulation spectroscopy of MNOS diode devices in which negative charge has been stored indicates there are two trap levels in the nitride gap that are associated with the negative charge. These levels are presumably the nitride electron traps. Photodepopulation spectroscopy of MNOS diode devices in which positive charge has been stored is being done in an attempt to identify hole trap levels in the nitride gap.
An IBM 3277 Graphics Attachment was installed during the quarter. This equipment combines a high-speed alphanumeric display terminal with a vector-writing storage tube to provide a powerful interactive graphics system. The IBM 3277 terminal, which has been in use at the Laboratory for some time, is capable of data transmission at 1.2 Mbps, but is limited to handling alphanumeric information. The Tektronix 4000 series storage-tube terminal, also in use for some time, is capable of both alphanumeric and vector displays, but is limited to data rates of only 4800 bps on the Lincoln system. A further limitation of the Tektronix is that it must function successively as both an interactive terminal and a graphics display.

The Graphics Attachment fits between the IBM 3277 terminal and a Tektronix storage tube. This means that the display system gains the advantage of the 1.2-megabit transfer rate for graphic output. The 3277 communicates with the central computer system as usual to control the processing. Graphic output data, however, is passed through the 3277 to the Graphics Attachment where it is converted to vector form to drive the Tektronix display terminal. The 3277 controls the operation while the Tektronix is free to function as a high-speed graphic output device. Supporting software for both the Laboratory's graphics package, GRLL, and for APL has been developed.

The inevitable expansion of the ARPA Network has required an enlarged addressing capability. A new 32-bit format has been mandated. A limited, but workable, mechanism has been installed in the Lincoln host software to handle the new format. Work is in progress on a more general capability along with consideration of a rewrite of the ten-year-old code. Since Lincoln is the only current node using the VM/370 Operating System, inquiries have been received from prospective new users who also intend to run under VM/370.

Minor hardware changes during the quarter involved the conversion of two seven-track tape drives to nine track and the addition of two spindles (634 megabytes) of direct-access storage. The system now includes over six gigabytes of disk file storage, 26 tapes, and more than 400 user terminals. Further additions to each of these three subsystems are in progress.
INTRODUCTION

This section of the report summarizes progress during the period 1 August through 31 October 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, and DOE.

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Head, Division 8

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**PUBLISHED REPORTS**

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### Meeting Speeches

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<tr>
<td>5271</td>
<td>Vapor-Phase Epitaxy of InP and GaInAsP</td>
<td>P. Vohl</td>
<td>Proc. 1980 NATO-sponsored InP Workshop, Harwichport, Massachusetts, 17-19 June 1980, pp. 305-311</td>
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<tr>
<td>5071</td>
<td>Phase Diagram for LPE Growth of GaInAsP Layers Lattice-Matched to InP Substrates</td>
<td>J. J. Hsieh</td>
<td>Accepted by IEEE J. Quantum Electron.</td>
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<td>5120</td>
<td>Avalanche Multiplication and Noise Characteristics of Low Dark-Current GaInAsP/InP Avalanche Photodetectors</td>
<td>V. Diadiuk, S. H. Groves, C. E. Hurwitz</td>
<td>Accepted by Appl. Phys. Lett.</td>
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<td>5127</td>
<td>Heteroepitaxy of Ge(_{1-x})Si(_x) on Si by Transient Heating of Ge-Coated Si Substrates</td>
<td>J. C. C. Fan, R. P. Gale, F. M. Davis, G. H. Foley</td>
<td>Accepted by Appl. Phys. Lett.</td>
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<td>5129</td>
<td>A Comparison of Flash-Lamp-Excited Nd(<em>{x})La(</em>{1-x})P(_2)O(_4) (x = 1.0, 0.75, 0.20) Lasers</td>
<td>S. R. Chinn, W. K. Zwicker*</td>
<td>Accepted by J. Appl. Phys.</td>
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<td>5144</td>
<td>Low Dark-Current, High-Gain, GaInAsP/InP Avalanche Photodetectors</td>
<td>V. Diadiuk, S. H. Groves, C. E. Hurwitz, G. W. Iseler</td>
<td>Accepted by IEEE J. Quantum Electron.</td>
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5163  Efficient Si Solar Cells by Laser Photochemical Doping  
T. F. Deutsch  
J. C. C. Fan  
G. W. Turner  
R. L. Chapman  
D. J. Ehrlich  
R. M. Osgood, Jr.  
Accepted by Appl. Phys. Lett.

5167  Spectral Characteristics of External-Cavity-Controlled Semiconductor Lasers  
M. W. Fleming  
A. Mooradian  
Accepted by IEEE J. Quantum Electron.

5174  Liquid-Phase Epitaxial Growth of InP and InGaAsP Alloys  
S. H. Groves  
M. C. Plonko  
Accepted by J. Cryst. Growth

5175  Synthesis and Crystal Growth of InP  
G. W. Iseler  
Accepted by J. Cryst. Growth

5176  Vapor-Phase Epitaxy of GaInAsP and InP  
P. Vohl  
Accepted by J. Cryst. Growth

5178  Laser Microchemistry: Applications in Semiconductor Processing  
T. F. Deutsch  
R. M. Osgood, Jr.  
D. J. Ehrlich  
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Meeting Speeches*

MS No.

4530E  High-Resolution Molecular Spectroscopy Using a Tunable Difference-Frequency Laser System  
A. S. Pine  

5053B  Wideband SAW Fourier-Transform Processor Design and Applications  
R. C. Williamson  
Seminar, General Electric, Syracuse, New York, 24 September 1980

5236B, D,E  Laser-Induced Photochemical Reactions for Electronic-Device Fabrication  
J. J. Ehrlich  
R. M. Osgood, Jr.  
T. F. Deutsch  
Symposium Allied Chemical, Morristown, New Jersey, 2 October 1980; Seminar, Raytheon, Waltham, Massachusetts, 22 October 1980; Bell Laboratories, Holmdel, New Jersey, 5 November 1980

5236C  Direct-Write Laser Processing for Microelectronics  
R. M. Osgood, Jr.  
D. J. Ehrlich  
T. F. Deutsch  
VLSI Symposium, M.I.T., 7 October 1980

5248A  Acoustoelectric Signal-Processing Technology  
R. W. Ralston  
Global Positioning Satellite Seminar, Dayton, Ohio, 8 October 1980

*Titles of Meeting Speeches are listed for information only. No copies are available for distribution.
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<td>5278E</td>
<td>Graphoepitaxy of Silicon</td>
<td>M. W. Geis</td>
<td>Seminar, IBM, Yorktown Heights, New York, 19 August 1980</td>
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<td>5358B</td>
<td>The CLEFT Process: A Peeled Film Technique</td>
<td>C. O. Bozler, R. W. McClelland, J. C. C. Fan</td>
<td>1980 International Symposium on Gallium Arsenide and Related Compounds, Vienna, Austria, 22-24 September 1980</td>
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<td>5478</td>
<td>Submicrometer Structures</td>
<td>H. I. Smith</td>
<td>Intl. Conf. on Microlithography, Amsterdam, The Netherlands, 30 September 1980</td>
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SOLID STATE
DIVISION, 8

I. SOLID STATE DEVICE RESEARCH

Low-loss GaAs semiconductor optical waveguides have been formed by the lateral epitaxial growth of single-crystal GaAs over SiO₂. Single-mode rib waveguides have exhibited losses of only 2.3 dB/cm, which are 2 to 3 dB/cm lower than those generally reported for GaAs optical waveguides. Furthermore, the guides should have smaller allowable bend radii (<1 mm) than previously reported guides and could form the basis of a new class of guided-wave structures.

The gain spectra for TE polarization in a GaInAsP/InP laser have been measured as a function of DC bias current below laser threshold. The results have been used to relate the maximum net gain to the nominal current density and radiative quantum efficiency, yielding coefficients important for the optimization of laser design.

High-quality n⁺-InP layers over InGaAs have been grown from Sn solutions. The technique is generally applicable to the growth of an alloy of very low As content over one of high As content. The ability to grow these layers may facilitate the fabrication of improved InGaAs lasers and detectors operating at 1.55 μm.

II. QUANTUM ELECTRONICS

A study of the effect of averaging over a large number of pulses indicates that improvement in signal-to-noise ratio in a LIDAR system is limited by statistical variations due to atmospheric turbulence. This has motivated construction of a dual CO₂ differential-absorption system. Initial temporal correlation studies with this system have been made using various targets.

The spectral width of a GaAlAs CW single-mode diode laser has been shown to vary linearly with reciprocal output power at 300 K with a slope 50 times greater than predicted by the Schawlow-Townes expression without the partial inversion factor. Spectral narrowing observed at 77 K for constant mode power is consistent with the predicted temperature dependence of the partial inversion factor.

A program to apply the techniques of nonlinear spectroscopy to diagnostic problems in semiconductors has been initiated. Preliminary results of CARS measurements of phonons and plasmons in a number of semiconductor materials have been obtained.

Liquid N₂ Raman laser characteristics in both tight focusing and collimated-beam geometries have been investigated. A quantum conversion efficiency of 92% into the first Stokes output has been observed for the collimated-beam geometry.

Using molecular beams and a tunable submillimeter laser sideband spectrometer, sub-Doppler linewidth rotational transitions at 700 GHz have been observed for the first time. The separation between two closely spaced CH₃F lines has been measured to an accuracy of 70 kHz.

III. MATERIALS RESEARCH

It has been demonstrated that under suitable experimental conditions the deposition rate of InP layers grown by vapor-phase epitaxy varies significantly with crystallographic orientation, and this orientation dependence has been utilized to obtain structures in which single-crystal InP layers are grown laterally over phosphosilicate-glass films. Structures of this type are of potential interest as waveguides for infrared radiation in integrated optical circuits.
Since amorphous films in the Ge-Si alloy system, as well as films which have undergone amorphous-to-crystalline transitions, have potential applications in solar cells and other devices, differential scanning calorimetry has been used to measure the transition temperature ($T_t$) and latent heat of crystallization ($\Delta H_l$) for $Ge_{1-x}Si_x$ films covering the entire composition range from Ge to Si. The measured values of $T_t$ and $\Delta H_l$ (per gram) increase linearly with $x$.

Heteroepitaxial Ge films have been grown by solid-phase epitaxy (SPE) on single-crystal $<100>$ Si substrates and then treated by ion implantation and reannealing to reduce their twin density. Heteroepitaxial GaAs layers of good crystal quality have been grown by chemical vapor deposition on the reannealed Ge films, indicating that it should be possible to use SPE-Ge/Si substrates in the fabrication of low-cost, high-efficiency GaAs thin-film solar cells.

IV. MICROELECTRONICS

The low-light-level characterization of the 100-× 400-element CCD imager being built for the GEOSS (Ground-based Electro-Optical Deep Space Surveillance) Program has continued. Charge transfer inefficiency of $1.2 \times 10^{-4}$ per transfer has been measured for charge packets of about 100 electrons, and for larger charge packets a value of less than $1 \times 10^{-5}$ per transfer has been measured for packets up to 500,000 electrons. Low-light-level operation of the device has revealed a heretofore unobserved trapping mechanism in isolated CCD wells.

Long-term anneals in a hydrogen ambient at temperatures compatible with aluminum metallization ($\leq 500^\circ C$) have proven effective in removing surface states at the SiO$_2$-Si interface in dual-dielectric ($Si_3N_4$ over SiO$_2$) gate structures where the $Si_3N_4$ acts as a diffusion barrier to the hydrogen. The annealing takes place by lateral diffusion of hydrogen through the SiO$_2$ under the $Si_3N_4$, and is initiated at the periphery of the device at openings in the $Si_3N_4$ layer. Rate measurements of this process made on the GEOSS imager using video techniques are in agreement with published results.

Variations in input-gate capacitance and threshold voltage among the multiple inputs of the previously reported CCD programmable transversal filter structures limit the dynamic range and bit accuracy of these devices. The current CCD fabrication process has reduced the relative input-gate capacitance variation to less than 1% on a typical device, and by eliminating the boron offset implant under the surface channel input gates, the threshold voltage variation has been reduced to a 1σ value of 2 mV.

A technique has been developed for integrating Schottky-barrier mixer diodes and FETs in a monolithic GaAs receiver for operation at 31 GHz. For IFs between 2.0 and 2.3 GHz, the conversion gain and noise figure are approximately 4 and 11.5 dB, respectively. Measurement and analysis indicate that with improved matching and two IF amplifier stages a noise figure below 10 dB and a conversion gain of 14 dB can be achieved.

An all-polyimide mask for the proton exposure of resists has been developed, and a resolution of 1.2 μm has been demonstrated with a grating pattern of 1.2-μm lines on 3.8-μm centers. The mask consists of a freestanding polyimide membrane about 2 μm thick with the pattern etched into the membrane to a depth of 1 μm by oxygen reactive-ion etching.

The crystallographic and electrical properties of graphoepitaxial silicon films in which the crystallization was induced with a strip-heater oven have been measured and compared with the properties of graphoepitaxial silicon films in which the crystallization was induced with a scanning laser. The range of orientations of the crystallites in the silicon was considerably reduced for the strip-heater-oven crystallized films. FETs fabricated in oven-crystallized
silicon have surface mobilities between 300 and 460 cm²/V-s, while similar devices could not be fabricated in laser-crystallized films because of surface microcracks.

V. ANALOG DEVICE TECHNOLOGY

A wideband, low-loss, temperature-stable matched filter has been developed using surface-acoustic-wave (SAW) reflective-array-compressor (RAC) technology. This device is fabricated on a special cut of quartz. It has a time-bandwidth (TB) product of 1900, which is comparable with TB products achieved with conventional LiNbO₃, but with a temperature stability about 100 times better than LiNbO₃ RACs. The quartz RAC incorporates both edge-bonded transducers to achieve 40% fractional bandwidth and beam-steering compensation in the etched reflection gratings to achieve 38-μs dispersion.

Controllable attenuation of SAWs on LiNbO₃ has been accomplished by using resistive cermet films. Attenuation varying from 0.06 to 0.4 dB/wavelength at 300 MHz was obtained by using sputtered 70% Cr₂O₃ - 30% Cr films about 1000 Å thick. These rugged and stable films have been used in RAC devices as a contaminant-free method of suppressing edge reflections in order to eliminate spurious responses. Such films appear appropriate to trim the amplitude response of RACs as well.

A hybrid analog/binary signal-processing technique has been developed which offers 40 to 60 dB of processing gain for spread-spectrum communication and wideband radar systems. The hybrid approach is a generic concept which very effectively combines the attributes and compensates for the limitations of the separate techniques alone. Hybrid processing can be implemented with several technologies. A preliminary demonstration employing SAW convolvers with Si integrated circuits has provided the expected 46-dB signal-processing gain.
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