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Final Technical Report
October 1977

MICROBEAM ANALYSIS TECHNIQUES FOR ICs

Texas Instruments Incorporated

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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The ion microprobe mass analyzer was used for a general chemical characterization of actual integrated circuits. Simple operational amplifiers, general purpose amplifiers, inverters, emitter coupled flip-flops, and radiation hardened NAND gates were chosen as representative of the bipolar family. CMOS gates with both doped and undoped oxides and CMOS-SOS devices represented the field effect device family. All devices were randomly chosen without regard to actual operational characteristics.

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The analysis technique was designed to determine impurities at the surface, in the deposited oxide, in the thermal oxide, in the metallization, and at the various interfaces between these layers. The identification of the intentional dopants in the silicon was performed where concentrations were above the detection limit. In-depth concentration profiles of intentional dopants such as phosphorus were obtained by monitoring the dopant ion signal as a function of sputter time. A quantitative estimate of some of the common dopants and/or impurities was accomplished using an emperical calibration. Depths were determined by emperically calibrating the sputter rates as a function of area, total primary ion current, and primary ion species. Interface regions were identified by sputter time analysis of layers where successive layers have an elemental matrix change. The interfaces between layers of similar matrix elements, such as deposited oxide - thermal oxide were assumed to have the same sputter time as dissimilar matrices, i.e., deposited oxide over metal has the same thickness and sputter characteristics as over thermal oxide. Negative or positive oxygen was used as the primary sputtering ion for data collection. Positive argon was used as the primary sputtering ion for data collection. Positive argon was used to rapidly sputter through layers for interfacial analysis. Dielectric films were observed to be contaminated with carbon, fluorine, tin, lead, barium and other impurities, while oxides over nichrome resistors were observed to contain lead and tin.

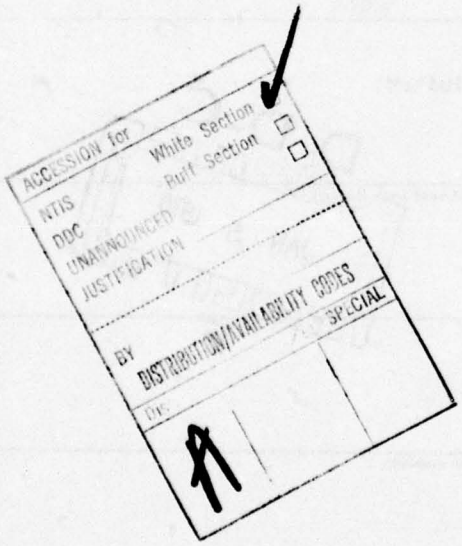

TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

LIST OF APPENDIXES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

(Continued)

LIST OF TABLES

EVALUATION

This technical report describes the chemical evaluation of a variety of microcircuits using the ion microprobe mass analyzer. The data are presented in sufficient detail to permit a critical evaluation of the strengths and limitations of this secondary ion mass spectrometry technique especially for small scale integrated circuit analysis.

The description of the role that the IMMA can have in conjunction with other more standard analytical techniques such as electron probe analysis, Auger electron spectroscopy and scanning electron microscopy is valuable to those individuals responsible for decisions on how to approach device chemical characterization and failure analysis.

The study has shown that many of today's questions can be answered with available instrumentation. The challenge remains to refine and apply these analytical techniques to the study of large scale integrated microcircuits. While costly and time-consuming these efforts are necessary and proper for the assurance of the reliable design and performance of future electronic devices.

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SECTION I
INTRODUCTION AND SUMMARY

The objective of Contract No. F30602-76-C-0316 was to apply secondary ion mass spectroscopy (SIMS) using an ion microprobe mass analyzer (IMMA) to evaluate the chemical nature of the laminar structures found in integrated circuits. This application was effected through the analysis of specific devices supplied by RADC. These devices were in two classes: (1) CMOS group and (2) general technology group.

Some of the major accomplishments under this contract were:

(1) Establishment of integrated circuit sample preparation and coating procedures to enable the successful use of the IMMA on such devices.

(2) Identification and in-depth characterization of heretofore undetected impurities in integrated circuit structures, e.g., F and Li.

(3) Development and application of an Ar^{+}_{40} ion sputtering technique for the localization and identification of interfaces.

(4) Measurement of the in-depth concentration profiles of dopants in specific areas of integrated circuits, e.g., P in SiO_2.

(5) Establishment of the spatial resolution capabilities of the IMMA technique for integrated circuit analysis.

(6) Determination of the most probable detection limits for impurities in structures on devices.

(7) Prognostication of the role of secondary ion mass spectroscopy and the ion microprobe mass analyzer in device failure analysis and materials characterization.

The remainder of this report is organized as follows. The status of various microbeam characterization techniques is discussed in Section II. The ion microprobe mass analyzer is described in Section III. Sample analysis procedures are detailed in Section IV. The analytical results for the CMOS

technology group are given in Section V and those of the general technology group in Section VI. Conclusions are given in Section VII and Recommendations in Section VIII.

SECTION II
STATUS OF MICROBEAM TECHNIQUES

Two types of microbeam techniques, electron and ion beam, are available for the characterization of integrated circuit structures and microdefects in silicon materials. The most widely used techniques with their associated acronyms are shown in Table 1. Initial examination might seem to indicate the duplication of techniques in this list. However, it is important to understand that while scanning Auger microscopy (SAM) is Auger spectroscopy (AES), the converse is not true. SAM has microbeam capability, while AES does not. Similarly, while ion microprobe mass analysis (IMMA) is secondary ion mass spectroscopy (SIMS), again, the converse is not true. This difference is best shown in Table 2 where the diameter of the analysis area is shown for each analytical technique. As can be seen, the electron beam techniques have significantly better resolution capabilities and can simultaneously perform microanalysis and high resolution imaging. The ion beam techniques generally cannot analyze areas as small as 10 μm in diameter, nor do they have high resolution imaging capabilities. To achieve optimum resolution, all characterization techniques must use small beam diameters, and inherent with small beam diameters are small beam currents. As a result, at optimum resolution all techniques have the smallest beam currents and therefore substantially degraded elemental sensitivities. This is shown in Table 3, where both analysis area and depth of analysis are taken into consideration. It is readily apparent that detection limits for all techniques are in the percent range. The ion beam techniques have the better sensitivities.

To obtain maximum analytical sensitivity, it is necessary to maximize the analytical volume, as shown in Table 4. The diameters analyzed can become quite large, particularly for the analysis of integrated circuit structures. The IMMA and SIMS techniques have the best analytical sensitivities. IMMA covers one specific class of SIMS instruments because it is a microbeam technique. SIMS, on the other hand, covers many different instruments, from the ion microscope to inexpensive quadrupole mass spectrometers attached to broad beam (~ 1 mm) ion sputtering techniques such as ISS, AES, and ESCA or XPS.

TABLE 1. ELECTRON AND ION MICROBEAM TECHNIQUES USED FOR INTEGRATED CIRCUIT AND SILICON ANALYSIS

Electron Beam	Acronym
Auger Electron Spectroscopy	AES
Electron Microprobe	EMP
Scanning Auger Microscopy	SAM
Scanning Electron Microscopy	SEM
SEM with Silicon Detector	SEM-Si (Li)

Ion Beam	Acronym
Rutherford Backscattering	BS
Ion Induced X-Ray Fluorescence	IIXF
Ion Microprobe Mass Analysis	IMMA
Ion Scattering Spectroscopy	ISS
Secondary Ion Mass Spectroscopy	SIMS

TABLE 4. MAXIMUM SENSITIVITY: ASSOCIATED ANALYTICAL VOLUME AND PROBE DIAMETER

Technique	Detection Limit, ppma	Minimum Detection Limit		Volume cc Analyzed	Diameter Analyzed
		Atoms	Grams		
Electron Beam					
AES	1000 - 10,000	2×10^{9}	1×10^{-13}	1×10^{-10}	250 μm
EMP	100 - 10,000	2×10^{10}	8×10^{-13}	8×10^{-9}	25 μm
SAM	1 - 50%	3×10^{5}	2×10^{-17}	2×10^{-15}	1 μm
SEM-Si(Li)	100 - 10,000	2×10^{10}	8×10^{-13}	8×10^{-9}	25 μm
Ion Beam					
BS	100 - 10,000	2×10^{11}	8×10^{-12}	8×10^{-8}	0.1 cm
IIXF	1 - 100	4×10^{10}	2×10^{-12}	2×10^{-6}	0.1 cm
IMMA	0.01 - 100	1×10^{5}	5×10^{-18}	2×10^{-10}	150 μm
ISS	10,000	2×10^{13}	1×10^{-9}	4×10^{-9}	0.1 cm
SIMS	0.1 - 1000	2×10^{6}	1×10^{-16}	5×10^{-10}	250 μm

Assumptions used for calculating volume analyzed:

AES - 2 nm x 250 μm diameter

EMP and SEM-Si(Li) - 25 μm diameter sphere

SAM - 2 nm x 1 μm diameter

BS - 100 nm x 1 cm diameter

IIXF - 2.5 μm x 0.1 cm diameter

IMMA - 10 nm x $(150\ \mu m)^2$

ISS - 5 nm x 0.1 cm diameter

SIMS - 10 nm x 250 μm diameter

The effect of analysis area is best shown in Figure 1, which is a plot of "typical" detection limits versus the diameter of the analyzed area. Superimposed on this figure are shaded areas that show the detection limits and diameters of areas of interest in integrated circuits analysis. Notice that only IMMA and SIMS are applicable for the determination of impurities and dopants in silicon. The electron beam techniques, SEM-SI(Li), EMP, and SAM have excellent resolution, but detection limits that prevent measurement of chemical variations within integrated circuit dielectric films and diffused silicon areas. The importance of IMMA, an ion microbeam technique, as a potential technique for integrated circuit analysis can be seen in this figure. The work in this report was directed toward establishing the capabilities of IMMA for device failure analysis.

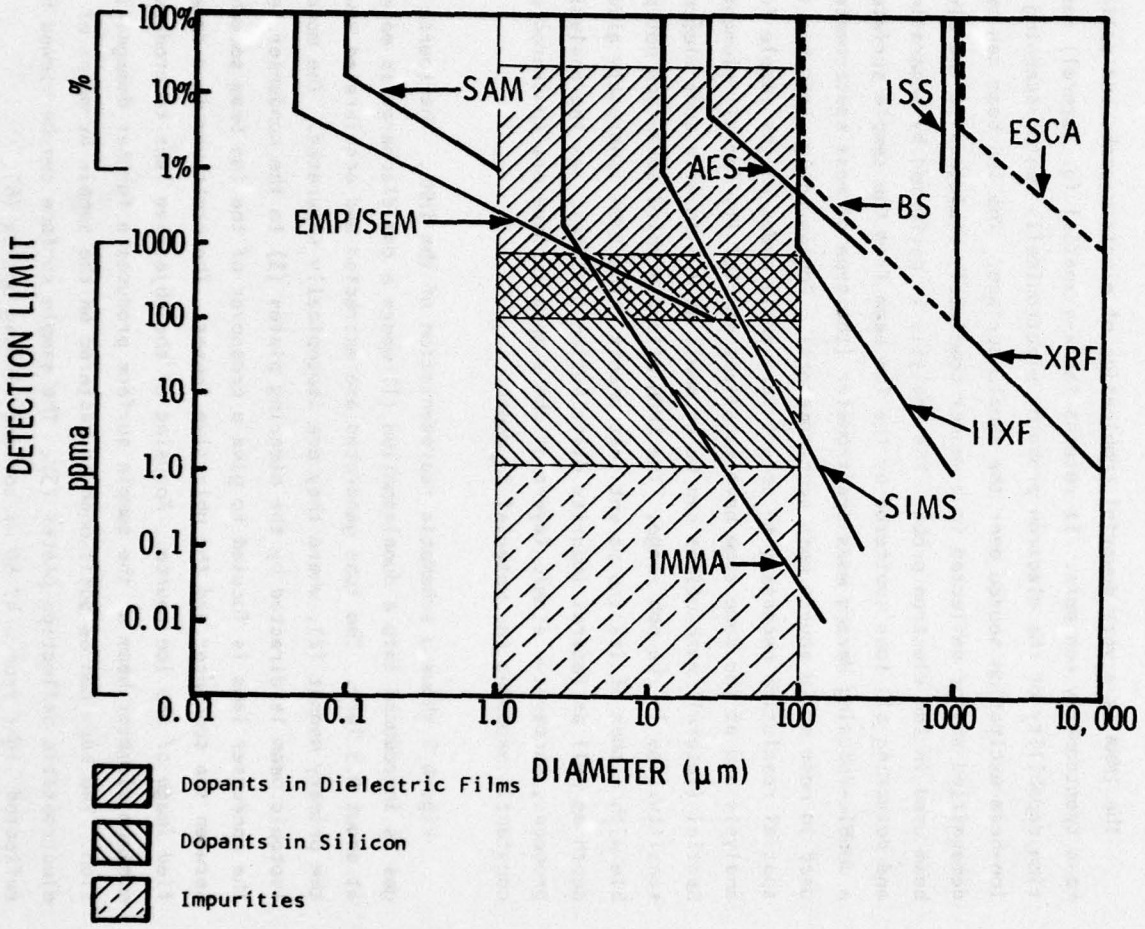

Figure 1 Effect of Diameter of Analyzed Area on Detection Limit

SECTION III
ION MICROPROBE MASS ANALYZER

The IMMA is a very powerful combination of electron-probe and solids mass spectrometry concepts. It retains the x-y spatial (or lateral) resolution capability of the electron probe by electronically raster-scanning an ion-beam excitation source over the sample surface. The ion beam can be demagnified and/or deflected in a manner completely analogous to the electron beam used in the electron probe. The analysis is performed by separating and detecting all ions sputtered by the ion beam from the sample surface with a double-focusing Herzog mass spectrometer (the type of mass spectrometer used in most solid source mass spectrometers). Consequently, IMMA has the spatial resolution necessary to select very small areas on the sample for analysis and at the same time have excellent sensitivity for all elements. Spatial (lateral) resolutions can be as small as 2.5 μm with some elemental sensitivities in the ppb range. The IMMA offers a third advantage not possible with either of its two parent instruments. The IMMA inherently gives depth as well as lateral impurity distribution profiles: as the analysis proceeds, successive atomic layers of the sample surface are sputtered away, constantly exposing the material in depth.

Figure 2 shows a schematic representation of the IMMA. The source ion gas is introduced into a duoplasmation (1) where a gas discharge is maintained at about 0.3 Torr. The ions generated are extracted and accelerated toward the primary magnet (2), where they are isotopically separated. The monoisotopic beam is directed by the steering plates (3) to the condenser lens (4). The condenser lens is focused to give a crossover of the ion beam somewhere between the condenser and the objective lenses. The crossover is a demagnified image of the ion source. Focusing of the objective lens to produce a minimum diameter beam at the sample surface produces a further demagnification. The beam can be positioned or rastered on the sample by means of the electrostatic deflection plates (5). The sample surface can be viewed by reflected light from a 47.50 mirror and viewing optics (6).

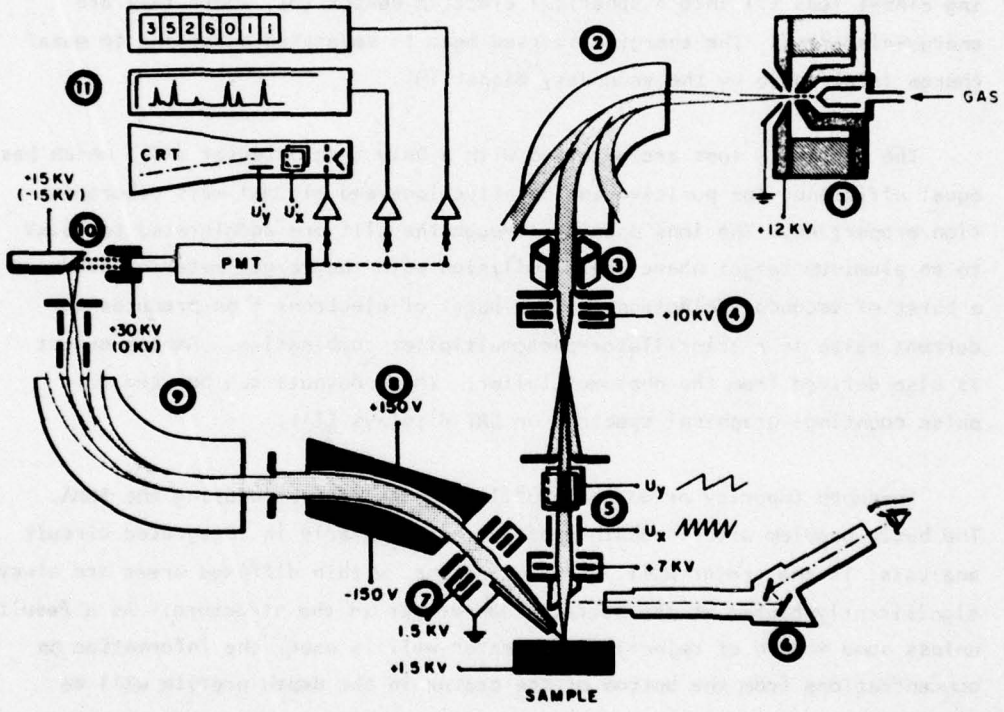

Figure 2 Schematic of the Applied Research Laboratories Ion Microprobe Mass Analyzer

The impact of the primary beam on the sample results in both implantation of primary ions and sputtering of the sample surface. The sputtered, or secondary, ions are accelerated to a pickup electrode by a bias potential applied to the sample. The polarity of the ions collected is controlled by polarity of this potential bias. The collected ions pass through a focusing Einzel lens (7) into a spherical electric sector (8), where they are energy-dispersed. The energy-dispersed beam is separated according to mass/charge (m/e) ratio by the secondary magnet (9).

The secondary ions are detected with a Daly type detector (10), which has equal efficiency for positive and negative ions and minimal mass discrimination properties. The ions passing through the slit are accelerated to 15 kV to an aluminum target where their collision with the target material produces a burst of secondary electrons. This burst of electrons then produces a current pulse in a scintillator-photomultiplier combination. Analog output is also derived from the photomultiplier. These outputs can be used for pulse counting, graphical spectra, or CRT displays (11).

In-depth impurity or dopant profiles can be performed using the IMMA. The basic problem with in-depth profiles, particularly in integrated circuit analysis, is the crater wall. Concentrations within diffused areas are always significantly higher at the surface than deeper in the structure. As a result, unless some method of rejecting the crater wall is used, the information on concentrations from the bottom of the crater in the depth profile will be dominated by the high surface concentration. The IMMA circumvents this problem by rastering the ion beam in the form of a rectangle as shown in Figure 3. The sputtered ions are accepted or rejected by electronic gating of the detector, depending on the position of the sputtering ion beam. In Figure 3, this is illustrated by the inner rectangle where the detector is gated on at point A of the raster and off at point B. This inner rectangle is commonly referred to as an electronic aperture of secondary ion acceptance.

The IMMA, as described in this section, has been used for all the analyses on the integrated circuits described in the remaining sections of this report.

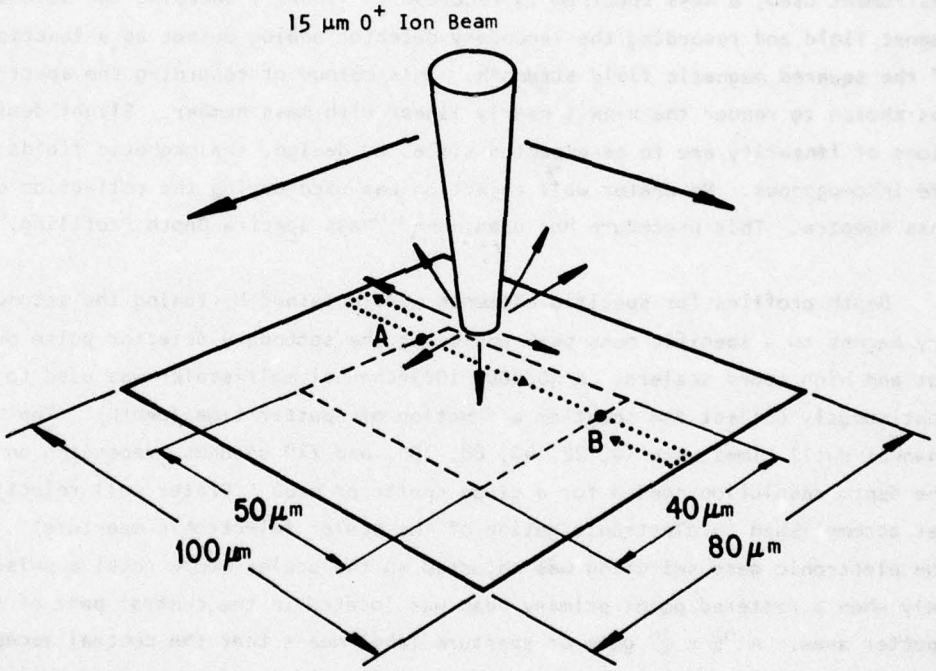

Figure 3 Illustration of Electronic Gating

SECTION IV
SAMPLE ANALYSIS PROCEDURE*

The analysis procedure most commonly used was to sputter the area of interest and collect complete mass spectra as a function of time. In the instrument used, a mass spectrum is recorded by linearly sweeping the secondary magnet field and recording the secondary detector analog output as a function of the squared magnetic field strength. This method of recording the spectrum was chosen to render the x-axis nearly linear with mass number. Slight deviations of linearity are to be expected since, by design, the magnetic fields are inhomogenous. No crater wall rejection was used during the collection of mass spectra. This procedure has been named "Mass Spectra Depth Profiling."

Depth profiles for specific elements were obtained by tuning the secondary magnet to a specific mass peak and using the secondary detector pulse output and high speed scalers. A ND2400, 1023-channel multiscaler was used to continuously collect the count as a function of sputter time (depth). The channel dwell times were 10, 22, 40, 88, 100, and 220 seconds, depending on the depth resolution needed for a given sputtered area. Crater wall rejection was accomplished by electronic gating of the scaler (electronic aperture). The electronic gate switching was adjusted so the scaler would receive pulses only when a rastered point primary beam was located in the central part of the sputter area. A "$\frac{1}{4} \times \frac{1}{4}$" gate or aperture label means that the central acceptance area was one-fourth the X raster dimension and one-fourth the Y raster dimension. Two masses can be monitored nearly simultaneously by electrostatic peak switching just before the secondary detector entrance slit. The requirement is that both mass peaks must simultaneously pass through the analyzing magnet and be resolved. Normally, this is true for masses of $M \pm 0.07M$. The switching is done between the two masses every 100 ms with a 10 ms pause in a blank position. This feature allowed mass pairs such as Si-P, Cr-Ni, Si_2O-As, etc., to be collected from the same sputtered crater. This technique has been named "Point Count Depth Profiling."

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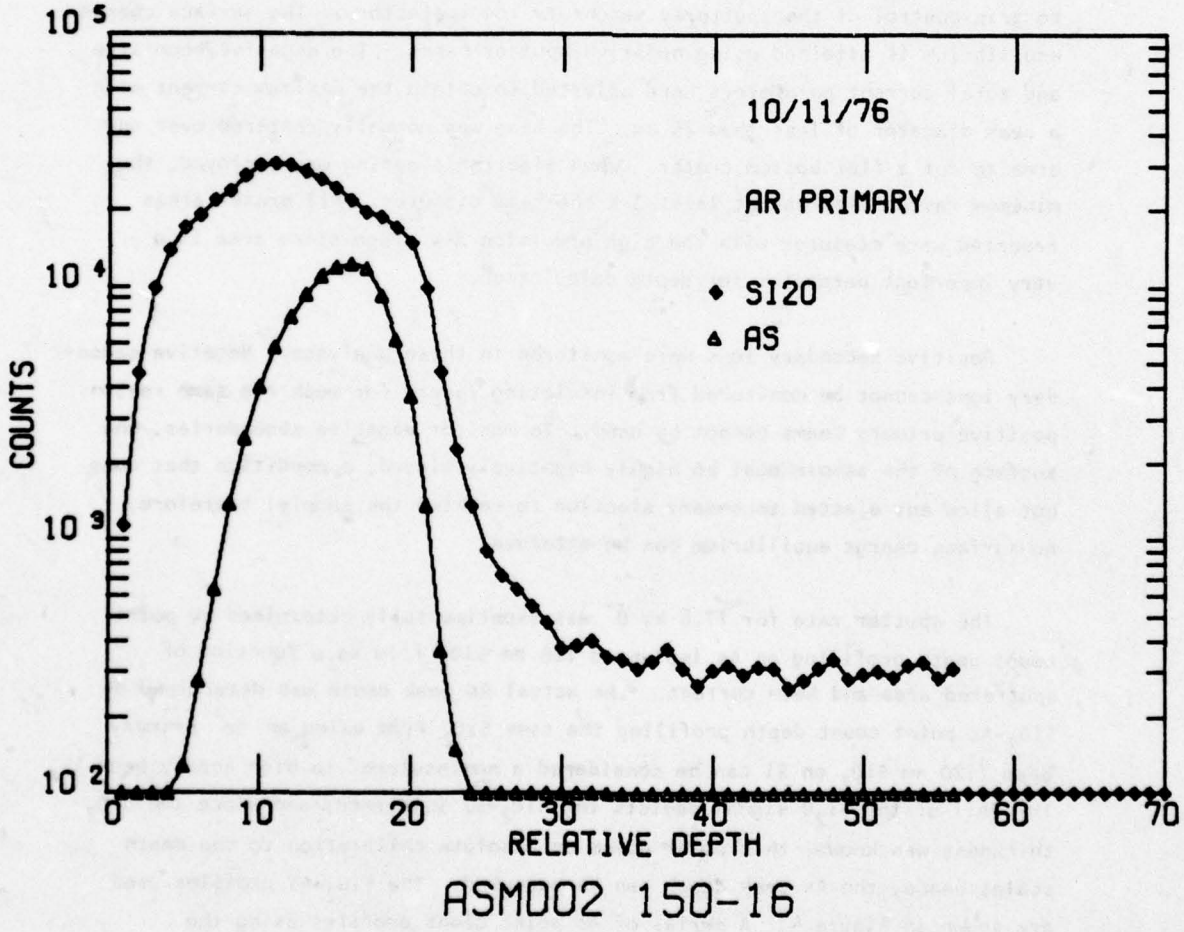
* Sample preparation procedures developed and employed are discussed in Section VII.A of this report.

The primary beam used for all data collection on devices where thick oxide remained intact was 17.8 kV O^- (negative oxygen). Positive primary beams could not be used since the ejection of secondary electrons from the sample upon impact and simultaneous injection of positive particles render it impossible to reach an equilibrium surface charge state, which is mandatory to gain control of the sputtered secondary ion trajectory. The surface charge equilibrium is attained using negative sputter beams. The negative beam size and total current parameters were adjusted to obtain the maximum current with a beam diameter of less than 25 μm. The beam was normally rastered over an area to cut a flat bottom crater. When electronic gating was employed, the minimum raster size was at least 3 X the beam diameter. All crater areas reported were measured with the high precision x-y stage since area is a very important parameter for depth calculation.

Positive secondary ions were monitored in these analyses. Negative secondary ions cannot be monitored from insulating layers for much the same reason positive primary beams cannot be used. To monitor negative secondaries, the surface of the sample must be highly negatively biased, a condition that does not allow any ejected secondary electron to reenter the sample; therefore, no surface charge equilibrium can be attained.

The sputter rate for 17.8 kV O^- was experimentally determined by point count depth profiling an As implanted 120 nm SiO_2 film as a function of sputtered area and beam current. The actual As peak depth was determined by SiO_2-As point count depth profiling the same SiO_2 film using an Ar^+ primary beam (120 nm SiO_2 on Si can be considered a noninsulator to high energy beams). The fall of the Si_2O signal depicts the SiO_2-Si interface, and since the SiO_2 thickness was known, this point gives an absolute calibration to the depth scale; hence, the As peak depth can be measured. The SiO_2-As profiles used are shown in Figure 4. A series of As point count profiles using the 17.8 kV O^- beam for this calibration is shown in Figure 5. A summary of the sputter rate determination is given in Table 5.

Ar^+ ion sputtering was used for rapid sputtering through the glassivation for an interface analysis. The preceding discussion on the inapplicability of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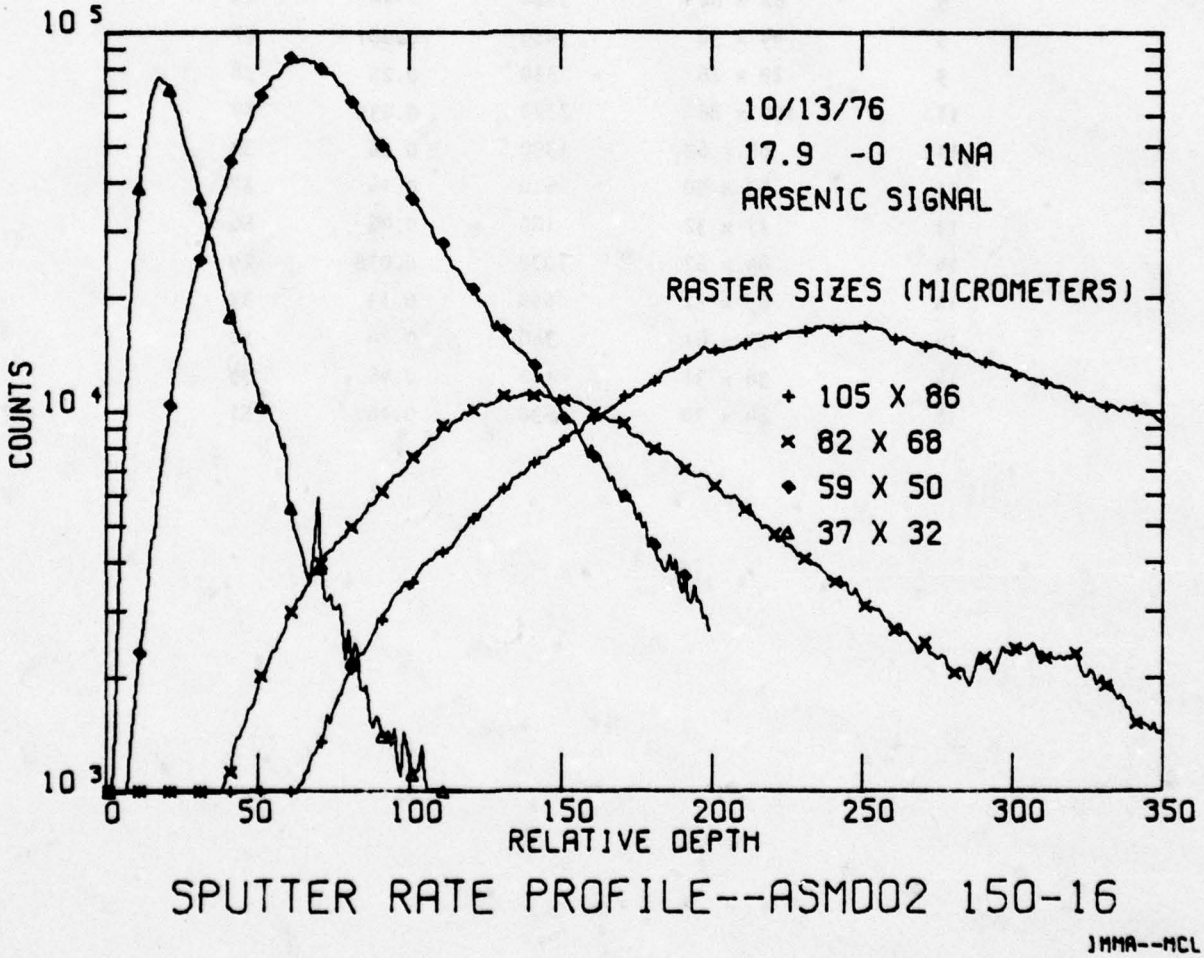
10 4
10 3
10 2
COUNTS
10/11/76
AR PRIMARY
SI20
AS
0
10
20
30
40
50
60
70
RELATIVE DEPTH
ASM002 150-16
JMMA--MCL

Figure 4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+ 105 X 86
× 82 X 68
• 59 X 50
37 X 32
0
50
100
150
200
250
300
350
RELATIVE DEPTH
SPUTTER RATE PROFILE--ASM002 150-16
JMMA--MCL

Figure 5

TABLE 5. SPUTTER RATE FOR 17.9 O^- PRIMARY BEAM

Beam Current nA	Raster Size (μm x μm)	Sec to 83.4 nm	nm/Sec	$\frac{(nm)\ (\mu m^2)}{(Sec)\ (nA)}$
5	82 x 68	3880	0.021	24
5	44 x 38	1030	0.081	27
5	29 x 26	330	0.25	38
11	105 x 86	2370	0.035	29
11	85 x 69	1390	0.06	32
11	59 x 50	610	0.14	37
11	37 x 32	180	0.46	50
14	84 x 62	1070	0.078	29
14	68 x 52	650	0.13	32
14	53 x 41	340	0.24	38
14	38 x 31	180	0.46	39
18	84 x 70	530	0.16	51

positive primary beams applies only to secondary ion detection, not sample sputtering. The time necessary to sputter through the glassivation was determined by sputtering a small crater over aluminum metallization and monitoring the Al^+ signal. At the aluminum layer, the sputtered surface becomes a conductor with a major matrix change which is apparent in the Al^+ signal. Large craters were opened in selected interface analysis areas using the reciprocity relationship among depth, current, and area. The actual interface analysis used a 17.8 kV O^- beam that was rastered in only the central part of the area opened; this, in effect, gave surface and crater wall rejection.

All mass spectra were taken with a 4.8 mm entrance aperture (α) and a 12.7 mm exit aperture (β) for the energy analyzer. A 0.25 mm resolving slit was used between the momentum analyzer and secondary ion detector. These parameters give a resolution number ($M/\Delta M$ at 10% valley) of 320, which is sufficient to resolve the Pb isotopes. The point count depth profiles normally used the same α and β apertures with a 0.5 mm resolving slit for a resolution number of 190.

The sample chamber vacuum attained before analysis with no oxygen leak to the duoplasmatron was 1 to 5 x 10^{-8} torr. The sample chamber pressure increased to about 4 x 10^{-7} torr during analysis when the duoplasmatron was pressured at 200 to 300 torr. The vacuum was measured by the ion pump current.

SECTION V
CMOS TECHNOLOGY GROUP

The general analyses of the entire CMOS technology group (about 300 mass spectra) are summarized qualitatively in Table 6. The symbols used in this table are T for trace (just detectable), S for small quantity, M for medium amounts, and L for large concentrations such as P in phosphosilicate glasses. The symbol was entered if the element was detected in any mass spectrum from any area on the device. Appendix A contains a more detailed analysis of Set #1 spectra, along with optical pictures identifying the exact areas sputtered. Scanning electron micrographs of each area analyzed, depicting oxide defects, metallization problems, and silicon quality, are included for one set of circuits.

A. CMOS-Undoped Silicon Dioxide Gate Circuit on Sapphire Substrate

CMOS-SOS-clean oxide, Unit #739: An Aℓ-P peak count depth profile was prepared to show the variation in P concentration through the glassivation into the thermal oxide. The raster was cut over oxide as well as aluminum metal to sample the thermal oxide. The profile is shown in Figure 6. The phosphorus concentration increased until the glassivation-aluminum interface was reached at about 280 to 300 nm. At this point, the P decreases slightly due to the reduced oxide surface area. This suggests the thermal oxide is uniformly doped with P. Figure 7 shows the F-Ca (Ca^{+2}) depth profile of an area over n-type channels. The profile indicates Ca is highly localized at the surface, in contrast to the F, which has concentration maxima and minima as a function of depth. Figure 8 shows a quantitative P profile of the oxide in the n-channel region. The P levels are at about 1.5×10^{21} atoms/cc. Attempts to strip the circuit stepwise using HF gas were unsuccessful because the first one-minute exposure removed all the oxide and metal over oxide. The surface mass spectra of the device after this chemical stripping were very complicated, showing strong impurity peaks (see Appendix A). Figures 9 and 10 show the relative B-P concentrations found in n-channel and p-channel regions. Figures 11 and 12 are attempts to determine the Aℓ up-diffusion from the sapphire during

TABLE 6. CMOS TECHNOLOGY GROUP

DEVICE		Li	B	F	Na	Mg	P	Cl	K	Ca	Ti	Cr	Ni	Cu	Zn	Ga	Mo	Ag	Sn	Ba	Pb
SOS	739			M	M	M	L		M	L	M	S		T	T				S		
SOS	746	T	M	M	M	S	L		S	L	S	T		T	T	T			T		T
SOS	743		T	S	S	T	L		S	T	T										
BULK CLEAN	R202	T		T	L	M	T		M	M	T	S		T	T			T	T		
BULK CLEAN	R203			T	S	T			T	S	T	T		T		T			T		
BULK CLEAN	R198																				
NAND GATE	86			T	S	T	L		S	T	T	T		T			T	T			
NAND GATE	63	T	T	T	S	T	L		M	M	T	T	T	T		T		T	T		
NAND GATE	50	T	T	T	S	T	L		S	S		T									
Cr DOPED	504	T	T	T	S	S	T		S	S	T	T		T	T				T		
Cr DOPED	506	T	T	T	T	T	T		T	S	T	L		T	T				T		T
Cr DOPED	500																				
Al IMPLANT	890		T	T	T	T	T		T	T	T	T		T	T				T		
Al IMPLANT	92		T	T	T	T	T		T	S	T	T		T	T						
Al IMPLANT	25	T	T	T	S	T	T		T	T	T	T		T	T		T				
Al_2O_3	A259	T	T	T	S	T	T		S	T	T	T		T	T			T	T		
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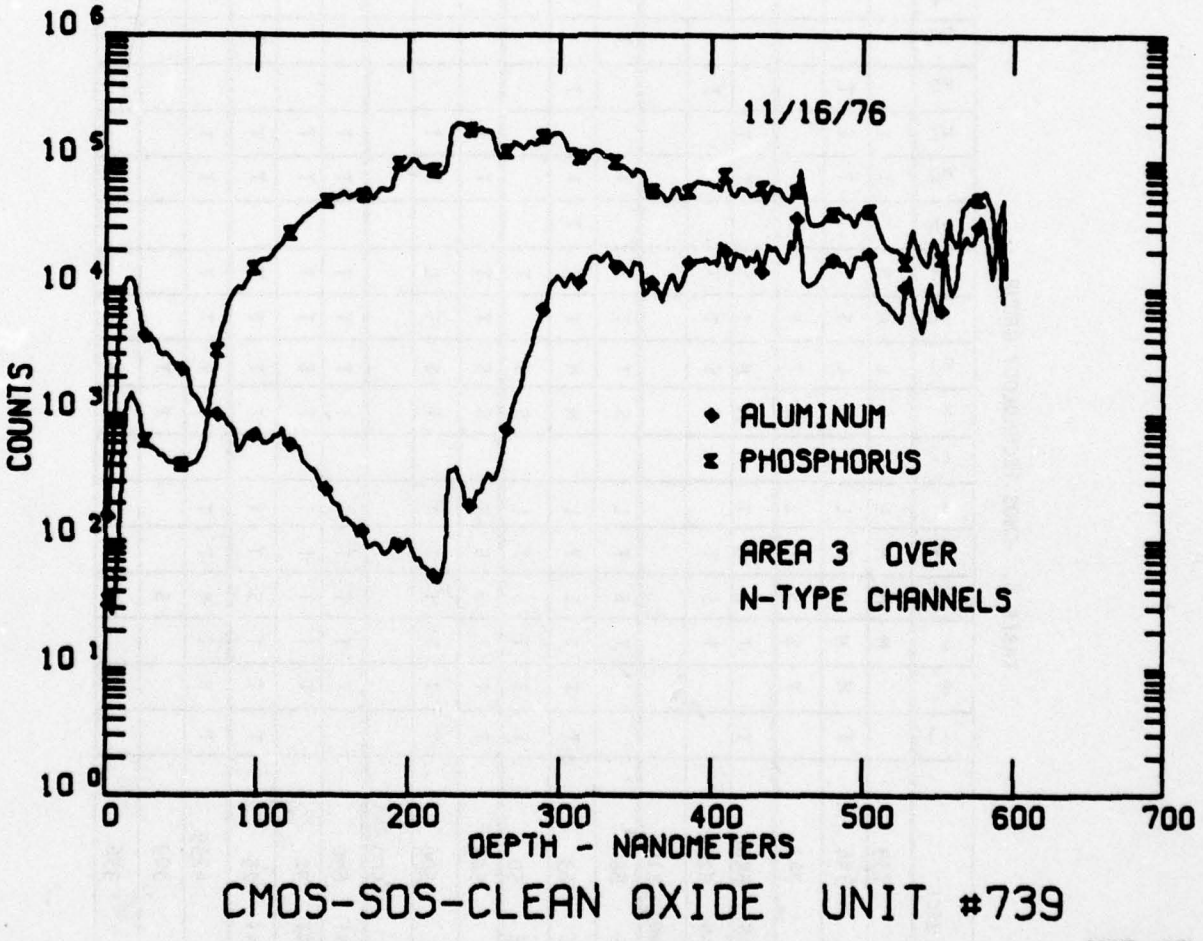
Al_2O_3	356				T	T			T	S											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DEPTH - NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JMMA--MCL

Figure 6

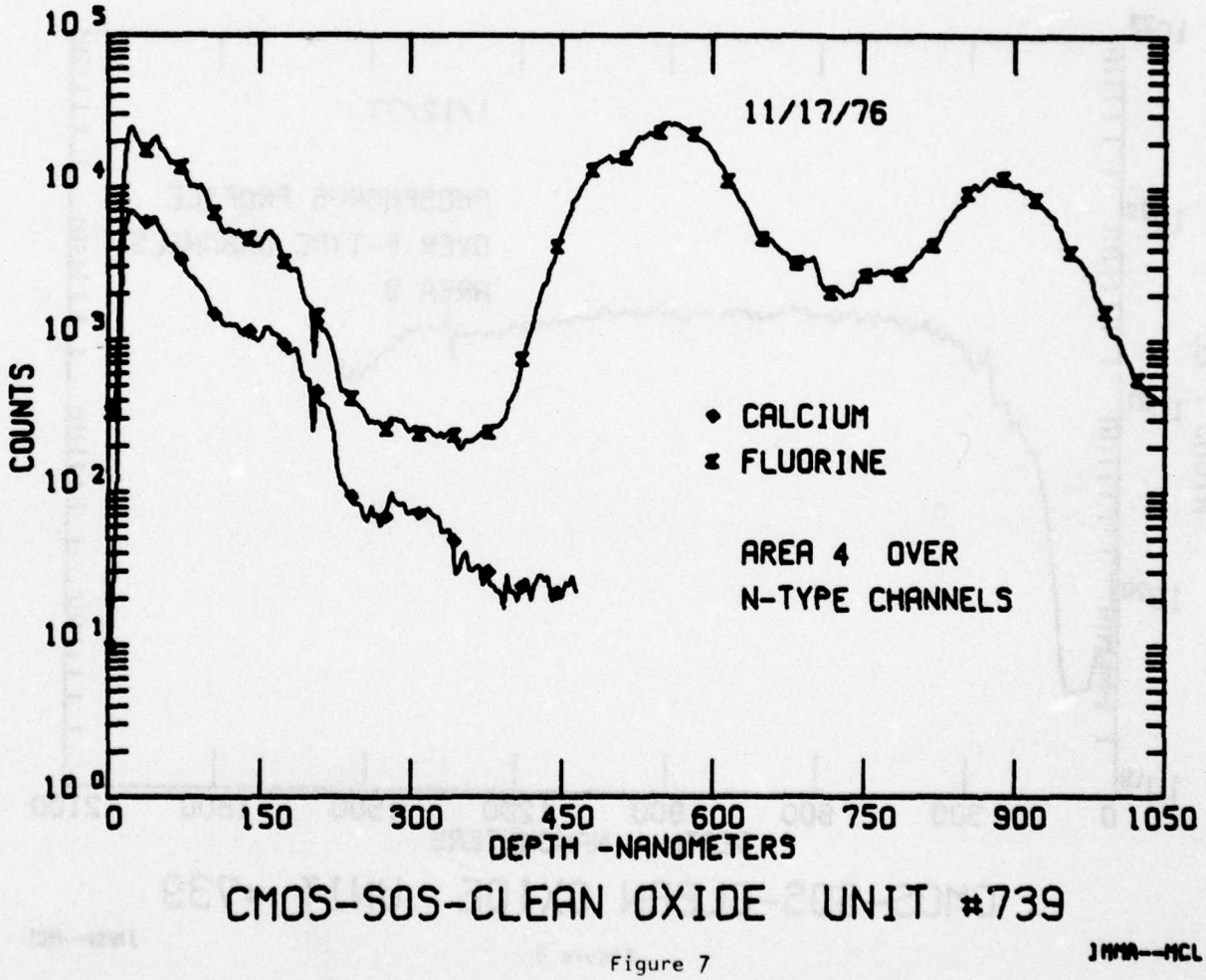

11/17/76
CALCIUM
FLUORINE
AREA 4 OVER
N-TYPE CHANNELS
COUNTS
DEPTH -NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JMMA--MCL

Figure 7

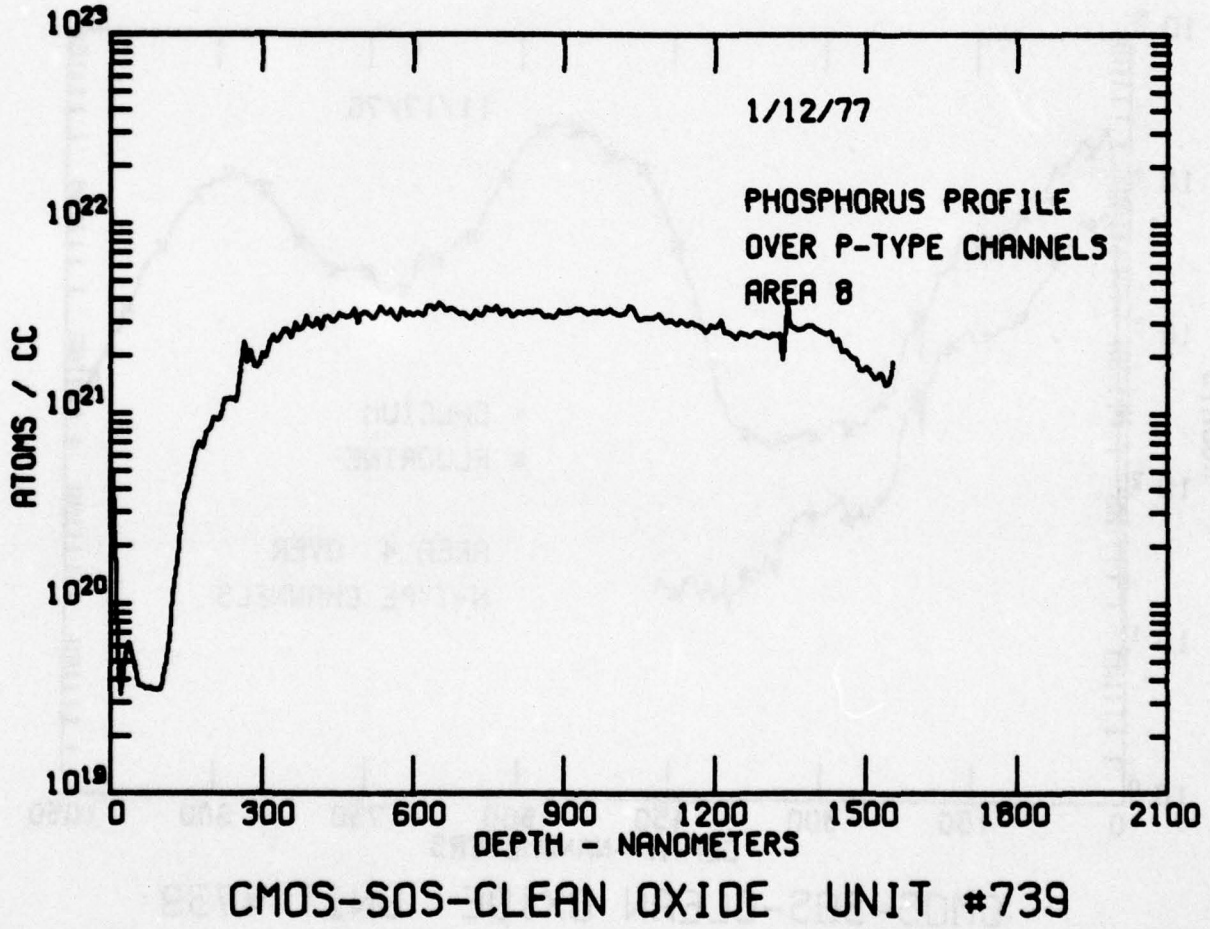

1/12/77
PHOSPHORUS PROFILE
OVER P-TYPE CHANNELS
AREA 8
ATOMS / CC
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
0
300
600
900
1200
1500
1800
2100
DEPTH - NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JMM--MCL

Figure 8

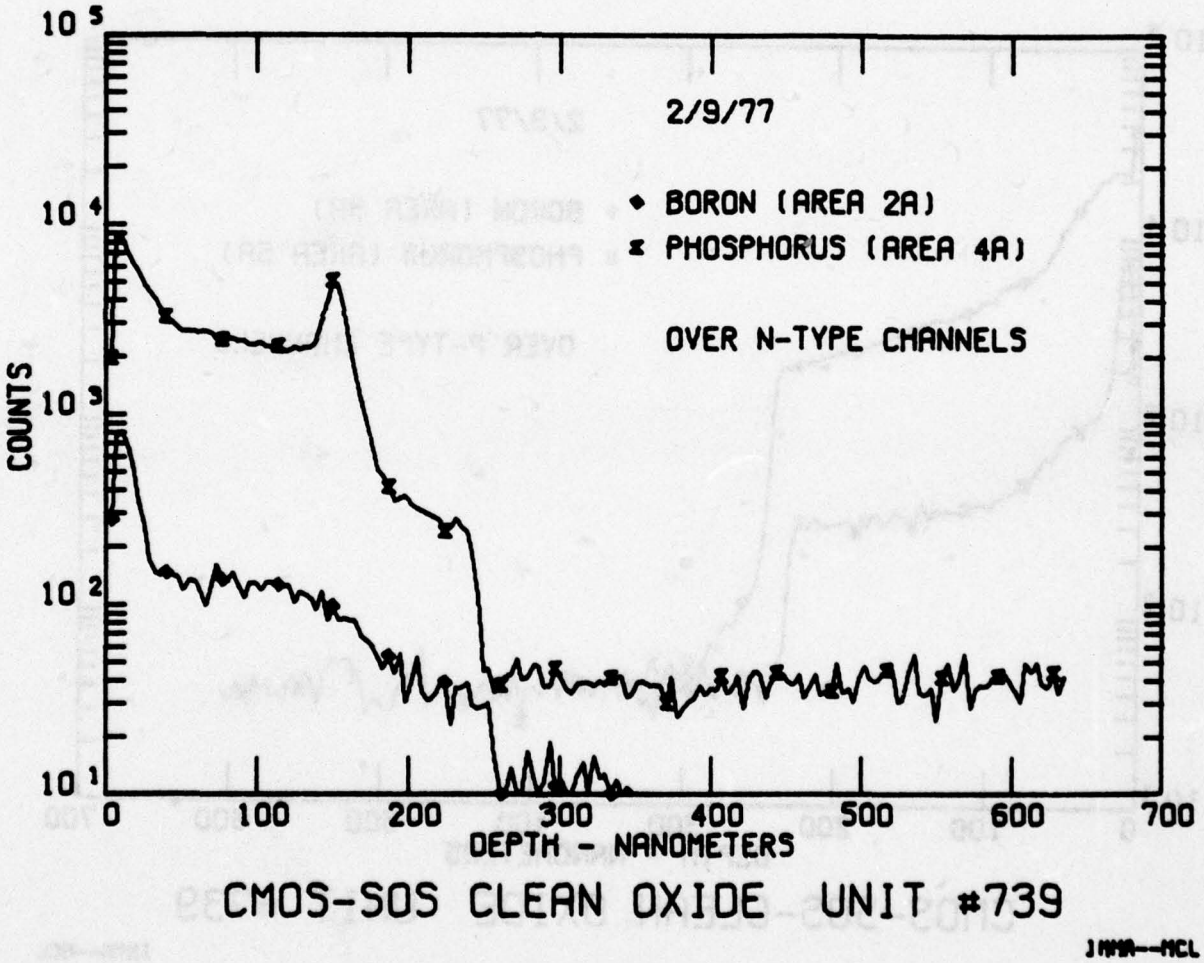

2/9/77
◆ BORON (AREA 2A)
⧗ PHOSPHORUS (AREA 4A)
OVER N-TYPE CHANNELS
COUNTS
10 5
10 4
10 3
10 2
10 1
0
100
200
300
400
500
600
700
DEPTH - NANOMETERS
CMOS-SOS CLEAN OXIDE UNIT #739
JMMA--MCL

Figure 9

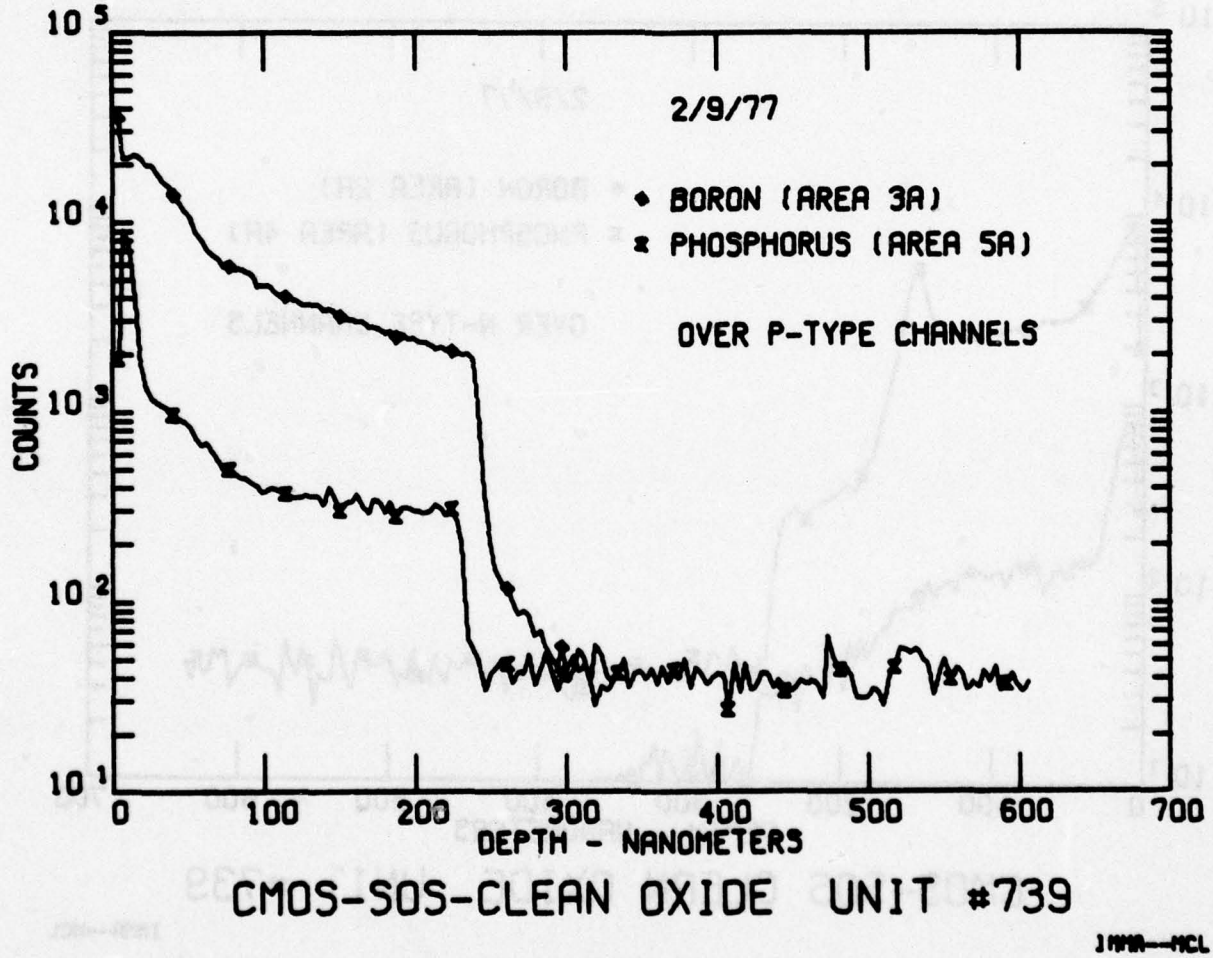

2/9/77
◆ BORON (AREA 3A)
x PHOSPHORUS (AREA 5A)
OVER P-TYPE CHANNELS
COUNTS
DEPTH - NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JMMR—MCL

Figure 10

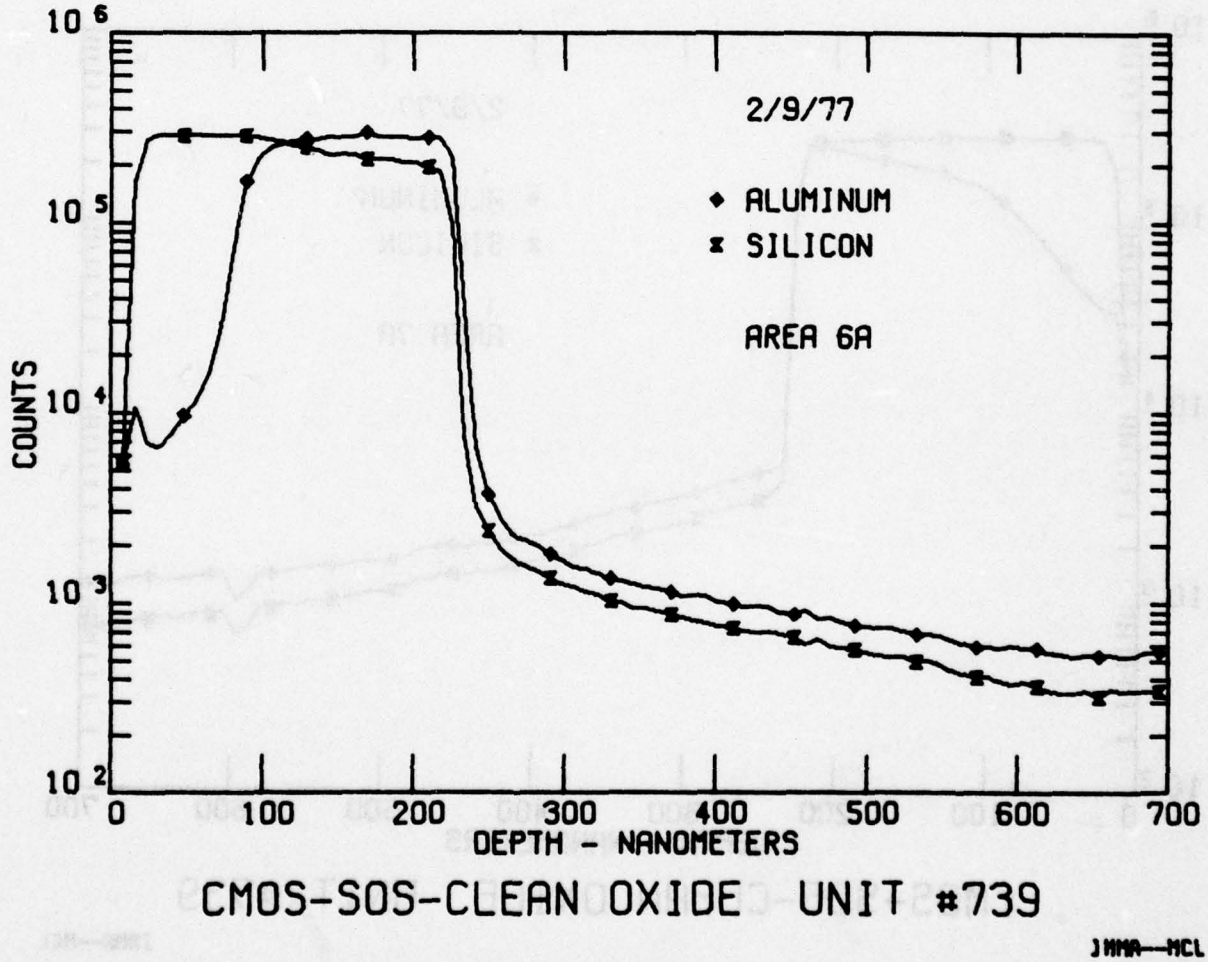

10 6
10 5
10 4
10 3
10 2
COUNTS
2/9/77
◆ ALUMINUM
⧗ SILICON
AREA 6A
0
100
200
300
400
500
600
700
DEPTH - NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JMMA--MCL

Figure 11

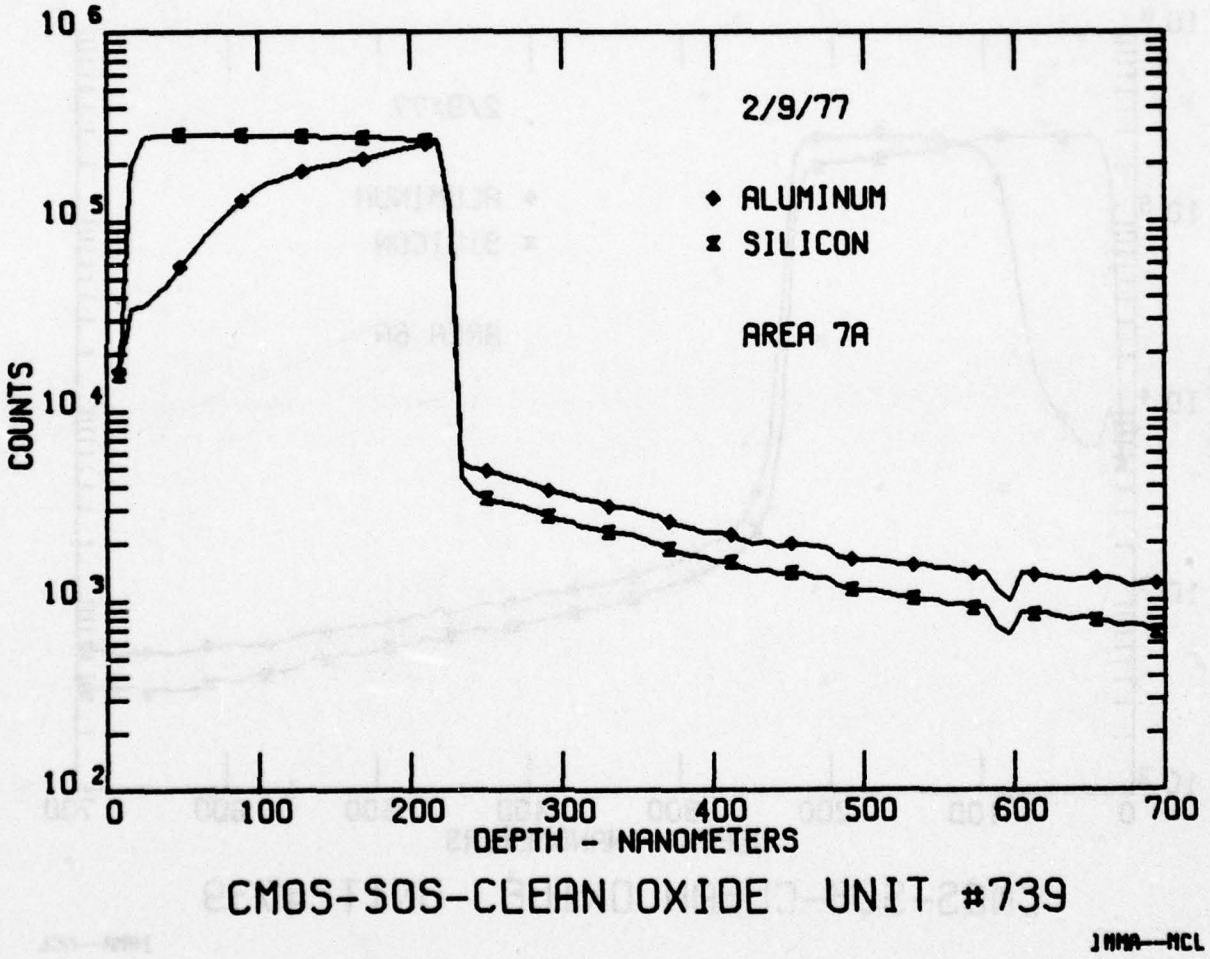

2/9/77
◆ ALUMINUM
⧗ SILICON
AREA 7A
COUNTS
10^6
10^5
10^4
10^3
10^2
0
100
200
300
400
500
600
700
DEPTH - NANOMETERS
CMOS-SOS-CLEAN OXIDE UNIT #739
JAMA—MCL

Figure 12

silicon growth by depth profiling the Aℓ-Si signals. The silicon was so completely consumed by the upper metal layer that this analysis is inconclusive. The silicon dissolution by aluminum can occur in SOS structures during elevated temperature processing and/or testing. The SEM of the bond pad shown in Appendix A confirmed the porous silicon layer.

B. CMOS-Undoped Silicon Dioxide Gate Insulator

CMOS bulk clean oxide, Unit #R202: Only mass spectra depth profile data were gathered on this circuit. No P was detected in the oxide.

CMOS-Nand gate, Unit #86: The P profile taken over an oxide area is shown in Figure 13. The P starts at about 150 nm, stays level at about 10^{21} atoms/cc until the 1.2 μm depth is reached, then drops sharply. An interpretation is that the glassivation is P-free and about 150 nm thick and that the thermal oxide (not necessarily gate oxide) is about 1 μm thick, uniformly doped with P. The sharp drop then represents either the thermal oxide-gate oxide interface or the thermal oxide-silicon interface. This shows the difficulty in interpreting this type of spectral information.

C. CMOS Aluminum Implanted Silicon Dioxide Gate Structure

CMOS-Aℓ implant, Unit #890: The oxides were not doped with P. Figure 14 is the Aℓ-Ti point count profile in this device to a depth of about 2.2 μm. The Ti contaminant appears to track the Aℓ through the oxide into the gate oxide, which suggests it could be related to the implant process.

D. Aluminum Oxide Gate Dielectric

Only mass spectra depth profiles were collected on this circuit. No phosphorus was found in the dielectric.

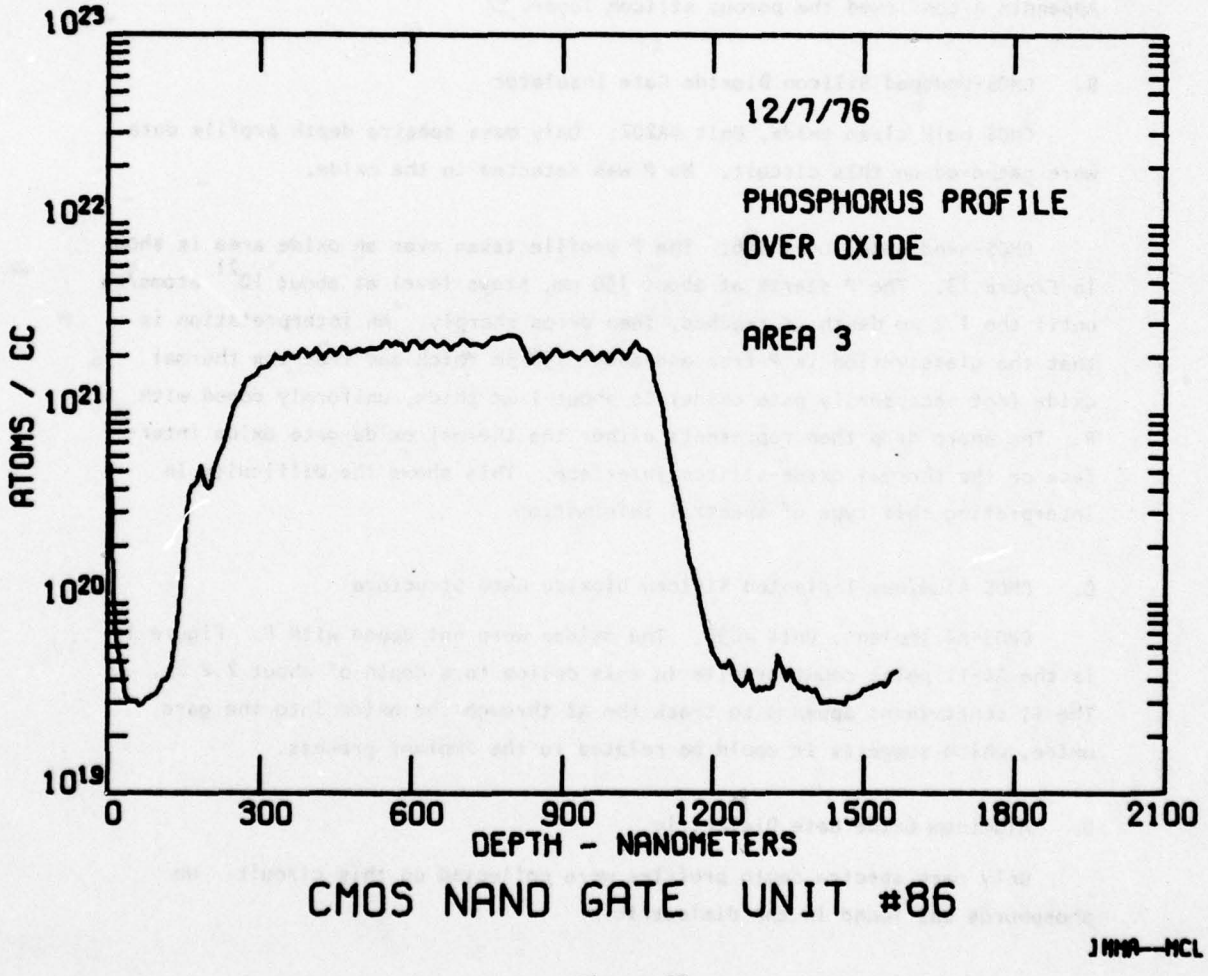

12/7/76
PHOSPHORUS PROFILE
OVER OXIDE
AREA 3
ATOMS / CC
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
0
300
600
900
1200
1500
1800
2100
DEPTH - NANOMETERS
CMOS NAND GATE UNIT #86
JHMA—MCL

Figure 13

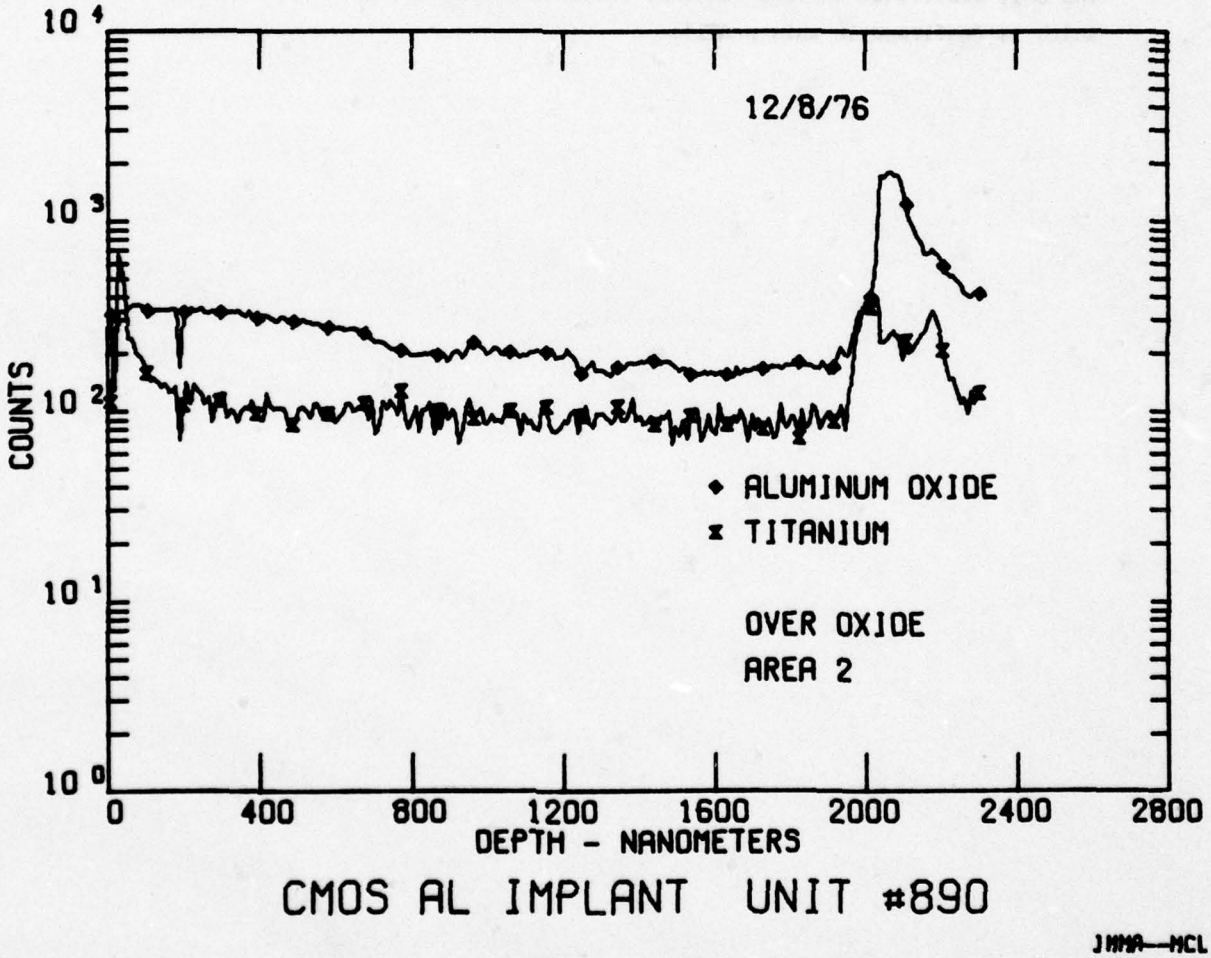

12/8/76
COUNTS
10^4
10^3
10^2
10^1
10^0
ALUMINUM OXIDE
TITANIUM
OVER OXIDE
AREA 2
0
400
800
1200
1600
2000
2400
2800
DEPTH - NANOMETERS
CMOS AL IMPLANT UNIT #890
JMMA—MCL

Figure 14

E. CMOS-Chromium Doped Silicon Dioxide Gate Circuit on Sapphire Substrate

CMOS-Cr doped; Unit #504: The oxides were not P doped. Figure 15 gives a shallow Cr profile in this device. The Cr concentration does not appear to be uniform in this region. The gate oxide region was not profiled, since the only additional information that could be gained was the fact Cr is present, which is confirmed in this profile.

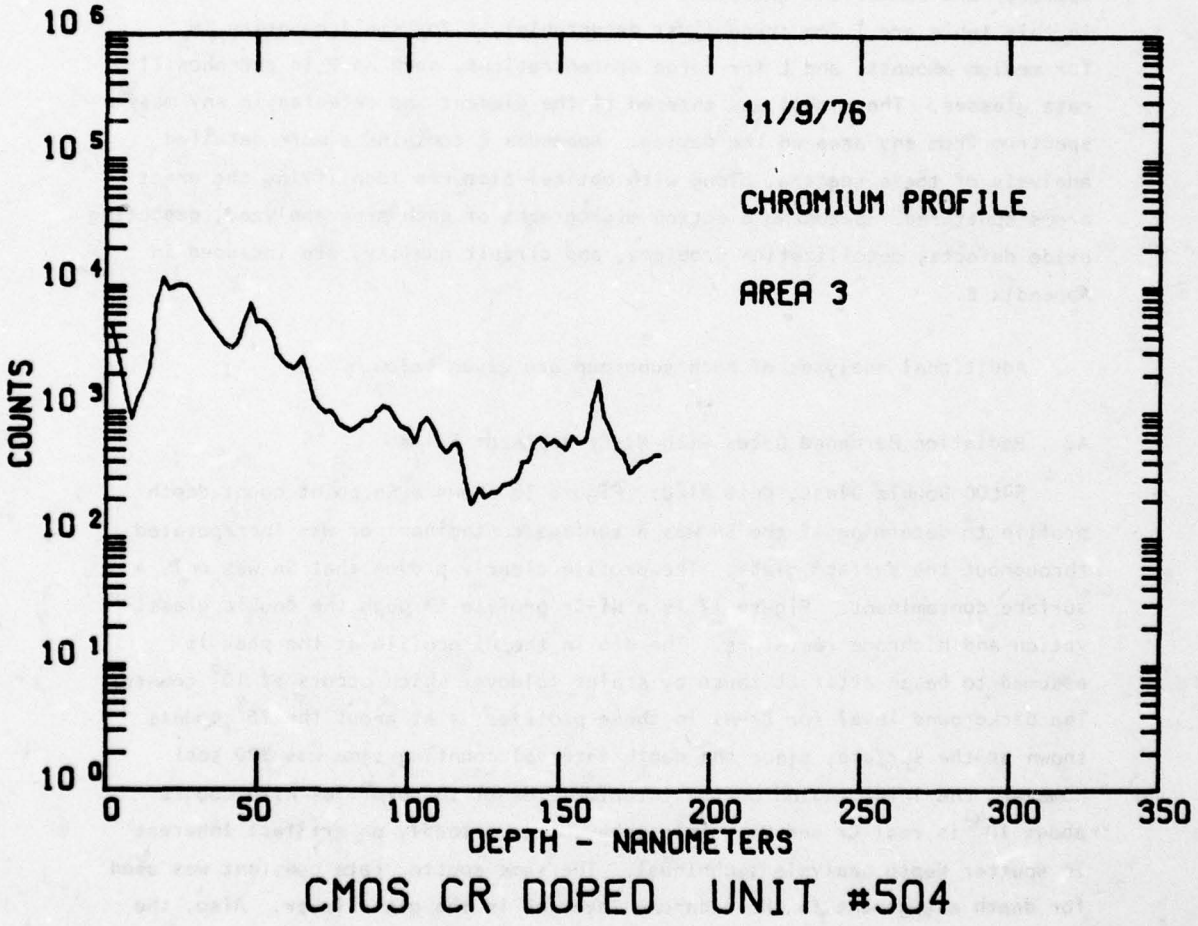

11/9/76
CHROMIUM PROFILE
AREA 3
COUNTS
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0
50
100
150
200
250
300
350
DEPTH - NANOMETERS
CMOS CR DOPED UNIT #504
JMMA—MCL

Figure 15

SECTION VI
GENERAL TECHNOLOGY GROUP

The analyses of the entire general technology group (about 400 mass spectra) are summarized qualitatively in Tables 7 and 8. The symbols used in this table are T for trace (just detectable), S for small quantity, M for medium amounts, and L for large concentrations, such as P in phosphosilicate glasses. The symbol was entered if the element was detected in any mass spectrum from any area on the device. Appendix B contains a more detailed analysis of these spectra, along with optical pictures identifying the exact areas sputtered. Scanning electron micrographs of each area analyzed, depicting oxide defects, metallization problems, and circuit quality, are included in Appendix B.

Additional analyses of each subgroup are given below.

A. Radiation Hardened Gates with Ni-Cr Resistor Films

54L00 Double Glass, Unit #120: Figure 16 shows a Sn point count depth profile to determine if the Sn was a surface contaminant or was incorporated throughout the surface glass. The profile clearly proves that Sn was only a surface contaminant. Figure 17 is a Ni-Cr profile through the double glassivation and nichrome resistors. The dip in the Ni profile at the peak is assumed to be an artifact cause by scaler foldover which occurs at 10^6 counts. The background level for Cr-Ni in these profiles is at about the 10^3 counts shown at the surface, since the depth interval counting time was 200 sec. However, the level region on the interior side of the profiles with counts about 10^4 is real Cr and Ni. This behavior is probably an artifact inherent in sputter depth analysis techniques. The same sputter rate constant was used for depth assignment in the nichrome layer as in the glass layer. Also, the nichrome layer was assumed to be uniformly surface cleaned of the glass coating at the start of the Ni and Cr signal. Each of these assumptions, along with the normal sputtering broadening effect, would result in an apparent thicker nichrome layer than is actually present. The glass layers over the nichrome on this device were sputtered quartz and chemical vapor deposited oxide. The

TABLE 7

RADIATION HARDENED GATES

DEVICE	Li	B	F	Na	Mg	P	Cl	K	Ca	Ti	Cr	Ni	Cu	Zn	Ga	Mo	Ag	Sn	Ba	Pb
54L00 DG 120		T	T	S	S	M		S	S	T	L	L	T	T	T	T		M		T
54L00 DG 55	T	T	T	S	T			S	T	T										
54L00 DG 57	T	T		T	T			T	T	T			T							T
54L00 OLD 103		T	T	T	T	S		S	T	T	T							T	T	
54L00 OLD 100		T	T	T	T			S	S	T	T		T		T	T				T
54L00 OLD 960	T	M	T	T	T	T		T	T	T	T		T	T		T		T		M

TABLE 8

ALUMINUM METALLIZED GLASSIVATED DEVICES

DEVICE		Li	B	F	Na	Mg	P	Cl	K	Ca	Ti	Cr	Ni	Cu	Zn	Ga	Mo	Ag	Sn	Ba	Pb
Op Amp 1	3	T	T		S	S	L		M	T	T	T			T	T				S	T
Op Amp 1	48		T	T	L	L	L		L	L	S	S		L	L			T	S	S	T
Op Amp 1	50	T	T	T	S	T	L		M	S	T	T			T				T		T
Op Amp 2	62	M	M	T	M	T			L	S	T	T								M	
Op Amp 2	64	T	T	T	L	M	T		L	L	M	T		T					S	T	T
Op Amp 2	16	T	T	T	S	T	T		S	S	S	T		T	T				T		T
Op Amp 3	13		T		M	T	L		M	M	T			T	T	T				T	
Op Amp 3	165		T	T	M	M			L	L	M	T			T				T	T	T
Op Amp 3	33				S		L		T	T				T		T					
Gen Pur Amp	64		S	T	T		L		T	T											
Gen Pur Amp	2	S	S	T	M	S	L		M	M		M		M	T	T	T	T		M	T
Gen Pur Amp	3	S	M	S	M	S	L		S	T							S			M	
ECL D	21	S			S	T	L		T	T		T			T				T		
ECL D	39	T	T		M	T	L		S	M	T	T		T	T						T
ECL D	92	T	T		T	S	L		T	S	T	T		T	T				T		T
Hex Inverter	94		T	T	T	T	L		T	T	T	T		T	T				T		S
Hex Inverter	125	T	T	T	L	S	T		S	M	T	T		T	T		T		T		
Hex Inverter	29	T	T	T	T	T	T		T	S	T	T		T	T	T					T

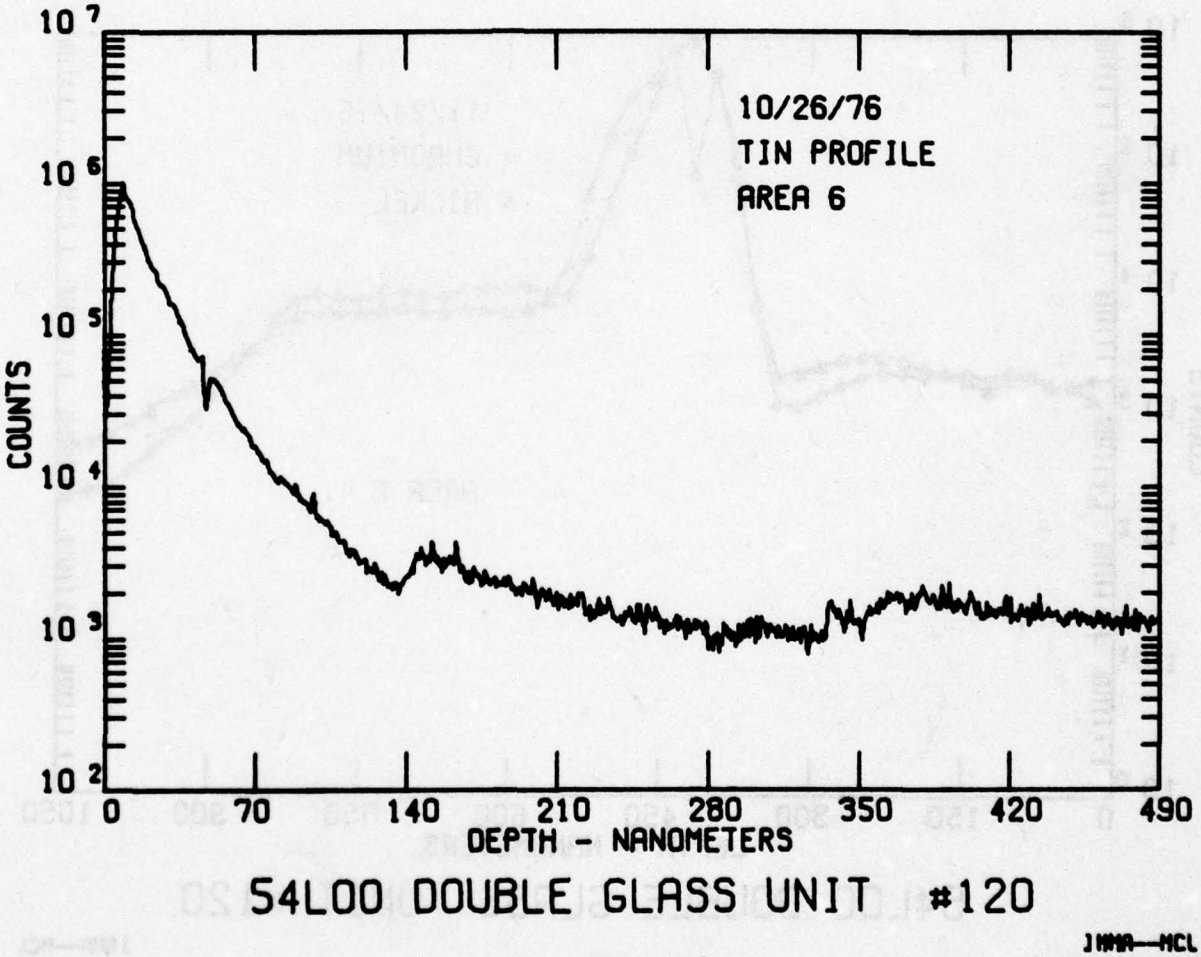

10/26/76
TIN PROFILE
AREA 6
COUNTS
10 7
10 6
10 5
10 4
10 3
10 2
0
70
140
210
280
350
420
490
DEPTH - NANOMETERS
54L00 DOUBLE GLASS UNIT #120
JHMA—MCL

Figure 16

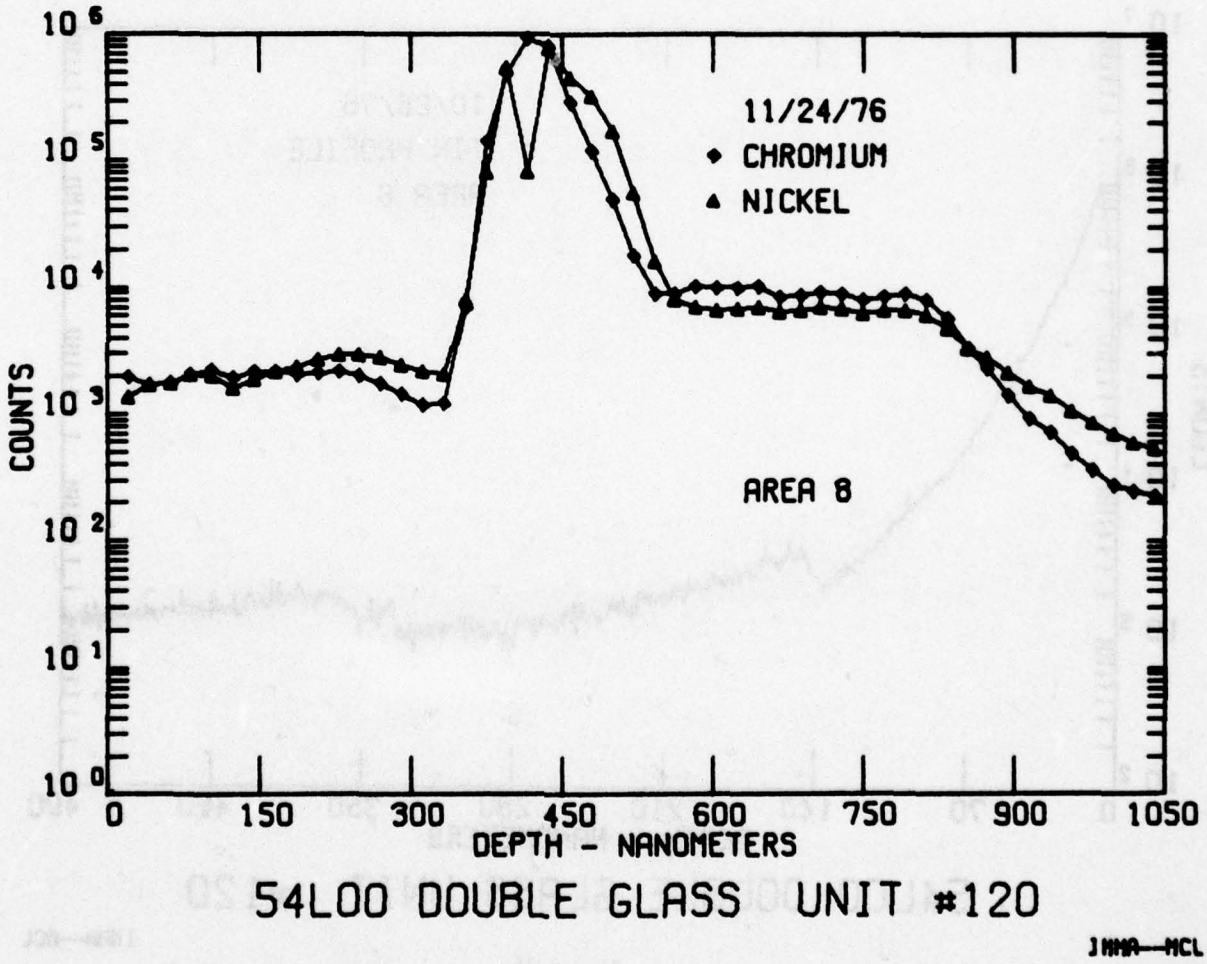

11/24/76
CHROMIUM
NICKEL
AREA 8
COUNTS
DEPTH - NANOMETERS
54L00 DOUBLE GLASS UNIT #120
JHMA—MCL

Figure 17

sputtered quartz is known to have a columnar-type structure that, when sputtered, would tend to leave small islands of quartz scattered over the nichrome. These islands would then slowly sputter away, resulting in a profile as shown in Figure 17, where the Ni-Cr signal sharply drops off the peak as the main portion of the nichrome is sputtered away, but levels out above background while the quartz islands and the underlying nichrome is sputtered away.

No chemistry of the double glass information can be obtained by this type of analysis. Both glasses are basically SiO_2, and when saturated with implanted oxygen during the sputtering process, they become indistinguishable. Without prior knowledge of the manufacturing process, it is extremely difficult to devise experiments to determine chemistry of types of SiO_2 deposits, especially on such small samples. The interface analysis is included in the mass spectra depth profile data on this circuit. Ar sputtering the glassivation over the Aℓ metal indicated an extremely thin glass overcoat.

54L00 Old, Unit #103: In addition to the mass spectra depth profiles of the surface layers, several craters were opened by Ar^+ sputtering. Figure 18 is the Aℓ profile used to determine the Ar^+ sputter time necessary to remove the glassivation layer. Figure 19 is the Cr-Ni profile of a nichrome resistor after the glass had been removed from the surface. The depth scale was left in relative units, since no surface SiO_2 was present to control the sputter rate and the sputter rate of nichrome is unknown. Mass spectra were collected from the other areas opened. These spectra indicated the interfaces are relatively free of impurities.

B. Aluminum Metalized and Glassivated Devices

Op Amp #1, Unit #3: Figure 20 is a phosphorus profile through the glassivation layer over aluminum metalization. The slope down in the profile is assumed background level for this particular analysis due to narrow dynamic range of the instrument when going high to low with a negative beam and small craters. The interface analysis using Ar^+ sputtering to remove the glassivation showed the interfaces was relatively free of impurities. The attempt to

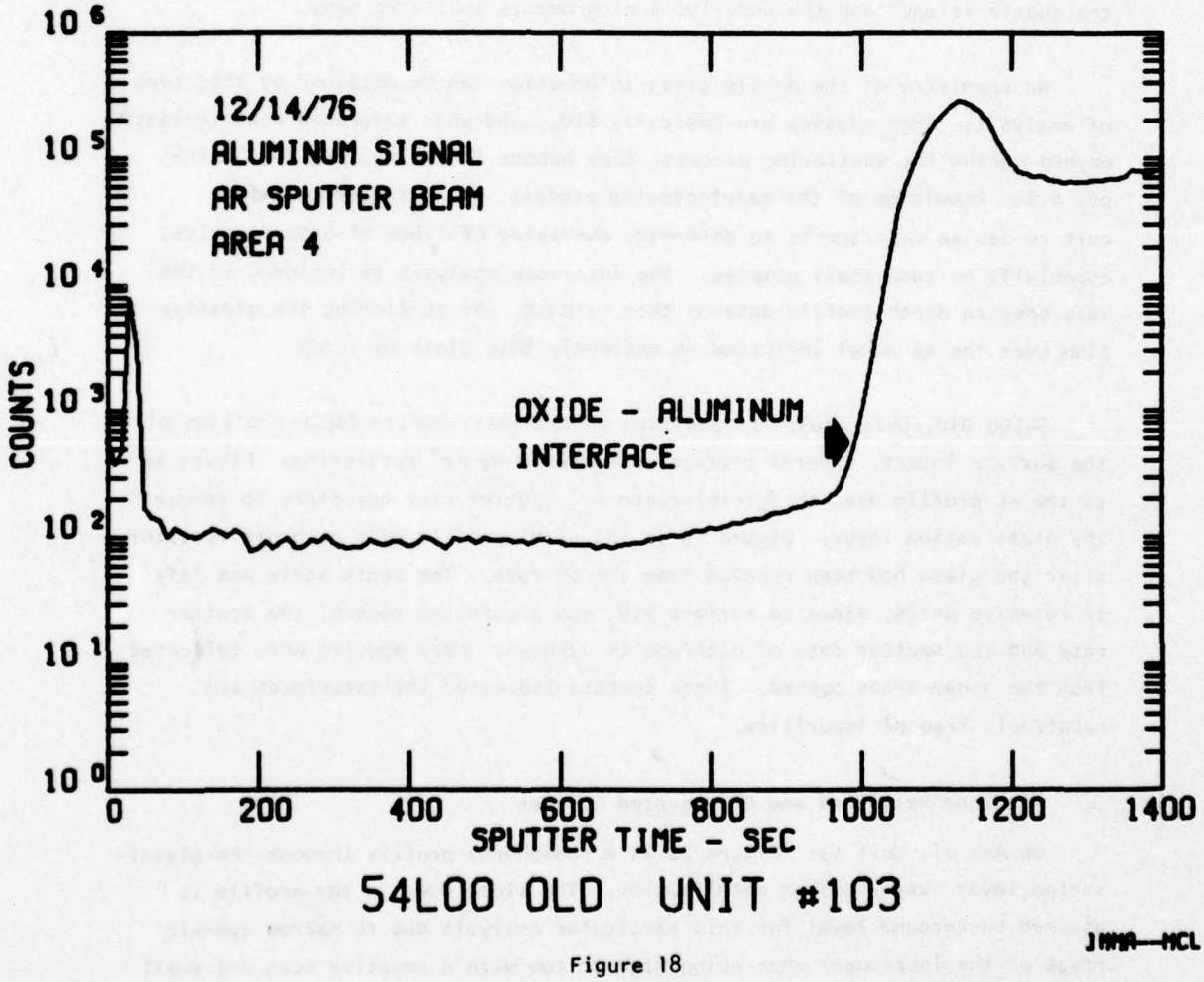

12/14/76
ALUMINUM SIGNAL
AR SPUTTER BEAM
AREA 4
OXIDE - ALUMINUM
INTERFACE
COUNTS
SPUTTER TIME - SEC
54L00 OLD UNIT #103
JMMA—MCL

Figure 18

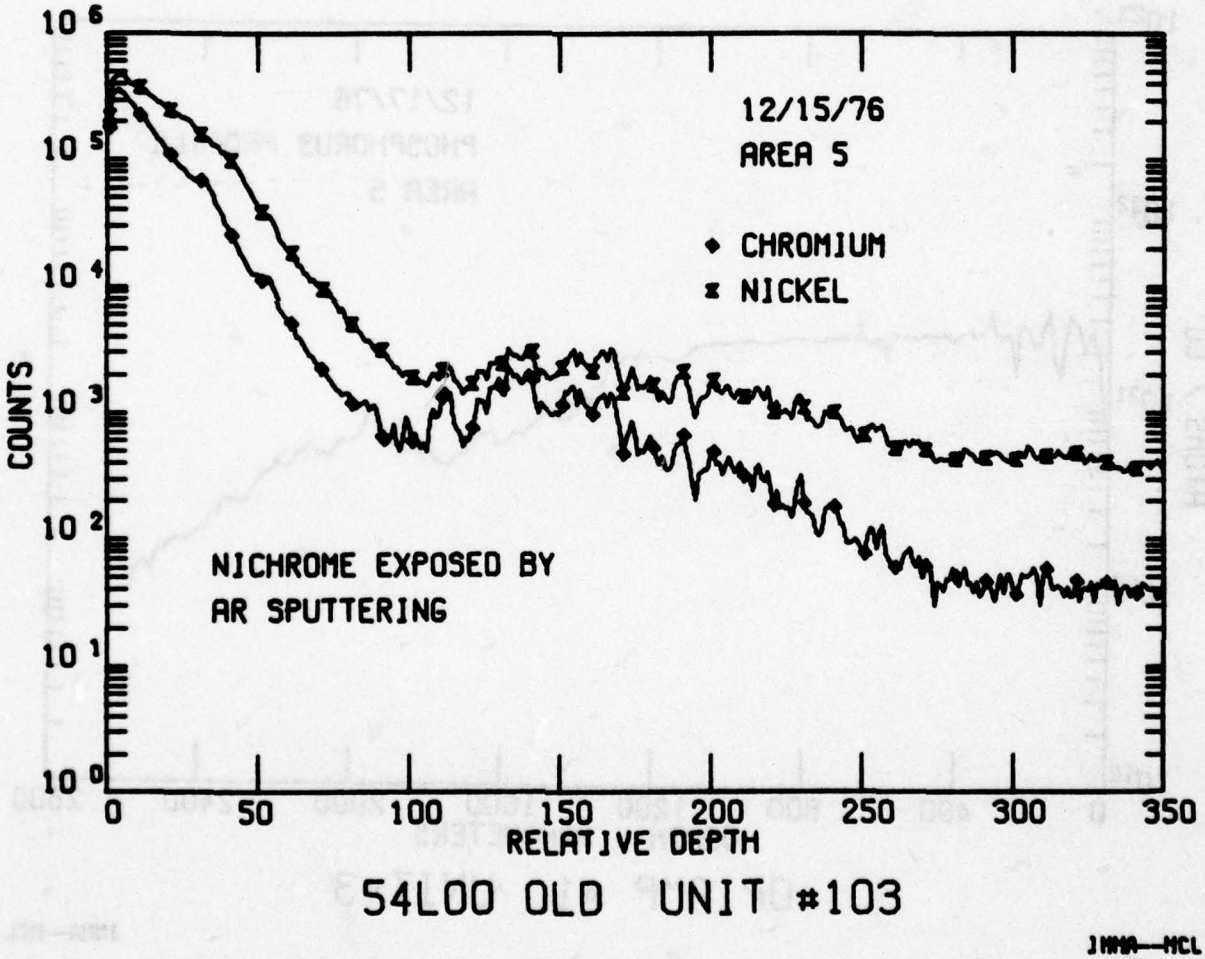

12/15/76
AREA 5
CHROMIUM
NICKEL
NICHROME EXPOSED BY
AR SPUTTERING
COUNTS
RELATIVE DEPTH
54L00 OLD UNIT #103
JHMA—MCL

Figure 19

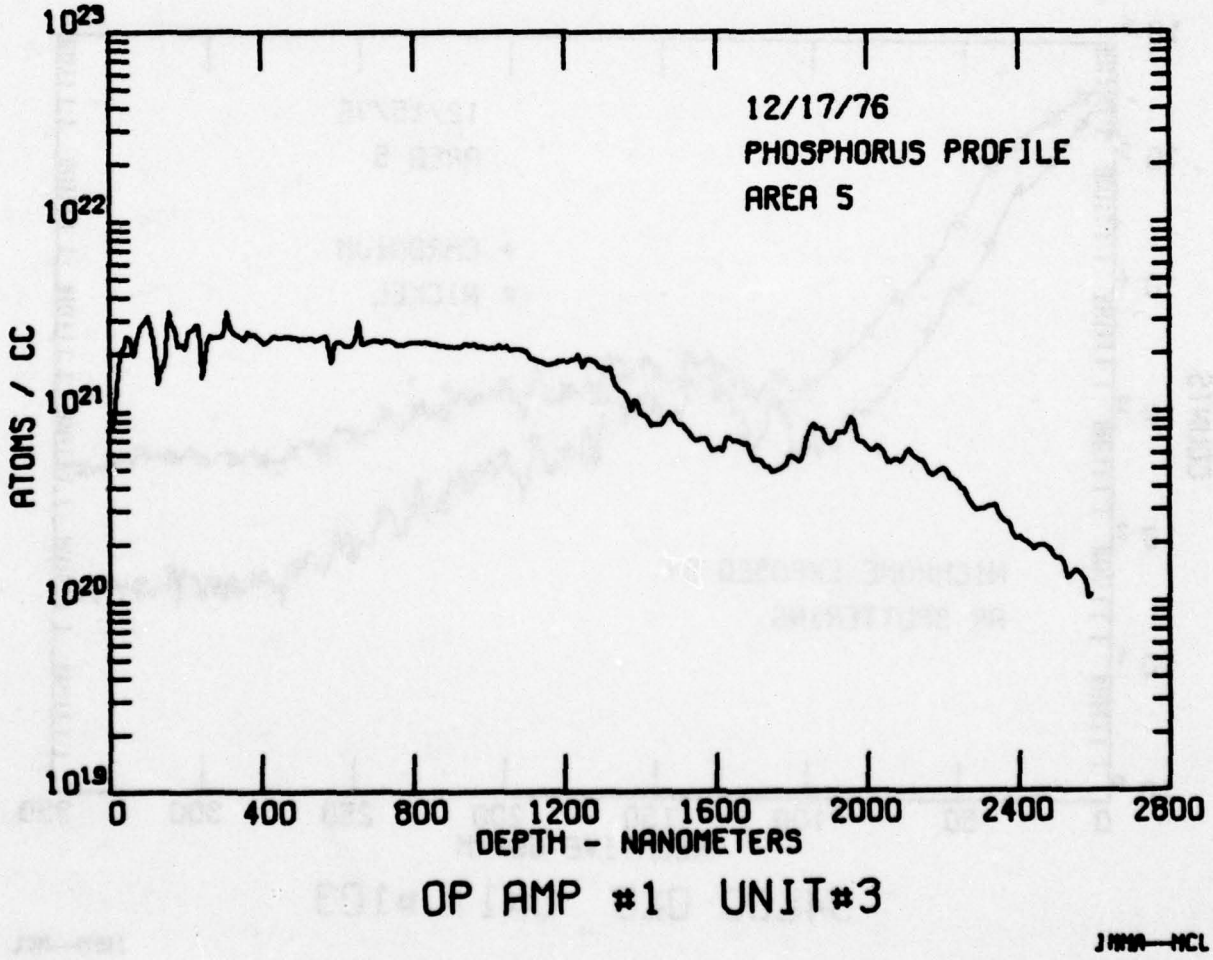

12/17/76
PHOSPHORUS PROFILE
AREA 5
ATOMS / CC
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
0
400
800
1200
1600
2000
2400
2800
DEPTH - NANOMETERS
OP AMP #1 UNIT#3
JMMA—MCL

Figure 20

chemically stepwise remove the SiO_2 layers with HF gas was unsuccessful. The first etch time period of five minutes removed all SiO_2 and most of the metalization. Figure 21 summarizes the electrically active silicon dopant identification. The n- or p-type dopants were identified from mass spectra taken from each point marked with a chemical symbol. An n-dopant, P, was positively identified only in the MIS region. The n-type transistor elements are probably P doped, but these regions are too small to supply a sufficient number of P ions for positive identification. Quantitative B data were taken from the three regions labeled with concentrations. The difference between 2.3×10^{18} and 1.7×10^{18} atoms/cc B between the two transistors tanks is within experimental error, considering that the physical size is limited. The p^+ region used for isolation shows B in the 9×10^{19} range. The small dots inside larger circles illustrate the potential capability of the ion probe to sputter a small area leaving the surrounding area essentially undisturbed. The large rectangular shadows are where unsuccessful attempts were made to image dopants.

Op Amp #2, Unit #62: Figure 22 shows a mass 31 (either P^+ or SiH^+) point count profile through the glassivation layer. The low count obtained is at the same level normally expected from the SiH^+ molecular species, which strongly suggests that P is not present, at least, certainly not in the concentrations found in phosphosilicate glasses. Figure 23 shows the Ar^+ sputter time necessary to remove the glassivation layer. Both the glassivation-aluminum and glassivation-thermal oxide interfaces were relatively free of impurities.

Op Amp #3, Unit #13: Figure 24 shows a P profile in the glassivation layer. After the initial surface depletion, the P reaches a constant concentration at about the 2×10^{21} atoms/cc level. Figure 25 is the Ar^+ sputter time determination needed for removal of the glassivation layer. Both the glassivation-aluminum and glassivation-thermal oxide interfaces were relatively free of impurities.

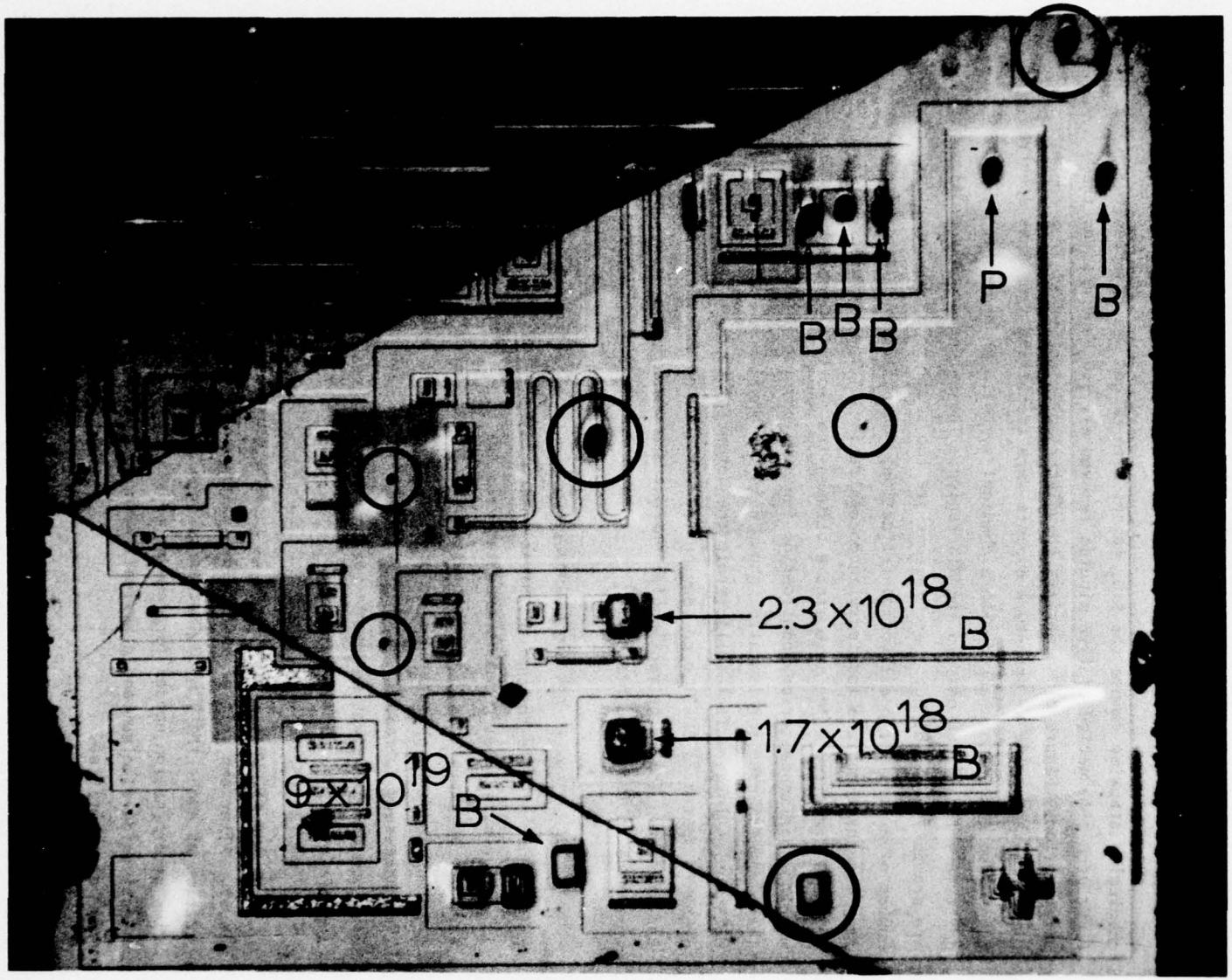


Figure 21 Dopant Analysis in Active Silicon Regions on Op Amp #1, Unit #3

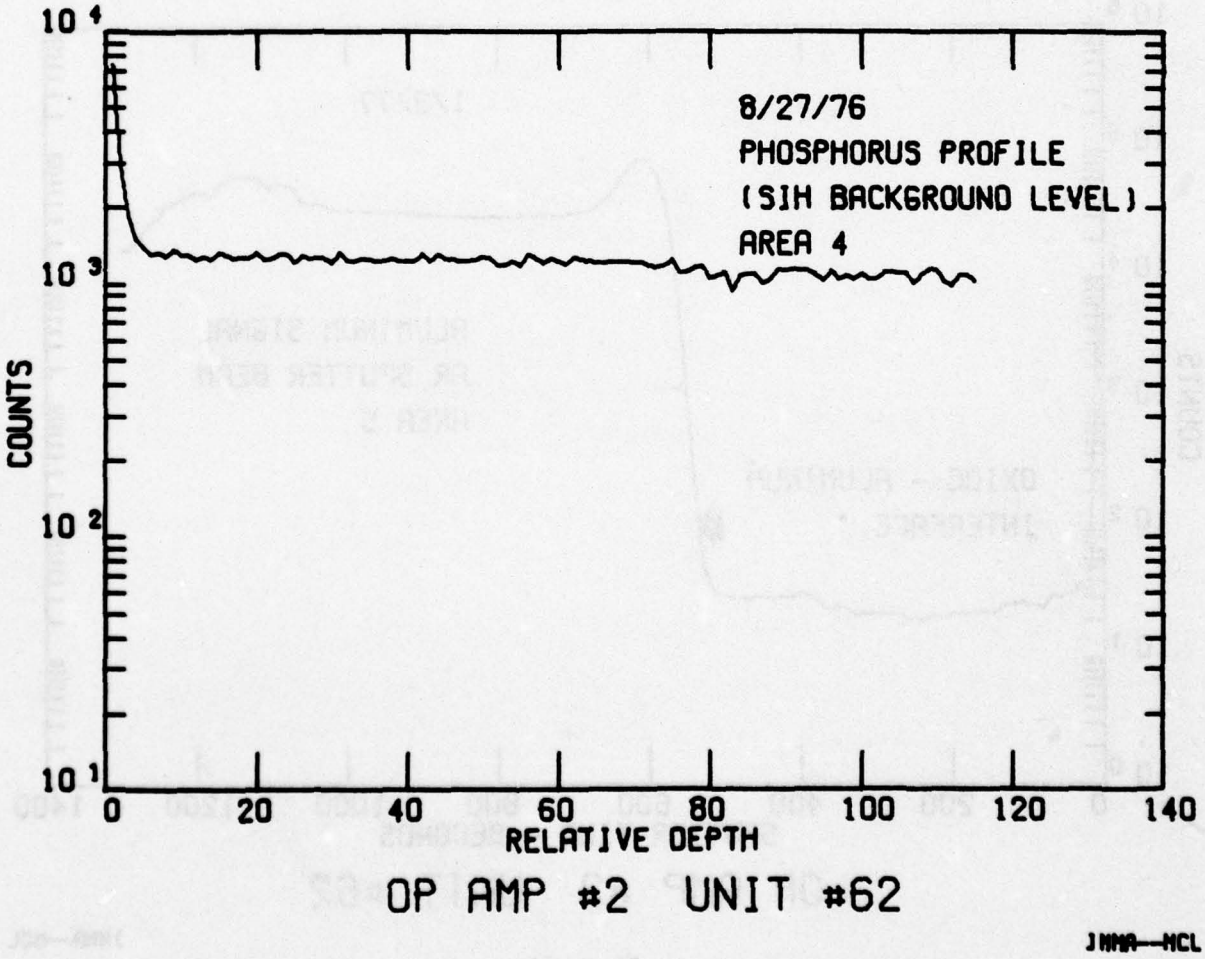

8/27/76
PHOSPHORUS PROFILE
(SIH BACKGROUND LEVEL)
AREA 4
COUNTS
10 4
10 3
10 2
10 1
0
20
40
60
80
100
120
140
RELATIVE DEPTH
OP AMP #2 UNIT #62
JMMA—MCL

Figure 22

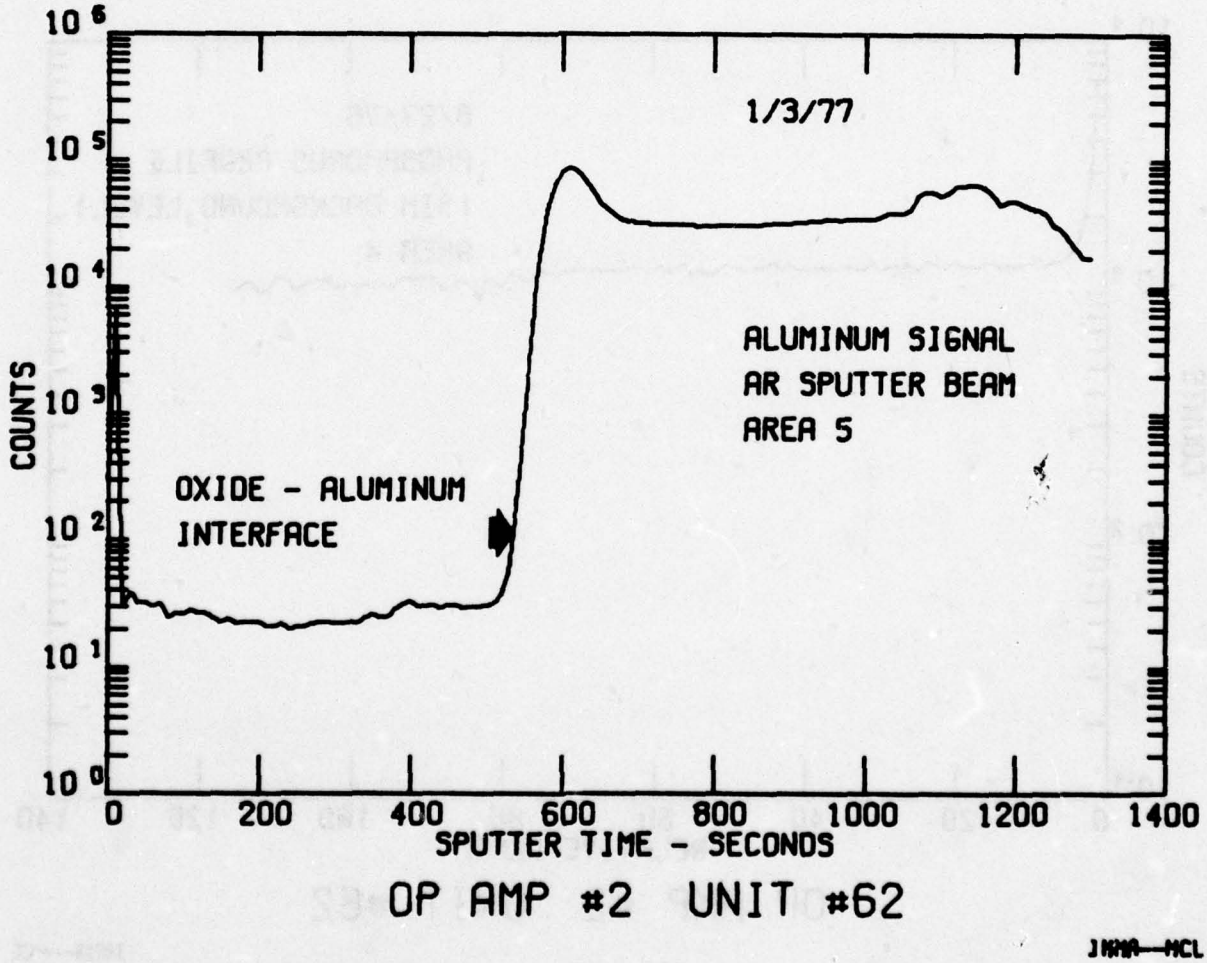

1/3/77
ALUMINUM SIGNAL
AR SPUTTER BEAM
AREA 5
OXIDE - ALUMINUM
INTERFACE
COUNTS
SPUTTER TIME - SECONDS
OP AMP #2 UNIT #62
JMMA—MCL

Figure 23

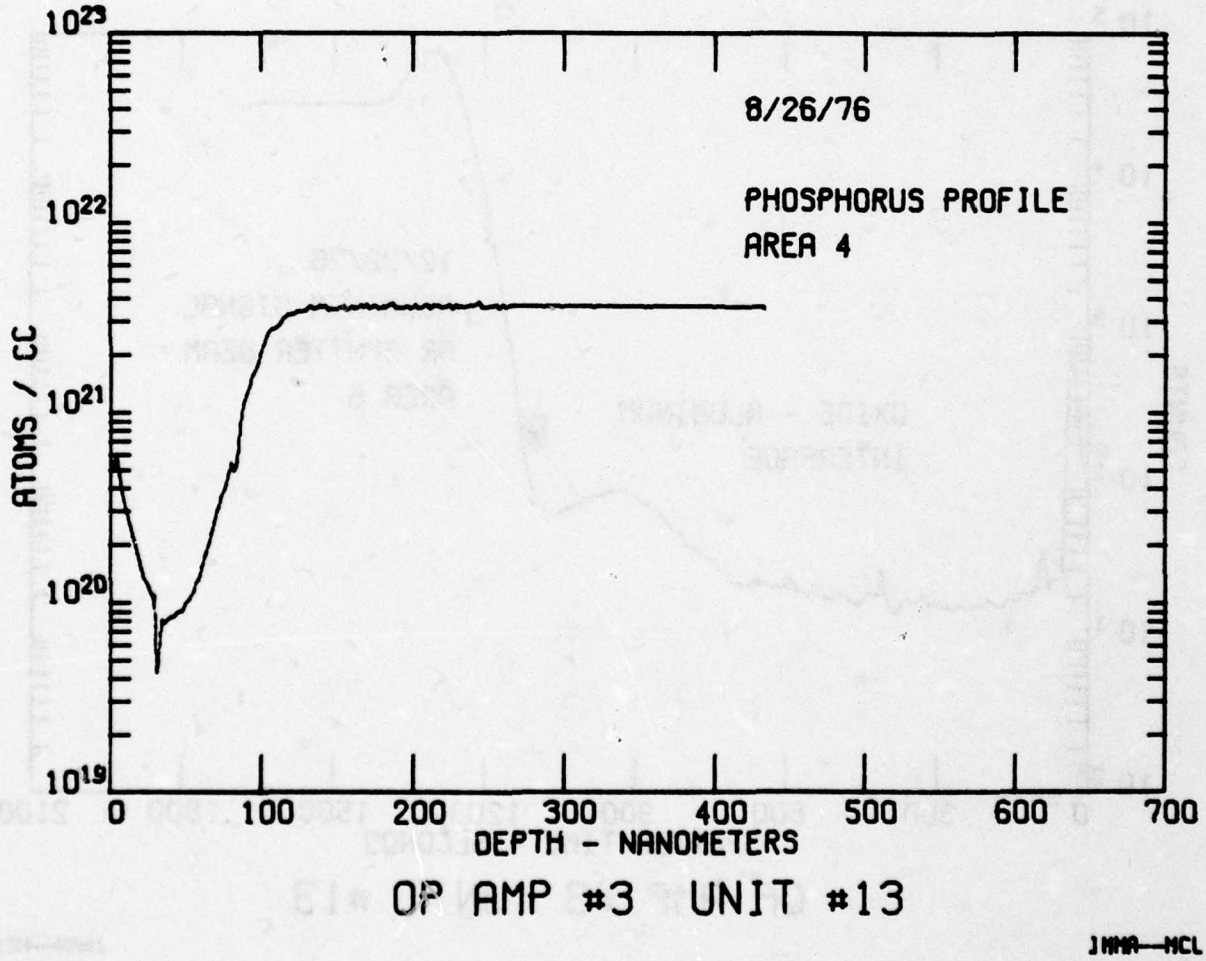

8/26/76
PHOSPHORUS PROFILE
AREA 4
ATOMS / CC
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
0
100
200
300
400
500
600
700
DEPTH - NANOMETERS
OP AMP #3 UNIT #13
JMMA—MCL

Figure 24

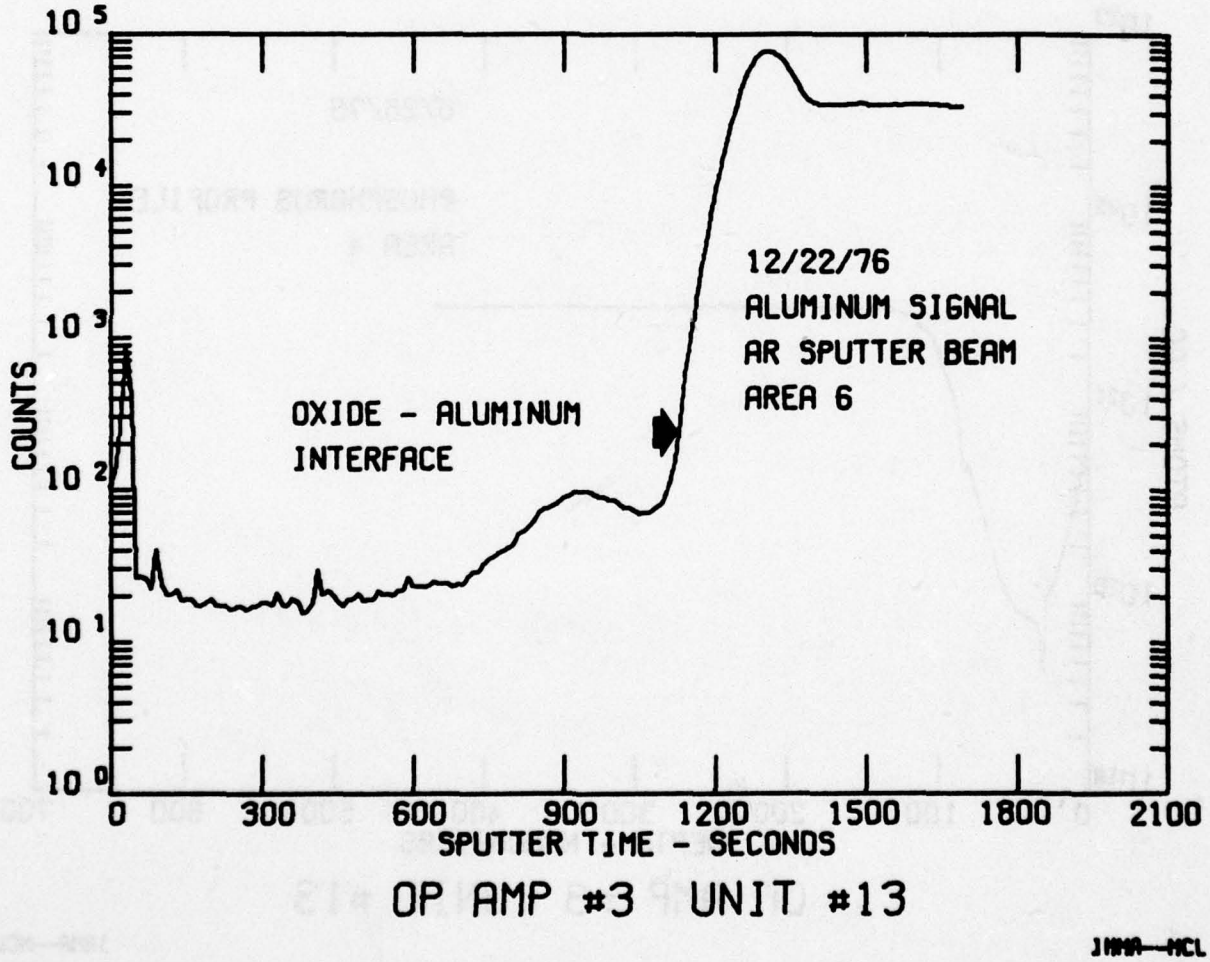

10 5
10 4
10 3
10 2
10 1
10 0
COUNTS
0
300
600
900
1200
1500
1800
2100
SPUTTER TIME - SECONDS
12/22/76
ALUMINUM SIGNAL
AR SPUTTER BEAM
AREA 6
OXIDE - ALUMINUM
INTERFACE
OP AMP #3 UNIT #13
JMMA—MCL

Figure 25

General Purpose Amplifier, Unit #64: Only mass spectra depth profiles were taken on this device. Phosphosilicate glass was used, but not profiled. No interface analysis was attempted.

ECL D Flip Flop, Unit #21: Figure 26 is the P profile through the glassivation and insulator oxide of the device. The P remained at the same concentration within experimental error throughout the entire depth. Figure 27 shows the Ar^+ sputter time determination for removal of the glassivation layer, second level metal, and insulator dielectric for interface analysis. Interface analysis at the glassivation-insulator oxide and glassivation-aluminum interfaces showed the interfaces were relatively free of impurities. No attempt was made to analyze deeper interfaces.

Hex Inverter, Unit #94: The glassivation and thermal oxides were P-free. Figure 28 is a Pb profile taken through the glassivation to determine if the Pb found by the mass spectra profiles was a surface contaminant or a component of the glassivation. The high surface peak (after gold coating sputtered away) shows the Pb was a surface contaminant. Figure 29 is the Ar^+ sputter time determination needed for interface analysis. The glassivation-aluminum and the glassivation-thermal oxide interfaces were relatively free of impurities. Neither of these interfaces opened by Ar sputtering showed the impurity types and/or amounts found on interfaces analyzed where the glassivation had delaminated from the thermal oxide. Experiments to determine if impurities concentrated in glassivation cracks gave only negative results.

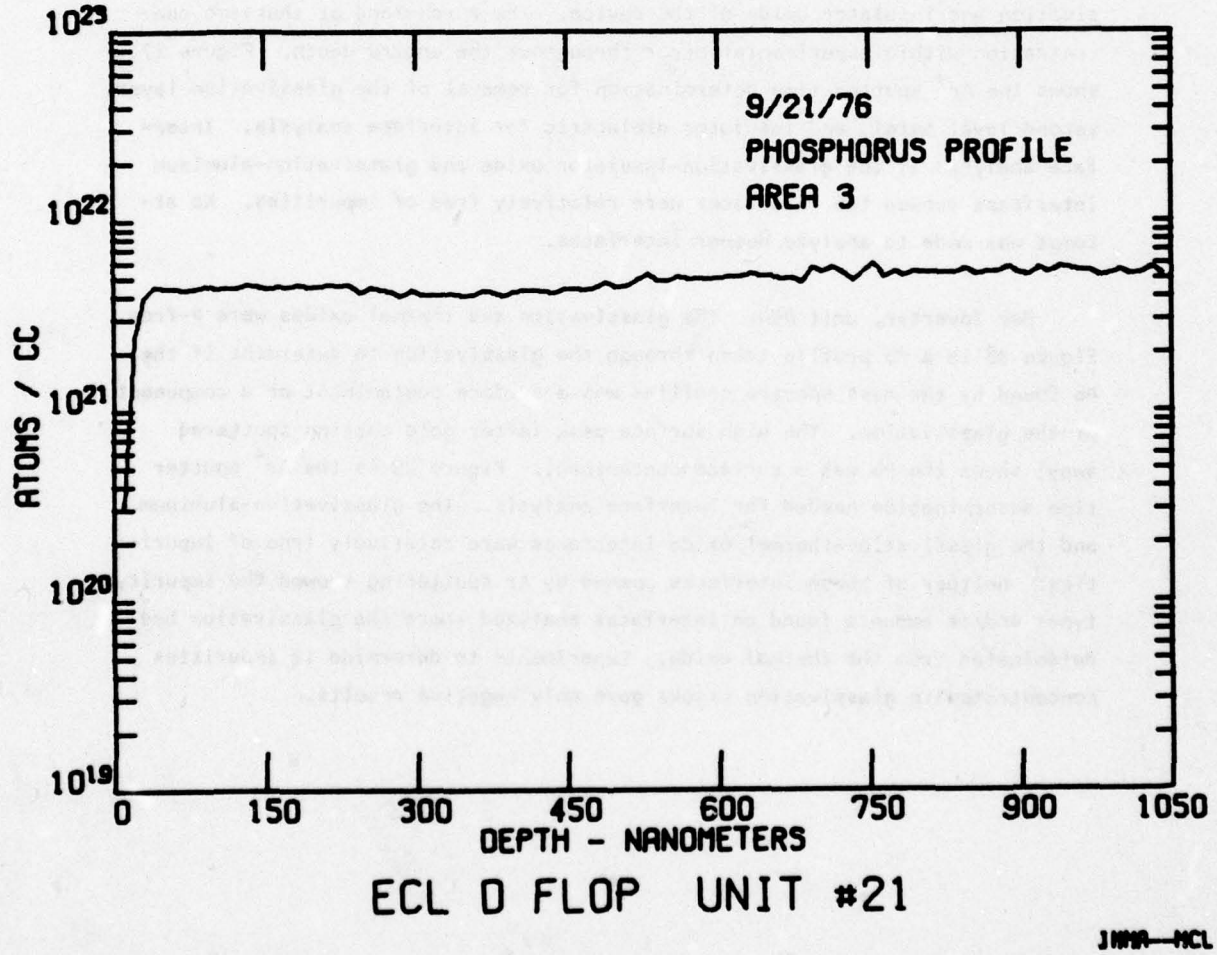

9/21/76
PHOSPHORUS PROFILE
AREA 3
ATOMS / CC
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
0
150
300
450
600
750
900
1050
DEPTH - NANOMETERS
ECL D FLOP UNIT #21
JHMR—MCL

Figure 26

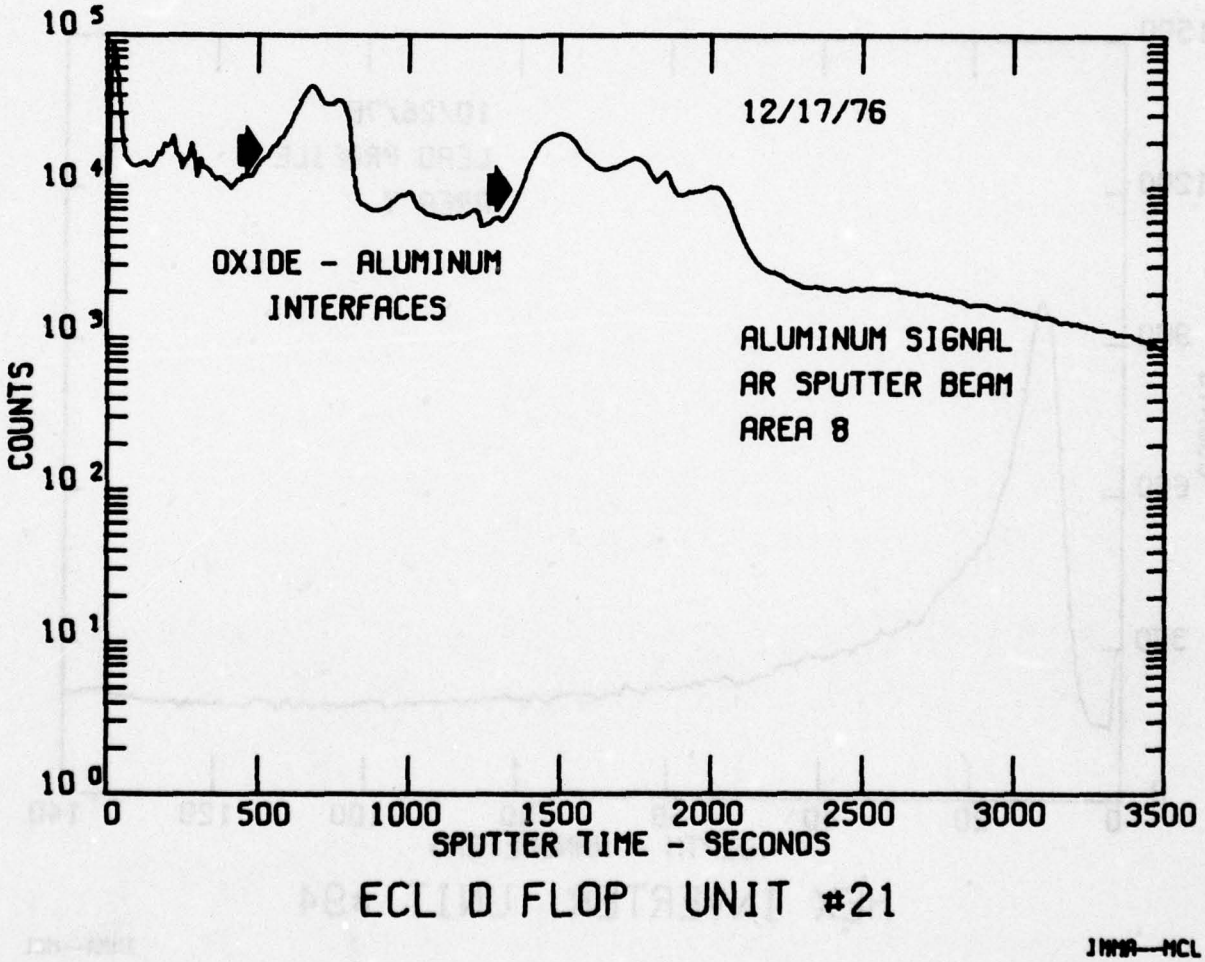

10 5
10 4
10 3
10 2
10 1
10 0
COUNTS
12/17/76
OXIDE - ALUMINUM
INTERFACES
ALUMINUM SIGNAL
AR SPUTTER BEAM
AREA 8
0
500
1000
1500
2000
2500
3000
3500
SPUTTER TIME - SECONDS
ECL D FLOP UNIT #21
JMMA—MCL

Figure 27

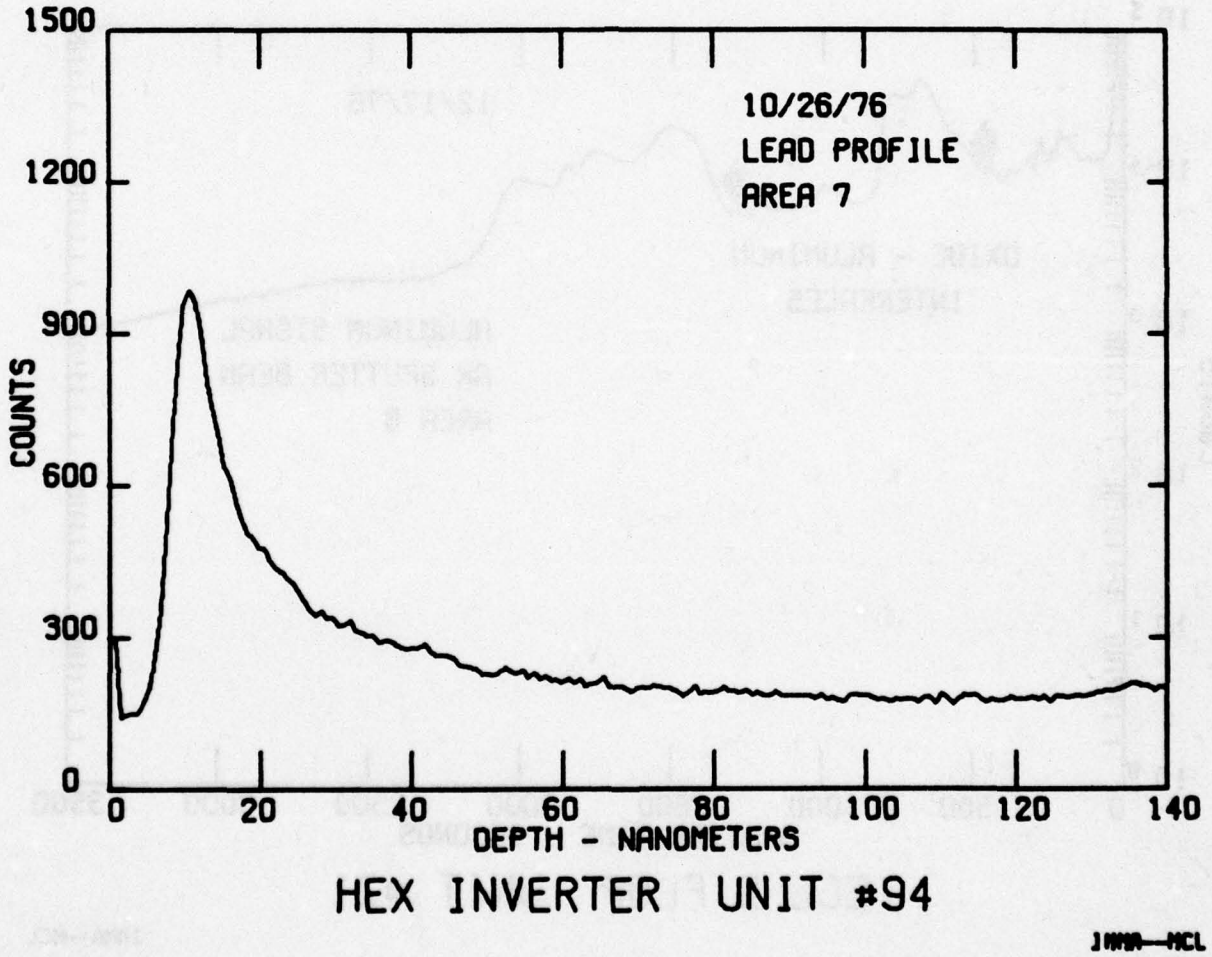

1500
1200
900
600
300
0
COUNTS
10/26/76
LEAD PROFILE
AREA 7
0
20
40
60
80
100
120
140
DEPTH - NANOMETERS
HEX INVERTER UNIT #94

Figure 28

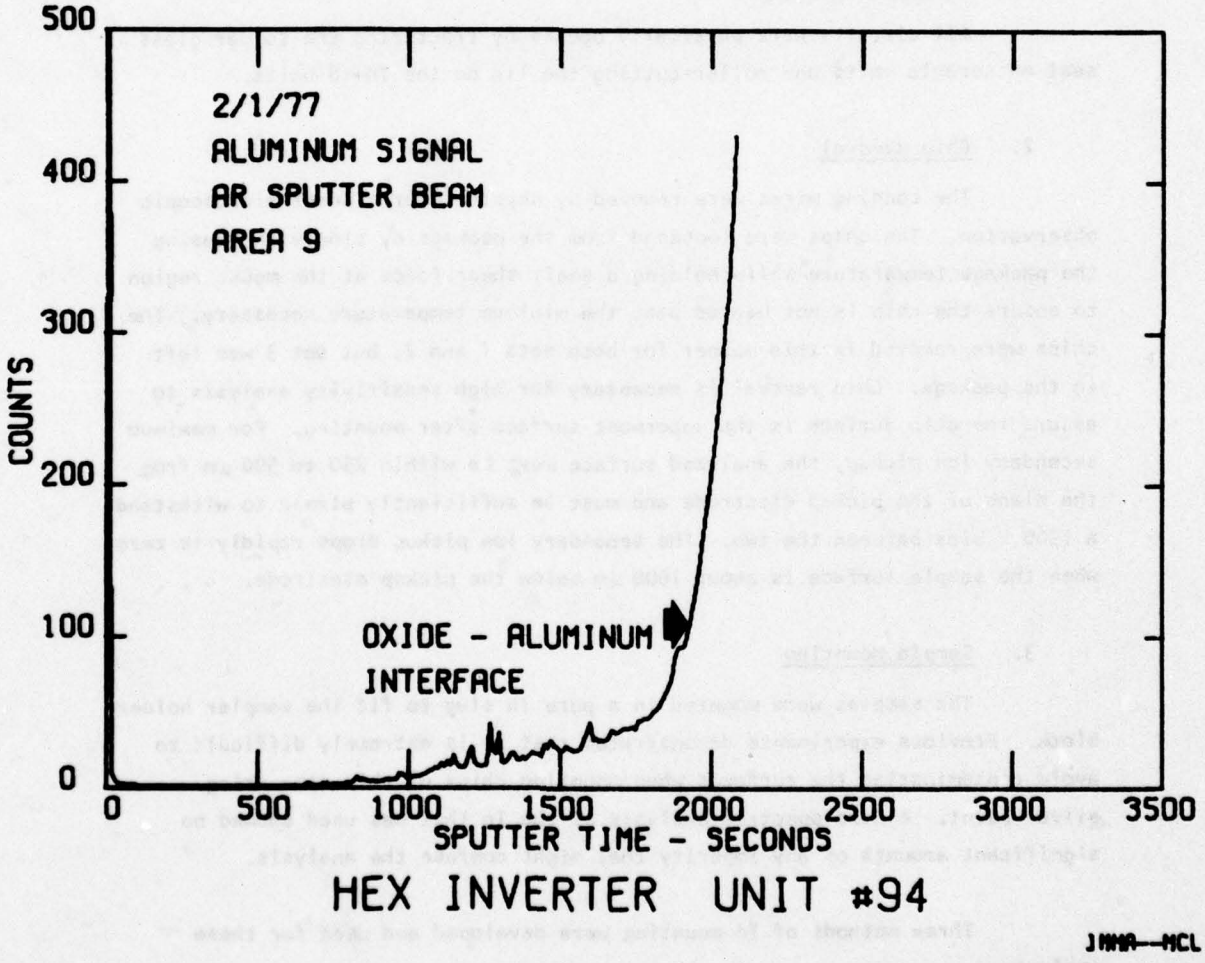

500
400
300
200
100
0
COUNTS
2/1/77
ALUMINUM SIGNAL
AR SPUTTER BEAM
AREA 9
OXIDE - ALUMINUM
INTERFACE
0
500
1000
1500
2000
2500
3000
3500
SPUTTER TIME - SECONDS
HEX INVERTER UNIT #94
JMMA--MCL

Figure 29

SECTION VII
SIMS PROCEDURE EVALUATION

A. Special Sample Preparation Procedures

1. Package Delidding

All circuits were physically opened by fracturing the solder glass seal on ceramic units and roller-cutting the lid on the TO-18 units.

2. Chip Removal

The bonding wires were removed by physical force under microscopic observation. The chips were loosened from the package by slowly increasing the package temperature while holding a small shear force at the mount region to ensure the chip is not heated past the minimum temperature necessary. The chips were removed in this manner for both sets 1 and 2, but set 3 was left in the package. Chip removal is necessary for high sensitivity analysis to assure the chip surface is the uppermost surface after mounting. For maximum secondary ion pickup, the analyzed surface must be within 250 to 500 μm from the plane of the pickup electrode and must be sufficiently planar to withstand a 1500 V bias between the two. The secondary ion pickup drops rapidly to zero when the sample surface is about 1000 μm below the pickup electrode.

3. Sample Mounting

The samples were mounted in a pure In slug to fit the sampler holder block. Previous experiments demonstrated that it is extremely difficult to avoid contaminating the surfaces when mounting chips of this size using silver paint. A mass spectrum analysis of the In that was used showed no significant amounts of any impurity that might confuse the analysis.

Three methods of In mounting were developed and used for these analyses:

(1) The chips were placed face down on a cleaned stainless steel block. A cleaned, large copper ring was placed around the chips rested on the stainless block. Molten In was poured into the ring and solidified immediately upon contact with the stainless heat sink. The technique was successful because there was very little In migration onto the chip surface, as evidenced by the very small In peaks in the mass spectra. The problems with the method were that the chip had a tendency to move when the molten In was poured in and adhered poorly to the In; in addition, an excessive amount of In was required for each mount, which made it economically necessary to recycle the In slugs.

(2) The second method is similar to the first, except that the large copper ring is replaced with a small, 8.3 mm O.D. stainless steel tube. In this technique, only one chip per tube was mounted, whereas in method (1) an array of chips was mounted in each ring. A second difference is that the stainless tube had to be kept at the melting temperature of In to keep the In from solidifying before it surrounded the chip. The main problems with this method are that considerable In migrated over the surface of the chip, which resulted in strong In peaks in many of the mass spectra; and that unless the procedure was done quickly, the chip had a tendency to float in the molten In.

(3) The third method is a further refinement of method (2) and is the method recommended for future analysis. The end of the stainless steel tube is filled with molten pure In in any convenient manner, and the surface is mechanically scraped clean. The chip is placed face down on the cleaned stainless steel block and cold-pressed into the In end of the stainless steel tube. No samples were mounted by this method that had not been previously mounted by method (2) so the In migration is not known; however, since only cold flow takes place, no migration should occur. The only problem that might develop is physical fracture of the chip, but none occurred (due to mounting) on the few chips mounted by this method.

4. Conductive Coating

To direct the secondary ions toward the pickup electrode, most of the sample surface must be biased + 1500 V with respect to the pickup electrode. High purity gold is sputtered over the surface after mounting to provide this conductive plane. The sputter apparatus used an aluminum target with all exposed surfaces wrapped with a high purity gold foil. A high purity quartz liner was used between the sample and target to shield the sample from line-of-sight impurities of other other parts of the sputtering system. The gold was dc-sputtered, using an Ar ambient, to a thickness of 20 to 50 nm. Figure 30 is the mass spectrum obtained from a cleaned silicon slice before gold coating in this sputter apparatus. Figure 31 is the mass spectrum of a second portion of the silicon slice that had been gold coated. These spectra demonstrate that the only element added by coating was gold.

5. Instrument Mounting

The array of chips mounted by method (1) was clamped into the standard sample holder and placed in one position of the carrousel. The tubes used in methods (2) and (3) were mounted in a specially designed sample holder that held six tubes on the circumference of a 25 mm diameter circle.

B. Spatial Resolution

The minimum beam diameter of the ion microprobe mass analyzer is 2.5 μm. This beam diameter is achieved when all operating parameters of the instrument are optimized for this purpose. However, these parameters are not necessarily optimized for analysis of solids. In fact, the working ion beam diameters are typically in the 10 to 25 μm range. Since ion sputtering and in-depth concentration profiles require crater wall rejection, it is necessary to raster the beam 4 to 6 beam diameters in the x-y plane. This means that the criterion of crater wall rejection dictates a minimum raster size of on the order of 40 x 40 μm.

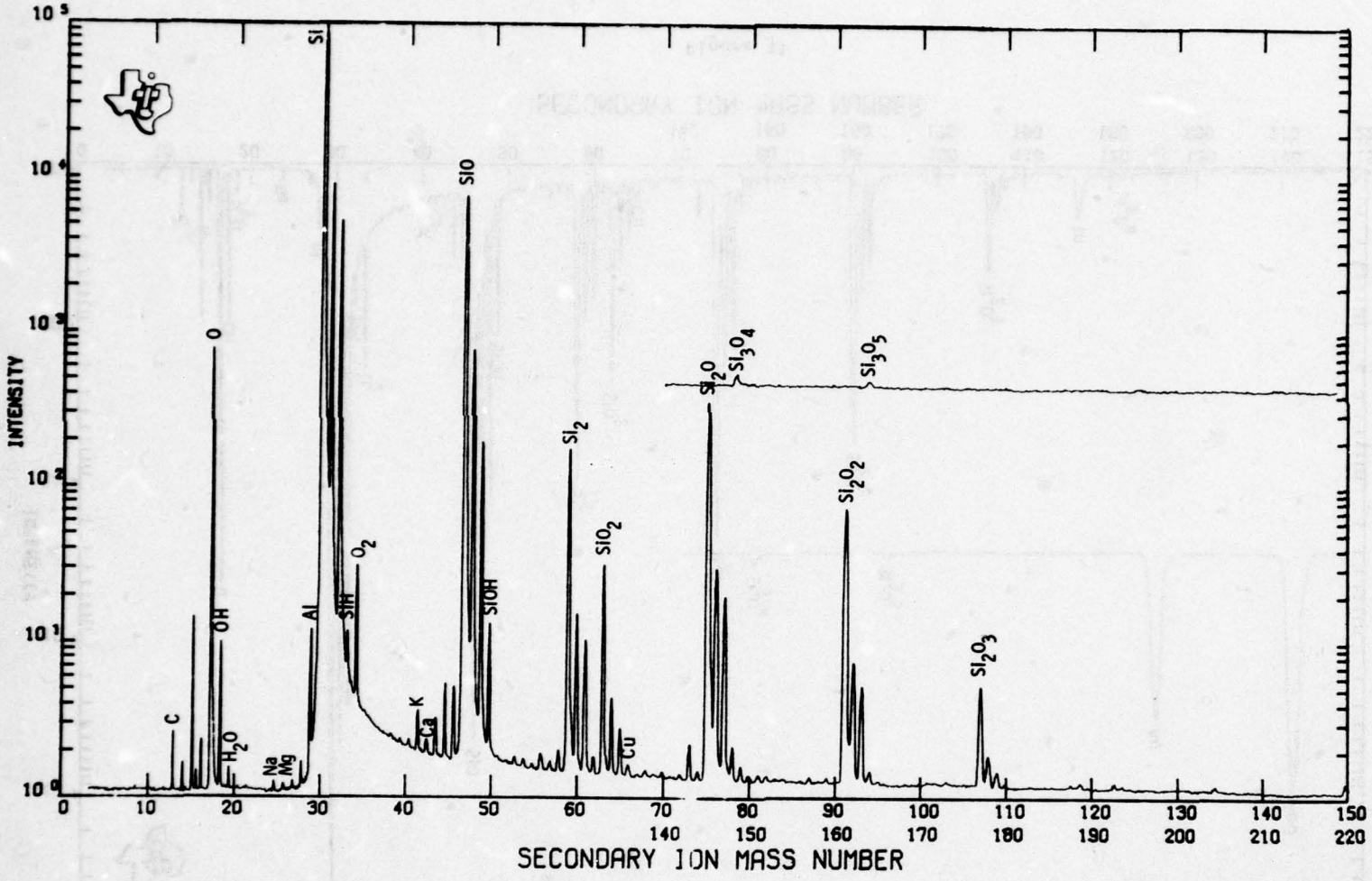

INTENSITY
SECONDARY ION MASS NUMBER
C
O
OH
H2O
Na
Mg
Al
Si
SiH
O2
K
Ca
SiO
SiOH
Si2
SiO2
Cu
Si2O
Si3O4
Si3O5
Si2O2
Si2O3

Figure 30

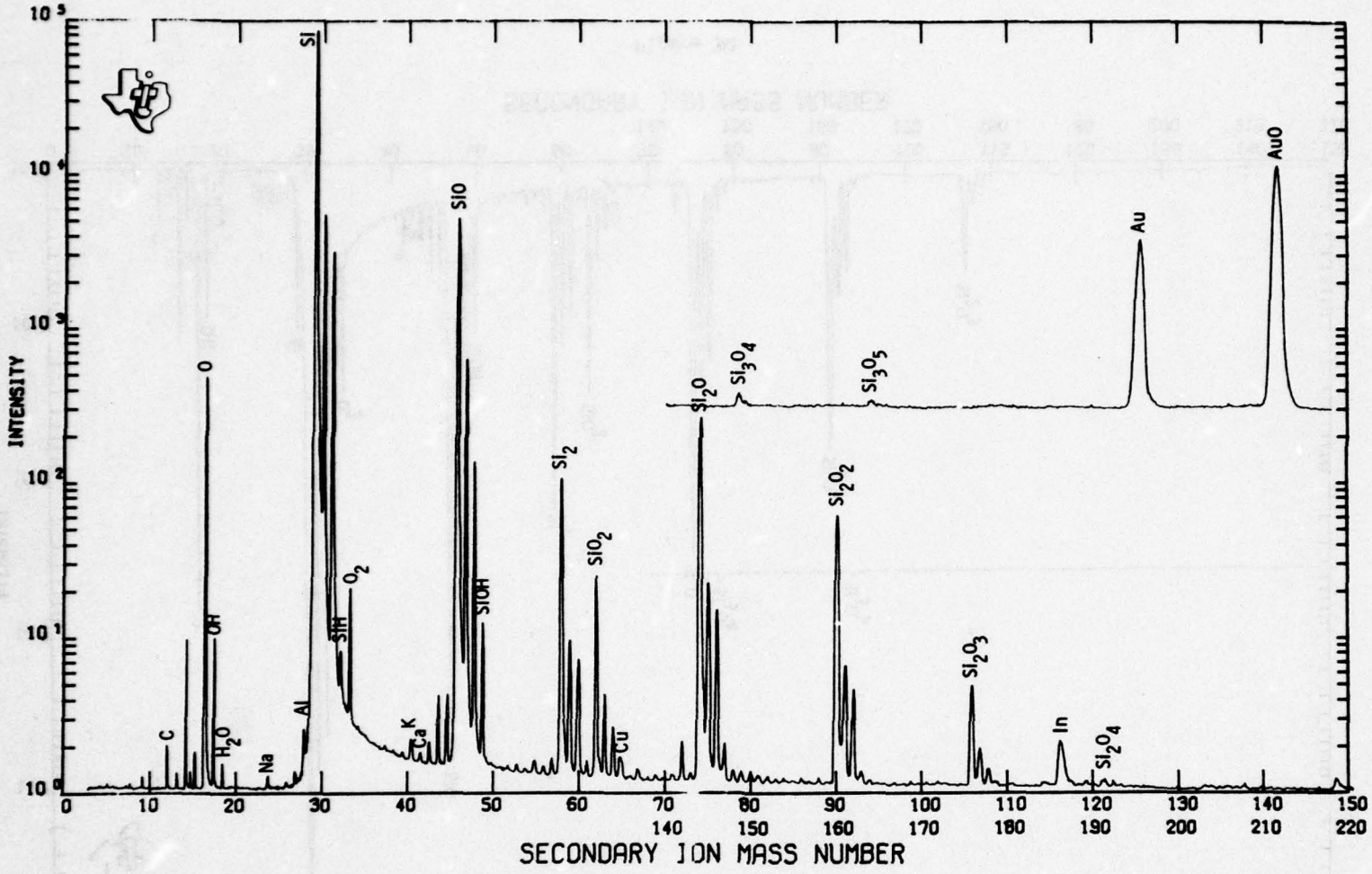

INTENSITY
SECONDARY ION MASS NUMBER
C
O
OH
H2O
Na
Al
Si
SiH
O2
K
Ca
SiO
SiOH
Si2
SiO2
Cu
Si2O
Si3O4
Si3O5
Si2O2
Si2O3
In
Si2O4
Au
AuO

Figure 31

The second, and perhaps most stringent requirement on raster size, or analysis area, is detection limit optimization. Since the detection limit (see Sections II and VII-E) is a direct function of the analysis area, it is necessary to use the largest area possible for integrated circuit analysis. Maximum sensitivity is achieved during in-depth profiling with a 150 x 150 μm rastered analysis area. This area is obviously large when compared with today's integrated circuit devices. Design rules in 1977 are 5 μm; that is, the smallest opening in an oxide will be 5 μm. Thus, a typical emitter will be 10 x 10 μm and a base 20 x 25 μm in a bipolar device. In CMOS or MOS devices the MOS gate will be 10 x 10 μm and the source/drain in the 10 x 15 μm range. Obviously, these design rules severely restrict the applicability of the microprobe in device failure analysis and for microdefect characterization. However, as was demonstrated in the work reported in Sections V and VI of this report, the ion microprobe can analyze many parts of a circuit and provide meaningful analytical data. The direct analysis of electrically active areas on MSI and LSI devices is very difficult. However, metalization, resistors, bond pads, capacitors, and dielectric film can be analyzed.

C. In-Depth Resolution

The ion sputtering technique is inherently capable of providing in-depth compositional analysis with a resolution of 2 to 3 nm. The sputter rate for an O_{32}^{+} ion beam in silicon is 0.25 nm/sec, and data are taken at 10 second intervals. It is generally believed that the mean escape depth of secondary ions from a sputtered surface is in the 2 nm range. These latter two factors confine the in-depth resolution to the 2 to 3 nm range.

Absolute or positional accuracy in a depth profile is more difficult to define. In the sputtering process, the oxygen ion beam implants oxygen about 20 nm ahead of the surface. This process continues as the in-depth sputtering continues with an oxygen saturated front continually moving about 20 nm ahead of the bottom of the sputtered crater. This is a violent process; it converts single crystal silicon to amorphous silicon saturated with oxygen. The process causes a continual mixing of atoms in the region of the implant. Sharp interfaces are mixed and turned into diffuse interfaces. As a result of these

processes, the assignment of an absolute position of an interface is difficult. It is generally accepted by workers in the field of ion sputtering that the range of error or standard deviation is ±10% of the assigned depth. Therefore, typical uncertainties would be:

Metal films:	2,000 ± 200 nm
Dielectric films:	500 ± 50 nm
Ion implants:	100 ± 10 nm

These uncertainties do not include possible changes in sputter rates due to matrix changes, structure and/or thickness variations. These latter uncertainties were all encountered in the nichrome resistor analysis of the radiation hardened devices.

This same implantation process severely limits the effectiveness of secondary ion mass spectroscopy for the analysis of the first 15 to 20 nm of depth into a sample. Equilibrium of the plasma is established only when the sputtered crater has reached the oxygen-saturated front (~ 20 nm). At that point, data in the depth profile will be in equilibrium with the matrix as well as all subsequent volumes of material consumed in the depth profile.

D. SIMS Parameter Control

1. Primary Ions

All high sensitivity ion microprobe or secondary ion mass spectroscopy analysis on conductors is done with a positive oxygen ion (O^+_{32}) primary ion beam. Significantly higher secondary ion yields, and therefore sensitivities, are obtained with O^+_{32} over the noble ion (Ar^+_{40}) primary ion beams. However, positive primary ion beams cannot be used on insulators such as SiO_2 and Si_3N_4 films because of charging problems on the surface of the insulator. The charging results from secondary electrons being ejected from the sample surface by high energy ion impact. The positive surface created by this secondary electron emission is further aggravated by the implantation of positive ions. Since in insulators, electrons cannot flow from ground to neutralize this positive charge, the potential will build until there is sufficient field strength to jump some gap to ground, at which time the process starts over again. This surface charging has very little effect on the high

energy primary beam which allows the use of Ar^+ sputtering for rapid removal of material. However, the charge has a major effect on the secondary ion trajectory, since these ions normally have very low energies. In fact, with the present instrumentation, very few secondary ions ever reach the detector. Dielectric films can be sputtered and analyzed using negative (O^-_{16} in this work) primary ion beams. The injection of negative ions tends to stabilize the charge at an equilibrium state where secondary ions can be controlled. Sputter rates are a factor of five slower with the O^-_{16} beam than with the O^+_{32} beam because of the lower total ion current generated, only half the number of sputtering particles, and an effective higher energy, which results in deeper implantation with a reduced sputter yield. This increases analysis time proportionately.

Since virtually all integrated circuit devices have dielectric films over the device, it is necessary to use the slower and less sensitive O^-_{16} primary ion beams. On metal films, thin dielectric films (< 150 nm), and on silicon, (O^+_{32}) primary ion beams are employed.

2. Secondary Ions

SIMS instruments normally use unit or half-unit mass resolutions for secondary ion detection. Higher resolutions are possible, but are not generally employed because there is a strong inverse relationship between resolution and sensitivity. Since the actual sample volume that can be consumed per second is very small, most analysts prefer to use the lower resolution to gain sensitivity. This type of operation precludes the low level of detection of some elements because of matrix molecular ion interference. Examples of this type of interference on silicon integrated circuits include:

Mass 14 N^+ or Si^{+2}	Mass 55 Mn or $SiAl^+$
Mass 31 P^+ or SiH^+	Mass 56 Fe or Si^+_2
Mass 45 Sc or SiO^+	Mass 75 As or Si_2O^+.
Mass 54 Fe or Al^+_2	

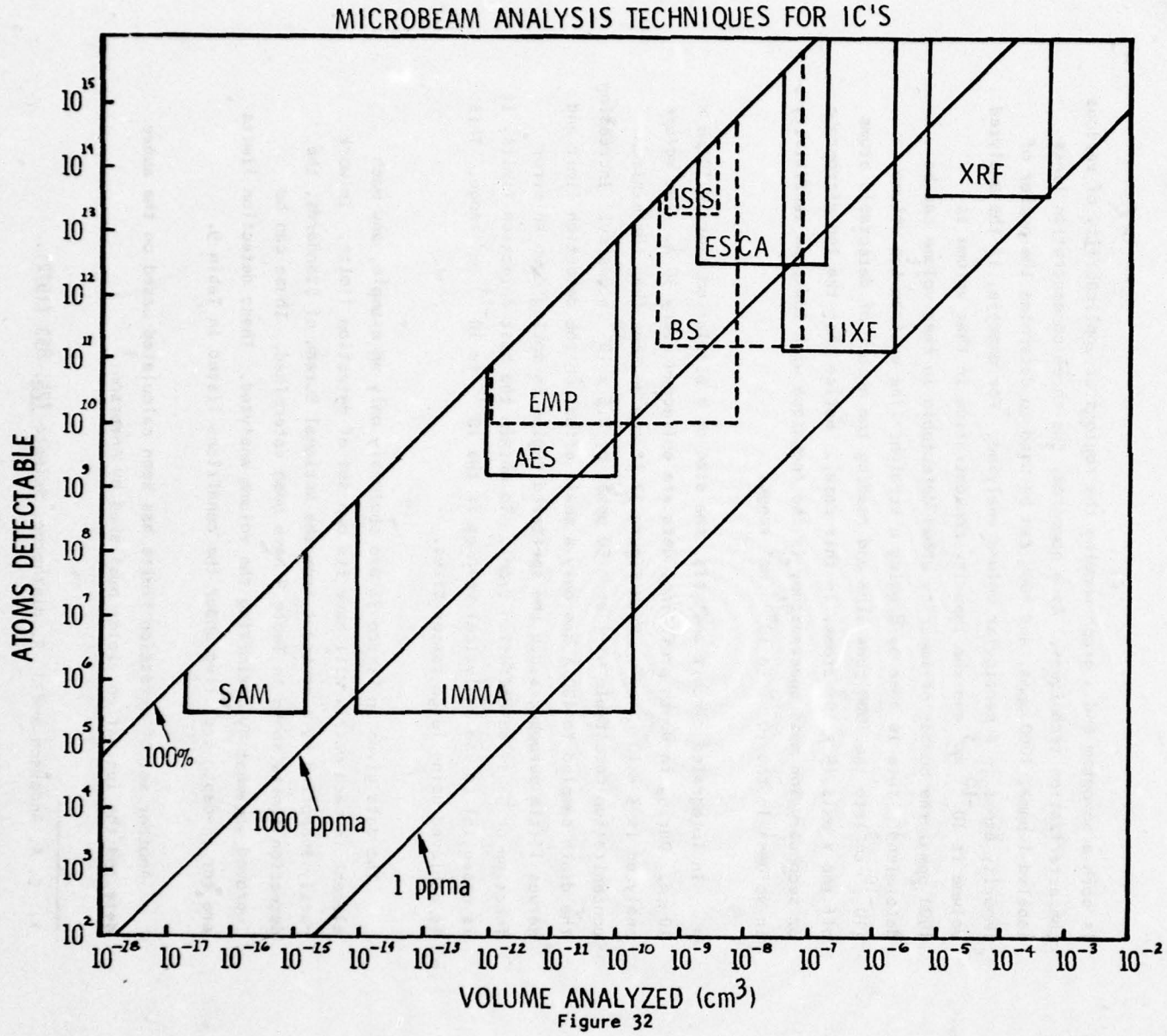
Fortunately, very few molecular ions are formed in the ambient after sputtering, and the high energy sputter processes do not favor molecular particles being ejected. This minimizes the ambiguity.

3. Dynamic Range

The dynamic range of SIMS in depth profiles is 10 to 10,000 and is strongly dependent on the element, matrix, vacuum, and other experimental conditions. The primary dynamic range limitation is the crater wall effect, discussed in the preceding section. The secondary limitation is that a point primary beam cannot be obtained in practice, but it is actually made up of three components: a central hot spot, a small charged particle halo, and a much larger (300 μm or objective aperture size) neutral particle halo. The charged particle halo arises from a slight energy spread of the ions emitted from the ion source and energy loss by glazing angle collisions with various aperture walls. The neutral particle halo results from ions that were directed toward the sample, but were neutralized before passing through the objective lens, thereby escaping focus. Both of these secondary effects can be minimized by hard vacuums and cutting large area craters. The latter is quite time consuming when using negative beams; hence, in many cases, the dynamic range was sacrificed in the interest of reasonable analysis time.

E. Detection Limits

The question of detection limits in ion microprobe analysis is complex. Ultimately, detectability will be controlled by the number of impurity ions per second sputtered and detected. This comes down to the volume of the analytical region sputtered. In integrated circuit analysis, the areas available for analysis tend to be small, particularly when it is realized that maximum sensitivity is achieved with a raster size of 150 x 150 μm. Therefore, in small areas the volume of sample must be maximized by sputtering deeply and integrating all signal over the sputter period. This mode of operation precluded in-depth concentration profiling. Alternatively, if in-depth concentration profiling is required, then large raster sizes or analysis areas are essential. This effect is illustrated in Figure 32. This figure


MICROBEAM ANALYSIS TECHNIQUES FOR IC'S
ATOMS DETECTABLE
VOLUME ANALYZED (cm3)
SAM
IMMA
EMP
AES
ISS
ESCA
BS
IIXF
XRF
100%
1000 ppma
1 ppma
Figure 32

is both a nomogram and a graph showing the regions of applicability of various characterization techniques. As a nomogram, the three concentration lines labeled 1 ppma, 1000 ppma, and 100% can be used to determine the number of impurity atoms in a particular volume analyzed. For example, if the analyzed volume is 10^{-10} cm^3 and the impurity concentration in that volume is 1000 ppma, the number of impurity atoms detectable in that volume can be determined. This is done by drawing a straight line up from the volume (10^{-10} cm^3) to the 1000 ppma line and reading the number of detectable atoms off the Y axis (5×10^9 atoms, in this case). Notice that the ion microprobe or secondary ion mass spectroscopy is the technique with low ppma sensitivity in volumes in the 10^{-10} to 10^{-14} cm^3 range.

In integrated circuit analysis, the size of a bipolar emitter is 10 μm x 10 μm. During in-depth profiling, data are collected every 30 Å. The volume analyzed is 3×10^{-13} cm^2. From Figure 32 it can be seen that the minimum concentration detectable will be ≃ 50 ppma, or 2.5×10^{18} atoms/cc. Increasing the depth sampled to 100 Å has only a small effect on the detection limit and serves little purpose, since the sputtered region is moving down an error function or Gaussian diffusion front. To obtain the best detection limits, it is essential to use analytical volumes in the 10^{-10} to 10^{-11} cm^3 range. This is achieved using large raster sizes.

The data given in Figure 32 are obviously only an example, and each element in each matrix will have its own set of detection limits. In work partly supported by a contract from the National Bureau of Standards, the detection limits shown in Table 9 have been determined. These can be improved somewhat by maximizing the volume analyzed. These detection limits are for in-depth profiling under the conditions listed in Table 9.

Another set of detection limits has been calculated based on the above data and the ionization yields published by Anderson:[1]

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1. C. A. Anderson and J. R. Hinthorne, Science 175, 853 (1972).

TABLE 9. DETECTION LIMITS* DETERMINED FOR THE ION MICROPROBE MASS ANALYZER IN SILICON AND SILICON DIOXIDE

Element	ppma	Atoms/cm^3	Atoms
Boron	0.1	5×10^{15}	1.5×10^{5}
Phosphorus	10	5×10^{17}	1.5×10^{7}
Arsenic	10	5×10^{17}	1.5×10^{7}
Antimony	0.2	1×10^{16}	3.0×10^{5}

*Raster size 125 μm x 95 μm with 25 Å depth sampled ($2.97 \times 10^{-11} cm^3$)

10 to 100 ppba - Mg, Al, Ti, Cr, Mn, Ga, Zr, Mo, In, Na, Li, K and Ca
100 to 1000 ppba - Cu, Ta, and W
1 ppma to 1000 ppma - Fe, Ni, Ge, C, Zn, Se, Sn, Ag, Cd, Te, Pb, and Bi
> 1000 ppma - noble metals and rare gases.

In summary, and as shown in Figure 32, the only analytical microbeam technique with the detection limits required for integrated circuit analysis are the ion microprobe or some microbeam secondary ion mass spectroscopy technique.

F. Analysis Time

The analysis of an integrated circuit device covers the sequence of events and typical times shown in Table 10. The time elapsed between receiving the device and starting the SIMS analysis is usually from four to five hours. The major part of the time of the ion microprobe process is taken up by the sputtering process. The sputtering time for each area analyzed depends, as indicated below, on the primary ion used for analysis:

Silicon or metal films with $O_{32}^{+} \simeq 2.5$ Å/sec
Dielectric films with $O_{16}^{-} \simeq 0.5$ Å/sec
All films with $Ar_{40}^{+} \simeq 6$ Å/sec

These sputter rates transpose into the analysis times for each area analyzed, as shown in Table 10. Thus, if two dielectric areas, two silicon areas, and one metal area are analyzed, the ion microprobe sputter time could be in the 12 to 24 hour range, depending on the thickness of the films. This represents a total analysis time of 16 to 29 hours per device without data reduction. Data reduction times vary depending on the analyst, but in this laboratory, using a 960A computer, one to four hours are required.

These analysis times assume that in each of the six areas, the data collected are mass spectra depth profile if a complete survey of all impurities is to be taken. For single element, high sensitivity depth profiles, or quantitative determinations, a six to twelve hour time period could apply to each element determined per area, depending on the depth and accuracy desired.

TABLE 10. ANALYSIS TIMES REQUIRED FOR SIMS ANALYSIS OF AN INTEGRATED CIRCUIT

Process	Typical Time
Open device and photograph	30-45 minutes
Remove bonds and dealloy chip	45-60 minutes
Mount chip and gold coat	45-60 minutes
SEM inspection, pictures and select areas for analyses	60-90 minutes
Introduce in IMMA and pump down	30-45 minutes
Locate areas in IMMA and start analysis	10-20 minutes
O_{32}^{+} ion sputter of silicon/metal area*	60-180 minutes
$O_{16}^{}$ ion sputter of dielectric area	300-900 minutes
A_{40}^{+} ion sputter of device area	10-60 minutes

*Assumes silicon/metal area is exposed

G. Quantitation

Two methods are employed to obtain quantitative ion microprobe analysis. The first method is based on a model using the Saha-Eggert ionization equation which is based on the ion production process. Anderson and Hinthorne[2] have developed a computer program, CARISMA, for the ion microprobe and have reported success with their method on a variety of matrices. Efforts at Texas Instruments to apply this program to the quantitation of trace impurities in silicon have not demonstrated confidence in its accuracy.

The second method of quantitation is based on empirical calibration using standards. Work at Texas Instruments sponsored in part by a National Bureau of Standards contract[3] has been successful in establishing calibration curves for boron, arsenic, antimony, and phosphorus in silicon and silicon dioxide. These detection limits are discussed in Section VII.E. The standards used to obtain these calibration curves were infinite plane samples, that is, very large compared to the size of the raster used for the analysis.

Quantitation during integrated circuit analysis will be extremely difficult. Most of the problems result from the large areas or raster sizes required for ion microprobe analysis. Areas of the required size available for analysis on integrated circuits seldom have a single matrix, e.g., silicon or silicon dioxide. Since calibration curves are set up on a single matrix, any mixing of matrices, e.g., metalization, dielectric films, etc., will keep the results from being quantitative.

In summary, quantitation in ion microprobe analysis of integrated circuits is possible if there is available an area of sufficient size, i.e., 100 x 100 μm, and of a single matrix of silicon or silicon dioxide. In reality, this will occur only with dielectric films, metalization, bond pads, resistor films, large area capacitors, and bulk or epitaxial silicon regions outside the bar.

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2. C. A. Anderson and J. R. Hinthorne, Anal. Chem. 45, 1421 (1973).
3. National Bureau of Standards Contract No. 5-35917, "Development of Techniques for the Preparation and Analysis of Standard Silicon Semiconductor Specimens for the Ion Microprobe Mass Analyzer."

The electrically active regions, e.g., emitters, bases in bipolar devices, and source-drain-bases in MOS devices, are very difficult to analyze, and much more to so quantitate.

SECTION VIII
CONCLUSIONS

The ion microprobe mass analyzer analysis of these 42 integrated circuits has amply demonstrated the power of this technique to chemically characterize actual packaged commercial devices. The results reported here confirm the statement made in Section II of this report that IMMA (SIMS) is the only analytical technique that will even approach the analysis of integrated circuits with the geometrical resolution and sensitivity needed for 1977 time-frame devices. IMMA techniques must be extended even further by additional studies such as this one, coupled with more instrument research to meet the needs for the 1980 timeframe, large-scale integrated circuits.

The data presented here have successfully demonstrated the following analysis capabilities, many of which are not possible with any other analytical technique.

(1) Surface analysis: The surface analysis of small areas was obtained in the first and second mass spectra of any mass spectra depth profile series. The entire surface was not sputtered for any analysis, which allowed proof that some elements were found only on the surface, i.e., the Pb and Sn depth profile from the general technology group.

(2) Interface analysis: A technique was developed to open in-situ an interface for chemical analysis. The actual point of small area for this analysis could be readily chosen, again leaving the rest of the circuit intact for other types of analyses.

(3) Dopant identification: The ability to identify dopants and depth-profile the dopants in electrically active areas of the silicon was presented in Sections V and VI. Even though in some areas the dopant was not positively identified in this study, this does not detract from IMMA's potential.

(4) Depth profile: Many examples of the depth profiling capability have been presented. This type of analysis cannot be performed on actual circuits by any other technique presently known.

(5) Quantitation: Quantitation of dopants and/or impurities in the small total material volumes found in these circuits is extremely difficult. However, quantitation is possible, as evidenced by the many quantitative phosphorus profiles and the boron concentration in electrically active silicon areas. The Cr-Ni profiles of the nichrome resistors could have been quantitative had suitable standards been prepared to calibrate the observed signals.

These features and the many others discussed in this report prove conclusively that IMMA (SIMS) has a very important role in the analysis of all types of integrated circuits and other solid state devices.

SECTION IX

RECOMMENDATIONS

A. Failure Analysis

The ion probe can be an extremely valuable tool in the area of failure analysis if the failure mechanism is chemical in nature. However, because of the time involved in sample preparation and depth sputtering, the ion probe should be used only after exhaustive analysis has been done by electron probe techniques. For example, total phosphorus can be determined by the electron probe; however, it samples a depth of several micrometers, so if it is important to know the depth at which phosphorus is located, the ion probe must be used. In addition, only the ion probe has a real sensitivity for elements such as H, Li, B, and F, and it is several orders of magnitude more sensitive for the alkali elements.

The results presented in this report have shown that ion probe analysis does indeed yield copious amounts of chemical information from a single circuit chip. However, in terms of failure analysis, these results mean very little by themselves. A data base must be acquired which relates device performance, degradation, and/or failures to the chemical characterization by ion probe analysis. When such a data base is available, ion probe analysis will be one of the most powerful tools for failure analysis and determination of long-term reliability from actual integrated circuit chips.

B. Device Process Evaluation

Most of the reliability of any integrated circuit is built in during device processing. A major portion of the cost of integrated circuits is also determined by device processing, since yield is a critical cost factor. Most of the circuits built today use test subcomponents on each bar and/or replace one or more bars with test patterns on each slice. These testers are evaluated by electrical measurements, which are extrapolated back to the processing parameters. As circuits become more complex with higher densities and much

smaller geometries, these built-in test patterns are becoming infeasible, in that they no longer adequately represent the device processing and require too much usable real estate on the chip. In the near future, process evaluation and reliability will be determined by process evaluation slices where an entire slice is used for many types of test patterns designed for different types of testers. These testers include electrical, mechanical, and chemical types. The ion probe has a very real application here, since the necessary geometries can be included for maximum sensitivity. The ion probe can easily determine diffusion or ion implant profiles, junction depths, and/or impurities on these test patterns.

C. Instrumentation

The instrument used in this study was as delivered from the manufacturer, without automation. A TI 960A computer was interfaced to handle the data for point-counting depth profiles of either one or two elements in a given run. If more elements need to be profiled, separate craters must be sputtered. This can be a severe problem in failure analysis, since separate areas may not be available. Therefore, if failure analysis is the primary goal, the instrument should be equipped with secondary magnet, computer-controlled peak switching so several elements can be profiled in narrow 1 to 3 nm layers from one crater hole.

An ideal instrument for failure analysis would have the characteristics listed below:

(1) A basic ion probe capable of 1 to 2 μm diameter beams
(2) Computer-controlled secondary magnet system
(3) Computer-controlled data collection system
(4) Computer-controlled time clock for all beam rastering, electron gating, peak switching, beam blanking, and data collection
(5) Computer monitoring of the primary ion beam current
(6) Computer monitoring of the secondary ion non-mass analyzed ion current
(7) Computer control of sample stage movements.

D. Future Studies

This study has demonstrated the potential of the ion probe to provide valuable information about a circuit. The analyses and techniques developed in the course of this work have merely scratched the surface in showing the potential usefulness of the instrument. It is recommended that future study should involve correlations between device performance and ion probe results, rather than a general survey of many types of devices. A correlation matrix involving electrical performance, SEM appearance, EBIC-voltage contrast images, electron microprobe analysis, and ion probe analysis, all concentrated to solve a particular problem, would prove invaluable.

APPENDICES

These appendices are a more detailed summary of the ion probe characterization performed on each device. No data or profile are repeated in these appendices that appeared in the main text. For each device analyzed, the appendix includes the area identification optical photograph, typical mass spectra, and the mass spectra depth profile numerical summary.

The entries in the mass spectra depth are the measured peak heights from each spectrum and are normalized by the Si_{30} peak height in order to obtain a common relative scale so meaningful comparisons can be made. The entry in the Si_{30} row is the actual measured peak height without normalization. The type of common intensity base is good for most spectra, but on some it could lead to gross error. The normalization assumed the Si was the major matrix element in each area analyzed. If not, the normalization gives a gross error. Examination of the Si_{30} row will reveal most of the error entries. Gross differences in the Si_{30} peak height are the indicator of the error.

The key to mass spectra depth profile table is:

Unit:	Unit number assigned by RADC to the circuit.
Area:	Area analysis, identified in optical photograph.
Spectra:	Numbers assigned to spectra for internal identification.
Raster:	Measured crater size sputter by primary beam.
Spot:	Measured primary beam diameter.
BC:	Primary beam current measured on circuit at 1500 V bias.
SR:	Calculated sputter rate in Å/sec.
Start (column):	Time in seconds to reach peak in mass spectrum.
Plus (row):	Sputter time in seconds before mass spectrum started.

APPENDIX A

CMOS-SOS-CLEAN OXIDE, UNIT #739

Area 1: Single Mass Spectrum for Surface Analysis

Area 2: Depth Profile Mass Spectra

Area 3: Aℓ-P Peak Count Depth Profile

Area 4: F-Ca Peak Count Depth Profile

Area 5: Aℓ-P Peak Count Depth Profile (not used)

Area 6: Depth Profile Mass Spectra

Area 7: False Start

Area 8: P Concentration in Depth Profile

Area 9: Mass Spectra Depth Profile After Oxide and Metal Stripping

Area 1A: Mass Spectra Depth Profile After Oxide and Metallization Removed

Area 2A: B Depth Profile After Stripping

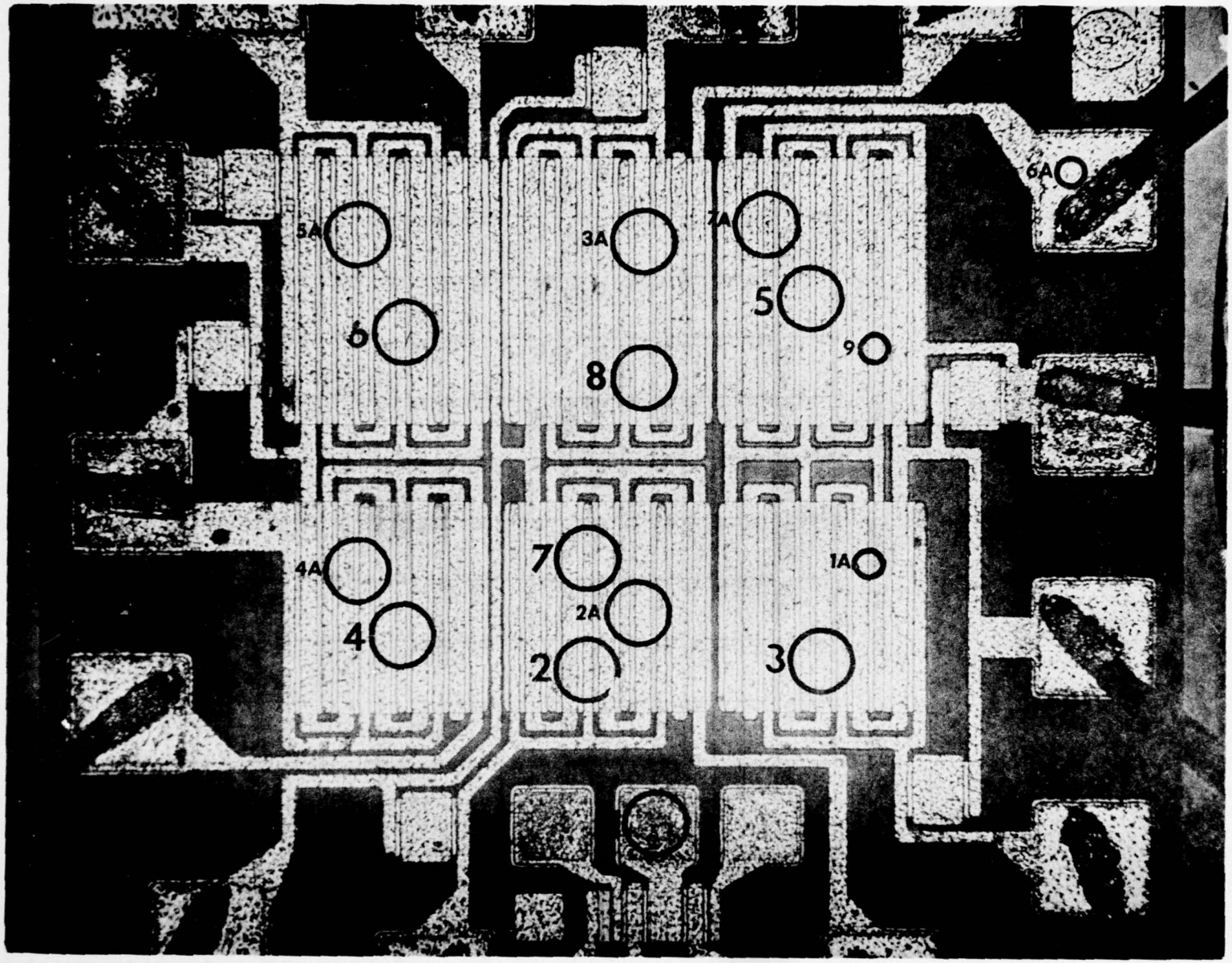
Area 3A: P Depth Profile After Stripping

Area 4A: B Depth Profile After Stripping

Area 5A: P Depth Profile After Stripping

Area 6A: Aℓ-Si Depth Profiles After Stripping

Area 7A: Aℓ-Si Depth Profiles After Stripping



CMOS-SOS-Clean Oxide Unit #739

CMOS SOS CLEAN OXIDE

UNIT #739 . AREA 2 . SPECTRA 145 - 155 .

RASTER 71X58 μm . SPOT 19 μm BC 11 NA SR (Å/SEC) .95 .

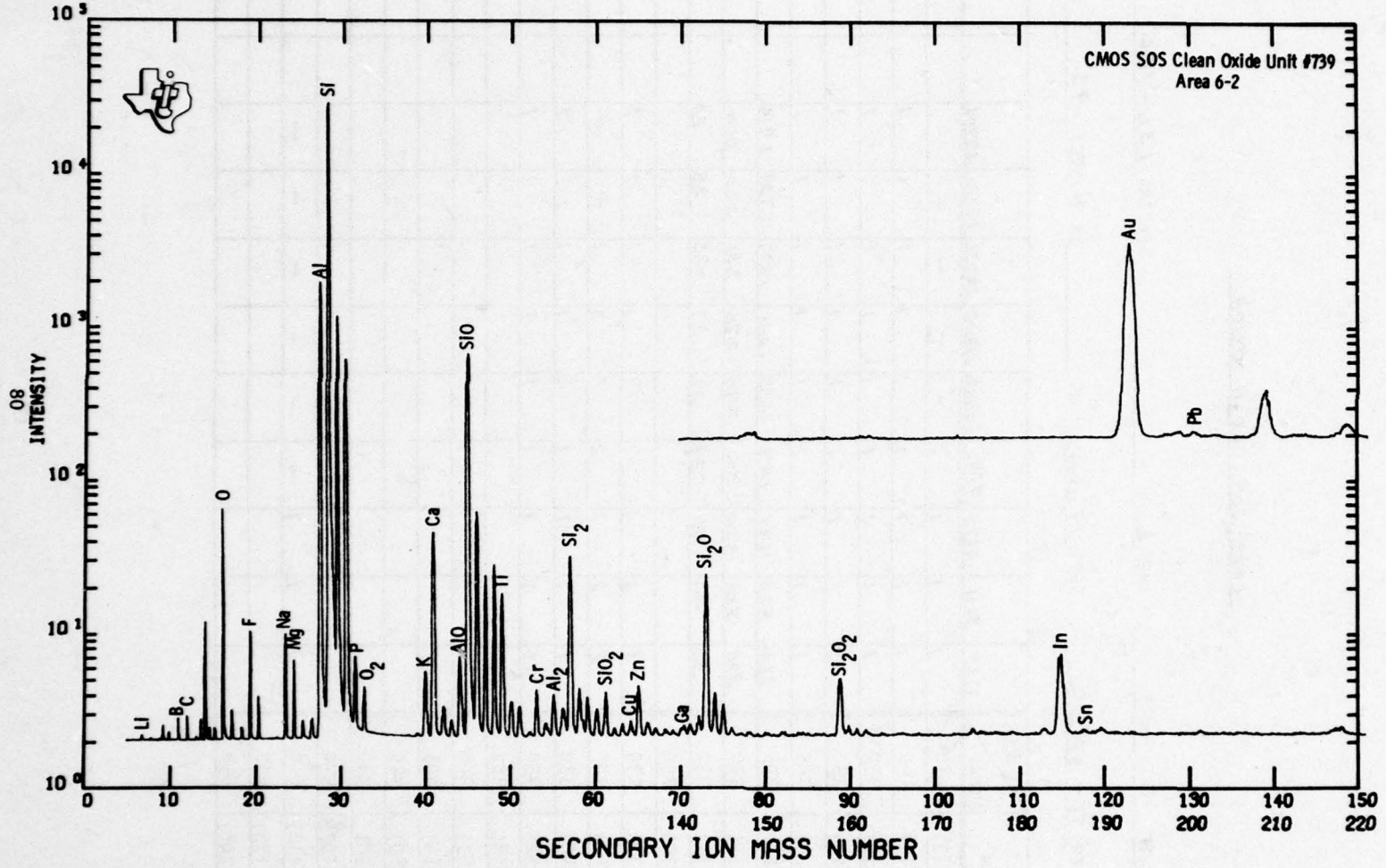
ELEM	PLUS / START	0	689	1379	2069	2758	3447	4135	4822	5510	6353	7038
Li (7)	30	–	1	1	1	1	1	1	1	1	1	1
B (11)	60	–	1	1	1	1	1	1	1	1	1	1
F (19)	150	2	3	2	1	1	2	1	1	1	1	1
Na (23)	180	23	2	1	1	1	2	2	1	1	1	1
Mg (24)	185	4	2	1	1	1	2	1	1	1	1	1
Al (27)	205	1663	335	239	189	100	243	81	60	83	81	206
Si (30)	220	25	180	210	350	240	280	260	330	290	320	330
P (31)	230	–	–	1	4	9	11	17	24	27	28	30
Cl (35)	250											
K (39)	290	19	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	171	22	10	11	5	17	9	6	7	5	3
Ti (48)	330	17	3	2	2	2	2	2	1	2	2	2
Cr (52)	350	–	1	–	–	–	1	1	1	1	1	–
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	1	1	1	1	1	1
Ba (138)	670											
Pb (208)	858											

CMOS SOS CLEAN OXIDE

UNIT # . AREA 2 . SPECTRA 156-164 .

RASTER 71 x 58 μm . SPOT 19 μm BC SR (Å/SEC) .95 .

ELEM	PLUS / START	7737	8511	9195	9891	10582	11265	12031	12716	13905		
Li (7)	30	1	1	1	1	–	–	–	–	–		
B (11)	60	1	1	1	1	1	1	1	1	1		
F (19)	150	1	1	1	1	1	1	1	1	1		
Na (23)	180	1	1	1	1	1	1	1	1	1		
Mg (24)	185	1	1	1	1	1	1	1	1	1		
Al (27)	205	324	820	1191	1471	1453	1635	1807	2739	2914		
Si (30)	220	340	330	320	300	290	270	250	220	200		
P (31)	230	32	33	31	28	26	27	25	25	24		
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1		
Ca (40)	295	2	2	2	2	3	3	2	–	–		
Ti (48)	330	1	1	1	1	1	1	1	1	1		
Cr (52)	350	1	1	1	1	1	1	1	1	1		
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	–	–	–	–	–	–		
Ba (138)	670											
Pb (208)	858											


CMOS SOS Clean Oxide Unit #739
Area 6-2
08 INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
F
Na
Mg
Al
Si
P
O2
K
Ca
AlO
SiO
Ti
Cr
Al2
Si2
SiO2
Cu
Zn
Ga
Si2O
Si2O2
In
Sn
Pb
Au

CMOS SOS CLEAN OXIDE

UNIT #739 . AREA 6 . SPECTRA 349 - 359 .

RASTER 69 X 56 μm . SPOT 12 μm BC 10 NA SR (Å/SEC) .92 .

ELEM	START \ PLUS	0	910	1831	2753	3735	4637	5549	6458	7386	8079	8808
Li (7)	30	1	1	1	-	-	-	-	-	-	-	-
B (11)	60	-	1	1	1	1	1	1	1	1	1	-
F (19)	150	1	2	1	1	1	1	1	1	1	1	1
Na (23)	180	3	2	1	1	1	1	1	1	1	1	1
Mg (24)	185	1	1	1	1	1	1	1	1	1	1	1
Al (27)	205	191	283	124	105	51	61	352	843	2061	2464	2401
Si (30)	220	220	170	170	190	160	180	160	110	98	74	96
P (31)	230	1	1	11	22	28	28	28	30	34	29	27
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	11	9	5	3	2	3	1	2	1	1	1
Ti (48)	330	2	4	1	1	1	1	1	1	1	1	1
Cr (52)	350	1	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400	1	1	1	1	1	1	1	1	1	1	1
Zn (64)	403	1	1	1	1	1	1	1	1	1	1	1
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	-	-	-	-	-	-	-	-
Ba (138)	670											
Pb (208)	858											

CMOS SOS CLEAN OXIDE

UNIT #739 . AREA 6 . SPECTRA 360 .

RASTER 69 X 56 μm . SPOT 12 μm BC 10 NA SR (Å/SEC) .92 .

ELEM	PLUS / START	9370										
Li (7)	30	–										
B (11)	60	1										
F (19)	150	1										
Na (23)	180	1										
Mg (24)	185	1										
Al (27)	205	2197										
Si (30)	220	92										
P (31)	230	25										
Cl (35)	250											
K (39)	290	1										
Ca (40)	295	1										
Ti (48)	330	1										
Cr (52)	350	1										
Ni (58)	380											
Cu (63)	400	1										
Zn (64)	403	1										
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	–										
Ba (138)	670											
Pb (208)	858											

CMOS SOS CLEAN OXIDE

UNIT # 739 . AREA 9 . SPECTRA 781 - 782 .

RASTER 62 X 53 μm . SPOT 17 μm BC 16 NA SR (Å/SEC) .

ELEM	PLUS / START	0	1082									
Li (7)	30	1	–									
B (11)	60	1	–									
F (19)	150	2	2									
Na (23)	180	11	10									
Mg (24)	185	6	5									
Al (27)	205	489	4787									
Si (30)	220	1800	72									
P (31)	230	-										
Cl (35)	250											
K (39)	290	1	6									
Ca (40)	295	40	37									
Ti (48)	330	1	1									
Cr (52)	350	1	1									
Ni (58)	380											
Cu (63)	400	1	6									
Zn (64)	403	1	1									
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1									
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

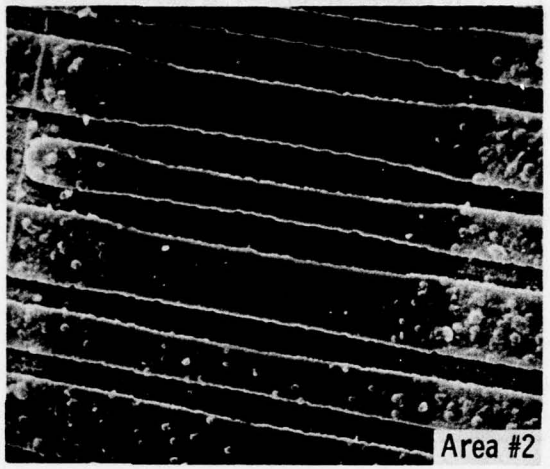
CMOS SOS CLEAN OXIDE

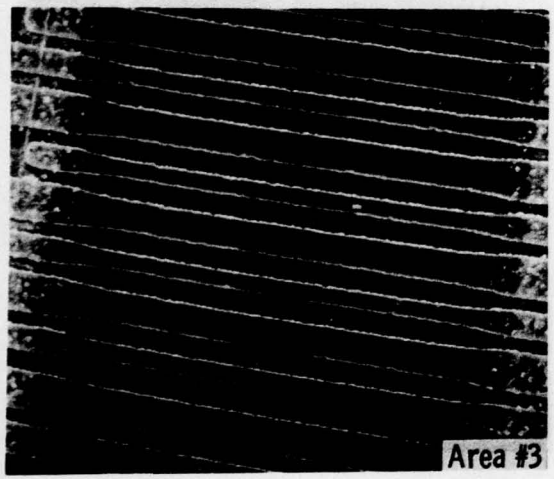
UNIT #739 . AREA 1A . SPECTRA 783 - 784 .

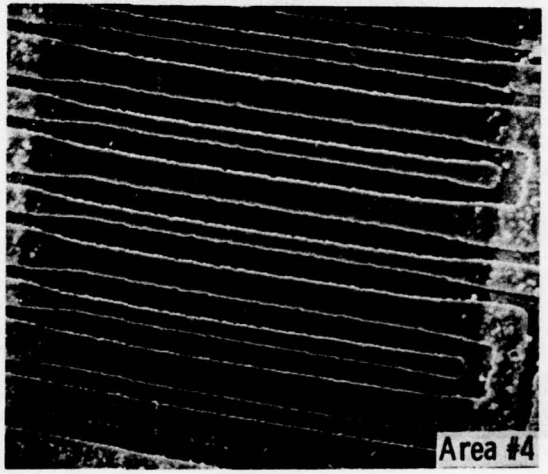
RASTER 62 X 53 μm . SPOT 17 μm BC 16 NA SR (Å/SEC) .

ELEM	START \ PLUS	0	1013									
Li (7)	30	1	1									
B (11)	60	1	1									
F (19)	150	6	1									
Na (23)	180	14	8									
Mg (24)	185	11	4									
Al (27)	205	764	4185									
Si (30)	220	1100	130									
P (31)	230											
Cl (35)	250											
K (39)	290	1	3									
Ca (40)	295	87	26									
Ti (48)	330	2	1									
Cr (52)	350	1	1									
Ni (58)	380											
Cu (63)	400	1	4									
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1									
Sn (118)	610	1	1									
Ba (138)	670											
Pb (208)	858											

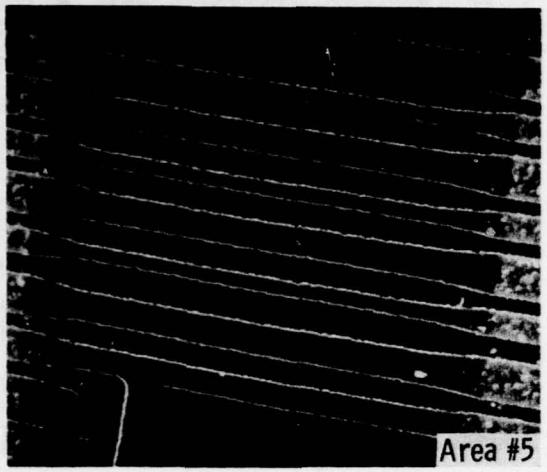
CMOS SOS Clean Oxide Unit #739

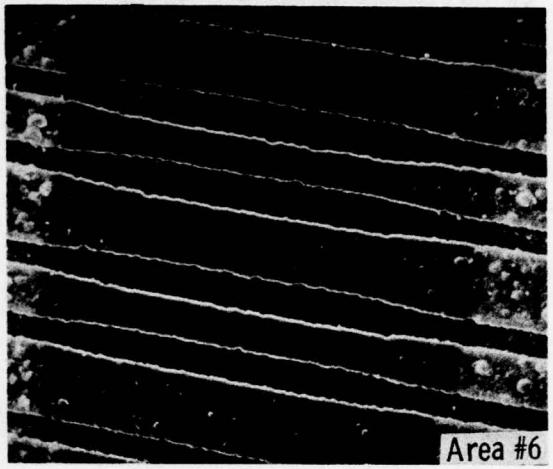


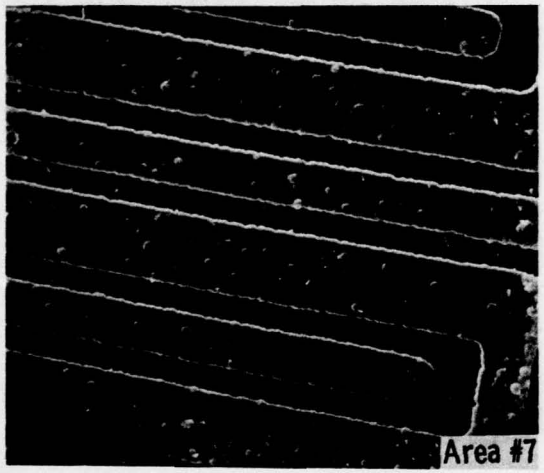


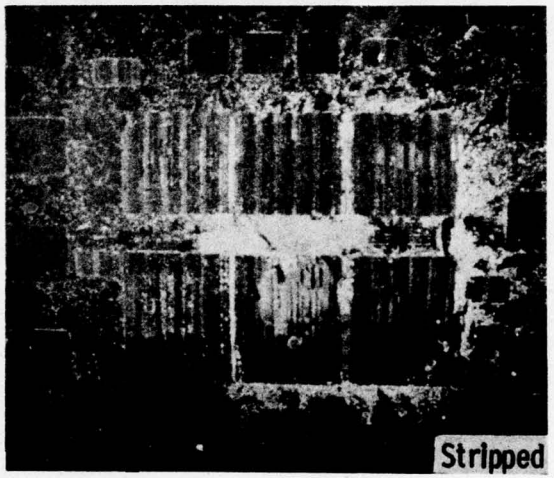


CMOS SOS Clean Oxide Unit #739









CMOS BULK CLEAN OXIDE, UNIT #R202

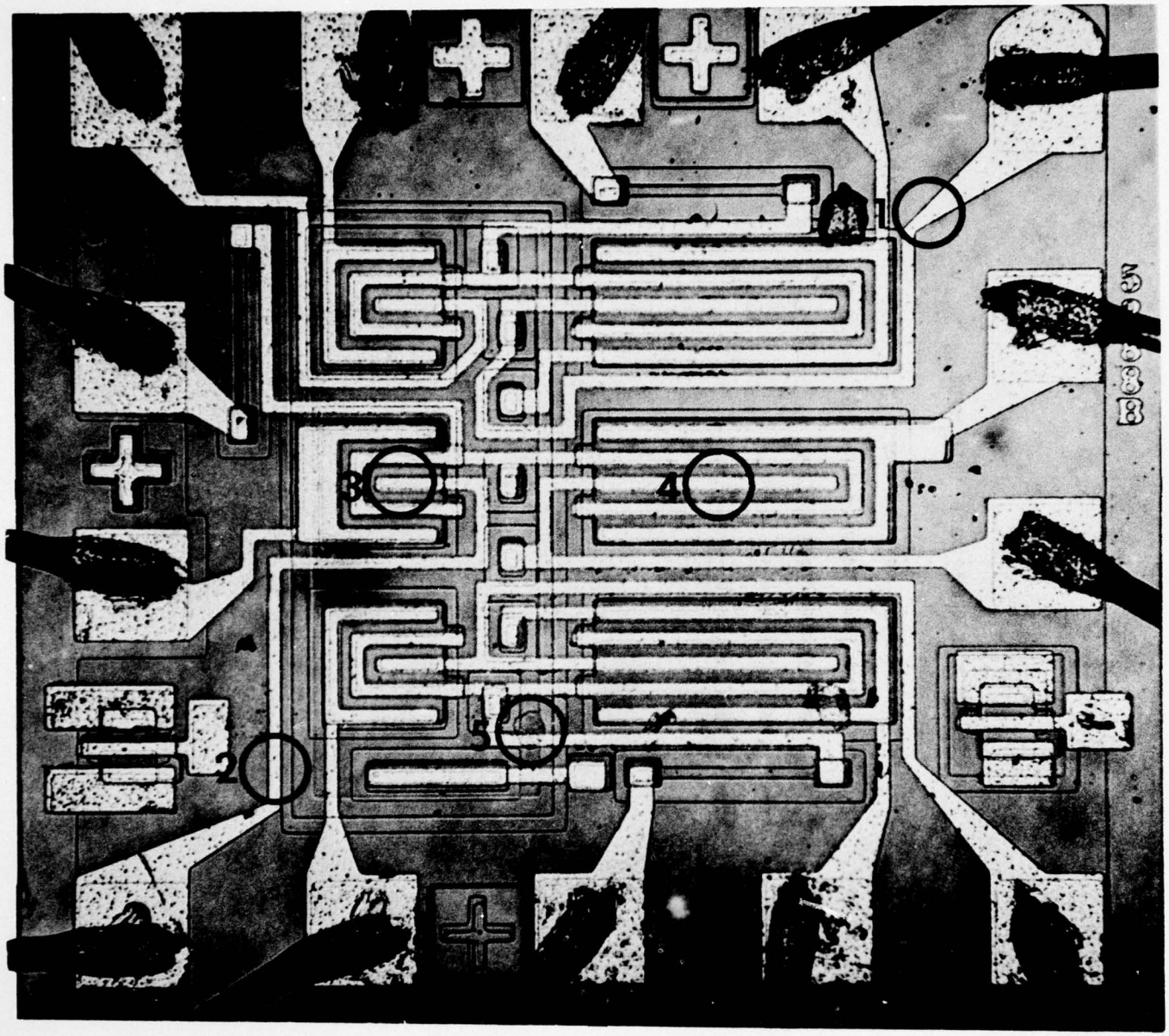
Area 1: Mass Spectra Depth Profiles

Area 2: Cr Peak Count Depth Profile (not included)

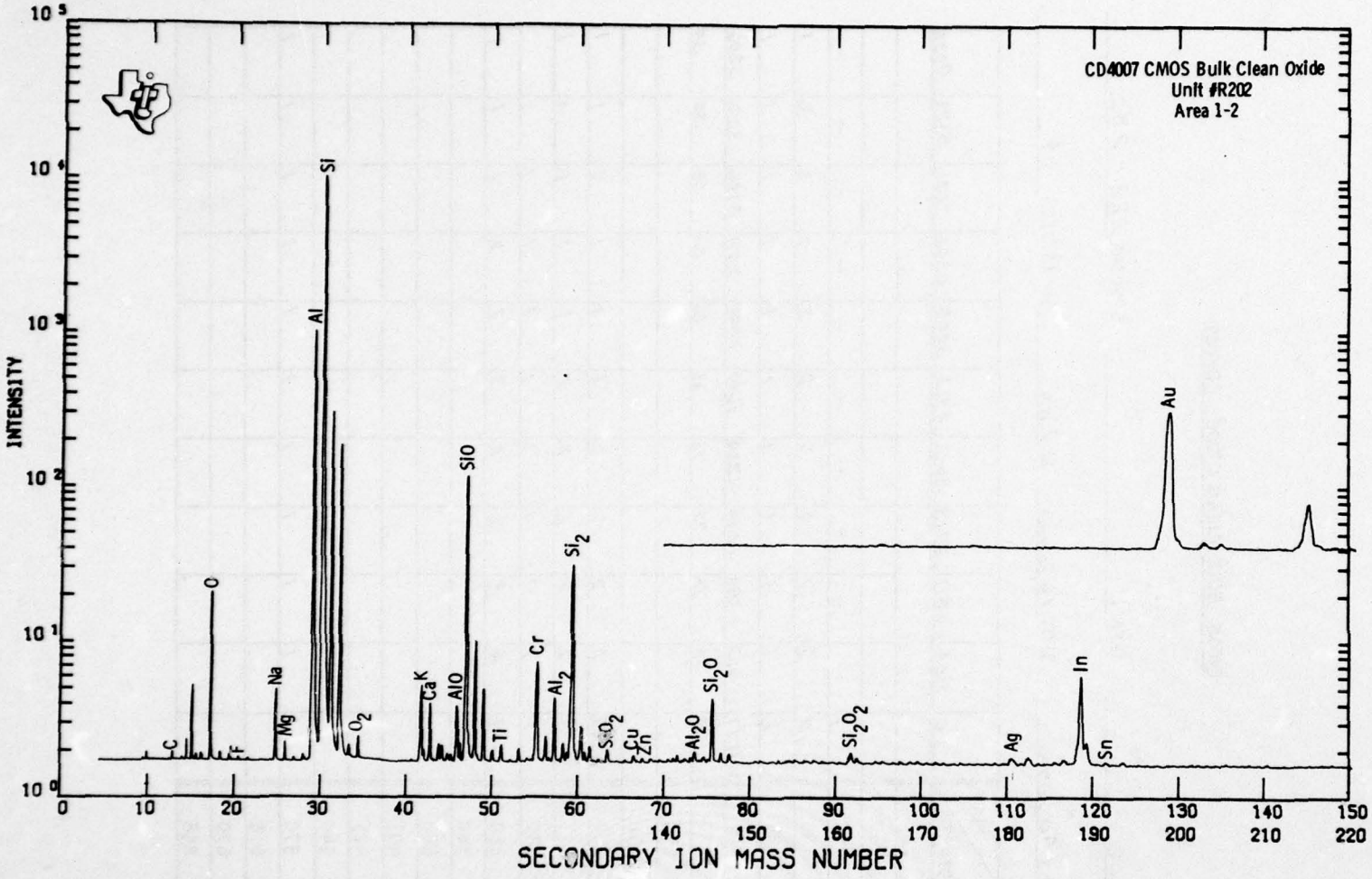
Area 3: Mass Spectra Depth Profile

Area 4: Mass Spectra Depth Profile

Area 5: Mass Spectra Depth Profile

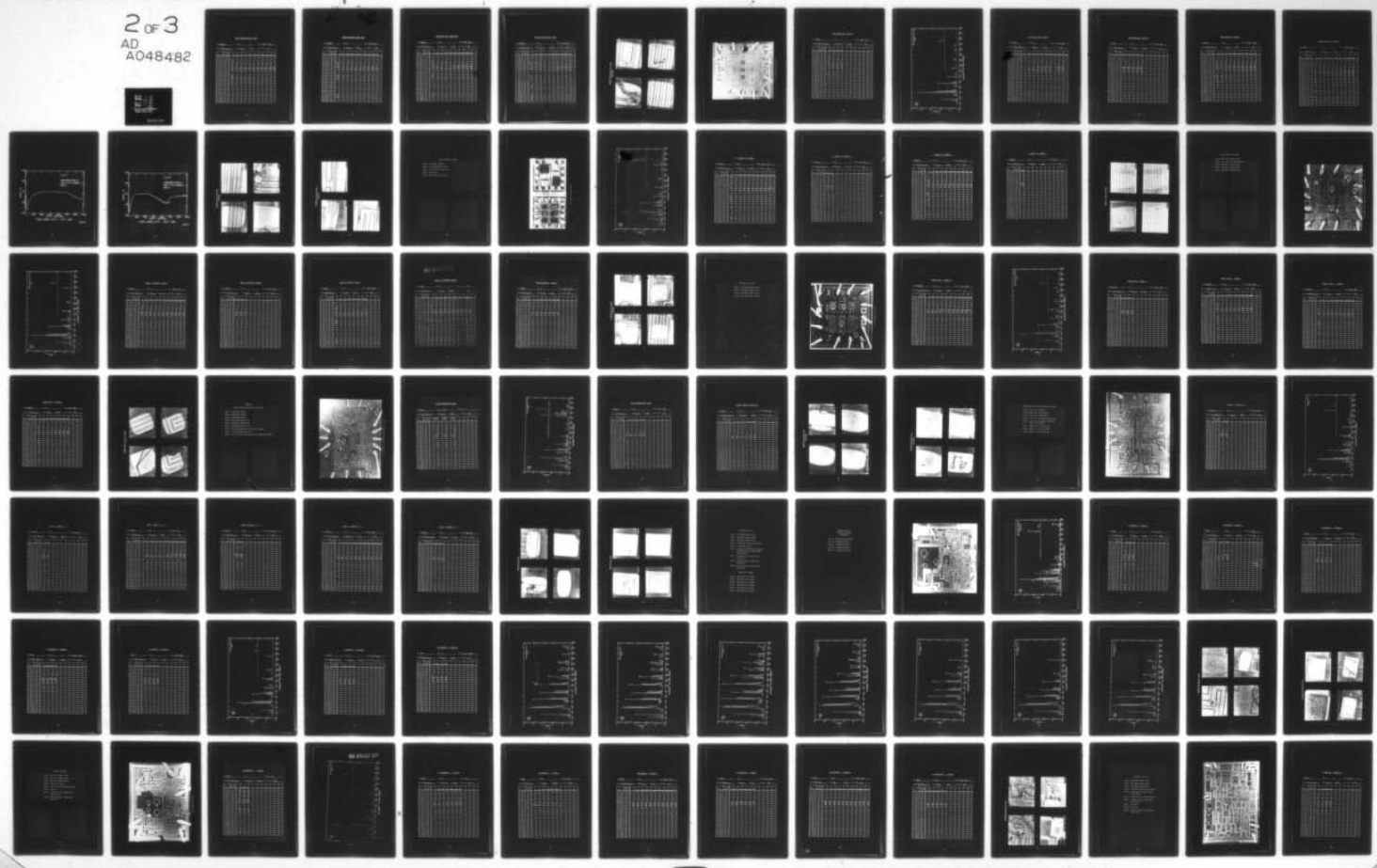


Set 1 CMOS Bulk Clean Oxide Unit #R202


CD4007 CMOS Bulk Clean Oxide
Unit #R202
Area 1-2
INTENSITY
SECONDARY ION MASS NUMBER
C
O
F
Na
Mg
Al
Si
O2
K
Ca
AlO
SiO
Ti
Cr
Al2
Si2
SiO2
Cu
Zn
Al2O
Si2O
Si2O2
Ag
In
Sn
Au

AD-A048 482 TEXAS INSTRUMENTS INC DALLAS CENTRAL RESEARCH LABS F/G 20/12
MICROBEAM ANALYSIS TECHNIQUES FOR ICS.(U)
OCT 77 G B LARRABEE, R D DOBROTT F30602-76-C-0316
UNCLASSIFIED TI-08-77-16 RADC-TR-77-339 NL

2 OF 3
AD
A048482



CMOS BULK CLEAN OXIDE CD4007

UNIT #R202 . AREA 1 . SPECTRA 222 - 232 .

RASTER 69 x 90 μm . SPOT 16 μm BC 7 NA SR (Å/SEC) .4 .

ELEM	PLUS / START	0	904	1811	2713	3612	4513	5423	6326	7231	8133	9030
Li (7)	30											
B (11)	60											
F (19)	150	1	–	–	–	–	–	–	–	–	–	–
Na (23)	180	19	2	2	2	2	2	2	2	2	2	1
Mg (24)	185	2	1	1	1	1	1	1	1	1	1	1
Al (27)	205	1177	462	399	1069	1332	1640	1998	2371	3156	3583	3206
Si (30)	220	23	70	76	72	70	68	66	60	58	54	54
P (31)	230											
Cl (35)	250											
K (39)	290	22	3	2	2	2	1	1	1	1	1	1
Ca (40)	295	9	2	2	2	2	2	1	1	1	1	1
Ti (48)	330	1	1	1	1	1	1	1	1	1	1	1
Cr (52)	350	17	4	3	6	4	3	2	2	1	1	1
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1	1	1	1	1	1	1	1	1
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

CMOS BULK CLEAN OXIDE CD4007

UNIT #R202 . AREA 3 . SPECTRA 444 - 453 .

RASTER 72 x 61 μm . SPOT 19 μm BC 6 NA SR (Å/SEC) .48 .

ELEM	START \ PLUS	0	907	1595	2286	2971	3641	4348	5056	5753	6435	
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	3000	3	2	2	1	1	1	1	1	1	
Mg (24)	185	100	1	1	1	1	1	1	1	1	1	
Al (27)	205	700	11	11	11	10	10	39	203	254	379	
Si (30)	220	1.1	36	37	38	36	38	42	40	36	35	
P (31)	230											
Cl (35)	250											
K (39)	290	1000	2	2	1	1	1	1	1	1	1	
Ca (40)	295	300	1	1	1	1	1	1	1	1	1	
Ti (48)	330	–	1	1	1	1	1	1	1	1	1	
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403	–	1	1	1	1	1	1	–	–	–	
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	100	1	–	–	–	–	–	–	–	–	
Sn (118)	610	100	1	1	–	–	–	–	–	–	–	
Ba (138)	670											
Pb (208)	858											

CMOS BULK CLEAN OXIDE CD4007

UNIT #R202 . AREA 4 . SPECTRA 454-465 .

RASTER 72x61 μm . SPOT 19 μm BC 6 nA SR (Å/SEC) .48 .

ELEM	PLUS / START	0	896	1573	2254	2930	3608	4286	4965	5645	6326	
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	200	5	3	3	2	1	1	1	1	1	
Mg (24)	185	8	4	3	2	1	1	1	1	1	1	
Al (27)	205	60	26	11	7	7	35	135	222	331	487	
Si (30)	220	3.5	40	48	52	52	52	52	50	46	48	
P (31)	230	1	1	1	1	1	1	1	–	1	1	
Cl (35)	250											
K (39)	290	64	4	3	2	2	1	1	1	1	1	
Ca (40)	295	20	2	1	1	1	1	1	1	1	1	
Ti (48)	330	1	2	2	2	1	1	1	1	1	1	
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	–	–	–	–	–	–	–	–	–	1	
Zn (64)	403	–	1	1	1	1	1	1	1	1	1	
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	4	1	1	1	1	1	1	1	–	–	
Sn (118)	610	4	1	1	1	–	–	–	–	–	–	
Ba (138)	670.											
Pb (208)	858											

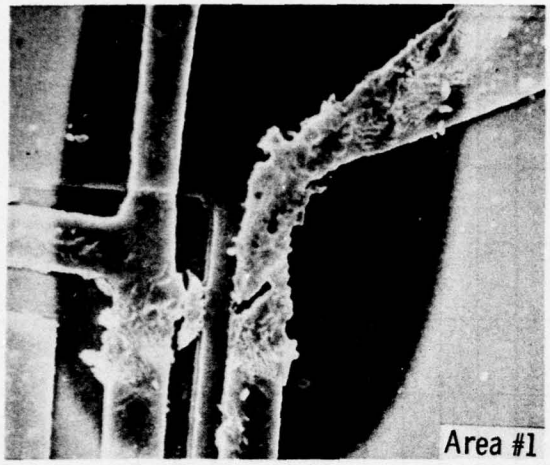
CMOS BULK CLEAN OXIDE CD4007

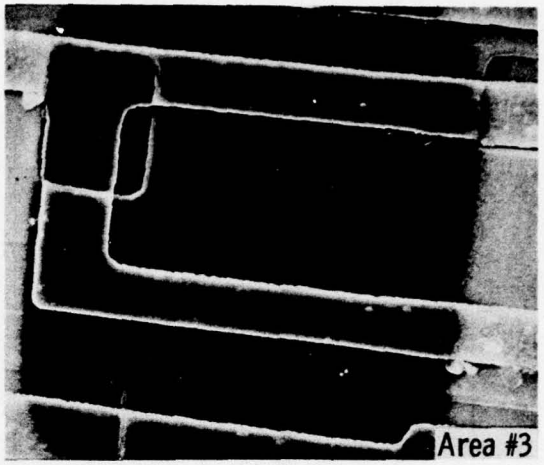
UNIT #R202 . AREA 5 . SPECTRA 464-473 .

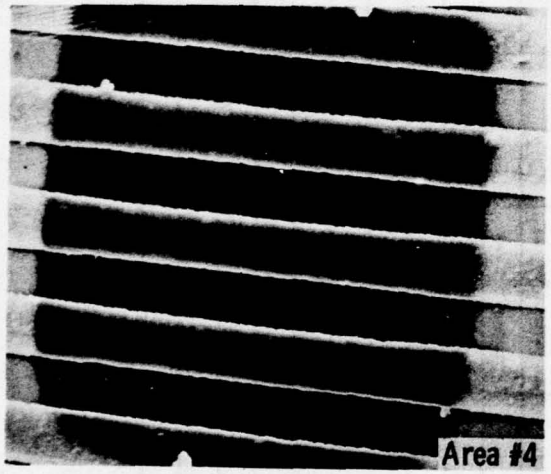
RASTER 72X61 μm . SPOT 19 μm BC 6 NA SR (Å/SEC) .48 .

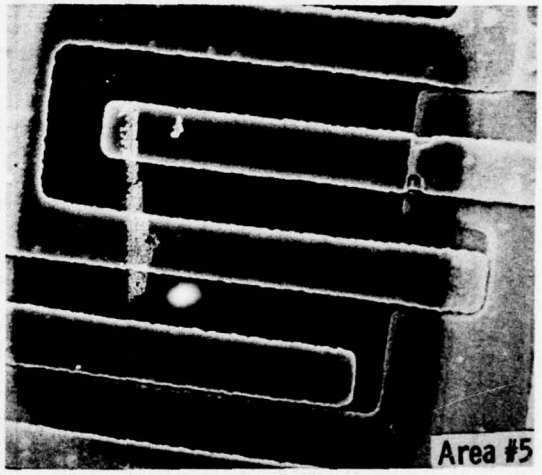
ELEM	PLUS / START	0	694	1379	2060	2740	3420	4099	4780	5484	6174	
Li (7)	30	1	1	1	–	–	–	–	–	–	–	
B (11)	60	–	1	1	–	–	–	–	–	–	–	
F (19)	150	–	1	1	–	–	–	–	–	–	–	
Na (23)	180	3250	88	81	12	7	5	4	5	4	4	
Mg (24)	185	50	13	12	8	8	6	6	7	6	6	
Al (27)	205	300	44	17	11	9	9	33	135	235	319	
Si (30)	220	1.4	55	54	60	60	52	56	52	56	54	
P (31)	230	–	2	1	1	1	1	1	1	1	1	
Cl (35)	250											
K (39)	290	1100	53	21	7	5	4	4	4	3	3	
Ca (40)	295	125	16	8	5	4	3	3	3	2	2	
Ti (48)	330	–	2	2	2	2	1	1	1	1	1	
Cr (52)	350	–	1	1	1	1	1	1	1	1	1	
Ni (58)	380											
Cu (63)	400	25	1	1	1	1	1	1	1	1	1	
Zn (64)	403	–	1	1	1	1	1	1	1	1	1	
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	75	1	1	1	1	1	1	1	1	1	
Sn (118)	610	25	1	1	1	1	1	1	–	–	–	
Ba (138)	670	25	1	–	–	–	–	–	–	–	–	
Pb (208)	858											

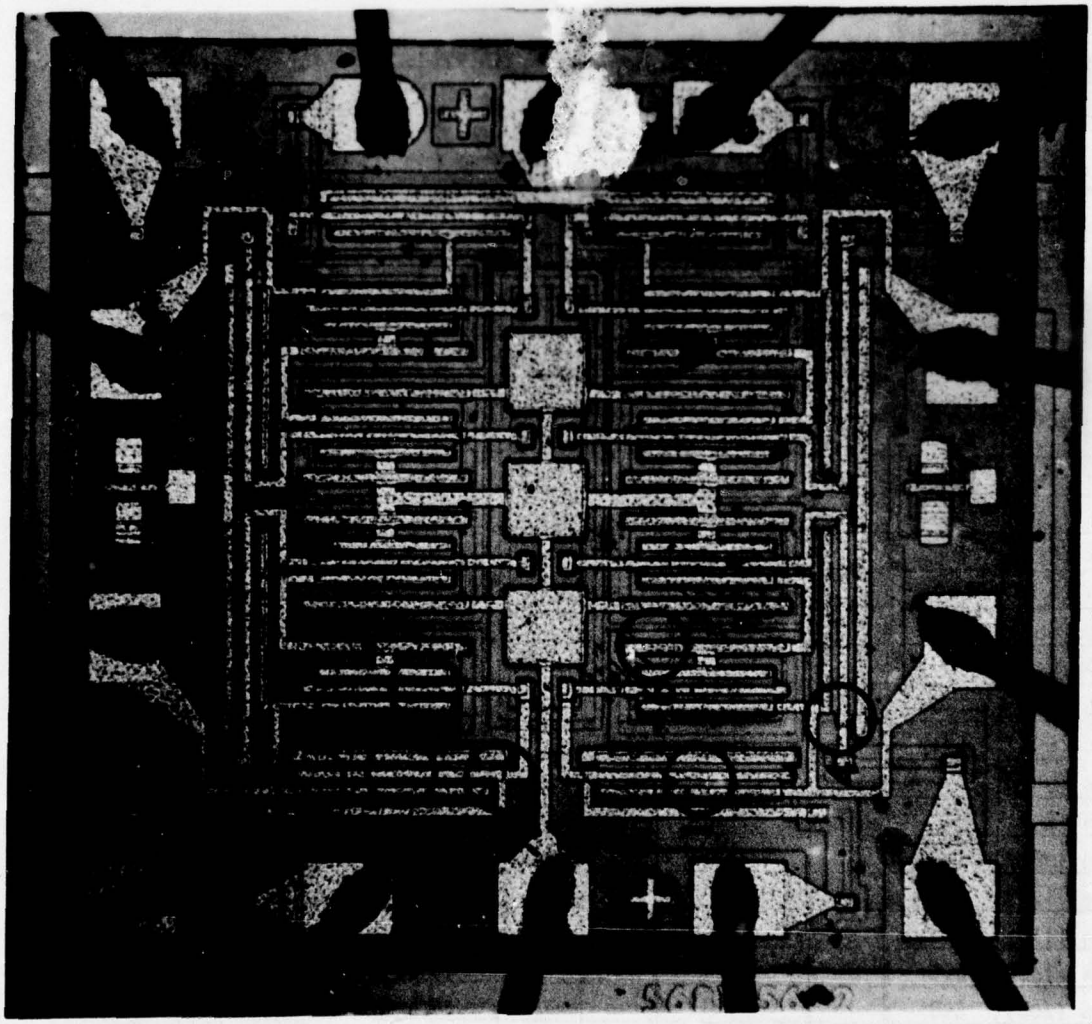
CD4007 CMOS Bulk Clean Oxide
Unit #R202











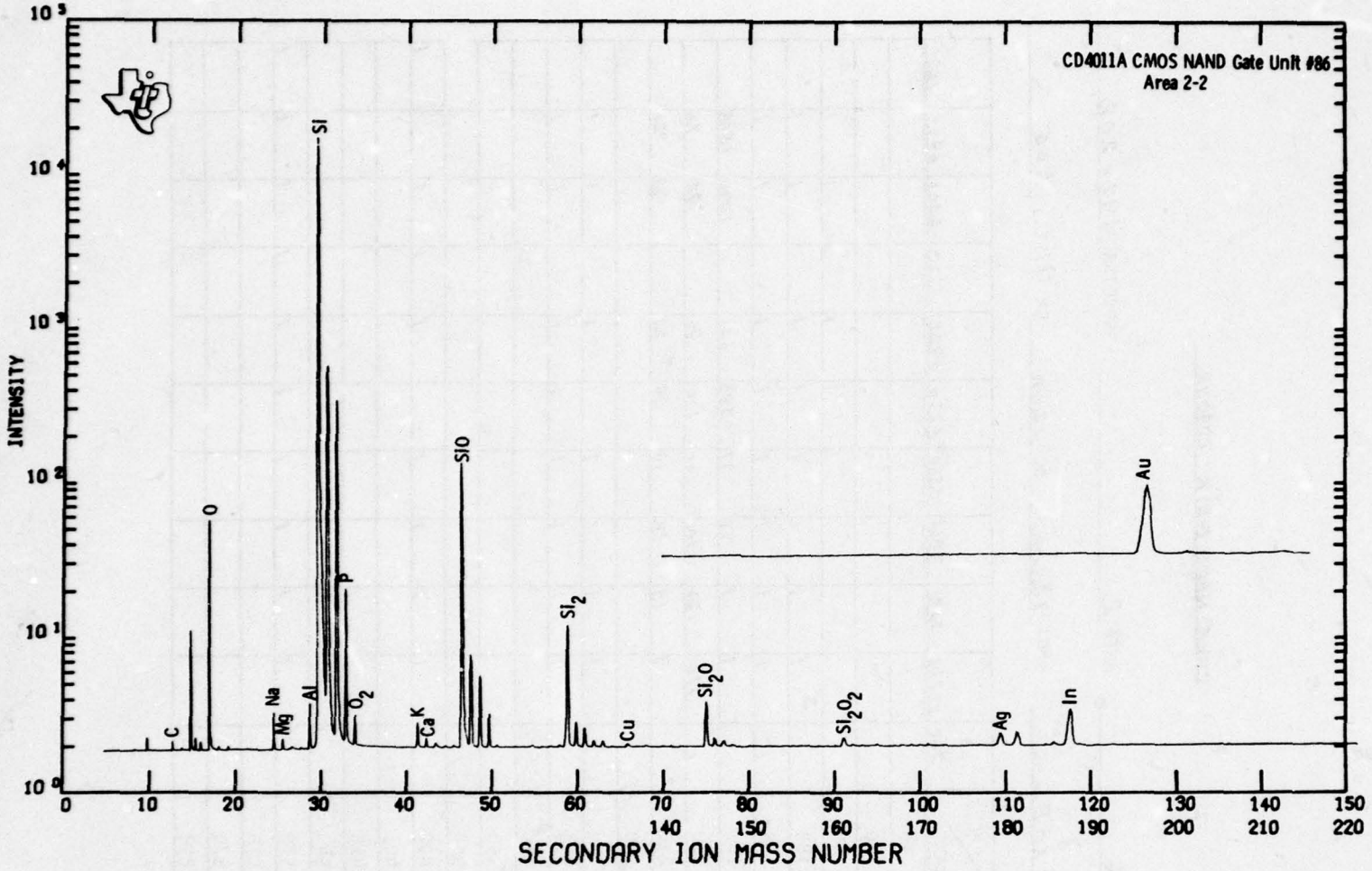
Set 1 CMOS NAND Gate Unit #86

CMOS NAND GATE CD4011A

UNIT #86 . AREA 1 . SPECTRA 188 - 191 .

RASTER 122 x 95 μm . SPOT 32 μm BC 18NA SR (Å/SEC) .55 .

ELEM	PLUS / START	0	1052	1979	2466							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	13	2	2	1							
Mg (24)	185	2	1	1	1							
Al (27)	205	30	9	10	10							
Si (30)	220	15	23	21	19							
P (31)	230	1	4	12	14							
Cl (35)	250											
K (39)	290	6	2	1	1							
Ca (40)	295	4	1	1	1							
Ti (48)	330	1	–	–	–							
Cr (52)	350	1	–	–	–							
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											


CD4011A CMOS NAND Gate Unit #86
Area 2-2
INTENSITY
SECONDARY ION MASS NUMBER
C
O
Na
Mg
Al
Si
P
O_2
K
Ca
SiO
Si_2
Cu
Si_2O
Si_2O_2
Ag
In
Au

CMOS NAND GATE CD4011A

UNIT #86 . AREA 2 . SPECTRA 192-202 .

RASTER 69X58 μm . SPOT 13 μm BC 12NA SR (Å/SEC) 1.06 .

ELEM	PLUS / START	360	1266	2181	2864	3550	4236	4922	5623	6307	6993	7681
Li (7)	30											
B (11)	60											
F (19)	150					1	1	1		1	1	
Na (23)	180		1	1	1	1	1	1		1	1	
Mg (24)	185		1	1	1	1	1	1		1	1	
Al (27)	205		1	1	16	17	383	651		1098	1548	
Si (30)	220		110	120	100	100	100	90		92	72	
P (31)	230		7	13	18	19	19	21		22	21	
Cl (35)	250											
K (39)	290		1	1	1	1	1	1		1	1	
Ca (40)	295		1	1	1	1	1	1		1	1	
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400		1	1	1	1		1	1	1		1
Zn (64)	403											
Ga (69)	425											
Mo (98)	540	1										
Ag (107)	570	1	1	1	1	1	1	1	1	1	1	1
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

CMOS NAND GATE CD4011A

UNIT #86 . AREA 2 . SPECTRA 203 - 207 .

RASTER 69x58 μm . SPOT 13 μm BC 12 NA SR (Å/SEC) 1.06 .

ELEM	PLUS / START	8391	9076	9764	10450	11133						
Li (7)	30											
B (11)	60											
F (19)	150	1	–	1	1	1						
Na (23)	180	1	1	1	-1	1						
Mg (24)	185	1	1	1	1	1						
Al (27)	205	1684	1684	3034	4466	4876						
Si (30)	220	90	90	57	48	42						
P (31)	230	20	18	20	185	163						
Cl (35)	250											
K (39)	290	1	1	1	1	1						
Ca (40)	295	1	1	1	1	1						
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	1	–	–	–	1						
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1	1	1						
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

CMOS NAND GATE CD4011A

UNIT #86 . AREA 4 . SPECTRA 399-408 .

RASTER 68 x 55 μm . SPOT [illegible] μm BC 9NA SR (Å/SEC) .85 .

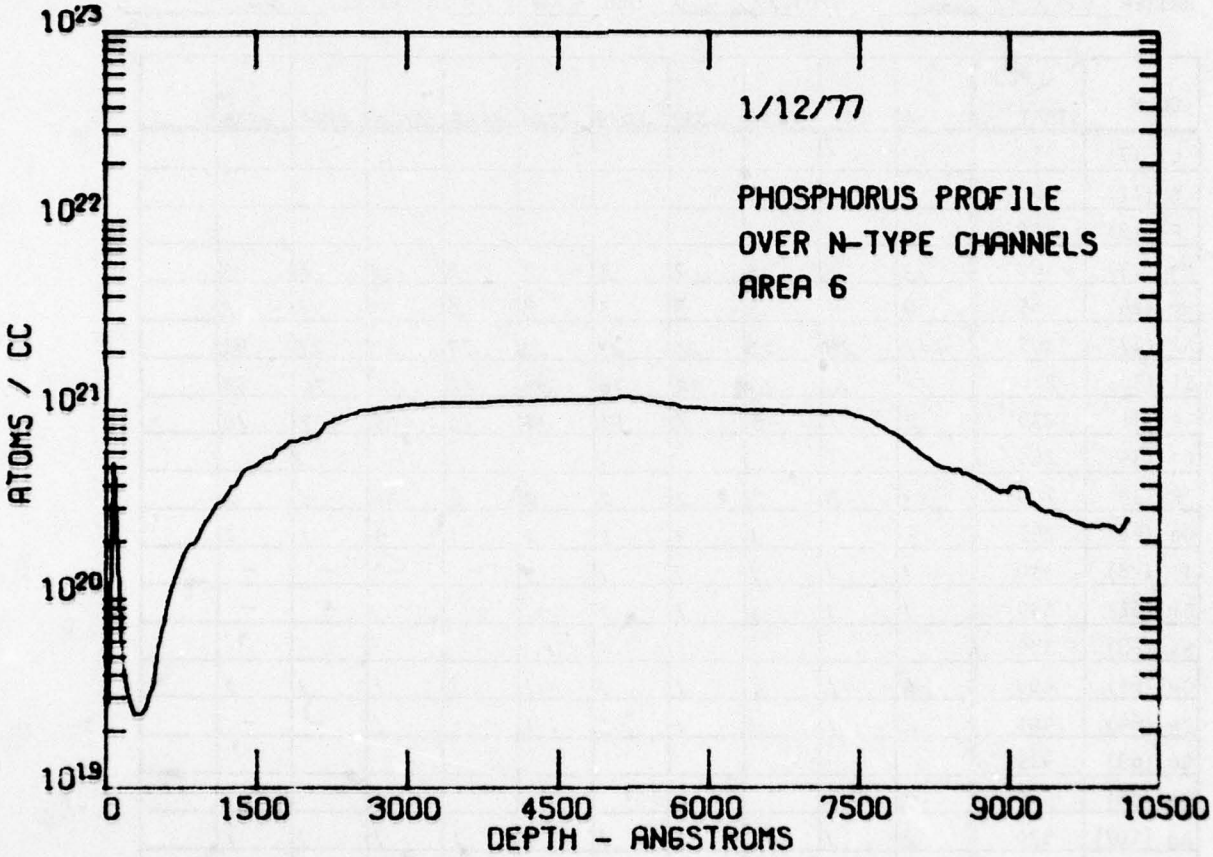
ELEM	PLUS / START	0	914	1600	2291	2981	3667	4355	5045	5732	6419	
Li (7)	30											
B (11)	60											
F (19)	150	1	1	1	1	1	1	1	1	1	1	
Na (23)	180	95	10	8	7	5	4	4	3	3	3	
Mg (24)	185	62	10	6	4	3	3	3	2	2	2	
Al (27)	205	176	111	73	80	82	74	252	471	599	859	
Si (30)	220	8.4	54	100	100	100	110	92	90	96	80	
P (31)	230	1	1	3	7	11	14	16	19	18	19	
Cl (35)	250											
K (39)	290	59	6	3	3	2	2	2	2	2	2	
Ca (40)	295	36	3	2	2	1	1	1	1	1	1	
Ti (48)	330	1	1	1	1	1	1	1	1	1	1	
Cr (52)	350	30	9	-	-	-	-	-	-	-	-	
Ni (58)	380											
Cu (63)	400	3	1	1	1	1	1	1	1	1	1	
Zn (64)	403	-	1	1	1	1	1	1	1	1	1	
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	7	1	1	1	1	1	1	1	1	1	
Sn (118)	610	1	-	-	-	-	-	-	-	-	-	
Ba (138)	670											
Pb (208)	858											

CMOS NAND GATE CD4011A

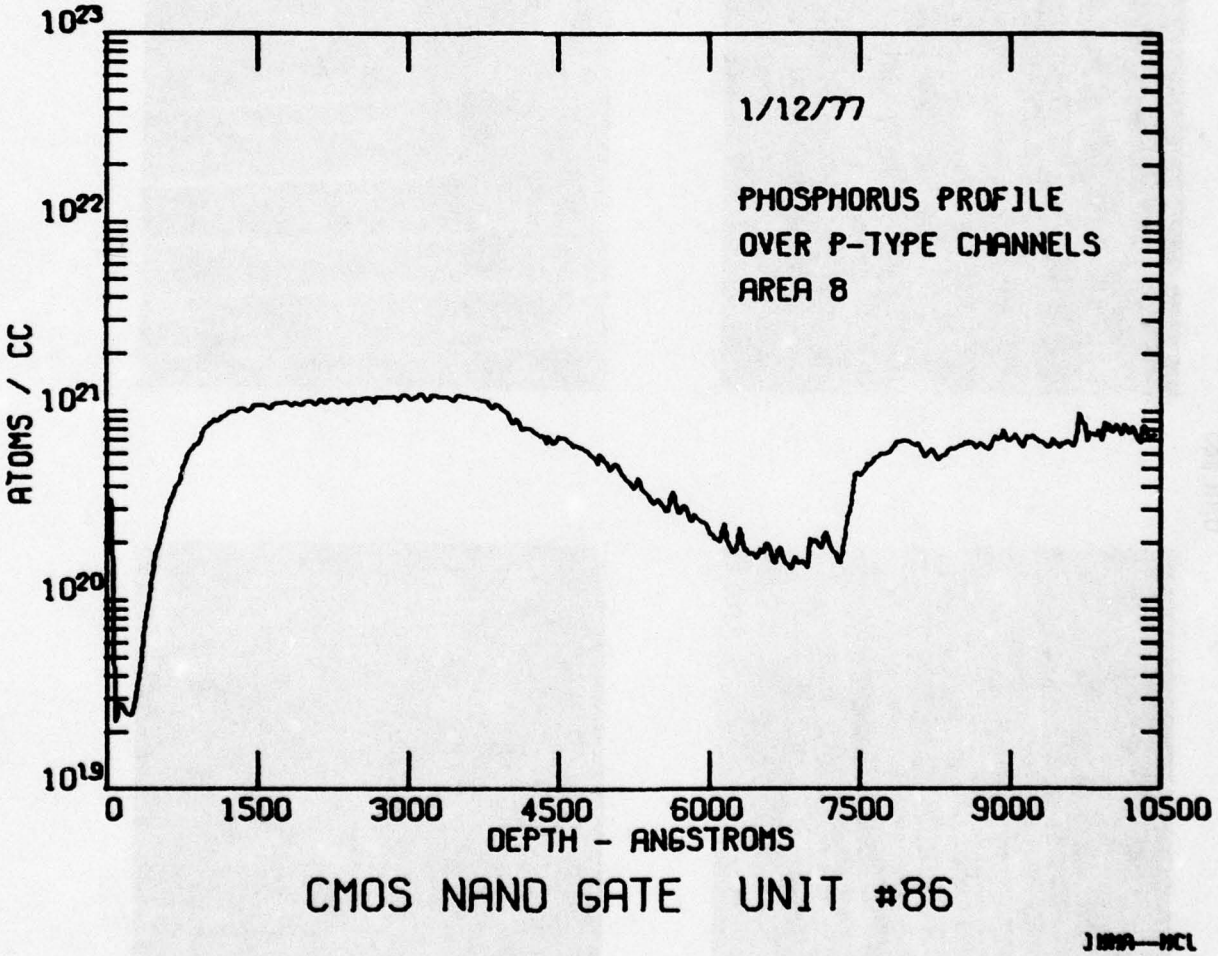
UNIT #86 . AREA 5 . SPECTRA 409-418 .

RASTER 68 X 55 μm . SPOT 17 μm) BC 9 NA SR (Å/SEC) .85 .

ELEM	START \ PLUS	0	961	1651	2339	3029	372A	4426	5120	5864	6532	
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	75	3	3	2	3	2	2	24	5	3	
Mg (24)	185	9	4	3	3	3	3	3	3	1	2	
Al (27)	205	141	29	25	25	23	26	57	53	28	92	
Si (30)	220	74	70	76	72	70	58	52	35	76	63	
P (31)	230	2	1	3	7	13	14	16	13	7	16	
Cl (35)	250											
K (39)	290	53	3	2	2	2	2	2	26	5	2	
Ca (40)	295	8	1	1	1	1	1	1	4	1	1	
Ti (48)	330	1	1	1	1	1	1	–	–	–	–	
Cr (52)	350	1	1	1	1	1	–	–	–	–	–	
Ni (58)	380											
Cu (63)	400	6	1	1	1	1	1	1	1	1	1	
Zn (64)	403	2	1	1	1	1	1	1	1	–	–	
Ga (69)	425											
Mo (98)	540	2										
Ag (107)	570	2	1	1	1	1	1	1	1	1	1	
Sn (118)	610	2	1	1	1	1	1	1	1	–	–	
Ba (138)	670											
Pb (208)	858											

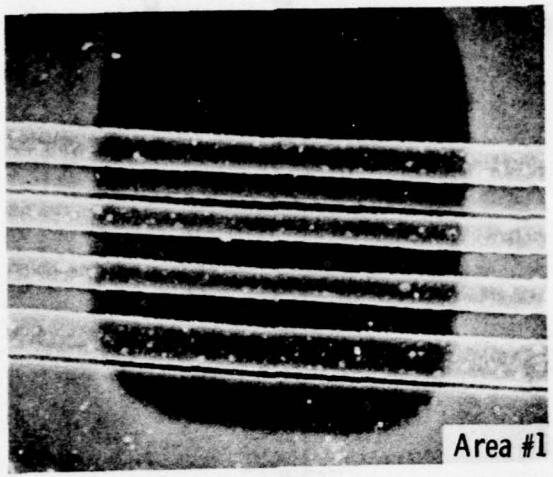


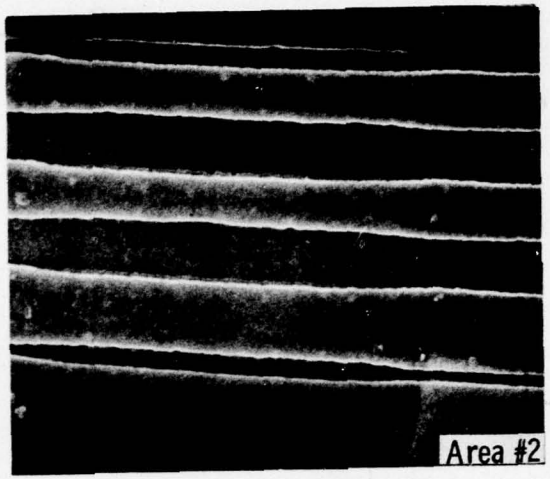
CMOS NAND GATE UNIT #86

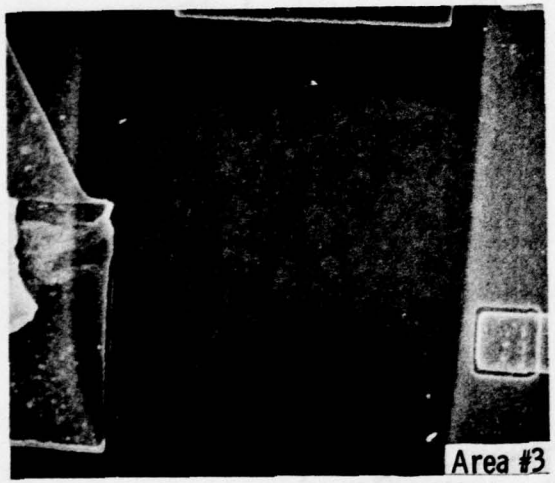


CMOS NAND GATE UNIT #86

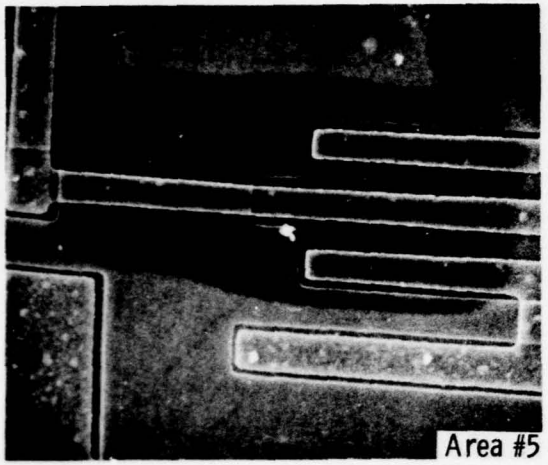
CD4011A CMOS Nand Gate
Unit #86

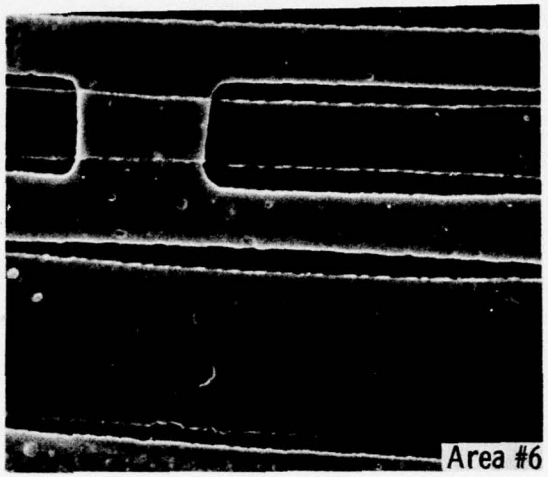


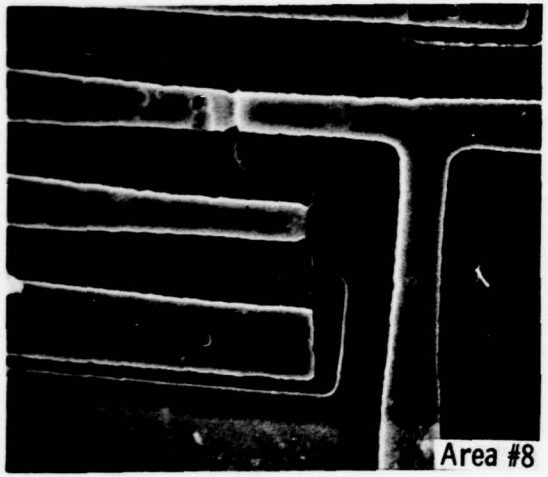




CD4011A CMOS Nand Gate
Unit #86


Area #5


Area #6


Area #8

CMOS Cr Doped, Unit #504

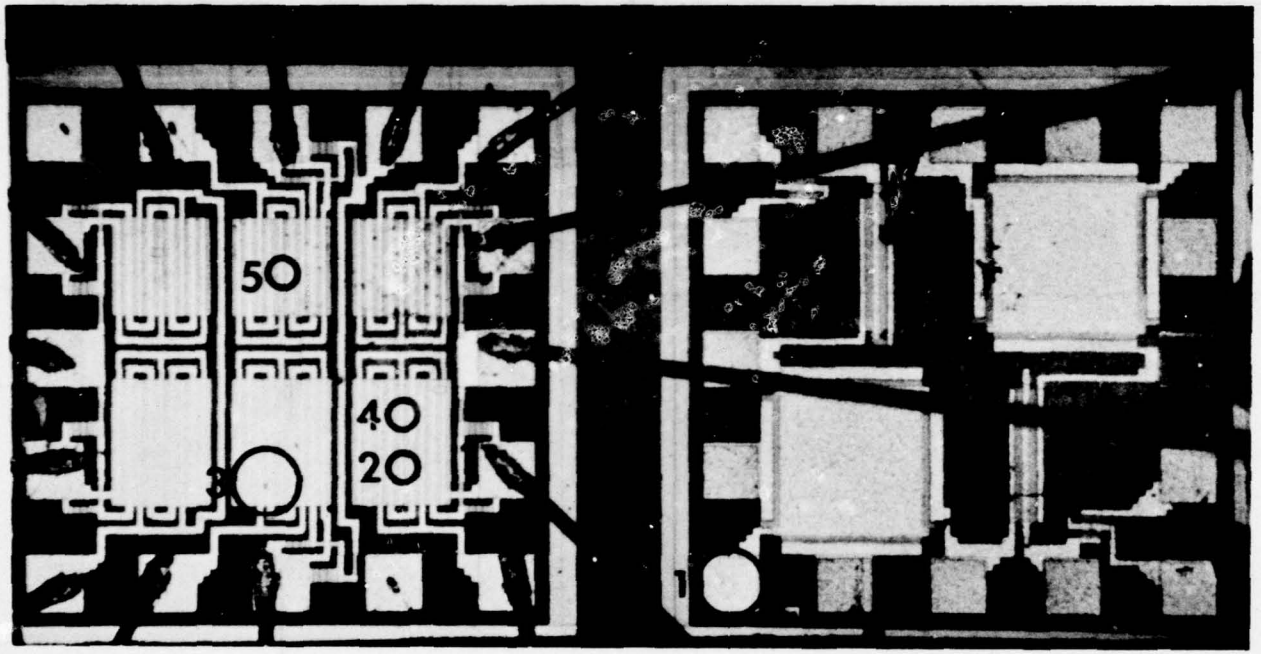
Area 1: Surface Mass Spectrum

Area 2: Mass Spectra Depth Profile

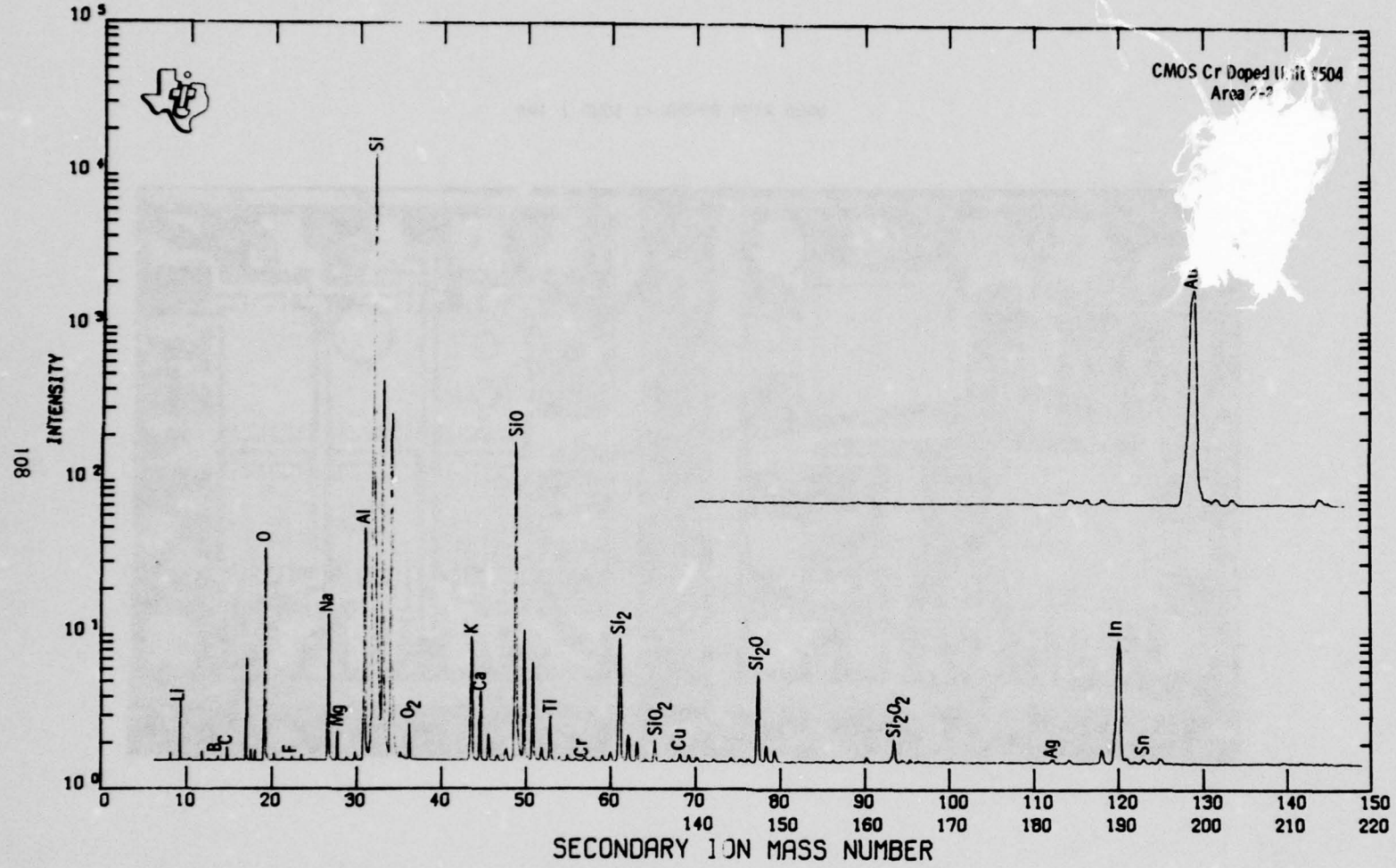
Area 3: Cr Point Count Depth Profile

Area 4: False Start

Area 5: Mass Spectra Depth Profile



Set 1 CMOS Cr Doped Unit #504


CMOS Cr Doped
INTENSITY
SECONDARY ION MASS NUMBER
Li
O
Na
Mg
Al
Si
O_2
K
Ca
SiO
Ti
Cr
Si_2
SiO_2
Cu
Si_2O
Si_2O_2
Ag
In
Sn

CMOS Cr DOPED

UNIT #504 . AREA 2 . SPECTRA 161 - 171 .

RASTER 85 X 66 μm . SPOT 19 μm BC 10NA SR (Å/SEC) .63 .

ELEM	PLUS / START	0	901	1793	2695	3567	4450	5363	6241	6920	7597	8274
Li (7)	30	260	1	1	1	1	1	1	1	1	1	1
B (11)	60	–	1	1	–	–	–	–	1	1	1	1
F (19)	150	1	1	1	1	1	1	1	1	1	1	1
Na (23)	180	640	6	4	3	3	4	5	4	3	4	4
Mg (24)	185	–	1	1	1	1	1	1	1	1	1	1
Al (27)	205	220	21	13	224	458	719	1078	1627	1705	2520	3210
Si (30)	220	2	110	150	130	140	140	140	130	130	120	110
P (31)	230											
Cl (35)	250											
K (39)	290	460	4	3	2	2	2	2	2	2	2	2
Ca (40)	295	80	1	1	1	1	1	2	2	2	1	1
Ti (48)	330	20	1	1	1	1	1	1	1	1	1	1
Cr (52)	350	10	1	1	–	1	1	1	5	6	5	4
Ni (58)	380											
Cu (63)	400	20	1	1	1	1	1	1	–	1	1	1
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	20	1	1	1	1	1	–	–	–	–	–
Ba (138)	670											
Pb (208)	858											

CMOS Cr DOPED

UNIT #504 . AREA 2 . SPECTRA 172-173 .

RASTER 85 X 66 μm . SPOT 19 μm BC 10 NA SR (Å/SEC) .63 .

ELEM	PLUS / START	8952	10307									
Li (7)	30	1	1									
B (11)	60	1	1									
F (19)	150	1	1									
Na (23)	180	4	4									
Mg (24)	185	1	1									
Al (27)	205	4219	4718									
Si (30)	220	110	90									
P (31)	230											
Cl (35)	250											
K (39)	290	2	2									
Ca (40)	295	1	1									
Ti (48)	330	1	1									
Cr (52)	350	4	4									
Ni (58)	380											
Cu (63)	400	1	–									
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	–	–									
Ba (138)	670											
Pb (208)	858											

CMOS Cr DOPED

UNIT #504 . AREA 5 . SPECTRA 361 - 371 .

RASTER 69 X 56 μm . SPOT 12 μm BC 10 NA SR (Å/SEC) .92 .

ELEM	PLUS / START	0	877	1479	2174	2872	3577	4290	5034	5783	6478	7242
Li (7)	30	–	2	1	1	1	1	1	1	1	1	1
B (11)	60	–	1	–	1	1	1	1	–	–	–	–
F (19)	150	–	1	–	1	1	1	1	1	1	1	1
Na (23)	180	1800	7	5	4	3	2	2	2	2	5	2
Mg (24)	185	20	3	4	5	4	2	1	1	1	1	1
Al (27)	205	1200	93	106	417	839	1344	3296	5537	6348	5973	7760
Si (30)	220	1.5	62	70	140	120	120	92	66	64	78	68
P (31)	230	–	1	1	1	1	1	1	1	1	1	1
Cl (35)	250											
K (39)	290	800	6	3	2	2	2	1	1	1	1	1
Ca (40)	295	800	7	3	2	2	1	1	1	1	1	1
Ti (48)	330	1	1	1	1	1	1	1	1	1	2	3
Cr (52)	350	100	1	1	1	2	4	5	6	6	5	5
Ni (58)	380											
Cu (63)	400	40	1	1	1	1	1	1	1	1	1	1
Zn (64)	403	1	1	1	1	1	1	1	1	1	1	1
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	20	–	1	–	–	–	–	–	–	–	–
Ba (138)	670											
Pb (208)	858											

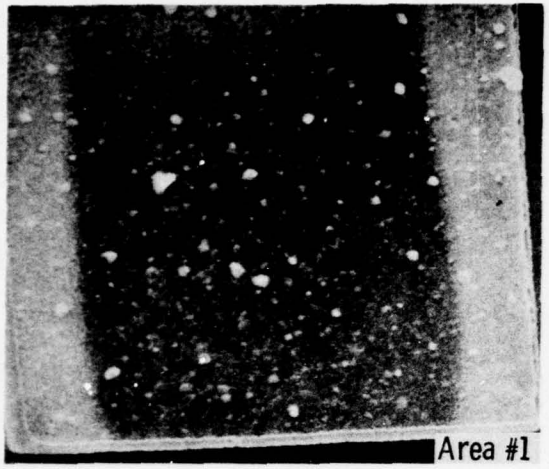
CMOS Cr DOPED

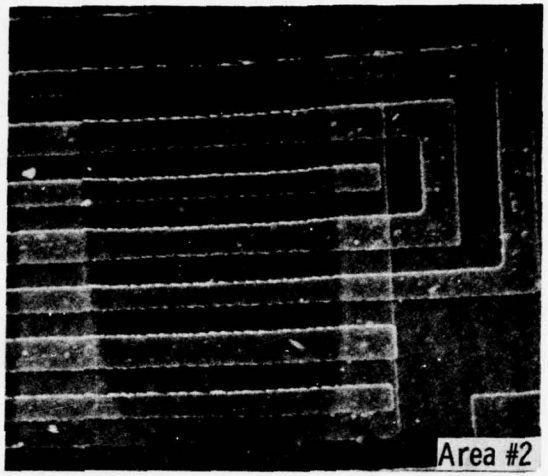
UNIT #504 . AREA 5 . SPECTRA 372 .

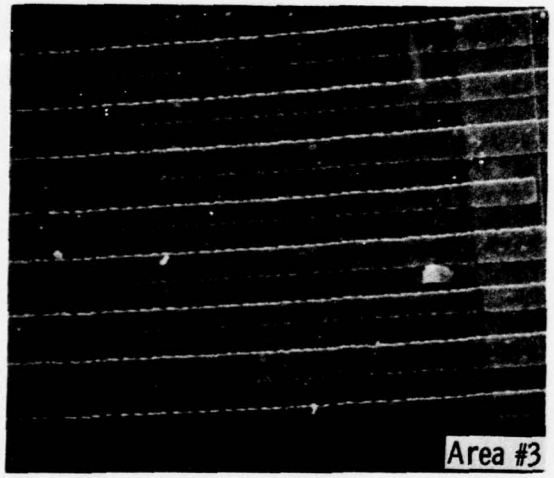
RASTER 69 x 56 μm . SPOT 12 μm BC 10 NA SR (Å/SEC) .92 .

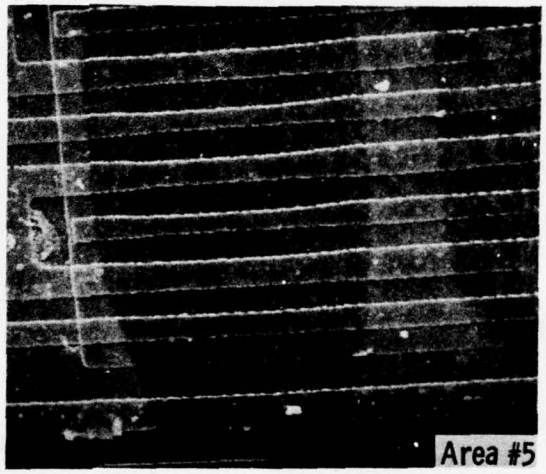
ELEM	START \ PLUS	7936										
Li (7)	30	1										
B (11)	60	–										
F (19)	150	1										
Na (23)	180	2										
Mg (24)	185	1										
Al (27)	205	8195										
Si (30)	220	62										
P (31)	230	1										
Cl (35)	250											
K (39)	290	1										
Ca (40)	295	1										
Ti (48)	330	1										
Cr (52)	350	6										
Ni (58)	380											
Cu (63)	400	1										
Zn (64)	403	1										
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	–										
Ba (138)	670											
Pb (208)	858											

CMOS Cr Doped Unit #504


Area #1


Area #2


Area #3


Area #5

CMOS Aℓ Implant, Unit #890

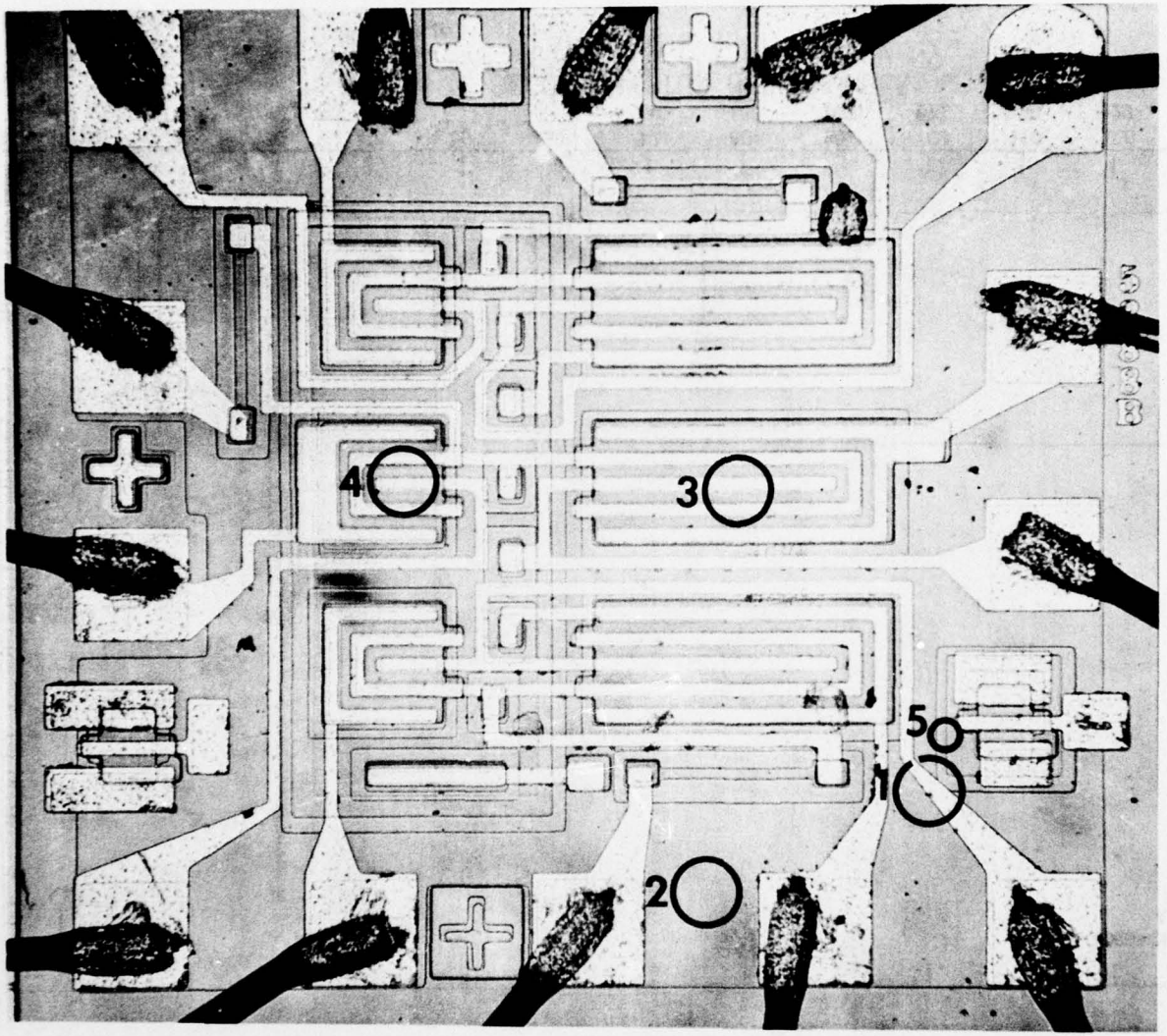
Area 1: Mass Spectra Depth Profile

Area 2: Aℓ, Ti Peak Count Depth Profile

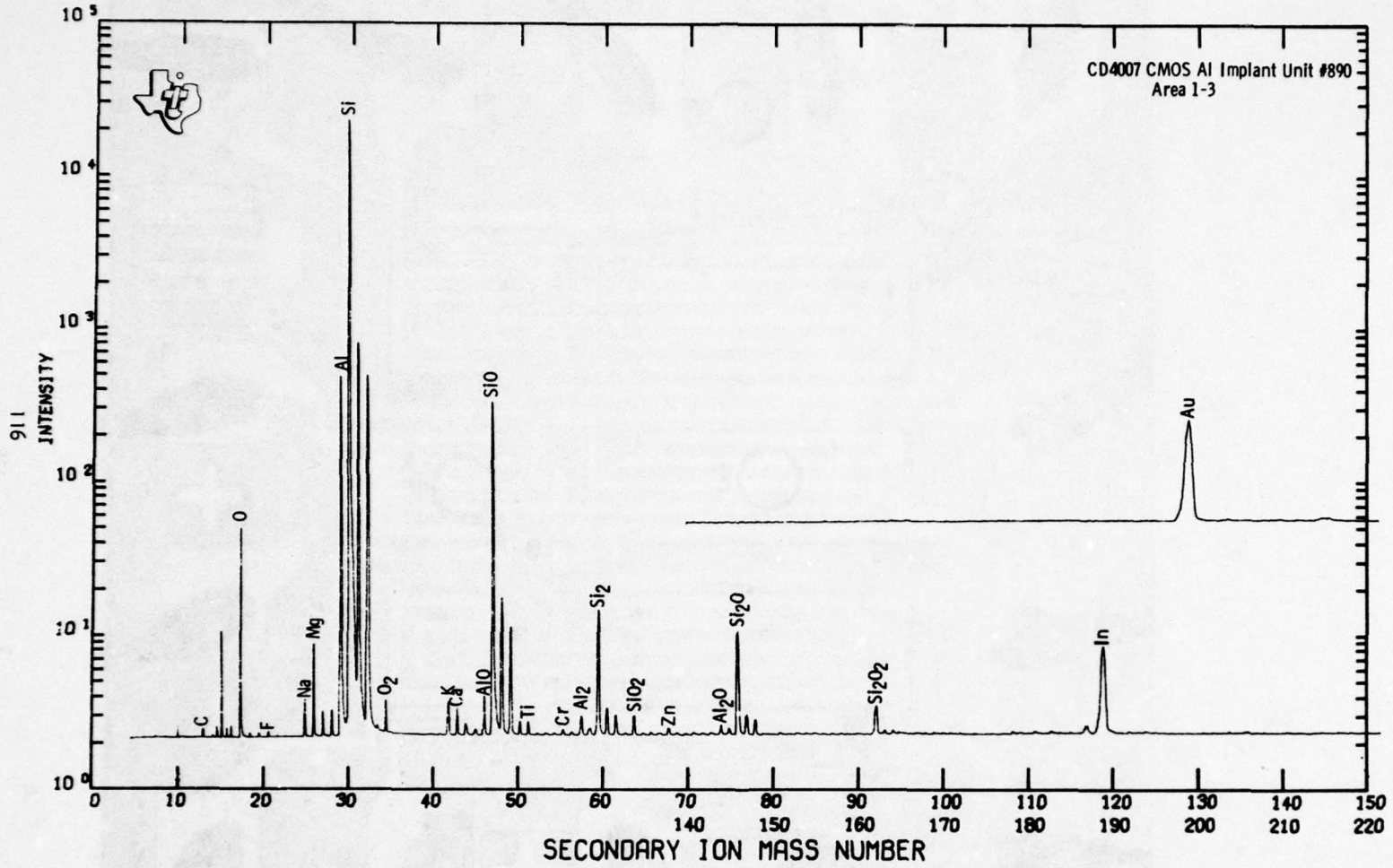
Area 3: Mass Spectra Depth Profile

Area 4: Mass Spectra Depth Profile

Area 5: Mass Spectra Depth Profile



Set 1 CMOS Aℓ Implant (Representative) CD 4007 Unit #890


CD4007 CMOS Al Implant Unit #890
Area 1-3
INTENSITY
SECONDARY ION MASS NUMBER
C
O
F
Na
Mg
Al
Si
O2
K
Ca
AlO
SiO
Ti
Cr
Al2
Si2
SiO2
Zn
Al2O
Si2O
Si2O2
In
Au

CMOS Al IMPLANT CD4007

UNIT #890 . AREA 1 . SPECTRA 208 - 218 .

RASTER 96 x 144 μm . SPOT 18 μm BC 10 nA SR (Å/SEC) .257 .

ELEM	START \ PLUS	0	929	1834	2752	3453	4146	4837	5521	6185	6846	7526
Li (7)	30											
B (11)	60											
F (19)	150	2	1	1	1	1	—	—	—	1	1	—
Na (23)	180	12	1	1	1	1	1	1	1	1	1	1
Mg (24)	185	5	2	2	1	1	1	1	1	1	1	1
Al (27)	205	1998	178	108	93	167	260	340	402	503	509	666
Si (30)	220	46	130	130	140	120	120	130	130	120	150	130
P (31)	230											
Cl (35)	250											
K (39)	290	7	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	3	1	1	1	1	1	1	1	1	1	1
Ti (48)	330	1	1	1	1	1	1	1	1	1	1	1
Cr (52)	350	1	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400	1	—	—	—	—	—	—	—	—	—	—
Zn (64)	403	1	1	1	1	1	1	1	1	1	1	1
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	—	—	—	—	—	—	—	—	—	—
Ba (138)	670											
Pb (208)	858											

CMOS Al IMPLANT CD4007

UNIT #890 . AREA 1 . SPECTRA 219 - 221 .

RASTER 96 X 44 μm . SPOT 18 μm BC 10 NA SR (Å/SEC) . 257 .

ELEM	PLUS / START	8215	8903	9599								
Li (7)	30											
B (11)	60											
F (19)	150	–	–	–								
Na (23)	180	1	1	1								
Mg (24)	185	1	1	1								
Al (27)	205	697	759	678								
Si (30)	220	130	130	110								
P (31)	230											
Cl (35)	250											
K (39)	290	1	1	1								
Ca (40)	295	1	1	1								
Ti (48)	330	1	1	1								
Cr (52)	350	1	1	1								
Ni (58)	380											
Cu (63)	400	–	–	–								
Zn (64)	403	1	1	1								
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	–	–	–								
Ba (138)	670											
Pb (208)	858											

CMOS AI IMPLANT CD4007

UNIT #890 . AREA 3 . SPECTRA 419 - 426 .

RASTER 68 X 55 μm . SPOT 17 μm BC 9 NA SR (Å/SEC) .85 .

ELEM	PLUS / START	0	690	1378	2068	2758	3460	4148	4828			
Li (7)	30											
B (11)	60	–	1	1	1	–	–	–	–			
F (19)	150	6	1	–	–	–	–	–	–			
Na (23)	180	188	3	2	2	2	1	1	1			
Mg (24)	185	6	1	1	1	1	1	1	1			
Al (27)	205	94	11	5	5	2	3	14	158			
Si (30)	220	2.6	80	82	80	80	78	72	70			
P (31)	230	1	1	1	1	1	1	1	1			
Cl (35)	250											
K (39)	290	69	1	1	1	1	1	1	1			
Ca (40)	295	88	1	1	1	1	1	1	1			
Ti (48)	330	–	1	1	1	1	1	1	–			
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	19	1	1	1	–	–	–	–			
Sn (118)	610	13	1	1	1	1	1	1	1			
Ba (138)	670											
Pb (208)	858											

CMOS Al IMPLANT CD4007

UNIT #890 . AREA 4 . SPECTRA 427-436 .

RASTER 61 X 50 μm . SPOT 11 μm BC BNA SR (Å/SEC) .93 .

ELEM	PLUS / START	0	914	1612	2309	3002	3703	4406	5087	5788	6476
Li (7)	30	1	–	–	–	–	–	–	–	–	–
B (11)	60	–	1	1	1	1	1	–	–	–	–
F (19)	150	–	1	1	1	1	1	1	–	–	–
Na (23)	180	52	1	1	1	1	1	1	1	1	1
Mg (24)	185	17	1	1	1	1	1	1	1	1	1
Al (27)	205	1119	154	119	72	76	107	316	537	719	849
Si (30)	220	5.2	88	84	105	100	84	64	66	76	72
P (31)	230										
Cl (35)	250										
K (39)	290	21	1	1	1	1	1	1	1	1	1
Ca (40)	295	119	4	3	2	1	1	1	1	1	1
Ti (48)	330										
Cr (52)	350	2	–	–	–	–	–	–	–	–	–
Ni (58)	380										
Cu (63)	400	1	–	–	–	–	–	–	–	–	–
Zn (64)	403	1	–	–	–	–	–	–	–	–	–
Ga (69)	425										
Mo (98)	540										
Ag (107)	570	1	1	1	1	1	1	1	1	1	1
Sn (118)	610	5	1	1	1	1	1	1	1	1	1
Ba (138)	670										
Pb (208)	858										

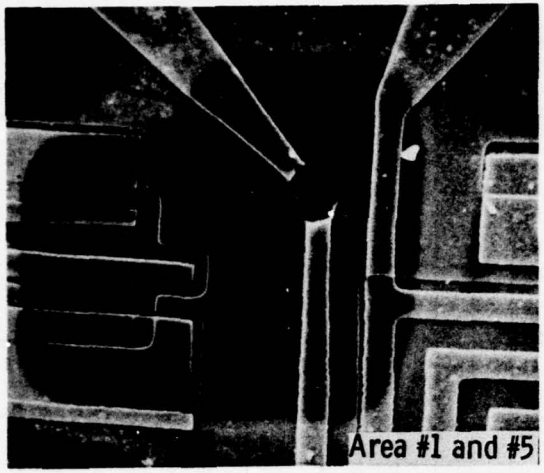
CMOS AL IMPLANT CD4007

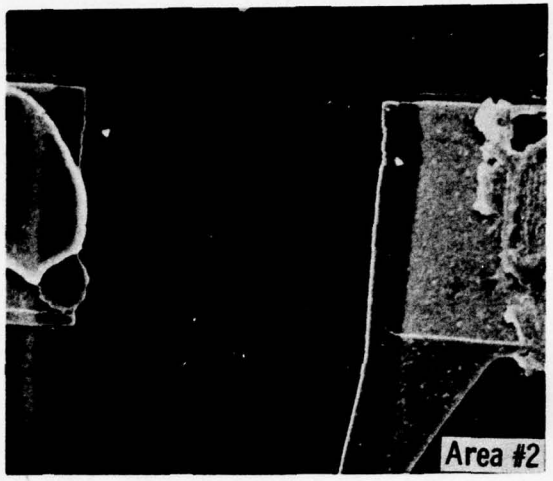
UNIT #890 . AREA 5 . SPECTRA 437-443 .

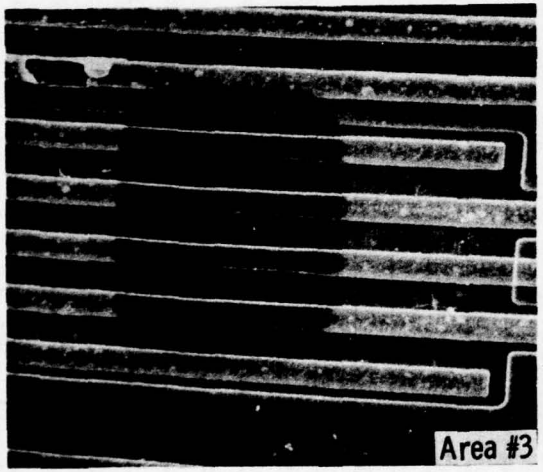
RASTER 61 X 50 μm . SPOT 11 μm BC 8 NA SR (Å/SEC) .93 .

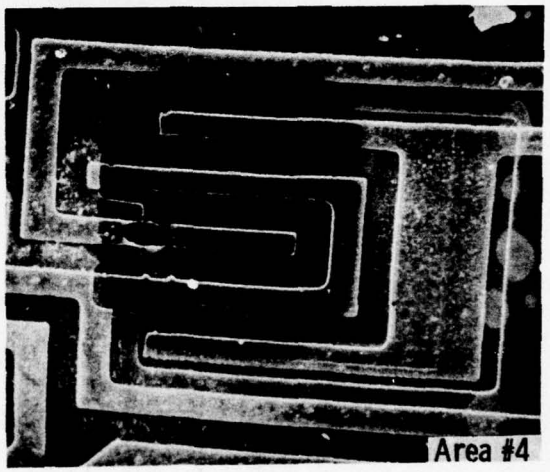
ELEM	PLUS / START	0	706	1403	2108	2801	3464	4296				
Li (7)	30											
B (11)	60											
F (19)	150	1	1	1	1	1	1	1				
Na (23)	180	7	1	1	1	1	1	1				
Mg (24)	185	1	1	1	1	–	–	–				
Al (27)	205	1217	1567	1525	1864	1719	1812	2497				
Si (30)	220	19	52	56	46	44	44	35				
P (31)	230											
Cl (35)	250											
K (39)	290	5	1	1	1	1	1	1				
Ca (40)	295	2	1	1	1	1	1	1				
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	1	1	1	1	1	–	–				
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	–	–				
Ba (138)	670											
Pb (208)	858											

CD4007 CMOS Al Implant
Unit #890









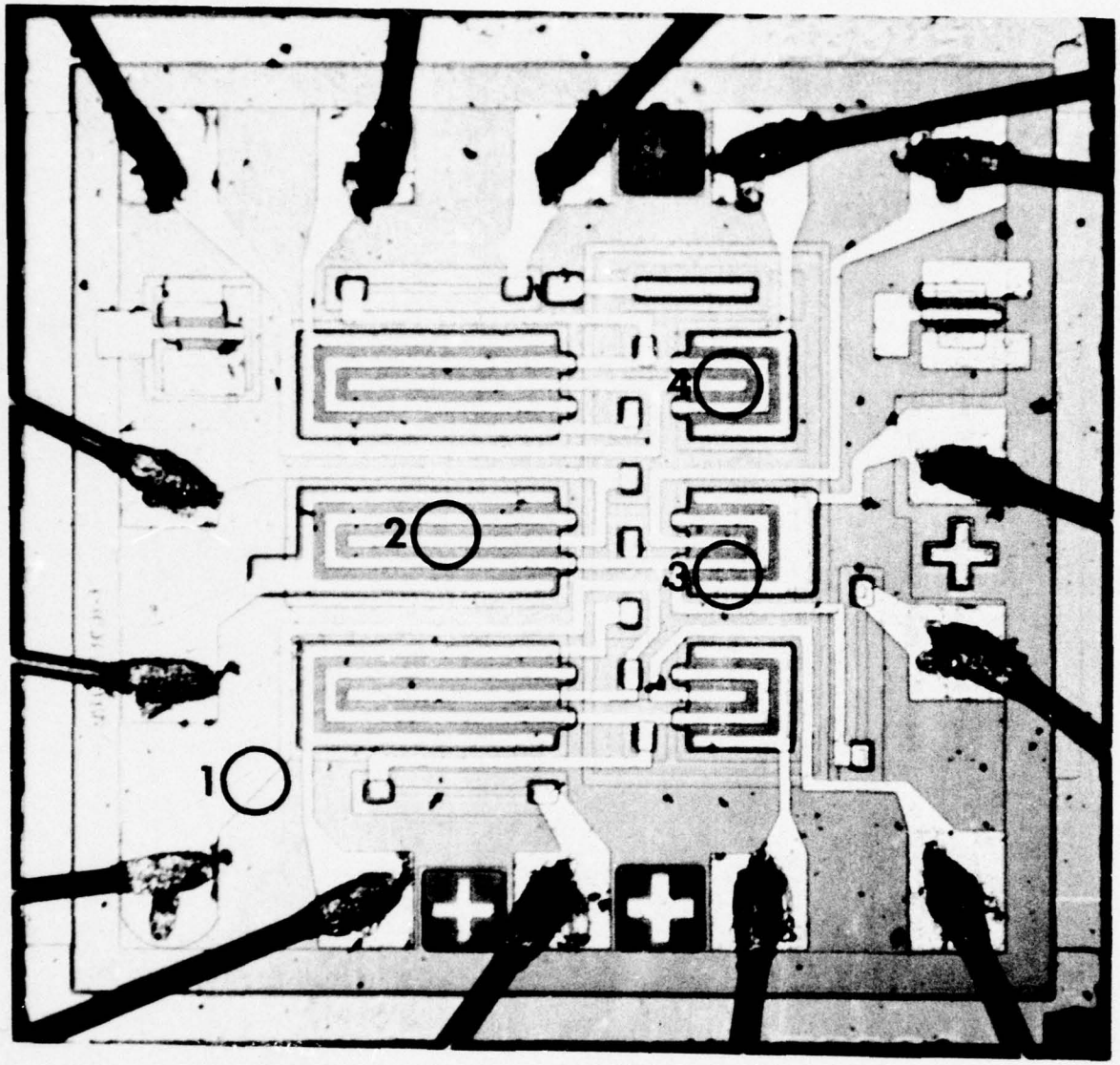
CMOS $A\ell_2O_3$, Unit #A259

Area 1: Mass Spectra Depth Profile

Area 2: Mass Spectra Depth Profile

Area 3: Mass Spectra Depth Profile

Area 4: Mass Spectra Depth Profile



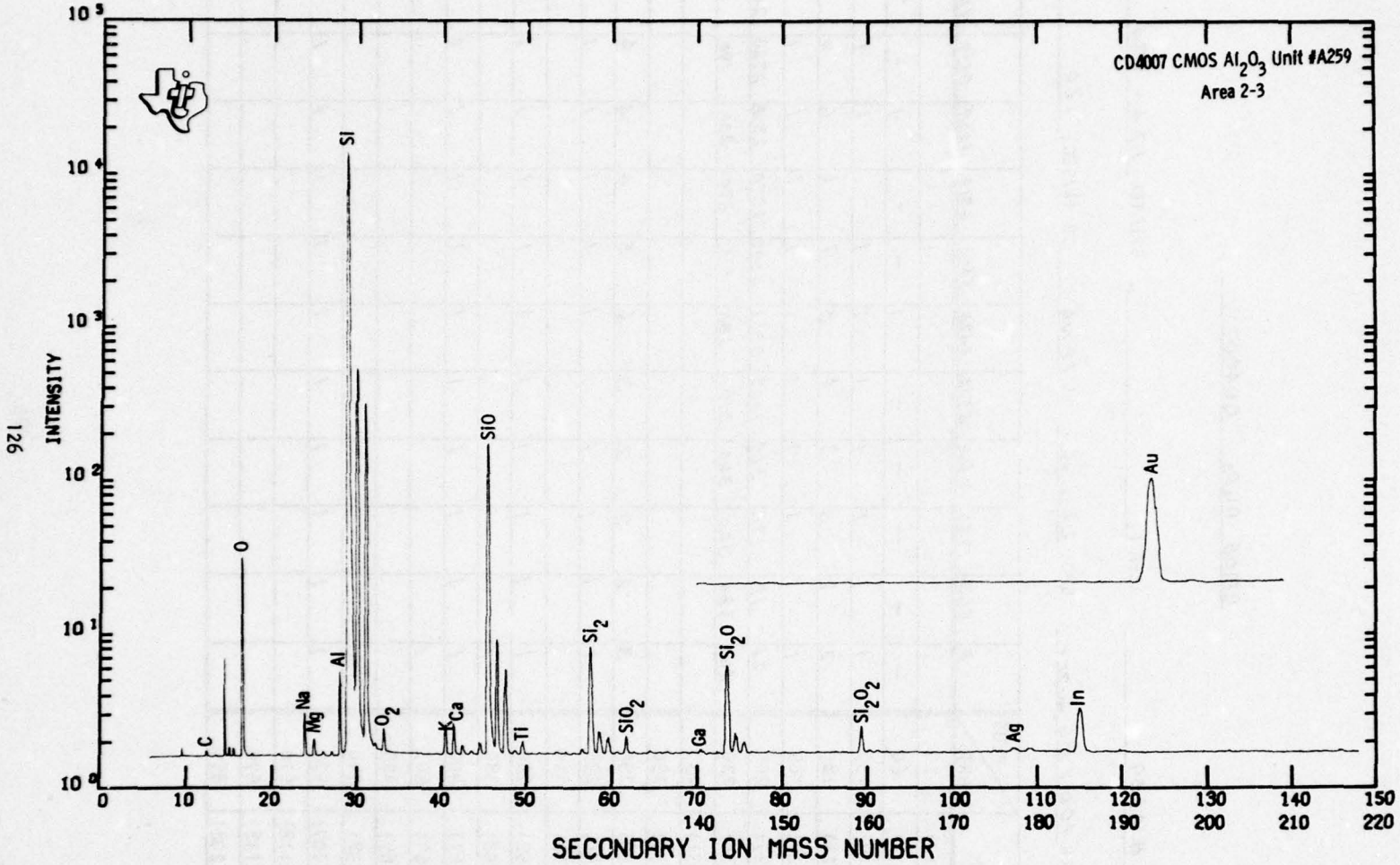
Set 1 CMOS Al_2O_3 Unit #A259

CMOS Al_2O_3 CD4007

UNIT # A259 . AREA 1 . SPECTRA 174 - 184 .

RASTER 106 x 86 μm . SPOT 22 μm BC 18 NA SR (Å/SEC) .70 .

ELEM \ PLUS / START	30	0	863	1766	2669	3572	4475	5400	6319	7229	8139	9066
Li (7)	30											
B (11)	60	–	–	–	–	–	1	–	–	1	–	–
F (19)	150	1	1	1	1	1	1	1	–	1	1	1
Na (23)	180	2	2	3	3	4	8	7	6	6	6	7
Mg (24)	185	1	1	1	1	1	1	1	1	1	1	1
Al (27)	205	27	18	175	529	1003	3351	3092	2270	2358	2328	2011
Si (30)	220	260	380	320	360	310	180	195	230	230	190	170
P (31)	230											
Cl (35)	250											
K (39)	290	3	2	3	2	3	6	5	4	4	4	4
Ca (40)	295	1	1	1	1	1	1	1	1	1	1	1
Ti (48)	330											
Cr (52)	350	1	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400	1	1	1	1	1	1	1	1	1	1	1
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1	1	1	1	1	1	1	1	1
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											


CD4007 CMOS Al_2O_3 Unit #A259
Area 2-3
INTENSITY
SECONDARY ION MASS NUMBER
C
O
Na
Mg
Al
Si
O_2
K
Ca
SiO
Ti
Si_2
SiO_2
Ga
Si_2O
Si_2O_2
Ag
In
Au

CMOS Al_2O_3 CD4007

UNIT #259 . AREA 1 . SPECTRA 185-187 .

RASTER 106 x 86 μm . SPOT 22 μm BC 18 NA SR (Å/SEC) .70 .

ELEM	PLUS / START	9761	10488	11200								
Li (7)	30											
B (11)	60	–	–	–								
F (19)	150	–	–	–								
Na (23)	180	6	5	5								
Mg (24)	185	1	1	1								
Al (27)	205	2290	1645	1673								
Si (30)	220	180	220	240								
P (31)	230		1	1								
Cl (35)	250											
K (39)	290	4	3	3								
Ca (40)	295	1	1	1								
Ti (48)	330											
Cr (52)	350	1	1	1								
Ni (58)	380											
Cu (63)	400	1	1	1								
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1								
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

CMOS Al_2O_3 CD4007

UNIT # A259 . AREA 2 . SPECTRA 373 - 381 .

RASTER 68X55 μm . SPOT 17 μm BC 9NA SR (Å/SEC) .85 .

ELEM	PLUS / START	0	877	1571	2436	3120	3816	4518	5208	5882		
Li (7)	30	6	–	–	–	–	–	–	–	–		
B (11)	60											
F (19)	150											
Na (23)	180	333	1	1	1	1	1	1	1	1		
Mg (24)	185	31	1	1	1	1	1	1	1	1		
Al (27)	205	139	4	2	31	231	312	493	631	838		
Si (30)	220	4.6	100	120	120	100	100	86	96	82		
P (31)	230											
Cl (35)	250											
K (39)	290	69	1	1	1	1	1	1	1	1		
Ca (40)	295	53	1	1	1	1	1	1	1	1		
Ti (48)	330	8	1	1	1	–	–	–	–	–		
Cr (52)	350	6	1	1	–	–	–	–	–	–		
Ni (58)	380											
Cu (63)	400	3	1	1	1	1	1	1	1	1		
Zn (64)	403	3	–	–	–	–	–	–	–	–		
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	3	1	1	1	1	1	1	1	1		
Sn (118)	610	3	1	–	–	–	–	–	–	–		
Ba (138)	670											
Pb (208)	858											

CMOS Al_2O_3 CD4007

UNIT #A259 . AREA 3 . SPECTRA 382-390 .

RASTER 68X55 μm . SPOT 17 μm BC 9 NA SR (Å/SEC) .85 .

ELEM	PLUS / START	0	692	1411	2106	2803	3490	4177	4880	5571		
Li (7)	30	1	–	–	–	–	–	–	–	–		
B (11)	60											
F (19)	150											
Na (23)	180	115	1	1	1	1	1	1	1	1		
Mg (24)	185	10	1	1	1	1	1	1	1	1		
Al (27)	205	185	21	18	22	23	421	586	768	1010		
Si (30)	220	5	110	120	130	120	110	110	105	90		
P (31)	230											
Cl (35)	250											
K (39)	290	58	1	1	1	1	1	1	1	1		
Ca (40)	295	33	1	1	1	1	1	1	1	1		
Ti (48)	330	5	1	1	1	1	–	–	–	–		
Cr (52)	350	3	1	1	1	1	1	1	1	1		
Ni (58)	380											
Cu (63)	400	3	1	1	1	1	1	1	1	1		
Zn (64)	403	3	–	–	–	–	–	–	–	–		
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	5	1	1	1	1	1	1	1	1		
Sn (118)	610	3	1	1	1	–	–	–	–	–		
Ba (138)	670											
Pb (208)	858											

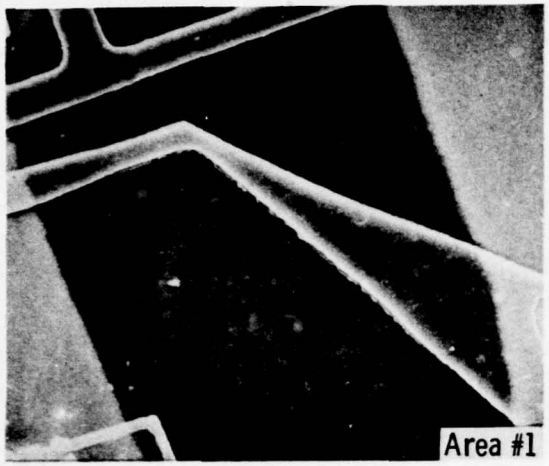
CMOS Al_2O_3 CD4007

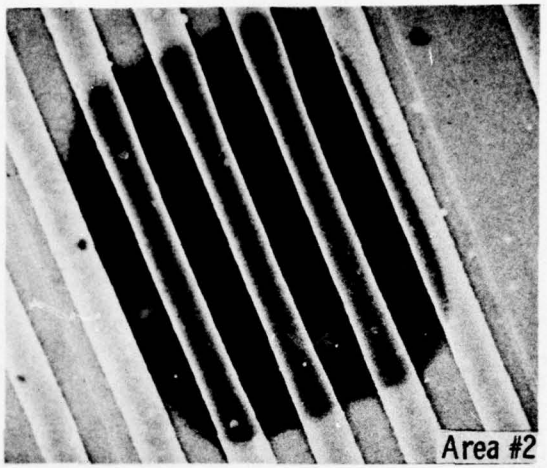
UNIT #A259 . AREA 4 . SPECTRA 391-398 .

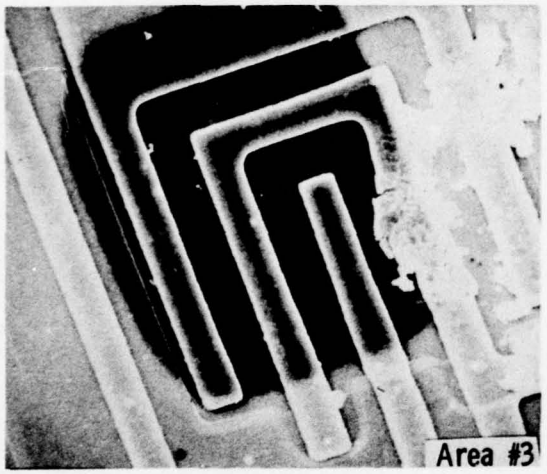
RASTER 68X55 μm . SPOT 17 μm BC 9NA SR (Å/SEC) .85 .

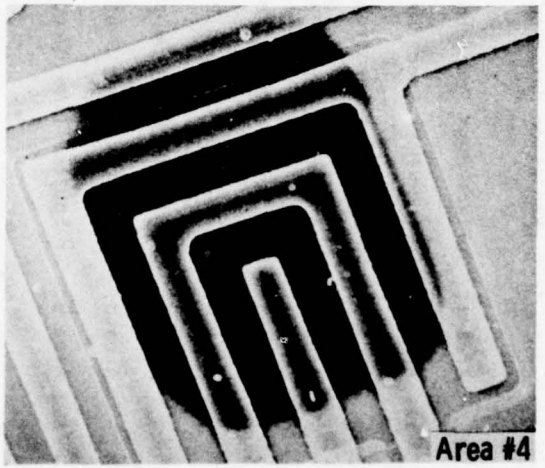
ELEM	PLUS / START	0	704	1400	2095	2787	3476	4169	4855			
Li (7)	30	1	-	-	-	-	-	-	-			
B (11)	60											
F (19)	150											
Na (23)	180	84	2	1	1	1	1	1	1			
Mg (24)	185	5	1	1	1	1	1	1	1			
Al (27)	205	113	10	6	4	146	373	538	698			
Si (30)	220	74	110	110	110	110	92	90	84			
P (31)	230											
Cl (35)	250											
K (39)	290	59	2	2	1	-	-	-	-			
Ca (40)	295	16	1	1	1	1	1	1	1			
Ti (48)	330	8	1	1	1	-	-	-	-			
Cr (52)	350	3	1	-	-	-	-	-	-			
Ni (58)	380											
Cu (63)	400	2	1	1	-	1	1	1	1			
Zn (64)	403	3	-	-	-	-	-	-	-			
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	2	1	1	1	1	1	1	1			
Sn (118)	610	2	1	-	-	-	-	-	-			
Ba (138)	670											
Pb (208)	858											

CD4007 CMOS Al_2O_3 Unit #A259


Area #1


Area #2


Area #3


Area #4

APPENDIX B

Radiation Hardened Double Glass, Unit #120

Area 1: Surface Mass Spectrum

Area 2: Surface Mass Spectrum

Area 3: Surface Mass Spectrum

Area 4: Mass Spectra Depth Profile

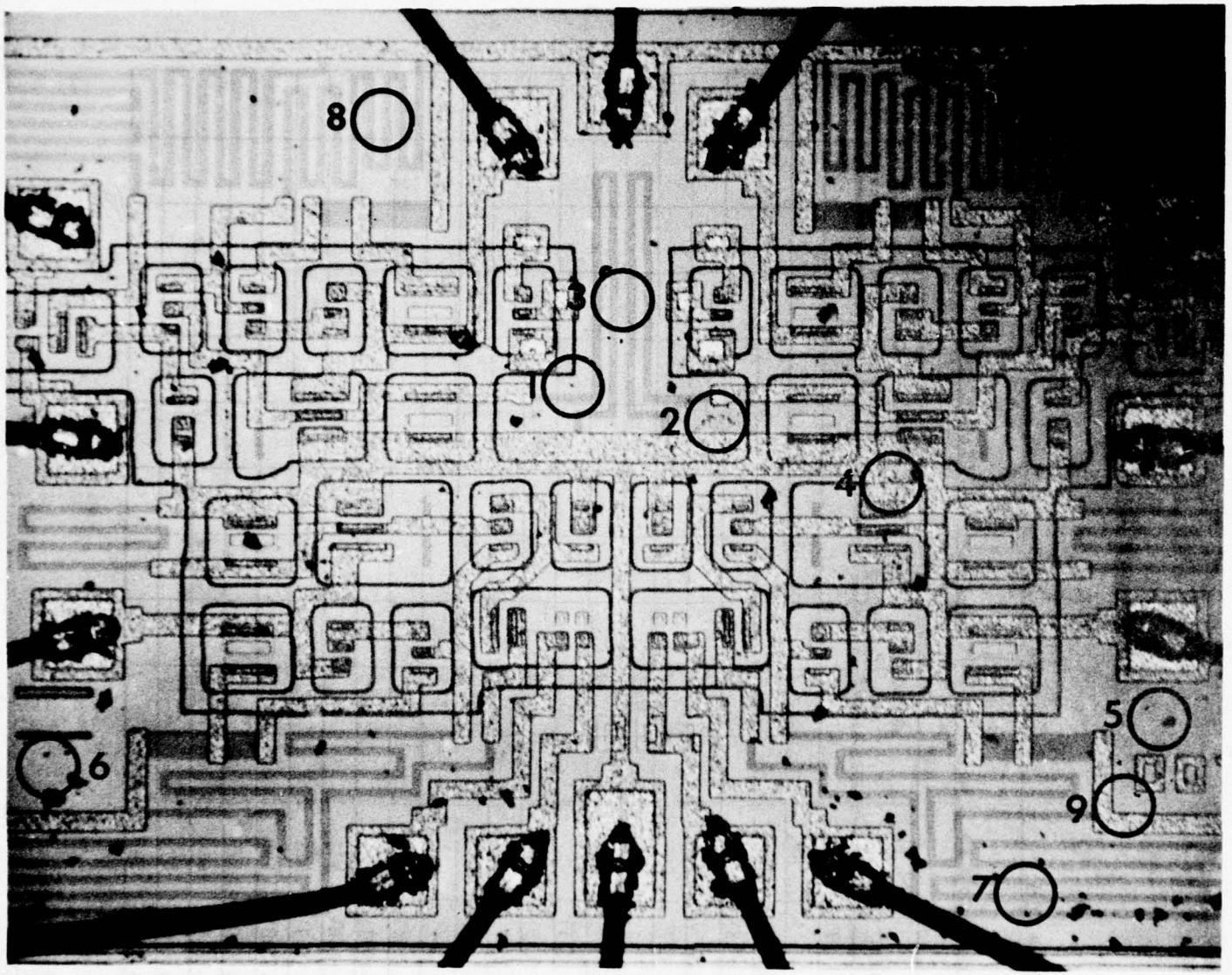
Area 5: Mass Spectra Depth Profile

Area 6: Sn Peak Count Depth Profile

Area 7: Cr-Ni Peak Count Depth Profile (not included)

Area 8: Cr-Ni Peak Count Depth Profile

Area 9: Ar Sputter Time Through Glassivation (immediate Aℓ signal)



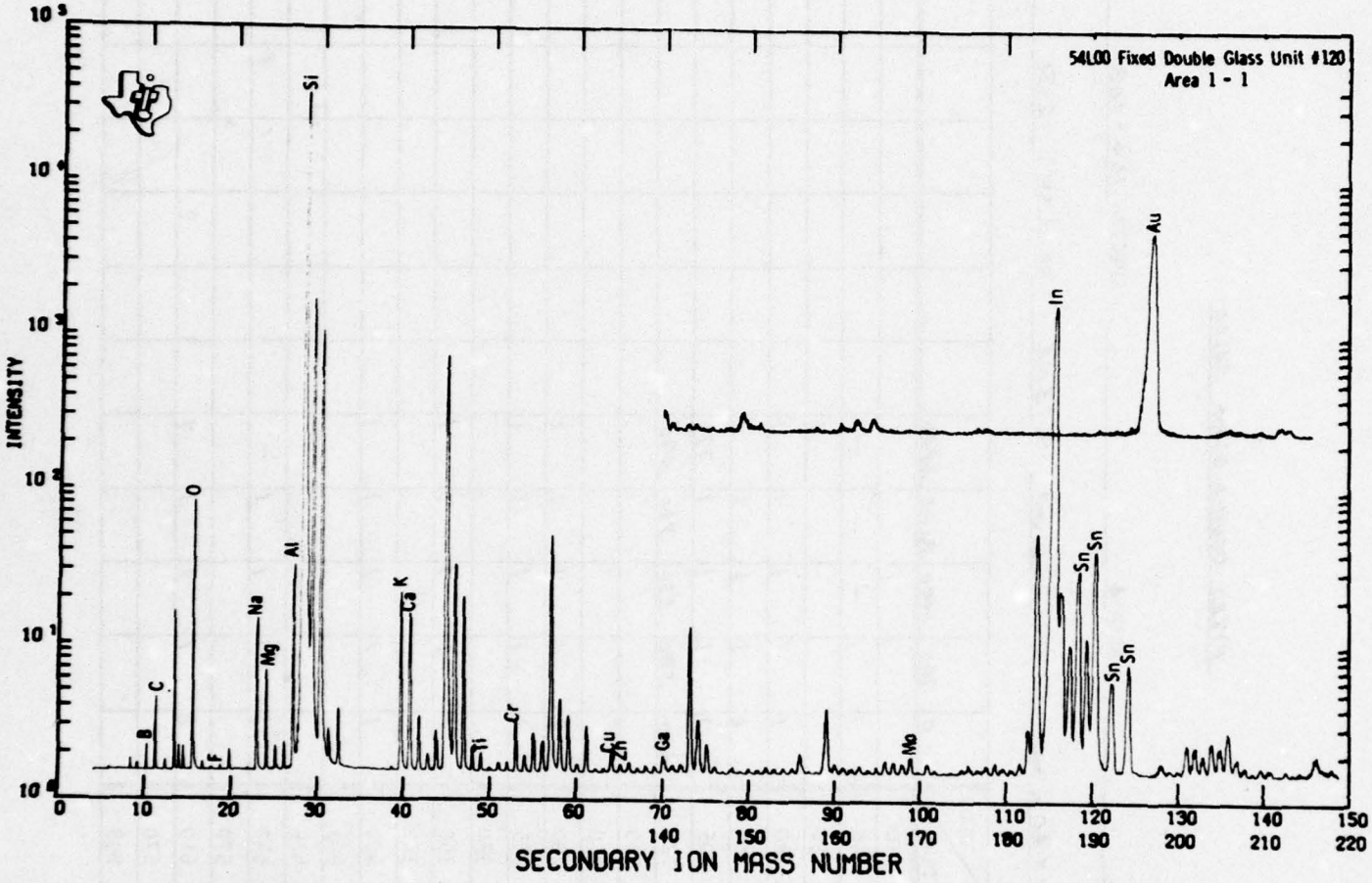
Set I 54L00 Radiation Hardened Double Glass Unit #120

FIXED DOUBLE GLASS 34L00

UNIT #120 . AREA 1-2-3 . SPECTRA .

RASTER 50 X 40 μm . SPOT 24 μm BC 13NA SR (Å/SEC) 2.31 .

ELEM	PLUS / START		AREA 1		AREA 2		AREA 3					
Li (7)	30											
B (11)	60		1		1		1					
F (19)	150		1		1		1					
Na (23)	180		2		3		6					
Mg (24)	185		1		1		3					
Al (27)	205		4		3		6					
Si (30)	220		350		550		270					
P (31)	230		1		1		1					
Cl (35)	250											
K (39)	290		3		2		9					
Ca (40)	295		2		3		6					
Ti (48)	330		1		1		1					
Cr (52)	350		1		1		1					
Ni (58)	380											
Cu (63)	400		1		1		1					
Zn (64)	403		1		1		1					
Ga (69)	425		1		1		1					
Mo (98)	540		1		1		1					
Ag (107)	570											
Sn (118)	610		5		4		7					
Ba (138)	670											
Pb (208)	858		1		1		1					


54L00 Fixed Double Glass Unit #120
Area 1 - 1
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Mg
Al
Si
K
Ca
Cr
Ti
Cu
Ga
Mo
In
Sn
Sn
Sn
Sn
Au

FIXED DOUBLE GLASS 54L00

UNIT #120 . AREA 4 . SPECTRA 104 - 108 .

RASTER 50 X 40 μm . SPOT 22 μm BC 13NA SR (Å/SEC) 2.31 .

ELEM	START \ PLUS	0	700	1400	2100	2800						
Li (7)	30											
B (11)	60	1	1	-	-	-						
F (19)	150					1						
Na (23)	180	1	1	1	1	1						
Mg (24)	185	1	1	1	1	1						
Al (27)	205	2	1	1	1	777						
Si (30)	220	610	580	550	520	490						
P (31)	230											
Cl (35)	250											
K (39)	290	2	1	1	1	1						
Ca (40)	295	1	1	1	1	1						
Ti (48)	330											
Cr (52)	350	1	1	1	1	1						
Ni (58)	380											
Cu (63)	400	1	1	1	1	1						
Zn (64)	403											
Ga (69)	425											
Mo (98)	540	1	1	1	1	-						
Ag (107)	570											
Sn (118)	610	2	1	1	1	1						
Ba (138)	670											
Pb (208)	858											

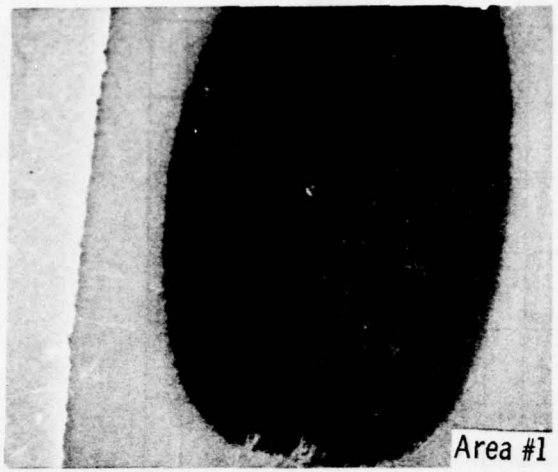
FIXED DOUBLE GLASS 34L00

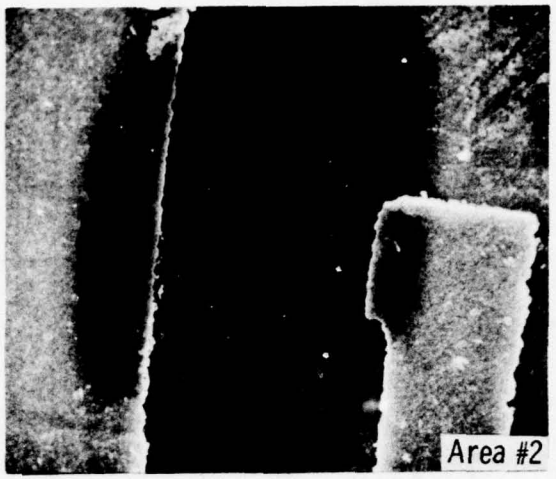
UNIT #120 . AREA 5 . SPECTRA 109-114 .

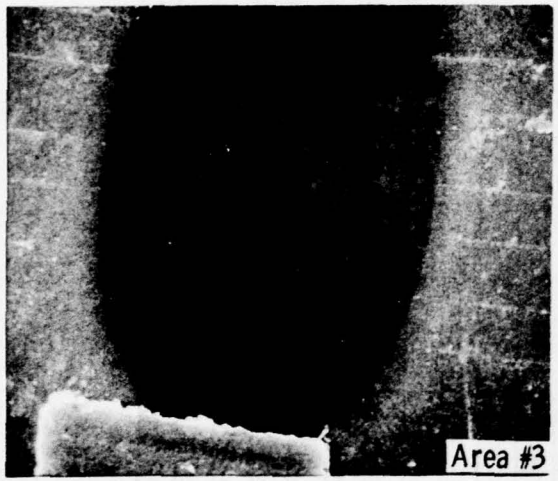
RASTER 50X40 μm . SPOT 22 μm BC 13NA SR (Å/SEC) 2.31 .

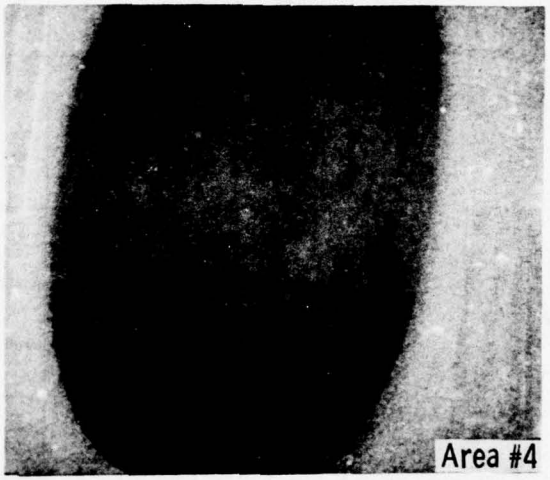
ELEM	PLUS / START	0	700	1400	2100	2800	3500					
Li (7)	30											
B (11)	60	1	–	–	–	–	1					
F (19)	150					1						
Na (23)	180	1	1	1	1	1	1					
Mg (24)	185	1	1	1	1	1	1					
Al (27)	205	1	1	1	1	8	6					
Si (30)	220	550	580	600	600	580	600					
P (31)	230	–	–	–	–	6	12					
Cl (35)	250											
K (39)	290	1	1	1	1	1	1					
Ca (40)	295	1	1	1	1	1	1					
Ti (48)	330											
Cr (52)	350	1	1	1	1	6	4					
Ni (58)	380	–	–	–	–	1	1					
Cu (63)	400	1	1	1	1	1	1					
Zn (64)	403											
Ga (69)	425											
Mo (98)	540	1	1	1	1	1	–					
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	1					
Ba (138)	670											
Pb (208)	858											

54L00 Fixed Double Glass
Unit #120


Area #1


Area #2

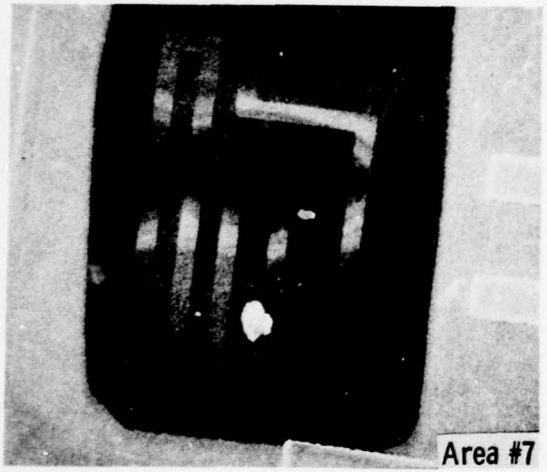

Area #3


Area #4

54L00 Fixed Double Glass
Unit #120


Area #5


Area #6


Area #7


Area #8

54L00 Radiation Hardened, Old Style, Unit #103

Area 1: Surface Mass Spectrum

Area 2: Mass Spectra Depth Profile

Area 3: Mass Spectra Depth Profile

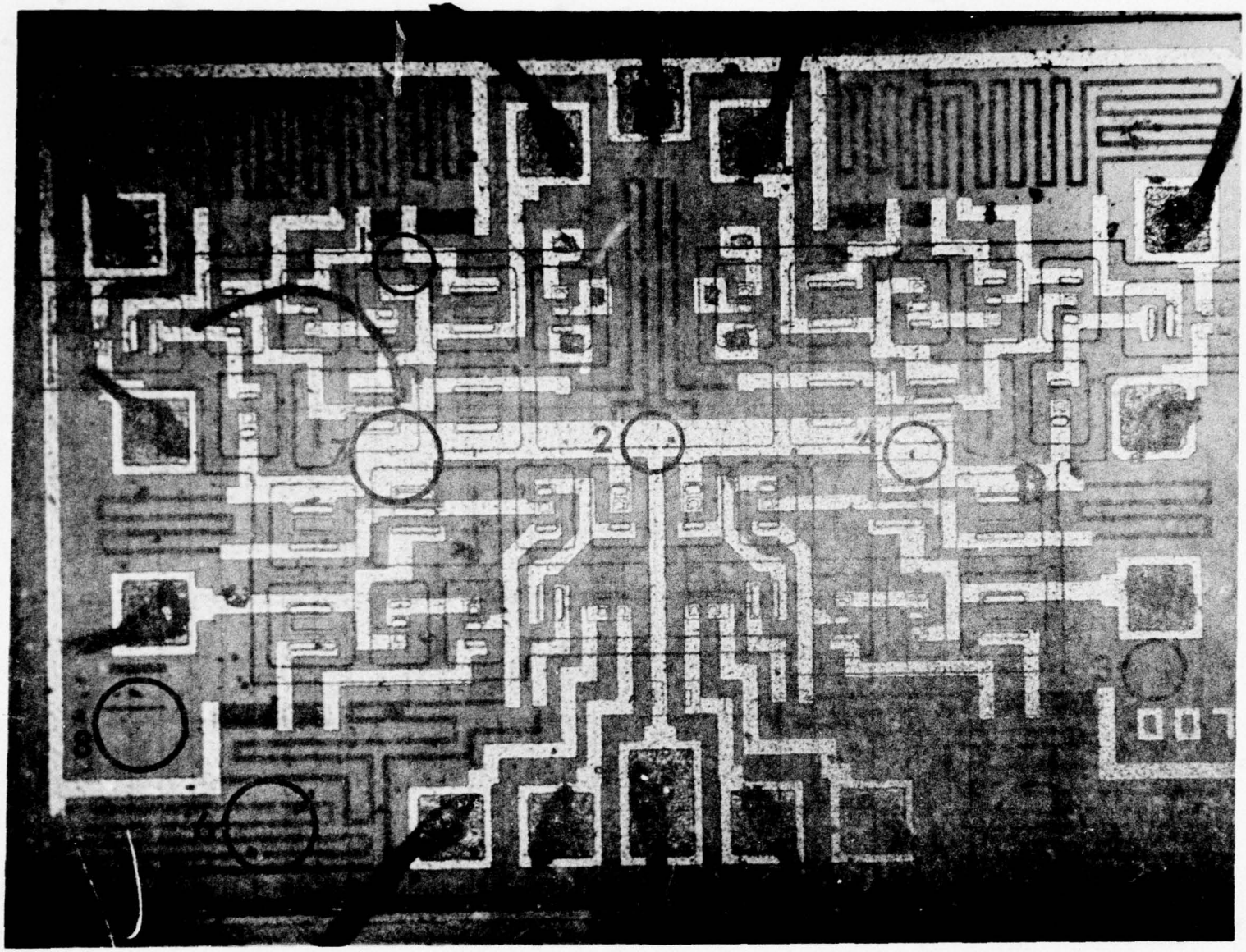
Area 4: Ar Sputter Time through Glassivation

Area 5: Cr-Ni Peak Count Depth Profile after Glassivation Removal

Area 6: Opened with Ar, But Not Used

Area 7: Opened with Ar, But not Used

Area 8: Opened with Ar, But not Used



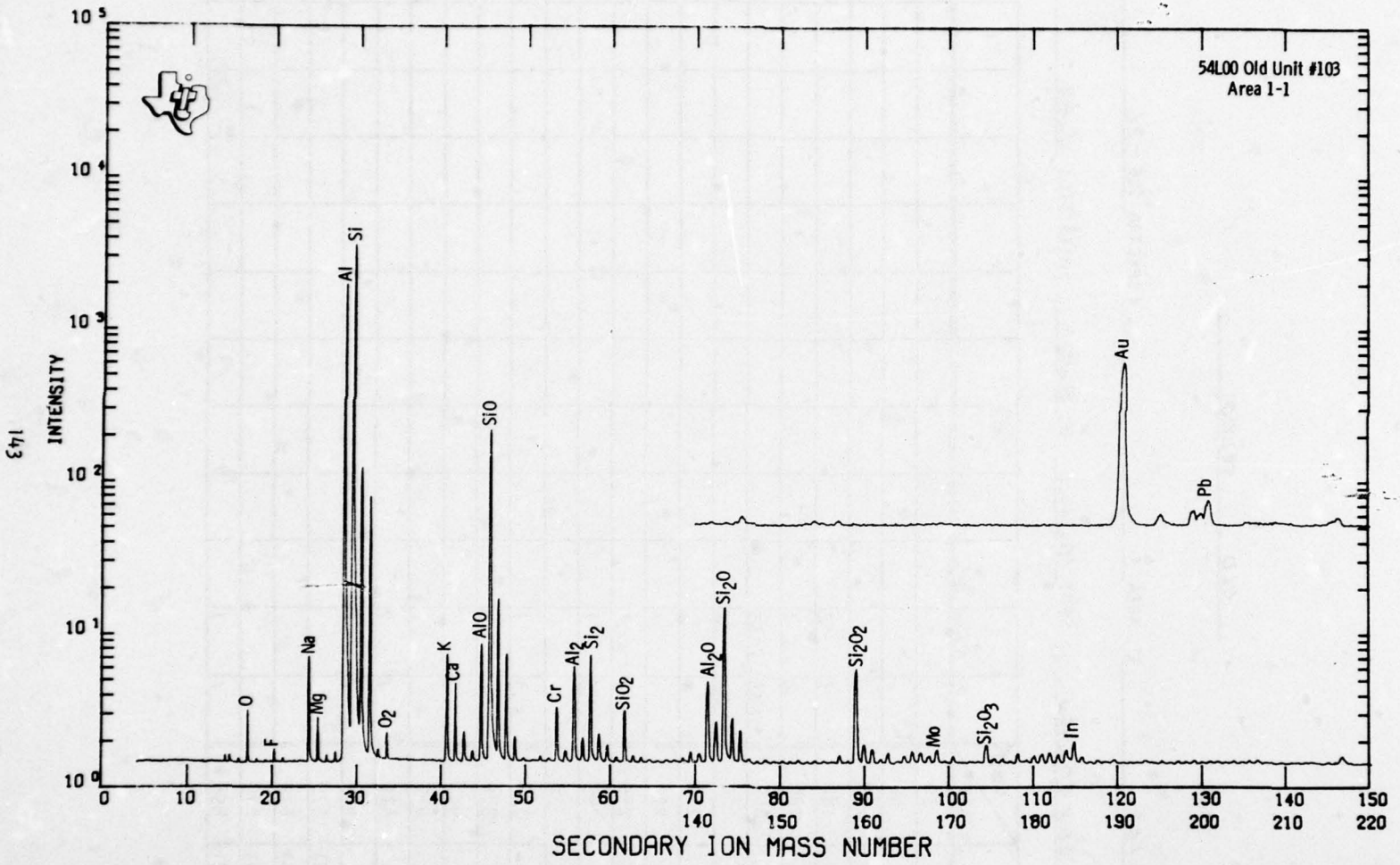
Set 1 54L00 Radiation Hardened Old Unit #103

OLD 54L00

UNIT #103 . AREA 1 . SPECTRA 75-76 .

RASTER 50x40μm . SPOT 16μm BC 8NA SR (Å/SEC) 1.42 .

ELEM	PLUS / START	0	926									
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	9	2									
Mg (24)	185	2	1									
Al (27)	205	1835	1053									
Si (30)	220	38	56									
P (31)	230											
Cl (35)	250											
K (39)	290	9	3									
Ca (40)	295	5	1									
Ti (48)	330											
Cr (52)	350	3	1									
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425	1	1									
Mo (98)	540	1	1									
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858	1	1									


54L00 Old Unit #103
Area 1-1
INTENSITY
SECONDARY ION MASS NUMBER
O
F
Na
Mg
Al
Si
O2
K
Ca
AlO
SiO
Cr
Al2
Si2
SiO2
Al2O
Si2O
Si2O2
Mo
Si2O3
In
Au
Pb

OLD 54L00

UNIT #103 . AREA 1 . SPECTRA 75-76 .

RASTER 50x40 μm . SPOT 16 μm BC 8NA SR (Å/SEC) 1.42 .

ELEM	PLUS / START	0	926									
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	9	2									
Mg (24)	185	2	1									
Al (27)	205	1835	1053									
Si (30)	220	38	56									
P (31)	230											
Cl (35)	250											
K (39)	290	9	3									
Ca (40)	295	5	1									
Ti (48)	330											
Cr (52)	350	3	1									
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425	1	1									
Mo (98)	540	1	1									
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858	1	1									

OLD 54L00

UNIT #103 . AREA 2 . SPECTRA 91-101 .

RASTER 75X60 μm . SPOT 22 μm BC 17NA SR (Å/SEC) 1.34 .

ELEM	PLUS / START	0	915	1615	2315	3015	3715	4415	5115	5815	6515	7215
Li (7)	30											
B (11)	60		1	1	1	1	1	1	1	1	1	1
F (19)	150											
Na (23)	180		2	1	1	1	1	1	1	1	2	1
Mg (24)	185		1	1	1	–	–	–	1	1	–	–
Al (27)	205		13	7	6	6	7	22	49	82	144	226
Si (30)	220		370	250	250	260	230	230	200	220	160	200
P (31)	230											
Cl (35)	250											
K (39)	290		3	2	2	3	3	3	3	3	4	3
Ca (40)	295		1	1	1	1	1	1	1	1	1	1
Ti (48)	330		1	1	1	1	1	1	1	–	1	1
Cr (52)	350		1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540		1	1	1	1	1	1	1	–	–	–
Ag (107)	570											
Sn (118)	610		1	1	1	1	1	1	1	1	1	1
Ba (138)	670											
Pb (208)	858											

OLD 54L00

UNIT #103 . AREA 2 . SPECTRA 102-103 .

RASTER 75 x 60 μm . SPOT 22 μm BC 17NA SR (Å/SEC) 1.34 .

ELEM	PLUS / START	7915	8615									
Li (7)	30											
B (11)	60	1	1									
F (19)	150	1	1									
Na (23)	180	1	1									
Mg (24)	185	–	–									
Al (27)	205	1798	1899									
Si (30)	220	190	180									
P (31)	230											
Cl (35)	250											
K (39)	290	3	3									
Ca (40)	295	1	1									
Ti (48)	330	1	–									
Cr (52)	350	1	1									
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540	–	–									
Ag (107)	570											
Sn (118)	610	1	1									
Ba (138)	670											
Pb (208)	858											

OLD 54L00

UNIT #103 . AREA 3 . SPECTRA 77-87 .

RASTER 75 X 60 μm . SPOT 22 μm BC 17 NA SR (Å/SEC) 1.34 .

ELEM	PLUS / START	0	700	1400	2100	2800	3500	4200	4900	5600	6300	7000
Li (7)	30											
B (11)	60	-	1	1	1	1	1	1	1	1	1	1
F (19)	150											
Na (23)	180	7	1	1	1	1	1	1	1	1	1	1
Mg (24)	185	-	1	1	-	-	-	1	1	1	1	1
Al (27)	205	9	2	1	1	2	1	1	2	1	1	1
Si (30)	220	42	220	215	210	175	180	240	220	280	280	250
P (31)	230											
Cl (35)	250											
K (39)	290	9	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	2	1	1	1	1	1	1	1	1	1	1
Ti (48)	330											
Cr (52)	350	6	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	1	1	-	1	1	1
Ba (138)	670	-	-	-	-	1	1	1	-	1	1	1
Pb (208)	858											

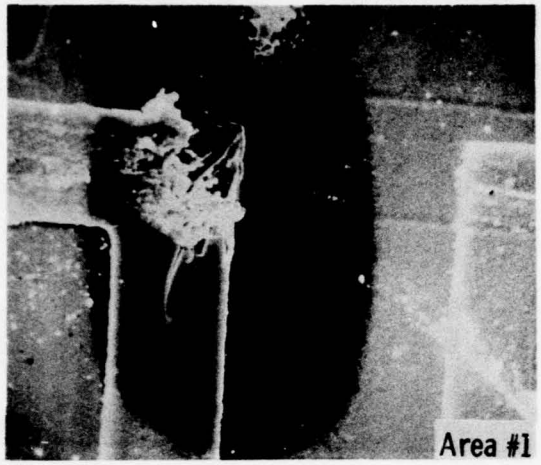
OLD 54L00

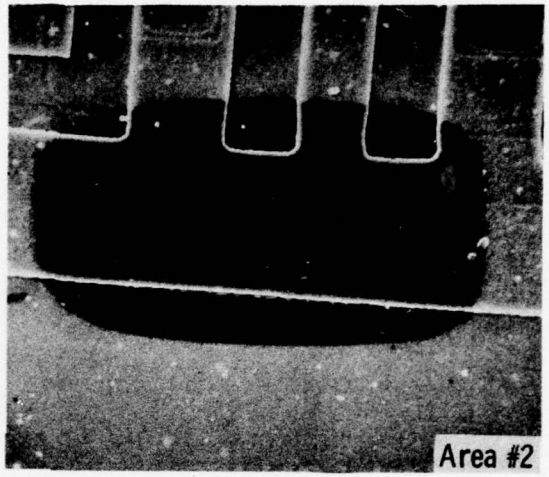
UNIT #103 . AREA 3 . SPECTRA 88 - 90 .

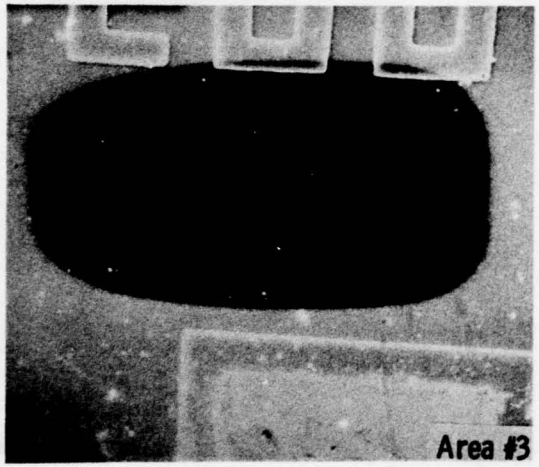
RASTER 75 X 60 μm . SPOT 22 μm BC 17NA SR (Å/SEC) 1.34 .

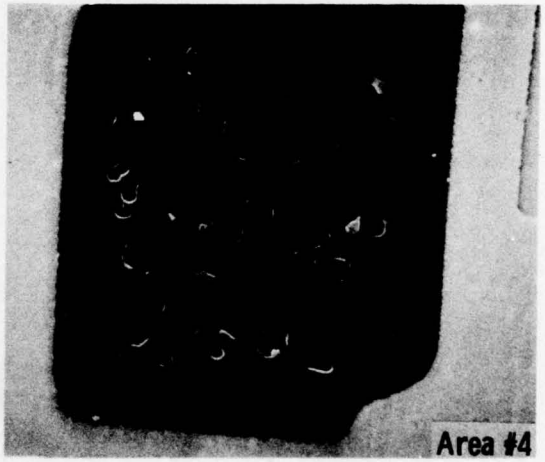
ELEM	PLUS / START	7700	8400	9100								
Li (7)	30											
B (11)	60	1	–	1								
F (19)	150											
Na (23)	180	2	1	2								
Mg (24)	185	–	–	–								
Al (27)	205	3	3	3								
Si (30)	220	240	250	230								
P (31)	230	–	1	8								
Cl (35)	250											
K (39)	290	1	–	1								
Ca (40)	295	1	–	1								
Ti (48)	330											
Cr (52)	350	1	–	1								
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	–	–								
Ba (138)	670	1	1	1								
Pb (208)	858											

54L00 Old Unit #103

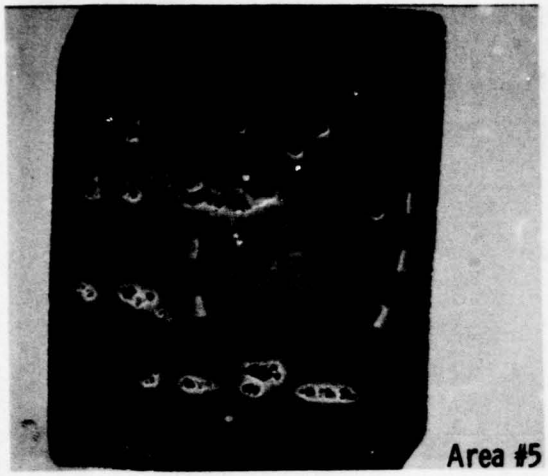

Area #1

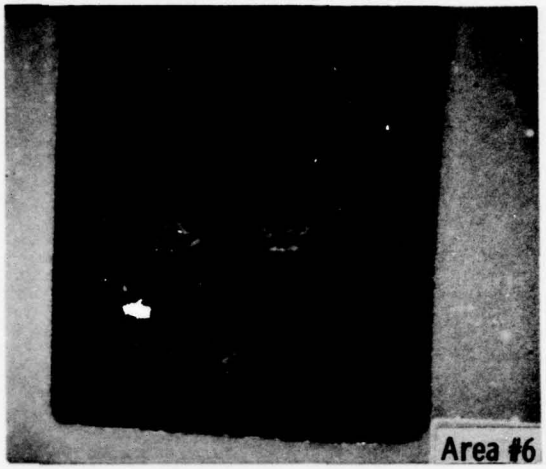

Area #2

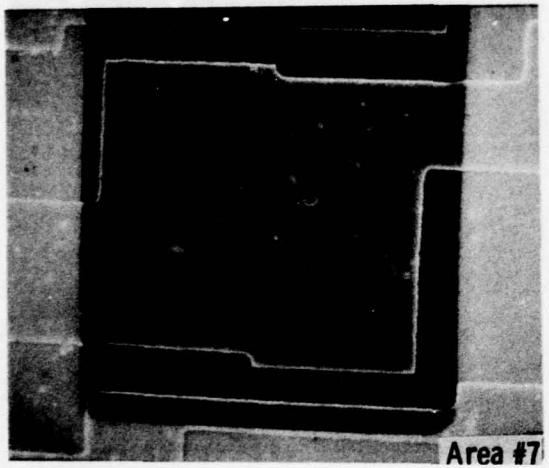

Area #3

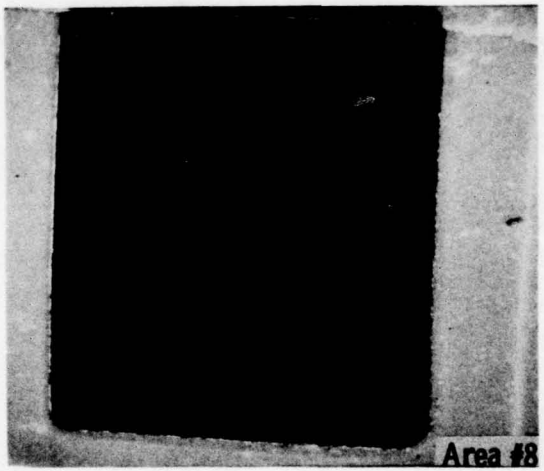

Area #4

54L00 Old Unit #103


Area #5


Area #6


Area #7


Area #8

Op Amp #1, Unit #3

Area 1: Mass Spectra Depth Profile

Area 2: Mass Spectra Depth Profile

Area 3: Mass Spectra Depth Profile

Area 4: P Peak Count Profile (not included)

Area 5: P Peak Count Profile

Area 6: Ar Sputter for Glassivation Thickness - Interface Analysis at Glassivation-Aluminum Layers

Area 7: Interface Analysis; Glassivation-Oxide Layers

Area 8: Interface Analysis; Glassivation-Oxide Layers

Area 9: Interface Analysis; Glassivation-Oxide Layers

Oxide-Metal Stripped

Area 1S: Mass Spectrum for Dopants

Area 2S: Mass Spectrum for Dopants

Area 3S: Mass Spectrum for Dopants

Area 4S: Mass Spectrum for Dopants

Area 5S: Mass Spectrum for Dopants

Area 6S: Mass Spectrum for Dopants

Op Amp #1, Unit #3
Oxide-Metal Stripped
(Continued)

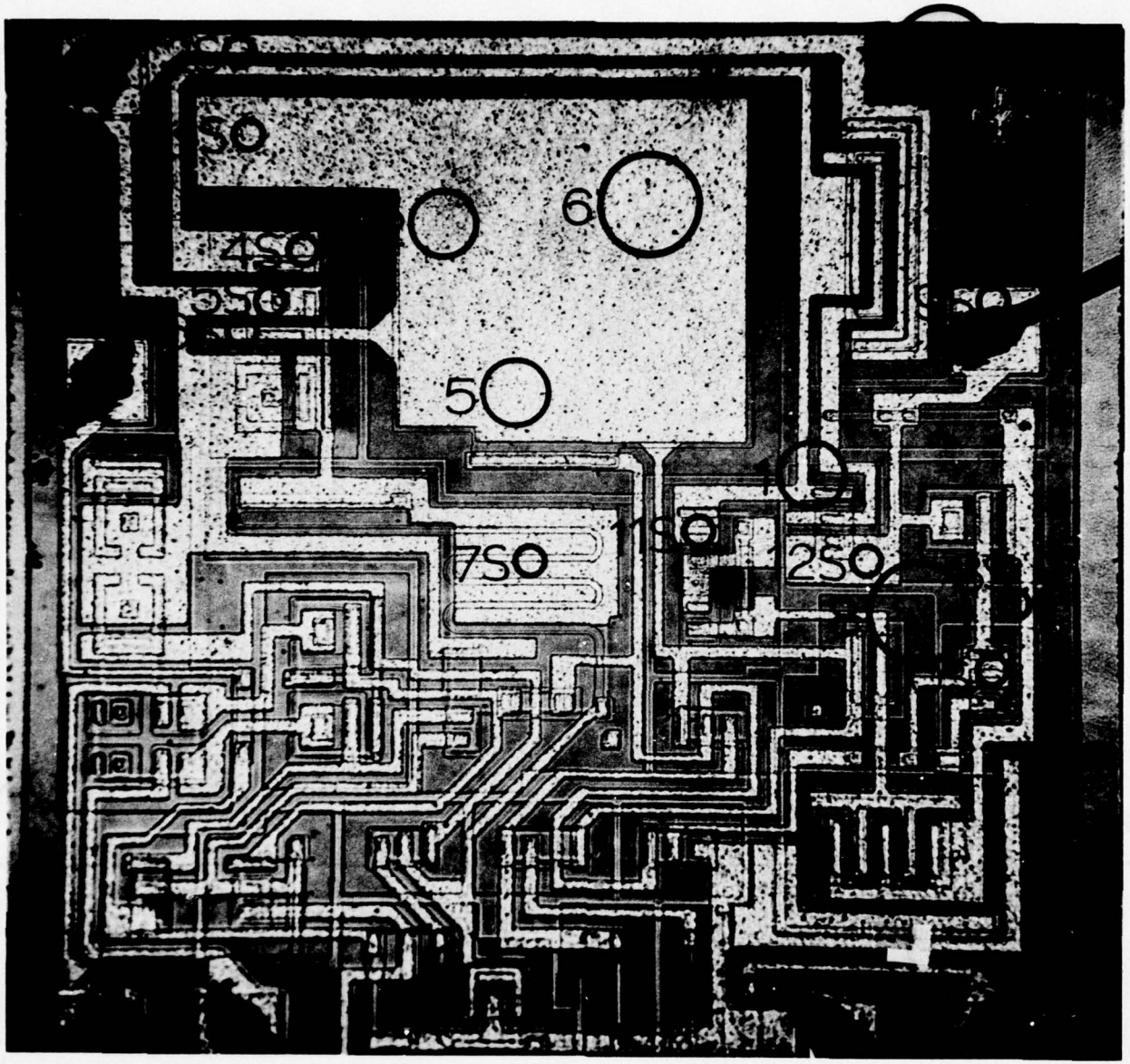
Area 7S: Mass Spectrum for Dopants

Area 8S: B Concentration Data

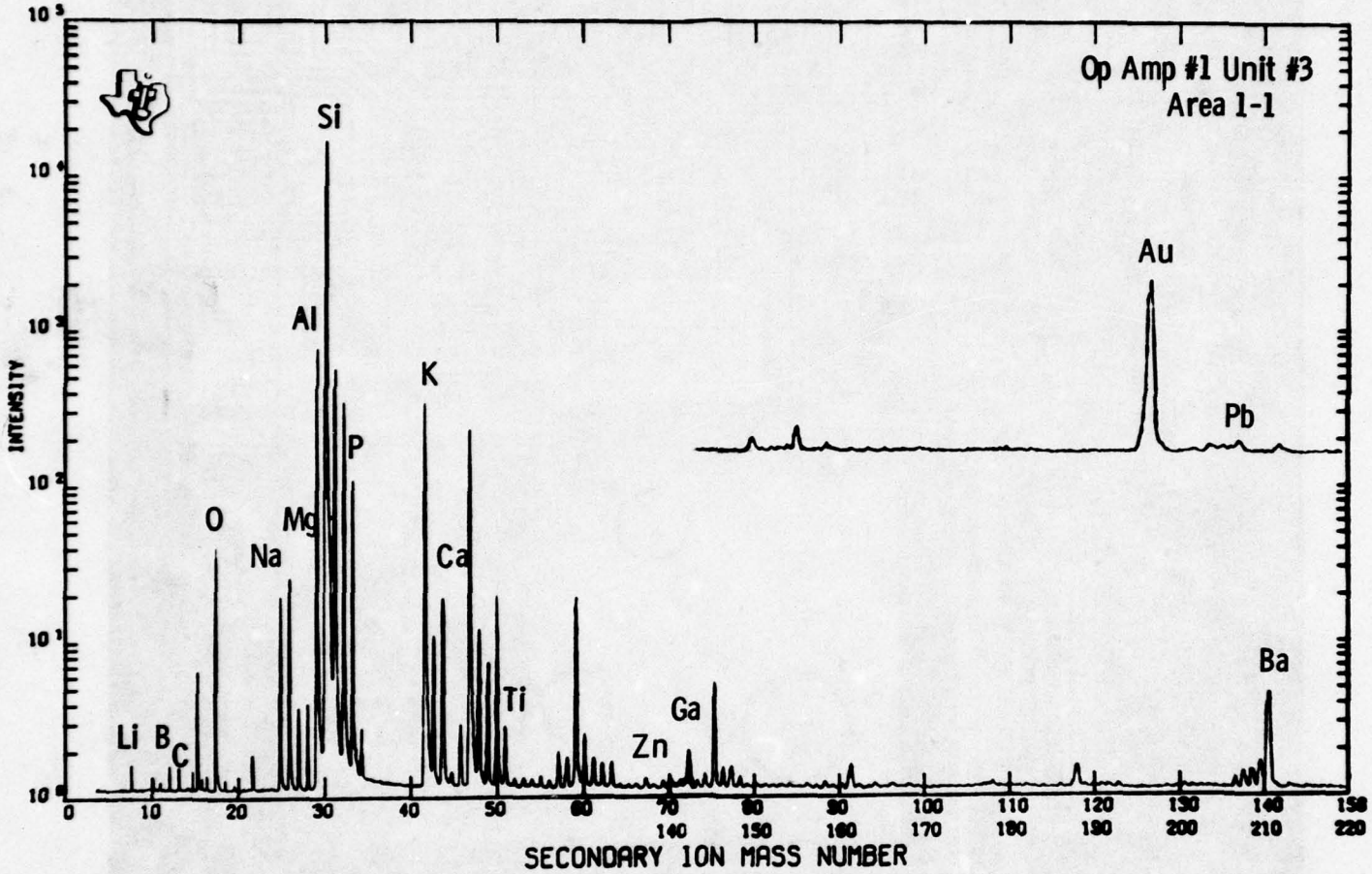
Area 9S: B Concentration Data

Area 10S: B Concentration Data

Area 11S: B Concentration Data



Set 1 Op Amp #1 Unit #3


Op Amp #1 Unit #3
Area 1-1
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
Na
Mg
Al
Si
P
K
Ca
Ti
Zn
Ga
Au
Pb
Ba

OP AMP #1 MC1471L

UNIT #3 . AREA 1 . SPECTRA 11-13 .

RASTER 50 X 40 μm . SPOT 26 μm BC 15NA SR (Å/SEC) 2.66 .

ELEM	START \ PLUS	0	3260	5060								
Li (7)	30	1	1	–								
B (11)	60	1	1	1								
F (19)	150											
Na (23)	180	9	3	2								
Mg (24)	185	12	5	2								
Al (27)	205	271	670	5431								
Si (30)	220	130	180	82								
P (31)	230	47	32	26								
Cl (35)	250											
K (39)	290	139	61	30								
Ca (40)	295	5	1	1								
Ti (48)	330	1	1	1								
Cr (52)	350	1	–	–								
Ni (58)	380											
Cu (63)	400											
Zn (64)	403	1	–	–								
Ga (69)	425	1	1	1								
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	–	–								
Ba (138)	670	2	1	1								
Pb (208)	858	1	1	1								

OP AMP #1 MC1471L

UNIT #3 . AREA 2 . SPECTRA 14-16 .

RASTER 50 x 40 μm . SPOT 17 μm BC 20 NA SR (Å/SEC) 3.55 .

ELEM	START \ PLUS	0	706	1412								
Li (7)	30	1	-	-								
B (11)	60	1	1	-								
F (19)	150											
Na (23)	180	4	1	1								
Mg (24)	185	1	1	-								
Al (27)	205	1	31	5955								
Si (30)	220	120	120	48								
P (31)	230	33	31	32								
Cl (35)	250											
K (39)	290	1	1	1								
Ca (40)	295	1	1	1								
Ti (48)	330											
Cr (52)	350	1	-	-								
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425	1	1	1								
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #1 MC1471L

UNIT #3 . AREA 3 . SPECTRA 17-20 .

RASTER 50 x 40 μm . SPOT 17 μm BC 20 NA SR (Å/SEC) 3.55 .

ELEM	PLUS / START	0	687	1375	2046							
Li (7)	30	5	1	1	1							
B (11)	60	1	1	1	2							
F (19)	150											
Na (23)	180	9	2	1	1							
Mg (24)	185	1	1	–	–							
Al (27)	205	8	6	5	2							
Si (30)	220	130	140	150	150							
P (31)	230	32	29	15	9							
Cl (35)	250											
K (39)	290	2	1	1	1							
Ca (40)	295	1	1	1	1							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425	1	1	1	1							
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #1 MC1741L

UNIT #3 . AREA 6 . SPECTRA 239 - 242 .

RASTER 86 X 59 μm . SPOT 14 μm BC 17NA SR (Å/SEC) 1.19 .

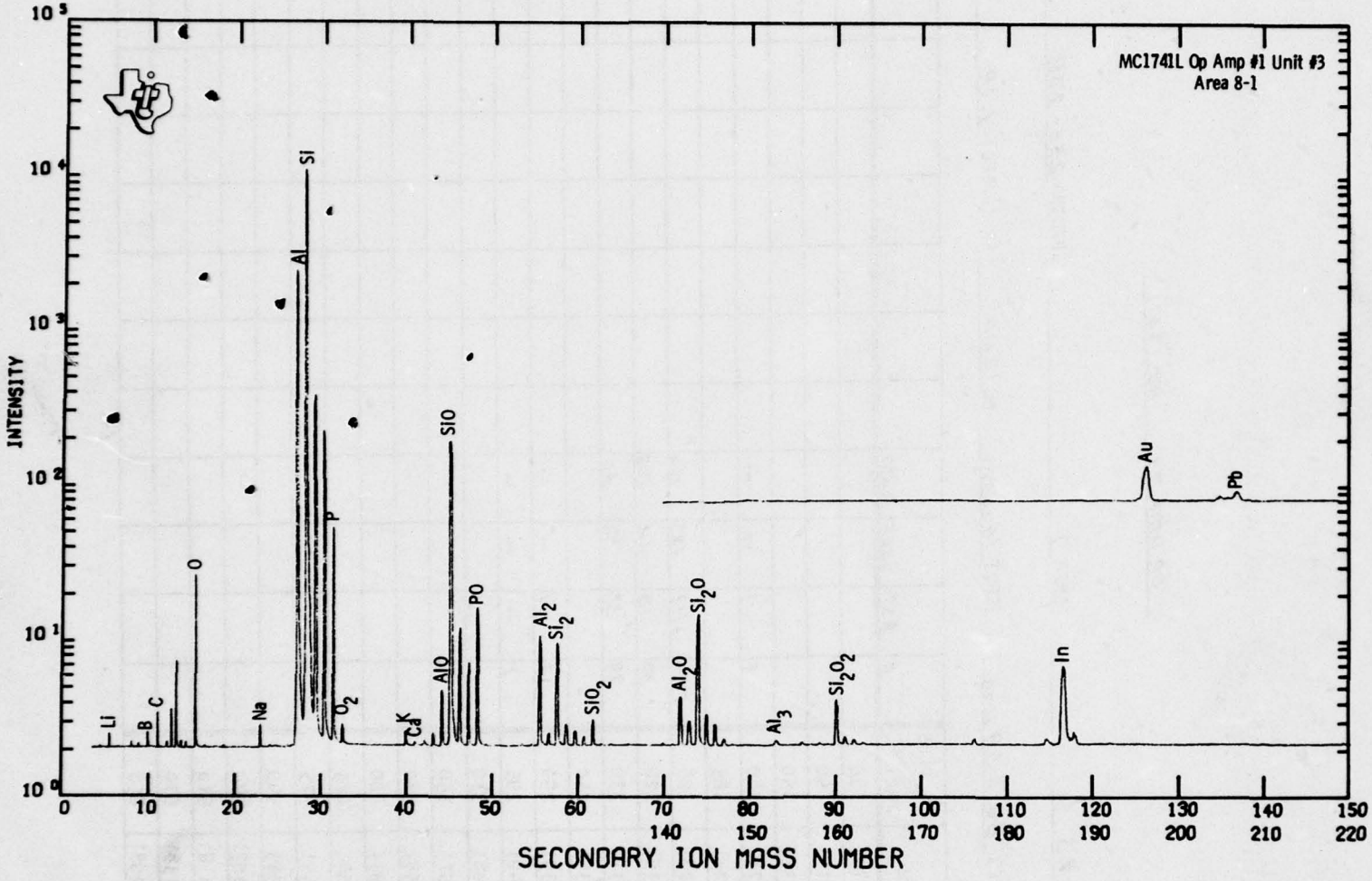
ELEM	START \ PLUS	0	884	1825	2497							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	3	2	4	2							
Mg (24)	185											
Al (27)	205	6534	3460	3325	3564							
Si (30)	220	6.8	16	13	15							
P (31)	230	16	12	18	17							
Cl (35)	250											
K (39)	290	2	1	2	1							
Ca (40)	295											
Ti (48)	330	–	1	2	1							
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #1 MC1741L

UNIT #3 . AREA 7 . SPECTRA 235-238 .

RASTER 86 X 59 μm . SPOT 14 μm BC 17NA SR (Å/SEC) 1.19 .

ELEM	START \ PLUS	0	857	1564	2237							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	–	–							
Mg (24)	185											
Al (27)	205	113	117	125	116							
Si (30)	220	32	13	6.6	3.5							
P (31)	230	29	33	38	40							
Cl (35)	250											
K (39)	290	1	1	–	–							
Ca (40)	295	1	–	–	–							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											


MC1741L Op Amp #1 Unit #3
Area 8-1
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
Na
Al
Si
P
O_2
K
Ca
AlO
SiO
PO
Al_2
Si_2
SiO_2
Al_2O
Si_2O
Al_3
Si_2O_2
In
Au
Pb

OP AMP #1 MC1741G

UNIT #3 . AREA 8 . SPECTRA 243-246 .

RASTER 86 x 59 μm . SPOT 14 μm BC 17 NA SR (Å/SEC) 1.19 .

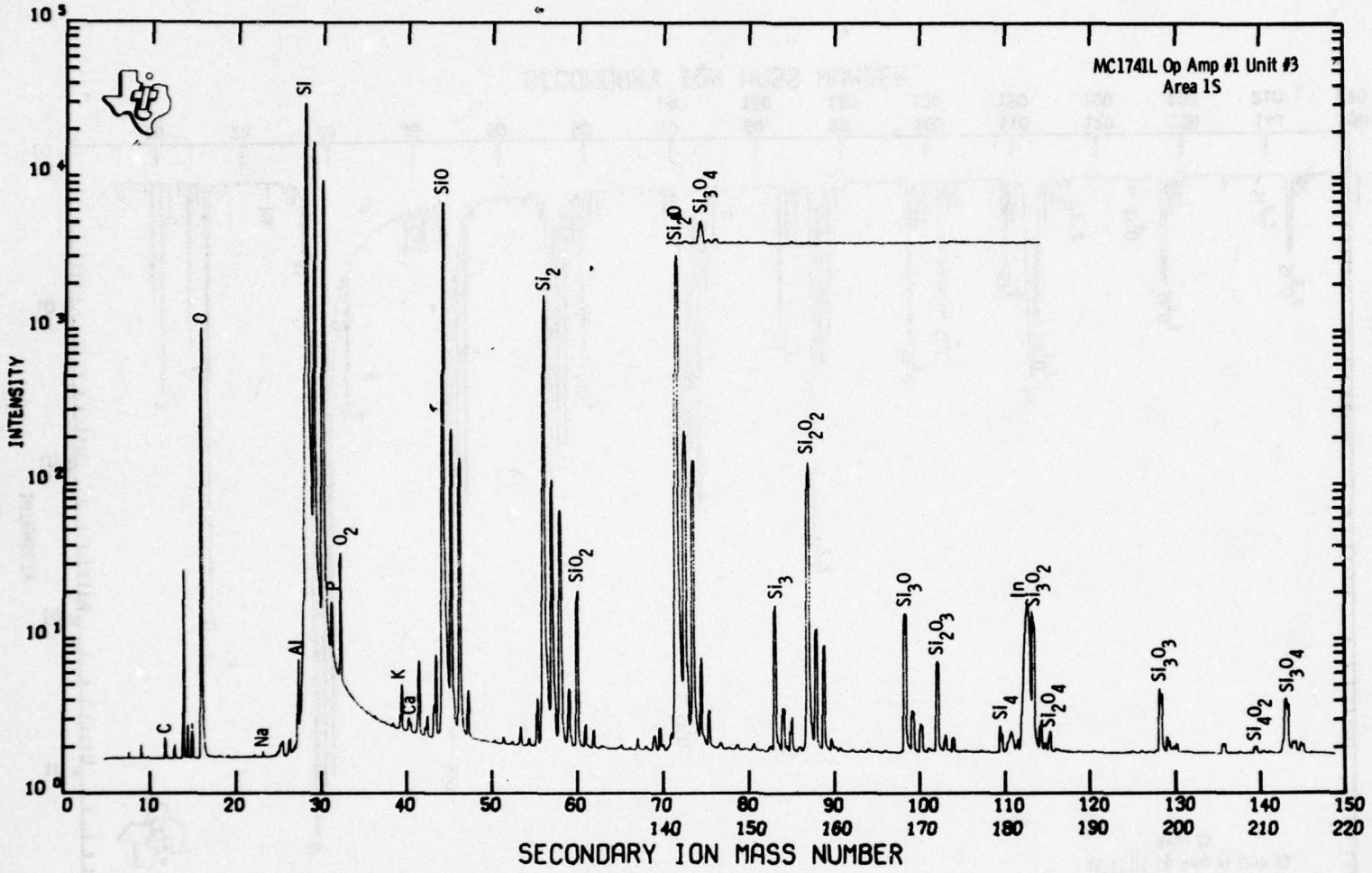
ELEM	PLUS / START	0	859	1578	2220							
Li (7)	30											
B (11)	60											
F (19)	150	1	–	–	–							
Na (23)	180	1	1	1	1							
Mg (24)	185											
Al (27)	205	107	43	33	35							
Si (30)	220	56	54	52	52							
P (31)	230	27	28	24	31							
Cl (35)	250											
K (39)	290	1	1	1	–							
Ca (40)	295											
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

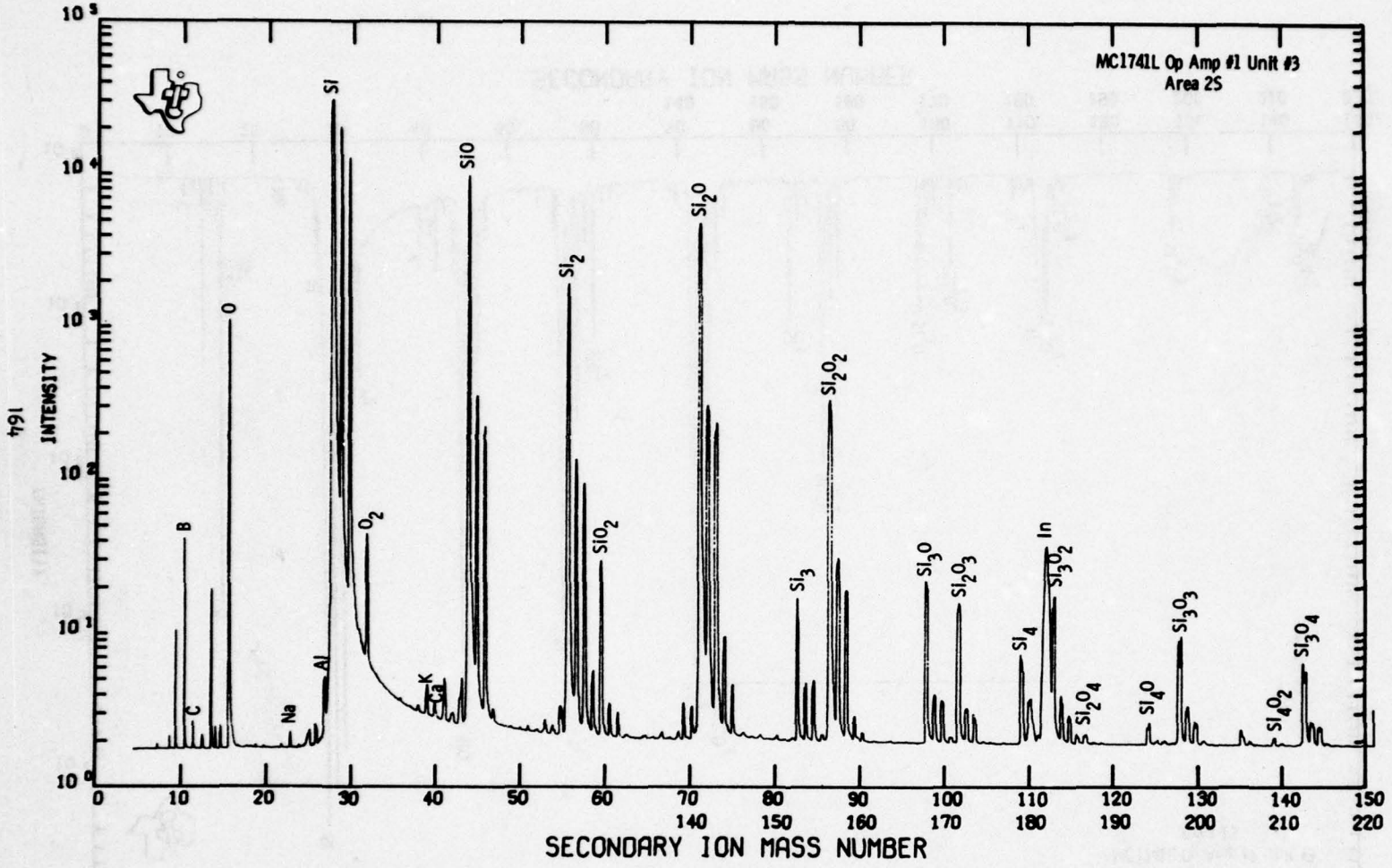
OP AMP #1 MC1741L

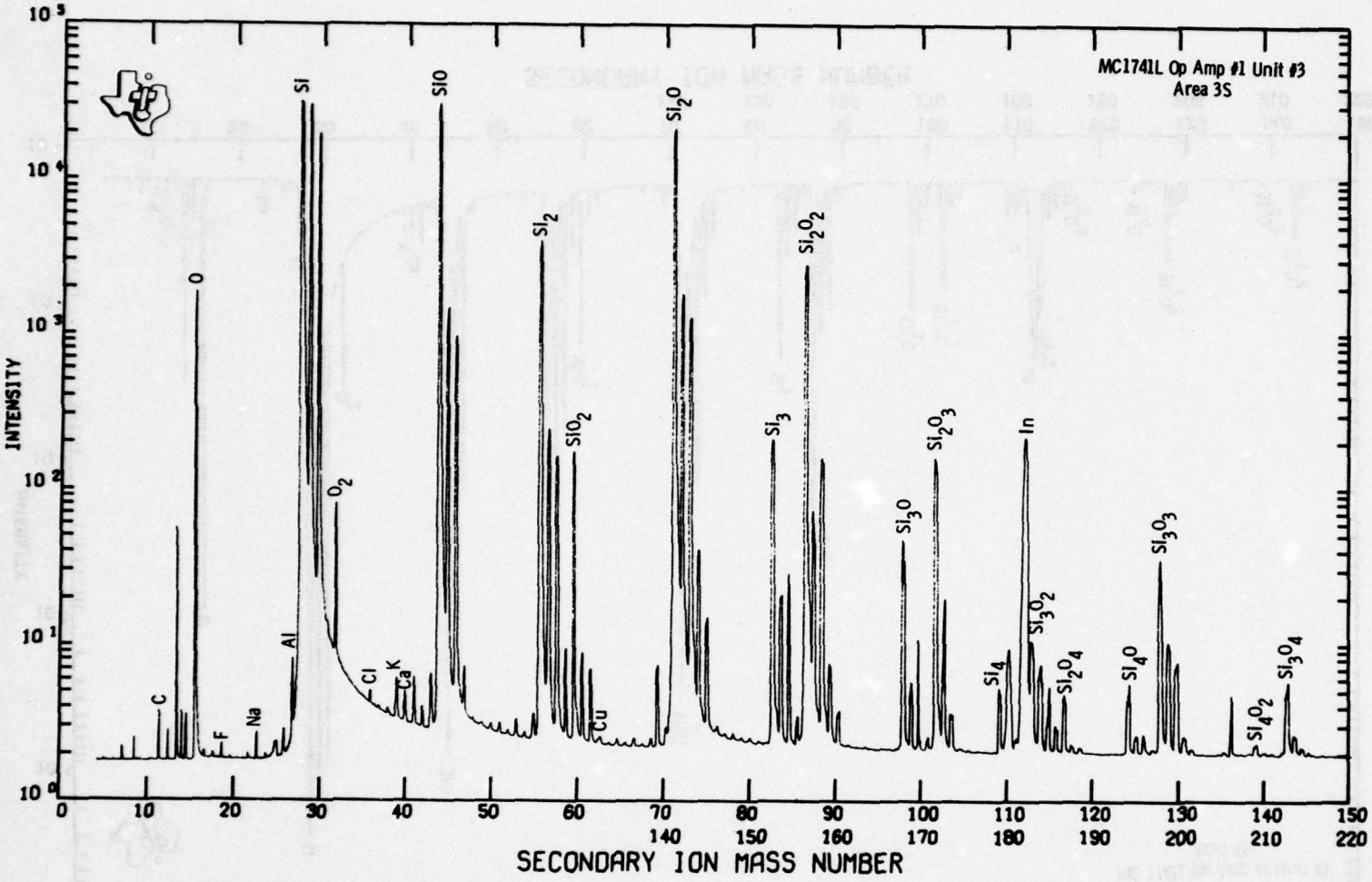
UNIT #3 . AREA 9 . SPECTRA 247-250 .

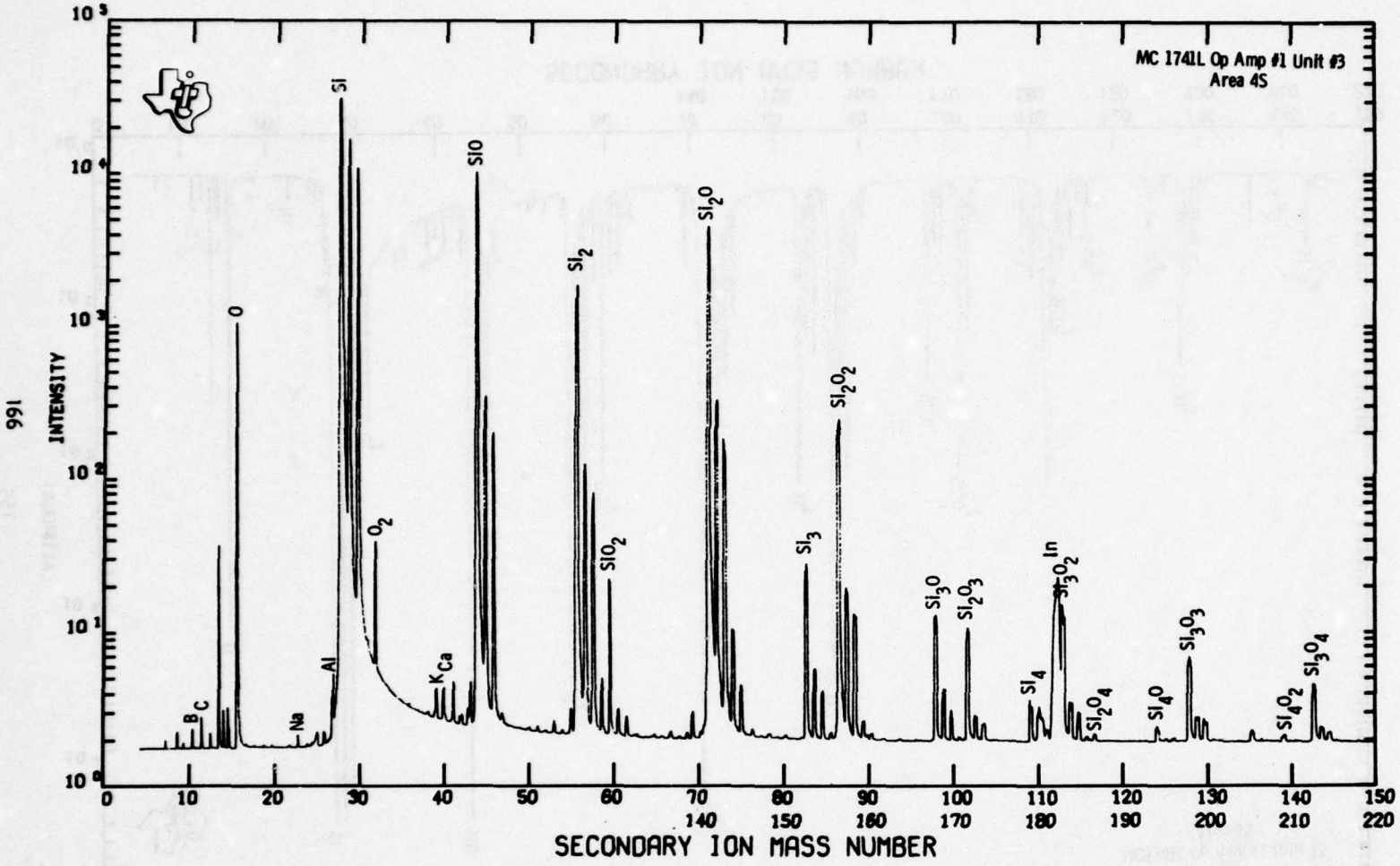
RASTER 86X59 μm . SPOT 14 μm BC 17 NA SR (Å/SEC) 1.19 .

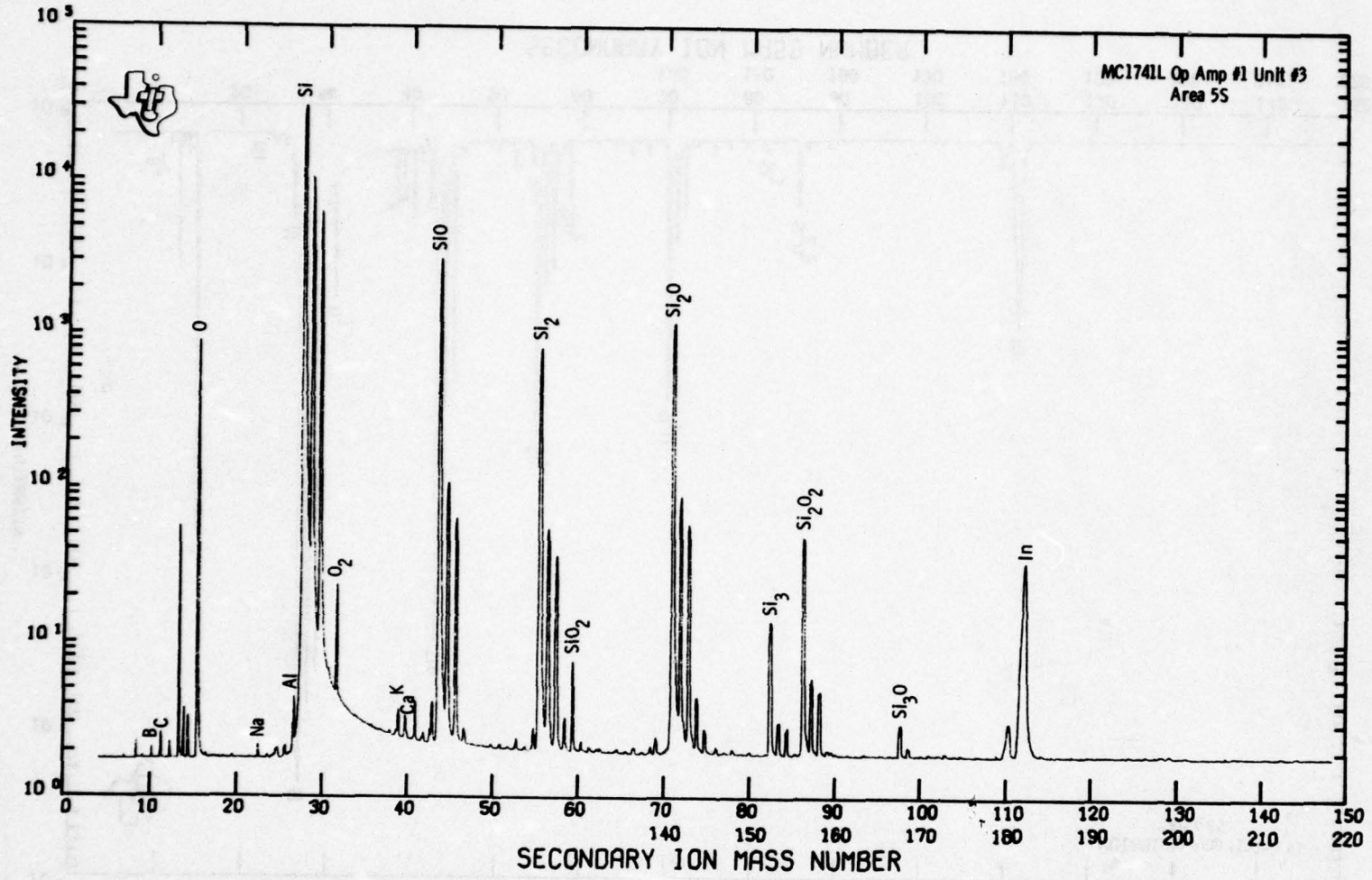
ELEM	PLUS / START	0	882	1562	2287							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	1	1							
Mg (24)	185											
Al (27)	205	926	201	355	348							
Si (30)	220	70	70	74	64							
P (31)	230	26	28	26	22							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295	1	1	1	1							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

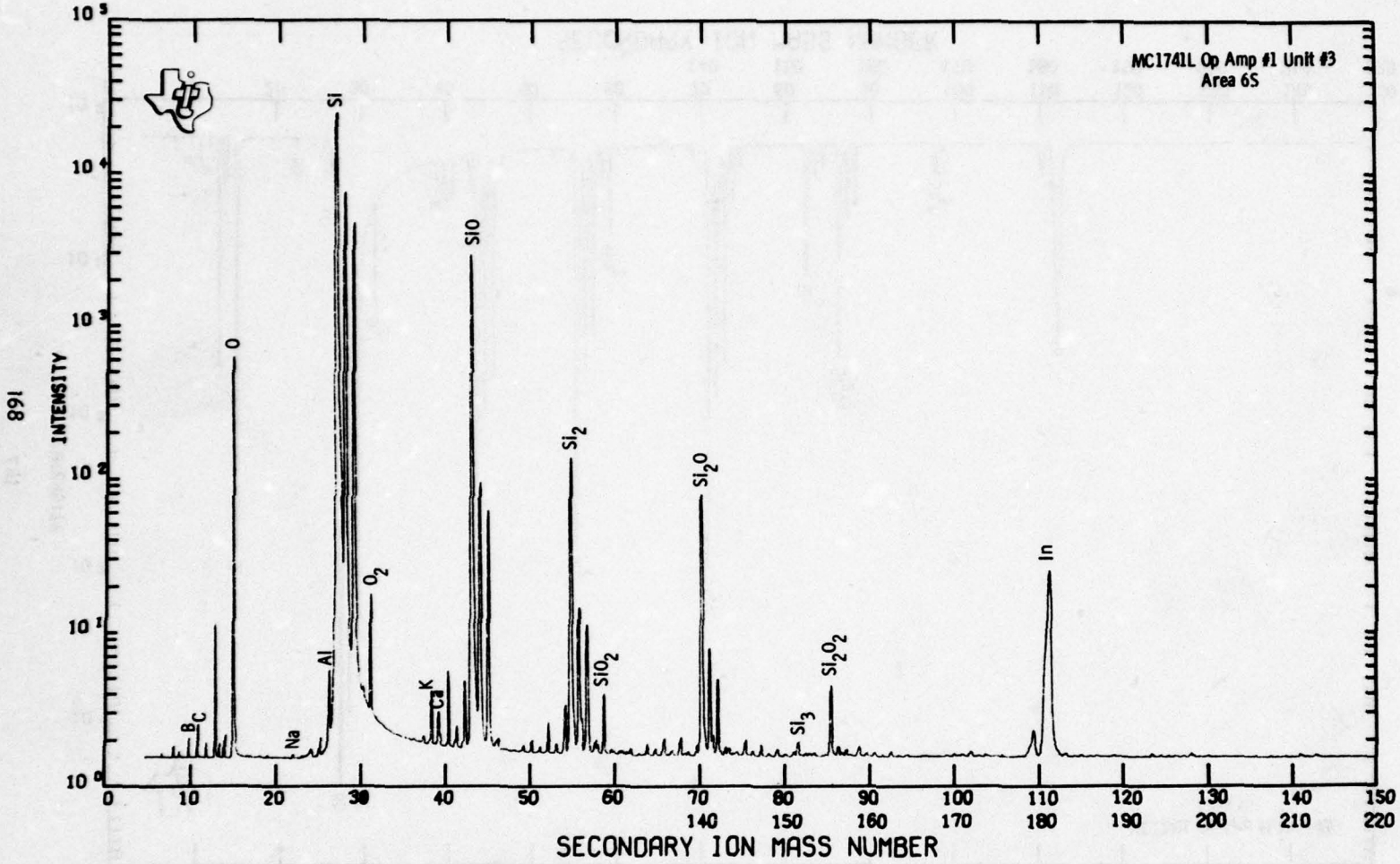

MC1741L Op Amp #1 Unit #3
Area 1S
INTENSITY
SECONDARY ION MASS NUMBER
C
O
Na
Al
Si
P
O2
K
Ca
SiO
Si2
SiO2
Si2O
Si3O4
Si3
Si2O2
Si3O
Si2O3
Si4
In
Si3O2
Si2O4
Si3O3
Si4O2
Si3O4

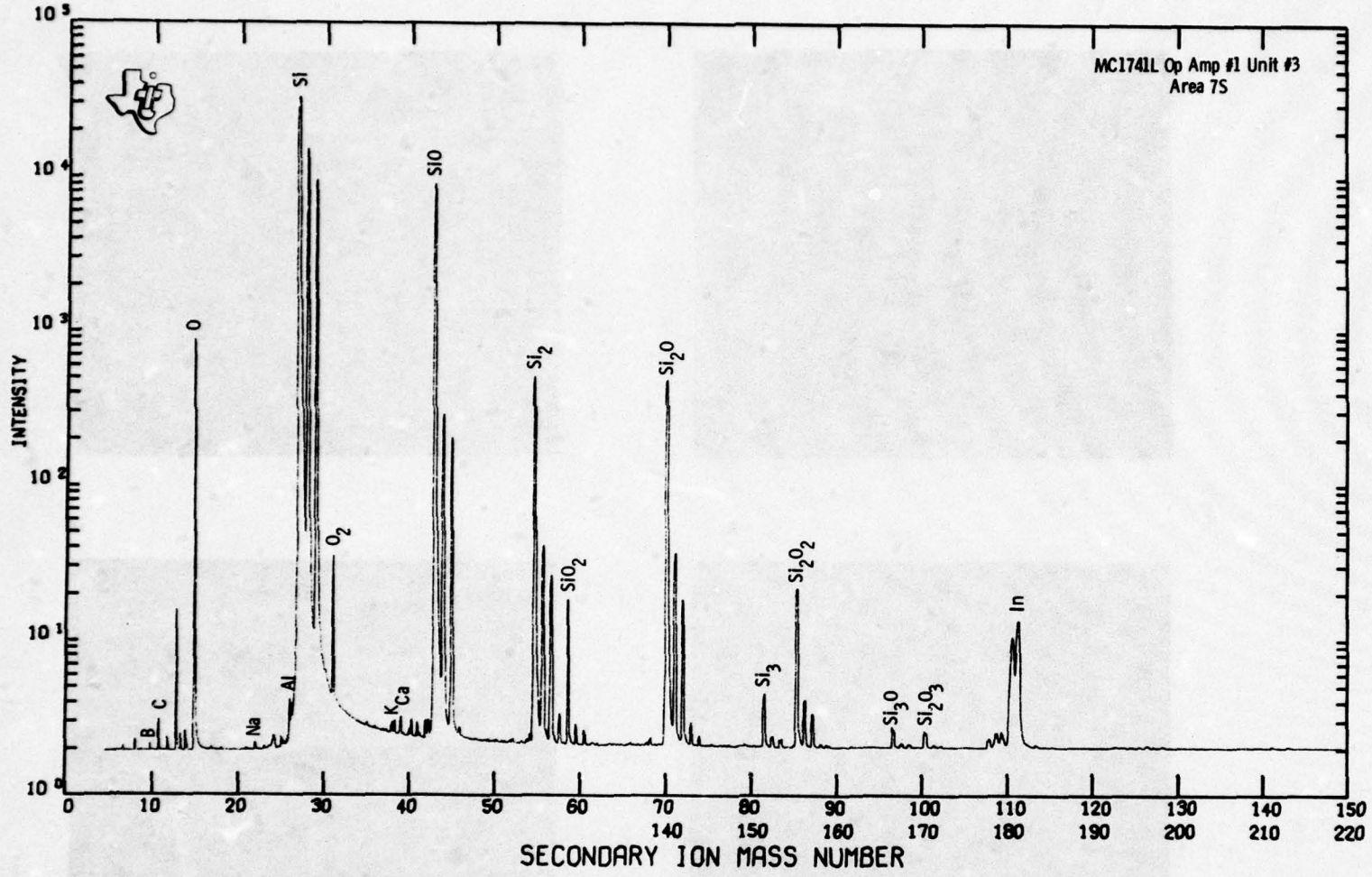

MC1741L Op Amp #1 Unit #3
Area 2S
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Al
Si
O2
K
Ka
SiO
Si2
SiO2
Si2O
Si3
Si2O2
Si3O
Si2O3
In
Si3O2
Si4
Si2O4
Si4O
Si3O3
Si4O2
Si3O4


MC1741L Op Amp #1 Unit #3
Area 3S
INTENSITY
SECONDARY ION MASS NUMBER
C
O
F
Na
Al
Si
O2
Cl
K
Ca
SiO
Si2
SiO2
Cu
Si2O
Si3
Si2O2
Si3O
Si2O3
In
Si4
Si3O2
Si2O4
Si4O
Si3O3
Si4O2
Si3O4

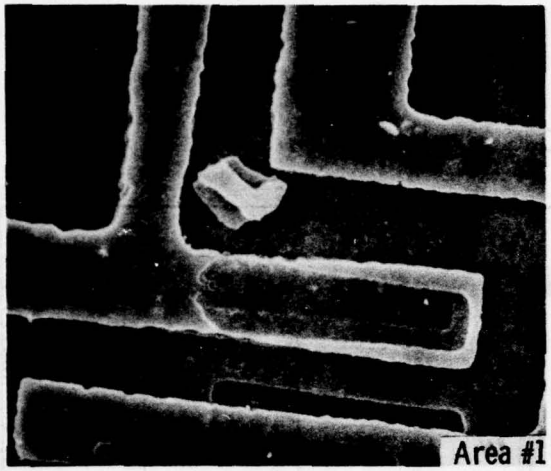

MC 1741L Op Amp #1 Unit #3
Area 4S
991
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Al
Si
O2
K
Ca
SiO
Si2
SiO2
Si2O
Si3
Si2O2
Si3O
Si2O3
In
Si3O2
Si4
Si2O4
Si4O
Si3O3
Si4O2
Si3O4


MC1741L Op Amp #1 Unit #3
Area 5S
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Al
Si
O2
K
Ca
SiO
Si2
SiO2
Si2O
Si3
Si2O2
Si3O
In


MC1741L Op Amp #1 Unit #3
Area 6S
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Al
Si
O2
K
Ca
SiO
Si2
SiO2
Si2O
Si3
Si2O2
In


MC1741L Op Amp #1 Unit #3
Area 7S
INTENSITY
SECONDARY ION MASS NUMBER
B
C
O
Na
Al
Si
O_2
K
Ca
SiO
Si_2
SiO_2
Si_2O
Si_3
Si_2O_2
Si_3O
Si_2O_3
In

MC1741L Op Amp #1 Unit #3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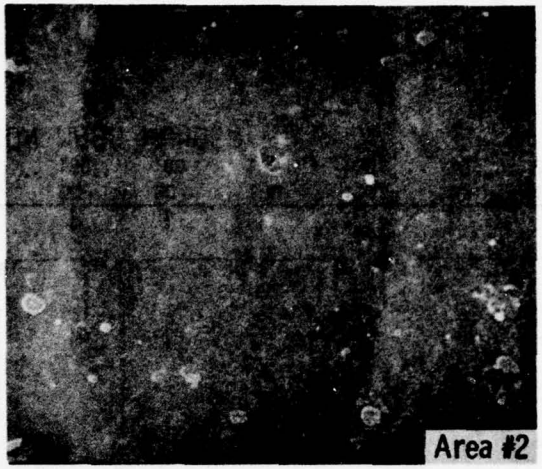
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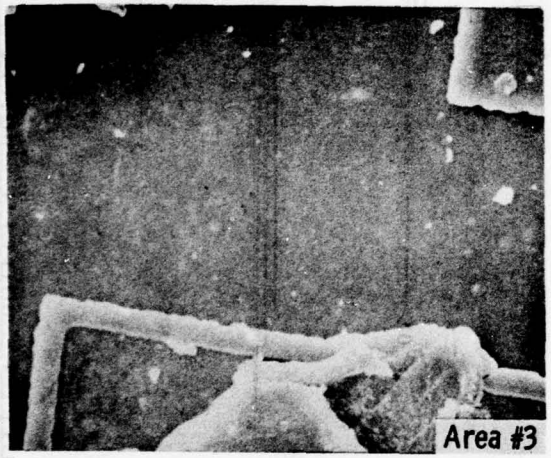
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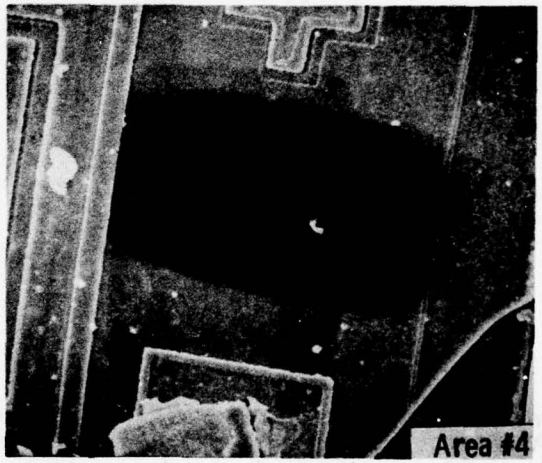
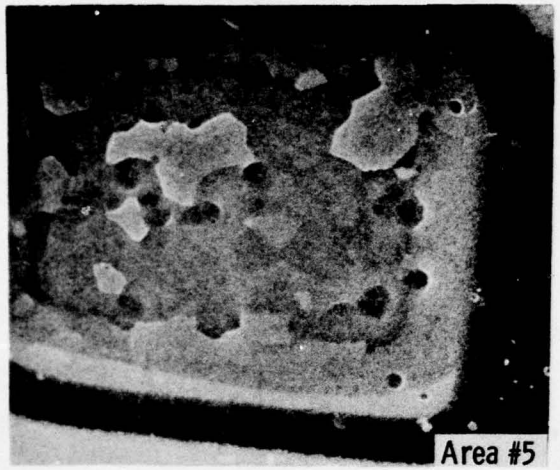
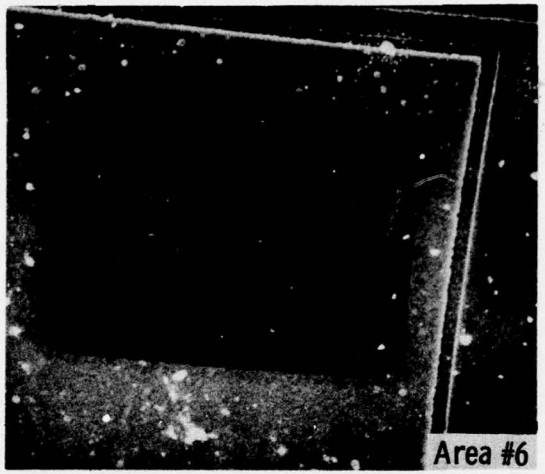
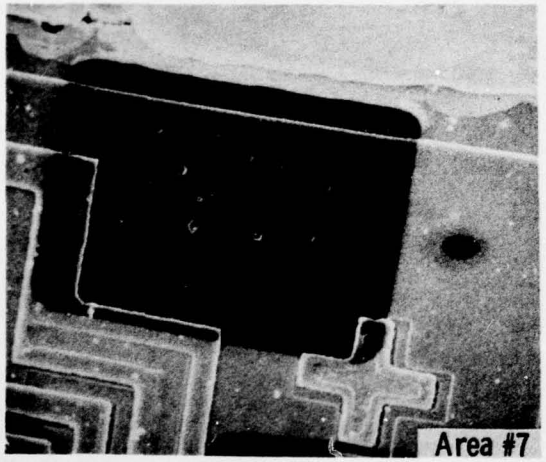
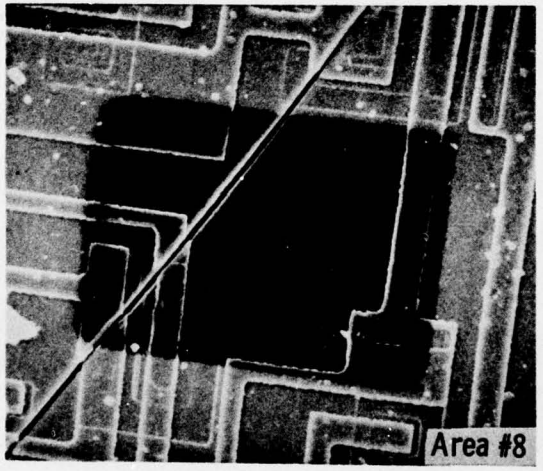

Area #4

MC1741L Op Amp #1 Unit #3









Op Amp #2, Unit #62

Area 1: Mass Spectra Depth Profile

Area 2: Mass Spectra Depth Profile

Area 3: Mass Spectra Depth Profile

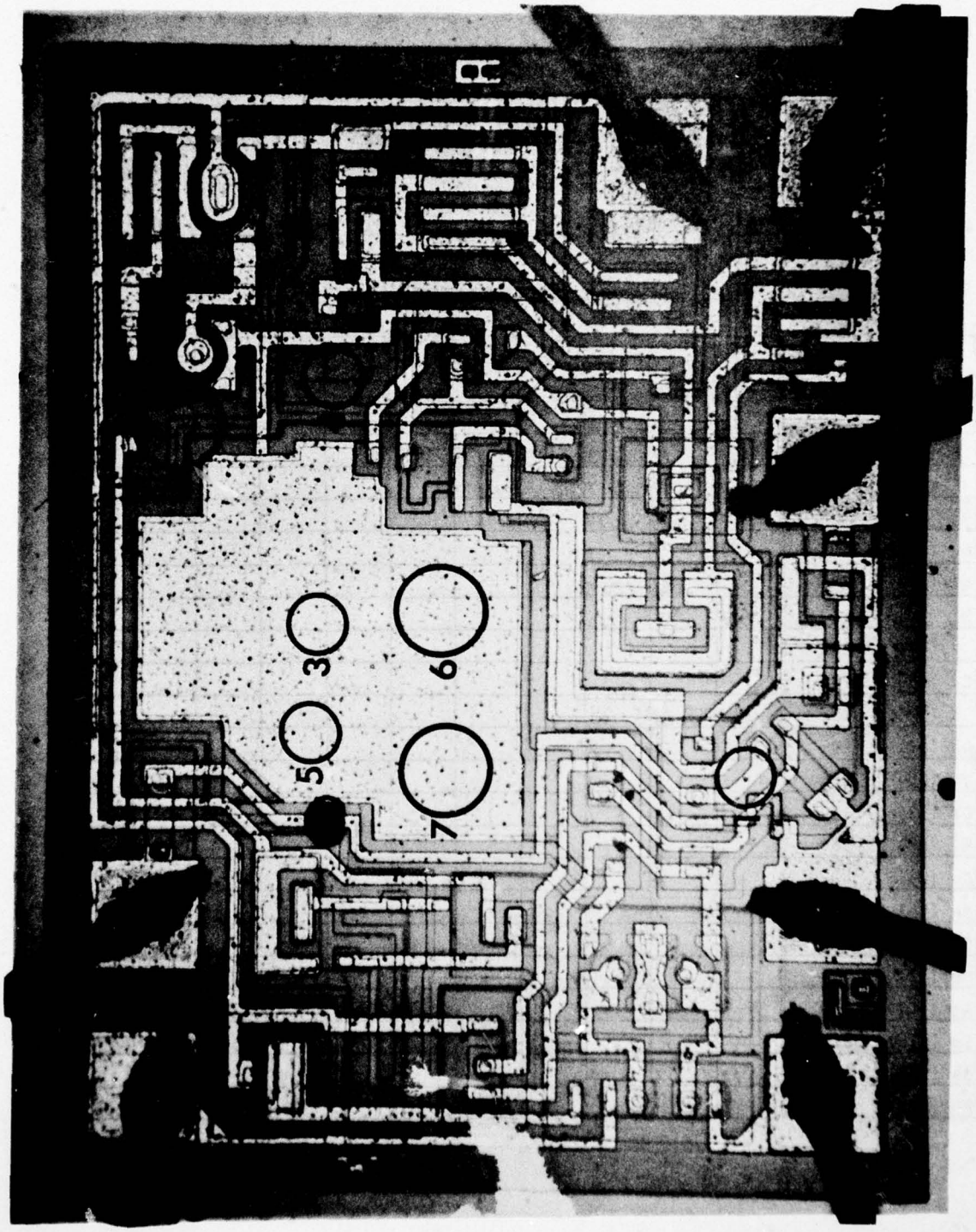
Area 4: P Peak Count Profile

Area 5: Ar Sputter Time Through Glassivation

Area 6: False Start

Area 7: Interface Analysis, Glassivation-Aluminum Layers

Area 8: Interface Analysis, Glassivation-Oxide Layers



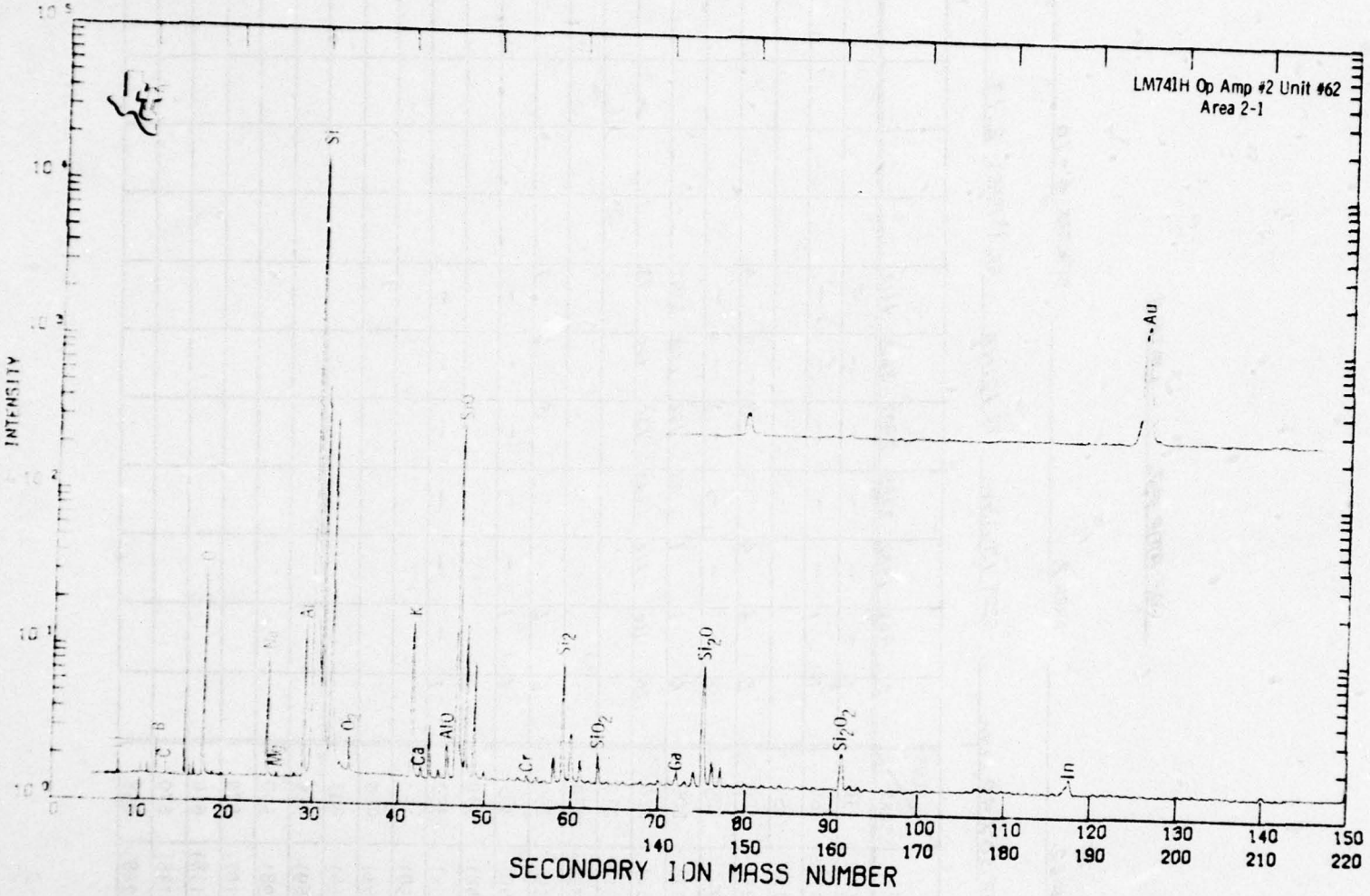
Set 1 Op Amp #2 Unit #62

OP AMP #2 LM741H

UNIT #62 . AREA 1 . SPECTRA 1-3 .

RASTER 50 x 40 μm . SPOT 26 μm BC 16 NA SR (Å/SEC) 2.84 .

ELEM	PLUS / START	0	1800	3400								
Li (7)	30	16	11	8								
B (11)	60	33	20	13								
F (19)	150	1	1	1								
Na (23)	180	47	29	19								
Mg (24)	185	1	1	1								
Al (27)	205	90	390	2325								
Si (30)	220	210	170	130								
P (31)	230											
Cl (35)	250											
K (39)	290	133	64	43								
Ca (40)	295	5	3	2								
Ti (48)	330	1	1	1								
Cr (52)	350	1	1	1								
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670	12	6	4								
Pb (208)	858											



OP AMP #2 LM741H

UNIT #62 . AREA 2 . SPECTRA 4-10 .

RASTER 50 x 40 μm . SPOT 13 μm BC 12 NA SR (Å/SEC) 2.13 .

ELEM	START \ PLUS	0	906	1582	2295	2997	3663	4412				
Li (7)	30	1	–	–	–	–	–	–				
B (11)	60	1	1	–	–	–	–	–				
F (19)	150											
Na (23)	180	3	4	4	3	3	3	4				
Mg (24)	185	1	–	–	–	–	–	–				
Al (27)	205	6	1	1	21	162	1312	2197				
Si (30)	220	120	110	110	140	130	100	92				
P (31)	230											
Cl (35)	250											
K (39)	290	6	6	7	5	5	6	7				
Ca (40)	295	1	1	–	–	–	–	–				
Ti (48)	330											
Cr (52)	350	1	–	–	–	–	–	–				
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP # 2 LM741H

UNIT #62 . AREA 3 . SPECTRA 21-27 .

RASTER 50 X 40 μm . SPOT 17μm BC 2BNA SR (Å/SEC) 4.97 .

ELEM	PLUS / START	0	716	1421	2124	2822	3592	4303				
Li (7)	30	1	1	1	1	1	1	1				
B (11)	60	1	1	1	1	1	1	1				
F (19)	150											
Na (23)	180	3	3	3	3	3	3	3				
Mg (24)	185	1	-	-	-	-	-	-				
Al (27)	205	6	3	3	19	14	2	1				
Si (30)	220	240	230	220	180	160	150	140				
P (31)	230											
Cl (35)	250											
K (39)	290	6	6	5	6	5	7	6				
Ca (40)	295	1	1	1	1	1	-	-				
Ti (48)	330											
Cr (52)	350	1	-	-	-	-	-	-				
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670	1	1	1	1	-	1	1				
Pb (208)	858											

OP AMP #2 LM741H

UNIT #62 . AREA 7 . SPECTRA 308-318 .

RASTER 92 x 68 μm . SPOT 14 μm BC 6 NA SR (Å/SEC) .34 .

ELEM	PLUS / START	0	907	1594	2285	2976	3668	4359	5045	5738	6424	7112
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	1	1	1	1	1	1	1	1	1
Mg (24)	185											
Al (27)	205	42	54	63	65	85	96	104	137	122	164	209
Si (30)	220	94	96	92	92	92	92	90	88	90	86	82
P (31)	230	1	1	1	–	–	–	–	–	–	–	–
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	1	–	–	–	–	–	–	–	–	–	–
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #2 LM741H

UNIT #62. AREA 7. SPECTRA 319-324.

RASTER 92X68 μm. SPOT 14μm BC 6 NA SR (Å/SEC) .34.

ELEM	PLUS / START	7799	8517	9218	9906	10595	11286					
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	1	1	1	1					
Mg (24)	185											
Al (27)	205	212	252	258	308	556	880					
Si (30)	220	90	84	78	72	62	60					
P (31)	230	–	–	–	–	–	–					
Cl (35)	250											
K (39)	290	1	1	1	1	1	1					
Ca (40)	295	–	–	–	–	–	–					
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #2 LM741H

UNIT #62 . AREA B . SPECTRA 292-302 .

RASTER 92X68 . SPOT 14μ BC 6 NA SR (Å/SEC) .34 .

ELEM	START \ PLUS	0	901	1591	2245	2935	3626	4315	5005	5698	6496	7187
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	1	1	1	1	1	1	1	1	1
Mg (24)	185											
Al (27)	205	286	408	454	596	570	556	467	596	612	825	752
Si (30)	220	88	84	80	78	78	80	80	78	76	76	78
P (31)	230	1	1	1	1	1	1	1	1	1	-	-
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	1	-	-	-	-	-	-	-	-	-	-
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1	1	1	1	1	1	1	1	1
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

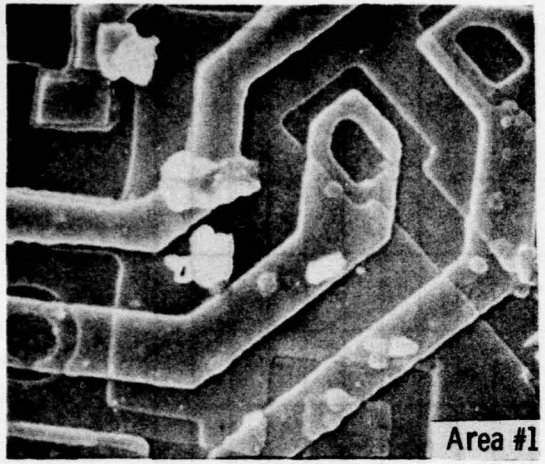
OP AMP #2 LM741H

UNIT #62 . AREA 8 . SPECTRA 303 - 307 .

RASTER 92 X 68 μm . SPOT 14 μm BC 6 NA SR (Å/SEC) .34 .

ELEM	PLUS / START	7883	8579	9272	9974	10673						
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	1	1	1	1	1						
Mg (24)	185											
Al (27)	205	682	852	799	852	821						
Si (30)	220	80	76	76	76	74						
P (31)	230	–	–	–	–	–						
Cl (35)	250											
K (39)	290	1	1	1	1	1						
Ca (40)	295	–	–	–	–	–						
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570	1	1	1	1	1						
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

LM741H Op Amp #2 Unit #62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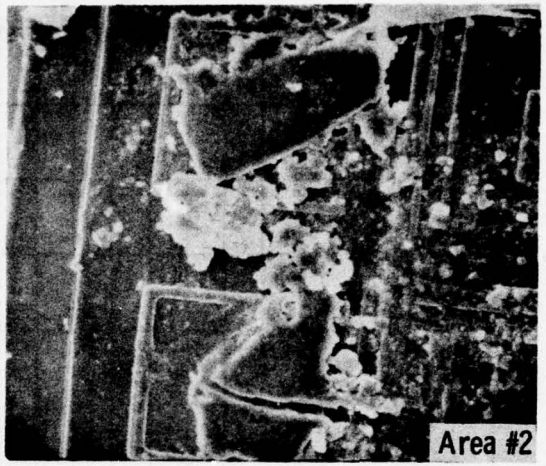
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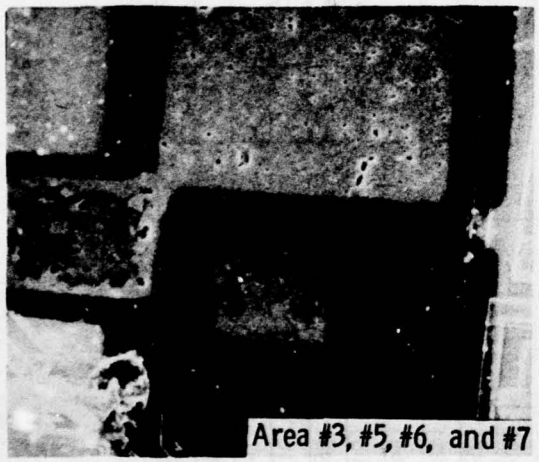
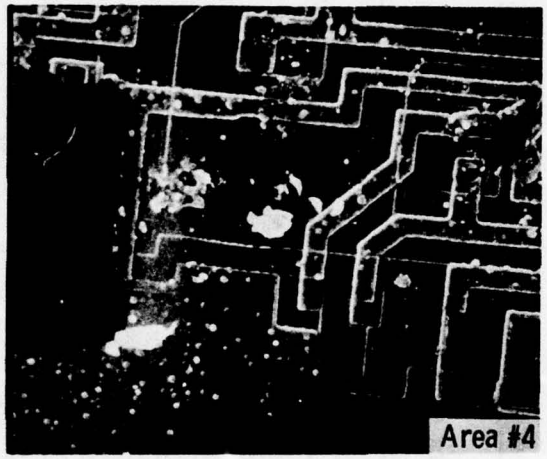

Area #3, #5, #6, and #7


Area #4

Op Amp #3, Unit #13

Area 1: Mass Spectra Depth Profile

Area 2: Mass Spectra Depth Profile

Area 3: Mass Spectra Depth Profile

Area 4: P Peak Count Profile Over Aluminum

Area 5: P Peak Count Profile Over Oxide (not included)

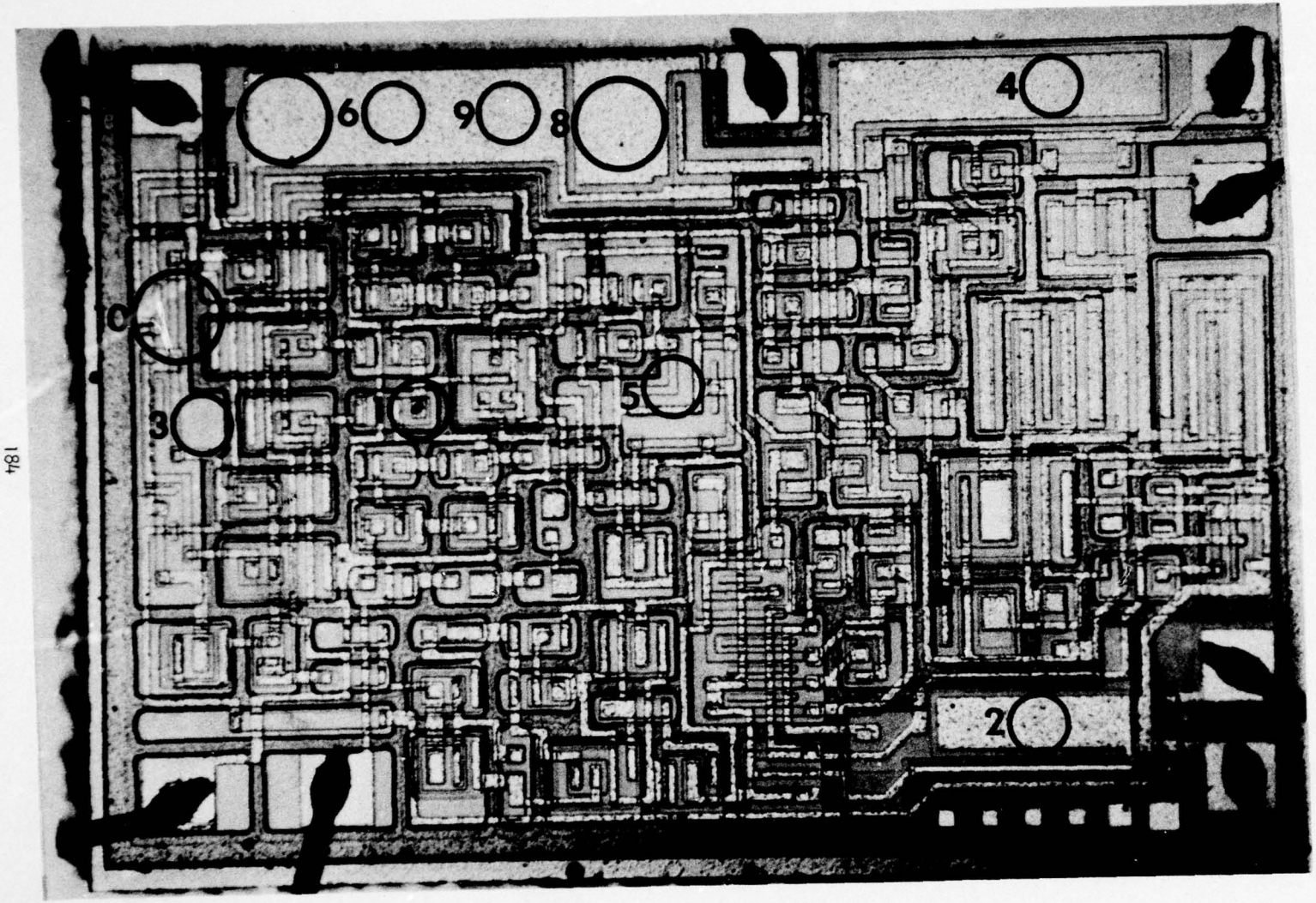
Area 6: Ar Sputter Time Through Glassivation

Area 7: Interface Analysis, Glassivation-Aluminum Layers

Area 8: False Start

Area 9: False Start

Area 10: Interface Analysis, Glassivation-Oxide Layers



Set 1 Op Amp #3 Unit #13

OP AMP #3 HA2600-02

UNIT #13 . AREA 1 . SPECTRA 28-31 .

RASTER 50 X 40 μm . SPOT 10 μm BC 10NA SR (Å/SEC) 1.78 .

ELEM	START \ PLUS	0	2660	4460	6260							
Li (7)	30											
B (11)	60	1	1	1	1							
F (19)	150											
Na (23)	180	461	14	27	2							
Mg (24)	185	19	1	1	1							
Al (27)	205	17	2	504	1926							
Si (30)	220	29	130	100	110							
P (31)	230	5	19	27	27							
Cl (35)	250											
K (39)	290	211	9	12	1							
Ca (40)	295	46	9	4	1							
Ti (48)	330	1	1	1	-							
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	1	1	1	-							
Zn (64)	403	1	1	1	-							
Ga (69)	425	1	1	1	-							
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

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MICROBEAM ANALYSIS TECHNIQUES FOR ICS.(U)
OCT 77 G B LARRABEE, R D DOBROTT F30602-76-C-0316
UNCLASSIFIED TI-08-77-16 RADC-TR-77-339 NL

3 OF 3
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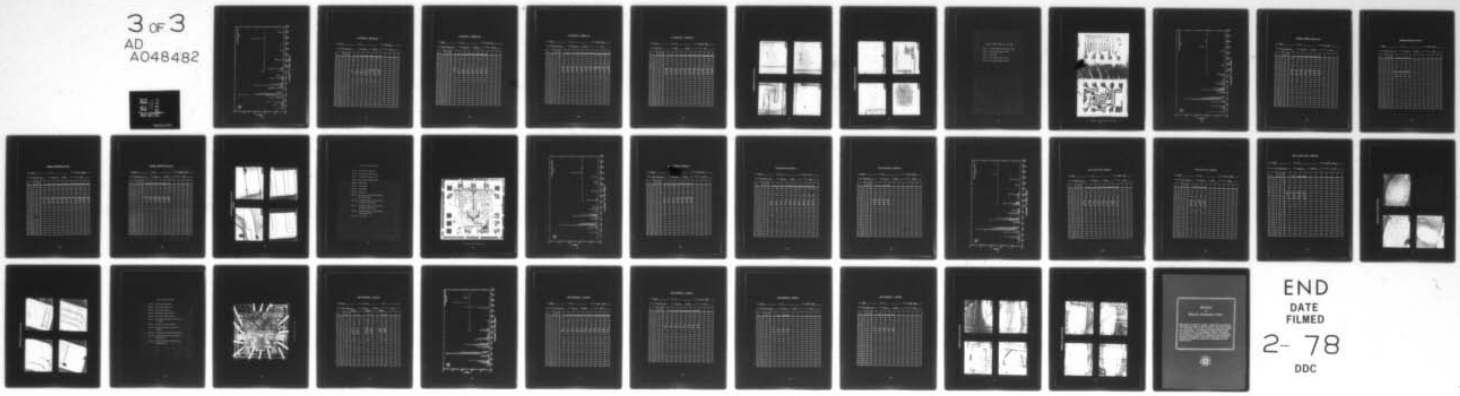
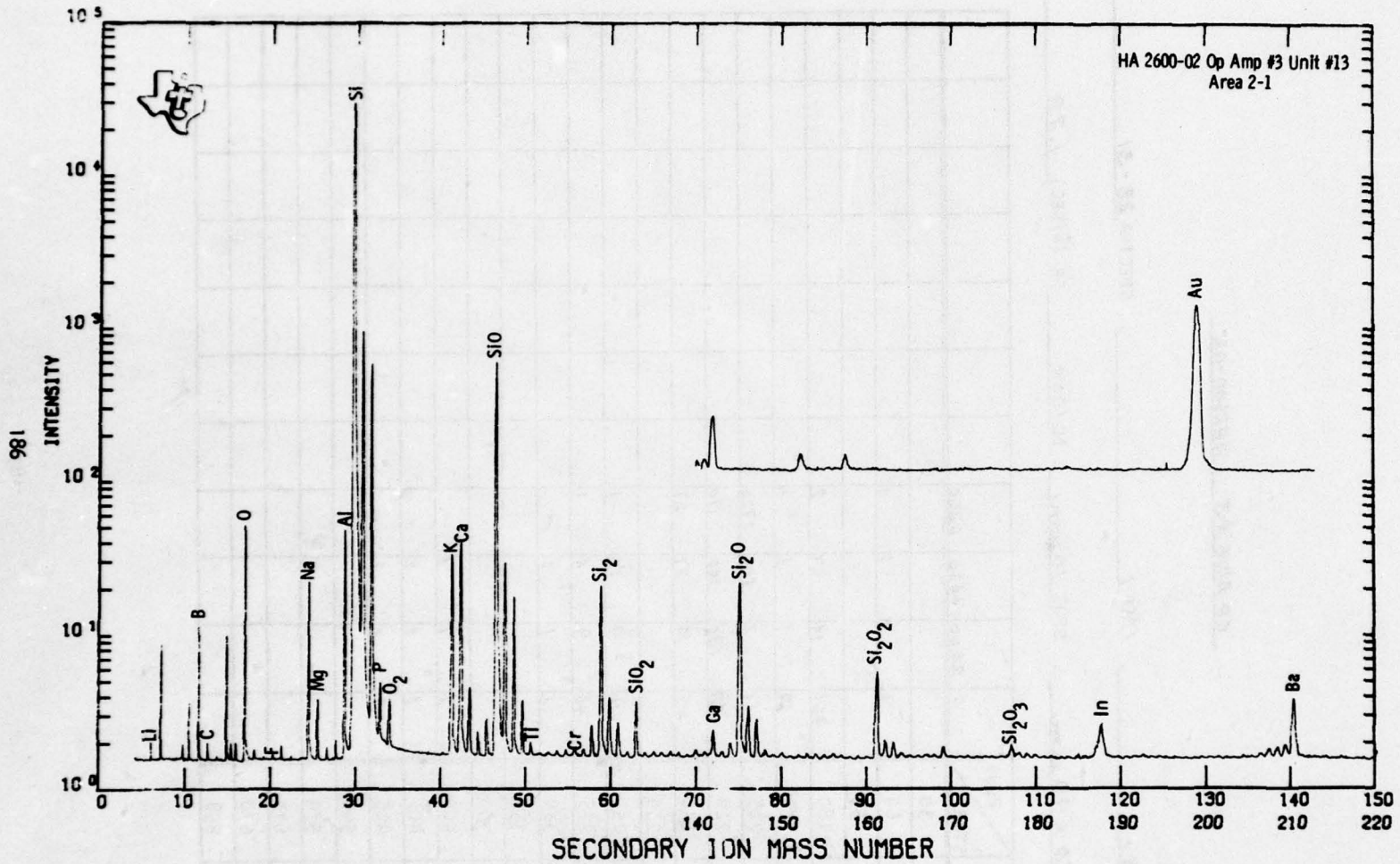


END
DATE
FILMED
2-78
DDC


HA 2600-02 Op Amp #3 Unit #13
Area 2-1
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
Na
Mg
Al
Si
P
O_2
K
Ca
SiO
Ti
Cr
Si_2
SiO_2
Ga
Si_2O
Si_2O_2
Si_2O_3
In
Au
Ba

OP AMP#3 HA2600-02

UNIT #13 . AREA 2 . SPECTRA 38-32 .

RASTER 50 x 40 μm . SPOT 12 μm BC 1BNA SR (Å/SEC) 3.20 .

ELEM	START \ PLUS	0	907	1829	2752	3668	4591	5462				
Li (7)	30	2	1	1	1	1	1	1				
B (11)	60	2	1	1	1	1	1	1				
F (19)	150											
Na (23)	180	5	2	1	2	1	2	2				
Mg (24)	185	1	1	1	1	1	1	1				
Al (27)	205	11	4	4	64	1608	3489	5426				
Si (30)	220	210	280	260	250	200	150	130				
P (31)	230	1	20	27	24	25	25	23				
Cl (35)	250											
K (39)	290	7	4	2	2	3	4	4				
Ca (40)	295	9	13	10	9	9	9	7				
Ti (48)	330	1	1	–	–	–	–	–				
Cr (52)	350	1	1	–	–	–	–	–				
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425	1	1	1	1	1	1	1				
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670	1	1	1	1	1	1	1				
Pb (208)	858											

OP AMP #3 HA2600-02

UNIT #13 . AREA 3 . SPECTRA 39-46 .

RASTER 50 X 40 μm . SPOT 18 μm BC 1.8 NA SR (Å/SEC) 3.20 .

ELEM	PLUS / START	0	920	1837	2752	3670	4582	5493	6198			
Li (7)	30											
B (11)	60	1	–	–	–	1	1	–	1			
F (19)	150											
Na (23)	180	1	1	1	1	1	1	1	1			
Mg (24)	185	1	1	1	–	–	–	–	–			
Al (27)	205	2	1	1	1	2	7	4	19			
Si (30)	220	190	170	150	160	140	130	260	160			
P (31)	230	1	22	29	28	32	30	25	23			
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1			
Ca (40)	295	1	1	1	1	1	–	–	–			
Ti (48)	330	1	–	–	–	–	–	–	–			
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

OP AMP #3 HA2600-02

UNIT #13 . AREA 7 . SPECTRA 325 - 335 .

RASTER 83 x 69 μm . SPOT 24 μm BC 10 NA SR (Å/SEC) .62 .

ELEM	PLUS / START	0	883	1570	2254	2931	3639	4324	5004	5690	6378	7054
Li (7)	30											
B (11)	60											
F (19)	150	1	–	–	–	–	–	–	–	–	–	–
Na (23)	180	1	1	1	1	1	1	1	1	1	1	1
Mg (24)	185	1	–	–	–	–	–	–	–	–	–	–
Al (27)	205	254	369	386	497	700	764	996	1829	3661	5707	7492
Si (30)	220	40	36	37	31	28	29	28	25	19	15	15
P (31)	230	28	29	24	17	12	9	7	7	7	9	8
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	1	1	1	1	1	1	–	–	–	–	–
Ti (48)	330											
Cr (52)	350	1	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

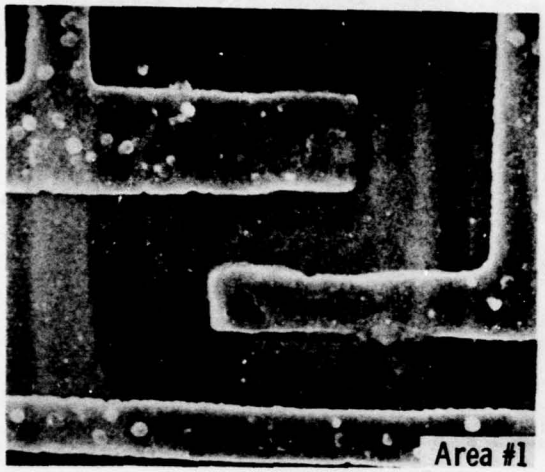
OP AMP #3 HA2600-02

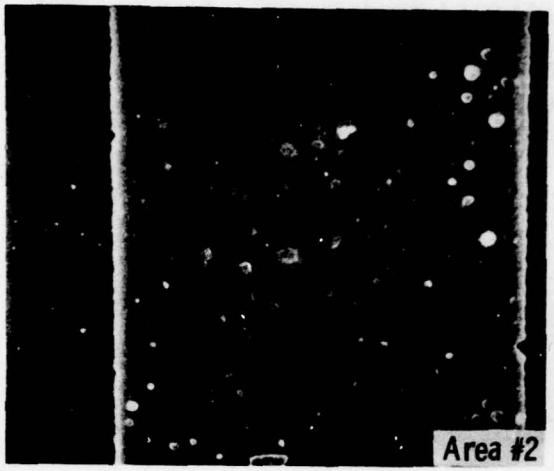
UNIT #13 . AREA 10 . SPECTRA 337-347 .

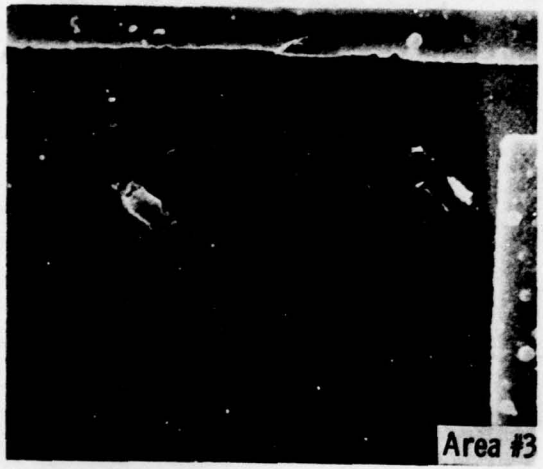
RASTER 72 x 49 . SPOT 19μ BC 5 NA SR (Å/SEC) .50 .

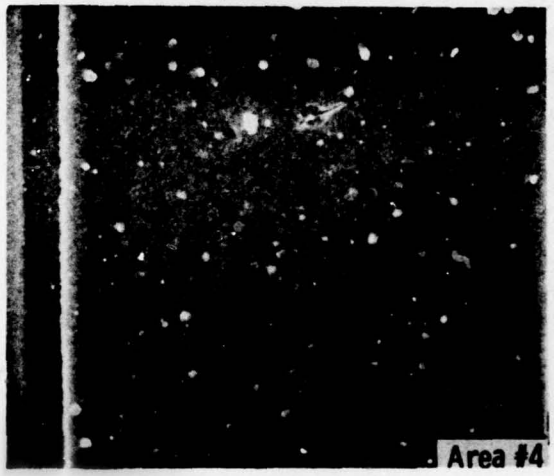
ELEM	START \ PLUS	0	893	1577	2261	2966	3724	4414	5105	5797	6488	7209
Li (7)	30											
B (11)	60	1	1	1	1	1	1	1	1	1	1	1
F (19)	150											
Na (23)	180	1	1	1	1	1	1	1	1	1	1	1
Mg (24)	185						1	1	1	1	—	—
Al (27)	205	858	973	1067	1315	1382	1457	1442	1442	1426	1085	938
Si (30)	220	44	42	44	42	40	38	37	37	36	35	35
P (31)	230	53	61	60	61	62	62	58	56	49	56	47
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	—	—	—
Ca (40)	295											
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

HA2600-02 Op Amp #3 Unit #13





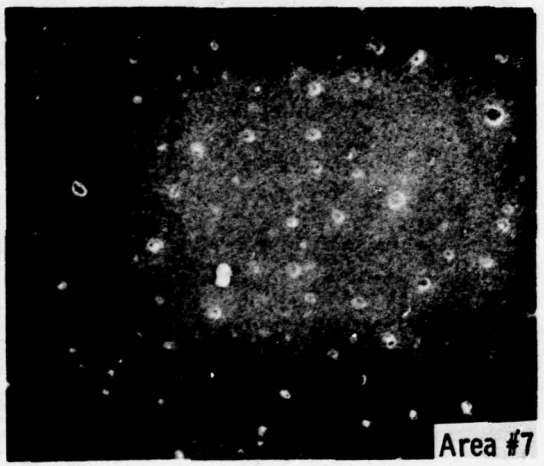


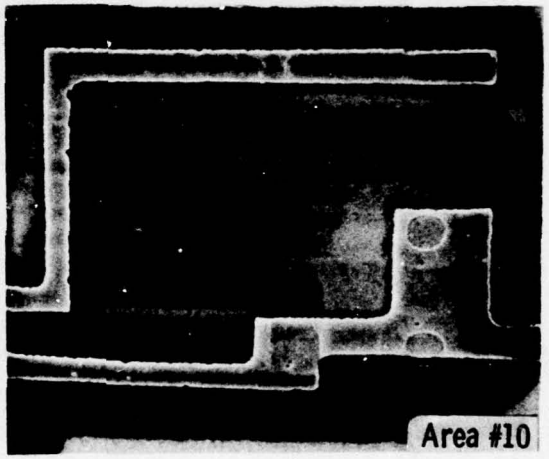


HA2600-02 Op Amp #3 Unit #13


Area #5


Area #6


Area #7


Area #10

General Purpose Amplifier, Unit #64

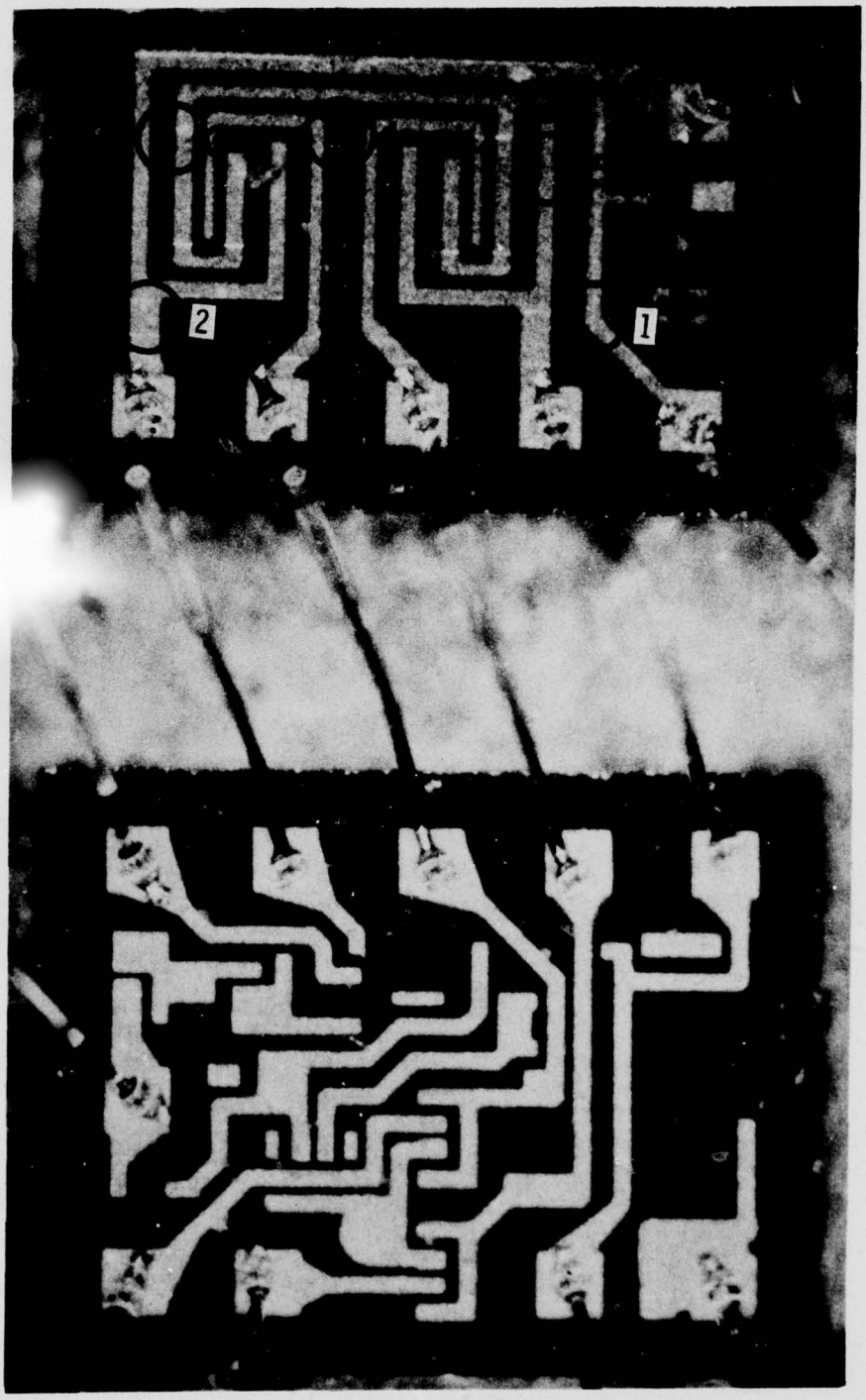
Area 1: Surface Mass Spectrum-line crater

Area 2: Mass Spectra Depth Profile

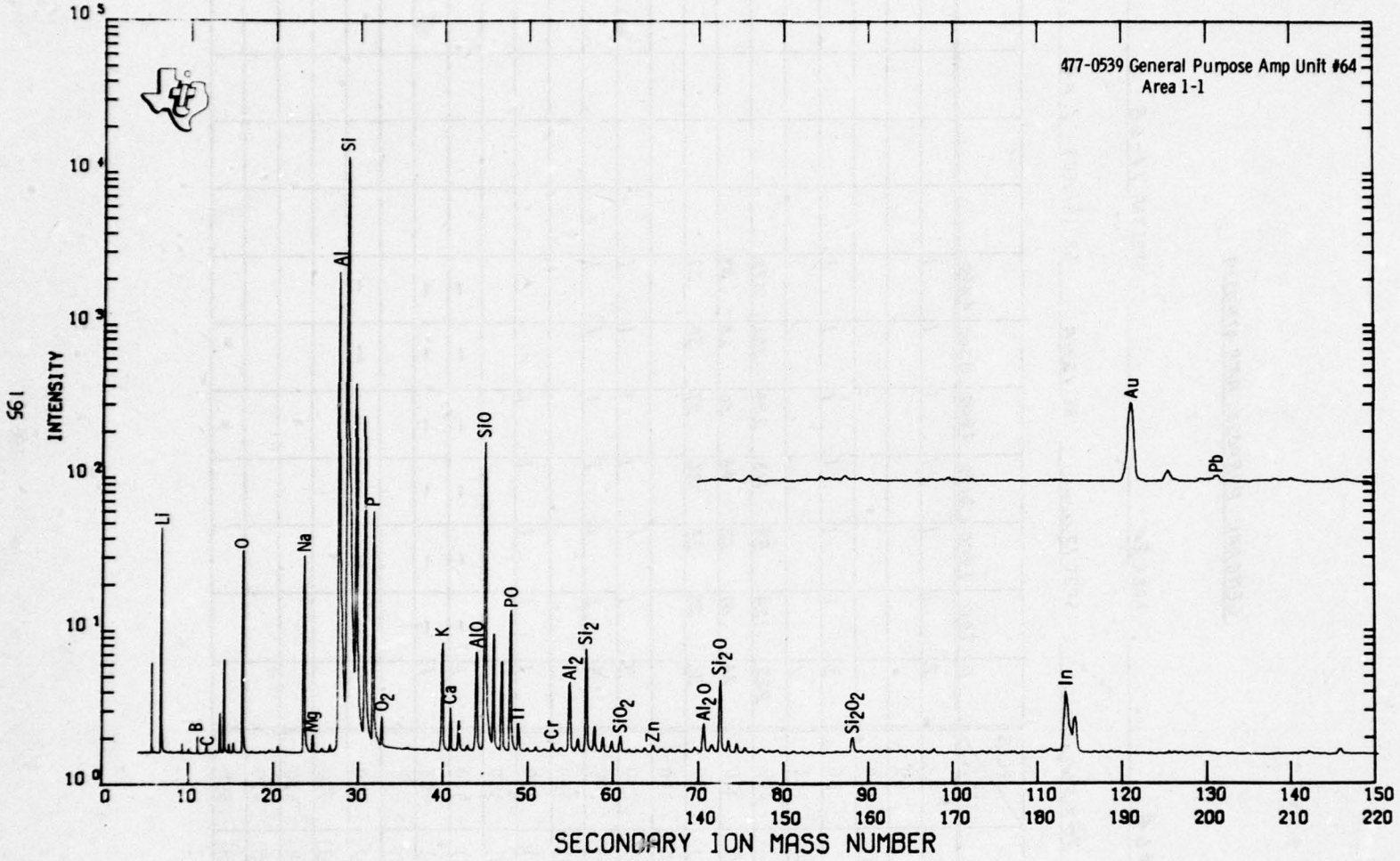
Area 3: False Start

Area 4: Mass Spectra Depth Profile

Area 5: Mass Spectra Depth Profile



Set 1 General Purpose Amplifier Unit #64


477-0539 General Purpose Amp Unit #64
Area 1-1
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
Na
Mg
Al
Si
P
O2
K
Ca
AlO
SiO
PO
Ti
Cr
Al2
Si2
SiO2
Zn
Al2O
Si2O
Si2O2
Au
Pb
In

GENERAL PURPOSE AMP 477-0539

UNIT #64 . AREA 2 . SPECTRA 74-68 .

RASTER 70 X 56 μm . SPOT 17 μm BC 12NA SR (Å/SEC) 1.09 .

ELEM	PLUS / START	0	700	1400	2100	2800	3500	4200				
Li (7)	30	2	1	1	1	1	1	1				
B (11)	60											
F (19)	150											
Na (23)	180	3	1	1	1	1	1	1				
Mg (24)	185	1										
Al (27)	205	222	124	89	115	284	322	372				
Si (30)	220	24	47	58	48	50	28	35				
P (31)	230	36	28	25	26	27	30	27				
Cl (35)	250											
K (39)	290	3	1	1	1	1	1	1				
Ca (40)	295	3	1	1	1	1	1	1				
Ti (48)	330											
Cr (52)	350	1	1	1	1	1	-	-				
Ni (58)	380											
Cu (63)	400	1	-	-	-	-	-	-				
Zn (64)	403	1	-	-	-	-	-	-				
Ga (69)	425											
Mo (98)	540	1	-	-	-	-	-	-				
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

GENERAL PURPOSE AMP 477-0539

UNIT #64 . AREA 4 . SPECTRA 271 - 274 .

RASTER 75 X 65 μm . SPOT 13 μm BC 5NA SR (Å/SEC) .36 .

ELEM	PLUS / START	0	685	1369	2117							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	3	1	1	1							
Mg (24)	185											
Al (27)	205	3990	3990	3890	3990							
Si (30)	220	11	11	11	11							
P (31)	230	28	28	27	24							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295											
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

GENERAL PURPOSE AMP 477-0539

UNIT #64 . AREA 5 . SPECTRA 275 - 285 .

RASTER 75 X 65 μm . SPOT 13 μm BC 5NA SR (Å/SEC) .36 .

ELEM	PLUS / START	0	685	1379	2063	2759	3444	4127	4810	5497	6180	6972
Li (7)	30											
B (11)	60	3	2	2	2	2	2	2	2	2	1	1
F (19)	150											
Na (23)	180	2	1	1	1	1	1	1	1	–	–	–
Mg (24)	185											
Al (27)	205	3718	3809	3809	3809	3990	4390	4990	5390	5989	6500	6738
Si (30)	220	12	12	12	12	12	11	11	11	10	9.6	9
P (31)	230	24	29	25	25	20	22	20	18	18	16	14
Cl (35)	250											
K (39)	290	1	–	–	–	–	–	–	–	–	–	–
Ca (40)	295	1	1	1	1	1	1	1	1	–	–	–
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

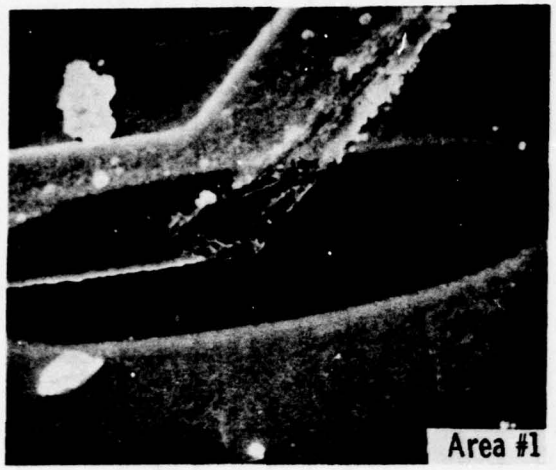
GENERAL PURPOSE AMP 477-0539

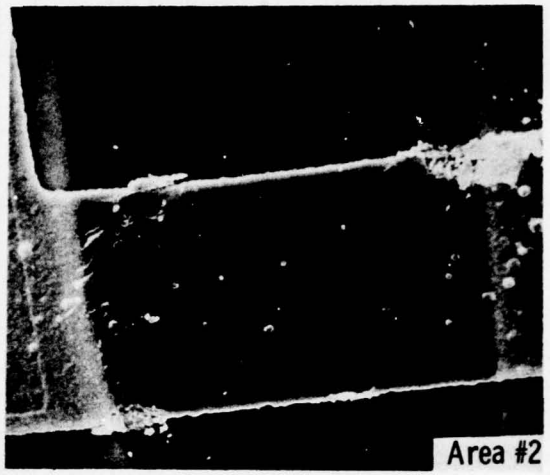
UNIT #64 . AREA 5 . SPECTRA 286 - 291 .

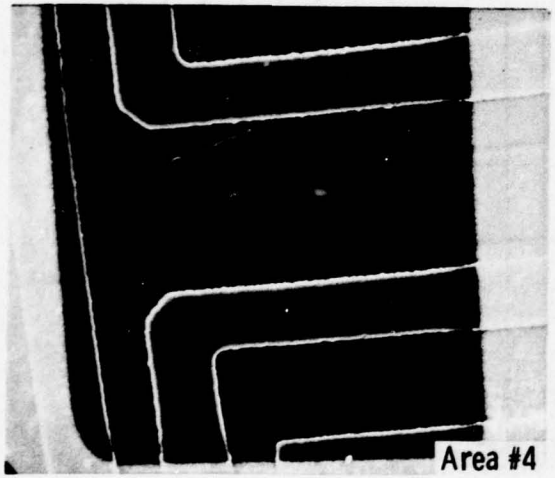
RASTER 75 X 65 μm . SPOT 13 μm BC 5NA SR (Å/SEC) .36 .

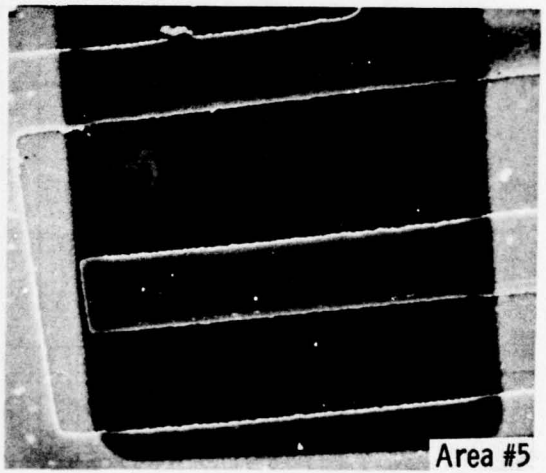
ELEM	PLUS / START	7788	8470	9169	9851	10535	11217					
Li (7)	30											
B (11)	60	1	1	1	1	1	1					
F (19)	150											
Na (23)	180	–	–	–	–	–	–					
Mg (24)	185											
Al (27)	205	7238	7554	7423	8365	8319	8192					
Si (30)	220	9	8.4	8.8	8.4	8.2	8.8					
P (31)	230	13	11	10	8	8	8					
Cl (35)	250											
K (39)	290	–	–	–	–	–	–					
Ca (40)	295	–	–	–	–	–	–					
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

477-0539 General Purpose Amp
Unit #64


Area #1


Area #2


Area #4


Area #5

ECL D Flip Flop, Unit #21

Area 1: Surface Mass Spectrum

Area 2: Mass Spectra Depth Profile

Area 3: P Peak Count Depth Profile

Area 4: Mass Spectra Depth Profile

Area 5: False Start

Area 6: False Start

Area 7: False Start

Area 8: False Start

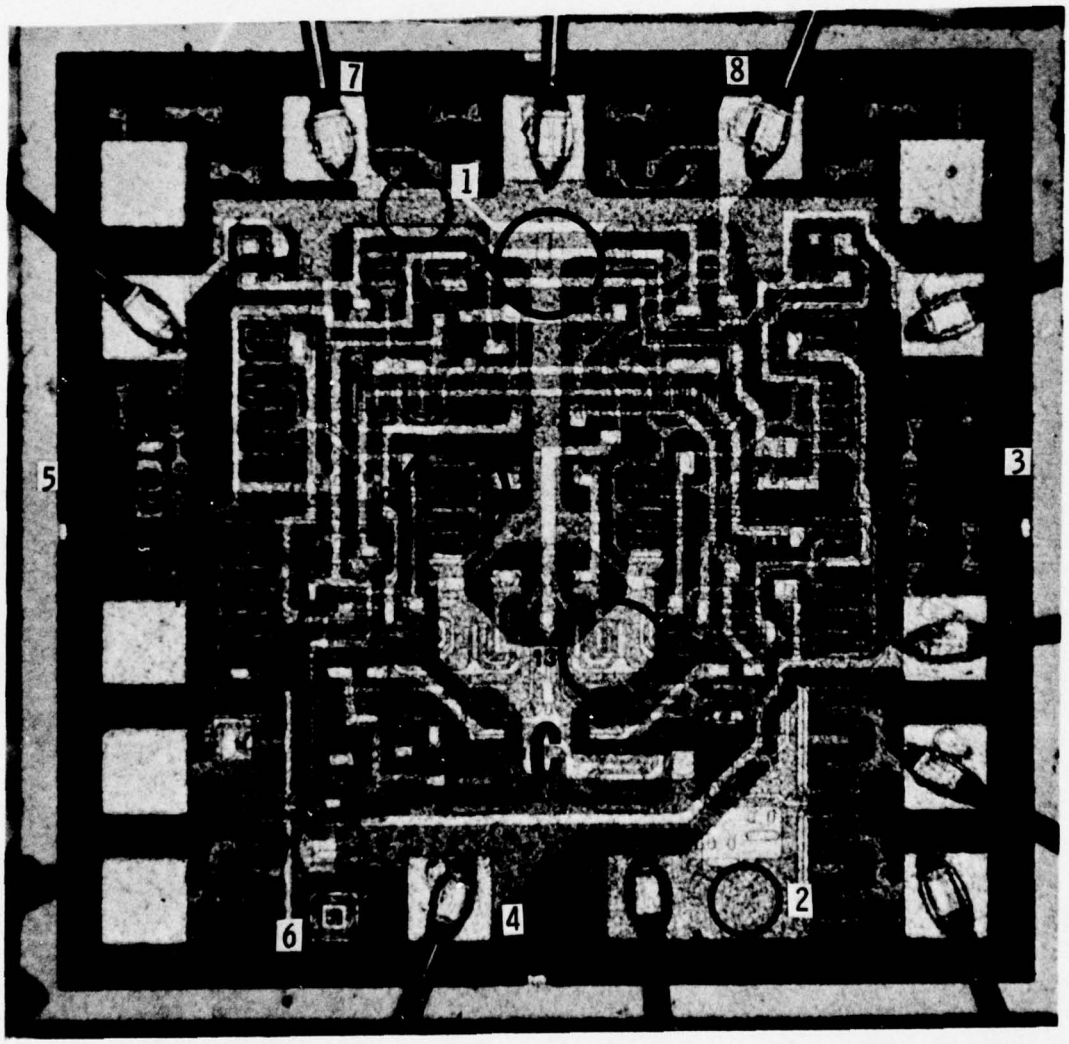
Area 9: Ar Sputter Time to Both Aluminum-Oxide Interfaces

Area 10: Interface Analysis, Glassivation-Insulator Oxide Layers

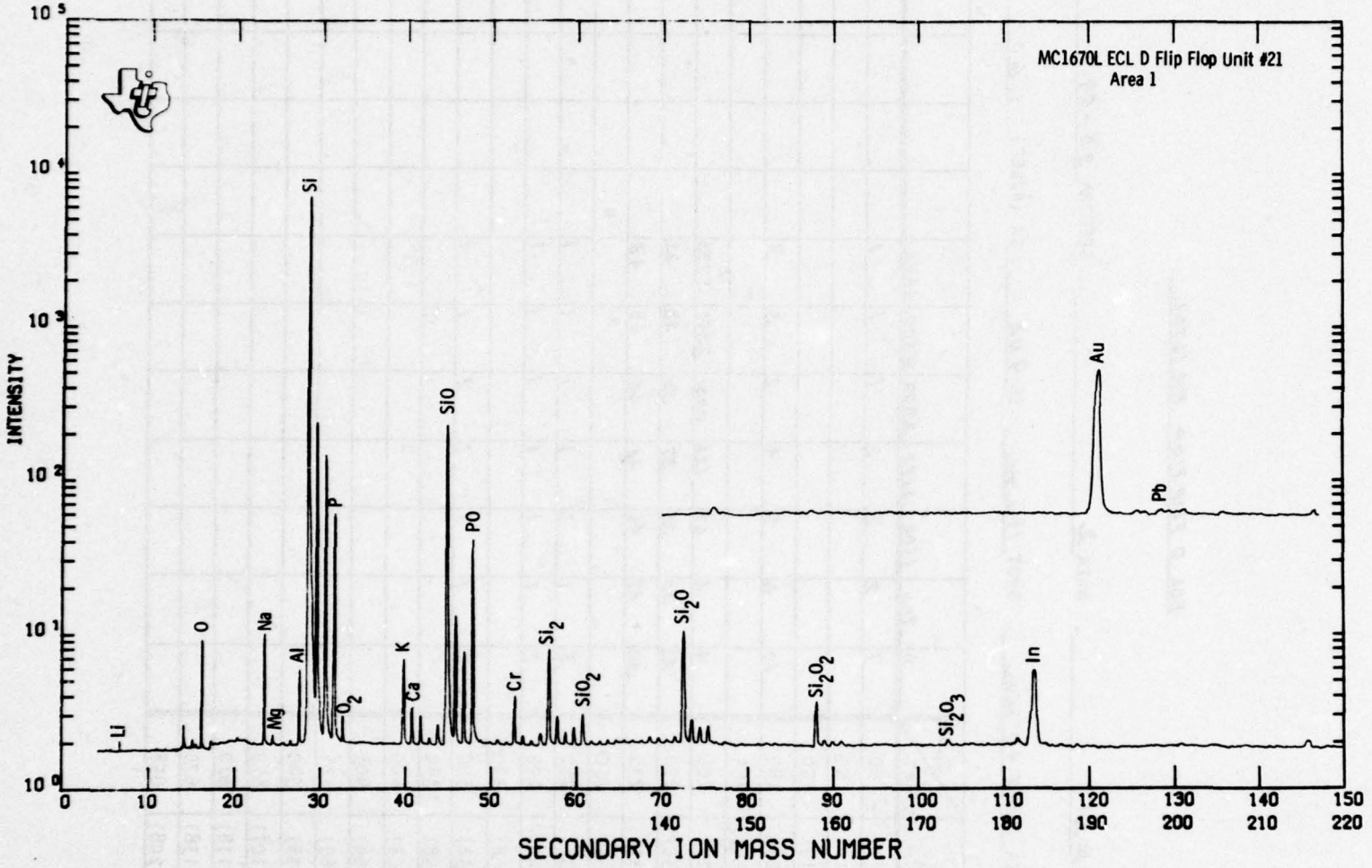
Area 11: Interface Analysis, Glassivation-Insulator Oxide Layers

Area 12: Interface Analysis, Glassivation-Second Level Metal

Area 13: False Start



Set 1 ECL D Flip Flop Unit #21


MC1670L ECL D Flip Flop Unit #21
Area 1
INTENSITY
SECONDARY ION MASS NUMBER
Li
O
Na
Mg
Al
Si
P
O_2
K
Ca
SiO
PO
Cr
Si_2
SiO_2
Si_2O
Si_2O_2
Si_2O_3
In
Au
Pb

ECL 8 FLIP FLOP MC1670L

UNIT #21 . AR[illegible] . SPECTRA 55-49 .

RASTER 50 X 40 μm . SPOT 1½ mm BC 9 NA SR (Å/SEC) 1.60 .

ELEM	PLUS / START	0	700	1400	2100	2800	3500	4200				
Li (7)	30	7	2	2	2	1	1	1				
B (11)	60											
F (19)	150											
Na (23)	180	10	6	5	4	2	3	3				
Mg (24)	185											
Al (27)	205	4	4	67	122	1031	2541	3233				
Si (30)	220	22	35	25	37	30	23	22				
P (31)	230	52	47	46	44	45	45	48				
Cl (35)	250											
K (39)	290	3	1	1	1	1	1	1				
Ca (40)	295	2	1	1	1	1	1	1				
Ti (48)	330											
Cr (52)	350	2	1	1	1	1	1	1				
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

ECL D FLIP FLOP MC 1670L

UNIT #21 . AREA 4 . SPECTRA 66-57 .

RASTER 50 X 40 μms . SPOT 16 μms BC 9NA SR (Å/SEC) 1.60 .

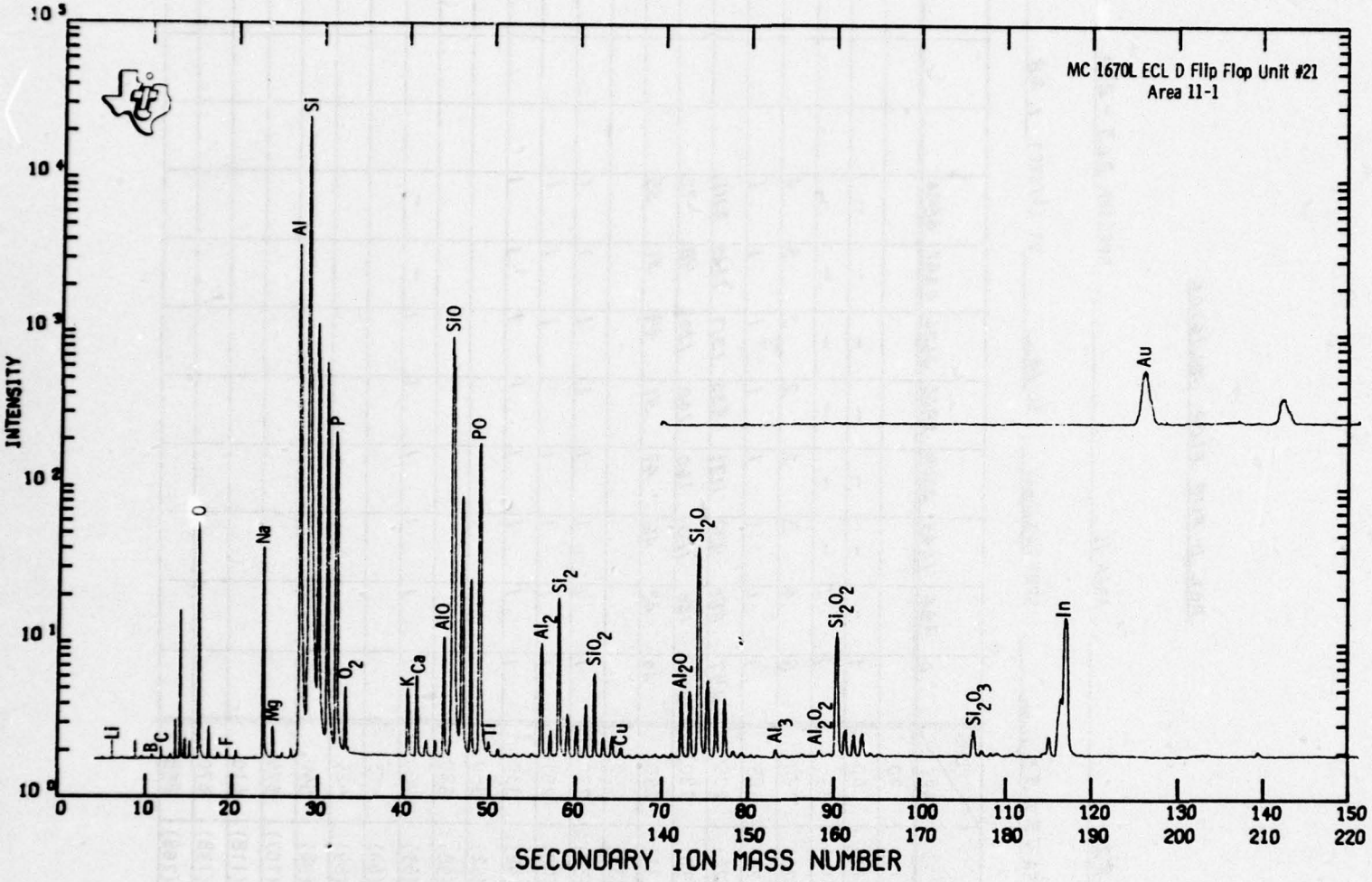
ELEM	START \ PLUS	0	700	1400	2100	2800	3500	4200	4900	5600	6300	
Li (7)	30	1	4	2	1	1	2	1	1	1	1	
B (11)	60											
F (19)	150											
Na (23)	180	10	8	4	5	5	5	4	4	4	3	
Mg (24)	185											
Al (27)	205	4	1	1	2	5	6	5	5	5	4	
Si (30)	220	36	60	90	66	54	42	80	63	62	60	
P (31)	230	49	44	29	37	43	44	44	48	48	53	
Cl (35)	250											
K (39)	290	7	2	1	1	1	1	1	1	1	1	
Ca (40)	295	2	1	1	1	1	1	1	1	1	1	
Ti (48)	330											
Cr (52)	350	3	1	1	1	1	1	1	1	1	1	
Ni (58)	380											
Cu (63)	400											
Zn (64)	403	1	1	-	-	-	-	-	-	-	-	
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	-	-	-	-	-	-	-	-	
Ba (138)	670											
Pb (208)	858											

ECL D FLIP FLOP MC1670L

UNIT #21 . AREA 10 . SPECTRA 251 - 254 .

RASTER 73 X 53 μm . SPOT 16 μm BC 14 NA SR (Å/SEC) 1.28 .

ELEM	PLUS / START	0	910	1592	2269							
Li (7)	30											
B (11)	60											
F (19)	150	1	-	-	-							
Na (23)	180	4	1	1	1							
Mg (24)	185	1	1	-	-							
Al (27)	205	323	1051	1222	1576							
Si (30)	220	78	58	50	39							
P (31)	230	45	51	49	58							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295	1	1	1	1							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											


MC 1670L ECL D Flip Flop Unit #21
Area 11-1
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
F
Na
Mg
Al
Si
P
O2
K
Ca
AlO
SiO
PO
Ti
Al2
Si2
SiO2
Cu
Al2O
Si2O
Al3
Al2O2
Si2O2
Si2O3
In
Au

ECL D FLIP FLOP MC1670L

UNIT #21 . AREA 11 . SPECTRA 263 - 270 .

RASTER 73 X 53 μm . SPOT 16 μm BC 14 μ SR (Å/SEC) 1.28 .

ELEM	PLUS / START	0	984	1645	2309	2966	3626	4287	4894			
Li (7)	30											
B (11)	60	1	-	-	-	-	-	-	-			
F (19)	150	1	1	-	-	-	-	-	-			
Na (23)	180	8	4	3	2	2	2	3	4			
Mg (24)	185	1	1	1	1	1	1	1	1			
Al (27)	205	497	880	939	1131	935	1317	1545	2111			
Si (30)	220	200	160	150	160	140	130	98	72			
P (31)	230	40	43	46	47	51	49	51	55			
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1			
Ca (40)	295	1	1	1	1	1	1	1	1			
Ti (48)	330	1	1	1	1	1	1	1	1			
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	1	1	1	1	1	1	-	-			
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

ECL D FLIP FLOP MC16701

UNIT #21 . AREA 13 . SPECTRA 255 - 258 .

RASTER 73 X 53 μm . SPOT 16μm BC 14NA SR (Å/SEC) 1.28 .

ELEM	START \ PLUS	0	878	1603	2320							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	3	2	2	1							
Mg (24)	185											
Al (27)	205	1996	3177	4837	7614							
Si (30)	220	28	23	20	22							
P (31)	230	44	45	53	52							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295	1	1	1	1							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

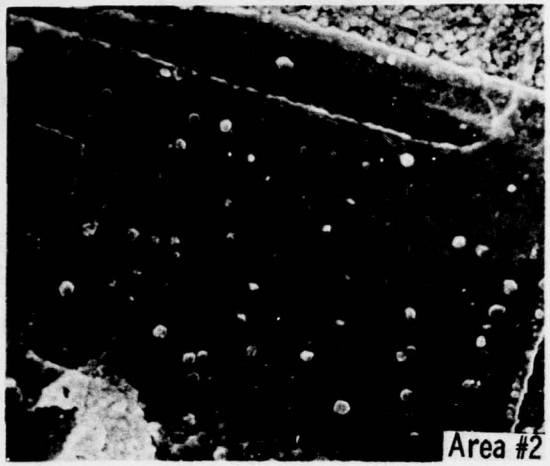
ECL D FLIP FLOP MC1670L

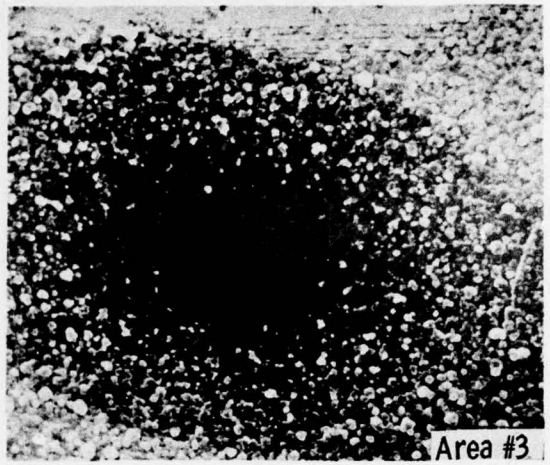
UNIT #21 . AREA 12 . SPECTRA 259 - 262 .

RASTER 73 X 53 μm . SPOT 16 μm BC 14 NA SR (Å/SEC) 1.28 .

ELEM	PLUS / START	0	905	1585	2263							
Li (7)	30											
B (11)	60											
F (19)	150											
Na (23)	180	2	1	1	1							
Mg (24)	185											
Al (27)	205	2556	2913	2995	2723							
Si (30)	220	26	25	23	23							
P (31)	230	56	63	68	68							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295	1	-	-	-							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

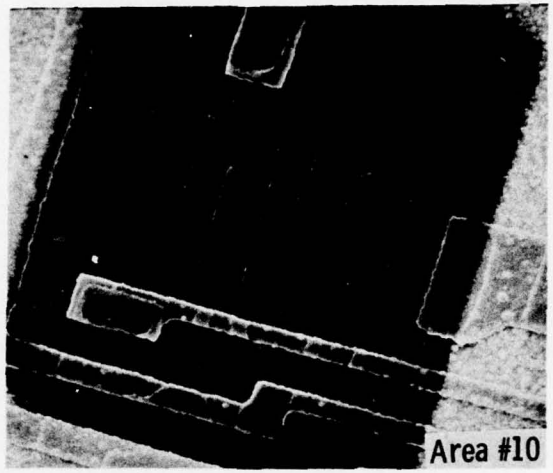
MC1670L ECL D Flip Flop Unit #21

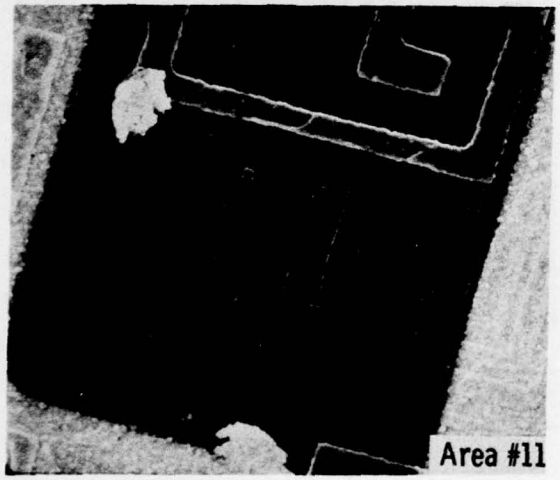


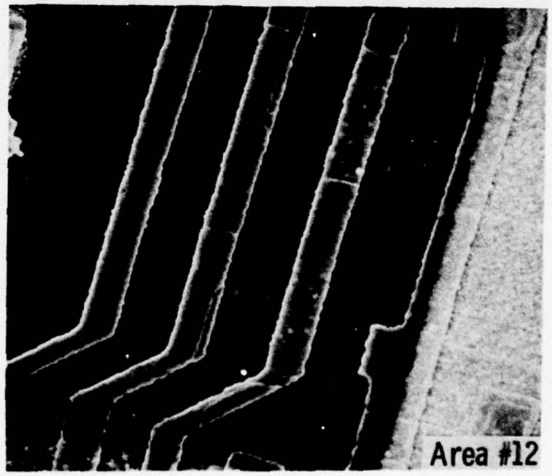


MC1670L ECL D Flip Flop Unit #21


Area #9


Area #10


Area #11


Area #12

Hex Inverter, Unit #94

Area 1: Surface Mass Spectrum

Area 2: Surface Mass Spectrum

Area 3: Surface Mass Spectrum

Area 4: Mass Spectra Depth Profile

Area 5: Mass Spectra Depth Profile

Area 6: Cr-Ni Peak Count Depth Profile (not included)

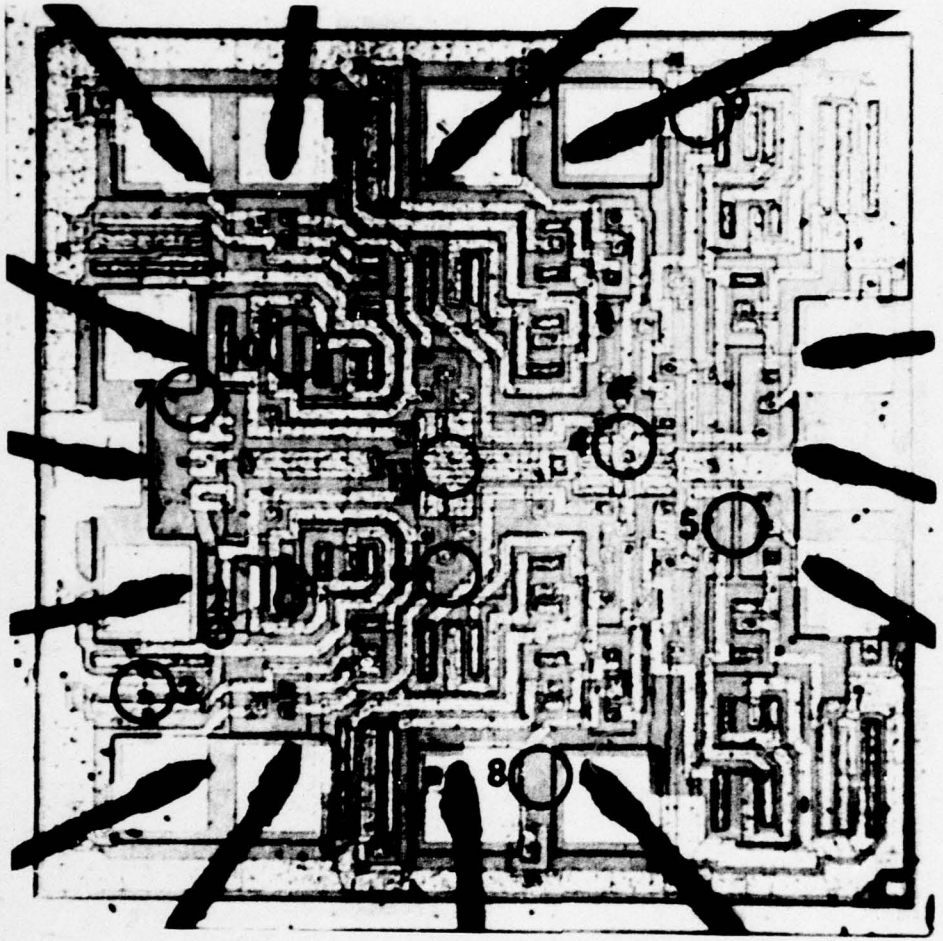
Area 7: Pb Peak Count Depth Profile

Area 8: Pb Peak Count Depth Profile (not included)

Area 9: Ar Sputter Time Through Glassivation

Area 10: Interface Analysis, Glassivation-Oxide Layers

Area 11: Interface Analysis, Glassivation-Aluminum Layers



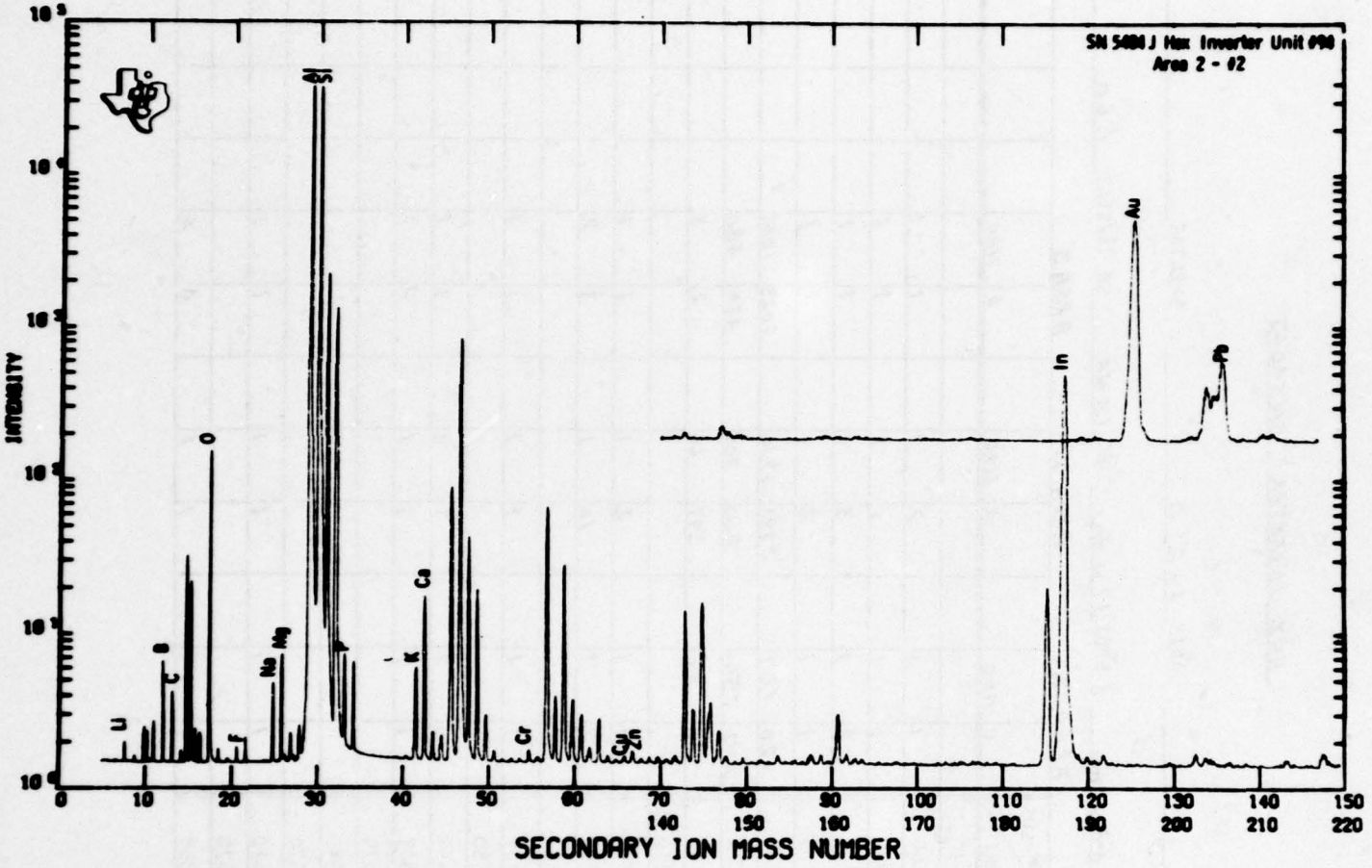
Set 1 Hex Inverter Unit #94

HEX INVERTER SN5404J

UNIT #94 . AREA 1-2-3 . SPECTRA .

RASTER 60X48 μm . SPOT 17 μm BC 13NA SR (Å/SEC) 1.60 .

ELEM	PLUS / START	AREA 1			AREA 2			AREA 3				
		0	1100		0	1100		0	1100			
Li (7)	30											
B (11)	60	1	1		2	1		1	1			
F (19)	150	1	1		1	1		1	1			
Na (23)	180	2	1		3	1		1	1			
Mg (24)	185	1	1		2	1		1	1			
Al (27)	205	120	167		3281	1216		1023	1085			
Si (30)	220	500	550		260	700		470	480			
P (31)	230	26	34		247	64		2	3			
Cl (35)	250											
K (39)	290	1	1		2	1		1	1			
Ca (40)	295	2	1		10	1		3	2			
Ti (48)	330											
Cr (52)	350	1	1		1	1		1	1			
Ni (58)	380											
Cu (63)	400	1	1		1	1		1	1			
Zn (64)	403	1	1		1	1		1	1			
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1		1	1		1	1			
Ba (138)	670											
Pb (208)	858	1	1		1	1		4	4			


SN 5484 J Hex Inverter Unit 090
Area 2 - 02
INTENSITY
SECONDARY ION MASS NUMBER
Li
B
C
O
F
Na
Mg
Si
K
Ca
Cr
Cu
In
Au

HEX INVERTER SN5404J

UNIT #94 . AREA 4 . SPECTRA 124 - 134 .

RASTER 70 X 56 μm . SPOT 17 μm BC 13 NA SR (Å/SEC) 1.18 .

ELEM	PLUS / START	0	900	1800	2700	3600	4727	5866	7017	8142	9241	10483
Li (7)	30											
B (11)	60	1	1	1	1	1	1	1	1	1	1	1
F (19)	150	1	1	–	–	–	–	–	–	–	–	–
Na (23)	180	1	1	1	1	1	1	1	1	1	1	1
Mg (24)	185	1	1	1	1	1	1	1	1	1	1	1
Al (27)	205	53	50	62	80	91	124	185	267	343	462	570
Si (30)	220	580	560	640	700	820	850	650	750	700	680	650
P (31)	230											
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1	1	1	1
Ca (40)	295	2	1	1	1	1	1	1	1	1	1	1
Ti (48)	330	1	1	1	1	1	1	–	–	–	–	1
Cr (52)	350	1	1	1	1	1	1	1	1	1	1	1
Ni (58)	380											
Cu (63)	400	1	1	1	–	–	–	–	–	1	1	1
Zn (64)	403	1	1	1	1	1	1	1	1	1	1	1
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	1	1	1	1	1	1
Ba (138)	670											
Pb (208)	858	1	1	1	1	1	1	1	1	1	1	1

HEX INVERTER SN5404J

UNIT #94 . AREA 5 . SPECTRA 136 - 143 .

RASTER 70 X 56 μm . SPOT 17 μm BC 13 NA SR (Å/SEC) 1.18 .

ELEM	PLUS / START	0	1125	2245	3362	4486	5619	6744	7868			
Li (7)	30											
B (11)	60	1	1	1	1	1	1	1	1			
F (19)	150	1	1		1	1	–	–	1			
Na (23)	180	1	1	1	1	1	1	1	1			
Mg (24)	185	1	1	1	1	1	1	1	1			
Al (27)	205	11	4	3	5	15	100	250	360			
Si (30)	220	480	760	850	1000	1200	1600	800	750			
P (31)	230											
Cl (35)	250											
K (39)	290	1	1	1	1	1	1	1	1			
Ca (40)	295	3	1	1	1	1	1	1	1			
Ti (48)	330	1	1	1	1	1	1	1	1			
Cr (52)	350	1	1	1	1	1	1	1	1			
Ni (58)	380											
Cu (63)	400	1	1	1	1	1	1	1	–			
Zn (64)	403	1	1	1	1	1	1	1	–			
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610	1	1	1	1	1	1	1	–			
Ba (138)	670											
Pb (208)	858	1	1	1	1	1	1	1	1			

HEX INVERTER SN5404J

UNIT #94 . AREA 10 . SPECTRA 687-690 .

RASTER 70 x 55 μm . SPOT 21 μm BC 11NA SR (Å/SEC) 1.01 .

ELEM	START \ PLUS	0	1054	1738	2428							
Li (7)	30											
B (11)	60	1	1	1	1							
F (19)	150											
Na (23)	180	1	1	1	1							
Mg (24)	185	1										
Al (27)	205	43	54	72	97							
Si (30)	220	110	84	72	66							
P (31)	230	1	1	–	–							
Cl (35)	250											
K (39)	290	1	1	1	1							
Ca (40)	295	1	1	1	1							
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400											
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

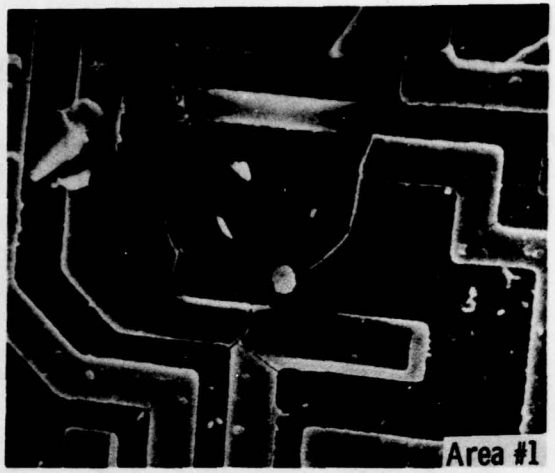
HEX INVERTER 9N5404J

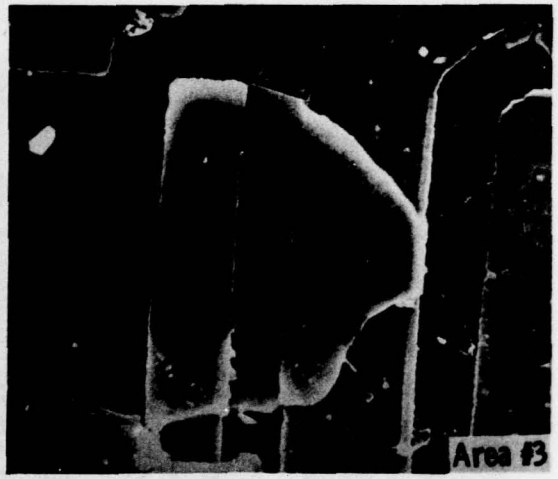
UNIT #94 . AREA 11 . SPECTRA 682-686 .

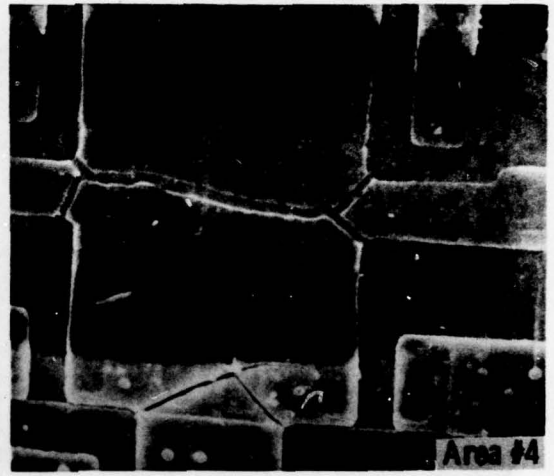
RASTER 44 X 28 μm . SPOT 9 μm BC 6NA SR (Å/SEC) 1.73 .

ELEM	START \ PLUS	0	887	1757	2620	3470						
Li (7)	30											
B (11)	60	1	1	1	1	1						
F (19)	150											
Na (23)	180	1	1	1	1	1						
Mg (24)	185	1	1	—	—	—						
Al (27)	205	319	259	122	180	160						
Si (30)	220	76	70	56	56	48						
P (31)	230	1	1	1	1	1						
Cl (35)	250											
K (39)	290	1	1	1	1	1						
Ca (40)	295	1	1	1	—	—						
Ti (48)	330											
Cr (52)	350											
Ni (58)	380											
Cu (63)	400	1	—	—	—	—						
Zn (64)	403											
Ga (69)	425											
Mo (98)	540											
Ag (107)	570											
Sn (118)	610											
Ba (138)	670											
Pb (208)	858											

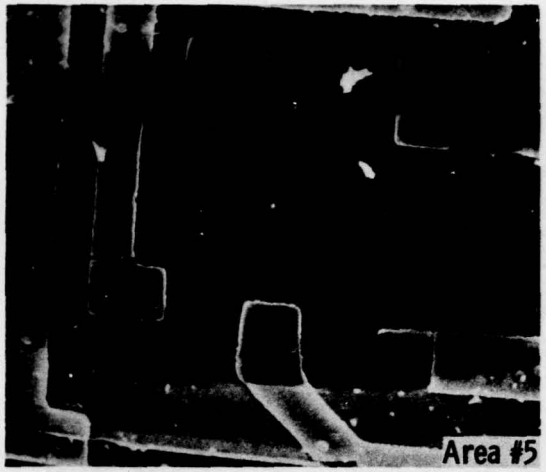
SN5404J Hex Inverter Unit #94

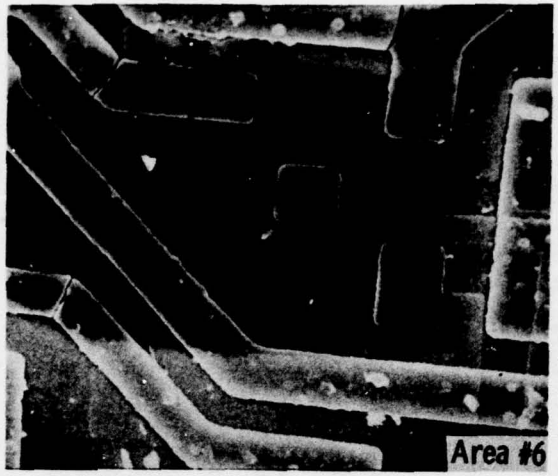


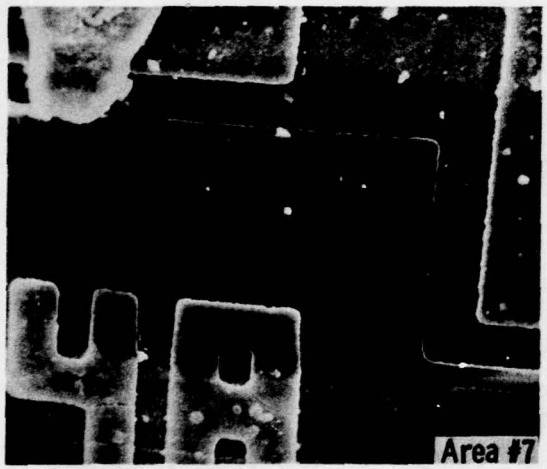


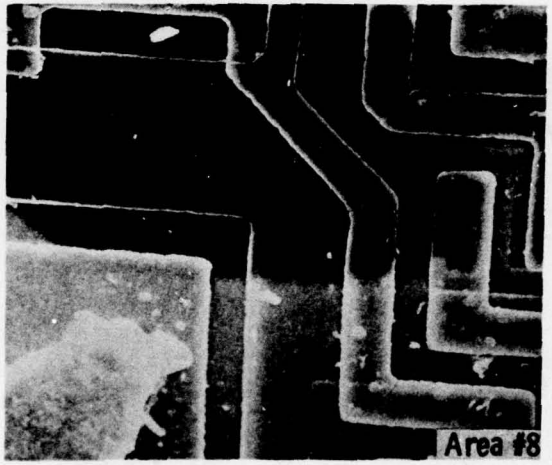


SN5404J Hex Inverter Unit #94









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