UNIVERSITY OF CENTRAL FLORIDA
COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

EEE5356
SOLID STATE DEVICE FABRICATION

Laboratory Manual

Spring 2009

I. ACKNOWLEDGEMENTS

This laboratory has been developed over the past eight years through the efforts of many different faculty and students. Every student who has worked in the laboratory as a teaching assistant or through management has made important contributions that have greatly aided in the development of the laboratory. Therefore, it is a pleasure to acknowledge the following people who have made significant contributions to the EEL 5355 Solid State Device Fabrication class and to the development of the microelectronics facilities at the University of Central Florida:

Students

Ben Abbott	Kwang Lee	Sara Rogers
Jeff Abbott	Faheem Mohamedi	Kara Salvo
Mary Angello	Seshan Sekariapuram	Hayden Hontgas
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Ramzi Delpak	Melanie West	Erica Wells
Jeanne Gallagher	Ray Yap	Daniel Gallagher
Scott Knapp	Alex Zajac	

Faculty and Staff

Kevin Casey	Sam Richie
J.J. Liou	K.B. Sundaram
Don Malocha	

Thanks to everyone,
Donald C. Malocha
Professor

II. INTRODUCTION

A. Requirements

You must have a lab notebook. This is bound and no spirals. It is used to take notes and write down procedures. Please read procedures for experiments prior to the lab. Labs will usually run the entire lab period and sometimes longer. Your lab notebook will be used for logging data, notes, observations, etc. during the completion of each experiment. Each page used in the lab notebook should be numbered and dated (at the time entries are first made). Your lab notebook must be available for review by the lab instructor.

B. Experiment Logbook and Laboratory Report

A LAB REPORT is required for each experiment and each student must write up his/her own lab report independently. Every laboratory report will consist of a:

1.) Title Page: Information that includes the laboratory experiment, your name, the dates over which the experiment was performed, and your laboratory instructor. This should be on one, single page.

2.) Introduction of the experiment performed in you own words.

3.) Procedure: Recorded as the laboratory progresses. Every detail concerning the lab should be recorded in this section including bake, processing, spinning, etc., times should be recorded. Every step should be recorded. This is very important for the instructor so that in case of problems, he or she can review the steps and see if an error has occurred.

4.) Data and Calculations: Usually detailed in the lab report, but should include all times, temperatures, flow settings, etc. Include all calculations, times, measurements, etc. This section should **not** be a reiteration of all material in the daily routine. This section should be a recap, a brief summary, of the daily routine. An example is the time, temperature, and gas flow settings for a diffusion process step. Include in this section all graphs, tables, and drawings necessary for a complete understanding of the process.

5.) Questions: Copy each question and answer them neatly and concisely. The questions are meant to have you ask yourself what you have learned in this experiment. Some questions are on fundamental principles, some are on your measurements, and others are trying to lead you to think about what you have done for the experiment.

6.) Conclusion: The student should discuss any results, problems, observations, etc. Comment on equipment and process used. This part of the report is the discussions and conclusions. In this portion of the report you will discuss what you have accomplished, what you may have learned or thought interesting, what you had problems with in the experiment, or any other conclusions or discussion you think would be of interest to the instructor or yourself in the future.

7.) Appendices: A machine photocopy of your Lab Notebook pages as the LAST appendix. The Appendices may only consist of one appendix or it may have several. At the very least, it should have a copy of your lab notes for which the report is being written.

C. Lab Grading

The lab is worth 700 points. Usually it consists of a large portion of the final grade in the class itself so the labs are graded diligently. The 700 points is broken down in the following distribution:

Lab 1: Vacuum System Familiarization Experiment -- 100 points
Lab 2: Photoresist Processing and Oxide Etch -- 100 points
Lab 3: Single Diffusion Experiment (MOSFET) -- 200 points
Lab 4: Double Diffusion Experiment (BJT) -- 200 points
Discretionary Points -- 100 points

The discretionary points are based on lab performance. Possible scenarios that would include a deduction of points are as follows:

1. Not wearing gloves or general chemical safety violations
2. Lateness to lab
3. Processing errors that were not verified with instructor
4. Not verifying all temperatures, pressures, etc for a given process
5. Any step or behavior that is detrimental to the lab

LABORATORY REPORT 1: VACUUM SYSTEM

Procedure: 32 points
Data and Calculations: 1. 10 points
2. 16 points (8 combinations)
Questions: All questions are worth 3 points except #8 (worth 6 points).
Total: 27 points
Conclusion: 5 points
Lab Notes: 10 points

Total for the LAB # 1: 100 POINTS

LABORATORY REPORT 2: PHOTORESIST PROCESSING AND OXIDE ETCH

Procedure: 33 points
Data and Calculations: 1. 5 points
2. 5 points
Questions: All questions are worth 3 points
Total: 42 points
Conclusion: 5 points
Lab Notes: 10 points

Total for the LAB # 2: 100 POINTS

LABORATORY REPORT 3: SINGLE DIFFUSION EXPERIMENT

Procedure: 35 points
Data and Calculations: 1. 10 points
2. 15 points
3. 10 points
4. 10 points
5. 15 points
6. 15 points
7. 20 points (10 each for a and b)
8. 5 points
Total: 100 points
Questions: All questions are worth 5 points
Total: 50 points
Conclusion: 5 points
Lab Notes: 10 points

Total for the LAB # 3: 200 POINTS

LABORATORY REPORT 4: DOUBLE DIFFUSION EXPERIMENT

Procedure: 20 points
Data and Calculations: 1. 10 points
2. 20 points
3. 10 points
4. 10 points
5. 20 points
6. 20 points
7. 15 points
Total: 105 points
Questions: All questions are worth 5 points
Total: 60 points
Conclusion: 5 points
Lab Notes: 10 points

Total for the LAB # 4: 200 POINTS

D. Laboratory report format

Use a 12-point font, preferably Times New Roman for the typed part of your report. Use single-space paragraphs with one line between paragraphs. Reports should be one-sided pages (blank on reverse side).

You may share data from the lab experiments, but you may not share reports. Identical reports between students will be given identical grades... If you share data, be certain to reflect the data as "shared" (identify where the data came from, i.e., whose notes were they?) in your lab notebook. DO NOT machine copy other students' notes and include them as part of your report - you *will* penalized for this. Hand-copy ONLY the lab notes you need from other students into your own lab notebook. Then machine copy your handwritten lab notes and include them as the last appendix of your report.

All data taken in this course is required to be recorded in your laboratory notebook. Since data has no correctness, i.e., whether it is right or wrong, but merely a recording of the facts, it is important that you record all pertinent observations, recordings, and data. This includes such items as settings of dials, temperatures or readings off scales, as well as any observations made while conducting the experiment. As an example, if you were running an oxidation experiment, you would typically write down the temperature of the furnace, the length of time you were in the furnace, the gases flowing in the furnace and their rates, the material put into the furnace, the rates at which you pushed the material in and out of the furnace, and the color of the material after it was finished.

This section of the laboratory book will be graded based on completeness, not necessarily on there being a correct answer to the data, since everybody's experiment will probably be slightly different.

During the laboratory you will continue to record all of your data and observations in ink. If, after recording data, you find that you recorded it in error, do not erase the data and do not scratch it out such that it is illegible. The proper form for taking data is to put one line through it so that you know the data is incorrect. Then follow with the corrected data. The reason for this is that although at the time you may think your data is in error, you may find after completing the experiment and taking all other subsequent data that your reasoning for thinking it was wrong was in error. This happens very often when practicing engineering.

The second part of the laboratory recording is the formal laboratory report. In this section, you are writing a summary of the data and observations in a neat and cohesive manner. The purpose for this is to review all the data and experimental results you have obtained and to allow you to formulate, based on the data and observations, the conclusions. The report will be written in your lab book following the experiment.

The grading of the report will be done on all of these various aspects of the laboratory report. In addition, there may be further instructions in the laboratory itself that may ask you for more detailed observations or discussion.

The laboratory report:

a) Must be neat.
b) Must be typed.
c) Drawings, data, graphs and diagrams must all be originals.
d) Label and answer all questions completely.

e) Each student must write his/her own lab report independently. Copied reports will receive a greatly reduced grade.

f) Reports are due one week after finishing the laboratory experiment. Unless an acceptable excuse is presented, late lab reports will be penalized.

g) Specific lab report formats will be provided by the instructor.

If you have large tables in your report, put them in as appendices (Appendix A, B, etc.) and reference them in your report. Graphs, figures and charts should be included in the "Data" part of your report (summarize).

Some students use photographs (using digital cameras) to collect data and paste these into lab reports. This is allowable, in lieu of the long, tedious process of drawing graphs and collecting data manually (as required in the Lab Manual), however, even photographic images pasted into the report MUST be appropriately annotated (axis, units, identified and marked, etc.). Points will be removed for improperly annotated digital images (you may not simply “paste” the images into your report).

You may "staple" your lab report, but it is preferable to have it neatly bound.

E. Grades

Grades will be based primarily on:

a) Laboratory technique, following procedures, and being prepared for lab.
b) Obtaining and explaining experimental results.
c) The answering of report questions.
d) Neatness and organization of report.

NOTE: Anyone caught stealing **anything** from the laboratory receives a failing "F" course grade.

F. Laboratory Procedure

You will need to read the entire set of processing steps, procedures, and lab questions prior to starting the experiment. This greatly aids in understanding the overall process.

G. Words of Caution

SAFETY FIRST - Eyes and hands must be protected, they cannot be replaced.
Use care at all times. When in doubt, protect all exposed body elements. The chemicals in this lab are potentially dangerous if handled improperly. If splashed with chemicals, wash profusely with water and call instructor immediately. (Use eye wash or shower when necessary.)
Hoods - When using the solvent, tube cleaning hood or the acid hoods. **You must wear gloves and safety glasses**.

Read instructions carefully; think what is being done and then do it carefully. Avoid idle chatter, since it breaks your concentration. To fight pollution and excessive costs, use only enough chemicals required, and use sparingly.

For more information refer to the Safety Rules and Operating Regulations.

If you must carry your wafer, carry in a petri dish or cup with your hand under tweezer-held wafer. Silicon breaks when it hits the floor.

Cleanliness is of paramount importance. Always clean your tweezers between steps. If the wafer looks dirty, it is dirty. Show any strange spots or stains to your lab instructor. Always have chemicals sheet the wafer from the top down to the tweezers and then blow dry. This tends to propagate contaminants towards the wafer edge at the tweezers.

Remember that the cleanroom is a very special environment, and professional behavior is expected. Think before doing - and then do it slowly.

III. EXPERIMENTS

EXPERIMENTS

Experiment 1

VACUUM SYSTEM FAMILIARIZATION EXPERIMENT

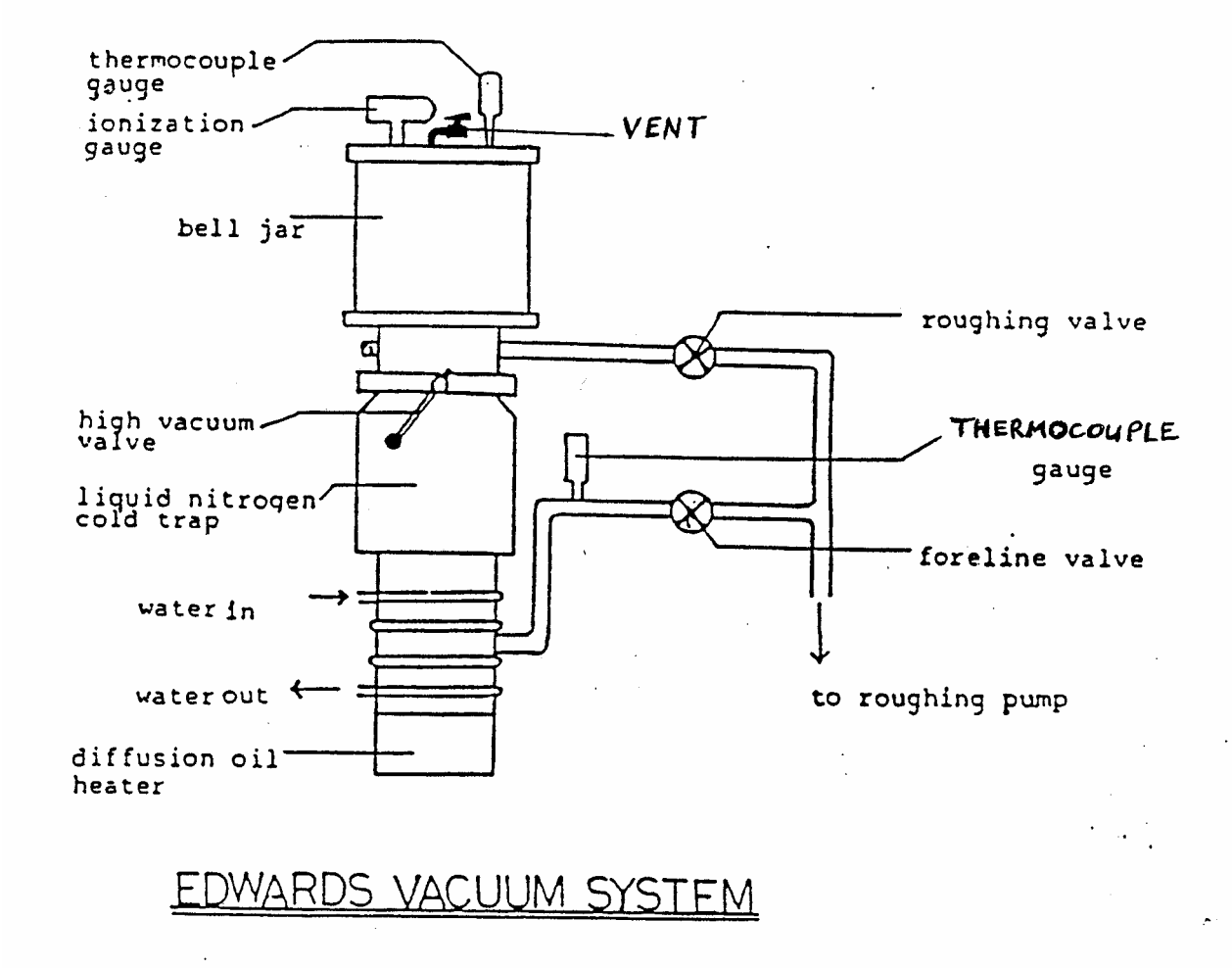
UNIVERSITY OF CENTRAL FLORIDA

COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

SEMICONDUCTOR DEVICE FABRICATION LAB

The Edwards Vacuum system was designed as a teaching aide for the introduction of thin-film vacuum systems. It is a simple system containing all the basic components that will be found in more complex and sophisticated vacuum systems in industry and research environments.



As shown in the figure above, the system consists of an O-ring sealed, aluminum vacuum chamber driven by a high vacuum diffusion pump and a rotary-roughing pump. The diffusion pump is water cooled and also has a liquid nitrogen cold trap, just below the high vacuum valve. There are three vacuum gauges that are present in the system. A thermocouple gauge on the chamber measures the vacuum during roughing and another thermocouple between the diffusion pump and the foreline valve monitors the foreline pressure at all times. Finally, a Grandville-Phillips ionization gauge on the chamber measures the high vacuum pressures.

The system is pumped down by a two-step process. First the roughing pump reduces the vacuum chamber pressure to below 50 microns. Then the diffusion pump is used to reduce the

pressure to about 3 X 10^{-5} torr. The pump down time of vacuum systems is dependent on the quantity of molecules that have to be removed. Cleanliness of the vacuum chamber is imperative to ensure that no outgassing from contaminants, such as body oils or water, within the chamber occurs. Outgassing increases the pumpdown time substantially. Therefore gloves must be worn whenever accessing the interior of the vacuum chamber.

Thin-films are produced by flash evaporation. Two electrodes inside the vacuum chamber are connected to an external power supply. A tungsten filament connected to the electrodes within the chamber, hold the thin-film material desired. The chamber is evacuated of most all of the molecules when it is under high vacuum, and a large current heats up the tungsten filament by resistance heating. This evaporates the thin-film material and the molecules land and adhere to any surfaces, thereby creating a thin-film on substrates that are placed in the chamber.

*Note: Always wear safety glasses around vacuum systems in case of implosion.

I. Diffusion pump start-up (performed by lab assistant 30 min prior to lab)

1. Turn on valve for cooling water to diffusion pump.

2. Turn on roughing pump.

3. Turn on the Grandville-Phillips ionization gauge and thermocouple controller.

4. Verify the following:

   High vacuum valve - closed

   Roughing valve - closed

   Foreline valve - open

5. When the thermocouple gauge at the foreline reads < 50 microns, switch on the diffusion pump.

6. Fill the cold trap with liquid nitrogen using funnel in place.

CAUTION: Liquid nitrogen "burns."

II. Vacuum system preparation:

1. Prepare a glass or Si sample according to Appendix A or your lab instructor's advice.

2. If the vacuum chamber is under vacuum, vent to air by opening the vent valve.

3. Lift top plate being careful not to damage any of the gauges on it.

4. Insert the clean samples on the sample holder of the top plate.

5. Place three 1-inch pieces of aluminum wire on the tungsten filament.

6. Making sure that the O-ring is seated properly in its groove; replace the top plate on the vacuum chamber and close off all vent valves.

III. Vacuum system pumpdown:

1. Close the foreline valve.

2. Open the roughing valve.

IMPORTANT Always monitor foreline pressure. If foreline pressure exceeds 75 microns, close roughing valve and then open foreline valve, until proper foreline pressure is observed. Then close foreline valve and then open roughing valve and return to pump down procedure.

4. Record time to reach < 50 microns during pumpdown.

5. Close the roughing valve.

6. Open the foreline valve.

7. Monitor the thermocouple gauge, make sure the foreline pressure is below 75 microns , then very slowly open the high vacuum valve.

8. Switch on the ionization gauge.

9. Record vacuum pump down time vs. pressure until you reach 3×10^{-5} torr.

IV. Metallization procedure

1. Turn off ionization gauge

2. Plug in the power supply, turn it on and turn up the variac to approximately 25 amps, for 1 minute, to outgas the tungsten filament and aluminum wire.

3. Slowly turn up the variac to approximately 65 amps and observe the filament and wires through the viewport. The tungsten filament will glow red-hot and then white hot. The aluminum wire will first melt and then evaporate, completing the evaporation procedure. Use the Amp meter to determine the amperage at which the aluminum evaporates.

4. Turn the variac back down to zero and switch it off.

V. Sample removal

1. Wait 1 minute for cooling of the filament and sample.

2. Close high vacuum valve.

3. Verify that vacuum system is in standby position with roughing and high-vacuum valves closed, and foreline valve open.

4. Vent vacuum chamber to air.

5. Remove top plate and extract the aluminized samples.

6. Replace top plate and rough down the chamber to 20 microns by closing foreline valve and opening roughing valve.

7. Place the system in its stand-by position.

8. Store your sample following laboratory instructor's instructions for future use.

VI. Vacuum system shutdown (to be performed by lab assistant after experiment is completed)

1. With the system is in its stand-by position, shut off the diffusion pump and allow the diffusion oil to cool for at least 1 hour.

2. After cool down, close the foreline valve.

3. Shut off the roughing pump.

4. Shut off the water.

5. Shut off all gauge controllers.

VII. Data

Record all data and graphs

1. From the pressure vs. time data, graph results and indicate the regions of roughing pumpdown and high vacuum pumpdown. Explain the shape of the graph you obtained.

2. Make a table of all the possible combinations of the positions (open or closed) of the high vacuum, foreline and roughing valves. Describe and comment on each position combination; whether normally used (allowed) or consequences of incorrect setting

(not allowed) and their effects. Note whether each combination is allowed or not allowed. If allowed, state operating mode and if not allowed, state consequences or problem.

VIII. Questions

1. Why is it necessary to use the roughing pump to evacuate the vacuum chamber before opening the high vacuum (gate) valve?

2. What are the practical vacuum measurement ranges of the thermocouple and the ionization gauge?

3. Why does the foreline pressure have to be monitored so carefully, and what are the consequences if the foreline pressure exceeds 75 microns?

4. What is the purpose of the liquid nitrogen in the cold trap?

5. Why is a high vacuum desirable for this process?

6. What was the amperage required to evaporate the aluminum?

7. What is the melting point of Al and of Si (in degrees Kelvin)?

8. What is the difference between a) Filament evaporation, b) Sputtering, and c) Electron beam evaporation? Describe methods, respectively.

Experiment 2

PHOTORESIST PROCESSING AND OXIDE ETCH

UNIVERSITY OF CENTRAL FLORIDA

COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

SEMICONDUCTOR DEVICE FABRICATION LAB

I. INTRODUCTION

In this experiment you will be introduced to photoresist (PR) processing and will also have the opportunity to perform a silicon oxide etch. The photoresist processing and oxide etching are two of the key processes used over and over again in the fabrication of silicon devices. The purpose of the experiment will be to familiarize you with the PR spin-on and bake procedures, mask aligner, and the chemicals used for the oxide etching. We will be using the negative PR for this experiment.

For negative photoresist processing, the exposed PR, i.e., the PR which is apparent to the ultraviolet light, remains. The unexposed PR, which is protected from the ultraviolet light by the mask, develops away. A way to remember what PR remains that dark develops away for negative PR. As an aside, positive PR behaves just the opposite: unexposed PR, protected by the dark areas of the mask, remain and the exposed PR in the clear areas of the mask develops away. The way to remember this is that for positive PR, dark sticks.

You will be given a piece of silicon, which has been oxidized. Your wafer should have a notable color somewhere between red and violet, which is different from the normal silver color for pure silicon. You will be instructed on how to apply the photoresist using the spinner, then baking the photoresist to drive off many of the solvents so that it is a dry, plastic type of material, and you will then be ready for the exposure process. You will be instructed as to which mask to use, how to load and use the mask aligner, and then you will be instructed in the procedure to expose the pattern from the mask onto your wafer. Then you will develop your pattern, which will remove the PR in the areas that have not been exposed. You will then perform a hard bake, which drives off any remaining solvents, prior to etching. You can then take your final wafer, and using the proper etch, etch the silicon dioxide from the wafer, which leaves a photo-engraved pattern of the image on the mask now transferred into the silicon dioxide.

At the end of the experiment, you should have appreciated the concept of compatible materials and processing, which is essential to semiconductor device fabrication.

1) Your instructor will provide you with a Si substrate covered with a thick oxide. The following information about your substrate should also be provided.

Substrate :
Thickness :
Oxide Thickness :
Majority Carrier :
Type :
Resistivity :
Orientation :

II. PROCEDURES

A. Photoresist Process

1. Obtain a sample that will be used for the PR processing. If the sample needs to be cleaned, follow the general cleaning procedure outlined in Appendix A.

2. Perform a **negative photoresist** process on the cleaned sample. The mask that will be used should be identified and provided by your laboratory instructor (MOS-1). Follow the procedure outlined in **Appendix C** for negative PR processing. If this is your first time through the laboratory, and if you have any questions, be sure to contact your instructor.

3. Once you are done applying the photoresist and baking, you need to expose the wafer using the mask aligner. You will be using a Karl Suss mask aligner, described in Appendix E. You should have read over this and have an idea of what needs to be done prior to entering this lab.

4. Having exposed the device, you need to develop the PR. Exposure procedures for negative PR processing are described in Appendix C.

5. Once you have finished the post-bake process, you are reading to etch the oxide in the areas where the photoresist has been developed away and removed.

B. Silicon Dioxide Etching

1. Etching of the silicon dioxide will take place in the Class 1000 clean room. You will be using the hoods marked for ACIDS ONLY. In order to etch the silicon dioxide, you will be using an oxide etch. The chemicals used for this are given in Appendix H. Please note that you cannot use an oxide etch in a glass beaker, **you must use plastic beakers**. Also, please look around the area under the hood to see if anyone else has used and labeled an oxide etch beaker. You will be able to use this beaker instead of pouring new chemicals. Do not use any unmarked beakers containing chemicals.

2. Place your wafer into the plastic petri dish or beaker until it is completed covered with etch. Watch the wafer to determine when the oxide has been removed in the non-photoresisted area. It may be necessary to take the wafer in and out of the beaker several times to observe. You will probably need to rinse with DI water and blow dry with N_2.

3. You will know that the etching process is complete by noting the color and noticing the way the water beads up in the etched areas. Silicon is hydrophobic. This means that water does not tend to wet the surface but rather, due to the lack of surface tension, tends to ball up. Therefore, when you are etching, if the water appears to be filling up the etched areas and vias, following the hole pattern and balling up, you are probably done with the etch process. If you have any question as to whether the etch is complete, you can typically place the

sample back into the etchant for another five to ten seconds, as long as the photoresist does not show any signs of deterioration. You can then pull it back out of the acid, rinse it off, and the etch process will be complete. Verify with your lab instructor if unsure of your results.

4. Once you have determined the etch process is complete, you can strip the photoresist as outline in Appendix C.

5. Store your wafer for use in the single diffusion experiment.

III. DATA

1. Record the approximate time it took to etch the silicon dioxide from your wafer.

2. Record the color of the remaining silicon dioxide and the color of the exposed silicon.

IV. QUESTIONS

1. Draw a clear field mask pattern of a simple resistor pattern. Cross hatch the chrome. (Dark area of the mask)

2. For positive photoresist and a clear field mask, what happens to a line width of a resistor pattern if you significantly underdevelop?

3. For negative photoresist and a clear field mask, what happens to a line width of a resistor pattern if you significantly overexpose?

4. For positive photoresist and a clear field mask, what happens to a line width of a resistor pattern if you significantly underexpose?

5. For negative photoresist and a clear field mask, what happens to a line width of a resistor pattern if you significantly overdevelop?

6. When doing your PR processing, what was the purpose of the soft bake?

7. After developing, what is the purpose of the hard bake?

8. Why should you use plastic beakers when using the buffered oxide etch (BOE)?

9. If you have completed a positive PR (Shipley) process, how do you remove (strip) the PR from the substrate?

10. If you have completed a negative PR (Futurrex) process, how do you remove (strip) the PR from the substrate?

11. Why is it necessary to examine your substrate under a microscope after a developing or etching process?

12. Explain briefly, why different oxide thickness yield different colors. Why is it necessary to view wafers vertically?

13. A Si wafer has two regions, one is unoxidized and the other has an oxide layer 1000 angstroms thick. The wafer is placed in a dry oxide furnace at 1200C for 30 minutes. Calculate and compare the thickness of new oxide in the two regions. Explain.

14. Explain why wet oxidation produces a thicker SiO_2 layer than dry oxidation using the same temperature and time.

Experiment 3

SINGLE DIFFUSION EXPERIMENT

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ELECTRICAL ENGINEERING DEPARTMENT

SEMICONDUCTOR DEVICES FABRICATION LAB

Most semiconductor devices operate due to the existence of a junction between n and p type material within a single crystal. Diodes, bipolar transistors, and field effect transistors are some examples of such devices. A method of creating these junctions with accurate control over junction depth and impurity concentration is essential for successful device fabrication.

At present there are several methods, such as diffusion, alloying, epitaxial growth and ion implantation, by which junctions may be formed. In this experiment, you will be introduced to the diffusion process. The theory behind diffusion is that areas of high concentration will tend to diffuse to the areas of lower concentration in an effort to achieve equilibrium. This phenomenon is utilized in the creation of junctions by diffusing either donor or acceptor impurities into a p or n Si substrate respectively.

This experiment to fabricate diffused resistors, MOS capacitors, MOS transistors and diodes, will require a single diffusion. It will also require all the other processing steps of oxidation, photolithography and metallization that you have learned from the previous experiments. Note that even for a single diffusion, a minimum of three masks are required.

You will be given a silicon substrate with an oxide already grown on it. The oxide will be thick enough to prevent doping of undesired regions on the substrate. After an initial cleaning, a photolithography process and oxide etch will define the areas for diffusion. The diffusion process is performed in two steps. The first is the pre-dep step where the impurity is deposited on the surface of the substrate. This is followed by a drive-in and oxidation step where the impurities are diffused into the substrate and a layer of oxide is grown at the same time. Next, contact windows will be defined via a photolithography process and oxide etch. You will then flash evaporate an aluminum film onto the substrate and aluminum etch the metal over the contact windows to form the metal contacts to the devices.

I. Photoresist process for diffusion (See Appendix C)

1. If you have completed the PR process and oxide etch from Experiment B, proceed to step II.

II. Pre-dep diffusion process

NOTE: Furnaces are <u>extremely</u> hot. Just the radiant heat can burn. You must use gloves to handle push rods and boats. Make sure push rods, boats, and wafers are <u>absolutely</u> clean. Be sure all PR is off the wafers.

1. If you have stored your wafer overnight or longer, you will need to do a ten second BOE 9:1 dip, then rinse with DI water and blow dry with the N_2 gun.

2. Remove the diffusion boat as described in Appendix G.

3. Place your wafers between the phosphorus diffusion sources in the quartz diffusion boat. The front side of the wafer should be facing the source. Make sure your wafers and the diffusion sources are placed as close together as possible. Prepare and include a control wafer.

4. After verifying the furnace settings, load the quartz boat and wafers into the furnace and perform a phosphorous pre-dep for 15 minutes.

   Phosphorous tube settings

   Furnace temperature = 950C

   N_2 pressure = 5 psi

   Flowrate = 4.0 on flowmeter tube scale

   Push-in/pull-out rate = 1 minute

III. Predep measurement on control wafer.

1. Use the four-point probe to determine the majority carrier type on the surface of the control wafer.

2. Use the four-point probe to measure the sheet resistance of the predep layer.

3. (NOTE) If the surface of your control wafer has not inverted to n type, stop and notify your lab instructor before proceeding.

IV. Drive-in diffusion and oxidation process.

1. Following the predep, verify the wet oxidation furnace settings and perform a combination drive-in and oxidation for 20 minutes.

   Drive-in and oxidation settings

   Furnace temperature = 1100C

   N_2 pressure = 5 psi

   Flowrate = 1.0 on flowmeter tube scale

   Bubbler temperature = 95-99C

   Push-in/pull-out rate = 3 minutes

V. Drive diffusion measurement on the control wafer (Appendix D)

1. Estimate the oxide thickness from the drive-in process parameters. Noting that the etch rate for 9:1 BOE is approximately 600 Å/minute, estimate the time required to completely etch the oxide. Then, etch the oxide on the **control wafer** in intervals, noting the actual etch time. Verify that all the oxide is removed.

2. Use the four-point probe to determine the majority carrier type on the surface of the control wafer.

3. Use the four-point probe to measure the sheet resistance of the diffused layer.

VI. Photoresist process for contact windows (Appendix C)

1. Spin-on Futurrex-NR9-1500 negative photoresist @ 3000 rpm for 30 seconds.

2. Softbake at 150C for 1 minutes on an Al hot plate in the Blue M oven.

3. Read Appendix E on mask alignment procedure. Obtain Mask MOS-2 and verify that it is in the Karl Suss mask aligner emulsion or chrome side down. Align the first level (oxide) pattern on your wafer to the mask pattern. When aligned properly, expose for 10.0 seconds.

4. Post Expose Bake- 100C for 1 min. (allow to cool)

5. Develop in Futurrex developer RD6 diluted 3:1 with DI water using a glass Petri dish for about 1 minute.

6. To stop the development, remove the wafer from the developer and rinse with DI-water.

7. Blow-dry with the N_2 gun and inspect the pattern for complete development.

MICROSCOPE

Inspect the developed pattern - look to see if the pattern is completely developed and the photoresist is gone. Pattern is developed if the oxide layer is clearly visible in the areas where photoresist should not be present.

REPEAT DEVELOPMENT AND RINSE IF NECESSARY

8. Hardbake at 150C for 3 minutes on a hot plate in the Blue M oven.

VII. Oxide etch (contact windows)

1. Following the hardbake, etch your wafer in 9:1 BOE until the contact windows are free of oxide. This may take approximately 10% more time than it took to etch the control wafer.

NOTE: Perform the etch in short intervals when you are within 1-2 minutes of your predicted etch time. Check for color, patterning and resist integrity EACH TIME.

2. To stop etching, remove your wafer from the etch solution, rinse with DI water, and blow dry with the N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if the exposed oxide is completely etched away. The silicon surface should appear gray in color and because silicon is hydrophobic, water sprayed in the etched areas will tend to ball up.

3. When etching is complete, strip the remaining photoresist using acetone then rinse with methanol, then DI water and blow-dry with N_2 gun.

VIII. Metallization procedure

1. Attach your wafer to the vacuum chamber planetary being used and mount the planetary in the Edwards vacuum chamber.

2. Place two 1-inch strips of Al wire onto the filament at the bottom of the chamber.

3. Following the procedure of the vacuum lab experiment, pump down to 3×10^{-5} torr, and evaporate Al onto your wafer.

4. Place Edwards vacuum system in standby and remove your wafer.

IX. Positive Photoresist process for metal contacts (See Appendix B)

1. Spin on Shipley 1813 positive photoresist at 3000 rpm for 30 seconds.

2. Softbake @ 100C for 3 minutes on a hot plate in the Blue M oven.

3. Read Appendix E on mask alignment procedure. Obtain Mask MOS-3 and verify it is in the Karl Suss mask aligner emulsion or chrome side down. Align the second level (contact) pattern on your wafer to the mask pattern. When aligned properly, expose for 10.0 seconds.

4. Develop in Shipley developer CD-26 Develop for about 1 minute.

5. Remove wafer from developer, rinse with DI water, and blow dry with N_2 gun.

MICROSCOPE

Inspect the developed pattern - look to see if the pattern is completely developed and the photoresist is gone. Pattern is developed if the metal layer is clearly visible in the areas where photoresist should not be present.

REPEAT DEVELOPMENT AND RINSE IF NECESSARY

6. Hardbake at 100C for 10 minutes on a hot plate in the Blue M oven.

X. Aluminum etch for metal contacts

1. Immerse your wafer in warm (35C) aluminum etch solution and monitor the metal etch pattern being formed. Total etch time is approximately 5-15 minutes depending on Al thickness.

2. To stop etching, remove your wafer from the Al etch solution, rinse with DI water, and blow dry with a N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if all of the unprotected aluminum is completely etched away. If not, go back into the etch solution in short intervals until pattern is clear.

3. When etching is complete, strip the remaining photoresist with acetone. Complete stripping should take about 1 minute.

4. Rinse with methanol, then DI water and blow-dry with N_2 gun.

XI. Report

Data and calculations you need to include:

1. Record the initial resistivity and doping of your wafer, the sheet resistance and majority carrier type of your control wafer, and all development and etch times used in processing your wafer.

2. Sketch complete cross-sections of the diode, MOS transistor, and the MOS capacitor after the phosphorous pre-dep, after the drive-in, and after the aluminum etch. Label the MOS transistor contacts.

3. Measure and tabulate your resistor values by size. Based on geometry considerations also calculate the sheet resistance, R_S, of your resistors. Average over all values.

4. Measure and sketch in detail the I-V characteristic of one of your MOS transistors. Also measure the threshold voltage.

5. Measure g_m vs. V_G for several MOSFETs. Using simple MOS theory and your process parameters compute g_m vs. V_G and compare with measured results.

6. What is V_T? Assume 8 x 10^{10} cm^{-2} interface charge. What is the theoretical threshold voltage of your MOS transistor? Compare with what you expect?

7. From process times and temperatures, and from the resistivity of your control wafer,

   a) Calculate N_o and x_j assuming the diffusion obeys the error function and Gaussian equations.

   b) Using the value of R_S calculated from the resistor measurements, and the value of x_j calculated in (a), use Irvin's curves to find the value of N_o(surface concentration). How does this compare to the value of N_o computed above in (a)?

8. Calculate your expected MOS oxide capacitance values (in pF) as designed on your mask.

XII. Questions

1. Describe curve tracer operation.

2. What is the effect of scaling your devices by 1/2 with respect to g_m, V_T, resistor values, diode currents, and capacitor values?

3. What purpose does the guard ring on the MOS capacitor serve?

4. Why did you etch the silicon wafer in BOE 9:1 before making sheet resistance measurements?

5. Why did you use BOE 9:1 rather than HF? What would happen if this mixture were not used?

6. Why is the slow pull used following the oxidation, drive and predep?

7. When you make a four-point probe measurement on the n-layer side of the silicon wafer, does the measured value of resistivity include the effect of the underlying p-layer? Why or why not?

8. Two separate but identical n-type substrates with identical oxide masking undergo p-type diffusions. If the same doping gradient is achieved, but in one sample the junction depth is 1 μm and the other is 2 μm, how would you expect the reverse breakdown voltages to compare? Explain. Hint: Consider the geometry of the corresponding diffused regions.

9. Would the phosphorous sheet resistance increase or decrease during the drive-in? Why?

10. Discuss any device problems or deviation from process.

Experiment 4

DOUBLE DIFFUSION EXPERIMENT

UNIVERSITY OF CENTRAL FLORIDA

COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

SEMICONDUCTOR DEVICES FABRICATION LAB

I. Substrate Cleaning and Preparation (See Appendix A)

1) Your instructor will provide you with a Si substrate covered with a thick oxide. The following information about your substrate should also be provided.

Substrate	:
Thickness	:
Oxide Thickness	:
Majority Carrier Type	:
Orientation	:
Resistivity	:

II. Photoresist Process for Base Diffusion (see Appendix C)

1. Spin on Futurrex NR9-1500 negative photoresist @ 3000 rpm for 30 seconds.

2. Softbake @ 150C for 1 minutes on a hot plate in Blue M oven.

3. Read Appendix E on operation of the mask aligner and use mask BJT-1.

4. Verify the mask is chrome side down, align your wafer under the mask, fitting as many cells as possible on the substrate. Expose for 10.0 seconds.

5. Post Expose Bake- 100C for 1 min. (allow to cool)

6. Develop in Futurrex developer RD6 dilute 3:1 with DI using a glass Petri dish for about 1 minute.

7. Stop developing by rinsing with DI water.

8. Blow dry with N_2 gun and inspect for pattern development.

MICROSCOPE

Inspect the developed pattern under the microscope. Look to see if the pattern is completely developed and if the photoresist is gone. Pattern is developed if the oxide layer is clearly visible in the areas where photoresist should not be present. (Note: All observations in log book data is to be entered in your lab report.)

Repeat developing and rinse procedure, if necessary.

9. Hardbake @ 150C for 3 minutes on a hot plate in the Blue M oven.

III. Oxide Etch Process

1. Etch your wafer in BOE 9:1 in intervals, checking for pattern development and resist integrity each time. The approximate etch rate for 9:1 BOE is 600 Å/minute.

2. Rinse with DI water and blow dry with N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if the oxide is completely etched away. The silicon surface should appear gray in color and the DI water should dewet from the surface. If not, go back and etch in 30 second intervals.

3. Strip photoresist with acetone.

4. Rinse with methanol, DI water, and blow dry with N_2 gun.

IV. Base Predeposition

1. Remove the diffusion boat as described in Appendix G.

2. Place wafers between the boron diffusion sources in the quartz diffusion boat. Make sure that the front side of the wafer is facing the source. Also make sure your wafers and the diffusion sources are placed as close together as possible. Prepare and include <u>two control wafers</u>.

3. Load boat into furnace and perform a boron predep as follows:

   time = 15 minutes

   furnace temperature = 900C

   N_2 pressure = 5 psi

   flow rate = 4.0 on flowmeter tube scale

   push in/pull out rate = 1 minute

V. Borosilicate Glass Etch of Both Control Wafers and Your Own Wafer

1. Etch in BOE 9:1 for 10 seconds

2. **RINSE WITH DI WATER** and dry with N_2 gun.

3. Immerse wafer in H_2SO_4:HNO_3 1:1 solution for 10 minutes.

4. **RINSE WITH DI WATER** and dry with N_2 gun.

3. Etch in BOE 9:1 for 10 seconds. Surface should be hydrophobic.

5. **RINSE WITH DI WATER** and dry with N_2 gun.

6. Use the four point probe to measure and record the majority carrier type and sheet resistance on both control wafers. If your majority carrier type is not p, stop and notify your instructor.

VI. Base Drive-in Diffusion and Oxidation Process

1. Verify the wet and dry oxidation furnace settings and perform the following drive-in and oxidation sequence.

Wet Drive-in and Oxidation settings

time = 30 minutes

temperature = 1100C

N_2 pressure = 5 psi

flow rate = 1.0 on flowmeter

DI Bubbler temperature = 95C

push/pull time = 3 minutes

Dry Drive-in and Oxidation settings

time = 2 hours

temperature = 1100C

O_2 pressure = 5 psi

flow rate = 4.0 on flowmeter

push/pull time = 3 minutes

VII. Measurement on Control Wafers

1. Estimate the oxide thickness from the diffusion times and temperatures.

   NOTE: The control wafer is emitter oxide, to etch through the collector (field thickness) you must add etch time to emitter etch time and monitor the collector for etch completion.

2. Determine the time necessary to etch the oxide layer using BOE 9:1 (based on BOE's etch rate) and etch the oxide on **one of the control wafers only**. Record the actual oxide etch time.

3. Use the 4 point probe to determine surface type and to measure sheet resistance of the etched control wafer. If your majority carrier type is not p, stop and notify your instructor.

VIII. Photoresist Process for Emitter and Collector Contact Diffusion

1. Spin on Futurrex NR9-1500 negative photoresist at 3000 rpm for 30 seconds.

2. Softbake @ 150C for 1 minutes on a hot plate in the Blue M oven.

3. Read Appendix E on alignment procedures. Align mask BJT-2 to the previous level.

4. Expose for 10 seconds.

5. Post expose bake 100C for 1 min. (allow to cool)

6. Develop in Futurrex developer RD6 dilute 3:1 with DI using a glass Petri dish for about 1 minute

7. Stop developing by rinsing with DI water.

8. Blow dry with N_2 gun.

   MICROSCOPE

   Inspect to see if the pattern is completely developed.

9. Repeat developing procedure if necessary.

10. Hardbake @ 150C for 3 minutes on a hot plate in the Blue M oven.

IX. Oxide Etch Process

1. Etch in BOE 9:1 in intervals until the desired oxide is removed. Check for color, patterning, and resist integrity each time. Be sure to verify that the collector contact via is free of oxide.

2. Rinse with DI water and blow dry with N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if the oxide is completely etched away. The silicon surface should appear gray in color and the DI water should dewet from the surface. If not, go back and etch in 30 second intervals.

3. Strip photoresist with acetone.

4. Rinse with methanol, DI water, and blow dry with N_2 gun.

X. Emitter and Collector Contact Predeposition

1. Place the phosphorous diffusion sources between the wafers in the quartz diffusion boat. Make sure that the front side of the wafer is facing the source. Ensure that your wafer and the diffusion source are in as close proximity as possible. Include both of the control wafers.

2. Perform the predep as follows:

   time = 10 minutes

   furnace temperature = 950C

   N_2 pressure = 5 psi

   flow rate = 4.0 on flow meter tube scale

   push in/pull out rate = 1 minute

3. Use the four point probe to determine the majority carrier type and sheet resistance of the one control wafer that has been previously etched. If the majority carrier type is not n, stop and notify your instructor.

XI. Emitter and Collector Contact Drive-in of Both Control Wafers and Your Wafer

1. Perform a 10 minute drive-in and wet oxidation as follows

   Wet Drive-in and Oxidation settings

   time = 10 minutes

   temperature = 1100C

   N_2 pressure = 5 psi

   flow rate = 1.0 on flowmeter

   DI Bubbler temperature = 95C

   push/pull time = 3 minutes

XII. Measurement on Control Wafer

1. Estimate the oxide thickness on each control wafer from the diffusion times and temperatures.

2. Determine the time necessary to etch the oxide layer using BOE 9:1 (based on BOE's etch rate) and etch the oxide on the **control wafers only**. Record actual oxide etch times.

3. Use the 4 point probe to determine surface type and to measure sheet resistance for both control wafers.

XIII. Photoresist Process for Via Holes

1. Spin on Futurrex NR9-1500 negative photoresist at 3000 rpm for 30 seconds.

2. Softbake at 150C for 1 minutes on a hot plate in the Blue M oven.

3. Align mask BJT-3 to the previous level.

4. Expose for 10 seconds.

5. Post expose bake 100C for 1 min. (allow to cool)

6. Develop in Futurrex developer RD6 dilute 3:1 with DI using a glass Petri dish for about 1 minute

7. Stop developing by rinsing with DI water.

8. Blow dry with N_2 gun.

MICROSCOPE

Inspect to see if the pattern is completely developed.

9. Repeat developing procedure if necessary.

10. Hardbake at 150C for 3 minutes on a hot plate in the Blue M oven.

XIV. Oxide Etch Process

1. Etch your wafer in BOE 9:1 in intervals until the metal contact vias are free of oxide. Check for color, patterning and resist integrity each time. Etch rate for 9:1 BOE is approximately 600 Å/minute.

2. Rinse with DI water and blow dry with N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if the oxide is completely etched away. The silicon surface should appear gray in color and the DI water should dewet from the surface. If not, go back and etch in 30 second intervals.

3. Strip photoresist with acetone.

4. Rinse with methanol, DI water, and blow dry with N_2 gun.

XV. Metallization

1. Attach wafer(s) to the planetary holder and place holder in Edwards Vacuum System.

2. Following the procedure for the operation of Edwards Vacuum System, pump down to 3×10^{-5} torr and evaporate four 1 inch pieces of aluminum onto wafer(s).

XVI. Photoresist Process for Metal Contacts (see Appendix B)

1. Spin on Shipley 1813 positive photoresist at 3000 rpm for 30 seconds.

2. Softbake at 100C for 3 minutes on a hot plate in the Blue M oven.

3. Align mask BJT-4 to the previous level.

4. Expose for 10 seconds.

5. Develop in Shipley developer CD-26 Develop for about 1 minute.

6. Stop developing with DI water.

7. Blow dry with N_2 gun.

MICROSCOPE

Inspect to see if the pattern is completely developed.

8. Repeat developing procedure if necessary.

9. Hardbake at 100C for 10 minutes on a hot plate in the Blue M oven.

XVII. Aluminum Etch for Metal Contacts

1. Immerse wafer in (warm 35C) aluminum etch solution for 5-15 minutes or until pattern develops.

2. Rinse with DI water and blow dry with N_2 gun.

MICROSCOPE

Inspect the etched pattern to see if the Al is completely etched away. If not, go back and etch in short intervals.

3. Strip photoresist by rinsing with acetone.

4. Rinse with methanol and DI water. Blow dry with N_2 gun.

XVIII. Data and Calculations

1. Record all parameters measured throughout the experiment.

2. Draw a cross section of all the device types found on mask set used in this experiment after each step performed in the experiment. Label all contacts and materials.

3. Measure the resistor values in several cells and tabulate by size. From geometry considerations compute the sheet resistance values of the n^+ and p diffused layers.

4. Use the curve tracer to measure the I-V characteristics of the several different diode types on your wafer. Sketch the I-V characteristics of some of the best ones and determine I_{sat} and V_0 for these diodes.

5. Use the curve tracer to inspect the I_C-V_{CE} characteristics of your transistors. Sketch in detail the I-V characteristic of some of your best transistors. From these sketches determine your current gain and $V_{CE(sat)}$ curve. Also measure and record BV_{CBO} and BV_{EBO} for these transistors.

6. Using the measured junction breakdown voltages of your transistors, determine the junction depths x_{jc} and x_{je}. Using simple diffusion theory and your process parameters, calculate x_{jc} and x_{je} and compare them to the values obtained from the breakdown voltage measurements.

7. Using your process parameters, calculate the base and emitter Gummel numbers for your transistors. Use the Gummel numbers to calculate a value for β. Compare this value to what you measured for your transistors.

XI X. Questions

1. How many of your BJTs that you measured actually work? What was the approximate yield of the transistors tested?

2. What relationships, if any, do you expect between the theoretical resistor values in a single cell of your wafer? Do the measured values agree with your conclusions?

3. How many different transistor geometries can you identify on your wafer? What is the difference between them? What are the advantages of one to another?

4. How many types of diodes are on your wafer? What is the difference between them?

5. What is the difference between the capacitors in a single cell of your wafer?

6. What is the advantage in using positive photoresist rather than negative photoresist in the process for metal contacts?

7. Why do we need n^+ emitters and collector contacts rather than just n? Why don't we have a p^+ contact region for the base?

8. Why do we always align the present mask level to the previous one and not to any of the others (i.e. the first level)?

9. Why does the Borosilicate glass need to be etched after the base predeposition step?

10. Suppose you increased your base drive-in time. How would this effect the current gain and collector current of your transistors?

11. Why do we use 2 control wafers?

12. Why do resistors (same size and shape) have different values from cell to cell?

1V. APPENDICES

APPENDICES

A. SUBSTRATE PREPARATION

APPENDIX A

SUBSTRATE PREPARATION

I. General cleaning procedure for most substrate materials

1. Scrub the substrate with Alconox (detergent) and DI water to remove bulk contaminants from the surface.

2. Rinse the detergent off the substrate using DI water.

3. Hold the substrate with tweezers such that the tip of the tweezers are at the bottom part of the substrate and as close to the edge as possible.

4. Rinse the substrate with tricholoroethane to remove the detergent residue. Spray from the top of the substrate so that the residue drips down towards the tweezers. This also prevents contaminants from the tweezers migrating onto the substrate surface.

5. Rinse the substrate with acetone to remove the tricholoroethane residue.

6. Rinse the substrate with methanol to remove the acetone residue.

7. Rinse the substrate with deionized water to remove the methanol residue.

8. Blow dry with N_2 gun.

9. (OPTIONAL) Construct a vapor degreaser by putting trichloroethane (TCE) in a glass beaker and boiling it on a hot plate. Set the temperature of the hot plate such that the vapor condenses near the top of the beaker and drips back into the TCE. Suspend the substrate in the beaker so that the vapor condenses on the surface and sheets down it. This removes any remaining contaminants. Slowly withdraw the substrate and place in a clean petri dish.

II. Silicon substrate cleaning procedure prior to oxidation

1. Turn on the tap water in the fume hood. Water should be left running in order to flush away all chemicals.

2. Pour sulfuric acid into a glass petri and use the ultrasonic cleaner to clean substrate surface.

3. Perform an oxide etch in Buffered Oxide Etch (BOE) 9:1 (premixed solution) for 30 seconds in a plastic petri dish. This is to remove any oxide from the surface.

4. Rinse with deionized H_2O and blow dry with N_2 gun.

B. POSITIVE PHOTORESIST PROCESSING

APPENDIX B

POSITIVE PHOTORESIST PROCESSING

1. Before beginning the PR process make the following preparations:

    a. Switch on two Blue M ovens and set one for 100C and the other to 150C. Allow 30 minutes for oven to stabilize.

    b. Ask lab assistant to fill the photoresist syringe with Shipley 1813 positive photoresist. Fill with enough for your processing needs, but do not overfill. Put a filter in the filter holder for the syringe and insert it on the syringe. This is to remove microscopic contaminants out of the photoresist.

    c. Pour photoresist developer CD-26 Develop (100%) into petri dish.

    d. Make sure that the mask to be used is free of contaminants and finger marks. Chrome masks can be cleaned by gently scrubbing with detergent, rinsing with tap water and then methanol, and drying with the air gun. Emulsion masks scratch easily and must be cleaned in an ultrasonic cleaner with a solution of detergent and water. DO NOT SCRUB THE EMULSION! Spray with methanol and dry with the N_2 gun.

2. Switch on the spinner control and the vacuum pump for the spinner table.

3. Set the time and speed of rotation by using a dummy substrate on the stage and pressing the foot switch. Set rotation for 3000 rpm and time for 30 seconds.

4. Place the substrate on the spinner and apply photoresist to the substrate using the syringe. It usually requires some force to pump the photoresist through the micron filter. Begin at the center of the substrate and move out to the edges. Make sure that there is enough photoresist to cover the entire surface upon spinning.

5. Start the spinner by using the foot switch.

6. After the spinner has stopped, check if the substrate surface is fully coated with photoresist. If it is not fully covered, remove all photoresist with acetone and go back to step 1.

7. Softbake the substrate in the 100C oven and for 3 minutes on an Al hot plate.

8. Read Appendix E on operating the Karl Suss mask aligner and, if necessary, obtain assistance from the lab instructor.

9. Make the necessary alignments.

10. Expose for 10.0 seconds on the Karl Suss mask aligner.

11. Develop the exposed photoresist in the developer for approximately one minute using a petri dish. Developing can be continued by returning the substrate to the developer. Rinse with DI water and blow dry with nitrogen.

12. Hardbake the substrate at 100C for 10 minutes on an Al hot plate.

13. At this stage perform the desired chemical (aluminum, oxide, etc.) etch.

14. Rinse the etch off with deionized water and determine if the etch is complete. If it is not, return to the substrate and continue etching until done.

15. When etching is complete, rinse with deionized water and then with acetone to strip off the baked on photoresist, then rinse with methanol and deionized water. Blow dry using the N_2 gun.

16. ** IMPORTANT ** Clean-up all photoresist equipment that was used (spinner, syringe, syringe filter, any spills, etc.) with acetone and kimwipes.

C. NEGATIVE PHOTORESIST PROCESSING

APPENDIX C

NEGATIVE PHOTORESIST PROCESSING

1. Before beginning the PR process make the following preparations:

   a. Switch on two Blue M ovens and set one for 100C and the other to 150C. Allow 30 minutes for ovens to stabilize.

   b. Ask lab assistant to fill the photoresist syringe with Futurrex NR9-1500 negative photoresist. Fill with enough for your processing needs, but do not overfill. Put a filter in the filter holder for the syringe and insert it on the syringe. This is to remove microscopic contaminants out of the photoresist.

   c. Make sure that the mask to be used is free of contaminants and finger marks. Chrome masks can be cleaned by gently scrubbing with detergent, rinsing with DI water and then methanol, and drying with the N_2 gun. Spray with methanol and dry with the N_2 gun.

2. Switch on the spinner control.

3. Set the time and speed of rotation by using a dummy substrate on the stage and pressing the foot switch. Set rotation for 3000 rpm and time for 30 seconds.

4. Place the substrate on the spinner and apply photoresist to the substrate using the syringe. It usually requires some force to pump the photoresist through the micron filter. Begin at the center of the substrate and move out to the edges. Make sure that there is enough photoresist to cover the entire surface upon spinning.

5. Start the spinner by using the foot switch.

6. After the spinner has stopped, check if the substrate surface is fully coated with photoresist. If it is not fully covered, remove all photoresist with acetone and go back to step 1.

7. Softbake the substrate in the 150C oven and for 1 minute on an Al hot plate.

8. Read the Appendix E on operating the Karl Suss mask aligner and if necessary, obtain assistance from the lab instructor.

9. Make the necessary alignments.

10. Expose for 10.0 seconds on the Karl Suss mask aligner.

11. Post exposure bake, (NOTE) after exposure bake the substrate in the oven @ 100C for 1 minute. Remove and let cool to room temp.

12. Developer Futurrex RD6 must be diluted (3:1) 3 parts developer and one part DI water. Half-fill a petri dish with dilute Futurrex negative developer. Develop the exposed photoresist in the developer for 1 minute.

13. Remove wafer from developer and immediately rinse with DI water. Blow dry with the N_2 gun. Inspect under microscope for complete development. If more development is required, return the wafer to the developer in one minute or 30 second intervals, following the procedure as above.

12. Hard bake the substrate at 150C for 3 minutes on an Al hot plate.

13. At this stage perform the desired chemical (aluminum, oxide, etc.) etch.

14. Rinse the etch off with deionized water and determine if the etch is complete. If not, return to the substrate and continue etching until done.

15. To remove the baked on photoresist, rinse with acetone, methanol and DI water. Blow dry using the N_2 gun.

16. ** IMPORTANT ** Clean-up all photoresist equipment that was used (spinner, syringe, syringe filter, any spills, etc.) with acetone and kimwipes.

D. FOUR POINT PROBE MEASUREMENTS

APPENDIX D

MAGNETRON M-700 RESISTIVITY/CONDUCTIVITY TEST SYSTEM

The model M-700 is an in-line four-point probe system that performs resistivity/conductivity measurements on semiconductor samples, metallized surfaces and thin film layers. Measurements can be made in ohms, ohm/square, and ohms-cm. (in mils or microns), and has a measurement range from 10^{-6} to 10^{+6}. In addition, typing measurements can be made on semiconductor substrates, by using the thermoelectric mode push-button.

Operating Instructions: (NOTE) Turn on the M-700 in test mode for 10 minutes before using.

I. Bulk resistivity measurements (Function switch set to ohms-cm.)

1. Enter the sample thickness on the thickness thumbwheel switch in either mils or microns. Use the lower multiplier to increase accuracy, i.e. 7.0 X 1 instead of 0.7 X 10. This switch has no effect in any other mode.

2. Set the polarity switch to either "+" or "-". "0" is the standby position.

3. Place the sample on the stage and lower the four-point probe onto the surface. Sufficient contact is obtained when a microswitch is heard to click on. DO NOT LOWER THE PROBE HEAD TOO MUCH FOR THIS WILL DAMAGE IT. There should be a slight gap between the probe headshell and the sample.

4. Starting with the lowest current level pushbutton (1 A) increase until the O/R (out-of-range) LED lights up. Back off one current level and the LED should go off.

5. Digital LED display should now display the desired bulk resistivity.

II. Sheet resistance measurements (Function switch set to ohms/square)

1. Follow same procedure as outlined above, beginning from step 3.

III. Typing measurements

1. Set function switch to TYPE.

2. Lower probe head to sample as outlined previously.

3. The N or P LED will light indicating the conductivity.

4. If the N & P LEDs flash, depress and hold the therm push-button momentarily until the conductivity type is displayed. This is used to heat the probe tips and penetrate thin oxide layers.

E. KARL SUSS MASK ALIGNER

APPENDIX E

OPERATION OF THE KARL SUSS MASK ALIGNER

I. This appendix only gives a brief description and operating procedure of the Karl Suss. Refer to the manufacturer's manual for more detailed information.

The functions of a mask aligner are:

1. To perform alignments of substrates to photomasks with great accuracy.

2. To hold the photoresist covered substrate in intimate contact with the photomask during the exposure sequence.

3. To provide exposure control of the UV light source

II. Brief Orientation

The operation of the MJB 3 is straightforward and easy to learn. First, load a mask into the machine. Then place the substrate on the chuck and insert the chuck into the alignment stage.

At this point bring the substrate into contact with the mask by turning the contact lever counterclockwise. The CONTACT light on the front panel illuminates. This operation also accomplishes wedge error (parallelity) compensation (WEC) using a unique 3-point leveling approach.

By pulling the separation level towards the front of the machine, the operator obtains sufficient separation for alignment, and the CONTACT light will go out as the SEPARATION light illuminates. The substrate can now be aligned to the mask using the X, Y, and Theta micrometers. The operator can easily scan the microscope over the substrate in either the X or Y direction, or both simultaneously, by using the precision microscope manipulator.

When satisfactory alignment has been achieved, move the substrate back into contact with the mask by pushing the separation lever all the way to its rearmost position until the SEPARATION light goes out and the CONTACT light re-illuminates. The substrate is now ready for exposure.

To initiate exposure, set the exposure time on the timer and press the EXPOSURE button. In most models, the microscope will then elevate a sufficient distance to allow the objective to clear the maskholder (this lifting is not necessary in all cases). The mirrorhouse now moves forward over the mask. When the mirrorhouse reaches its foremost position, the shutter opens and exposure takes place for the specified amount of time. After exposure is complete, the shutter closes, the mirrorhouse retracts, and the microscope moves back down to its original position.

The substrate may now be unloaded. Rotate the contact lever fully towards the front of the machine, releasing the substrate from the mask. Pull the transport slide to the right and carefully remove the substrate from the chuck.

2 OPERATING PROCEDURES

2.1 Machine Controls

All of the machine controls for the SUSS MJB 3 are described below.

2.1.1 Control Panel (Figure 2-1)

a. POWER button - Pressing the POWER button switches on the mask aligner. When the machine is powered or ON, the POWER button is illuminated.

b. CONTACT indicator - The CONTACT indicator is illuminated whenever both the contact lever and the separation lever are in the contact position. The substrate is then in contact with the mask. **Do not perform alignment when the contact indicator is lit.**

c. SEPARATION indicator - This indicator is illuminated when the contact lever is in the contact position and the separation lever is in the separation position. The substrate is then separated from the mask by a small distance to allow alignment to be performed. Exposure is not possible in this condition unless the aligner is equipped with a PROXIMITY button. (See Section 2.4.2.3)

d. EXPOSURE button - Pressing the EXPOSURE button initiates exposure and illuminates the button until exposure has been completed. The exposure time is determined by the setting on the exposure timer.

e. VACUUM MASK button - Pressing the VACUUM MASK button switches on the mask vacuum at the maskholder and illuminates the button.

f. VACUUM CHAMBER button - All MJB 3 machines are equipped with a VACUUM CHAMBER button except for the MJB 3 Standard which does not have a vacuum chamber. In the vacuum contact High Precision (HP) mode, the vacuum between mask and substrate is automatically pulled just before exposure. (Refer to Section 2.4.1 for a description of the HP mode.) However, it is possible to check the alignment with the mask and substrate in vacuum contact prior to making an exposure. This feature is particularly useful when using high magnification objectives with restricted depth of focus. Simply press the VACUUM CHAMBER button after moving the substrate to the contact position using the separation lever (CONTACT indicator illuminated), and the

vacuum will be pulled. The vacuum can be released by moving the separation lever to the separation position. If the EXPOSURE button is pressed while the VACUUM CHAMBER button is illuminated, the vacuum between mask and substrate is still preserved and exposure takes place in normal fashion.

g. HP/ST button - All MJB 3 models except the MJB 3 Standard are equipped with an HP/ST button which is used to select either vacuum chamber exposure mode (HP) or standard exposure mode (ST). The appropriate indicator light is illuminated to indicate the exposure mode selected. (Refer to Sections 2.4.1 and 2.4.2 for descriptions of the HP and ST exposure modes.)

h. SOFT CONTACT button - The SOFT CONTACT button is used to select the soft contact exposure mode. In this mode, the substrate is leveled against the mask, and the vacuum under the substrate remains on during exposure. To select soft contact exposure mode, the HP/ST button must be in the ST position.

i. PROXIMITY button (optional) - If the aligner is equipped with a button marked PROXIMITY on the front panel, exposures may be made with a small gap between the mask and the substrate. This proximity gap is determined by the position of the separation lever, and may be adjusted to a maximum distance of 50 microns, depending on the setting of the separation lever range. (A proximity gap of up to 150 microns can be achieved by ordering an optional lead screw when configuring the machine.) When the PROXIMITY button is pressed, it illuminates and defeats the interlock which normally prevents exposure unless the separation lever is in contact position. To select proximity exposure modes, the HP/ST button must be in the ST position.

> NOTE: Even when using the proximity exposure mode, two contacts will be made between mask and substrate: (1) prior to alignment in order to perform mask to substrate parallelity compensation, and (2) after exposure, when the parallelity compensation head brakes are switched off and the wedge head returns to its normal position.

j. Mechanical Exposure Timer - The exposure timer is located on the right side of the front panel. In order to set the timer, two controls are used: an inner knob marked "s", "10s", "m", "10m", "h", and "10h" (for seconds, minutes, and hours) which is used to set the multiplier, and an outer ring which is used to move the timer pointer. The scale for the timer pointer is graduated from 0 to 3. The exposure time is determined by multiplying the pointer setting by the multiplier set on the inner knob. The timer therefore has a range of 0.1 seconds to 30 hours. When the EXPOSURE button is pressed, the timer pointer rotates counterclockwise to 0 during exposure.

Example 1: To obtain an exposure time of 2 seconds, set the timer pointer at 2 and the multiplier to "s".

Example 2: To obtain an exposure time of 8 minutes, set the timer pointer to 0.8 and the multiplier to "10m".

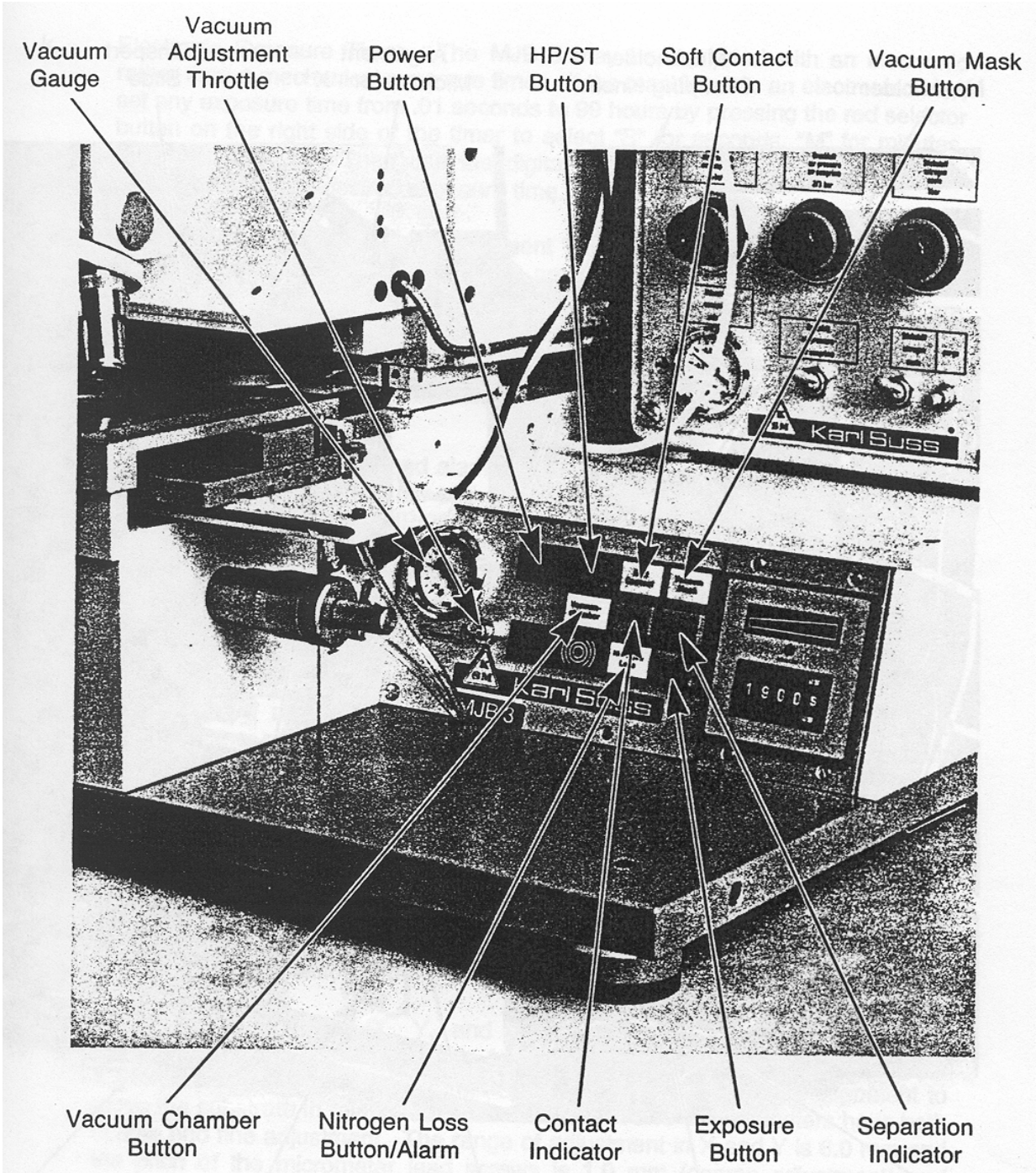


Figure 2 - 1 Front Control Panel

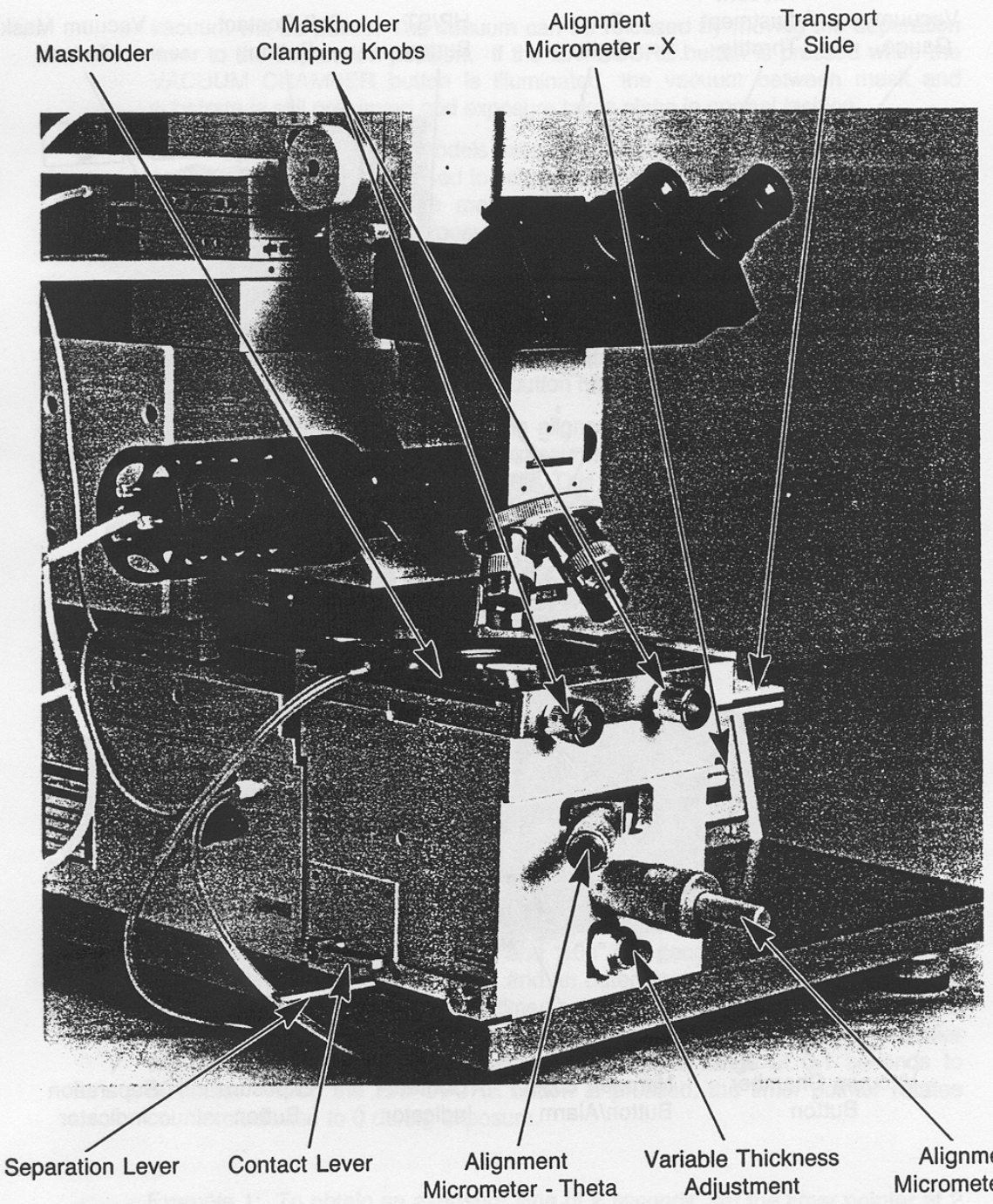


Figure 2 - 2 Alignment Stage

k. Electronic Exposure Timer - The MJB 3 may be equipped with an electronic rather than a mechanical exposure timer. If the machine has an electronic timer, set any exposure time from .01 seconds to 99 hours by pressing the red selector button on the right side of the timer to select "S" for seconds, "M" for minutes, and "H" for hours. Then use the digital switches located beneath the timer display to enter the desired exposure time.

l. Vacuum Gauge and Vacuum Adjustment Throttle - The vacuum gauge and the vacuum chamber adjustment throttles are located on the left end of the front panel for all MJB 3 models except the MJB 3 Standard where they are unnecessary. They are used to adjust the vacuum level in the vacuum chamber during exposure. This setting has no effect on the vacuum under the substrate during alignment. For instruction on setting the vacuum level, refer to Section 2.5.1.

m. NITROGEN LOSS button and alarm - The NITROGEN LOSS button and alarm are located at the lower center of the front panel on all MJB 3 models except the MJB 3 Standard or MJB 3HP/200W where they are unnecessary. The button is a latching type pushbutton that contains an indicator lamp; the alarm sounds a pulsating tone. The system monitors the flow of nitrogen used to cool the exposure lamp base. If the flow rate falls below a preset level, the system will be activated. If the NITROGEN LOSS button is in the "out" position, the button will flash and the alarm will be heard. If the NITROGEN LOSS button is in the depressed or "in" position, the button will flash, but the alarm will not sound. In either case, if nitrogen is not returned within approximately 3 minutes, the exposure lamp power supply will be automatically turned off, thereby significantly reducing the possibility of a lamp explosion due to overheating.

2.1.2 Alignment Stage (Figure 2-2)

a. Transport Slide - The transport slide is located near the top of the stage at the right hand side of the machine and is used to transport the chuck and substrate from the loading position into the stage.

b. Alignment Micrometers (X, Y, and Theta) - The Y and Theta alignment micrometers are located on the front of the alignment stage while the X micrometer is mounted on the right side. They are used during alignment to move the substrate in relation to the mask. The X and Y micrometers have both coarse and fine adjustment. The range of adjustment in X and Y is 6.0 mm and the pitch of the micrometer lead screws is 1.0 mm (coarse adjustment) and 0.05 mm (fine adjustment). The Theta (rotation) micrometer has a range of 30° with a pitch of 0.5 mm for the MJB Standard and 0.25 mm for the other models.

c. Contact Lever - The contact lever, which controls the Z-axis movement of the chuck, is located at the lower left side of the stage. After inserting a chuck and substrate into the stage using the transport slide, the contact lever is used to bring the substrate into contact with the mask for parallelity compensation.

d. Separation Lever - The separation lever is also located at the lower left side of the stage. This lever is used to move the substrate in and out of contact with the mask in order to perform alignment, once the contact lever has been engaged. Exposure can only be initiated when the separation lever is in the contact position (unless using the optional PROXIMITY program.)

e. The maskholder is securely clamped in the mask holder frame on the top of the stage using two knurled knobs. It is removed and reinserted into the maskholder frame from the left side of the stage.

f. Variable Thickness Adjustment - The variable thickness adjustment is located on the front of the stage immediately below the Y-micrometer. At the time of installation, the Z-travel of the stage is adjusted using a reference substrate and mask. If substrates or masks of different thicknesses are to be used, this thickness difference must be compensated for, using the variable thickness adjustment. This adjustment procedure is described in Section 2.5.3.

g. Nitrogen Purge - For work with negative resist, the stage is equipped with a purge which flushes the wafer and mask area with nitrogen to reduce the "oxygen effect". The nitrogen is introduced through a number of small holes in the back of the maskholder frame. The purge volume is adjusted using the throttle located on the lower right corner of the manometer box. (IR machines do not include this feature.)

2.1.3 Microscope Manipulator

The microscope manipulator, which controls the movement of the microscope over the alignment stage, is located on the left side of the machine. The manipulator rides on X–Y slides which are equipped with pneumatic brakes and mounted to the top of the mirrorhouse assembly. Two buttons located on the manipulator handle are used to unlock either or both brakes, thereby enabling the microscope to be scanned in either the X or Y directions exclusively, or in both directions simultaneously.

2.1.4 Microscope

The microscope is mounted on the MJB 3 by means of a microscope adapter which includes mechanical mounting parts, and a focusing rack. The focusing rack consists of a combined coarse/fine adjustment to allow rapid focusing of the microscope image. If the focus adjustment knob is turned in one direction only, the coarse focusing motion is in effect. The fine adjustment is automatically engaged as soon as the slightest turn is made in the opposite direction. The adjustment will switch back to the coarse focusing mode when the limits of fine adjustment are exceeded.

In addition, the microscope lift (if the microscope adapter is so equipped) raises the microscope to provide clearance between the objectives of the microscope and the maskholder. This lifting action will be automatically performed by the machine whenever the mirrorhouse travels to the front of the machine.

A number of microscope options are offered in both normalfield and splitfield types. The three basic configurations are described below. A more detailed description of the microscope supplied with your equipment may be found in the Appendix.

a. Splitfield Microscope - SUSS M200 - 200 Series (Figure 8-1)

The M200 microscope consists of the microscope head (either binocular or trinocular), eyepieces, microscope body, illuminator, and objectives. The choice of eyepieces and objectives depends upon the magnification desired. The objective separation distance is adjusted by using the two combination objective separation knobs which also adjust the fine focus. Two small knobs on the front of the body of the microscope are used to select either singlefield or splitfield operation.

b. Splitfield Revolver Microscope - SUSS M230 - 200 Series (Figure 8-2)

The M230 microscope is similar to the M200 except that it is supplied with three pairs of objectives. Locking screws located in the revolver mount dovetail allow the revolver to be rotated without changing the objective separation distance.

c. Normalfield Microscope - SUSS M400 (Figure 8-3)

The M400 microscope consists of the microscope head (either binocular or trinocular), eyepieces, microscope body, illuminator, objective turret, and objectives. It is offered in three versions: brightfield only, brightfield/darkfield, and an interference contrast combination of brightfield and darkfield. Interference contrast illumination is obtained, using an interference contrast objective, by inserting the analyzer and the polarizer into the illumination path. Darkfield illumination is achieved, using a darkfield objective, by inserting the darkfield stop into the light path.

2.1.5 Manometer Box

The manometer box contains the gauges and regulators used to control the machine pneumatics. There are three pressure gauges labelled Air Pressure (4 bar), Air Pressure (2 bar), and Nitrogen. These should be set at 4 bar (60 psi), 2 bar (30 psi), and 1 bar (15 psi) respectively, using the regulators located under each gauge. With the exception of parallelity compensation, the left Air Pressure Regulator located beneath the gauge labelled Air Pressure (4 bar) controls the pressure used for all machine functions controlled by air pressure (mirrorhouse movement, microscope lift and manipulator brakes, lamphouse heat sink cooling, etc.)

The Air Pressure Regulator which is located beneath the gauge labelled Air Pressure (2 bar) controls the pressure in the bladder ring located under the parallelity (wedge error) compensation plate.

The Nitrogen Regulator controls the nitrogen pressure to the machine. Nitrogen is used for lamp base cooling in the MJB 3/350W lamphouse, pressure under the wafer in standard exposure mode, the airing function, the nitrogen purge function, and to separate the wafer from the mask after exposure. Two pneumatic switches which control the compressed air and nitrogen supplies are located below the gauges and regulators, along with a throttle which is used to control the nitrogen purge to the wafer stage for work with negative resist. A gauge to show the vacuum supplied to the machine is situated at the bottom left of the manometer box.

2.2 Start Up Procedure

2.2.1 Pre-Operation Check List

Before starting the MJB 3, it is important to:

a. Switch on the nitrogen and compressed air (manometer box) and adjust the regulators to the proper settings (if necessary).

b. Switch on the vacuum to the machine.

2.2.2 Power Up

Assuming that the exposure lamp power supply is on and already in operation, turn on the MJB 3 by pressing the POWER button. The button will illuminate.

2.2.3 Exposure Lamp Ignition

If the exposure lamp power supply is not on, the MJB 3 main power should be off before switching on the power supply. The lamp ignition sequence is as follows:

a. Check that the machine is turned off.

b. Switch on the POWER to the exposure lamp power supply.

c. Press the lamp START button and release. If the lamp does not ignite after the firing sequence, press the button again.

d. For more detailed information about setup and operating procedures, refer to the Operator's Reference Manual for the Constant Intensity Controller (power supply).

2.3 Operation

2.3.1 Loading the Mask

NOTE: It is extremely important at all times to avoid scratching chucks and maskholders.

To load a mask into the machine, first loosen the two knurled knobs which clamp the maskholder onto the stage and withdraw the maskholder. Carefully place the maskholder on a flat surface, with the vacuum groove facing up.

Check that the MASK VACUUM button on the front panel is in the extended or off position. Place the mask on the maskholder with the patterned side up and then press the MASK VACUUM button. This will fix the mask to the maskholder by vacuum. Now invert the maskholder and reinsert it into the stage. Clamp the maskholder securely in place using the two knurled knobs.

2.3.2 Loading the Substrate

Place the substrate on the chuck, ensuring that it completely covers all the vacuum holes. Insert the chuck into the stage by carefully pushing the transport slide to the left until it reaches the stop. Bring the substrate into contact with the mask by rotating the contact lever 180° counterclockwise (toward the rear of the machine). The CONTACT indicator on the front panel will illuminate.

Where an MJB 3 is used in the standard exposure mode **with a standard chuck,** the operator may take advantage of the pre-vacuum feature when inserting the chuck into the stage. After the substrate is placed on the wafer chuck, squeeze the button on the front of the finger grip located at the right edge of the transport slide. This causes a vacuum to hold the wafer to the chuck during transport to the stage. Once the chuck is fully inserted into the stage, rotate the contact lever as above and release the pre-vacuum button.

> NOTE: The pre-vacuum feature will **only** function in the standard exposure (ST) mode with a standard chuck.

2.3.3 Aligning the Substrate to the Mask

First, select the exposure mode desired. Then focus the microscope on the mask and substrate using the focus adjustment knobs. If the microscope is equipped with an objective revolver, a low magnification objective should be used for coarse alignment and the magnification steadily increased until satisfactory alignment is obtained. In order to align the substrate, it must first be separated from the mask. Pull the separation lever toward the front of the machine until sufficient separation is obtained. The CONTACT indicator will go out and the SEPARATION indicator will illuminate. (The range of the separation stroke is adjustable and is set at the time of installation.) Now align the substrate to the mask using the X, Y, and Theta micrometers. The X and Y micrometers are equipped with both a coarse and fine adjustment.

If the aligner is equipped with a normalfield microscope, alignment is performed by scanning the microscope back and forth in either the X or the Y direction. The microscope manipulator is equipped with pneumatic brakes which are unlocked by pressing the buttons on the manipulator handle. Select either an X-only or Y-only scan by pressing just one button.

If the aligner is equipped with a splitfield microscope, the two objectives are aligned to two alignment features on opposite sides of the substrate using the microscope

manipulator and the objective separation controls. In this case, it is not necessary to scan the microscope across the mask during substrate alignment.

When satisfactory alignment is obtained, move the substrate back into contact with the mask by pushing the separation lever all the way to its rearmost position. The SEPARATION light will go out and the CONTACT light will illuminate.

When using high magnification, it is possible that the alignment position may be seen clearly only in the contact position because of depth of focus restrictions. If the alignment is unsatisfactory in contact position, repeat the alignment sequence until correct alignment is obtained.

For more detailed information, refer to the application note on alignment in the Appendix (Chapter 8).

2.3.4 Exposure

The substrate is now ready for exposure. (Exposure mode should be selected **before** alignment.) Set the exposure time on the timer located at the right end of the front panel. Sections 2.1.1.j or 2.1.1.k provide instructions on setting the timer.

Press the EXPOSURE button. (On some microscopes, the working distance of the high magnification objectives is so small that the objective extends into the maskholder opening when focused on the mask. In these cases, the microscope adapter on which the microscope is mounted is equipped with a lift mechanism.) When the EXPOSURE button is pressed, the microscope will first elevate an amount sufficient to allow the objective to clear the maskholder.

The mirrorhouse then moves forward into position over the mask. When the mirrorhouse reaches the foremost position, the exposure shutter opens and exposure takes place for the amount of time set on the exposure timer. After exposure, the shutter closes and the mirrorhouse automatically retracts. The microscope lift is then released and the microscope moves back down to its original position.

2.3.5 Unloading the Substrate

With exposure complete, the substrate may now be unloaded. Rotate the contact lever 180° clockwise (toward the front of the machine), which releases the substrate from the mask. Pull the transport slide to the right and carefully remove the substrate from the chuck.

2.4 Exposure Mode Options

2.4.1 Vacuum Contact (High Precision) Mode

In the HP mode, a vacuum is pulled between the mask and the substrate just before exposure. The highest possible resolution is obtained in this mode since the gap between substrate and mask (which is caused by flatness variations, dust particles, etc.) is as small as possible. Chucks fitted with vacuum gaskets must be used in this mode in order to obtain a vacuum between the substrate and the mask. Vacuum contact mode is not an option on the MJB 3 Standard model.

When printing in the vacuum contact mode, the following sequence of events occurs after the EXPOSURE button is pressed:

a. The vacuum under the substrate is switched off.

b. The vacuum between the substrate and the mask is switched on through the vacuum chamber hole located at the outer edge of the chuck.

c. The shutter opens, exposure takes place for the length of time set on the exposure timer, and the shutter closes, completing the exposure.

d. The vacuum between the substrate and the mask is switched off.

e. The vacuum under the substrate is switched on.

f. When the operator moves the contact lever to unload the substrate, a nitrogen burst is introduced through the vacuum chamber hole, breaking the vacuum between the substrate and the mask.

2.4.2 Standard (ST) Mode

In the ST mode, one of two (Standard or Soft Contact) exposure programs can be selected; this allows the greatest amount of flexibility in the use of the machine. Only chucks without vacuum gaskets should be used in the ST mode of operation.

2.4.2.1 Hard Contact

If the ST mode is illuminated, and both the SOFT CONTACT and PROXIMITY (if so equipped) buttons are not, exposure will be performed with nitrogen pressure pressing the substrate against the mask. The sequence of events after the EXPOSURE button is pushed is as follows:

a. The vacuum under the substrate is removed.

b. Nitrogen pressure is applied under the substrate. (This is adjustable by using throttle #18 located on the left side of the machine.)

> **CAUTION**: Too much nitrogen can cause the mask to bow.

c. The shutter opens, exposure takes place for the length of time selected on the exposure timer, and the shutter closes, completing the exposure.

d. The nitrogen pressure under the substrate is removed.

e. Vacuum is reapplied under the substrate.

2.4.2.2 Soft Contact

If the ST and SOFT CONTACT buttons are illuminated, then exposures will be performed with only mechanical pressure pressing the substrate against the mask. During exposure, the vacuum securing the substrate to the exposure chuck remains, and no nitrogen is applied.

2.4.2.3 Proximity Mode (Optional)

If the aligner is equipped with a button marked PROXIMITY (which is located on the front panel), exposures may be made with a small gap between the mask and the substrate. This proximity gap is determined by the position of the separation lever and may be adjusted to a maximum separation distance of 50 microns, depending on the setting of the separation lever range. (A separation gap of up to 150 microns can be achieved by ordering an optional lead screw when configuring the machine.)

When the PROXIMITY button is pressed, it defeats the interlock which normally prevents exposure unless the separation lever is in the contact position. The vacuum under the substrate remains on during exposure, which takes place in normal fashion.

> Note: Even when using the proximity exposure mode, two contacts will be made between mask and substrate: (1) prior to alignment in order to perform mask to substrate parallelity compensation, and (2) after exposure when the parallelity compensation head brakes are switched off and the wedge head returns to its normal position.

2.5 Adjustment Procedures

Certain features of the SUSS MJB 3 are user adjustable and are described in this section.

2.5.1 Vacuum Chamber Adjustment Procedure

The vacuum chamber is adjustable in all MJB 3 models except the MJB 3 Standard which has no vacuum chamber. Under certain circumstances, the operator may wish to expose substrates in vacuum contact mode with less than full vacuum in the vacuum chamber. If this is the case, a vacuum gauge and adjustment throttle are located at the left end of the control panel.

To set the vacuum level, bring a substrate to the contact position in vacuum chamber mode as outlined in Section 2.3.2, and press the VACUUM CHAMBER button. Use the throttle and vacuum gauge reading to adjust the vacuum as desired. Opening the throttle introduces a small leak into the vacuum chamber which offsets the vacuum from the vacuum source. Turn the throttle counterclockwise to decrease the vacuum, or clockwise to increase the vacuum.

> Note: This adjustment does not affect the amount of vacuum under the substrate during alignment.

The vacuum gauge can also be used to detect vacuum leaks in the vacuum chamber due to damaged chucks, vacuum gaskets, etc.

2.5.2 Airing Feature Adjustment Procedure

When using a chuck equipped with a vacuum gasket, a partial vacuum may unintentionally develop during alignment between substrate and mask due to an imperfect seal between the substrate and the chuck. This can occur if the backside of the substrate is unusually rough or scratched, or if scratches are present in the chuck surface. This partial vacuum can cause the substrate and mask to stick together and make alignment difficult or impossible. To overcome this problem, a small flow of nitrogen is introduced into the vacuum chamber whenever the substrate is separated from the mask. This nitrogen flow is controlled by throttle #12 located towards the back left panel of the machine (Figure 2-10).

The throttle can be adjusted as follows:

a. Bring a substrate to the separation (alignment) position as outlined in Sections 2.3.1 through 2.3.3.

b. Turn throttle #12 counterclockwise until the substrate and mask do not stick together in separation position and the substrate moves freely in relation to the mask when the alignment micrometers are adjusted.

c. Using the separation lever, move the substrate into contact with the mask and back into separation again. Observe the substrate and mask through the microscope throughout this operation.

d. If the substrate shifts in relation to the mask during this procedure, turn the throttle clockwise until there is no further shifting.

2.5.3 Setting the Variable Thickness Adjustment

The MJB 3 is equipped with a device to process substrates of various thicknesses. The device can also be used to vary the contact pressure on a given wafer.

When the equipment is installed, a reference mask and wafer are used to set the contact pressure between the mask and wafer. This setting can be changed by using the thickness adjustment knob located on the front of the stage towards the bottom of the machine.

One revolution or turn of the thickness adjustment knob corresponds to a 150 micron variation of substrate thicknesses or contact pressure. Rotate the knob counterclockwise to increase the contact pressure (or subtract wafer thickness), or clockwise to decrease contact pressure (or add wafer thickness).

EXAMPLES: Assume that in each of the three cases a reference mask of 60 mil (1500 microns) thickness and a reference wafer of 20 mil (500 microns) thickness is used to set up the machine at installation. Also assume that a contact pressure of 500 microns is set which corresponds to a setting of 5.0 on the thickness adjustment knob.

Example #1:

Task - process 14 mil (350 micron) thick wafers.

Procedure - rotate the thickness adjustment knob counterclockwise to a setting of 6.0 (500 microns - 350 microns = 150 microns = 1 revolution).

Example #2:

Task - decrease contact pressure from 500 to 350 microns.

Procedure - rotate the thickness adjustment knob clockwise to a setting of 4.0 (150 microns = 1 revolution).

Example #3:

Task - use a 63 mil thick mask.

Procedure - rotate the thickness adjustment knob clockwise to a setting of 4.5 (63 mil - 60 mil = 3 mil = 75 microns = 0.5 revolution).

F. MASK SETS

APPENDIX F

FABRICATION LAB MASK SETS

1. Mask OXI-1 is sometimes used in the oxidation experiment. The figure shows a single unit cell of the mask. The mask that is used in the experiment will have six unit cells.

2. Masks MOS-1, MOS-2 and MOS-3 are the masks used in the single diffusion experiment. The masks have four large unit cells and eight smaller unit cells plus several **very** small devices. Dimensions given for the unit cells are the dimensions of the large unit cells, and the smaller unit cells are the size.

   a. MOS-1 is the first level mask for defining the diffusion areas.

   b. MOS-2 is the second level mask for defining the contact windows.

   c. MOS-3 is the final level mask set for the metallization.

3. Masks BJT-1, BJT-2, BJT-3, and BJT-4 are the masks used in the double diffusion experiment. The masks have many large unit cells that each have two smaller unit cells. Dimensions given for the unit cells are the dimensions of the large unit cells, and the smaller unit cells are the size.

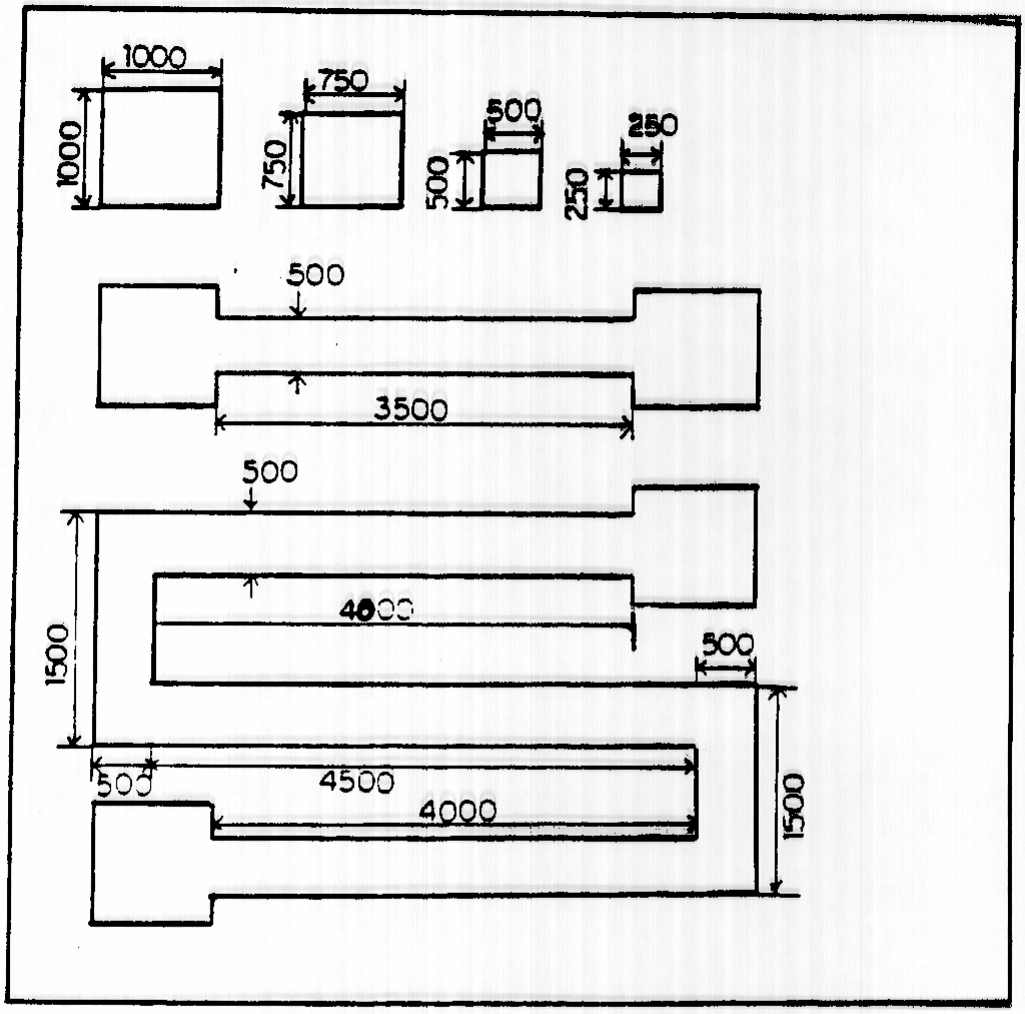
   a. BJT-1 is the first level mask for defining the base diffusion areas.

   b. BJT-2 is the second level mask for defining the emitter diffusion areas.

   c. BJT-3 is the third level mask for defining the contact windows.

   d. BJT-4 is the final level mask set for the metallization.

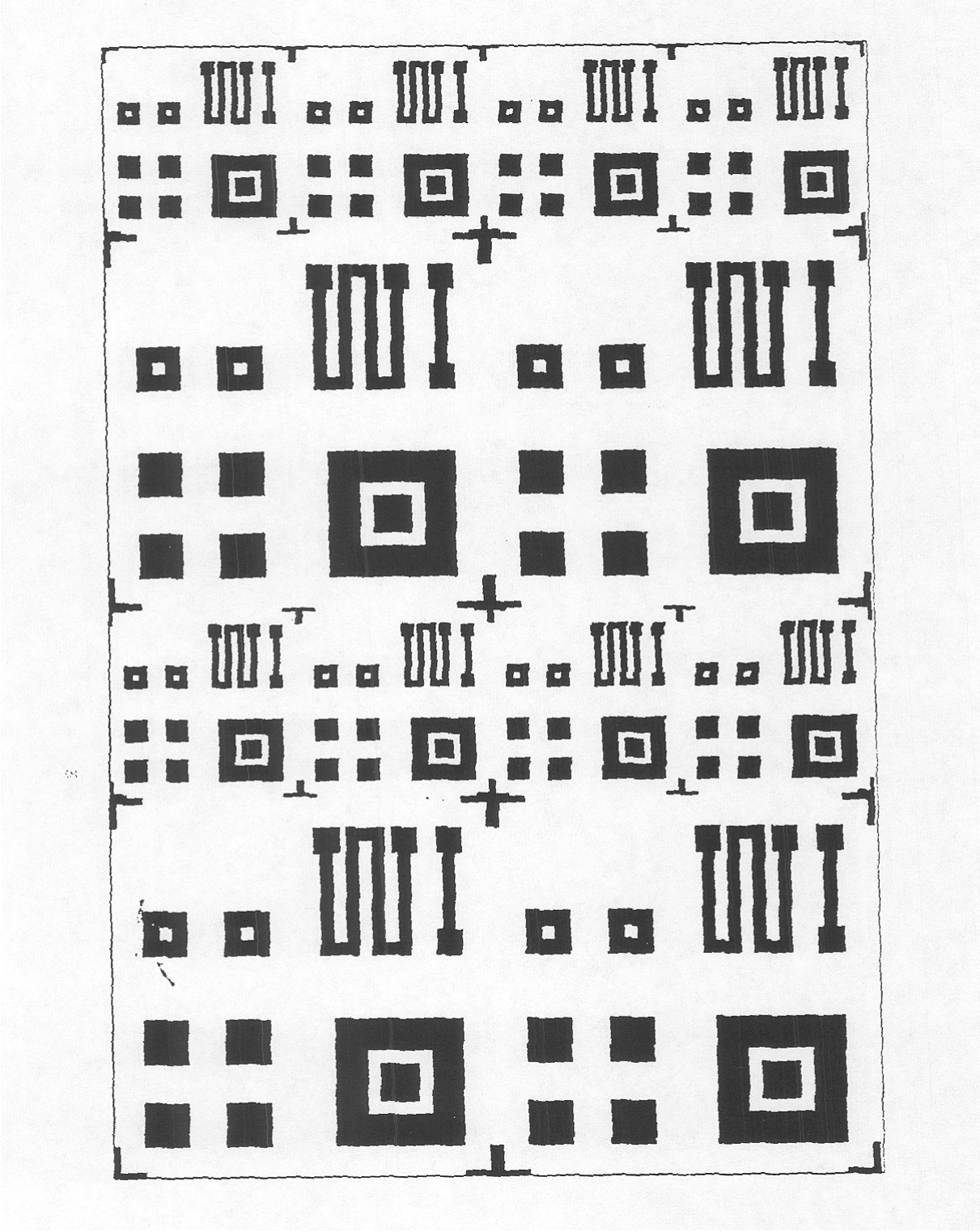
MASK OXY-1



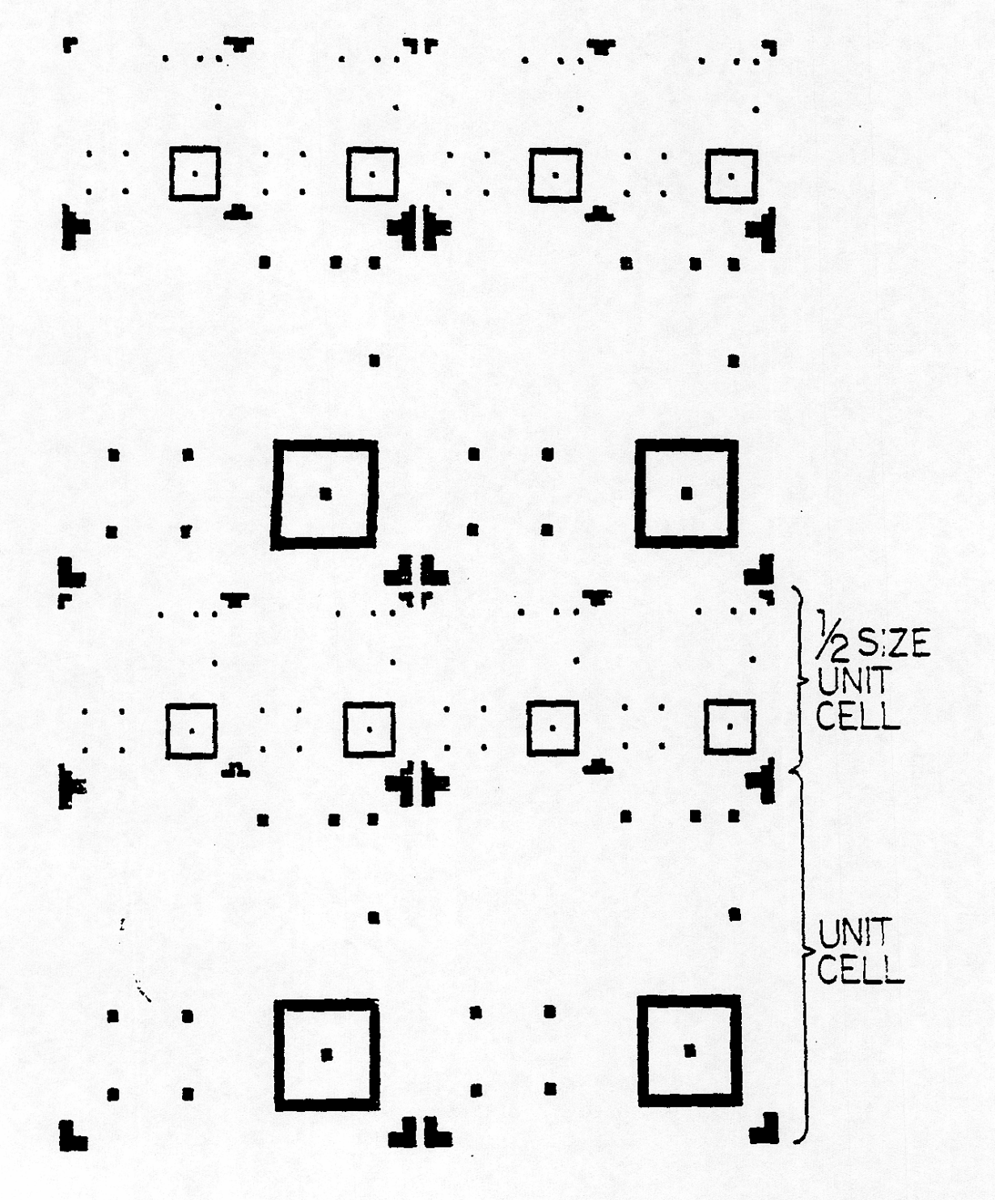
ALL DIMENSIONS ARE IN MICRONS.

RESISTOR PADS ARE 1000 X 1000 MICRONS

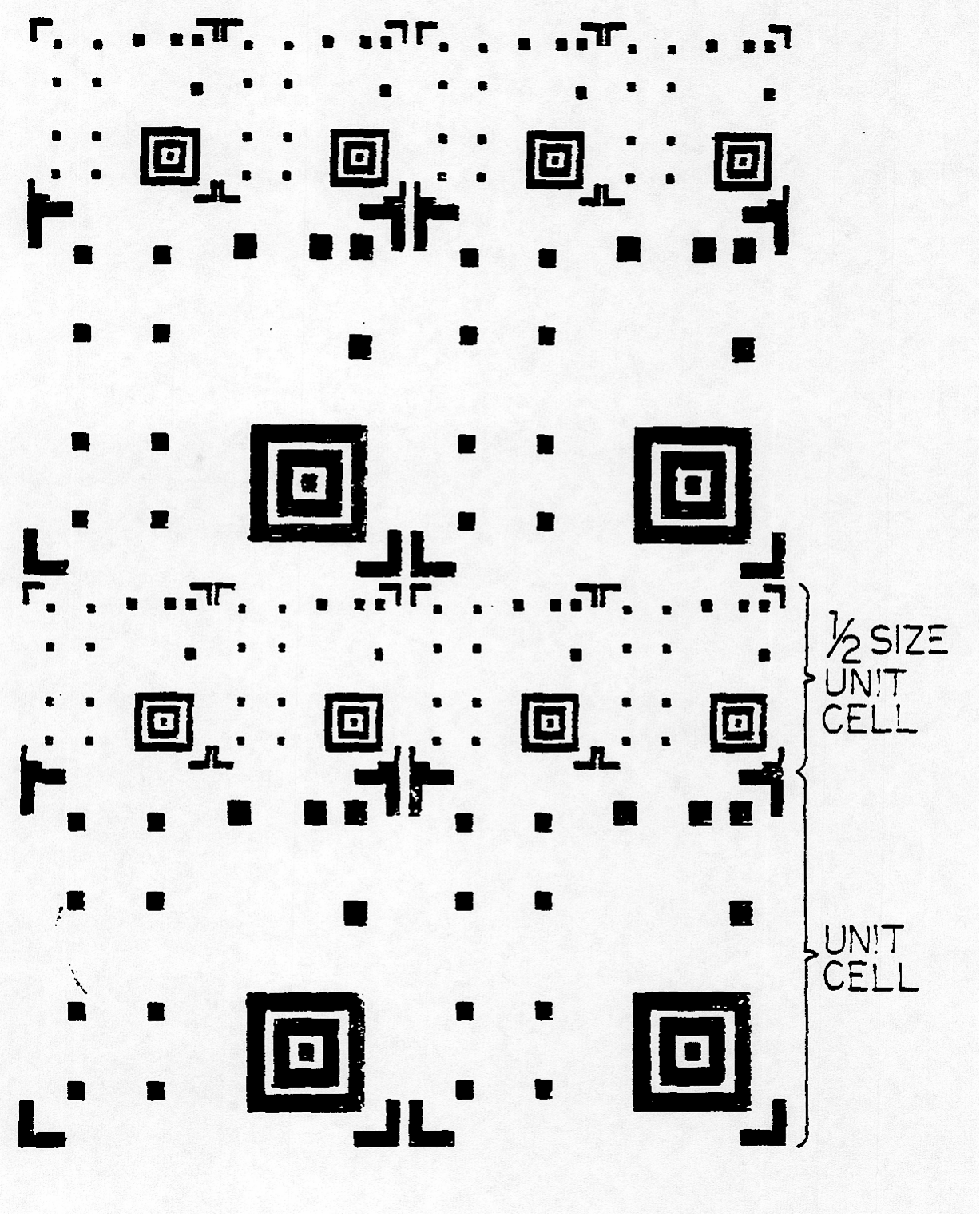
MASK MOS-1



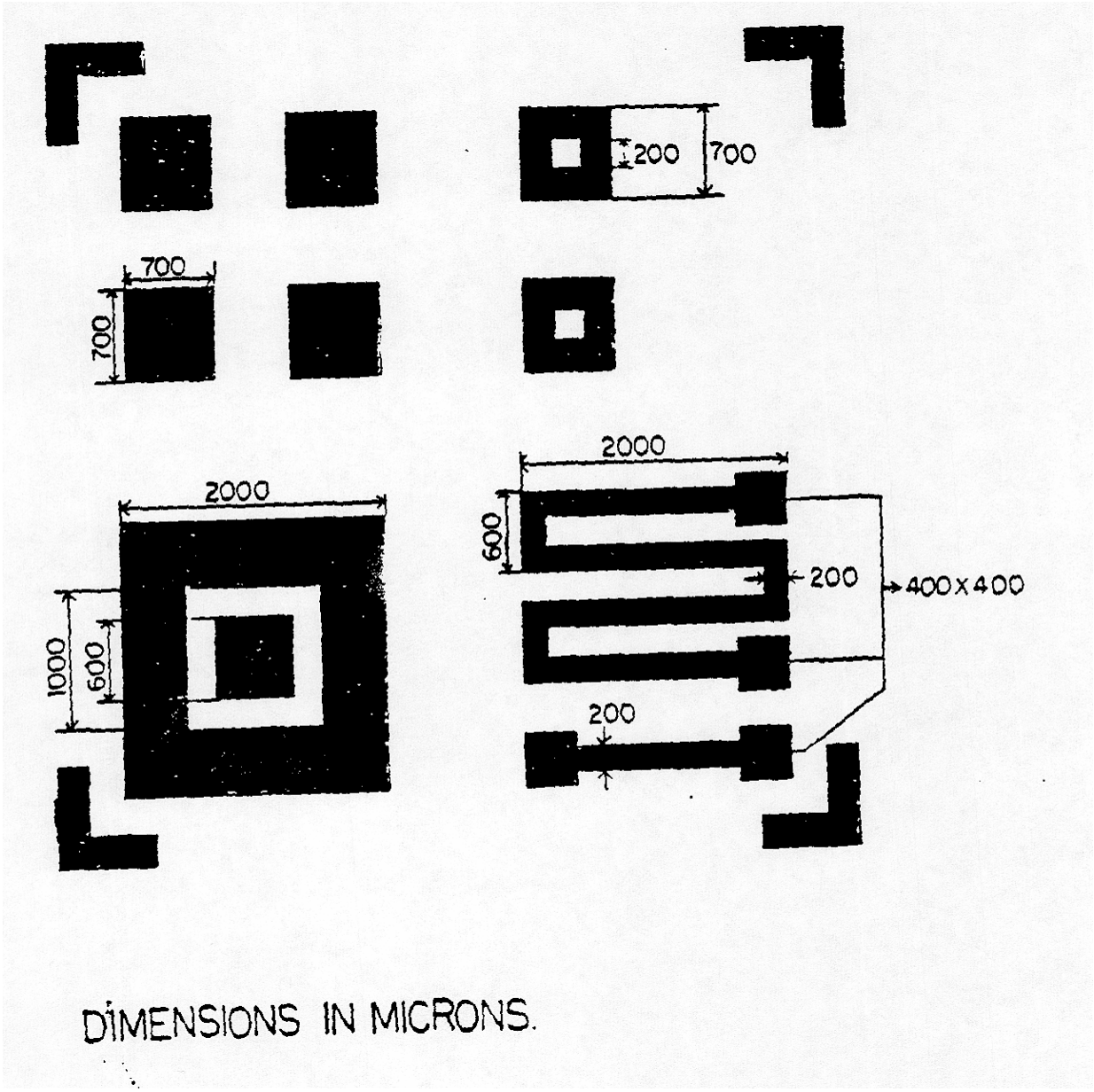
MASK MOS-2



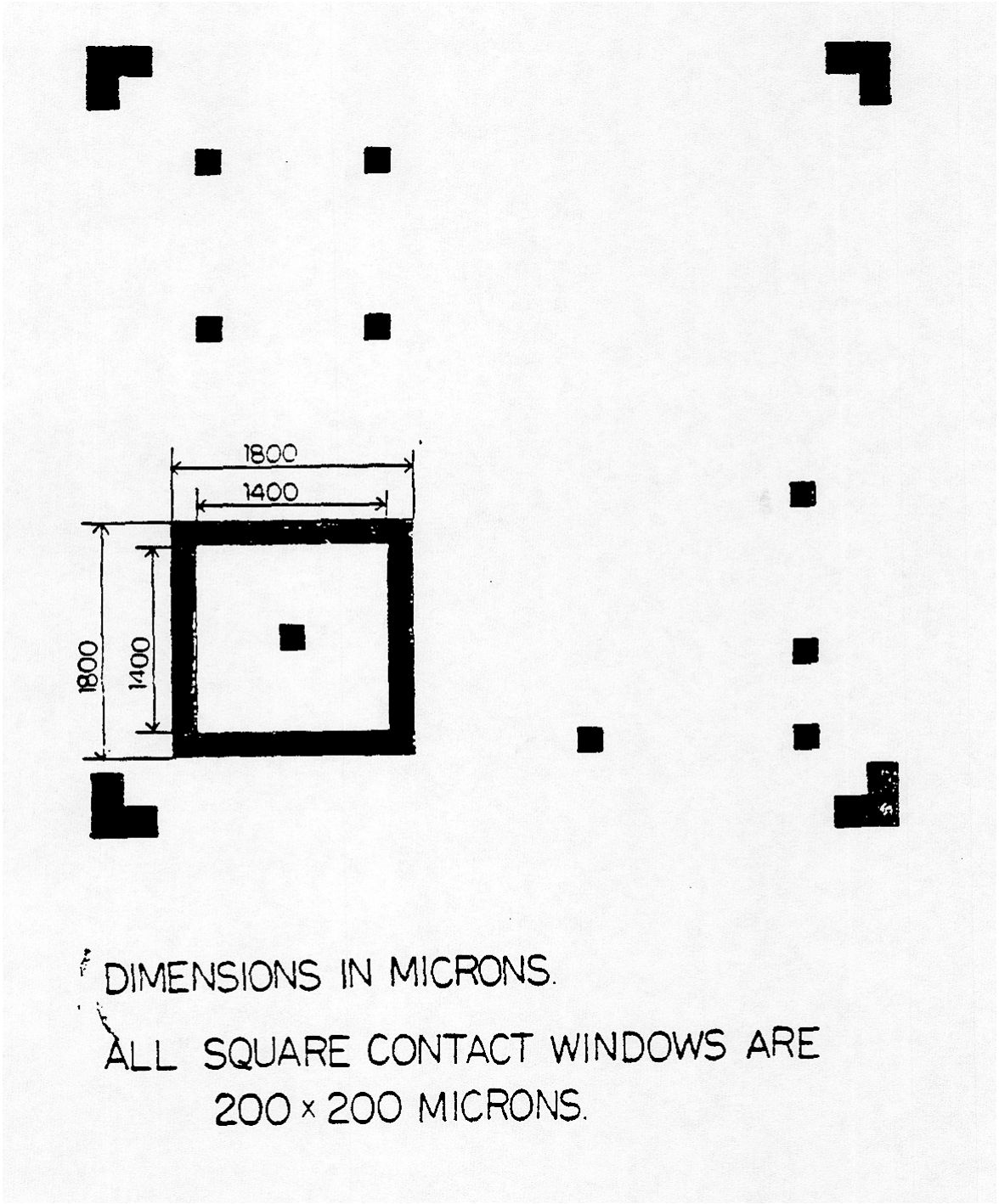
MASK MOS-3



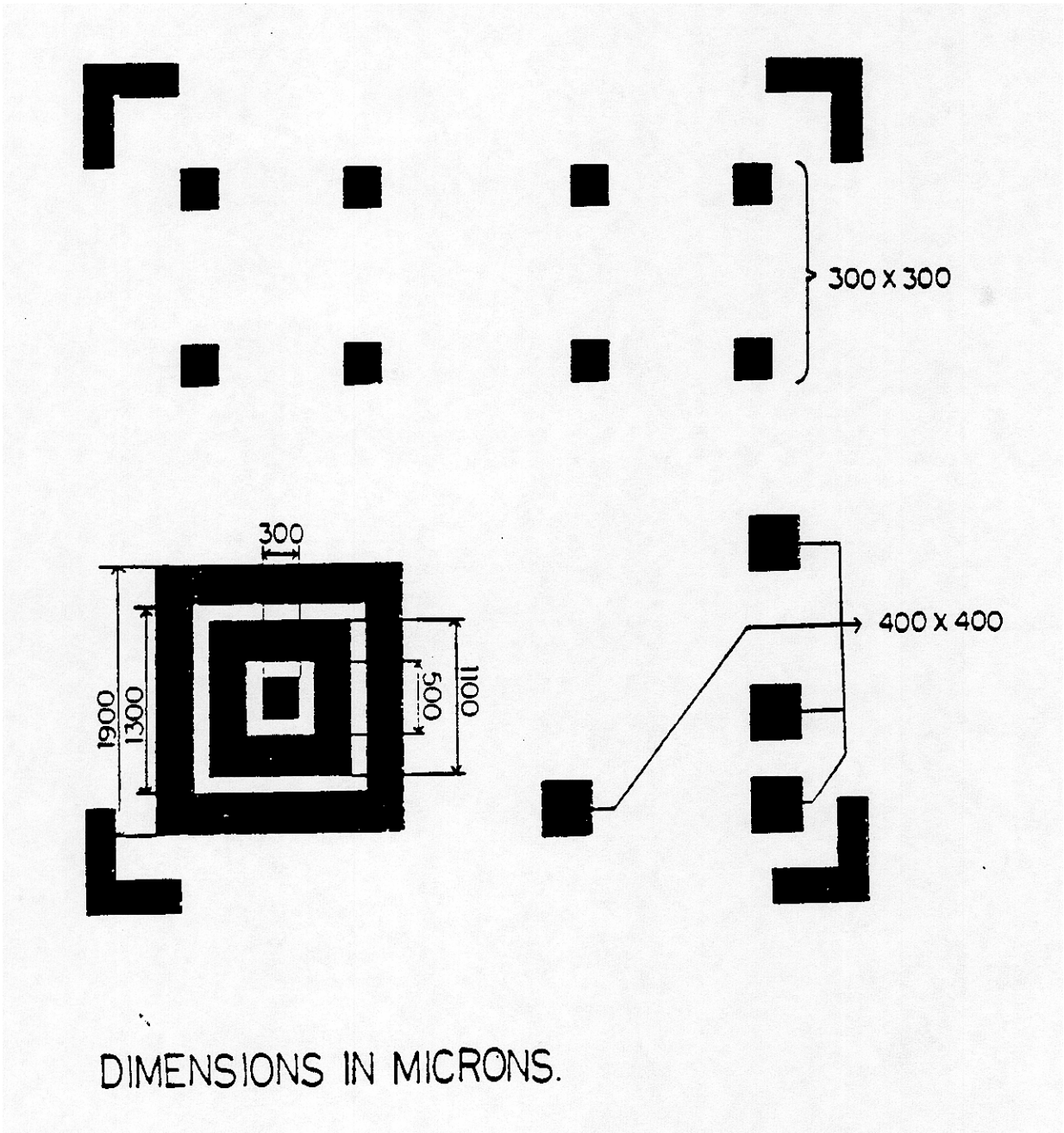
MASK MOS-1 (UNIT CELL)



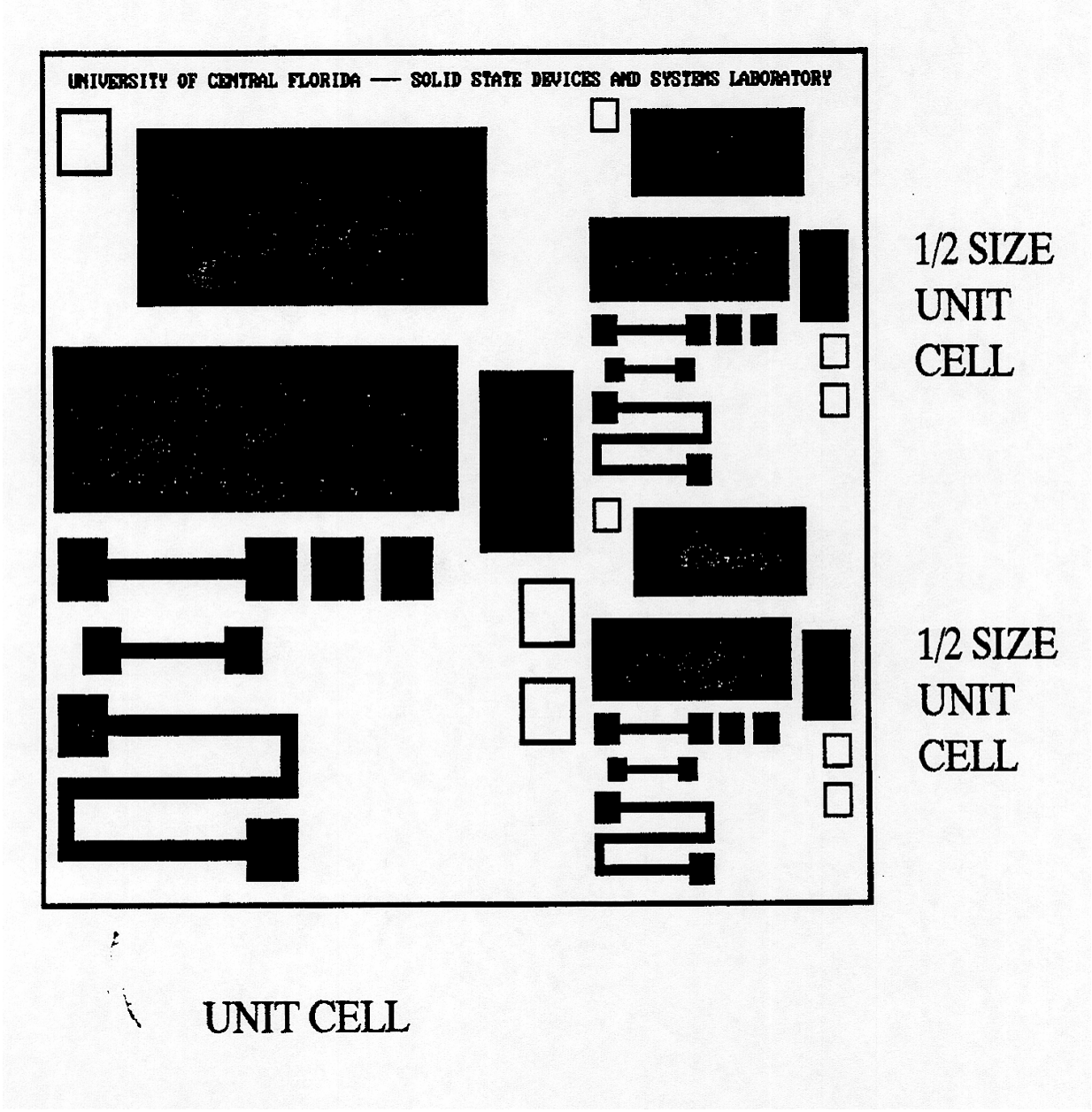
MASK MOS-2 (UNIT CELL)



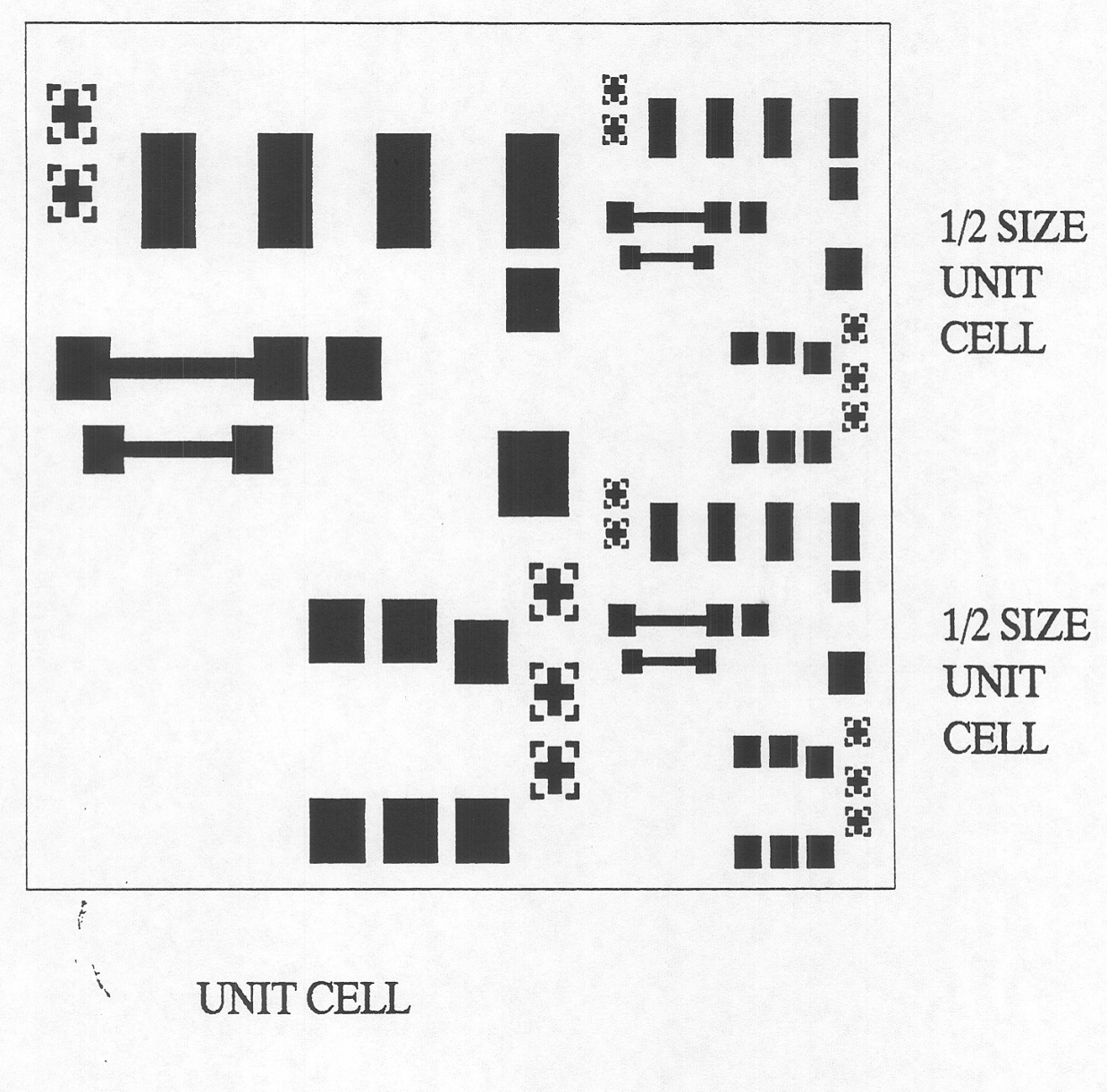
MASK MOS-3 (UNIT CELL)



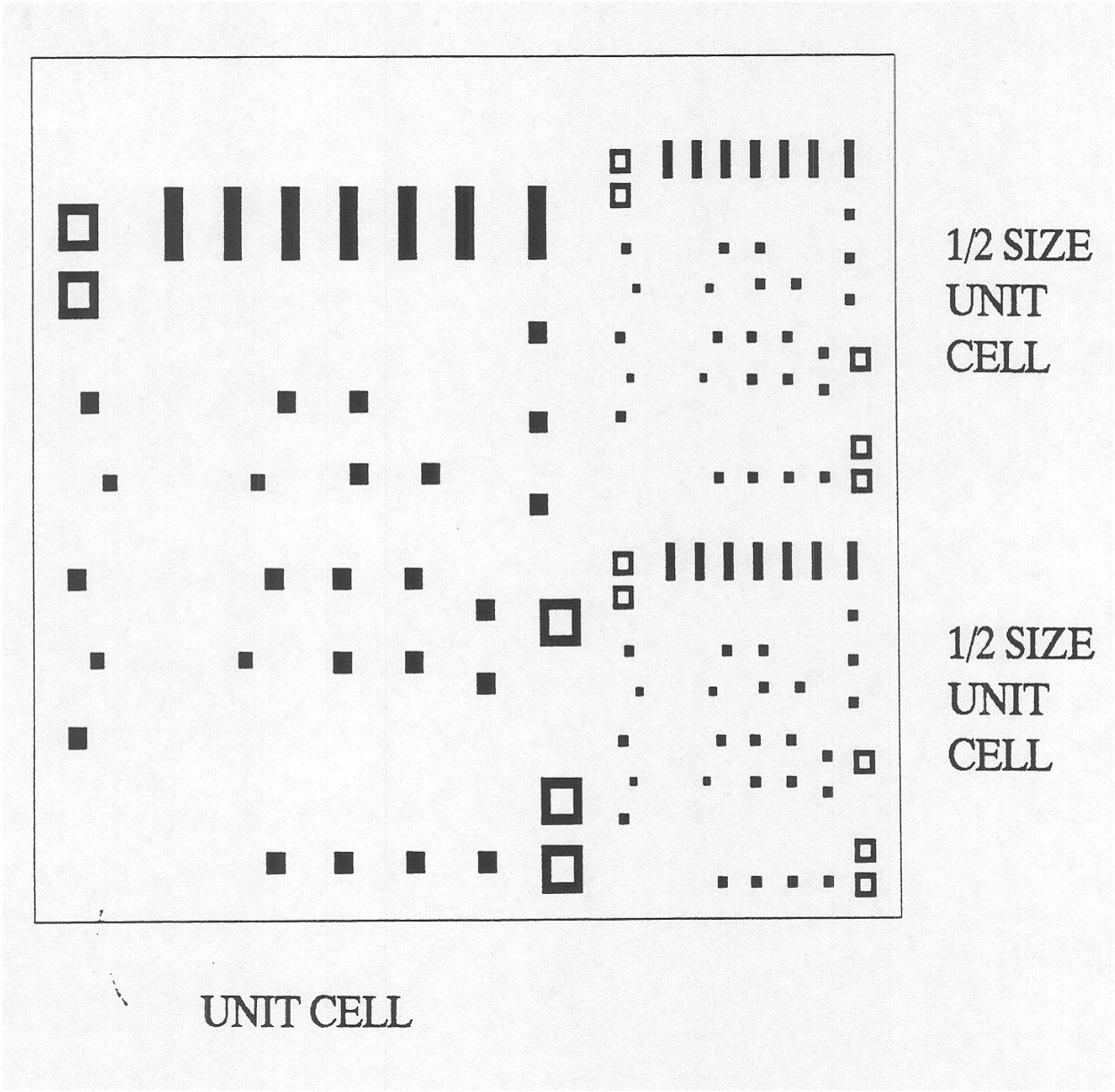
MASK BJT-1


UNIVERSITY OF CENTRAL FLORIDA — SOLID STATE DEVICES AND SYSTEMS LABORATORY
1/2 SIZE UNIT CELL
1/2 SIZE UNIT CELL
UNIT CELL

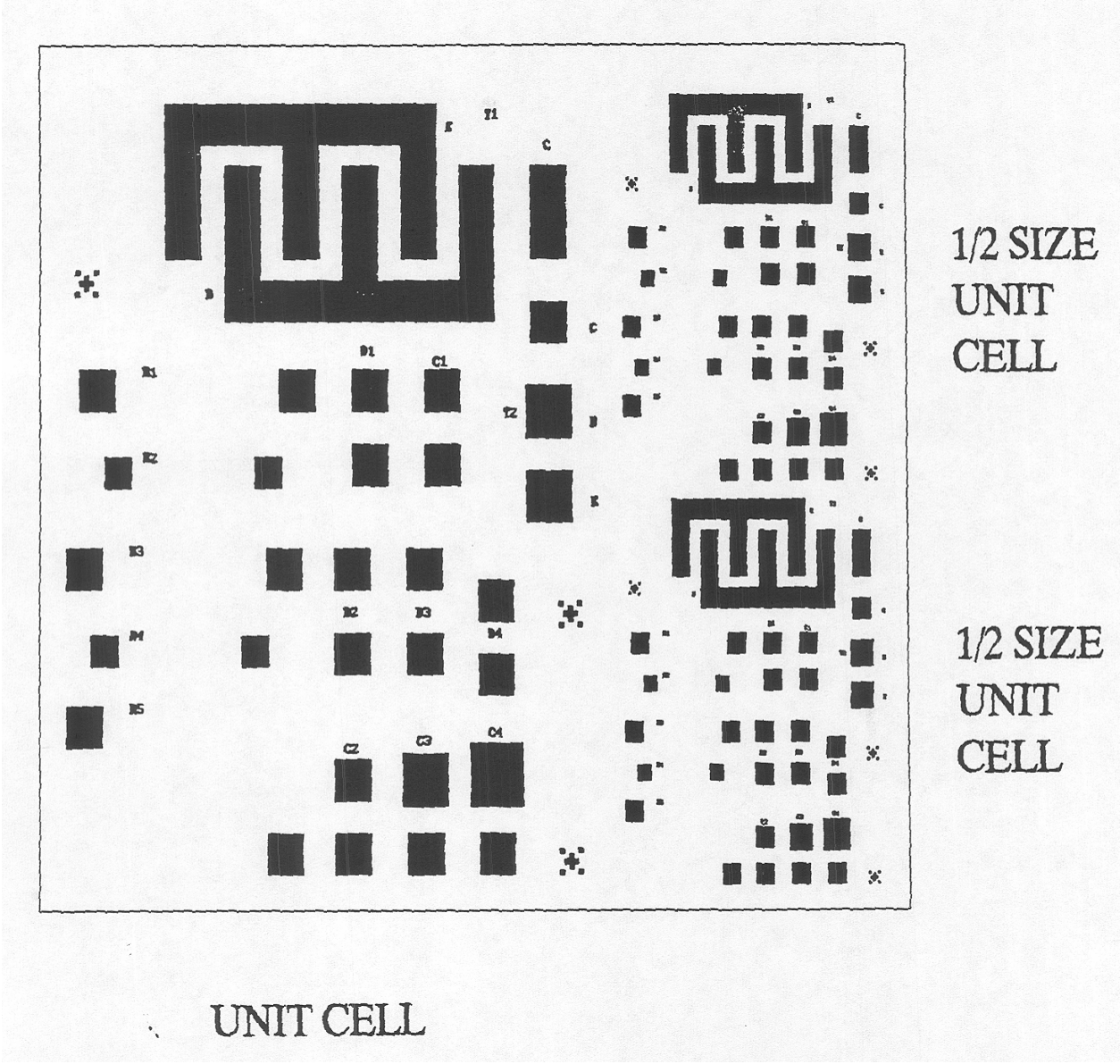
MASK BJT-2



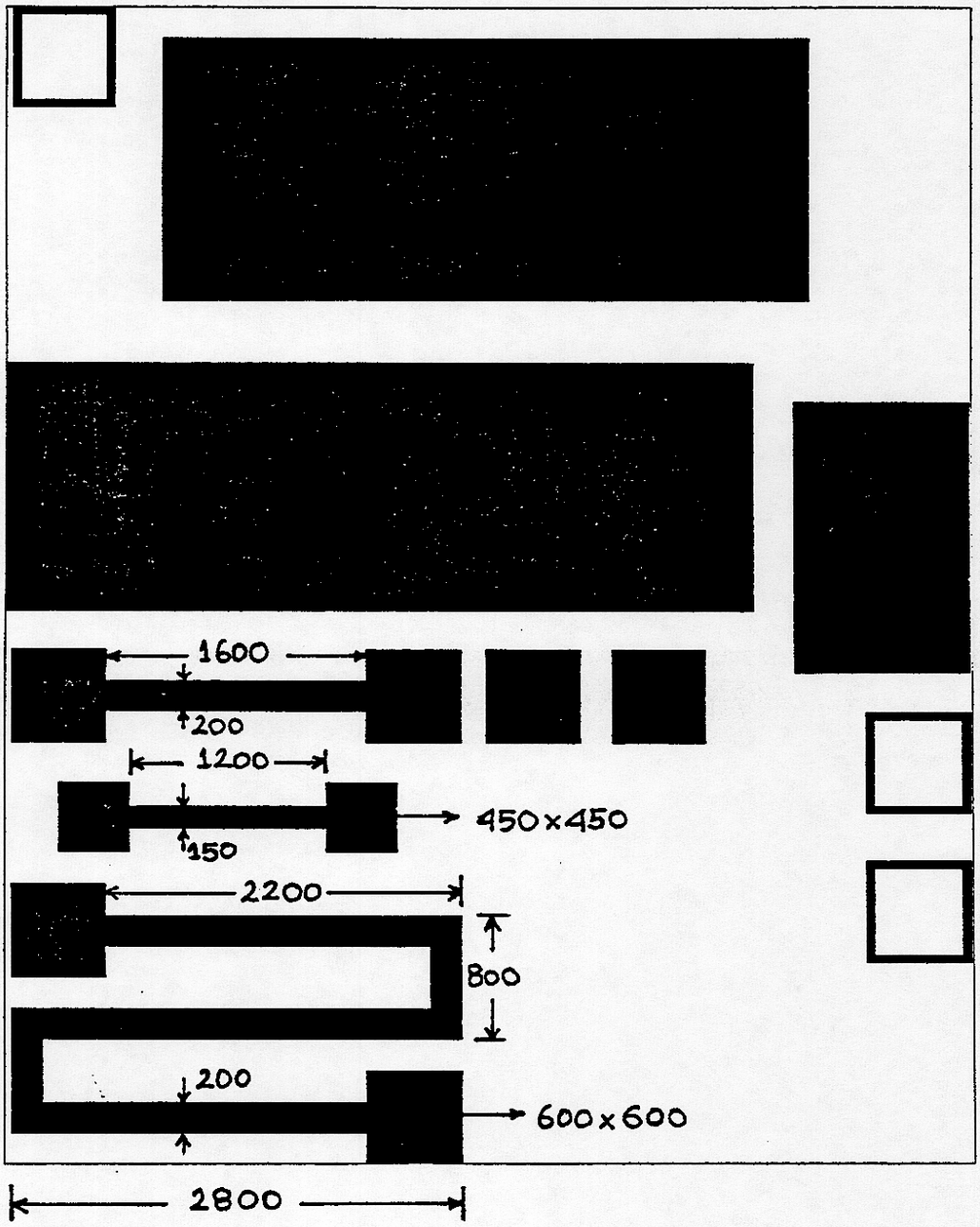
MASK BJT-3



MASK BJT-4

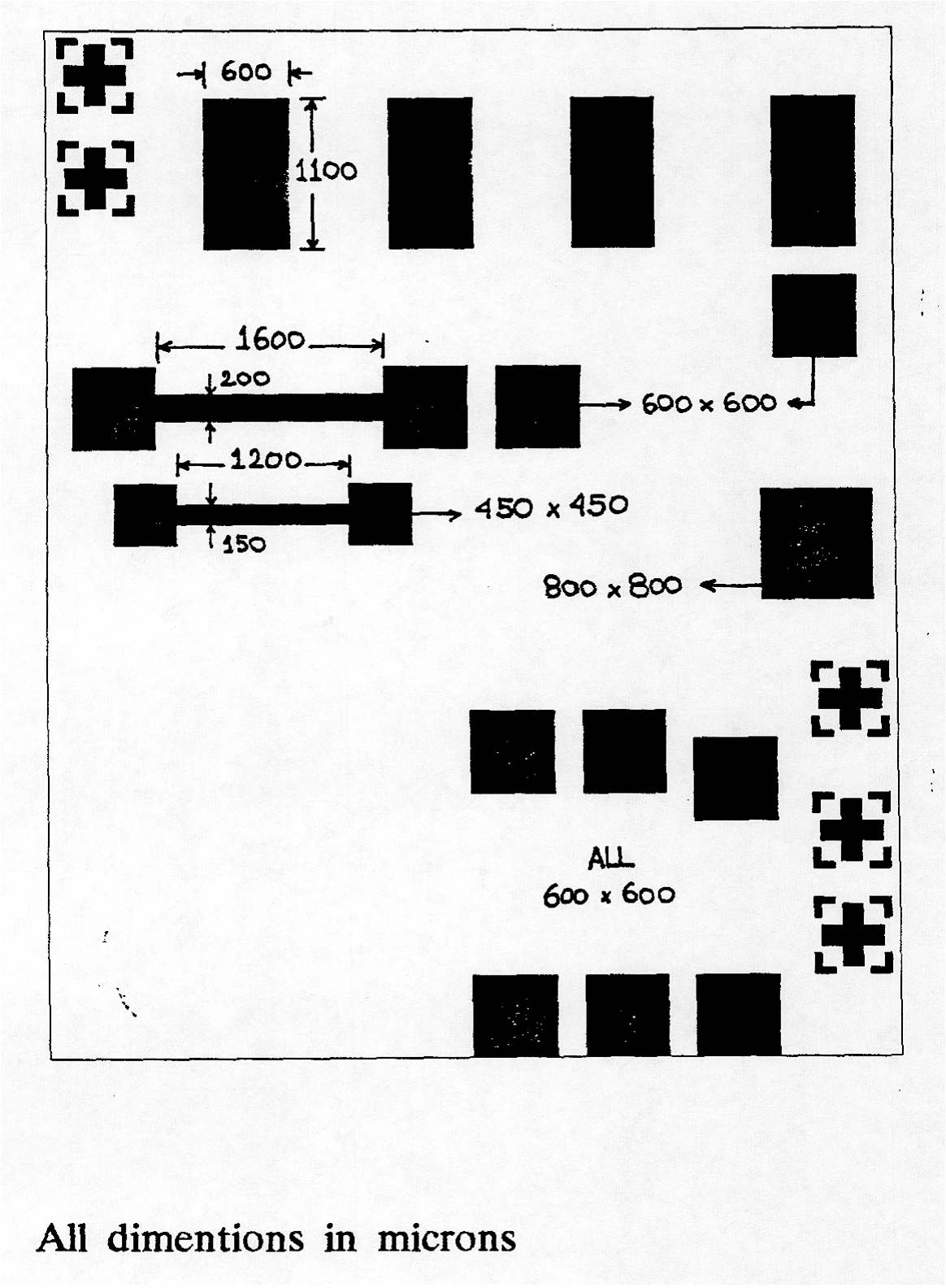


MASK BJT-1 (UNIT CELL)



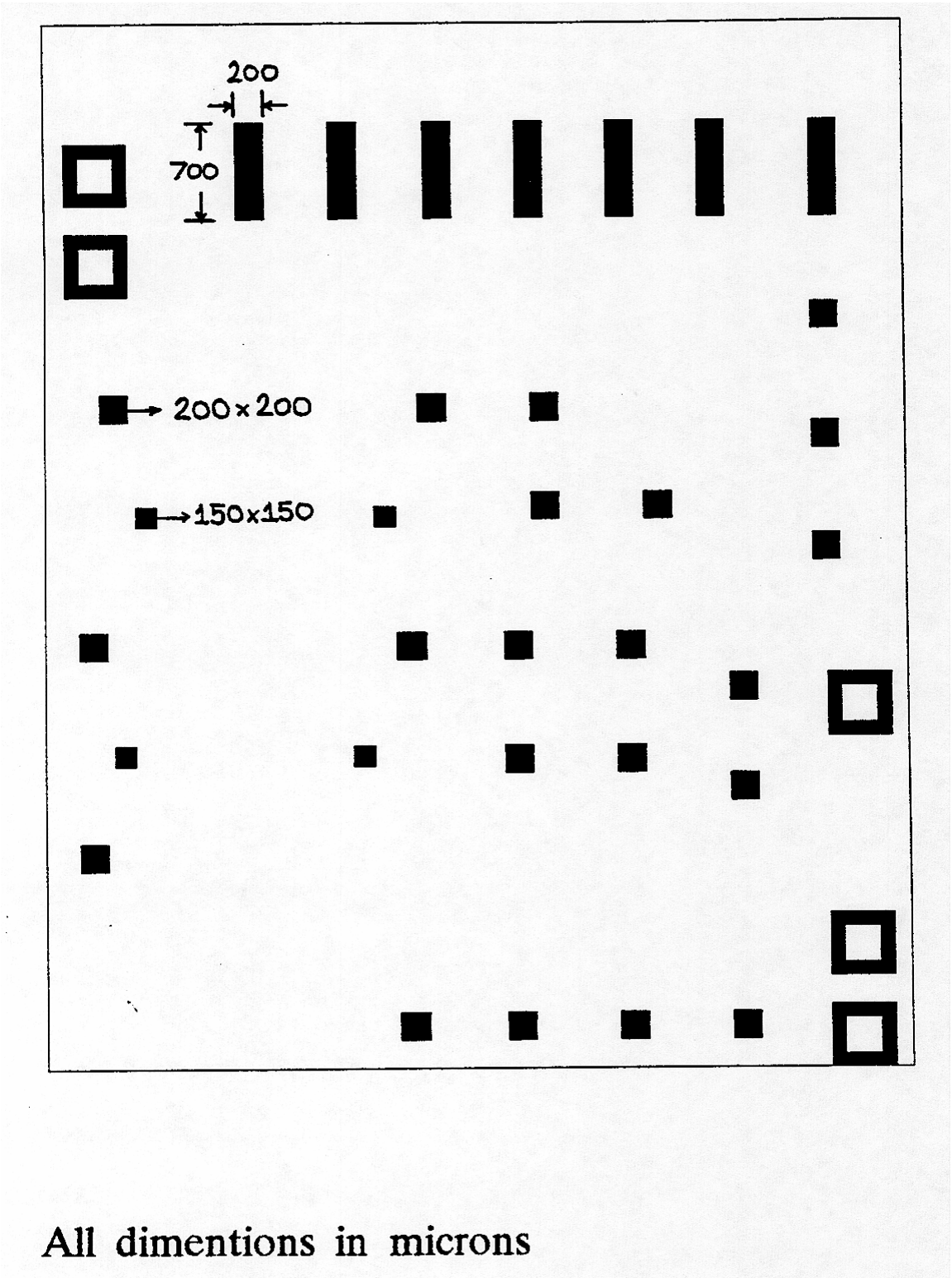
All dimentions in microns

MASK BJT-2 (UNIT CELL)



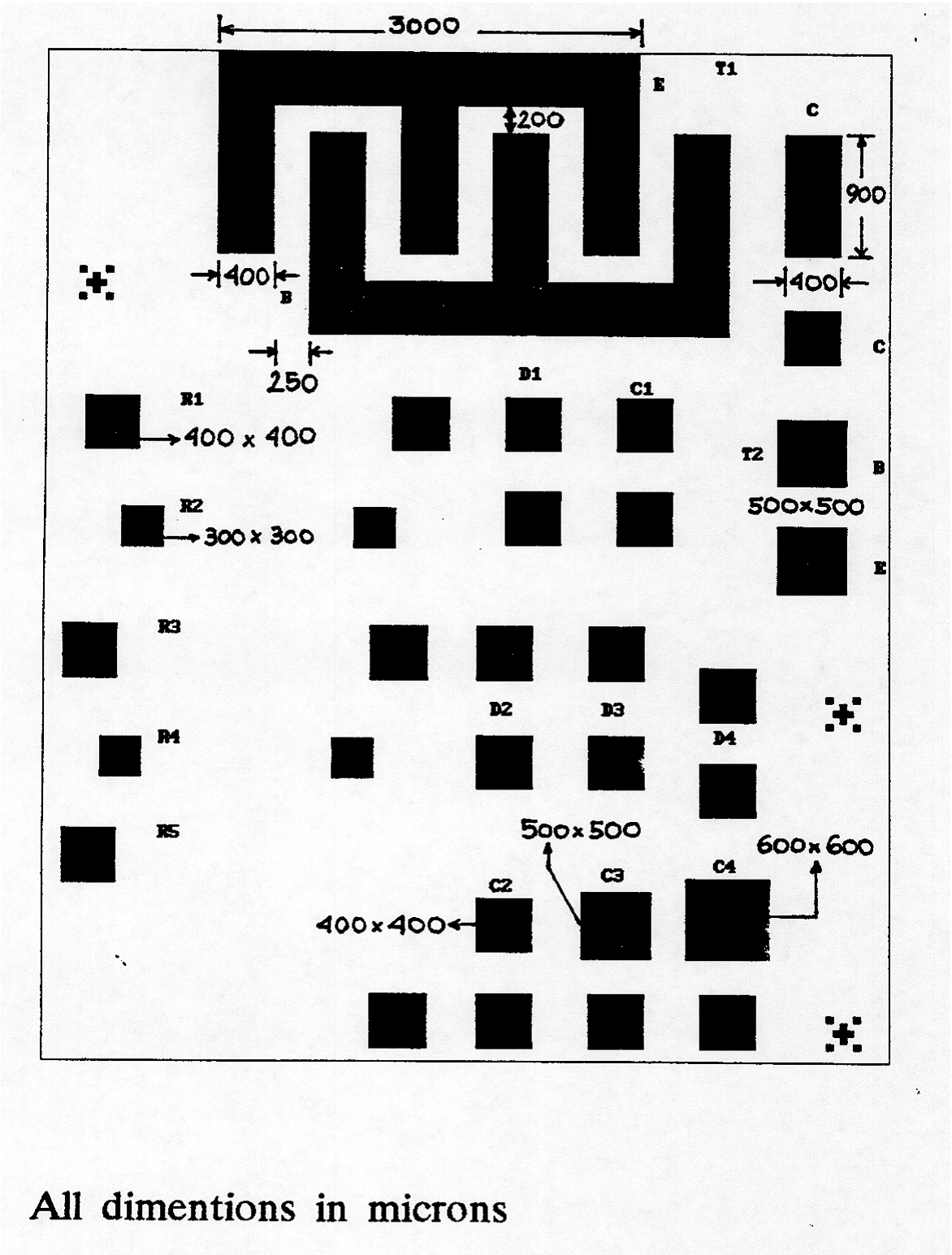
All dimentions in microns

MASK BJT-3 (UNIT CELL)



All dimentions in microns

MASK BJT-4 (UNIT CELL)



All dimentions in microns

G. THERMCO DIFFUSION FURNACES

APPENDIX G

THERMCO MINI-BRUTE, MODEL MB-71H, DIFFUSION FURNACES

The "Mini-Brute" diffusion furnaces are used in the oxidation and diffusion of semiconductor wafers, and have a stable operating temperature range of 400C-1300C. The furnace tubes are made of quartz which can withstand the high temperatures of semiconductor processing. It has a three zone heating element which is controlled by an accurate 3 zone control system.

I. Furnace operating information

1. The furnace tubes, push rods, diffusion boats and associated glassware are made of quartz. They are extremely fragile and care must be exercised when using them.

2. All quartz ware must be handled with gloves to avoid contamination.

3. The furnaces are operated at extremely high temperatures. Avoid touching any of the quartz ware with bare hands, especially the end caps, diffusion boats, push rod tips and the open end of the elephant.

4. Empty quartz boats are stored at the front end of the diffusion tube. Push rods are stored in the push rod holders just to the left of the controller.

5. When not in use the furnace temperature should be set to idle at 500C. This prolongs the life of the tube.

II. Temperature controller description (Figure H-1)

1. Deviation meters: Indicates temperature deviation from set point for two end zones and center zone.

2. Procheck indicators: Lights when temperature deviates from set point by more than plus or minus 2C.

3. Center zone set point dials: Sets center zone temperature. Subtract 400C from desired temperature to obtain dial setting. Example: to set temperature of 1050C, set (1050 - 400 = 650) 650 on set point dial. Left center zone set point dial is enabled when Low/Norm toggle switch, 5, is set at low, and right center zone set point dial is enabled when set on norm.

4. End zone set point dials: Sets end zone temperature, referenced to center zone, with a range of -50C to +50C. Setting 500 will cause end zone settings to be equal to center zone. Example: To set positive offset of 15.5C, set (50 + 15.5 = 65.5) 650 on set point dial. To set negative offset of 12.3C, set (50 - 12.3 = 37.7) 377 on set point dial.

5. Low/Norm toggle switch: Selects left or right center set point dial to control center zone temperature.

6. Excess temperature meter and dial: Sets excess temperature relay trip point with red pointer.

III. Basic operating instructions

A. Temperature set-up from idle (@500C)

1. At idle, low/norm toggle switch is at low and left center zone set dial is at 100 for a temperature of 500C.

2. Set excess temperature dial above the desired temperature.

3. Set the right center zone set point dial to the desired temperature using the instructions above.

4. Switch the low/norm toggle switch to norm.

5. The furnace should start ramping up to temperature and the procheck indicators will light indicating that the respective zones have not reached the desired temperature.

6. When the procheck indicators are extinguished, the furnace is up to temperature.

B. Furnace loading

1. Put on protective gloves.

2. Open furnace and remove end cap and place on top of the stainless steel furnace.

3. Insert elephant onto the furnace tube opening.

4. Using the push rod, carefully insert it into the outer end of the elephant and pull the empty boat into the elephant.

5. Withdraw push rod and replace in holder.

6. Remove elephant and boat to counter top. **CAUTION: HOT PARTS!!!

7. Use short push rod to pull boat towards end of elephant for loading.

8. Being careful not to touch the hot boat or elephant, load the wafers onto the grooves in the boat. If performing a diffusion experiment, load the solid source wafers between wafers.

9. Use the short push rod to push the boat back into the elephant.

10. Place the elephant back onto the furnace tube and use the long push rod to push the boat into the end of the tube.

11. Withdraw the push rod and return to holder.

12. Remove the elephant.

13. Use the push rod to slowly push the boat into the center zone of the furnace tube. Take one minute to move from the end zone to the center zone to avoid thermal stress.

14. Withdraw the push rod and return to holder.

15. Place end cap back onto furnace tube and close.

C. Furnace unloading

1. Put on protective gloves.

2. Open furnace and remove end cap and place on top of the stainless steel furnace.

3. Use the push rod to slowly pull the boat back into the end zone of the furnace tube. Take one minute to move from the center zone to the end zone to avoid thermal stress.

5. Return push rod to holder.

6. Insert elephant onto the furnace tube opening.

7. Using the push rod, carefully insert it into the outer end of the elephant and pull the boat into the elephant.

8. Withdraw push rod and replace in holder.

9. Remove elephant and boat to counter top. **__CAUTION__: HOT PARTS!!!

10. Use short push rod to pull boat towards end of elephant for unloading.

11. Being careful not to touch the hot boat or elephant, unload wafers.

12. Use the short push rod to push the boat back into the elephant.

13. Place the elephant back onto the furnace tube and use the long push rod to push the boat into the end of the tube.

14. Withdraw the push rod and return to holder.

15. Remove the elephant.

16. Place end cap back onto furnace tube and close.

H. LABORATORY CHEMICALS

APPENDIX H

LABORATORY CHEMICALS FOR SEMICONDUCTOR PROCESSING

I. Important general information

1. All the chemicals used in the laboratory are full strength.

2. Some give off potentially dangerous fumes, while the acids are concentrated and corrosive.

3. Exercise due caution when using all the chemicals.

4. Handle all chemicals under the hood. Make sure the blower to the hood is on, to remove any toxic fumes. Make sure the water is running to flush away and dilute the chemicals.

5. Use acids under the acid hood only and solvents under the solvent hood only.

6. While under wear protective lab apron, safety glasses, and gloves.

7. Flush all spills with large amounts of water.

II. Etchants

1. Aluminium etch (warm to 35C)

16 parts Phosphoric acid.

1 part Acetic acid

1 part Nitric acid

20 parts deionized water.

1a. Aluminium etch Heat Slightly
1:3 Phosphoric acid and DI water

2. Chrome etch

1 part solution of 500 gm of sodium hydroxide [NaOH] in 1 liter of deionized water to 3 parts solution of 333 gm of potassium ferricyanide [$K_3Fe(CN)_6$] in 1 liter of deionized water. Deteriorates with time.

3. Oxide etch

40% ammonium fluoride solution [50 grams NH_4F crystals in 755mL H_2O] with hydrofluoric acid.

regular etch

10:1 ratio - approximately 0.05 m/minute.

medium etch

8:1 ratio

hot etch

6:1 ratio - approximately 0.1 m/minute.

3a. Buffered Oxide etch

BOE 9:1

Approximate etch rate = 600 /minute

III. Solvents

1. Acetone: Rinsing agent. Cleaning agent for exposed and unexposed Shipley 1813 positive photoresist.

2. Deionized water: Cleaning and rinsing agent.

3. Methanol: Cleaning and rinsing agent.

4. Trichloroethylene: Rinsing agent. Cleaning agent for black wax and <u>unexposed</u> Waycoat HNR 120 negative photoresist. Also used in a vapor degreaser.

5. Xylene: Cleaning agent for <u>unexposed</u> Waycoat HNR 120 negative photoresist.

IV. Photoresist Processing Chemicals

1. Shipley 1813 Positive photoresist. Use in gold light to avoid polymerization. Cleans up with acetone.

2. Waycoat HNR 120: Negative photoresist. Use in gold light to avoid polymerization. Cleans up with trichloroethylene and xylene.

3. MF-312 developer: Used in a 1:1 solution with deionized water. Developer for Shipley 1400-27 positive photoresist.

4. Waycoat developer: Used full strength. Developer for Waycoat HNR 120 negative photoresist.

5. N-Butyl Acetate: Used as a rinse for negative photoresist during developing or stripping.

6. Microposit remover: Used at 90C to strip postbaked Waycoat HNR 120 negative photoresist.

V. Miscellaneous

1. Alconox: Powdered, mildly abrasive detergent for initial cleaning of substrates.

2. Hydrogen peroxide [H_2O_2]: Oxidizing agent, caustic.

3. Black (apiezon) wax: Temporary fastener. Cleans up with trichloroethylene.

I. CHEMICAL SAFETY

APPENDIX I

CHEMICAL SAFETY

1. Know what chemicals you are using and their hazards.

2. Always read the labels before using any chemicals and work in a vented hood.

3. 3. Never mix acids and solvents. Acids and solvents must never be stored or discarded together.

4. Acids and solvents must never be stored on the floor.

5. Never pour flammable solvents near a source of ignition.

6. When transporting bottles of chemicals, always use the rubber or plastic buckets.

7. If you work at a chemical station, keep all surfaces clean and free of moisture, for your safety as well as others.

8. Pour chemicals slowly to avoid splashing.

9. Always treat any liquid spill as if it were acid.

10. Chemicals splashed on arms or hands should be flushed immediately with water. Body splashes should be flushed with emergency showers.

11. When a large spill occurs, evacuate the area.

12. Learn the proper procedure for disposing of chemicals.

13. Remember the 3 As: ALWAYS ADD ACID to water, never add water to acid.

14. Always test rubber gloves for leaks.

15. Know the difference between vented and laminar hoods.

16. When wiping up sulphuric acid, always wet the aldex paper first to prevent a reaction between the acid and the aldex paper.

17. A-20 acid mixture must be disposed of in special red containers located in the fabrication area.

J. SAFETY ACTION

APPENDIX J

SAFETY ACTION

Acids/Solvents

Treat all liquid spills as if they were acid. If you contact an acid or solvent, or even if you suspect you have contacted an acid or solvent, do the following immediately:

1. Flush the skin or eyes with plenty of running water. Eyewashes are available for small and facial splashes. Safety showers are available for large body splashes.

2. Remove the affected clothing.

3. Do not rub the affected area.

4. Notify the supervisor.

5. In the vent of a minor acid spill, wipe it up immediately.

6. In the event of a major acid spill, notify the supervisor and evacuate.

7. The nurse or first aider should be notified of any acid burn.

Gas/Dopants/Solvent Fumes

If you smell fumes of any kind or become dizzy due to fumes, immediately:

1. Evacuate the area.

2. Notify the supervisor.

Major Emergency

In the event of a major emergency (i.e., fire, chemical spill, gas leak, power failure, etc.), evacuate the area under the direction of the area supervisor. Any announcement over the paging system should be followed immediately.

In the event of a power failure, this facility has an emergency power generator that will restore limited lighting within 5 to 10 seconds. Supervisors also have flashlights to aid in evacuation.

In the event of an earthquake, remain at your work station until the earthquake stops. As exceptions, people working at wet chemical stations, near highly charged electrical equipment, toxic gas systems, or in areas of heavy chemical storage should move to open vestibules or hallways. When the earthquake has stopped, a regular evacuation can commence.

K. CHEMICALS AND GASES

APPENDIX K

CHEMICALS AND GASES

The following are acids, acid mixtures, solvents, and safe and hazardous gases used in the fabrication area. In addition to their scientific symbols, some of their general characteristics are pointed out. More in-depth information on these chemicals will be provided to you if your specialized task requires their use.

Acids

All of the following acids are in glass bottles and burn on contact unless otherwise noted.

CH_3COOH	Acetic
H_2O_2	Hydrogen Peroxide (Plastic bottle/bleaches and burns the skin)
H_2SO_4	Sulfuric
H_3PO_4	Phosphoric
HF	Hydrofluoric (Plastic bottle/attacks the bone)
HNO_3	Nitric
NH_3OH	Ammonium Hydroxide
NH_4F	Ammonium Fluoride

Acid Mixtures

All of the following burn on contact except 10:1, which attacks the bone.

10:1	K Etch
750:1	Phosphoric
A-20	PIQ Etch
Aluminum Etch	Poly Etch
Buffered Oxide Etch (BOE)	RDE
Dielectric Etch	

Solvents

All the below sting on contact.

Xylene

Acetone

Alcohol (IPA)

N-Butyl Acetate

Hazardous Gases

The following are identified by having a strong odor unless otherwise noted.

ASH_3	Arsine
BF_3	Boron Trifluoride
CCl_4	Carbon Tetrachloride
H_2	Hydrogen (no smell, burns on contact with air)
HCl	Hydrochloric
NH_3	Ammonia
$POCl_3$	Phosphorous Oxychloride
SiH_2Cl_3	Dichlorosilane
SiH_4	Silane (no smell, burns on contact with air)

Safe Gases

N_2	**Nitrogen**
O_2	**Oxygen (will ignite some gases)**

L. NEGATIVE PHOTORESIST PROCESSING

APPENDIX L

NEGATIVE PHOTORESIST PROCESSING USING FUTURREX NR8 1500

Apply photoresist using pipette per instructor

Spin speed: 3000 RPM
Spin time: 30 seconds

Bake temperature: 130C
Bake time: 3 minute

Exposure time: 10 seconds

Post Expose bake @ 100C for 1 min.

Developer use ratio… 3 parts RD6 to 1 part DI.

Developer time: approx. 60 seconds, inspect under microscope. (Return to developer if not fully developed using 30 second intervals until completely developed. Ask instructor for help if longer than 3 minutes)

Developer temperature: ambient

Inspect under microscope.

Hard bake 150C for 3 minutes

V. GRAPHS AND TABLES

GRAPHS AND TABLES

1. COLOR CHART FOR SILICON DIOXIDE

Film thickness ( )	Color of Film
500	Tan
700	Brown
1,000	Dark violet to red-violet
1,200	Royal blue
1,500	Light blue to metallic blue
1,700	Metallic to very light yellow-green
2,000	Light gold or yellow (slightly metallic)
2,200	Gold with slight yellow-orange
2,500	Orange to melon
2,700	Red-violet
3,000	Blue to violet-blue
3,100	Blue
3,200	Blue to blue-green
3,400	Light green
3,500	Green to yellow-green
3,600	Yellow-green
3,700	Green-yellow
3,900	Yellow
4,100	Light orange
4,200	Carnation pink
4,400	Violet-red
4,600	Red-violet
4,700	Violet
4,800	Blue-violet
4,900	Blue
5,000	Blue-green
5,200	Green
5,400	Yellow-green
5,600	Green-yellow
5,700	Yellow to "yellowish" (at times appears light grey or metallic)
5,800	Light orange or yellow to pink
6,000	Carnation pink
6,300	Violet-red
6,800	"Bluish" (appears between violet-red and blue green, overall looks greyish)
7,200	Blue-green to green
7,700	"Yellowish"
8,000	Orange
8,200	Salmon
8,500	Dull, light red-violet
8,600	Violet
8,700	Blue-violet
8,900	Blue
9,200	Blue-green
9,500	Dull yellow-green
9,700	Yellow to "yellowish"
9,900	Orange

Note the cyclical reappearance of the colors as thickness increases. For example, compare 1000, 2700, 4600, and 6300 . the equation which shows this cyclical pattern in SiO_2 is $k = 5.84t/(2K+1)$). Where =wavelength, t=oxide thickness in , and k=0, 1, 2, ...

2. DIFFUSION DATA

A. Boron and Phosphorus in Silicon

T,C	B,P D, cm^2s^{-1}	B $N_{sl,\ cm}^{-3}$	P $N_{sl,\ cm}^{-3}$
900	1.5×10^{-15}	3.7×10^{20}	6.0×10^{20}
950	6.6×10^{-15}	3.9×10^{20}	7.8×10^{20}
1,000	2.6×10^{-14}	4.1×10^{20}	1.0×10^{21}
1,050	9.3×10^{-14}	4.3×10^{20}	1.2×10^{21}
1,100	3.0×10^{-13}	4.5×10^{20}	1.4×10^{21}
1,150	9.1×10^{-13}	4.8×10^{20}	1.5×10^{21}
1,200	2.5×10^{-12}	5.0×10^{20}	1.5×10^{21}
1,250	6.5×10^{-12}	5.2×10^{20}	1.4×10^{21}
1,300	1.6×10^{-11}	5.4×10^{20}	1.1×10^{21}
1,350	3.7×10^{-11}	5.7×10^{20}	7.1×10^{20}

$$D = D0 \exp(-Ea/kT)$$

B. Diffusivity data for dopants in silicon.

Dopant	P*	As**	Sb**	B*	Al**	Ga**	In*
$D_{0,\ cm}{}^2/s$	10.5	0.06	3.94	10.5	1.77	0.57	16.5
$E_{a/k,\ K}$	4.28×10^4	3.83×10^4	4.49×10^4	4.28×10^4	3.78×10^4	3.77×10^4	4.52×10^4

* Ref. Ghandi pg 71

** highly dependent on doping level. These are PLATO values.

C. Diffusivity data for Boron in SiO2

	$D_{0,\ cm}{}^2/s$	$E_{a,\ eV}$
T < 1000C	2.8×10^{-4}	3.06
T > 1000C	5.8×10^{-11}	1.25

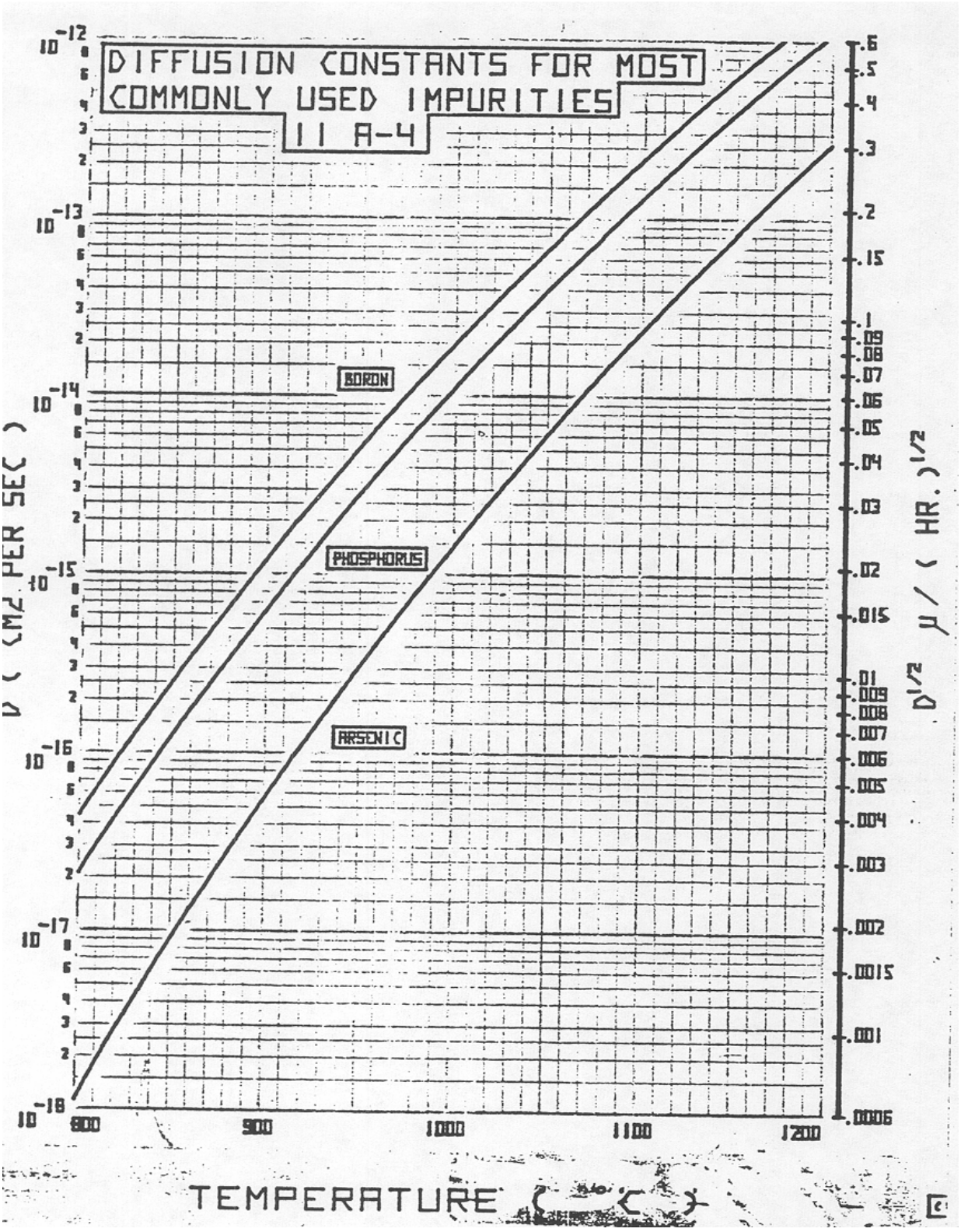
Ref. Burger and Donovan I, pg 159

D. Diffusivity data for Phosphorus in SiO2 (open tube, P2, O5 source. Highly variable.

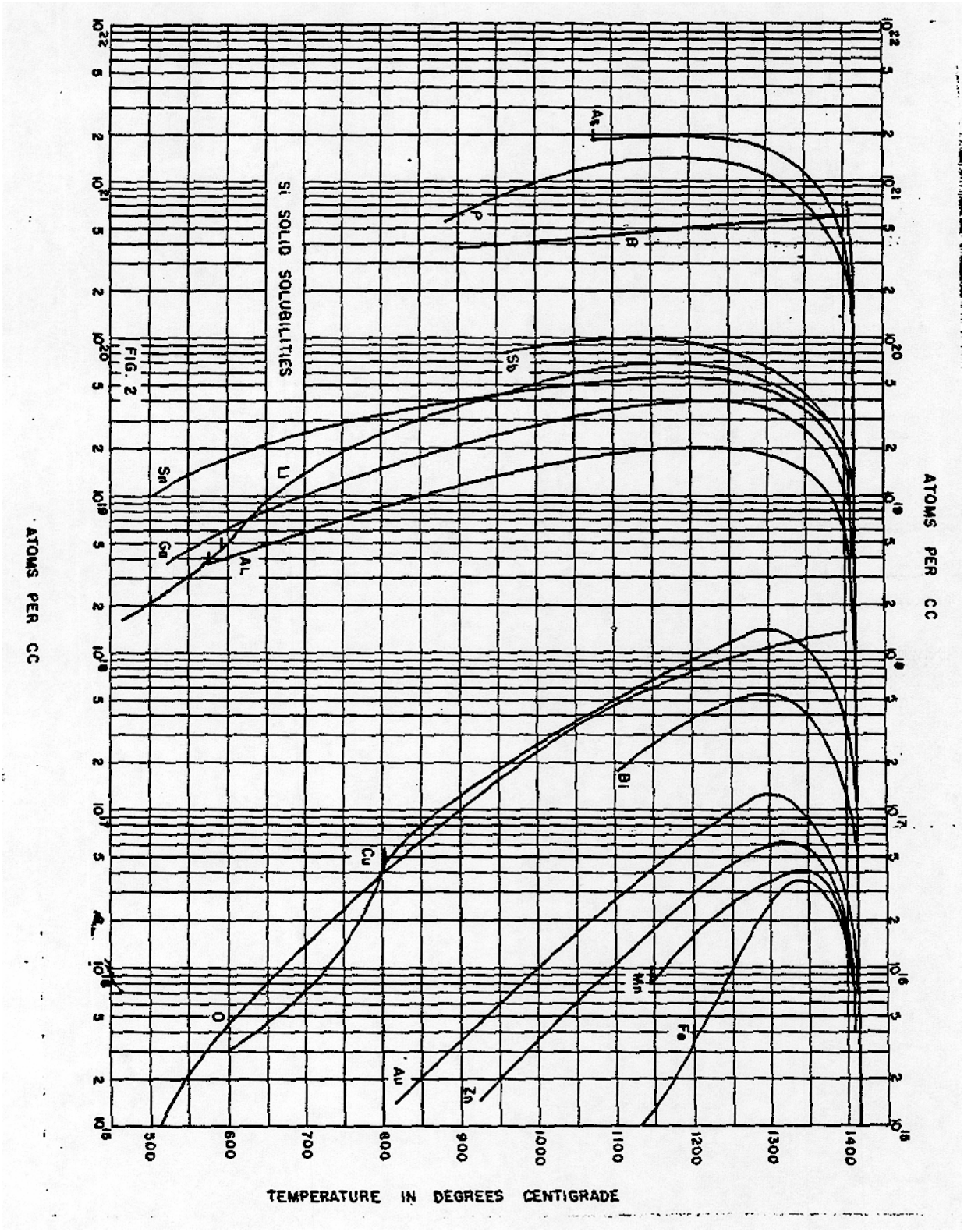
D0 = 1.59 x 10-11 cm2/s Ea = 1.1 eV

Ref. Burger and Donovan I, pg 159

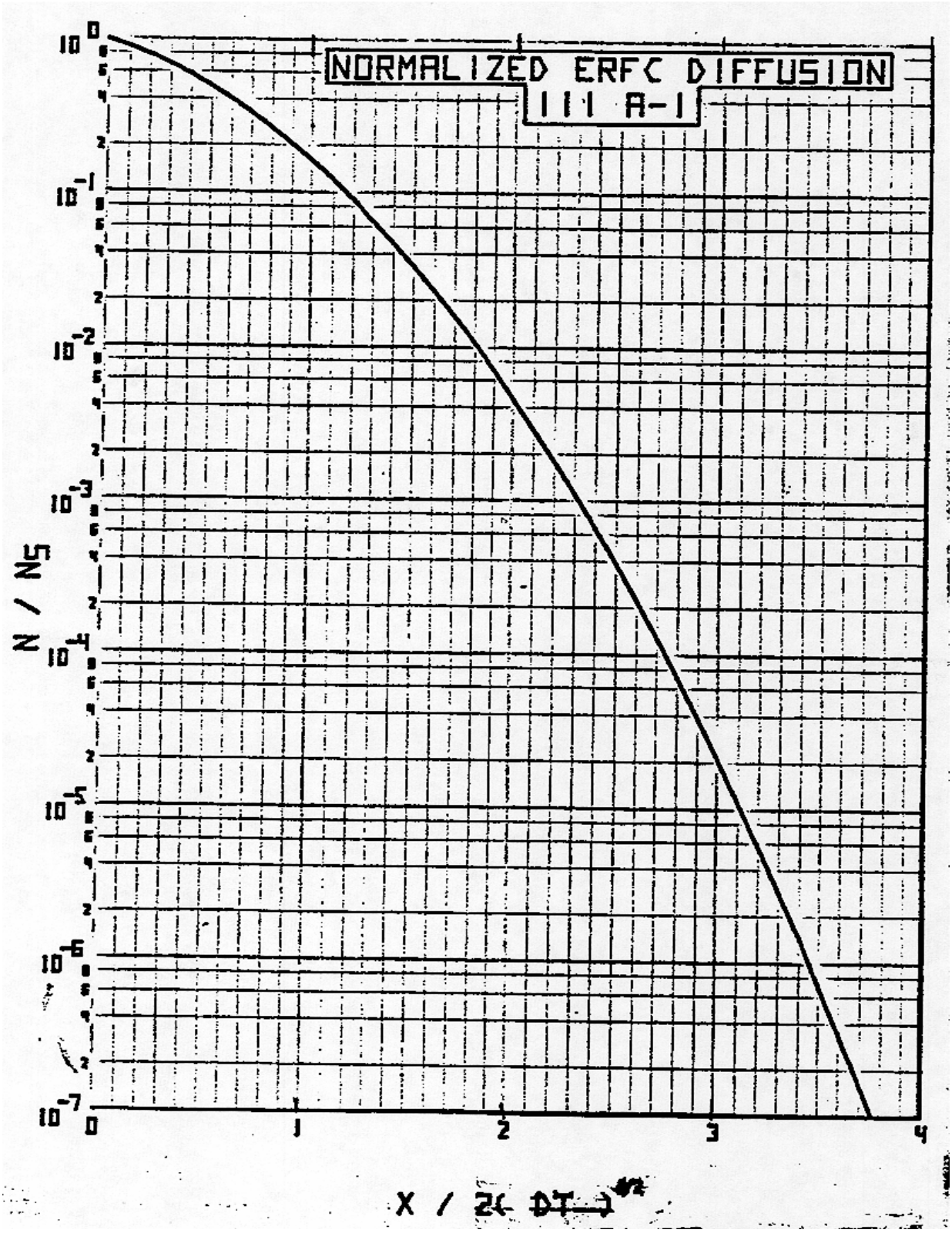
3. DIFFUSION CONSTANTS FOR MOST COMMONLY USED IMPURITIES



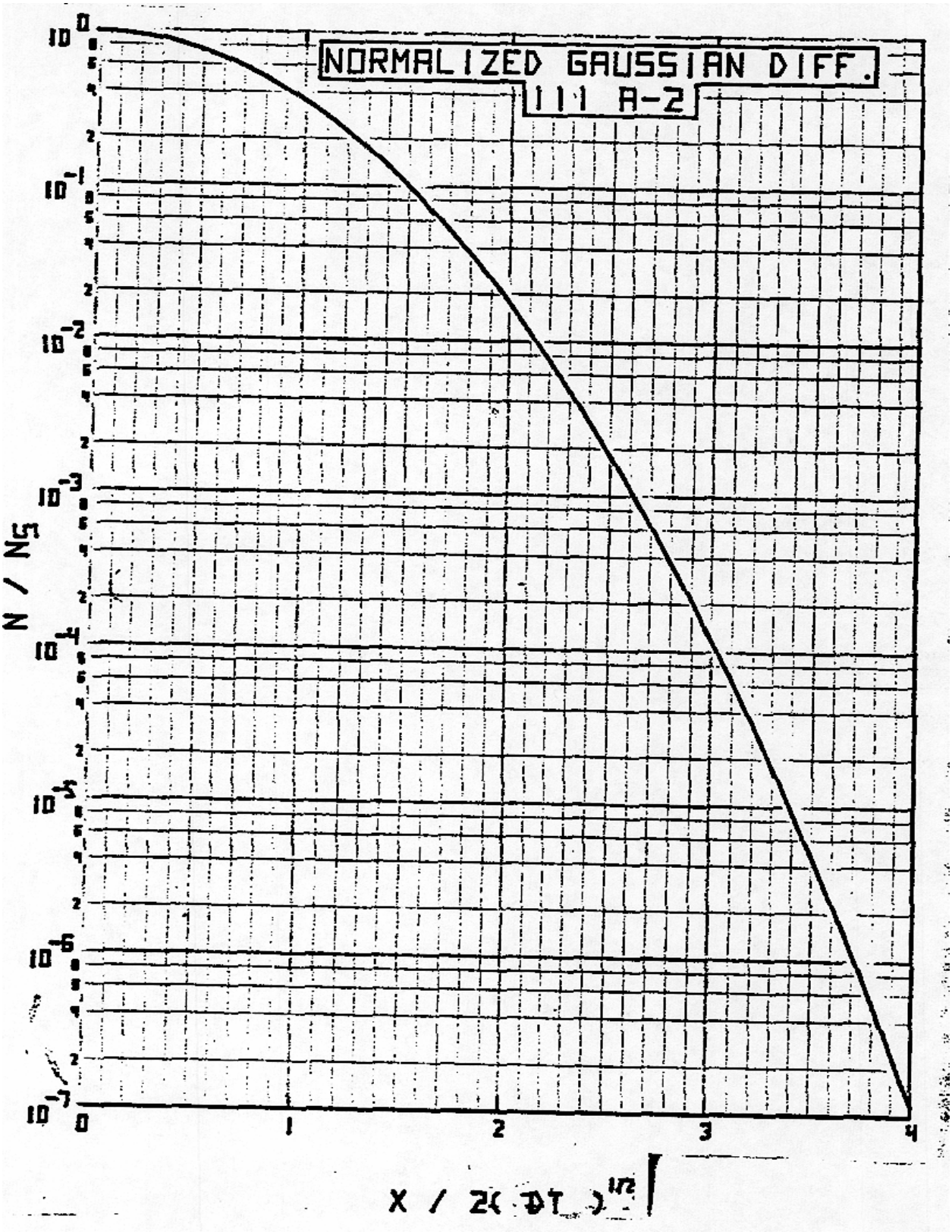
4. Si SOLID SOLUBILITIES



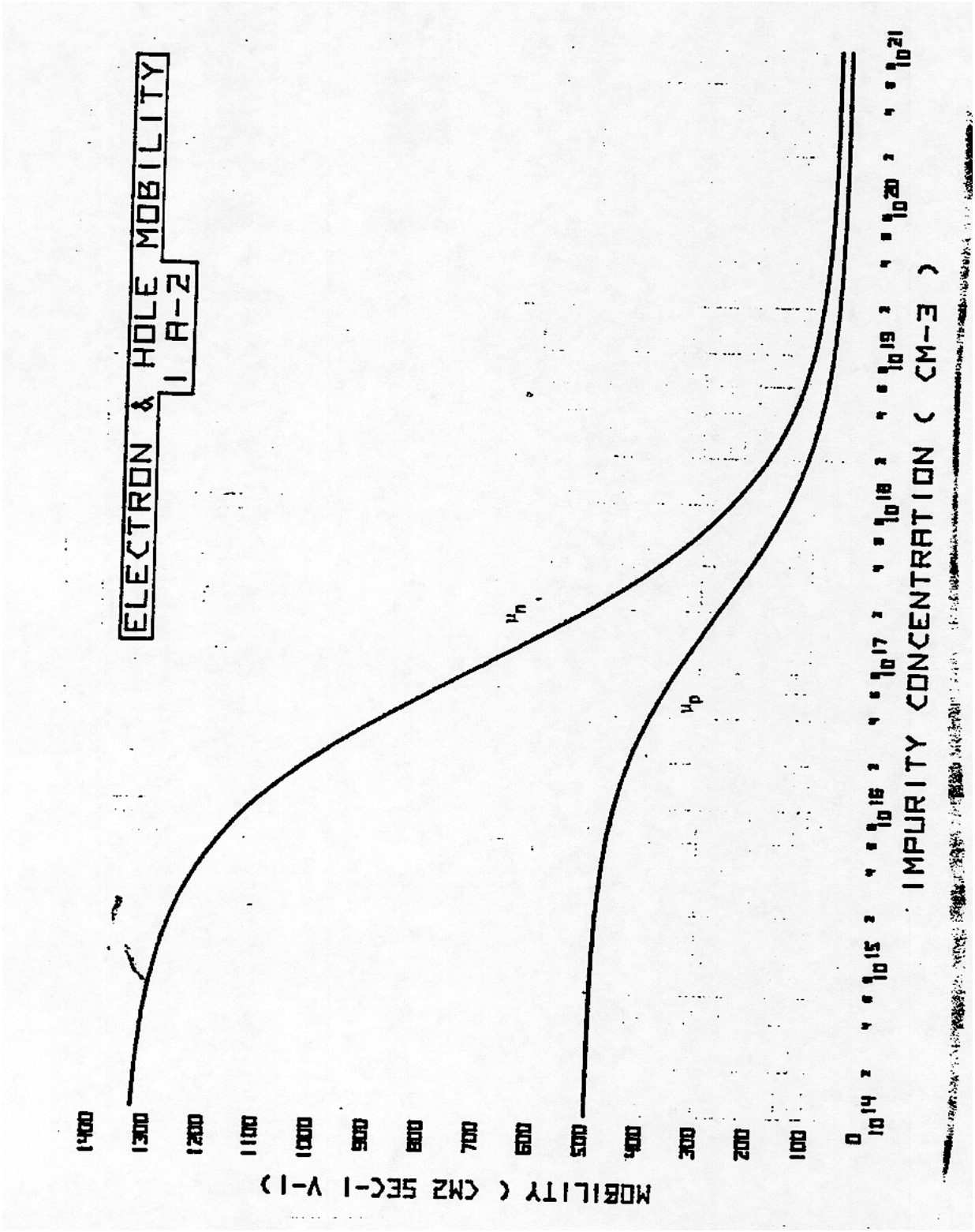
5. NORMALIZED ERFC DIFFUSION



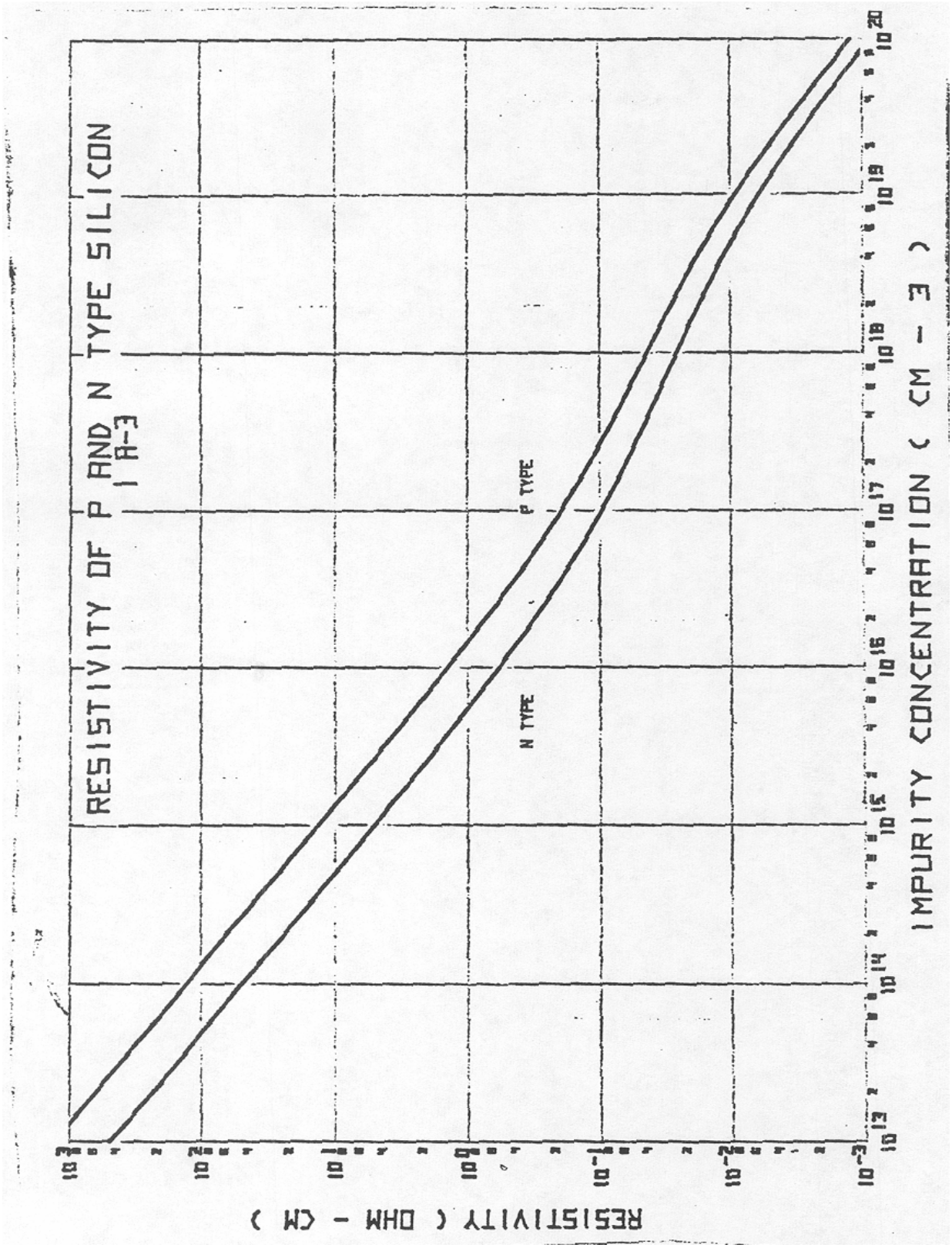
6. NORMALIZED GAUSSIAN DIFFUSION



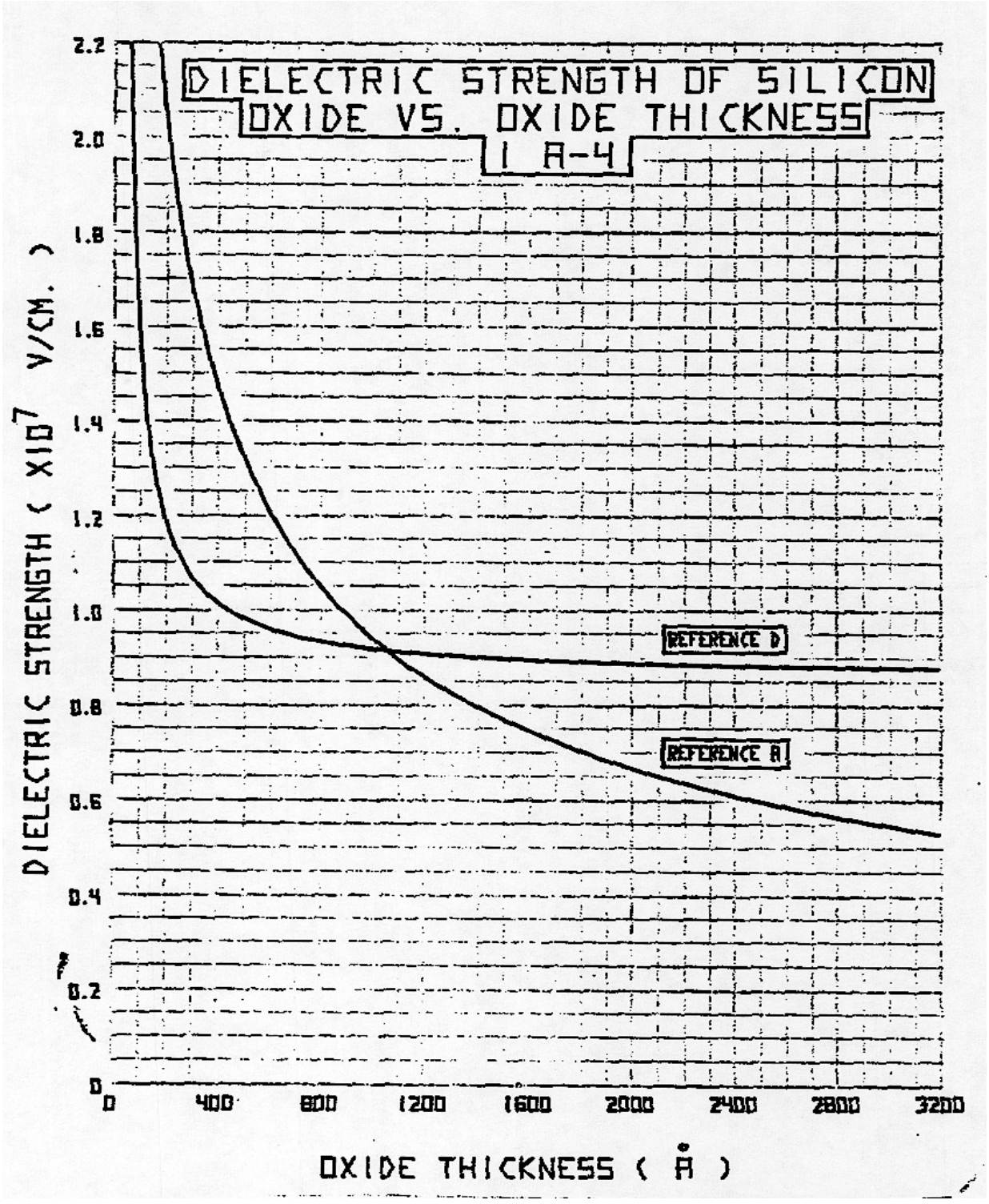
7. ELECTRON AND HOLE MOBILITY



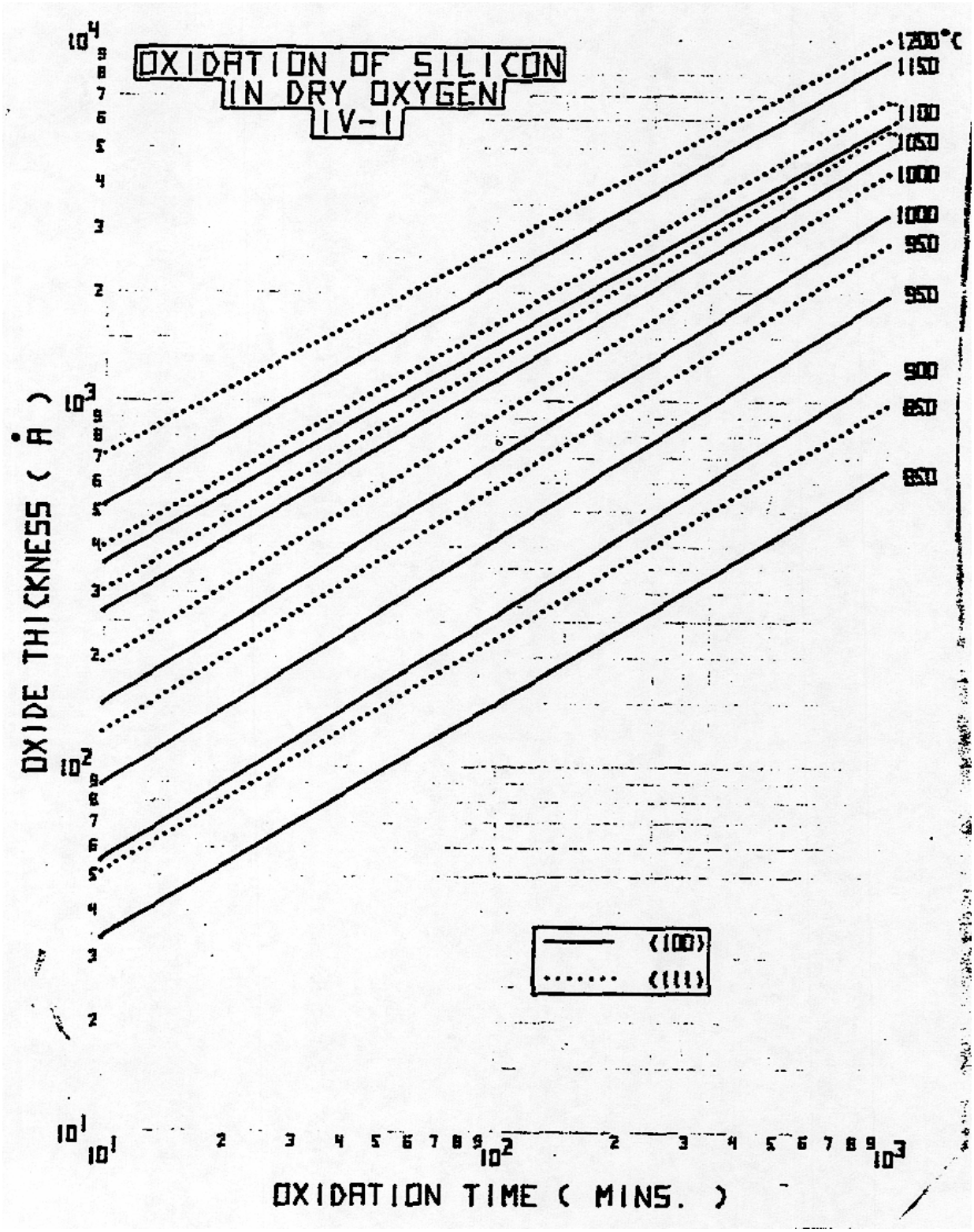
8. RESISTIVITY OF P AND N TYPE SILICON



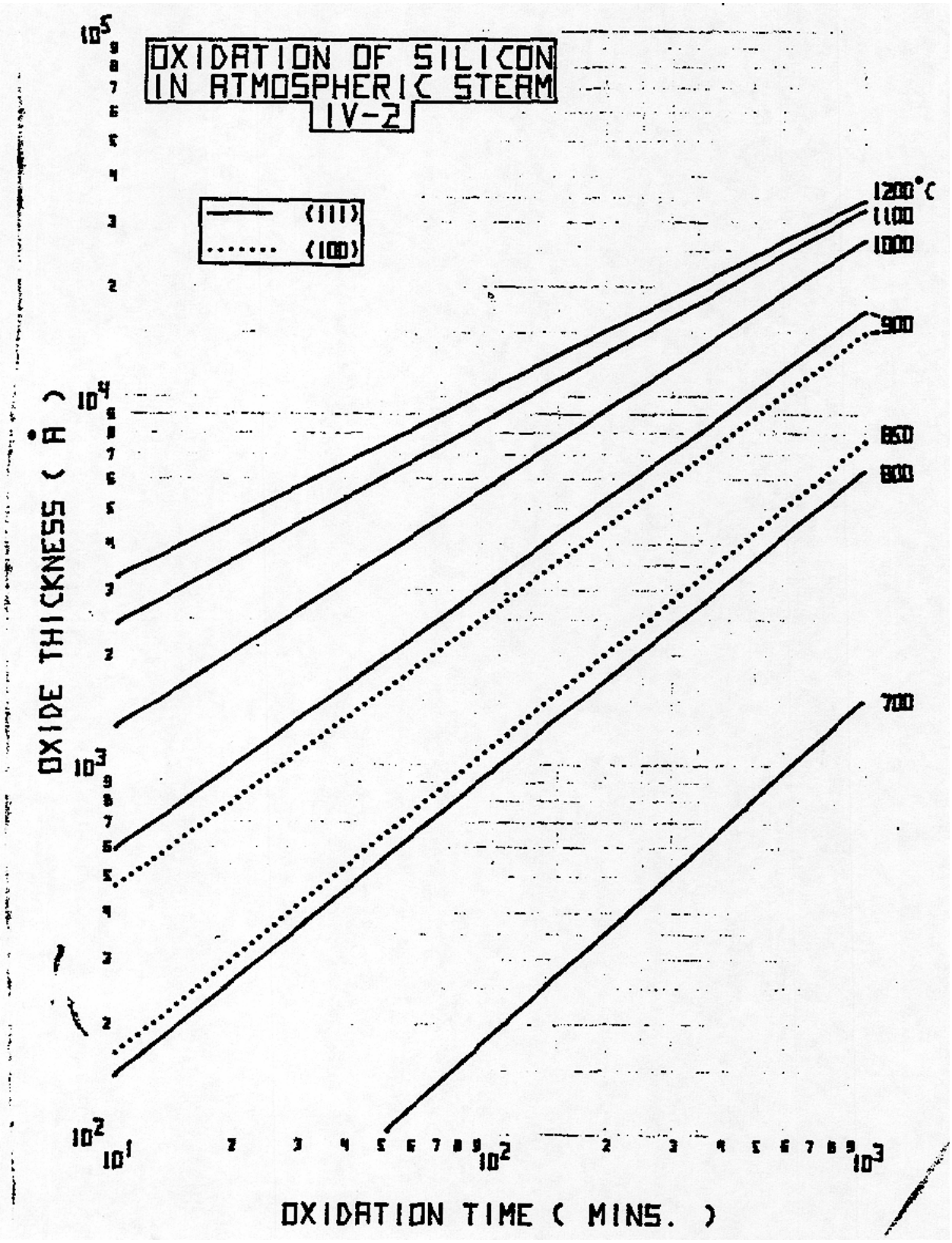
9. DIELECTRIC STRENGTH OF SILICON OXIDE VS. OXIDE THICKNESS



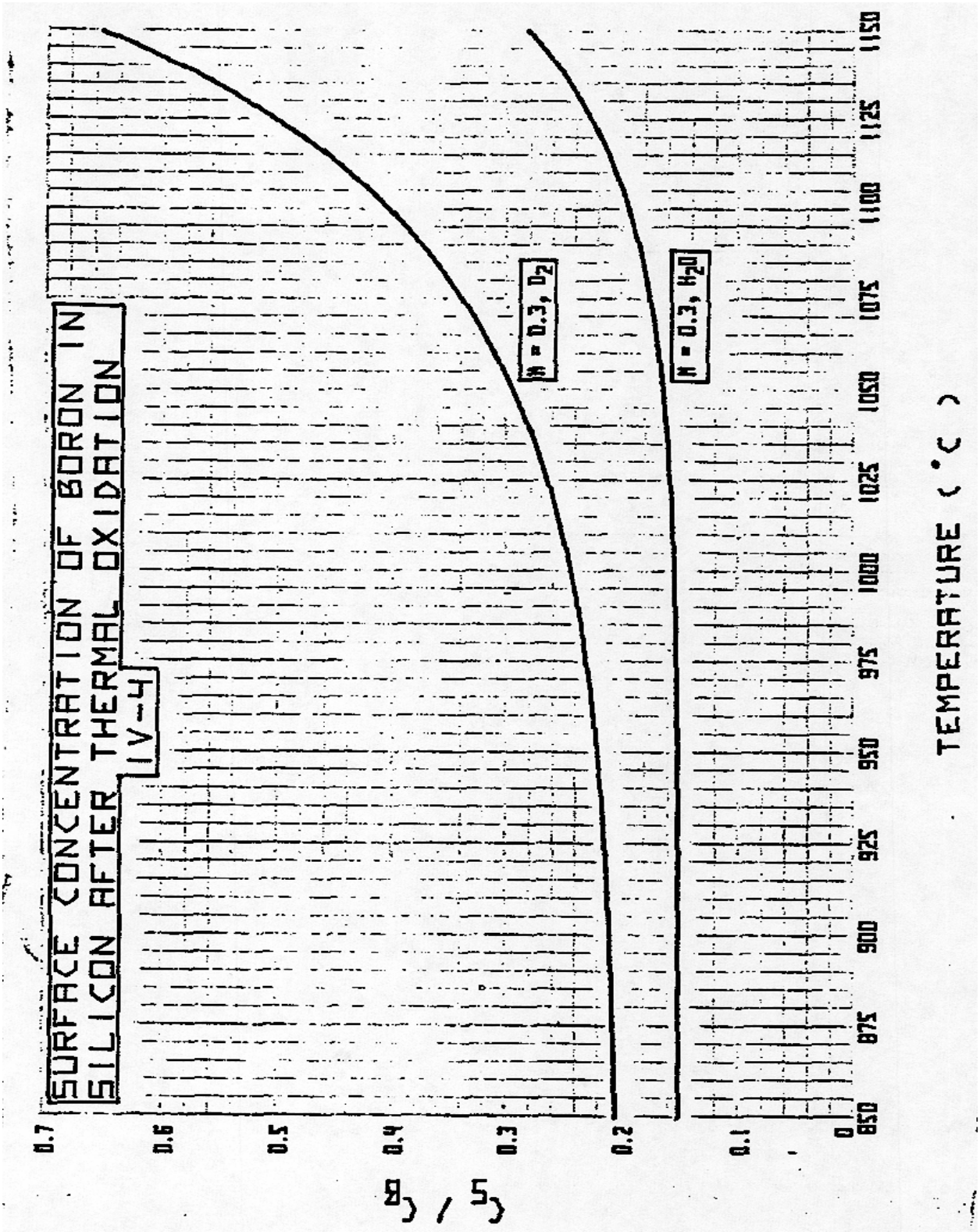
10. OXIDATION OF SILICON IN DRY OXYGEN



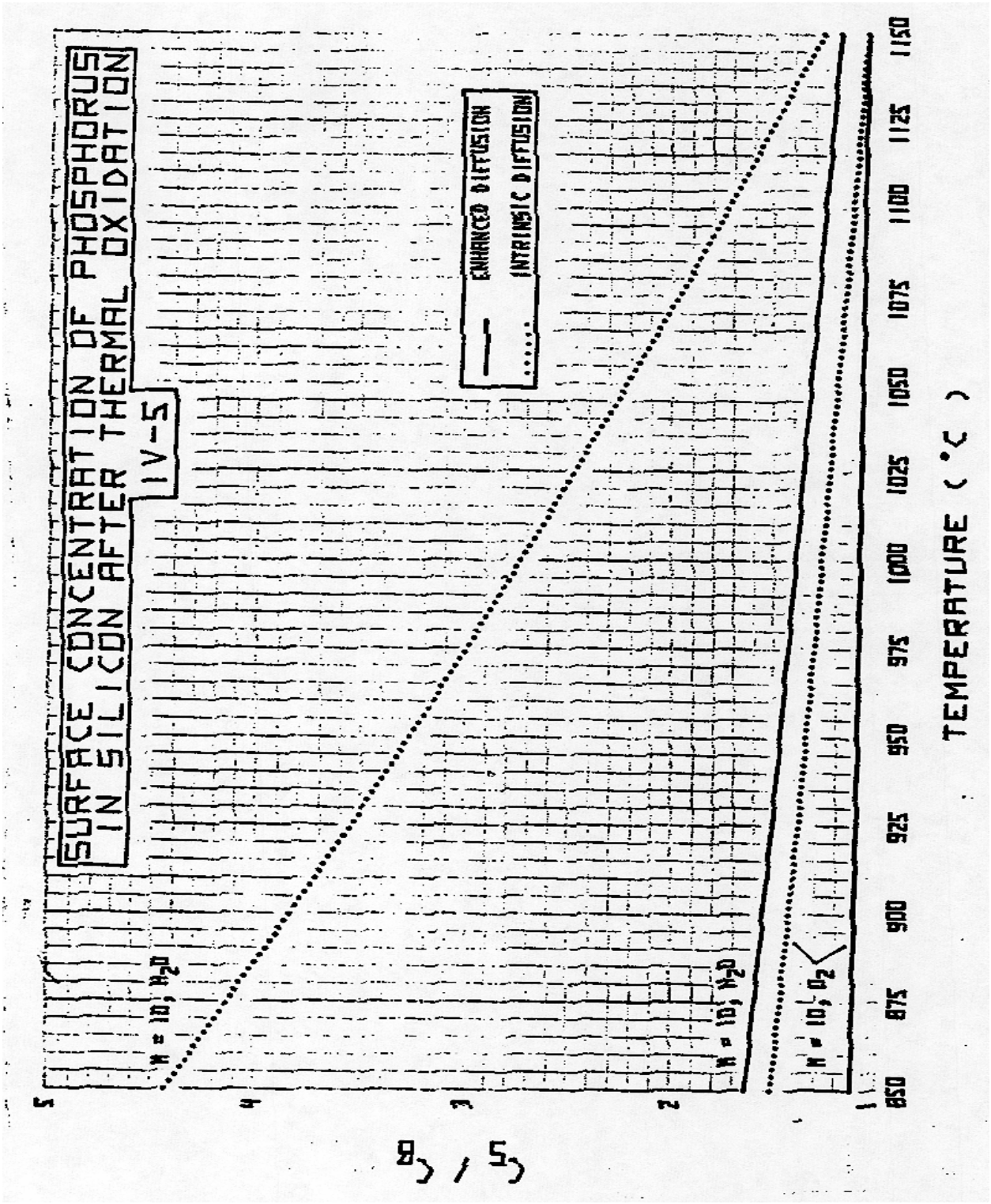
11. OXIDATION OF SILICON IN ATMOSPHERIC STEAM



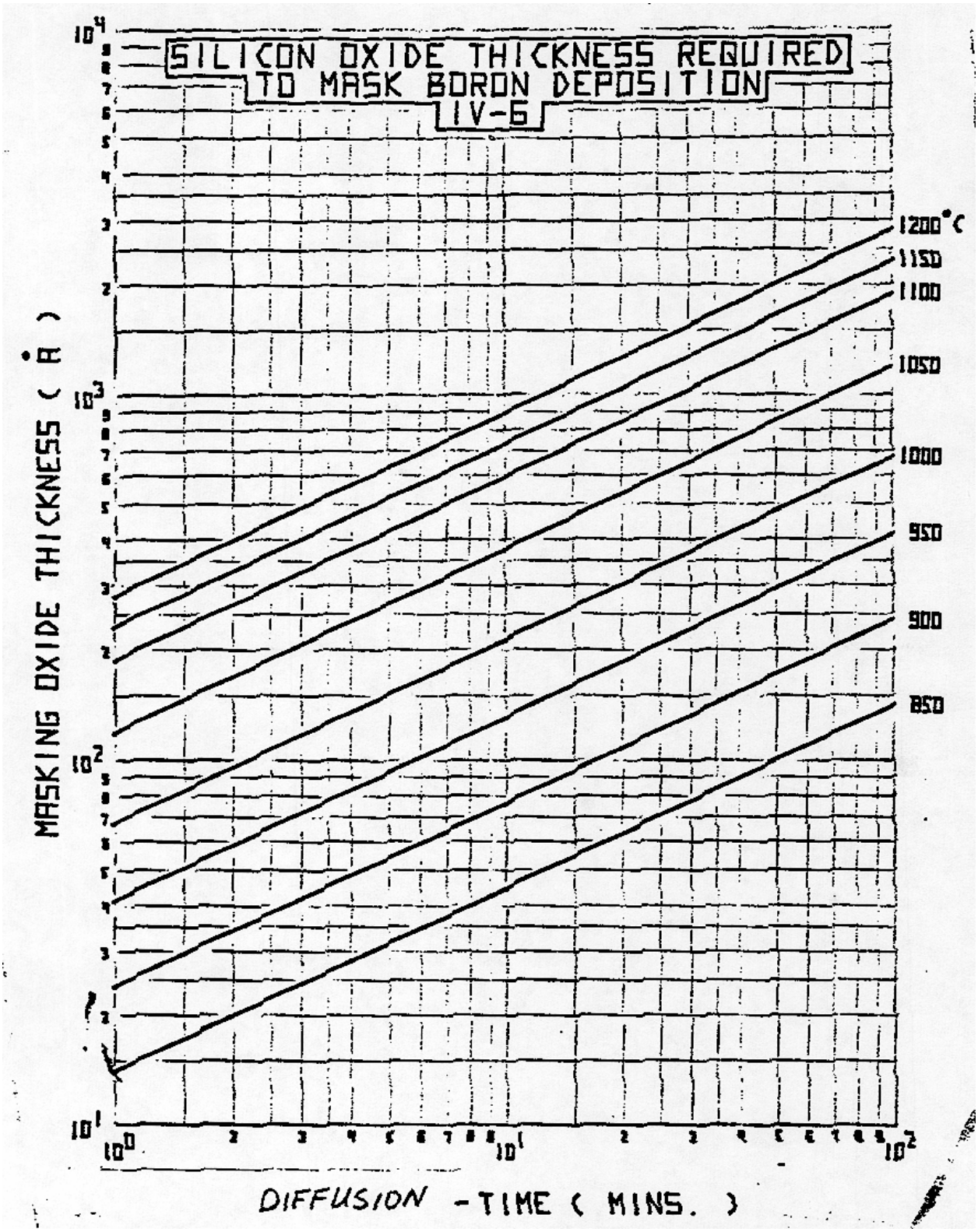
12. SURFACE CONCENTRATION OF BORON IN SILICON AFTER THERMAL OXIDATION



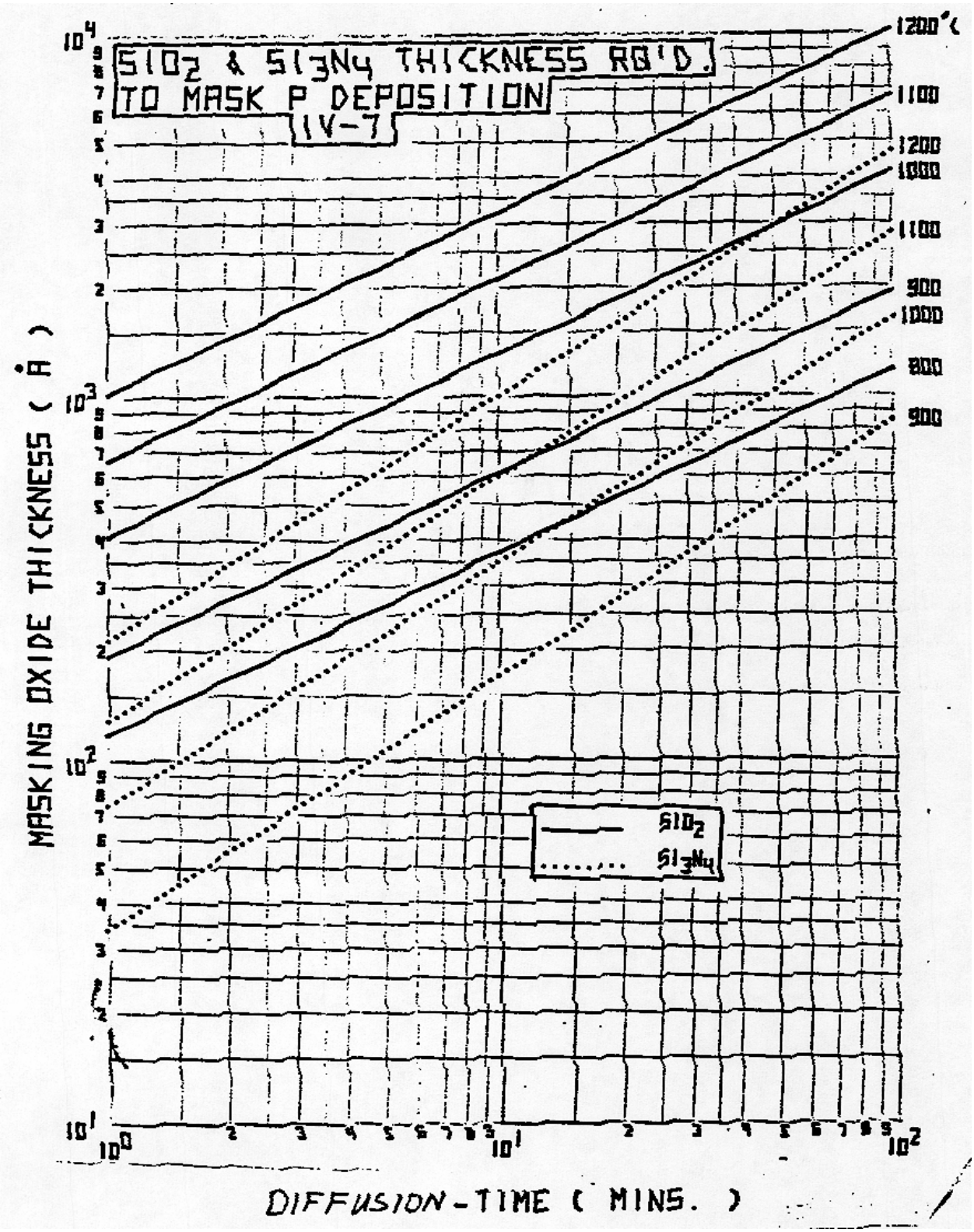
13. SURFACE CONCENTRATION OF PHOSPHORUS IN SILICON AFTER THERMAL OXIDATION



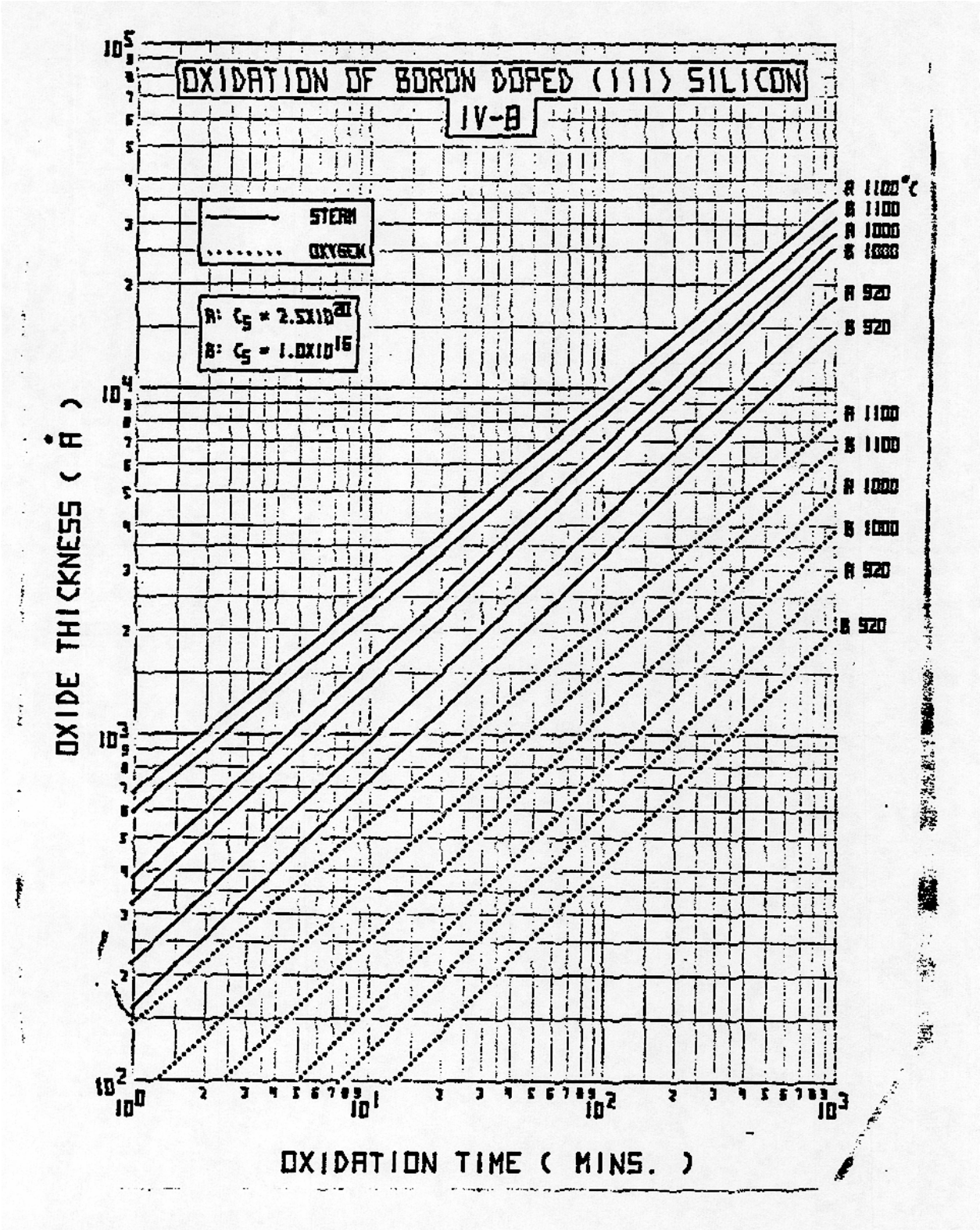
14. SILICON OXIDE THICKNESS REQUIRED TO MASK BORON DEPOSITION



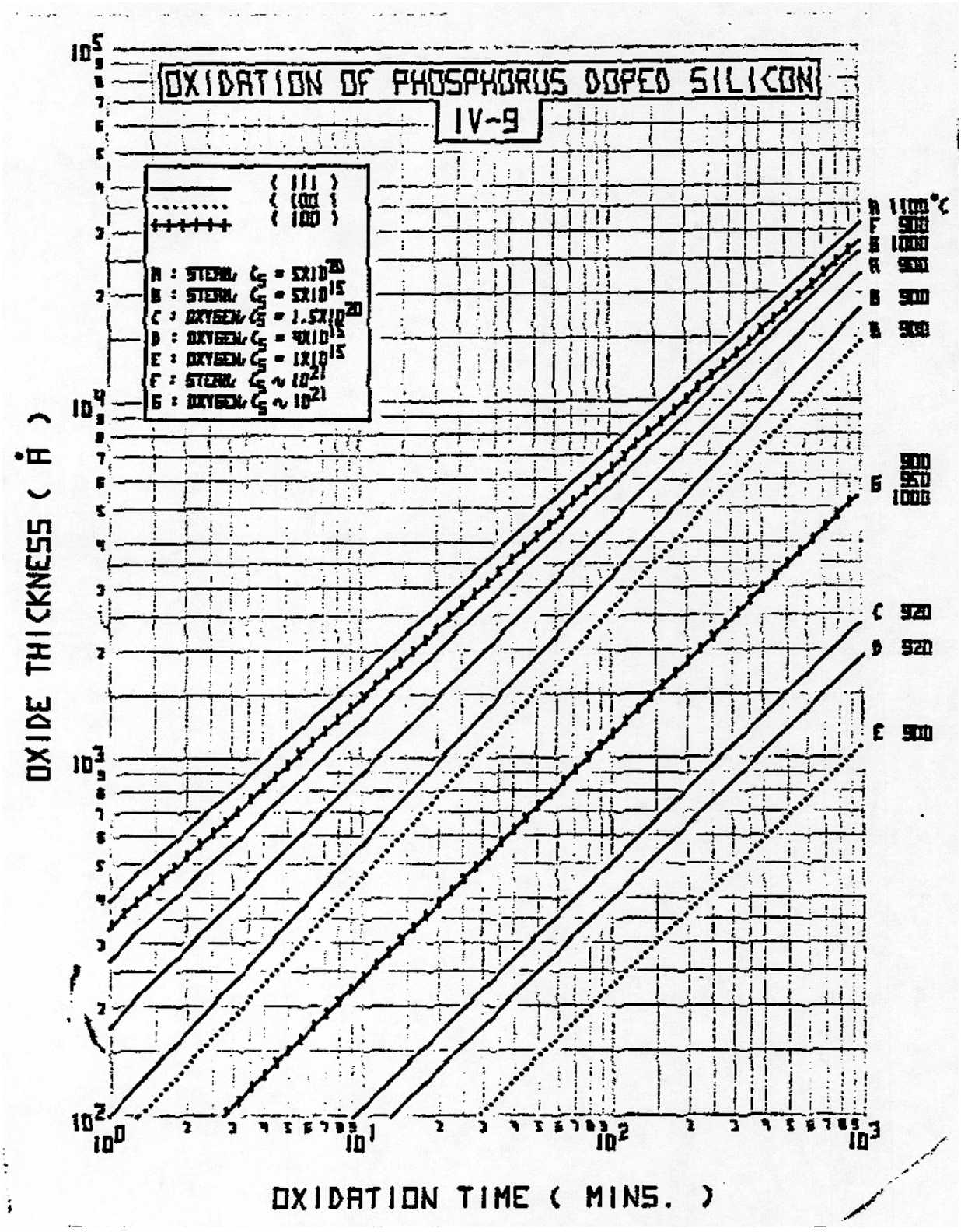
15. SiO_2 AND Si_3N_4 THICKNESS REQUIRED TO MASK P DEPOSITION



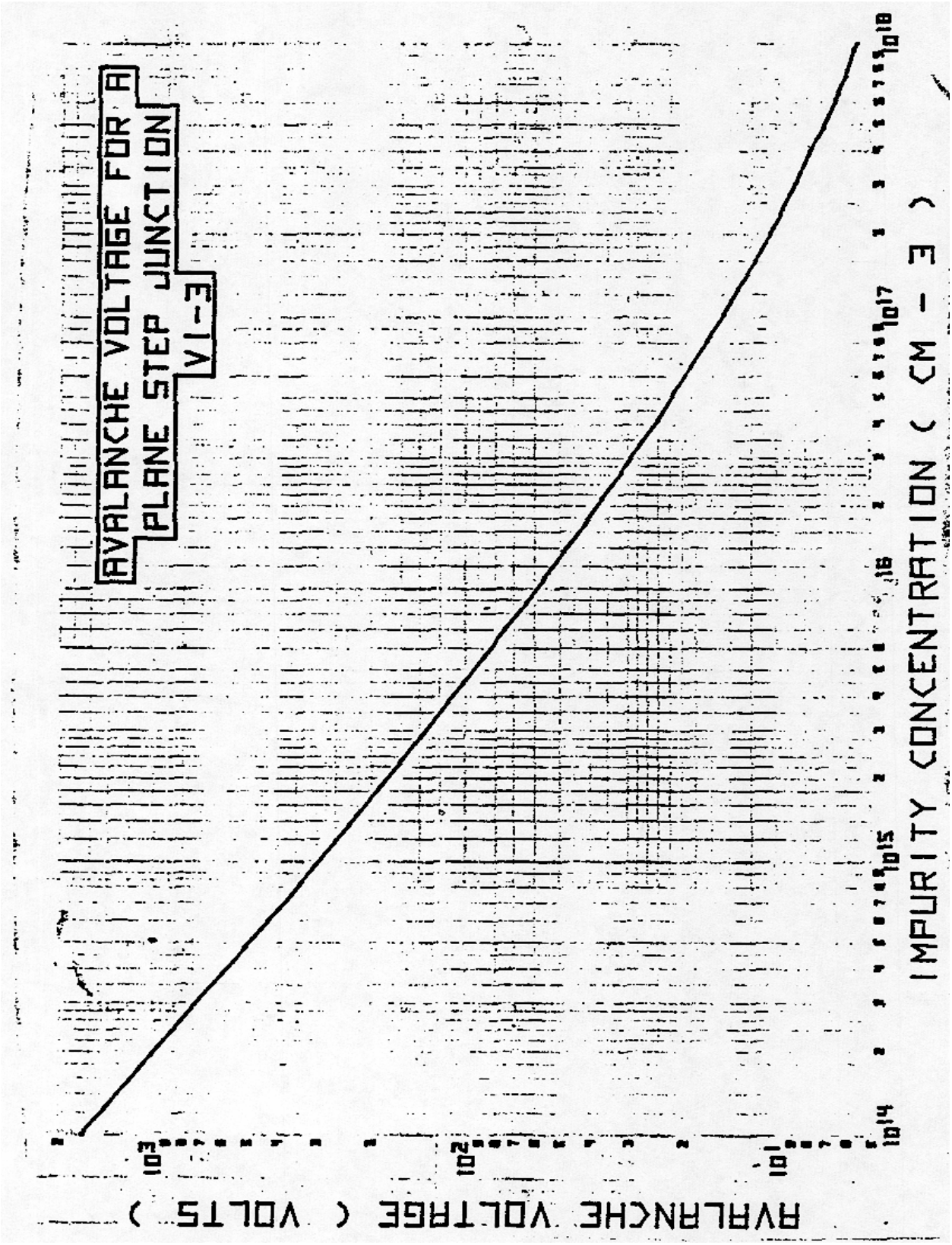
16. OXIDATION OF BORON DOPED <111> SILICON



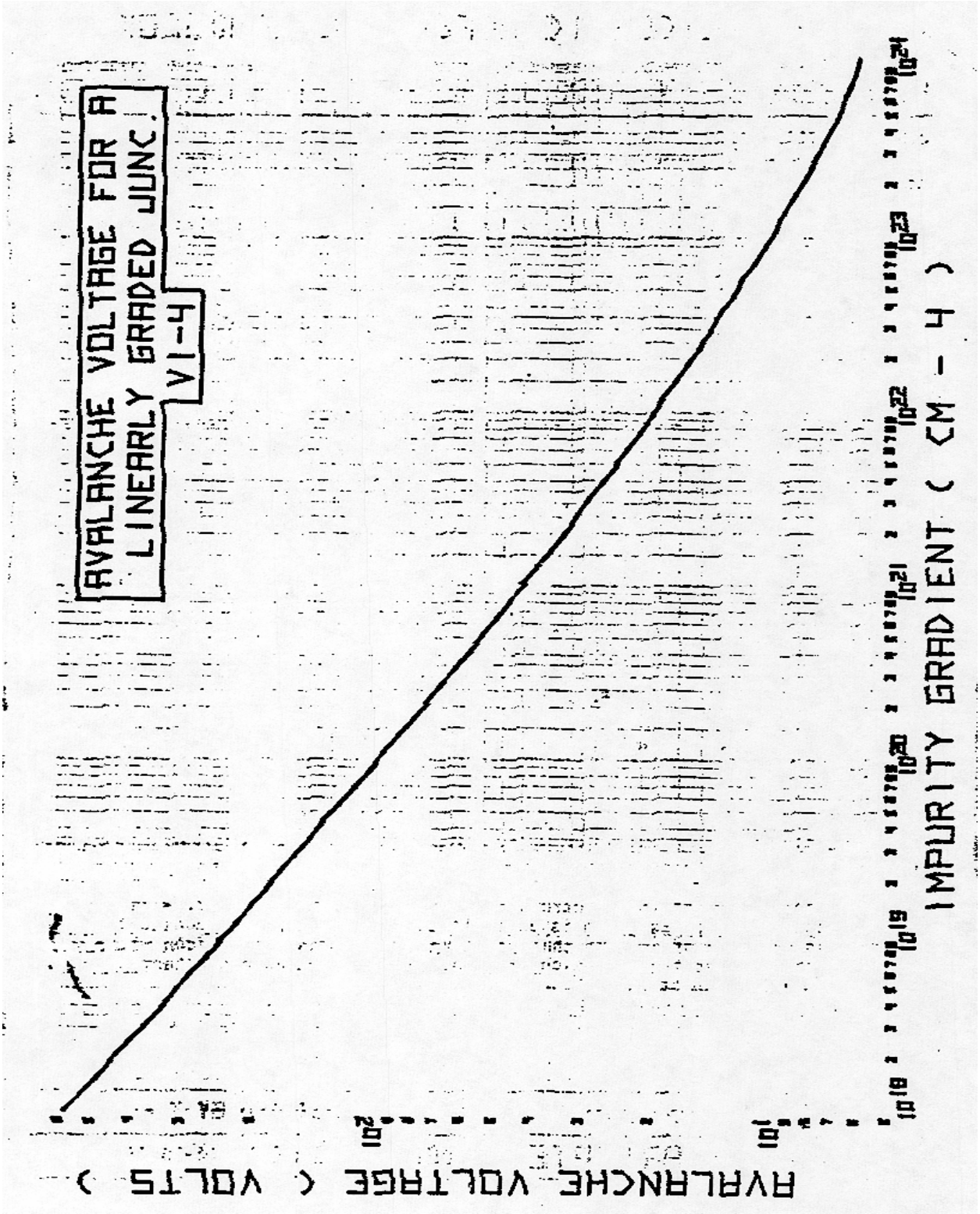
17. OXIDATION OF PHOSPHORUS DOPED SILICON



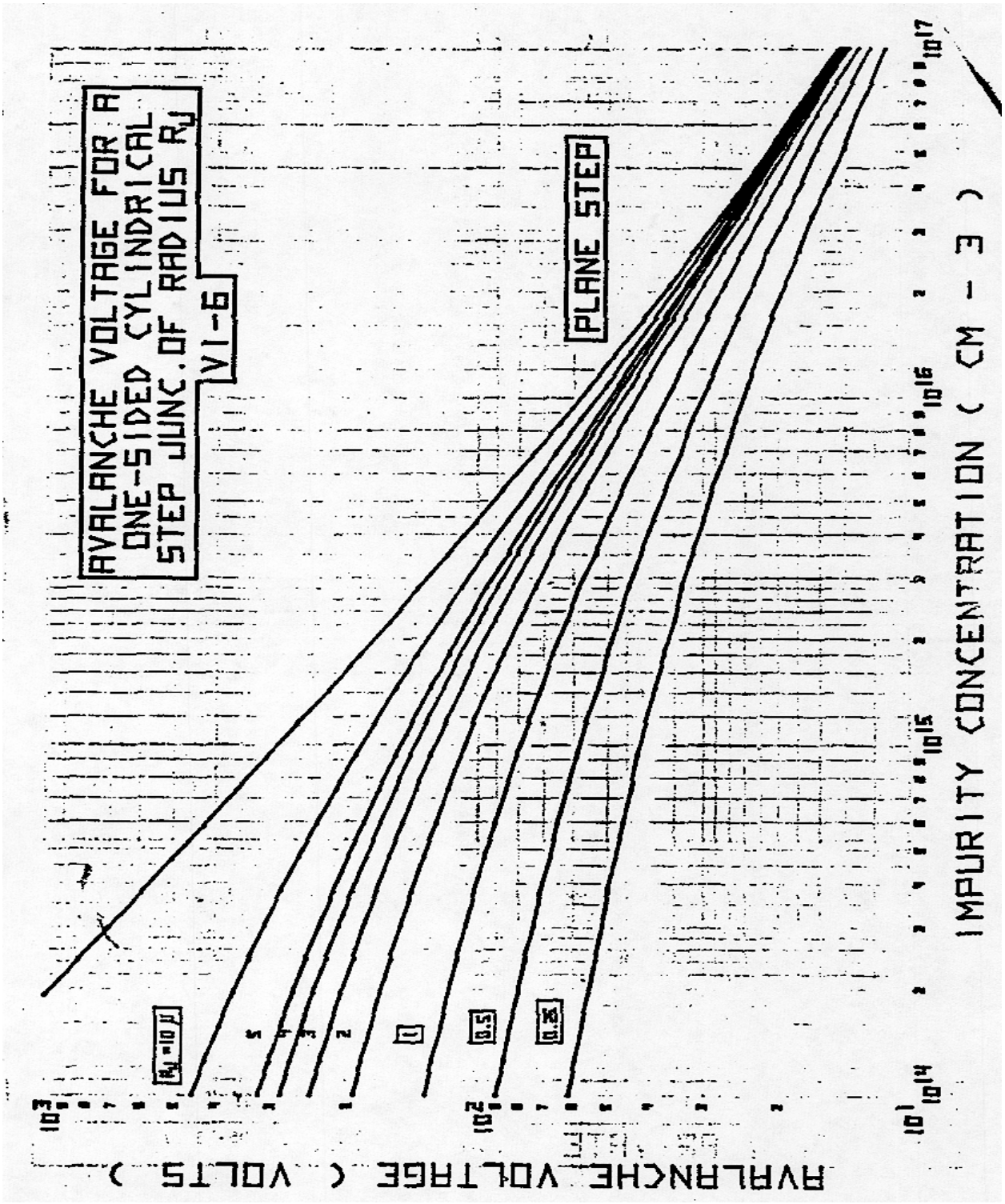
18. AVALANCHE VOLTAGE FOR A PLANE STEP JUNCTION



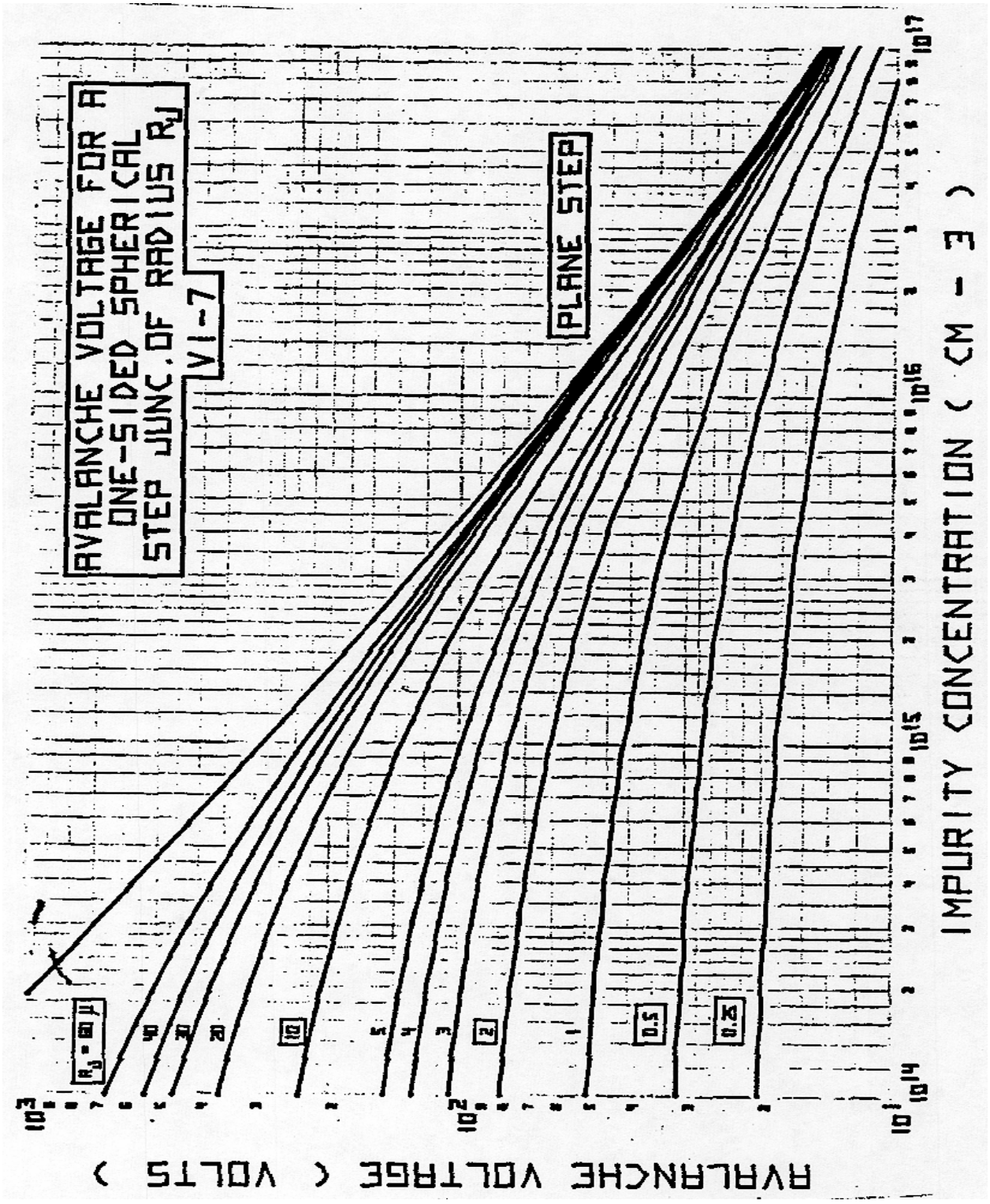
19. AVALANCHE VOLTAGE FOR A LINEARLY GRADED JUNCTION



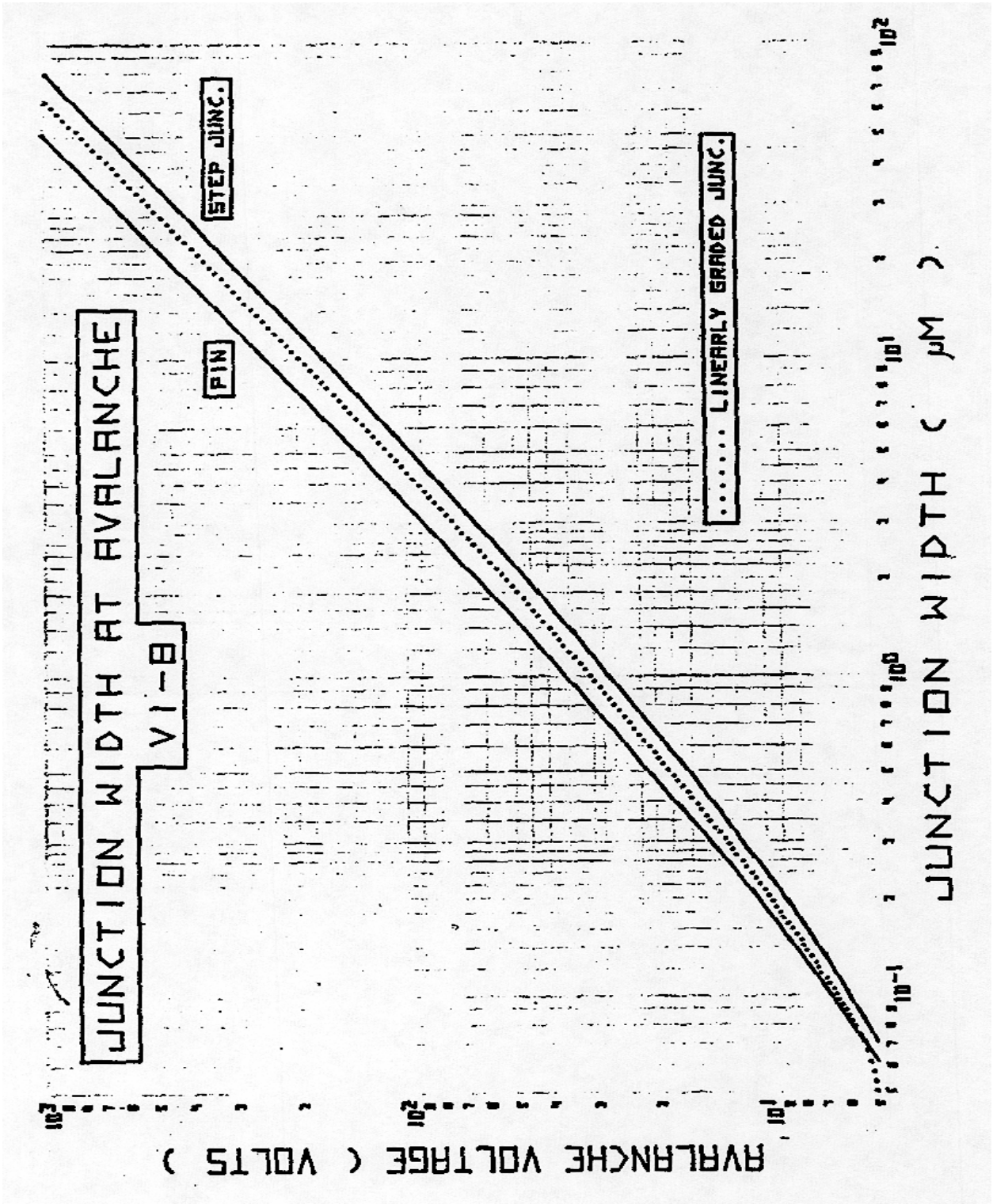
20. AVALANCHE VOLTAGE FOR A ONE-SIDED CYLINDRICAL STEP JUNCTION OF RADIUS R_J



21. AVALANCHE VOLTAGE FOR A ONE-SIDED SPHERICAL STEP JUNCTION OF RADIUS R_J



22. JUNCTION WIDTH AT AVALANCHE



EEL 5355 DATA SHEET FOR BIPOLAR JUNCTION TRANSISTOR PROCESS FLOW

NAME: _____

SEMESTER: _____

PROCESS	CONTROL #1	CONTROL #2
Wafer Type		
Orientation		
Initial Oxide		
BASE PREDEP		
Impurity Type		
Temperature		
Nitrogen Pressure		
Flowmeter		
Push Time		
Predep Time		
Pull Time		
Sheet Resistance (Before Deglass)		
Sheet Resistance (After Deglass)		
BASE DRIVE #1		
Oxidation Type		
Temperature		
Gas Pressure		
Flowmeter		
Push Time		
Drive Time		
Pull Time		
Sheet Resistance (If Applicable)		
BASE DRIVE #2		
Oxidation Type		
Temperature		
Gas Pressure		
Flowmeter		
Push Time		
Drive Time		
Pull Time		
Sheet Resistance (If Applicable)		

PROCESS (cont)	CONTROL #1	CONTROL #2
BASE DRIVE #3		
Oxidation Type		
Temperature		
Gas Pressure		
Flowmeter		
Push Time		
Drive Time		
Pull Time		
Sheet Resistance (If Applicable)		
Indicate which control wafer is etched.		
EMITTER PREDEP		
Impurity Type		
Temperature		
Nitrogen Pressure		
Flowmeter		
Push Time		
Predep Time		
Pull Time		
Sheet Resistance (Etched Wafer)		
EMITTER DRIVE #1		
Oxidation Type		
Temperature		
Gas Pressure		
Flowmeter		
Push Time		
Drive Time		
Pull Time		
Final Wafer Type		
Final Sheet Resistance		

TEST DATA

BJT DATA	Interdig. BJT	Logic BJT
Beta		
ICEO		
ICBO		
BVebo		
BVcbo		
VCE sat		
Early Voltage		

Resistor Data	Large Cell	Small Cell
R1		
R2		
R3		
R4		
R5		