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THERMALLY GROWN OXIDES AND DIFFUSIONS FOR AUTOMATIC PROCESSING OF INTEGRATED CIRCUITS

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TECHNICAL MEMORANDUM

THERMALLY GROWN OXIDES AND DIFFUSIONS FOR AUTOMATIC PROCESSING OF INTEGRATED CIRCUITS

I. INTRODUCTION

This report presents a discussion on the newly developed system of thermally grown oxides and diffusions for automatic processing of integrated circuits. The concept of this system was to develop a semiconductor diffusion and oxidation facility which was totally automated. Wafers would arrive at the facility on an air track, be automatically loaded into a furnace tube, processed, returned to the track, and sent on to the next operation. The entire process was to be controlled by a computer. Installation took place at the two 3-stack furnaces, and checkout was accomplished. The following diffusion and oxidation processes were demonstrated:

a) Wet and dry oxidation for general use.

b) Wet and dry oxidation for gate oxide.

c) Boron diffusion.

d) Phosphorous diffusion.

e) Sintering.

Part of the system consisted of state-of-the-art components and processes, such as the diffusion furnace and high temperature grown oxide. However, there were several major innovations that were demonstrated. These innovations were as follows:

a) A process controller specifically designed for semiconductor processing.

b) An automatic loading system to accept wafers from an air track, insert them into a quartz carrier, then place the carrier on a paddle for insertion into the furnace.

c) Automatic unloading of the wafers back onto the air track.

d) Boron diffusion using diborane with ±5 percent uniformity.

The system will perform oxidation and diffusion processes as required for P-Channel Metal Oxide Semiconductor (PMOS) processing. No experience is available on the productivity of the design; however, enough data have been gathered to suggest several improvements in future systems.

a) The Monitrol process controller is a first generation real-time controller for semiconductor processing. It has several shortcomings which have been identified — particularly in flexibility and capacity.

b) A major problem encountered in the subject facility was the technique of rotating the quartz carrier 90° and laying it on the paddle. This was accomplished by a separate microprocessor control which worked from limit switch inputs. Although it worked within specified limits, the design was awkward, involved many parts, and may require maintenance.

c) Boron diffusion using diborane is probably not possible at the present level of technology. Many different techniques and equipment variations were tried in order to make diborane diffusion successful, but to no avail. The process should be converted to solid boron diffusion or to boron tribromide.

d) The air track occasionally allowed wafers to "hang up." The adjustment to keep this from happening is rather critical. It is believed that this problem can be overcome.

Basic Operation

The overall diffusion system consists of the following:

a) Two existing Thermco 3-stack diffusion furnaces.

b) Two special load stations which incorporate a wafer track and buffer tee.

c) Two automatic wafer boat elevation systems.

d) Six automatic wafer boat insertion systems.

e) A computer-based process controller.

f) Two source cabinets for the gas blending systems.

g) Eight Max 1 boat loaders.

h) Six gas blending assemblies.

i) Expendable materials (quartz, silicon carbide, etc.).

Wafers arrive at the load station on a wafer track and are temporarily stored in a buffer-tee until required for loading into the furnace. When a furnace is ready, the wafers are sent along the track to a load station where a vertically oriented quartz carrier holding 100 wafers is located. The wafers are loaded into the carrier which is then lifted by an automatic "claw" mechanism above the furnace to be used. Next, the silicon carbide paddle is retracted from the furnace under the suspended carrier. At the proper time, the carrier is lowered onto the retracting paddle as the paddle retracts, until it is lying horizontally on the paddle. The claw opens and retracts upward. The paddle goes into the furnace, carrying the wafer boat and its load of 100 wafers, then the process begins. The control of all functions except the lowering of the wafers carrier on the paddle is accomplished by the Monitrol Process Controller. Carrier loading is directed by a separate microprocessor-based controller. Recipes for various processes are stored in the Monitrol. This unit contains a DEC PDP-8 minicomputer. It has complete manual backup of all functions as well as visual indication of operating state. It may be interfaced with an upstream computer for management data presentation.

II. THERMALLY GROWN OXIDES AND DIFFUSIONS

A. Oxides and Diffusions

Furnace operations are essential to the fabrication of semiconductor devices. The furnaces are used for thermal oxidation of the silicon, for diffusion of dopants, and annealing operations. All furnace operations are precisely timed and gas flows and temperatures are accurately metered. Fabrication of PMOS integrated circuits require four separate furnace operations, while other integrated circuits require more. Several silicon wafers are processed simultaneously during each operation. Quartz furnace tubes and boats (wafer holders) are carefully cleaned to maintain process control. Boats are supported on clean carriers as they are loaded or withdrawn from the furnace. The gases are filtered and passed through the quartz furnace tubes at controlled flow rates. Great care is taken to avoid contamination. The furnaces are capable of maintaining a temperature from 700° to 1300° ± 0.25°C over a 56-cm (22-in.) zone.

B. Silicon Dioxide

SiO_2 can be grown using steam in a resistance-heated furnace tube with a Mulite liner. The temperature is usually around 1150°C; however, it may vary from 900° to 1200°C for MOS devices. For an extremely clean SiO_2 layer, approximately 0.1 percent HCl is added to the steam. The HCl helps tie up any sodium ions in the tube. Sodium ions are very harmful and may cause the threshold voltage to shift under temperature and bias. After the wafer is thoroughlv cleaned it is oxidized at 1150°C using an oxidant of oxygen (O_2) by itself or with steam. The O_2 combines with the silicon to form a layer of SiO_2. The growth rate is dependent on the temperature of oxidation and the type of oxidant (dry O_2 or steam).

C. Diffusions

Duffusion is accomplished by placing silicon wafers that have been coated with an oxide and a pattern etch in the oxide in an 1100°C furnace. Either P-channel or N-channel diffusions are performed by flowing either diborane or phosphine using nitrogen as a carrier gas over the hot wafers. The ions of the particular gas are collected on the surface of the wafer and later are driven in to form the "P" or "N" channels for the source or drain.

Figures 1 through 4 show gas calibration and the thickness of thermally grown SiO_2.

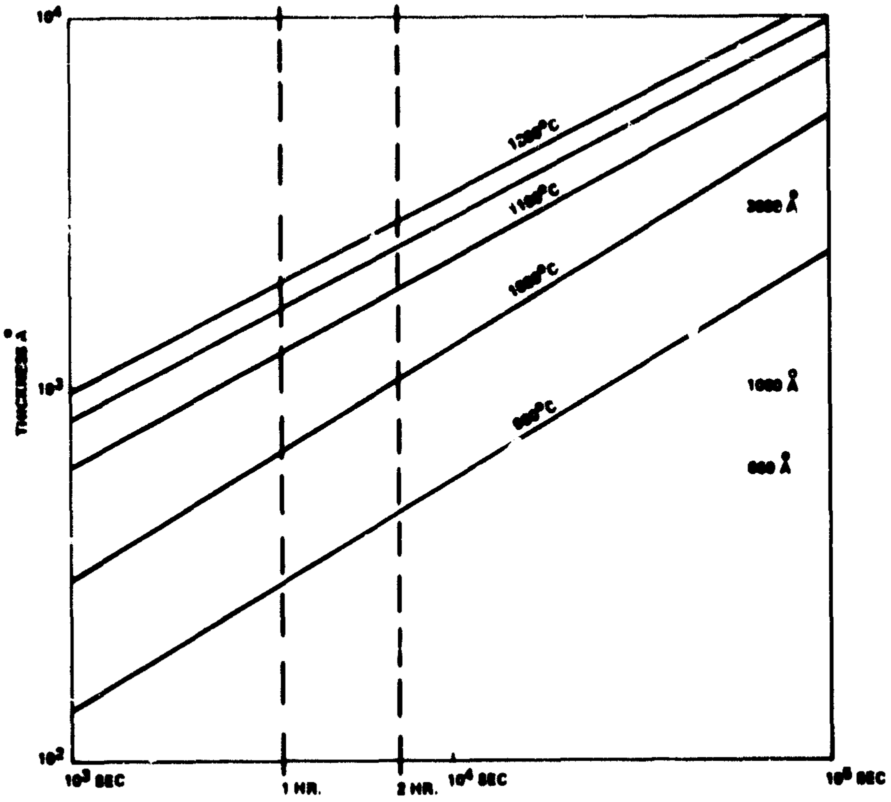

Figure 1. SiO_2 thickness versus time of growth in dry O_2.

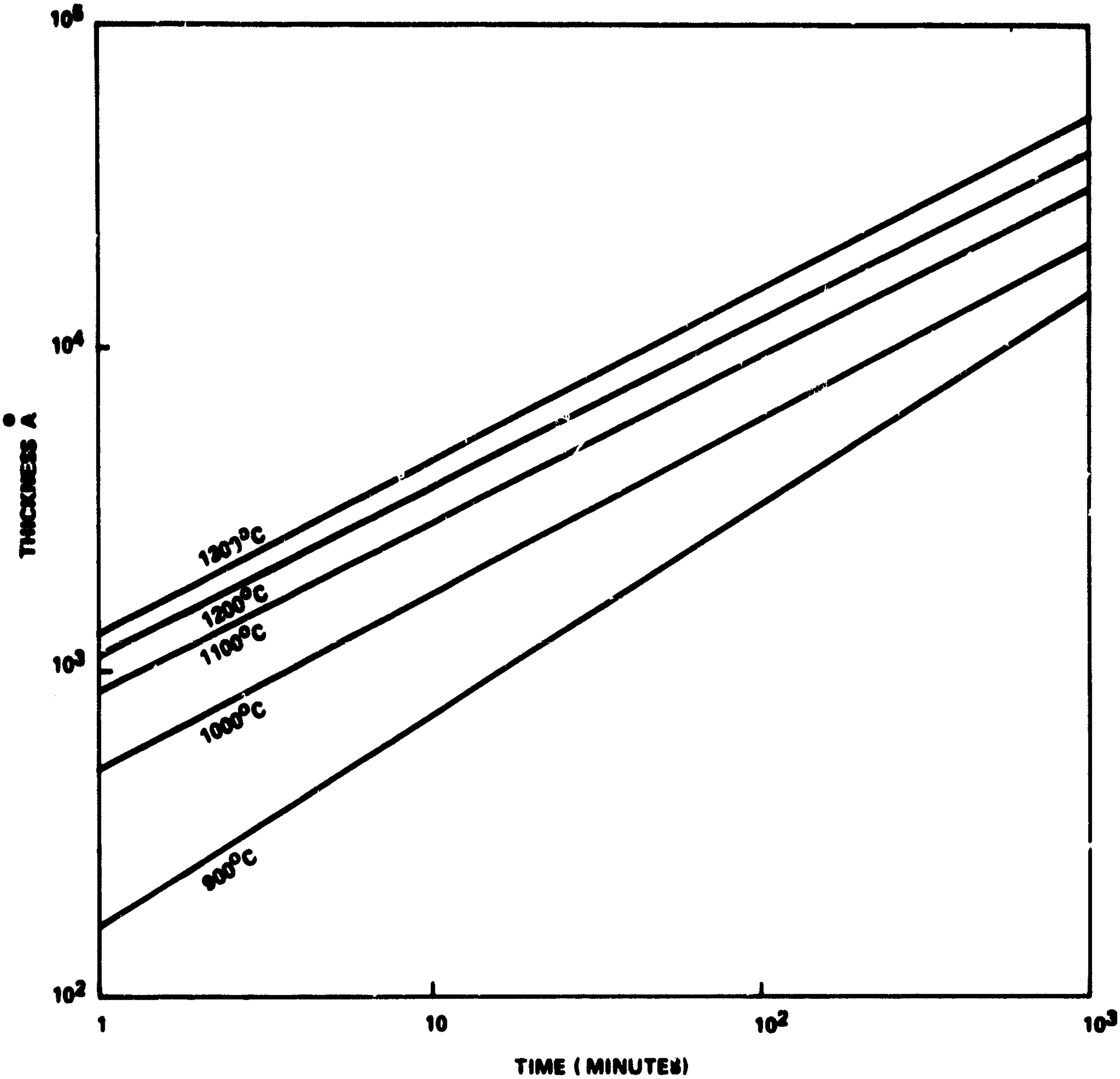

Figure 2. Oxide thickness versus time.

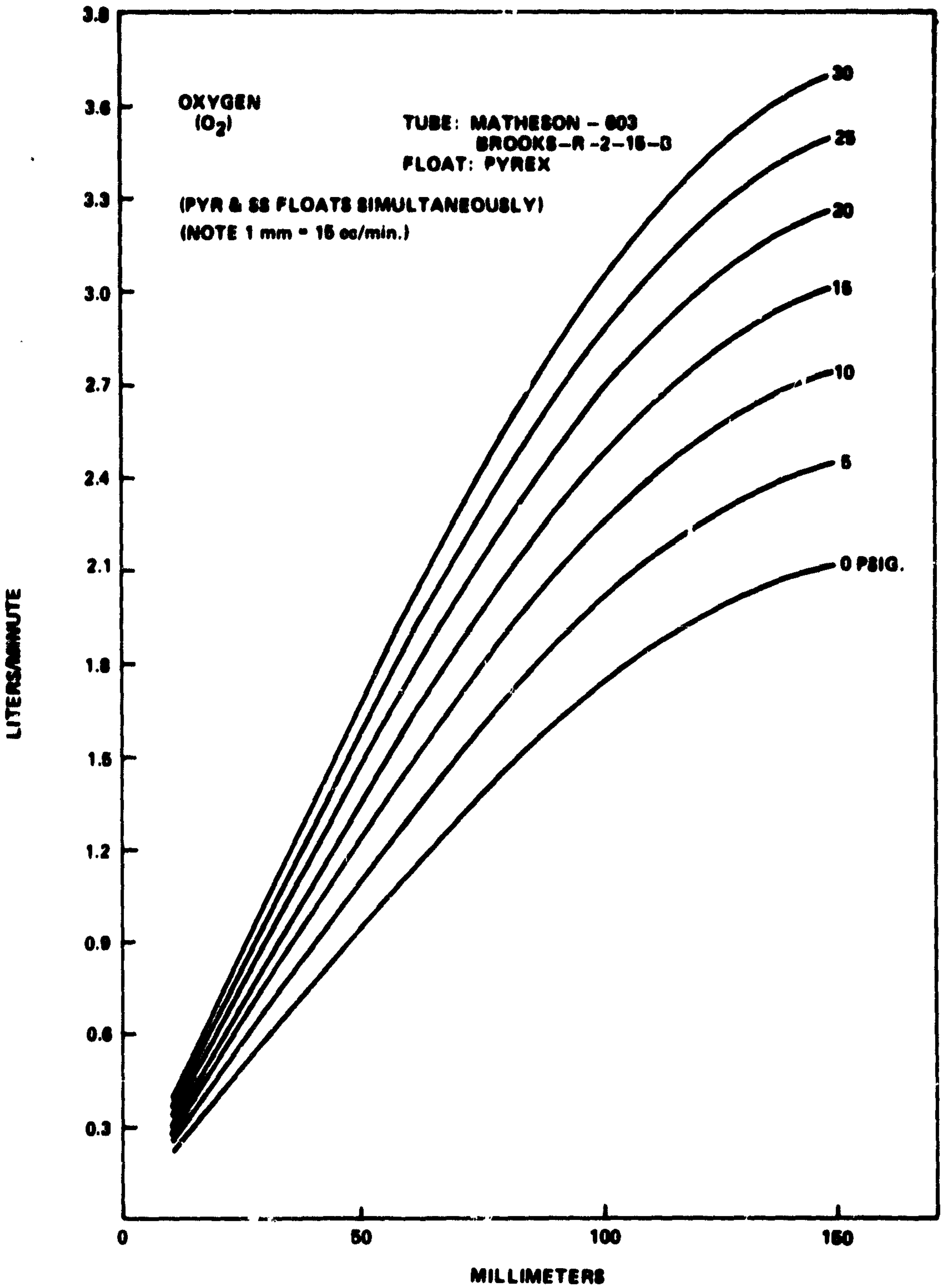

Figure 3. Calibration of float tubes for oxygen flow rate for dry oxide (to obtain saturation in furnace tube).

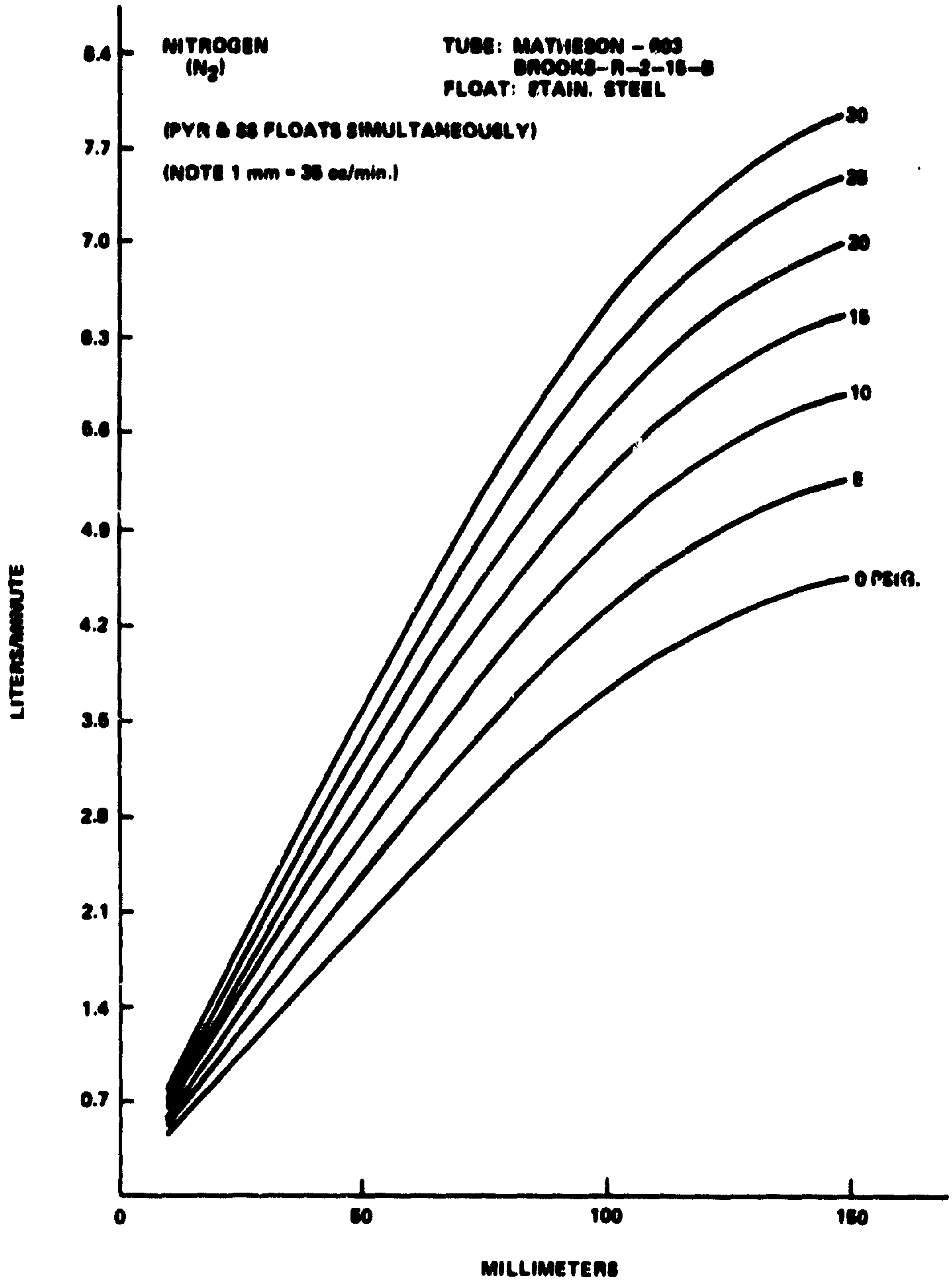

Figure 4. Calibration of float tubes for nitrogen flow rate for steam oxide (to obtain saturation in furnace tube).

III. AUTOMATIC DIFFUSION AND OXIDATION FURNACE CONTROL SYSTEM

A. Introduction Automatic Furnaces

The automatic hands off system is designed for inserting and removing integrated circuit wafers in and out of diffusion and oxidation furnaces under computer control. The system shall be capable of moving individual 3-in. diameter silicon and sapphire wafers from an air track (36 in. in height) using a mechanical device without damaging the circuit side of the wafer, and mounting them in a 25 wafer vertical quartz boat or an equivalent carrier system that will insert and remove wafers from the furnace. The boat shall be mounted on a (insertion and removal mechanism) puller-pusher system which inserts the wafers into and out of the diffusion and oxidation furnaces under computer control. The furnaces operate up to 1200°C. The wafers shall not be damaged or contaminated throughout the removing and inserting of the wafers in the furnaces and during the removing and remounting of the air track. The automatic diffusion and oxidation furnace control system shall include gas controls, wafer boat insertion and removal mechanism, a direct digital controller, a load station that removes and replaces the wafer on a GCA air track, and the related cabinets. The wafer shall be removed from the air track which shall be interfaced with other air tracks. Send and receive signals shall be sent to the air track to stop and start the wafer for loading into the furnaces (Figs. 5, 6, and 7).

B. General Requirements

All materials used shall not react chemically with the wafers or quartz tube or be chemically involved in the diffusion, oxidation, and annealing processes in the furnace tubes. The materials shall not crack, warp, stick, or deform in any manner during a minimum of 2000 hours of normal operation. The system shall be equipped with mass flow controllers for each of the gasses listed in paragraph II.A and for each of the 3-stack Thermoco Ranger model 3000 furnaces already located at Marshall Space Flight Center (MSFC). Cabinets and floor support and the necessary electrical wiring to connect the furnace to the controllers shall be furnished. The furnaces will remain in their present cabinet. In either case, the complete furnace complex shall occupy an area no more than 24 × 8 ft. The furnaces and puller-pusher system may be staggered in an inline operation to fit in the required space. Two standard and two modified GCA Buffer T Stations shall be furnished.

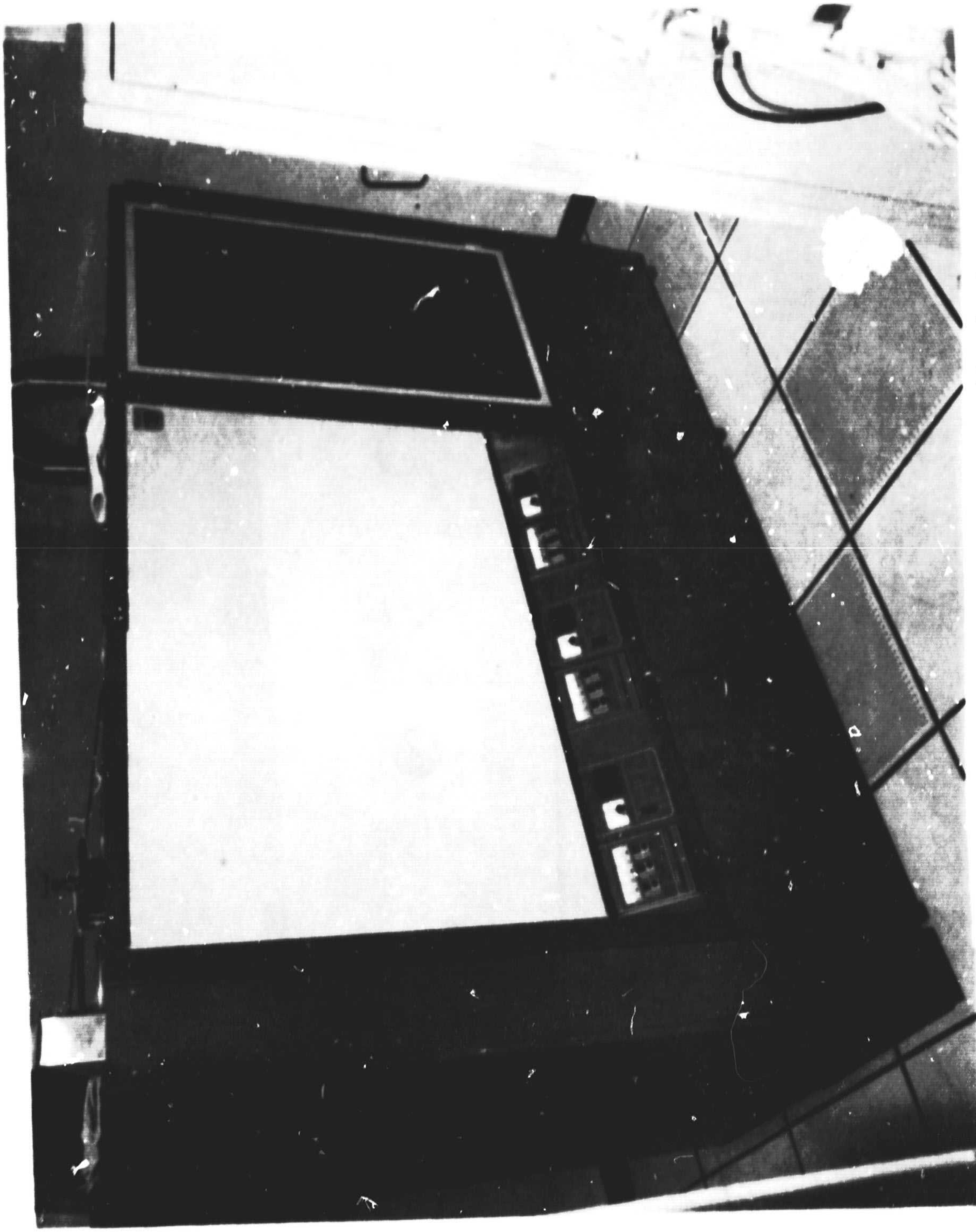

Figure 5. Oxidation and diffusion furnaces (side view).

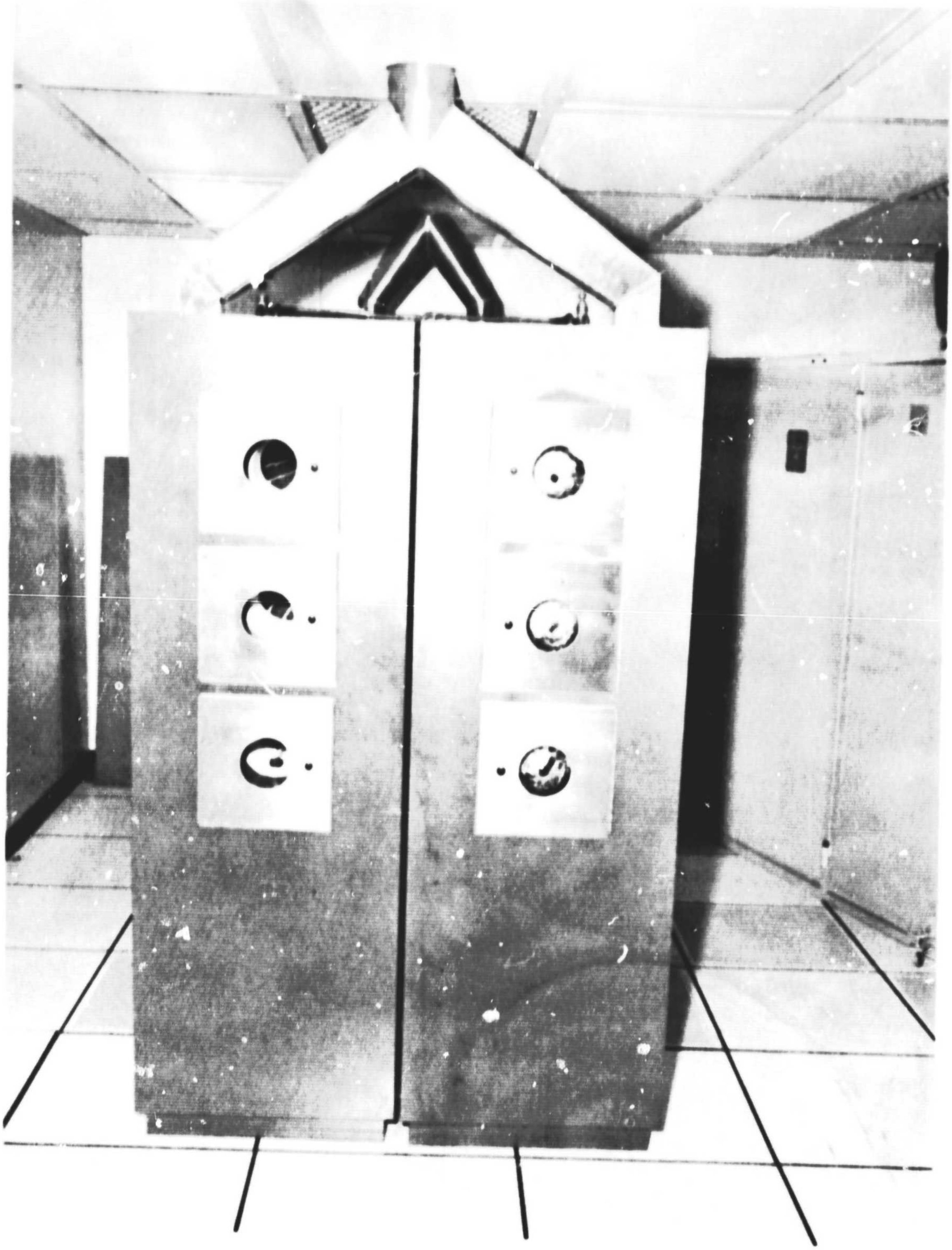

Figure 6. Oxidation and diffusion furnaces (front view).

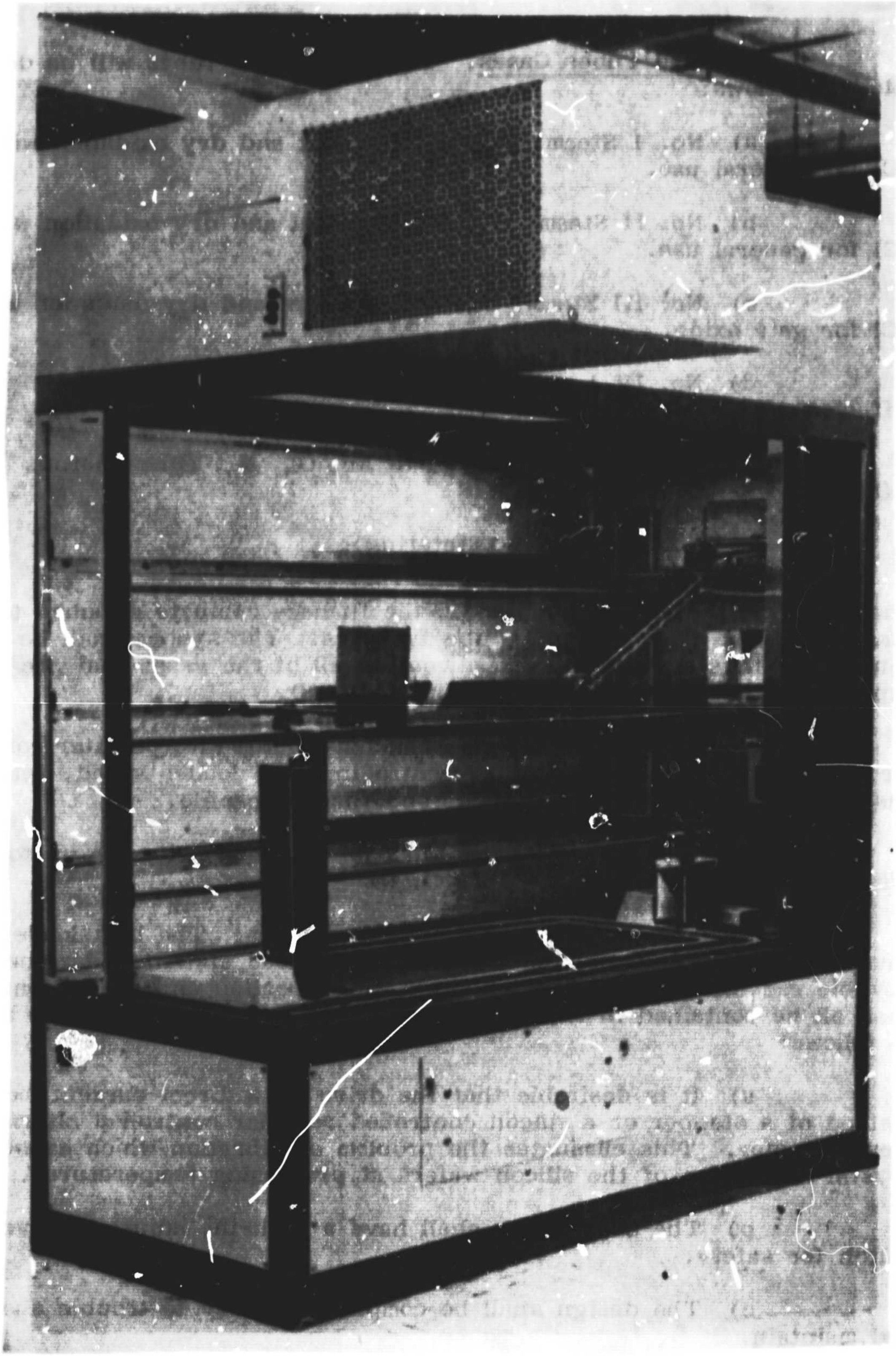

Figure 7. Automatic loading and unloading of oxidation and diffusion system.

1. Furnace Tubes Gases. The six furnace tubes will be dedicated as follows:

a) No. I Steam, O_2, N_2, H_2, wet and dry oxidation with HCl for general use.

b) No. II Steam, O_2, N_2, H_2, wet and dry oxidation with HCl for general use.

c) No. III Steam, O_2, N_2, H_2, wet and dry oxidation with HCl for gate oxide.

d) No. IV 1 percent B_2, H_6, in Ar, O_2, N_2, (boron diffusion).

e) No. V 1 percent PH_3 in Ar, O_2, N_2, (phosphorous diffusion).

f) No. VI O_2, N_2 (Sintering).

The preceding gases are mounted in the furnace cabinets attached to the rear of the two Thermco three-tube furnaces. The system shall be equipped with a scavenger system venting all of the gases that are being expelled out of the six furnaces tubes (Fig. 8).

2. Controls. The system shall have automatic computer control for time sequencing of all events, controlling boat loader speed, setting gas flows, maintaining temperatues, and furnace profile.

3. Capacity. The system shall have the capacity for up to 100 3-in. wafers per run.

4. Boat Loader - Wafer Transport System. The boat loader may have a stationary support rod mounted in the load station under the movable rod for greater stability. The timer portion and speed controls shall all be contained in the monitrol (Fig. 9). Important features are as follows:

a) It is desirable that the drive be a direct current motor instead of a stepper or a silicon controlled rectifier controlled alternating current motor. This eliminates the problem of vibration which causes crystal dislocation of the silicon wafers at processing temperatures.

b) The boat loader shall have a built-in, adjustable overload clutch for safety.

c) The design shall be compact and easy to trouble shoot and maintain.

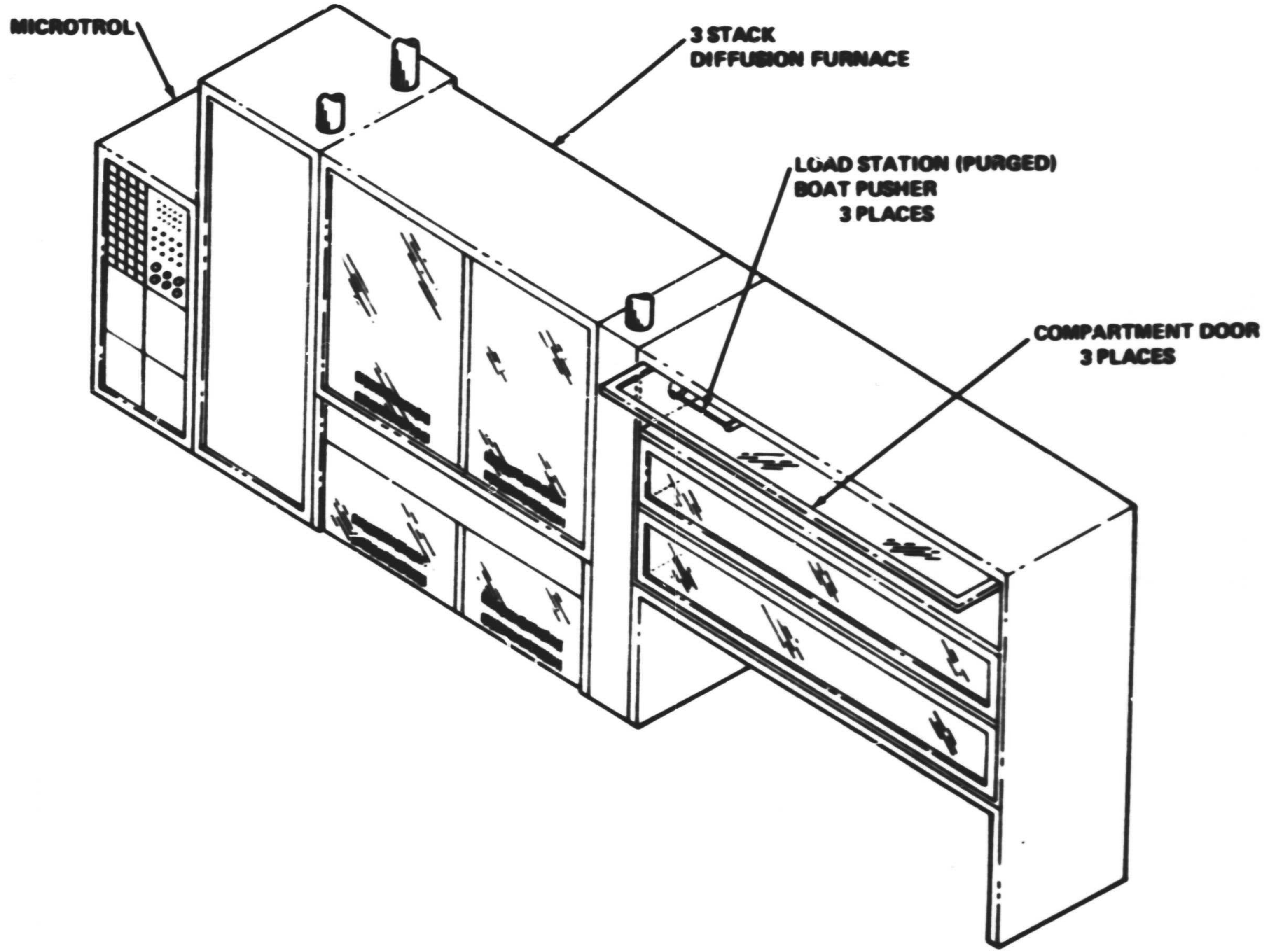

Figure 8. Automated oxidation and diffusion system.

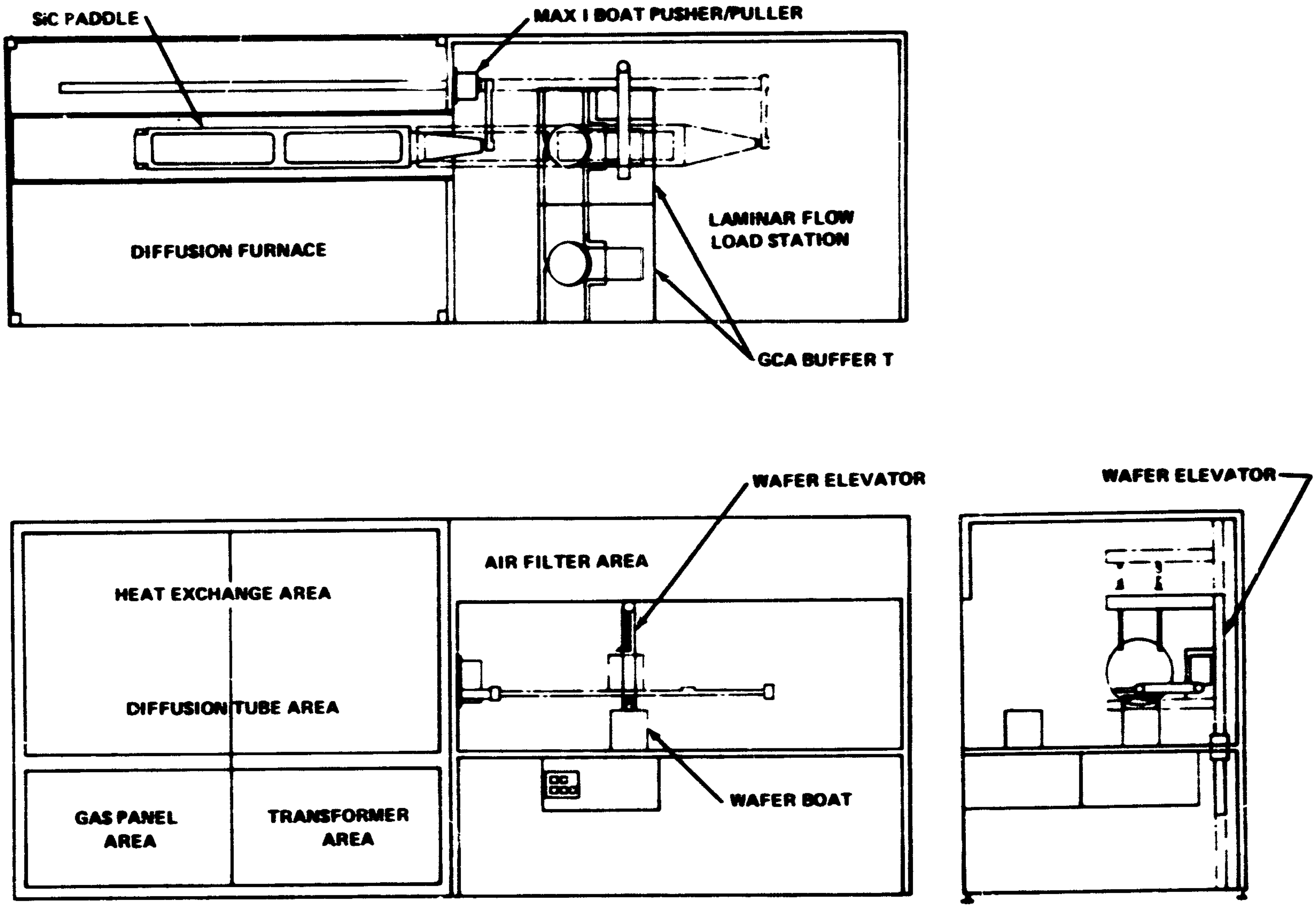

Figure 9. Automated oxidation and diffusion boat pusher/puller system.

d) Start-stop limit switches shall be solid state, photo diode type for long life.

e) The complete furnace loading and unloading operation shall be controlled by the controller.

5. Gas Control. All gases shall be mass flow controlled.

6. Electronics Error Warning (contained in the Monitrol).

7. Mass Flow Control of Gases. The system shall be equipped with mass flowmeters and controllers measuring and controlling the mass flow rate of a gas without the need for temperature or pressure connection.

The instruments shall measure and/or control the true mass flow rate of gases by heat transfer principles. The reading shall not be affected by changes in gas pressure or temperature within specific ranges. A flowmeter shall consist of a base assembly which contains the sensing elements, gas fittings, electronics to condition and amplify the flow signal, and a cover. The controllers shall contain, in addition, a thermal valve and proportional control electronics in the same package as the flowmeter. When low voltage direct current power is supplied to the electrical connector, there shall be an output voltage from 0 to 5 Vdc linearly proportional to flow which can be read on a standard voltmeter or recorder. All parts washed by the gas shall be 316 stainless steel. The case shall be easily opened to expose the complete electronic packages. An adjustment shall be provided for null, linearity, and gain. The inlet and outlet fittings each shall contain a line mesh metal screen to avoid accidental contamination which may plug the sensing element and bypass.

a. General Operation. When heat is applied to a gas stream the temperature rise is a function of the mass flow rate, the thermal properties of the gas, and the amount of heat added. In the mass flowmeters this principle is applied to the sensor, which is a small stainless steel tube with two resistance thermometers wound on the outside. A few milliwatts of heat applied by the sensors raises the gas stream temperature slightly, changing the relative reading of the two thermometers. The design parameters are such that the temperature difference signal between the resistance thermometers is directly proportional to the flow and is also linear. Since different gases have different thermal properties, each flowmeter shall be calibrated on the actual gas to be used.

To vary the flow range, an internal divider splits the gas stream in an exact ratio between the sensor and bypass. The unique bypass matches the linear flow characteristics of the sensor and is easily accessible for service through the inlet fitting. Since it is a laminar flow element (in contrast to an orifice), accuracy is maintained over the complete temperature range.

Thermal gradients around the flow sensor affect accuracy if they influence one resistance thermometer more than the other. For this reason, the sensor is surrounded by an insulating shroud. The power supply shall be designed to release insufficient energy to cause a spark in case of accidental leakage of gas. The mass flow sensor shall not be affected by gravity, so it may be mounted in any position.

Each mass flow instrument shall be calibrated for the specific gas and range for which it is to be used. In certain cases, where the gas is particularly hazardous or corrosive to the calibration equipment, a substitute gas shall be selected which has very similar thermal properties, standard calibration shall be ±0.5 percent of full scale. All units shall have a guaranteed combined accuracy and linearity equal to or better than ±2 percent of full scale under extremes of specified conditions. The calibration gas and range of each unit shall be indicated on the nameplate. Meters and controllers may be used on gases other than the ones for which they are calibrated by applying proper conversion factors as described in the instruction manual furnished with each unit. The accuracy of conversion shall be approximately ±4 percent; repeatability shall not be affected.

b. Flowmeters and Controllers. Each flowmeter or controller shall be calibrated for a specific gas and flow range. For example:

2 to 100 sccm

Hydrogen

1/8 in. fittings.

c. Power Supplies. Central power supplier will be provided.

d. Line Cords. Line cords shall be wired to connect to the proper connector pins for the line voltage available. <u>Caution:</u> Line cords for units with individual power shall not be interchangeable from one voltage to another, for example, a 25-ft cord for a flow controller with individual power supply and available line voltage of 115 Vac.

e. Error Warning. The Monitrol shall monitor all channels and alarm for one underflow or overflow condition.

h. General specifications for mass flow controller:

Input	±15 Vdc, ±5 percent, 20 mA, 600 mW (maximum)
Output	0 to 5 Vdc proportional to mass flow
Output impedance	2 ohms maximum
Output ripple	25 mV p-p

Accuracy	±1 percent of full scale over operating range
Linearity	±0.5 percent of full scale
Response	3 sec (typical) to within 2 percent of final reading
Repeatability	±0.2 percent of full scale for gas pressures of 5 to 50 psia and ambient temperatures from 60° to 80°F
Pressure drop	1.0 psi maximum at rated flow
Maximum gas pressure	150 psig
Gas temperature	40° to 110°F
Ambient temperature	40° to 110°F
Gas connection	Tube compression type 1/4 in. standard
Weight	2.0 lb (900 gm)

g. Flowmeter Ranges. Flowmeters shall have standard ranges which are set by installing the proper bypass. Flowmeter output in each case shall be zero at zero flow and 5 Vdc at maximum flow. Range changes shall be capable of being made in the field, provided calibration equipment is available to achieve specification accuracy ranges which shall be 0 to 10,000.

8. Gas Panels. The gas panels shall be designed and developed to incorporate the necessary features for process compatibility, control, proper range, maintainability, and safety. The panels shall be made in a vertical configuration for mounting in cabinets and the electronic controls shall be incorporated in a central direct digital controller. Important features of the panels shall be as follows:

a) All plumbing shall be type 316 stainless steel to be compatible with the process gas purity levels necessary and to insure leak-tightness.

b) All panels shall be leak-tested to 10^{-9} cc/sec of helium using a mass spectrometer leak detector.

c) Whenever practical, from a servicing point of view, plumbing joints shall be welded to eliminate leakage sources and trapped volumes.

d) Plumbing lines shall be short and direct to minimize purge times.

e) Cajon fittings shall be used at critical places to permit removal of components without bending or springing the plumbing.

f) All tubing shall be lox-cleaned, and assemblies shall be flushed and cleaned in accordance with Class I semiconductor standards.

g) Wiring shall be neatly harnessed and identified.

h) Accessory items such as fittings, filters, valves, regulators, gauges, etc. shall be chosen for quality and compatiblity rather than price.

i) The organization and arrangement of components shall be selected for correct gas mixing and ease of maintenance.

9. Oxidation Panels. "Hyoxcl' oxidizer in an all-mass-flow-control version shall be used to control hydrogen, oxygen, nitrogen, and HCl gases. The panel shall be mounted vertically, and the electronic portions may be removed to the central control. A manual shutoff valve and solenoid valve shall be on each gas circuit. Hyoxcl has several features of note:

a) The flow of hydrogen is slaved to the flow of oxygen for better, safer control. The chances of accidentally setting a dangerous gas mixture are greatly reduced. In this case, the oxygen flow and ratio of hydrogen-to-oxygen are independently set.

b) A temperature-ready circuit prevents hydrogen turn-on until a safe temperature is reached.

c) Automatic shutdown of hydrogen and turn-on of nitrogen occurs if the flows are out of tolerance.

d) Various interlocks prevent the turn-on or turn-off of gases in the wrong sequence.

e) Hyoxcl gas panel is an H_2-O_2 oxidation gas control console with HCl capability. It provides for the manufacture and research of H_2-O_2 oxidations and incorporates the ability to add HCl to the diffusion furnace. It uses mass flow measurement and control with automatic shutdown to guard against dangerous gas mixtures. Safety features are included to minimize hazardous operation. The panel is designed for simplicity of setup and running; it should significantly improve quality and safety in comparison with water bubbler systems or systems which do not have mass flow control.

It is well known that the presence of water vapor increases the growth rate of thermally grown SiO_2 films. Most existing processes obtain the water vapor by bubbling oxygen through a flask of water that is maintained at a constant temperature. In contrast, Hyoxcl produces the water vapor in the furnace by reacting hydrogen and oxygen. This system has the advantages of better control, less contamination, more versatility and convenience, automatic operation, and the ability to record flow data.

Hyoxcl also adds HCl capability to the oxidation process. HCl acts as a getter to improve SiO_2 film purity and maintain cleanliness of the furnace tube. Normally, the flow rate of HCl is not critical and it can be regulated with a manual valve and rotameter. However, it is important to consider the corrosive nature of the HCl gas in the event of an external leak. In the Hyoxcl panel, all lines are stainless steel and all joints are either welded or sealed with metal-to-metal compression fittings except for the N_2 rotameter. It is therefore recommended that a mass flowmeter be used on the HCl line to give greater leak integrity. For more critical applications and for computer controlled systems a mass flow controller can be substituted.

f) The Hyoxcl system shall contain the following:

Automatic Mass Flow Control	Type 316 stainless steel construction
2 percent absolute accuracy	Safety engineered
0.25 percent repeatability	All interlocks included
Linear flow indication	HCl gettering
No moving seals	Proven components

g) The design relies on the measurement of the mass flow of oxygen and the control of the mass ratio of hydrogen to oxygen. It works as follows:

1) Oxygen mass flow is approximately set by a pressure regulator and needle valve. The exact mass flow is measured with a mass flowmeter.

2) The flowmeter output signal is used to control the flow of hydrogen, thus establishing the ratio of hydrogen to oxygen demanded by the Monitrol. Hydrogen mass flow control is accomplished by a mass flow controller. If the H_2/O_2 ratio cannot be maintained for any reason, an over-ratio control shuts off the flow of hydrogen when the ratio exceeds a preset value above the setpoint for 10 sec or more.

The setting of this control is made from behind the panel with a screwdriver adjustment. In addition, the main H_2 and O_2 shutoff valve switches are interlocked so that hydrogen cannot be turned on until the oxygen valve is opened. There is also a safety interlock which works from the furnace temperature signal to prevent hydrogen from being introduced until a temperature is reached which assures combustion of the H_2 and O_2 in the tube.

h) To insure that inadvertent, dangerous, or improper operation of the Hyoxcl oxidation system is prevented, certain safety features and interlocks shall have been designed into the operating sequence and logic:

1) In the event of a power failure, the H_2, O_2, and HCl will be automatically shut off and N_2 will purge the tube.

2) An under-temperature relay prevents H_2 from being introduced into the reaction unless the temperature at the injection point is more than 610°C. This assures, along with the O_2 flow safety, that combustion of the H_2 will take place and unburned H_2 will not accumulate in the tube or exhaust.

3) The H_2 and O_2 solenoids shall be interlocked such that the H_2 cannot be turned on unless the O_2 is on, and if O_2 is shut off the H_2 will automatically be shut off. In addition, the H_2/O_2 ratio shall be equipped with a high level out-of-tolerance feature which shuts off the H_2 flow if the H_2/O_2 ratio becomes richer in H_2 than the value set by the reference potentiometer.

4) The HCl shall be interlocked with the O_2 shut-off solenoid; therefore, the HCl cannot be turned on unless the O_2 valve is on. This prevents excessive HCl concentration in the furnace which can cause rapid deterioration of the quartz liner.

5) The H_2-N_2 plumbing shall be designed to avoid concentrations of H_2 gas downstream of the H_2 shut-off valve. When the H_2 is shut-off, a low N_2 flow automatically purges the manifold.

The basic Hyoxcl panel shall have a hydrogen mass flow controller and an oxygen mass flowmeter so that the H_2/O_2 mass ratio is always regulated. Additional lines shall be capable of being added for nitrogen and HCl later.

Automatic operation of the Hyoxcl system shall be possible using a programmer. This unit shall be designed to mount to the right or left side of the gas panel. It shall have the same panel height and matching decoration.

i) Specifications for the Hyoxcl system standard flow ranges are as follows:

Mass flowmeters 0 to 10,000 SCCM	Mass flow controllers 100.0 to 10,000 SCCM
Power Input	105 to 125 Vac, 60 Hz, single phase
Gas pressures	6 to 150 psig
Ambient temperature	40° to 110°F (5° to 43°C)
Mounting	Panel will be mounted on a vertical plane

C. Gas Doping Panels

The gas doping panels shall have the same packaging configuration (vertical mount) as the Hyoxcl panels. One system shall control phosphine, oxygen and nitrogen, and other diborane, oxygen and nitrogen. All mass flow controllers shall be used and each line shall have a manual shut-off ball valve to isolate the line in case of repair or maintenance. A solenoid valve shall be downstream of the flow controller. The gases flow to a common manifold.

1. Sintering Panel. The sintering or drive-in panel shall have an oxygen and a nitrogen loop. The configuration shall be the same as the two panels described previously.

2. Process Control Computerization. The processes taking place in the six furnaces shall be computer controlled thus emphasizing convenient effective controls and displays without sacrificing capability for powerful high-level computer interaction. The ability of the process operator to be automatically informed of emergency conditions, to quickly read selected parameters in engineering units, and to instantly take over manual control when required is considered vital. These functions cannot be effectively performed through the typical computer keyboard console, i.e., by the time messages are assimilated and a decoded response typed out the process may be lost (Fig. 10).

In most industrial computer process control systems installed to date, operator interface has been achieved through standard control panels using conventional annunicator lights, analog controllers, and

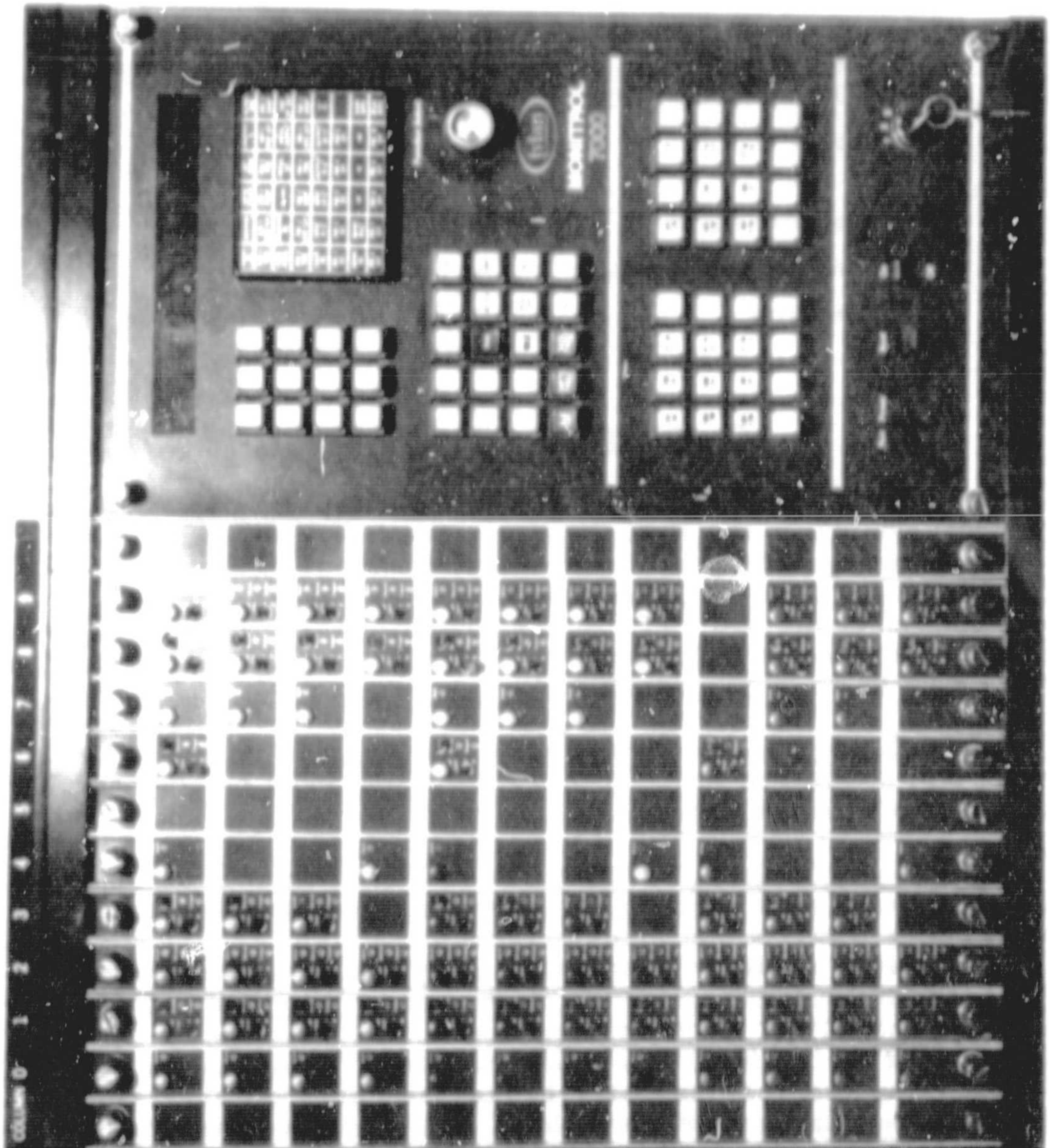

Figure 10. Mini controller for automated system.

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sometimes computer or manual controllers. Such systems, generally in the category of supervisory control, are usually large and expensive. The system shall provide set point monitoring and control with full self-contained manual backup, compact, unified, and exceptionally operator-oriented toward ease of understanding, acceptance, and use.

Two distinct categories of computer control function are as follows: the direct, on-line, repetitive, process loop control actions such as flow or temperature control, and the less frequent but more sophisticated optimization and business-oriented inputs to the process. Combining the two is seldom justified since it ties up expensive and powerful CPU's on highly repetitive tasks and complicates programming by getting these same tasks mixed up with high-level custom programming, data acquisition, and data analysis. Since the former should be programmed in assembly or even machine language to conserve processor time and memory space and the latter in high-level language to save programming time and cost, the two groups of functions are not very compatible. By using a dedicated microcomputer for the control functions and providing a serial communication link to an upstream general-purpose computer, an effective and economical computer control system for NASA semiconductor applications will prove to be most desirable.

A key factor in implementing this approach is the use of uniformly organized Control Point Data Tables (CPDT) to which the microcomputer refers during each loop service routine for setpoint limits, 3-mode control constants, rate or cascade multipliers, and so on. The CPDT also stores current operating loop conditions such as input value, alarm status, operating mode, and operator inputs. The upstream computer, therefore, must accomplish its end in the process simply by interrogating the microcomputer memory to find out what is going on, and by readjusting constants in memory to make the changes it has decided upon.

A complete computerized system (including system-tested hardware and software, provides installation supervision, start-up, and check out) shall be supplied and NASA shall be assured of a total functioning system. Each individual process shall be guaranteed to meet required specifications, and the vendor shall work with the equipment until diffusion or deposition process steps meet or exceed NASA requirements.

The system shall allow the retrofitting of existing equipment into a fully integrated computerized projection facility. None of the control functions and features nor any of the information management benefits shall be sacrificed by this approach.

The load and unload station for the automatic system for thermally grown oxides and diffusions are shown in Figures 11 and 12.

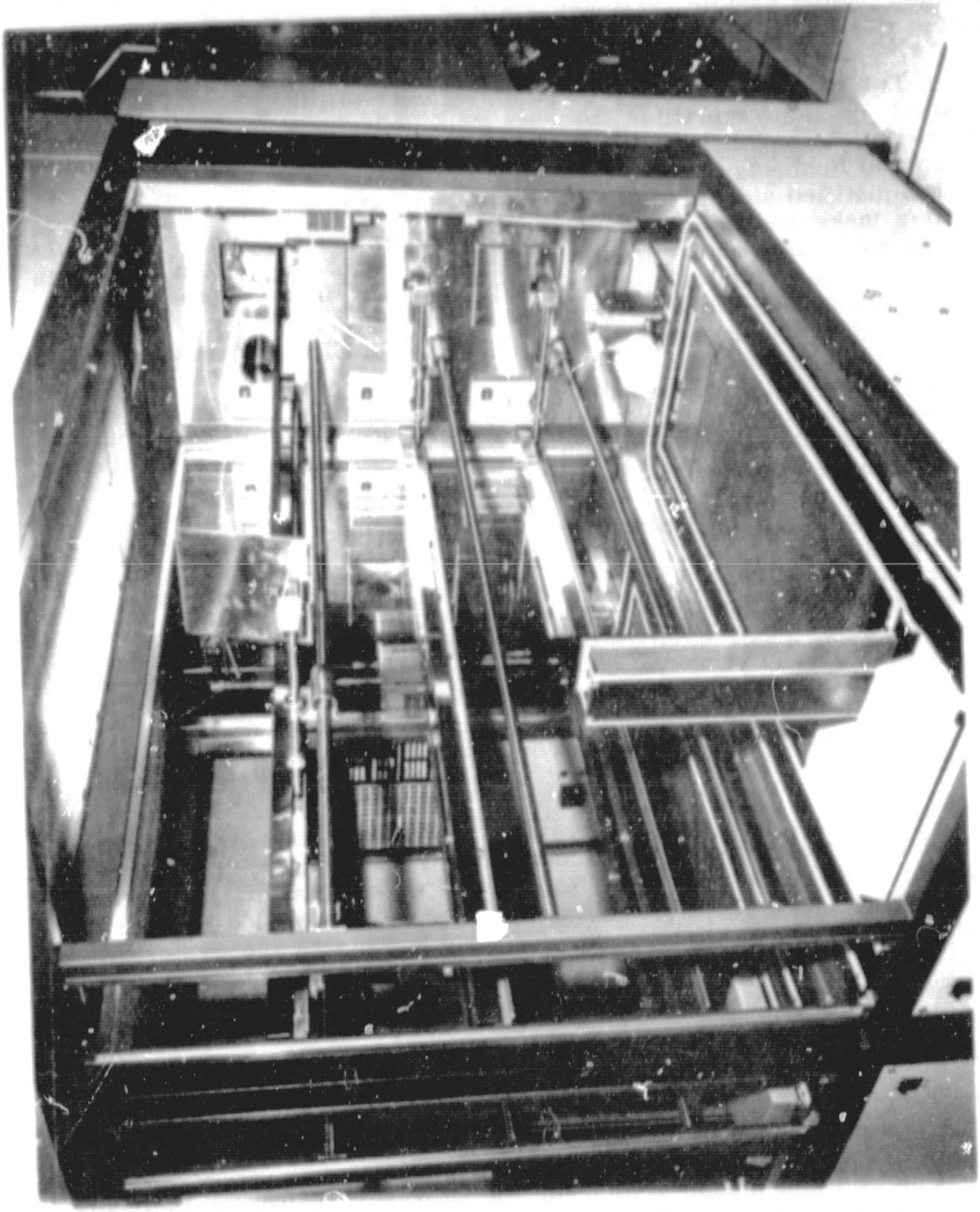

Figure 11. Wafer load and unload system.

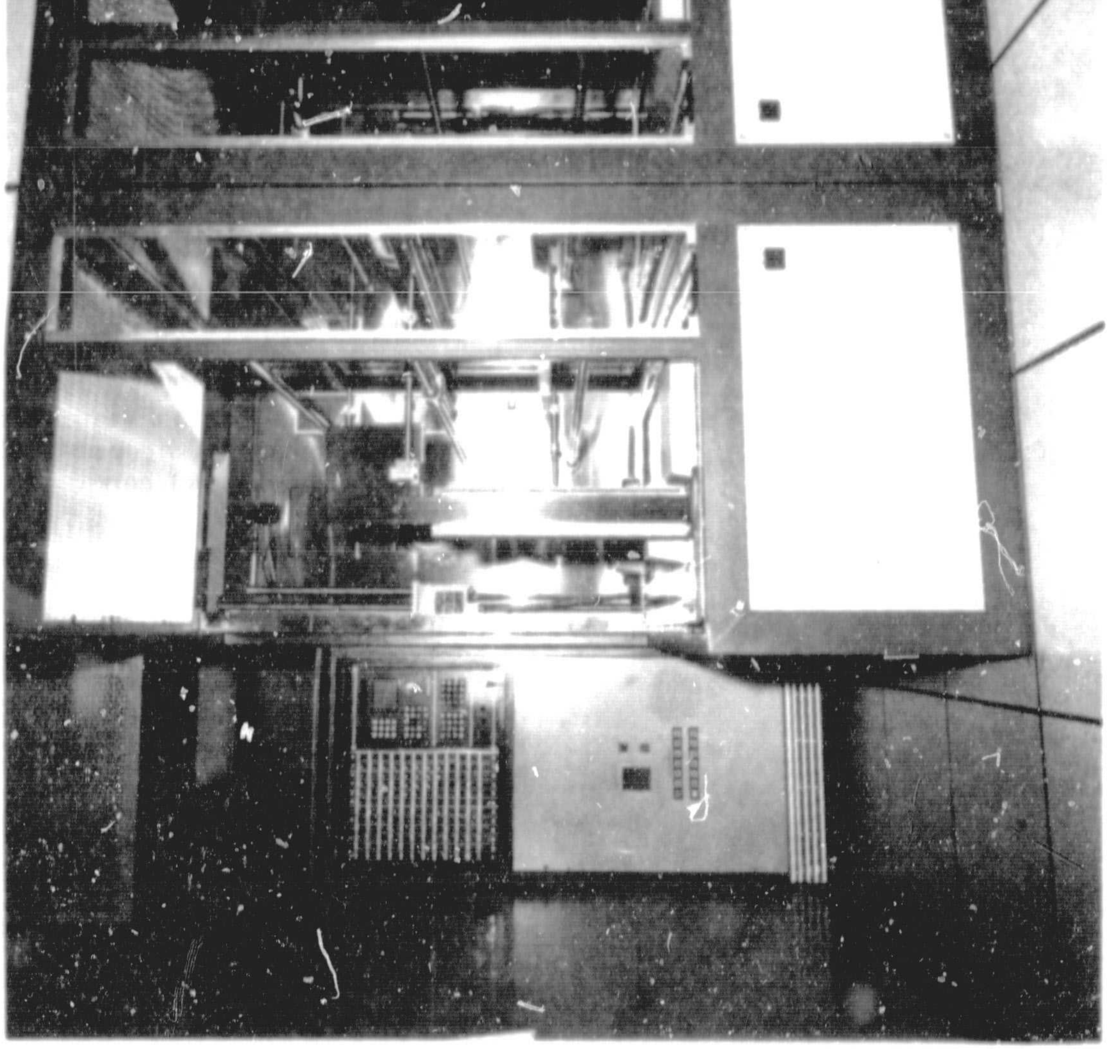

Figure 12. Wafer load station for automatic process of oxides and diffusions.

Specifications for the monitrol controller are as follows:

a. General

Control Points	12 to 120 inputs and outputs total, in sets of 12, analog or digital
Scanning Rate	60 input/output pairs of 60 inputs or outputs per second
Control Algorithm	Proportional + Integral + Differential (PID)
Control Modes	Direct, cascade, ratio, supervisory
Display	10 character numeric
Control Panels	1 to 5, each with 12 subsections. Typical Functions: Alarm indicator Auto/manual indicator Input signal indicator Output signal indicator Auto/manual switch Read input/read output SW
Operator Panel	Includes display for control point number and 5-digit parameter, 40-parameter selection switch and indicators, central alarm/acknowledge, and indicator/pushbutton switch array for complete control of process and stored operating control constants through computer.
Options Included	Optically coupled digital indicator/push button operator panel extension, up to 40 each inputs and outputs.
Software	Standard preprogrammed operating system for limit checking, three-mode control, cascade or ratio, alarm indication.

b. Electrical

Input Signals	All standard control signals, all standard thermocouple, and contact closures through system-supplied excitation voltage. System also supplies 24 V excitation for two-wire transmitters.

Resolution	1 part in 19999 full scale readout
Accuracy	±(0.1% + 20 uv RTI)
CMR	120 dB at 59 to 61 Hz
CM Voltage	500 Vdc or Peak ac
Output Signals	1.5 to 50 mA, 0 to 10 V. Contact closures - Reed Relay, dc, Contact rating 100 VA, maximum voltage 500, maximum current 2 amp.

c. Controller CPU

Computer	DEC PDP-8/A with selected options
Memory	8K core expandable to 16K
Work Length	12 bit
Cycle Time	1.5 μsec
Memory Options	RAM or ROM, 1K, 2K, 4K PROM 1K
Standard Features	Power fail/auto restart Memory extension control Bootstrap loader with 128 instructions Time share control Real-time clock
Interrupt	One level of priority interrupt, used to perform standard data acquisition, limit-checking, and control functions at precise 60/sec rate. All other peripheral functions on rotating, interruptable basis.
Software	Complete compatibility with PDP-8 family software plus complete controller operating package.
Options Included	Serial line interface Paper tape reader

d. Mechanical and Environmental

Cabinet	Enameled steel, totally enclosed, rack-mountable. Air internally circulated, cooling through external case convection.
Size	Panel 24-in. width × 21-in. height

External Wiring	To barrier-strip screw terminals inside of removable rear cover. Optional noise filtering installed as required in prewired modules.
Ambient Operating Temperature Range	-32° to 120°F

3. Furnace System Process Requirement Specification. All the furnace control equipment shall maintain the following process specification.

a) Oxidation – Thickness Uniformity
   ±70A°/run
   ±2 percent run to run
   25 to 100 3-in. wafer/run.

b) Doping – Uniformity when using PH_3 and B_2H_6.
   25 to 100 3-in. wafer per run
   ±5 percent doping uniformity within each run (5 to 20^ ohm/square range)
   ±3 percent run to run.

4. Furnace Control Source Cabinet. The source cabinets may contain all of the furnace controller equipment including computer and gas flow controllers.

The source cabinet design shall permit the diffusion tubes to be replaced by pulling them through the cabinet, providing the cabinets are behind the tubes. The gas panels may be mounted on the rear wall and accessible through the front or side. An internal door may isolate the furnace tube ends from the gas systems and form a vented compartment. When the door is opened, it can protect the gas system when a tube is pulled for service.

5. Outline of System.

Power Supply	3 each
Mass Gas Flow	20 each
Control Computer	1 each
Laminar Flow Cabinet for 3 tubes	2 each
Source Cabinets	2 each with 3 compartments
Gas Filters	8 each

6. Miscellaneous. Gas filters and dryers for each source cabinet shall be furnished. They shall be mounted on the top of the cabinet and plumbed to each panel. The use of this equipment shall appreciably prolong the time between regular maintenance procedures.

IV. SEQUENCE OF OPERATION OF THE AUTOMATIC LOADING STATION

A. Loading Sequence

The loading sequence is as follows:

1) Push BT RQST (X).

2) Horizontal B.P. (X) starts to pull and hits the out L.S. (S), B.P. (X) stops.

3) Claw opens, the vertical B.P. starts to come down.

4) It hits the vertical L.S. (X). The position L.S. on the claw is activated, the vertical B.P. stops.

5) Claw closes and the vertical B.P. starts going up with the boat.

6) Position L.S. is deactivated and horizontal B.P.(X) starts to push until the position L.S. is activated again, then it stops. The vertical B.P. is moving up all the time and the operation repeats until the horizontal B.P. hits the center L.S. (X).

7) The vertical B.P. goes up in a faster pace and the horizontal B.P. (X) continues to push in.

8) The vertical B.P. hits the upper L.S. and stops.

9) The horizontal B.P. (X) hits the in L.S. (X) and stops.

10) The vertical B.P. starts coming down.

11) It hits the B.T. limit switch and slows down.

12) It places the boat in the B.T. and the boat handle activates the position L.S. on the claw.

13) The claw opens and the carriage starts to go down with the boat.

14) The carriage stops at the bottom of the B.T.

15) The other B.T. starts to send wafers.

16) The wafer is caught in the boat and the carriage indexes up one slot.

17) The operation repeats until all wafers are received.

18) The carriage moves to the upmost position.

19) The claw closes and picks up the boat.

20) The vertical B.P. starts to go up until it hits the upper L.S. and stops.

21) The horizontal B.P. (X) starts to pull out.

22) It hits the middle L.S. (X) and stops.

23) The vertical B.P. starts to come down slow.

24) It places the boat onto the paddle and stops when the position L.S. on the claw is activated.

25) The horizontal B.P. (X) starts to pull out very slowly.

26) When the position L.S. deactivates, the vertical B.P. starts to drop again.

27) Operation repeats until either:

a) The horizontal B.P. (X) hits the out L.S. (X) and stops. The vertical B.P. continues to come down until it hits either the position L.S. or the vertical L.S. (X) and stops.

b) The vertical B.P. hits the vertical L.S. (X) and stops. The horizontal B.P. (X) stops at the same time.

28) Claw opens up and the vertical B.P. goes up to the top limit position.

29) The horizontal B.P. (X) starts to push in with the boat until it hits the in L.S. (X).

B. Unloading Sequence

The unloading sequence is as follows:

1) Push PCS END (X).

2) Same as A-2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13.

3) When the air sensor senses the wafer, the carriage stops and sends out a wafer.

4) The operation repeats until all the wafers are sent.

5) Same as A-14.

6) Same as A-18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29.

C. Oxidation and Diffusion Process System Documentation

3874-010	Installation Drawing	E		10- 7-76
3874-021	Schematic, Input and Output Bds.	E	3-shts	9 -24-76
3874-022	Schematic, Input Bd.	E	3-shts	9 -24-76
3874-023	Interface Bd. Ass'y	C		9 -27-76
3874-024	Wiring Schematic, E.E. Box	E		9 -29-76
3874-025	NASA PROM Bd.	D		9 -29-76
3874-026	Wiring and Sch. Hz Boat Pusher	C		10-18-76
3874-027	Wiring Sch. Position Sw. Hort.	C		10- 1-76
3874-028	Wiring and Dwg. Temp. Controller	C		10-15-76
3874-029	Wiring Dwg. Vertical Drive	D		10-18-76
3874-030	Schematic, Boat Pusher, Speed Cont.	D		10-18-76
3874-031	Computer Interface Bd. NASA I	D		4 -26-78
3874-040	Wiring Diag. Hort. Boat Pusher	C		8 -19-76
3874-041	Serial Interface Conn. NASA I	B		4 -25-78
3874-100	Parts List GPS-1010-1	B		3 -25-76
3874-101	Frame Ass'y	E	3-shts	3 -25-76
3874-102	Side Door Ass'y	D		3 -25-76
3874-103	Front Door Ass'y	D		3 -25-76
3874-104	Top Ass'y	C		3 -25-76
3874-105	Rear Ass'y	D		3 -25-76
3874-106	Source Cab. Ass'y, Right Hd.	D		3 -25-76
3874-107	Source Cab. Ass'y, Left Hd.	D		3 -25-76
3874-108	Heat Shield	C		3 -25-76
3874-109	Monitrol Cabinet Ass'y	E		4 -28-76
3874-110	Panel, Paper Tape Reader	D		6 - 1-76
3874-111	Input and Output Bd. Ass'y	C		8 - 3-76
3874-112	Process Tube, Cross Flow	E		7 -12-77

3874-113	Input and Output Bd. Ass'y	C		6 -27-78
3874-121	Detail, Load Station	E	3-shts	5 - 6-76
3874-122	Bracket, Support Shaft Bearing	C		4 -20-76
3874-123	Front Panel, Boat Pusher	C		4 -20-76
3874-124	Front Panel, Vert. Drive	C		4 -20-76
3874-126	Shaft, Support	C		4 -20-76
3874-127	Shaft, Vert. Drive	C		4 -20-76
3874-128	Access Panel	C		4 -20-76
3874-129	Bracket, Support Shaft	C		4 -20-76
3874-131	Hort. Drive Switch Brkt.	B		5 -17-76
3874-132	Hort. Drive Support Mtg. Plate	B		5 -17-76
3874-133	Hort. Drive Cover	D		5 -17-76
3874-134	Cover, Vert. Drive	D		5 -17-76
3874-135	Support, Shaft, Vert. Drive	C		5 -17-76
3874-136	Plate, Switch Mtg. Vert. Drive	B		5 -17-76
3874-137	Bracket, Sw. Mtg., Vert. Drive	B		5 -17-76
3874-138	Plate, Guide, Vert. Drive	B		5 -17-76
3874-142	Boat, Auto-Load	D		7 -14-76
3874-143	Panel Enclosure Modification	C		9 - 2-76
3874-144	Heat Shield	C		5 -17-76
3874-145	Air Strip	D		5 -20-76
3874-146	Base Pla'e, Corner	D		5 -20-76
3874-147	Corner Plate	C		5 -20-76
3874-148	Base Plate, Wafer Carrier	C		5 -20-76
3874-149	Holder, Air Strip	C		5 -20-76
3874-150	Outer Corner Guide	C		5 -20-76
3874-151	Inner Corner Guide	B		5 -20-76
3874-152	Guide Strip	B		5 -20-76
3874-153	Carrier Side, Outer	C		5 - 6-76
3874-154	Carrier Side, Inner	C		5 - 6-76
3874-155	Bracket, Carrier Side	C		5 - 6-76
3874-156	Shaft 25 in., Vert. Drive	B		5 -17-76
3874-158	Bracket, Speed Control	C		8 - 2-76
3874-159	Cover, Speed Control	C		8 - 2-76
3874-160	Shaft, Speed Control	B		7 -22-76
3874-169	Chassis, Control Logic	D		6 -10-76
3874-170	Support	C		5 -27-76
3874-171	Guide, Vertical — Wafer Boat	D		6 -23-76
3874-172	Guide Block, Front	B		6 -23-76
3874-173	E/E Compt.	D		8 -19-76
3874-174	W/D — Vertical Drive Assembly	C		3 -14-77
3874-175	Guide, Wafer Carrier	C		6 -17-76
3874-176	Bracket, Wafer Carrier	C		6 -17-76
3874-177	Wheel, Wafer Carrier	B		6 -17-76
3874-179	Clamp, Narrow Flange	C		6 -18-76
3874-180	Clamp, Wide Flange	C		6 -18-76
3874-181	Shaft, Clamp	C		6 -18-76
3874-182	Extension, Shaft	B		6 -18-76

3874-183	Bracket, Switch Mtg.	B	6 -18-76
3874-184	Bumper, Actuator	B	6 -18-76
3874-185	Bracket, Inlet	C	6 -21-76
3874-186	Pad, Vertical	B	6 -23-78
3874-187	Guide Block, Rear	B	6 -23-78
3874-188	Plate, Slide Mtg.	B	6 -29-76
3874-189	Angle, Side Mtg.	C	6 -29-76
3874-190	Panel, Conn.	C	6 -28-76
3874-191	Front Panel, E/E, Compt.	C	6 -27-76
3874-192	Adapter, Front Guide Block	B	7 -14-76
3874-193	Spur Gear Modification	B	7 -14-76
3874-162	Conduit, Vert. Dr.	C	5 -17-76

APPROVAL

THERMALLY GROWN OXIDES AND DIFFUSIONS FOR AUTOMATIC PROCESSING OF INTEGRATED CIRCUITS

By Bobby W. Kennedy

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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