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# NASA TECHNICAL MEMORANDUM



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## CHEMICAL ETCHING FOR AUTOMATIC PROCESSING OF INTEGRATED CIRCUITS

By Bobby W. Kennedy  
Electronics and Control Laboratory



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## TECHNICAL MEMORANDUM

# CHEMICAL ETCHING FOR AUTOMATIC PROCESSING OF INTEGRATED CIRCUITS

## PART I: CHEMICAL ETCHING

### A. INTRODUCTION

To produce repeatable high-quality integrated circuit patterns on either metal or insulating oxides by using corrosive acid as the etchant requires a highly controlled process which had to be automated. Integrated circuit wafer etching has been a lagging technology in most semiconductor processing. About 85 percent of wafer etching is performed manually by an operator-oriented method classified as a bench operation.

### B. WAFER ETCHING TECHNIQUE - "DIP AND DUNK"

In this method, open Pyrex or quartz beakers and, in some cases, plastic tanks are filled with acid etchant. For etching silicon, these beakers may contain nitric acid and hydrofluoric acid, while oxides are etched with buffered hydrofluoric acid, and silicon nitride with boiling phosphoric acid. The operator's task involves manually transferring a basket of wafers in and out of the various beakers (including DI rinse) at timed intervals, usually between 20 sec. and 20 min. This operation, often termed "dip and dunk" appears crude and hazardous against the general backdrop of sophisticated semiconductor technology. Seven chemical dip positions are arranged around a cascade rinse assembly so that wafers withdrawn from an etching dip by an operator are always immediately accessible to a rinse tank. The purpose of the automated etching equipment is to eliminate this archaic step in the process.

## PART II: AUTOMATIC IN-LINE CHEMICAL ETCHING

### A. INTRODUCTION

The Fluorocarbon Model 4000 can handle a wide range of processing tasks, such as oxide and metal etching, cleaning and photo-resist stripping. Figure 1 presents the Automatic Wafer Etch System. All processes become completely automatic and extremely accurate, since synchronized timing and transfer mechanisms perform the required functions according to the set process sequence — from self-loading to unloading. Modular system design and optional accessories allow for adaptation to solution temperature control, nitrogen agitation, various process tank materials, solution heaters and deionized water flow control. All features are geared to increase output, insure quality, and give complete control in the processing.

### B. WAFER ETCH LOAD AND UNLOAD

Wafers are loaded into (25 slot) teflon carriers and placed in the holder of the etch station. Two carriers at a time are moved through the process by a walking beam for each etching process. The time spent in each etching solution is programmable and the system is equipped with an ion resistivity meter in each water rinse tank to insure that all ion contamination from the previous etch process has been removed.

### C. DESIGN AND PERFORMANCE FEATURES

- a. Built-in fume exhaust and solution drain plenum with recess-mounted tanks.
- b. Setting the timer for automatic load stage starts the carrier process sequence.
- c. Timer dials provide independent settings for each tank. New process times can easily be dialed in.
- d. Modular slide-out control panels with push button process function switches permit easy servicing and fast control changes. Sensors (operating by nitrogen fluidic pressure or air fluidic pressure) and electronic switches eliminate all micro or mechanical switching devices near the process environment.
- e. Process rack designs are available for a number of different carrier types.



Figure 1. Automatic Wafer Etch System.



f. Epoxy-coated cabinet. Stainless steel and modern plastics used throughout the system insure long-lasting performance.

g. Transfer mechanisms are enclosed in easy-access modular stainless steel housings. Each mechanism features a slip clutch to guard and to provide operator safety.

h. The unloading stage can be set to be completely automatic with audiovisual alarms signalling "full load" condition.

i. Touch-lock doors allow easy access to plumbing and system interiors. The unloading station can also be used as a temporary holding chamber. Carriers are easily removed at the operator's convenience.

The system is automated for air track inline operation; however, computer control for the system is being worked out for total automation. The design uses a standard buffer T for loading wafers into the Teflon carriers. Figure 2 presents the automatic Teflon carrier transport, and Figure 3 presents the automatic wafer transfer system. These carriers are picked up using two digital control furnace loaders and are lowered onto the rack which is supported by the walking beam. Figure 4 presents the sequence for the automated etch system.

The "dry" technique of plasma-etching eliminates all the problems associated with the handling and storage of chemical etchants. Plasma is created by coupling RF energy into a gaseous atmosphere. The resulting high-energy species thus created erode (etch) the wafer's surface. The perforated metal cylinder confines the plasma glow to the external volume and results in lower processing temperatures and better wafer protection. Presently, the etching in the Hands-Off facility is wet processing. However, several processes may be better adapted to plasma-etching such as photoresist strip than to wet chemistry. This process will be investigated and may be incorporated in several process steps.

Equipment-wise, semiconductor wafer etching is a lagging technology in most semiconductor processing. About 85 percent of wafer etching is performed manually by an operator-oriented method classified as a bench operation. In this method the operator transfers a basket of wafers or a single wafer using a special holder in and out of strong acid solutions to remove unwanted oxides, silicon nitride, etc., that have been left exposed after the masking operation. The wafers are rinsed using distilled or deionized water to remove the acid solutions. This entire process is performed at various time intervals, usually between 20 seconds and 20 minutes. This operation is crude and hazardous against the general backdrop of sophisticated semiconductor technology. The purpose of the automated etching equipment is to eliminate this archaic step in the processing and to obtain better control over the etching process, thus insuring more reliable integrated circuits.

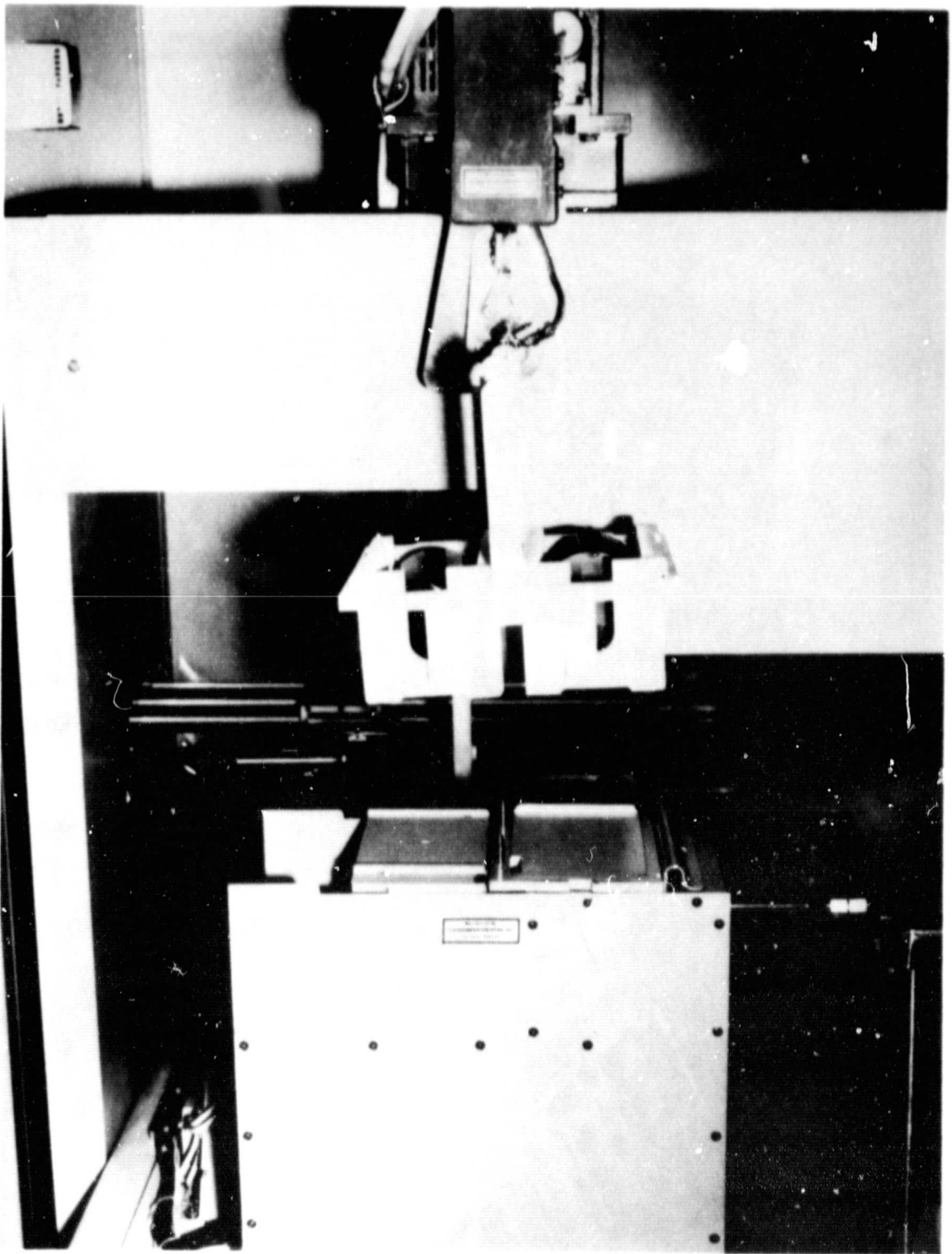


Figure 2. Automatic Teflon carrier transport.

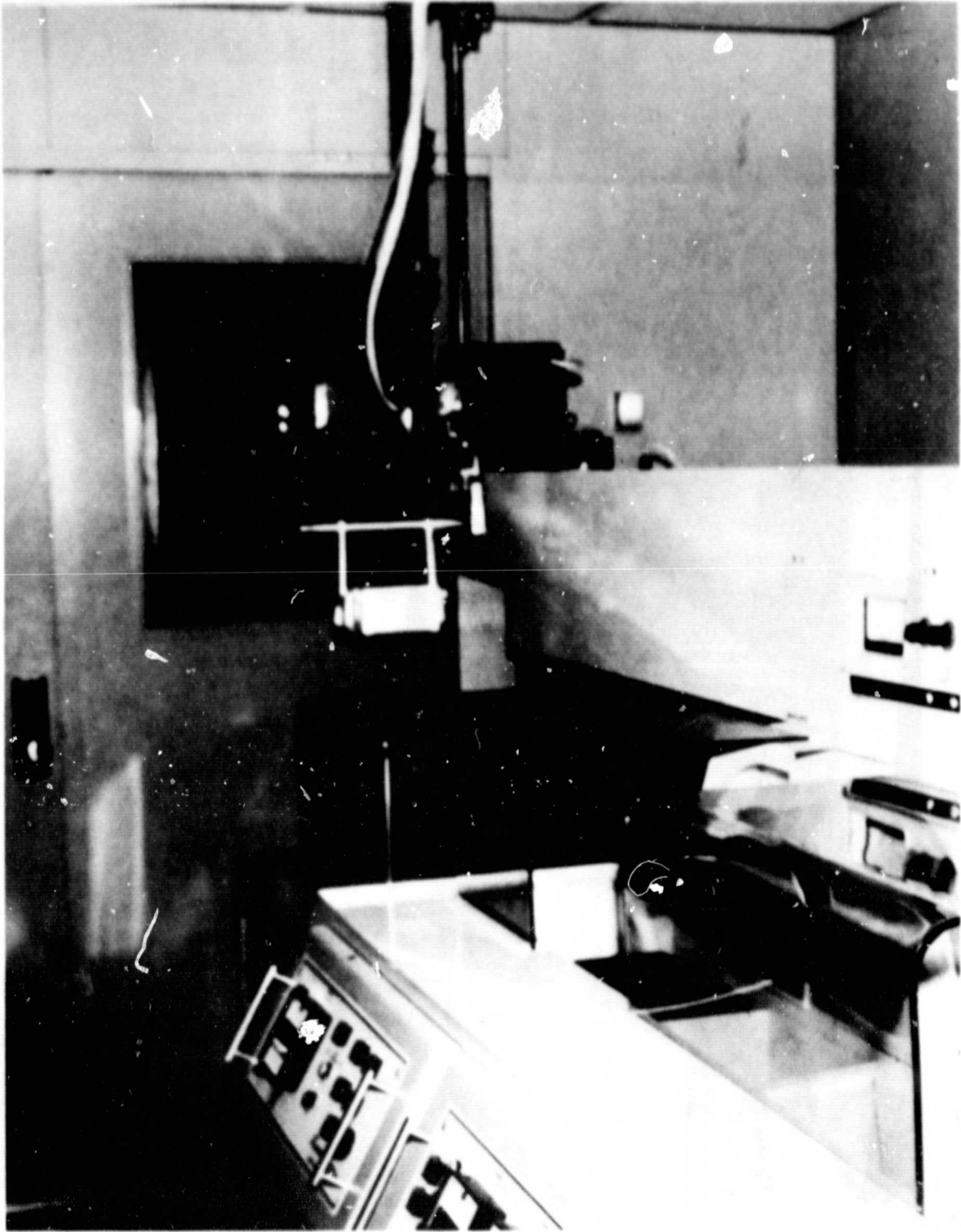


Figure 3. Automatic wafer transfer system.

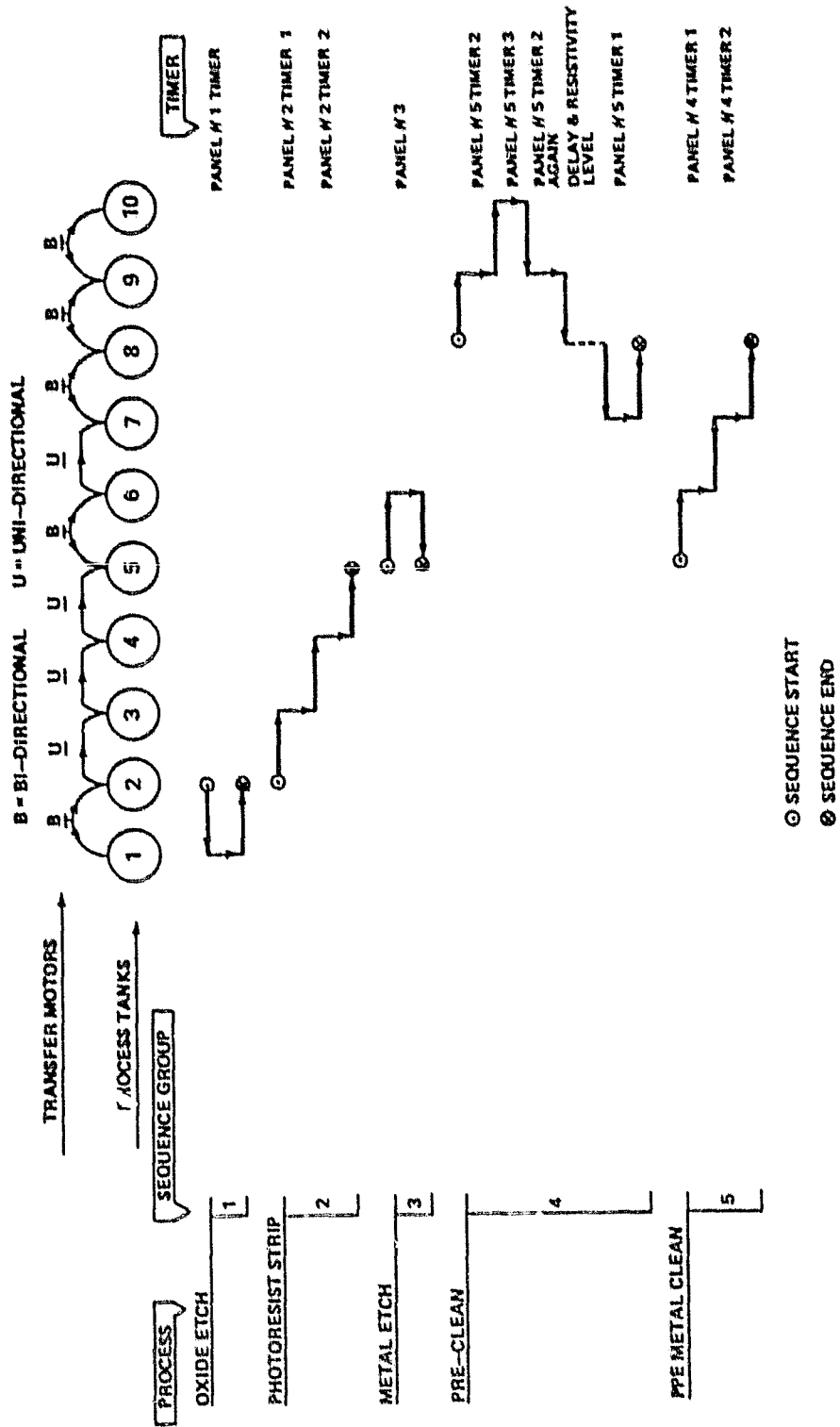


Figure 4. Sequence for automated etch system.

#### D. AUTOMATED ETCH SYSTEMS

The mechanized equipment presently available for chemical etching (the "wet" process, as differentiated from the "dry" process of plasma etching) consists of walking-beam systems, in-line sprayers and centrifugal sprayers.

The walking-beam system, as shown in Figure 5, involves the same principle as manual dip etching but eliminates operator dependency in transferring the wafer basket at specified intervals. In this system, a mechanical arm lifts the wafer-filled basket from or lowers it to the appropriate etching tank. Movement of the mechanical arm, or walking beam, is controlled by an automatic timing system.

The advantage of such a system, from the wafer fabricator's point of view, is that it closely duplicates the manual dip and dunk method, and there are no significant changes in the established processing technology. The system simply offers a mechanized version of dip etching.

The disadvantage remains in that it is still an "open" system and has exposed tanks of acid. The entire machine must also be protected against the detrimental effects of acid fumes, hence the extensive use of plastic parts and epoxy-coated metal structural members.

In-line spray etching systems which convey single wafers or groups of wafers through etching, cleaning, and drying chambers are available as a single-tray, conveyORIZED spray etcher or as a high-volume in-line processing version. The latter is presently being adapted by the supplier for automatic wafer handling. At present, this machine can automatically etch and rinse but will eventually be able to process wafers from a cassette to a tray, carrying them through etch and rinse and dry cycles, and then transferring them from the tray back to the cassette.

#### E. WET VERSUS DRY

Semiconductor etching has been performed via the "wet" method since the very beginning of semiconductor processing. By choosing the proper chemicals, any material used in wafer fabrication can be etched successfully. The batch or in-line chemical processes offer a high rate of throughput. Some additional advantages of the wet process are as follows: (1) with the appropriate venting and safety controls, almost any etchant can be housed in a clean-room atmosphere; (2) chemicals can etch deeply into any material, and etch rates are generally faster than with plasma etching; and (3) specific acids can be chosen to etch one material without etching adjacent materials.

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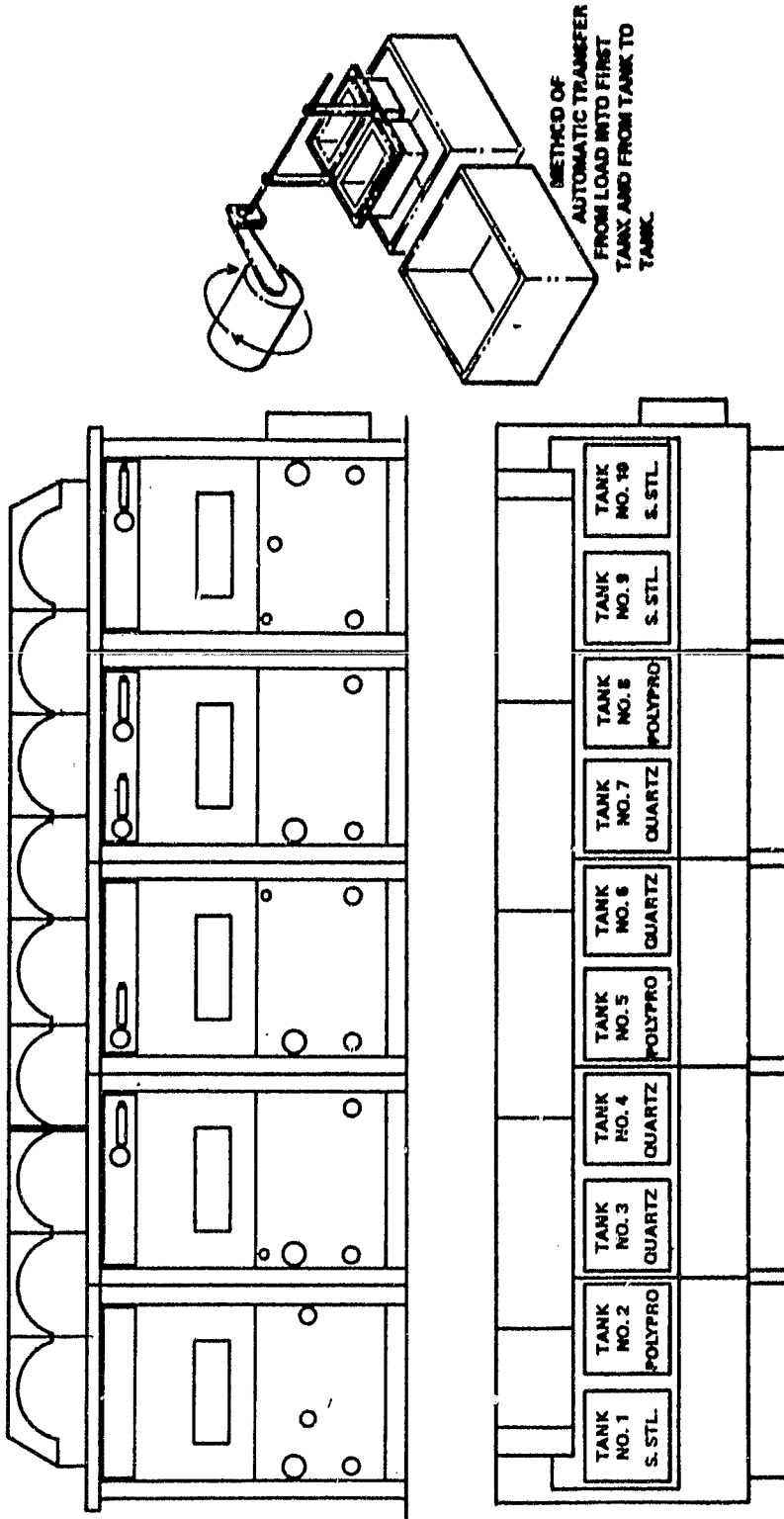


Figure 5. Automated etch system.

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Chemical etching, however, does possess some inherent disadvantages, such as the following: (1) Procurement, storage, handling and disposal of chemicals are expensive, troublesome and hazardous; (2) the space requirement is excessive for wet benches, automated equipment and chemical storage; and (3) chemical purity is of constant concern.

The "dry" technique of plasma etching eliminates all the problems associated with chemicals. In the system the plasma is created by coupling RF energy by means of an impedance-matching network into a gas such as Freon-14 (carbon tetrafluoride) at a pressure of about 500 mm. The highly energized particles thus created are utilized to react with the substrate to be etched. The volatile products of the reaction are removed from the chamber by the vacuum pump.

Various other types of gases, or mixtures of gases, are employed for etching specific materials. For example, LFE's patented method for etching silicon nitride is based on the simultaneous, inductively coupled RF discharge through a binary mixture of oxygen and tetrafluormethane ( $\text{CF}_4$ ).

Plasma etching is commonly used to pattern such materials as thermally grown  $\text{SiO}_2$ , deposited  $\text{SiO}_2$  (both doped and undoped), silicon nitride ( $\text{Si}_3\text{N}_4$ ), polycrystalline silicon, single-crystal silicon, tantalum, tantalum nitride, tantalum oxide, molybdenum, tungsten and other metals.

Many of the previous problems associated with plasma etching, such as overheating, wafer damage and overetching, have been alleviated by improvements in reactor design. One improvement is the use of a perforated metal cylinder which creates a zone of evenly dispersed, electrically neutral, active particles and results in a substantial reduction in wafer temperature during etching. Confining the plasma glow to the volume external to the perforated cylinder also has reduced the surface damage caused by UV radiation and electric charges.

Earlier plasma systems were unable to completely etch silicon nitride and silicon dioxide layers without causing subsequent etching of the silicon surface. There are now some exotic means to achieve better control. For example, Tegal's reactor uses a photocell detector which monitors the gas and essentially measures the intensity of light in the discharge. This allows a means to differentiate between the spectrum of the various materials being etched. The system is sensitive to any changes which are indicative of etching through one layer into another.

One of the prime applications of plasma etching, and where the process offers an obvious advantage, is in the etching of silicon nitride ( $\text{Si}_3\text{N}_4$ ). Chemical etching of silicon nitride requires the use of hot phosphoric acid. The 100°C temperature of the acid necessary to achieve an etch rate of 100 Å/min is attained by increasing the  $\text{H}_3\text{PO}_4$  concentration in standard phosphoric acid through a decrease in the amount of water, or by the addition

of phosphorous pentoxide. The harshness of chemical etching requires the use of an oxide rather than a photoresist mask. In contrast, the low-temperature, highly reactive plasma permits the use of a normal photoresist masking process combined with an etching rate of 800 to 1200 Å/min.

## F. CLEANLINESS AND SAFETY

Cleanliness and safety are the biggest factors involved in designing today's chemical etching systems. Cleanliness is necessary for maintaining high yields, and safety is a prime requisite for satisfying OSHA guidelines. These factors indicate the desirability of replacing the dip-etching operation with some form of mechanization which provides the necessary controls.

The following is a list of specifications for the Model 4000 Automatic Process System for Semiconductor Wafers.

### SPECIFICATIONS

#### Electrical System

Voltage 115 Vac, 60 Hz  
220 Vac, 50 Hz

Amps 20

Add 15 amp for each temperature  
Controlled tank.

#### Liquids

DI Water, 2 gpm per tank, 10-30 psi, 1/2 in. NPT  
Plenum Main Drain 1-1/4 NPT  
Acid Drain 1/2 NPT

#### Gases

Nitrogen 40 psi, 3/8 NPT  
Exhaust 200 cfm per module minimum  
Weight 325 lb/module

### Rinser - Dryer

After etching has taken place the wafers are placed in the Fluorocarbon Model 1500 Rinser Dryer (Fig. 6) and rinsed and then dried; all taking place in the same 25 wafer Ticon carriers that etching occurred in. This system does not have automatic handling for wafer loading and unloading; however, a design may be worked out in the near future. The system does have the following important features:

- 1) Kynar coated lid for added rust prevention.
- 2) Improved safety interlock latch assembly prevents opening of lid while rotor is turning.



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Figure 6. Wafer dryer and rinser.

- 3) Silicone rubber encapsulated lid heating assembly eliminates "fallout" into bowl.
- 4) Teflon spray manifold with 3/16 stainless steel nozzles for maximum rust prevention.
- 5) Stainless steel bowl with electropolished interior and kynar coated exterior surfaces for maximum resistance to rust and corrosion.
- 6) Dynamically balanced, electropolished stainless steel rotor. Available with both tilt back and fixed holders. Four wafer carriers of any design may be accommodated at any one time.
- 7) Double O-ring, spring loaded motor bearing assembly eliminates unwanted spilling of seal material into bowl.
- 8) Gasketed flush mount assembly with built-in vibration isolators.
- 9) Remote mountable start-stop switch panel.
- 10) High accuracy rinse and dry cycle timers.
- 11) Motor speed tachometer.
- 12) Rinse and dry cycle motor speed setpoint potentiometers.
- 13) High reliability solid state motor speed controller.
- 14) Control switches and cycle indicator lights.
- 15) Load imbalance sensor shuts off unit in case of out of balance load condition.
- 16) Compact flush mount design.
- 17) Vibration isolation installation.
- 18) Adaptable to any size carriers.
- 19) Plug-in timers.
- 20) Cycle light indicators.
- 21) Push button lighted switches.
- 22) Automatic reset.
- 23) Rinse/dry or dry only functions.
- 24) Dynamic electrical braking.
- 25) Remote operator controls.
- 26) Safety interlock door switch.
- 27) Safety door lock.

The Model 1500 covers a wide range of rinsing and drying requirements. It integrates automatic timing and solid-state controls, along with a compact centrifuge unit. This centrifuge can be recessed mounted into a vibration-free assembly for efficient rinsing and drying of silicon wafers.

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Wafers are thoroughly cleaned by rotating through a low RPM random spray pattern and a continuous spray of fresh DI water.

The combination of centrifugal force and heated nitrogen results in complete fluid run-off and fast, efficient drying.

The following are specifications on the rinser-dryer (Fig. 7).

General:

Rinse Cycle	—	Variable 0.500 rpm
Dry Cycle	—	Variable 0-2000 rpm
Rinse Time	—	0.6 min (other ranges optional)
Dry Time	—	0-6 min (other ranges optional)
Weight	—	100 lb

Plumbing:

DI Water	—	20-40 psi—3/8 NPT
Nitrogen	—	0-50 psi—3/8 NPT
Drain	—	1-1.2 in. I.D. Tube

Electrical:

Power	—	115 Vac 60 Cycle 10 amps
	—	230 Vac 50 Cycle

Materials:

Bowl	—	Stainless Steel -- Kynar coated exterior Electro-polished interior.
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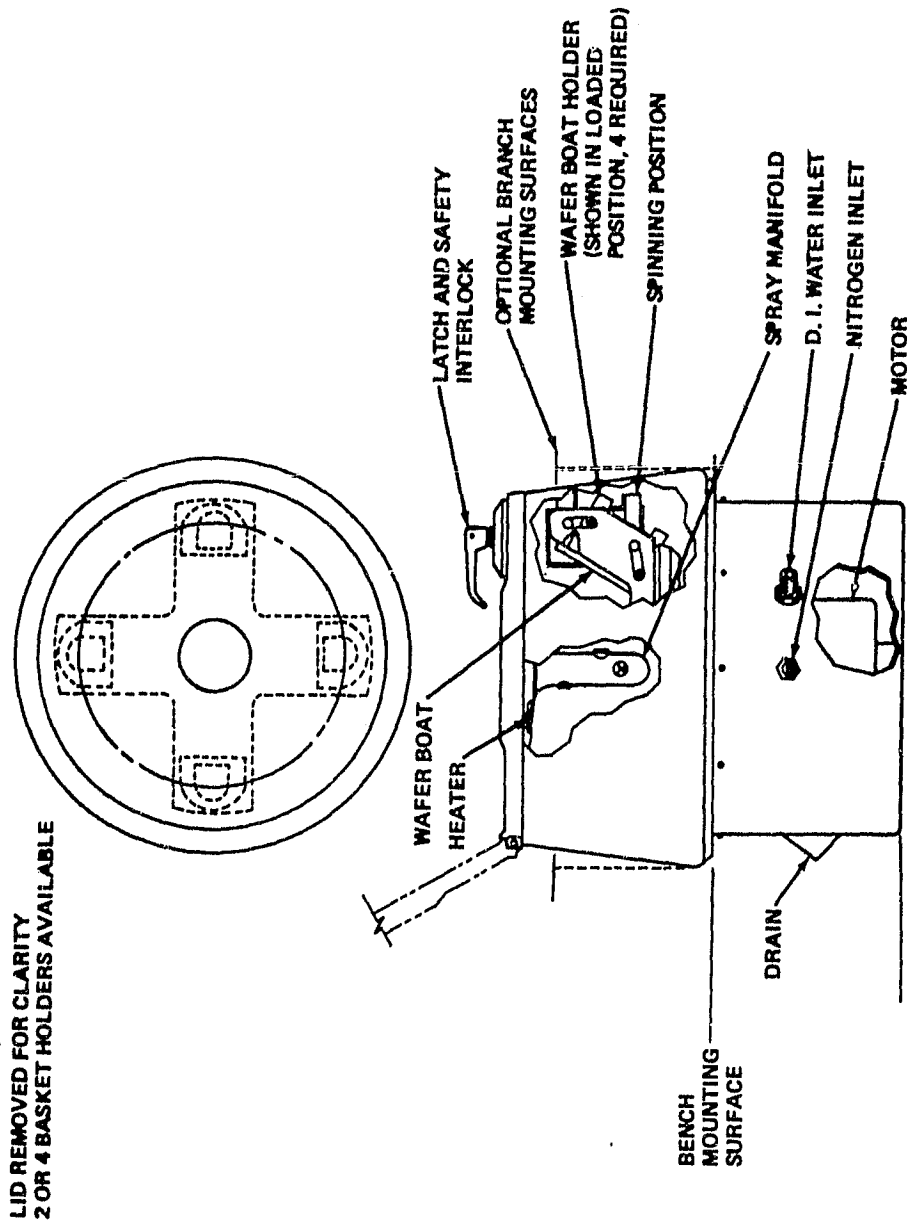


Figure 7. Rinser-dryer.