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Space Products

CENTRALAB SEMICONDUCTOR DIVISION
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NASA Lewis Research Center
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16. Abstract Work under contract NAS 3-15345 covered the development and production of 1,000 N+/P wraparound solar cells of two different design configurations: Design I, a bar configuration wraparound and Design II , a "corner pad" configuration wraparound. The project goal consisted of determining which of the two designs was better with regard to production cost where the typical cost of a conventional solar cell was considered as the norm. Emphasis was also placed on obtaining the highest possible output efficiency, although a minimum efficiency of 10.5% was required.

Five hundred cells of Design I and 500 cells of Design II were fabricated: Design I, which used similar procedures to those used in the fabrication of conventional cells, was the less expensive with a cost very close to that of a conventional cell. Design II was more expensive mainly because the more exotic process procedures used were less developed than those used for Design I. However, Design II processing technology demonstrated a feasibility that should warrant future investigation toward improvement and refinement.

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1.0 SUMMARY

Work under contract NAS 3-15345 covered the development and production of 1,000 N+/P solderless wraparound TiAg contact cells of two different design configurations. Design I featured a bar contact along one edge and wrapping around the edge .030" on to the back side of the cell. Design II featured two .030" wide by .015" long N-contact pads on the back side of the cell; the contact material on the edge of the cell was common between the pads and the grids. The required efficiences were 10.5% AMO 28°C. The major goal of the contract was to determine which of the two designs could be produced at a cost closest to, or equivalent to, the production cost of a conventional solar cell.

Five hundred cells of each type were fabricated and delivered to NASA. Data resulting from the two fabrication runs indicated the following:

Design I was the least expensive of the two designs to produce and could be produced at a cost approximately equivalent to that of a conventional cell. The procedures used for this design were very similar to procedures presently used to fabricate conventional solar cells and included standard prediffusion cleaning, standard diffusion and standard taping and etching technique. The only major deviation was the use of chemical milling of the cells prior to diffusion instead

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of lapping and polishing. Because of the similarity of procedures, comparison of process yields and interrelationships facilitated the process development work.

Design II was the more expensive to produce, although the potential electrical output was higher. A more basic development task was required to develop procedures for deposition of the oxide diffusion mask and the related photo-resist technique for removal of the oxide where desired. Both kinds of high volume equipment and the process history were lacking to achieve the same degree of process control that was achieved for the Design I cells. However, the degree of process feasibility demonstrated indicates great potential for further development.

Future development that could be undertaken to further cost reduction and improve efficiencies of wraparound solar cells would lie in the area of diffusion masking and evaporation technology where the complexity and number of process steps could be greatly reduced.

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2.0 INTRODUCTION

During the last few years, CRL, as well as other companies engaged in the manufacture of solar cells, have produced small quantities of cells with wraparound contacts. Because of a lack of demand on the part of the panel manufacturers, the wraparound cell has not thus far been developed to the status of a high volume production item, competitive in cost to the conventional cells now being produced.

Cells with both the "N" and "P" contacts on the back side of the cell will permit significant advances in the assembly of flexible arrays through reduced lay down costs, improved packing factor and greater reliability of the array due to simplification of the interconnect system. More power per unit area can be attained because of the increased active area per cell. Furthermore, it can be seen that the entire active surface of the cell can be easily and economically shielded from low energy proton damage because the cover glass can be procured to looser tolerances and can be readily installed on the cell without elaborate fixturing for precision alignment. This design also lends itself to the application of FEP Teflon Coating recently developed by NASA-Lewis Research Center.

Consequently in accordance with the above advantages obtainable from the use of wraparound cells, CRL has endeavored to attain

2.0 the following objectives with respect to the design and manufacture of wraparound cells:

a) A N^+/P (2x2) cm solderless wraparound cell with electrical power output equal to or better than conventional space quality cells.

b) The development of wraparound cell fabrication techniques cost-competitive with conventional cell fabrication techniques.

c) The production and delivery of 1000 wraparound cells of the chosen design or designs, produced by the developed fabrication techniques. These cells shall have a minimum efficiency of 10.5% measured at AMO @ 25°C.

3.0 CELL DESIGN

3.1 Basic Materials

Contract Specifications called for solderless, anti-reflection coated, 7-14 ohm cm, 2x2 cm silicon solar cells with wraparound contacts. These cells should have silver top layer contacts and space quality electrical and mechanical properties including a minimum efficiency of 10.5% measured at AMO 25°C. Fabrication processes should be competitive costwise with those for conventional cells.

The solar cell blanks used as basic starting materials were cut from CRL grown Czochralski ingots of 7-14 ohm cm resistivity.

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3.1 The sizes of the blanks were such as to yield 2x2 cm cells .012 to .015 inches thick. These blanks were diffused with $POCl_3$ to a sheet resistivity of 45 Ω/□. Contacts were vacuum deposited titanium - silver.

3.2 Contact Configurations

Two different contact configurations were proposed. In both designs the junction extended from the top surface of the cell, around the edge and onto the back of the cell with the finger contacts following the junction. This method presented the problems of leakage attributable to the edge wraparound junction, plus the high series resistance effect described by R. Gereth, et.al. of Telefunken (ref. 1).

Design I, illustrated in Figure 1, featured a bar contact along one edge and around onto the back side. The contact wrapped .030 inches around the back while the diffused region extended to .040 inches. This size was considered minimum for the use of mechanical masking and for an adequate interconnecting area. This design offered the advantage of a low fabrication cost.

Design II, illustrated in Figure 2, featured two .030 inch wide x .150 inch long N-layer contact pads in two of the corners of the back side. In this case, only the edge of the cell common to the tabs acted as the collector for the individual grids. The size of the pads was chosen to be as small as possible

3.2 for adequate interconnecting of cells. Thus series resistance effects would be kept at a minimum. This design involved more sophisticated and expensive processing techniques but offered a versatility of contact configuration and a greater potential for electrical efficiency.

4.0 CELL PROCESSING

4.1 The Design I process flow chart is shown in Figure 3. The chart for conventional cells is also shown for comparison. Design I was nearly identical to the conventional cell in the number of process steps. However, the manner of carrying out the steps Clean and Etch, Tape and Etch, and TiAg Evap. was different.

In Cleaning and Etching for the Design I cell, the entire blank front, back, and sides, was subjected to a chemical milling technique which removed most of the sawing and lapping damage. The edges thus had the same surface finish as the front and back surfaces. This eliminated the problem of poor output characteristics due to shunting of the junction at the wraparound edge. Here the damage in the, "as cut", sawed surface of the blanks was most likely to be of such an extent that the quality and uniformity of the N+ region was greatly impaired.

4.1 For the Tape and Etch step, the tape must be applied not only on the fronts but also on one edge and on a narrow strip on the back. The blanks were etched for 4 seconds in a mixture of 66 2/3 parts 49% Hydrofluoric acid to 33 2/3 parts 71% Nitric acid (by volume).

In order to deposit titanium and silver on the edge as well as on the fronts and backs, the cells were placed in a mechanical mask (Figures 4a,4b and 4c) and rotated on a rotisserie (Figure5) for the TiAg evaporation step. This makes it possible to deposit a uniform layer of titanium with a layer of silver over it. Such a deposition technique has resulted in much better adherence of the TiAg on the wraparound edge of the cell than had been previously achieved by evaporating TiAg on the edge at an acute angle. In the latter case, many times little or no titanium was present under the silver which resulted in poor or unreliable contact adherence.

4.2 The Design II process flow chart is also shown in Figure 3. It is more lengthy than the chart for the Design I or for the conventional cell. The Clean & Etch step is the same as for the Design I cell. Two Photo-Resist steps are involved, the first for selective removal of the oxide diffusion mask where it is required to have a N+ layer; the second, for removal of the TiAg matallization over the junction on the back side of the cell. Both of these steps require application, (and exposure)

4.2 of the Photo-Resist, etching of the oxide or metallization, and removal of the Photo-Resist.

The oxide formation was accomplished with a $SiCL_4$-Methyl Alcohol system at approximately 700°C. Evaluations have shown that use of a high temperature steam oxide has detrimental effects on the electrical characteristics of the cells.

Titanium-silver contacts were applied as for the Design I cells using the rotisserie. A Nitric Acid etch, followed by the Nitric-Hydrofluoric etch mixture, refered on page 7, was used to effect the separation of the back contacts. Titanium-silver had to be evaporated over the entire back surface because mechanical masks could not be fabricated to produce the isolation needed.

5.0 RESULTS AND DISCUSSION

5.1 Cell Performance

Table I lists typical values of Open Circuit Voltage Voc, Short Circuit Current Isc, Curve Factor, Series Resistance, Maximum Power and Efficiency for populations of typical Design I, Design II, and conventional (2x2) cells .012" thick. There was little or no significant difference between the two wraparound designs in any of these categories, particularly for Maximum Power and Conversion Efficiency which are the essential parameters. Both designs were superior to the conventional cell in Efficiency, Maximum Power and Isc.

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5.1 The short circuit current values of the wraparound cells are 4 percent higher than for the conventional cell. When all factors are considered, such as increase in active area the effect of the N wraparound regions on cell series resistance and the diode effect of the -N regions on the back side of cell (ref.1), the increase in cell output due to the Isc increase is substantial and may approach the maximum that can be achieved.

Table II lists the distributions of the 500 Design I and the 500 Design II cells that were shipped to NASA-Lewis: column I contains the current at 430 mV listed in increments of 2 mA, column II contains the corresponding Maximum Power Value, column III contains the efficiency, IV and V contain the number of cells and percentage in each current group for the Design I and Design II cells, respectively, Figure 6 shows the data in graphical form. The Design II category contains more cells in both the lowest and highest current levels. Thus it would appear that the process control for the Design I cells was somewhat superior to that for the Design II cells.

Average performance of the two Designs was nearly equivalent although Design II is theoretically superior due to decreased N contact area on the back side of the cell (ref.1). The poorer results with Design II probably lies in the radically different production techniques used.

5.2 Cell Processing

Gridline resistances were a source of difficulty early in the investigation. Table III compares gridline resistances of some Design I wraparound contact cells with gridline resistance of standard, conventional bar, solderless solar cells. The data for the wraparound cells include values for cells evaporated to a thickness of 1, 2½, and 4 microns of silver. The wraparound cells were rotated during evaporation. In all cases the source-to-substrate distances were equivalent. The gridline resistance of the wraparound cells evaporated with 1 and 2½ microns of silver were considerably higher than the gridline resistances of the conventional cells.

Only when 4 microns of silver was evaporated on the wraparound cells did the gridline resistance decrease to a value close to that usually encountered with conventional solderless cells. Since the quantity of silver evaporated on cells when they are rotated with respect to the source approaches a Cosine function, it would appear that a minimum of 1½ times the normal amount of silver has to be evaporated to obtain a thickness equivalent to that obtained in a single run, in which the cell is not rotated. In actuality, the empirical data seems to indicate a slightly larger quantity of silver is necessary. The 1000 NASA cells were fabricated using 1½ times the quantity of silver that would have been used to manufacture the same quantity

5.2 of conventional cells. It would seem that an even larger quantity of silver could be evaporated to further reduce series resistance. However the economics of the technique (i.e. number of evaporation runs necessary), at the present time, seem to indicate that the 4 micron thickness of silver is adequate to meet the power output requirements of the contract. More investigation in this area however might lead to a further augmentation of wraparound cell output capability.

When compared to conventional solderless cells, the mechanical integrity of the wraparound Design I and Design II seem to be equivalent. Time or the scope of the contract did not permit an exhausting battery of environmental tests; however, from the test, no difference in the behavior of the wraparound cells could be detected.

The only feature that did appear to be a possible design weakness and process technology problem, was the width of the Design II connector bar between the pads which is connected to the tops of the gridlines. This bar is exactly the thickness of the cell and does not itself wraparound to the back side of the cell. It appeared to be somewhat difficult from the process control point of view, to avoid etching the pattern so that a portion of, or the entire width of the connector bar was not removed, thus severely restricting or severing the connector bar in one or more places. Fig. 7 illustrates a proposed modification.

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5.3 Cell Costs

When the wraparound cell Design I and II are compared to conventional solderless cells (with respect to fabrication processes) the prime criterion for consideration is cost. The Design I cells differed from conventional cells only in cleaning and etching of blanks, tape application, and titanium-silver evaporation.

The chemical-milling process applied to Design I cells eliminated much of the lapping, polishing and cleaning techniques that are necessary in the fabrication of a typical CRL mechanically-polished silicon blank. Consequently, the Design I wraparound cell (and also the Design II cell) would have a lower blank fabrication cost and the magnitude of this cost savings in the case of the Design I cell would probably balance the cost increases in taping and evaporation areas, when large quantities (10K - 100K) are considered.

The fixture for application of tape to conventional cells would readily lend itself to the production of wraparound Design I cells up to quantities of 10,000, at a cost only slightly higher than for conventional cells. For quantities greater than 10,000 cells, a more efficient method of applying the tape must be devised to retain a competitive fabrication cost ratio of Design I cells to conventional cells. It would appear that a more efficient taping machine could be devised when necessary, without undue cost or difficulty.

5.3 The rotisserie method of titanium-silver contact evaporation increases the cost of wraparound cells when compared to conventional cells, particularly for quantities between 1 and 10K. For quantities of 10-100K, major evaporator refixturing and the use of an elactron beam evaporation technique could be used, which would considerably reduce the cost difference in this area. The amount of silver and titanium not reaching the cells would be reduced and it would not be necessary to make multiple charges to the evaporator.

For Design II cells, the double Photo-Resist method was time consuming and thus costly. The present technology does not lend itself to efficient production techniques for 1,000 to 10,000 cell quantities as well as the tape masking technique used in Design I. For quantities in the 10,000 to 100,000 piece range, the development of the proper type of capital equipment, geared to handling the larger quantities, would probably result in lower costs and higher yields.

6.0 CONCLUSIONS

When the results from the 1,000 cells that have been fabricated and shipped to NASA are analyzed with respect to yield distribution from the cost point of view, it has to be concluded that with present process technology, the Design I wraparound cell is the lower-cost design of the two wraparound designs. Any immediate requirement for large quantities (10K-100K) of

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6.0 cells in the immediate future would have to be fabricated using the Design I approach to maintain the lowest possible cell costs. This design could be done at a very similar, or at worst a slightly higher cost than a conventional cell.

The Design I cells exhibited efficiencies equal to the Design II cells and greater than conventional cells. The mechanical integrity also seemed to be equivalent to that of conventional cells.

7.0 RECOMMENDATIONS

If even further reduction of the cost of wraparound cells is desired, particularly for very large quantity orders i.e. greater than 100K, then further development would be necessary in the following areas:

(1) Diffusion Masking: Development of a technique of evaporating the oxide mask on the cell for the Design II cells. This would make it possible to preferentially deposit the oxide on those areas of the back of the cell blank where the P region is desired; this would eliminate having to cover the whole blank with oxide and then remove it where not desired by Photo Resist techniques.

(2) Evaporation Techniques: Development of an Electron Beam Gun technique for evaporating the TiAg. This would reduce the silver loss to approximately one half that occuring with the existing evaporation technique.

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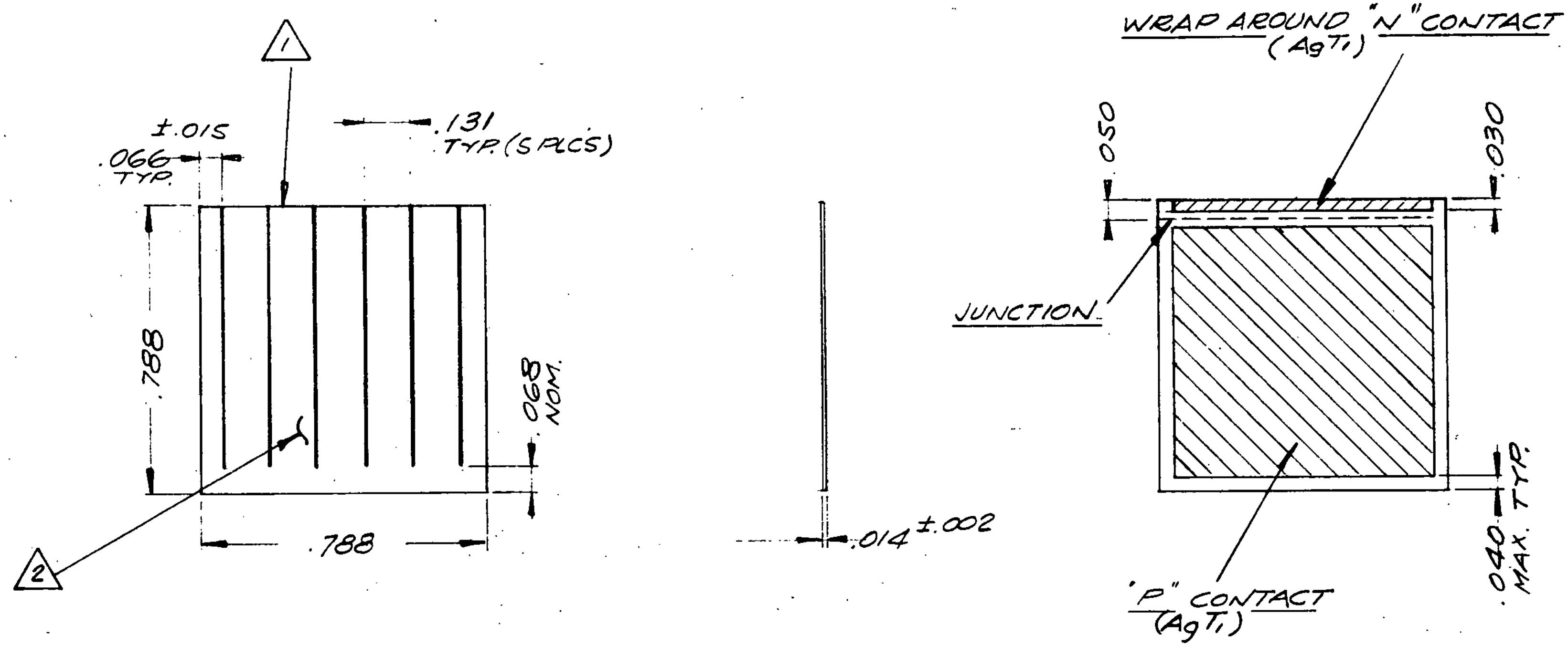
7.0 (3) Silver-Titanium Fixturing: Development of fixturing which would completely eliminate leakage of silver to the active area at the wraparound edge of Design II cells.

A modification of Design II configuration would be recommended especially for use on thin cells. In this case the pad connector bar is so narrow that it could be easily severed or be highly resistive. The modification is shown in Figure 7. In this case the connector bar is wrapped around the edge approximately .010 inch. This moves the photo-resist geometry away from the edge of the cell and eliminates the edge effect problems of mask definition and etching. It would also facilitate development of diffusion masking and new silver-titanium fixturing.

The processing flow chart for the modified Design II using a junction-protecting titanium-silver mask would be as shown in Figure 3. Cells were made in the Design I configuration using this flow chart processing and exhibited efficiencies approaching 10.5%.



NOTES:

1. METAL (AgTi) WRAPS AROUND THIS EDGE CONNECTING GRIDLINES WITH "N" CONTACT.
2. ACTIVE AREA COVERED WITH SiO.
3. TOLER. UNLESS NOTED TO BE ±.005.
4. UNLESS NOTED ALL DIMENSIONS ARE IN INCHES.

Figure 1 - Contact Configuration for Design I Wraparound Cells

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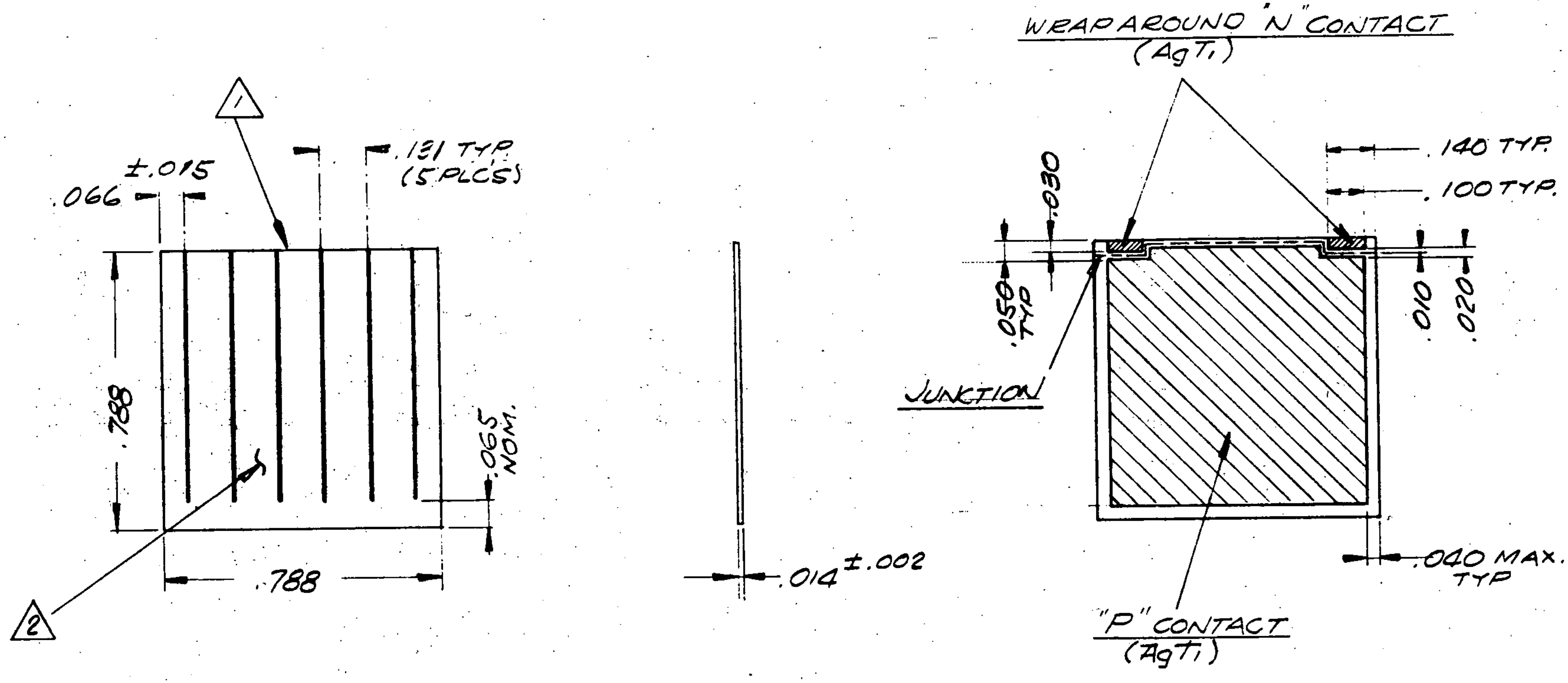

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2. ACTIVE AREA COVERED WITH SiO.
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4. UNLESS NOTED ALL DIMENSIONS ARE IN INCHES.

Figure 2 - Contact Configurations for Design II Wraparound Cells

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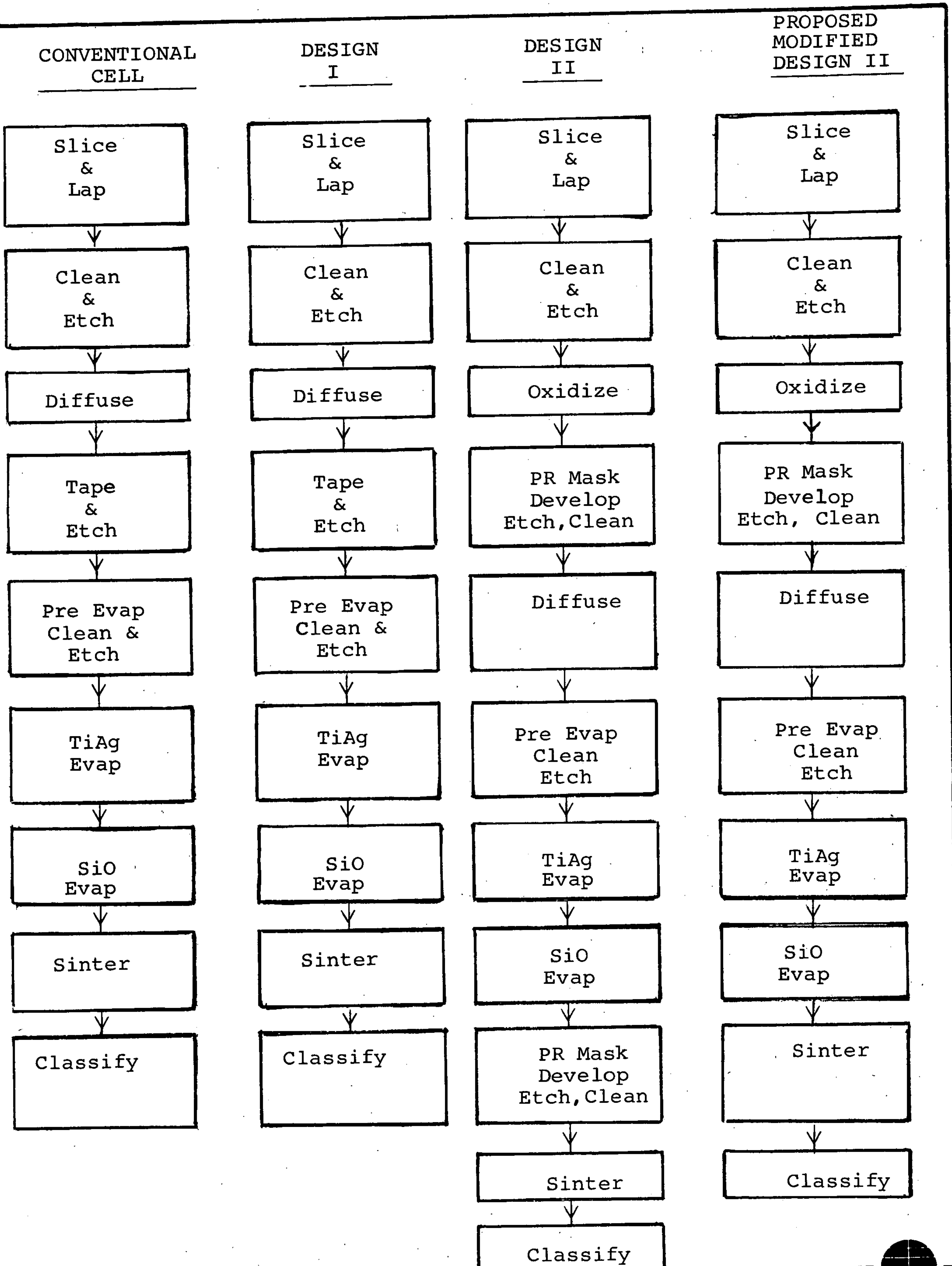

Figure 3 - Flow Chart for Wraparound Designs

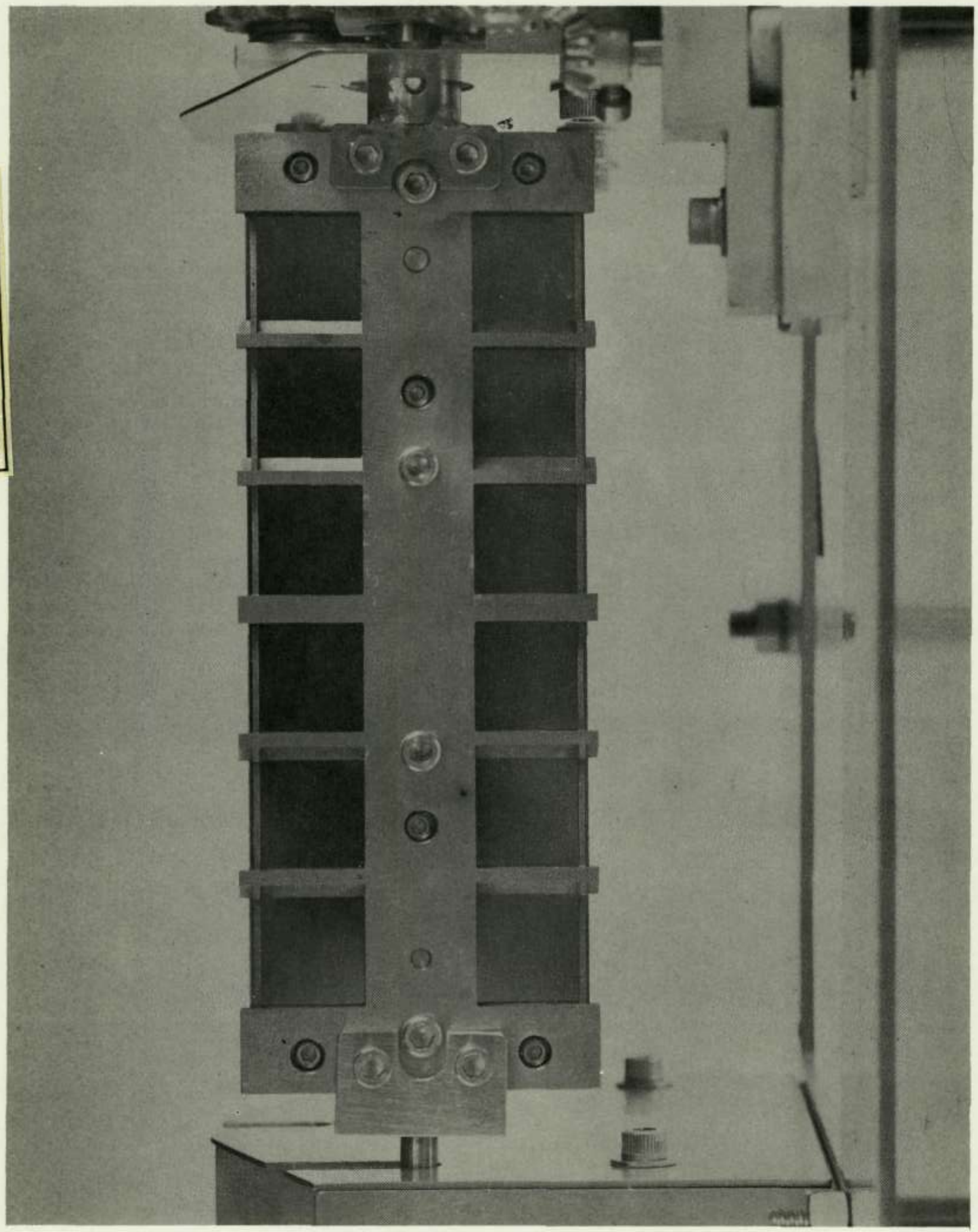

Figure 4 (a) - Design I Mask, Top View

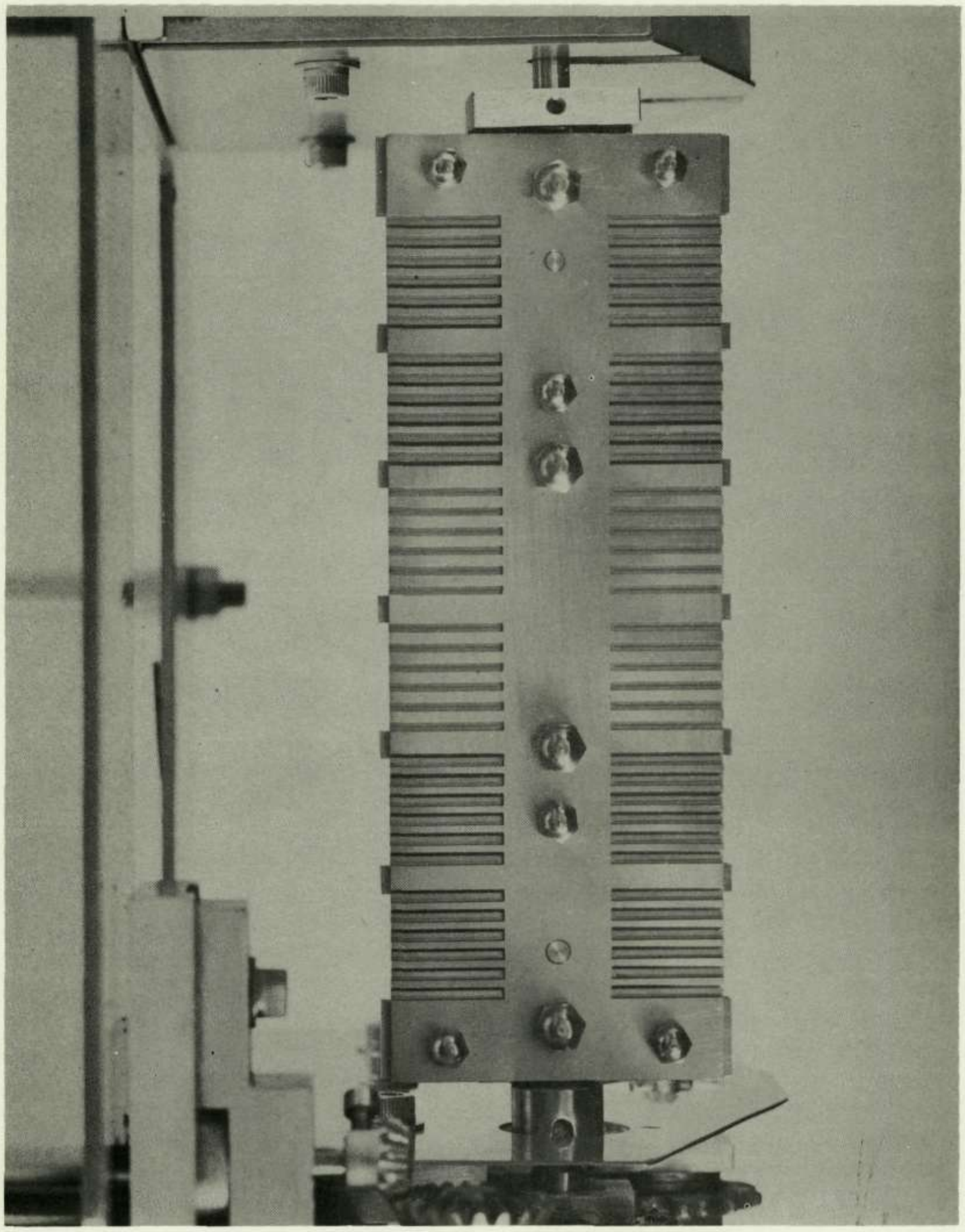

Figure 4 (b) - Design I Mask, Bottom View

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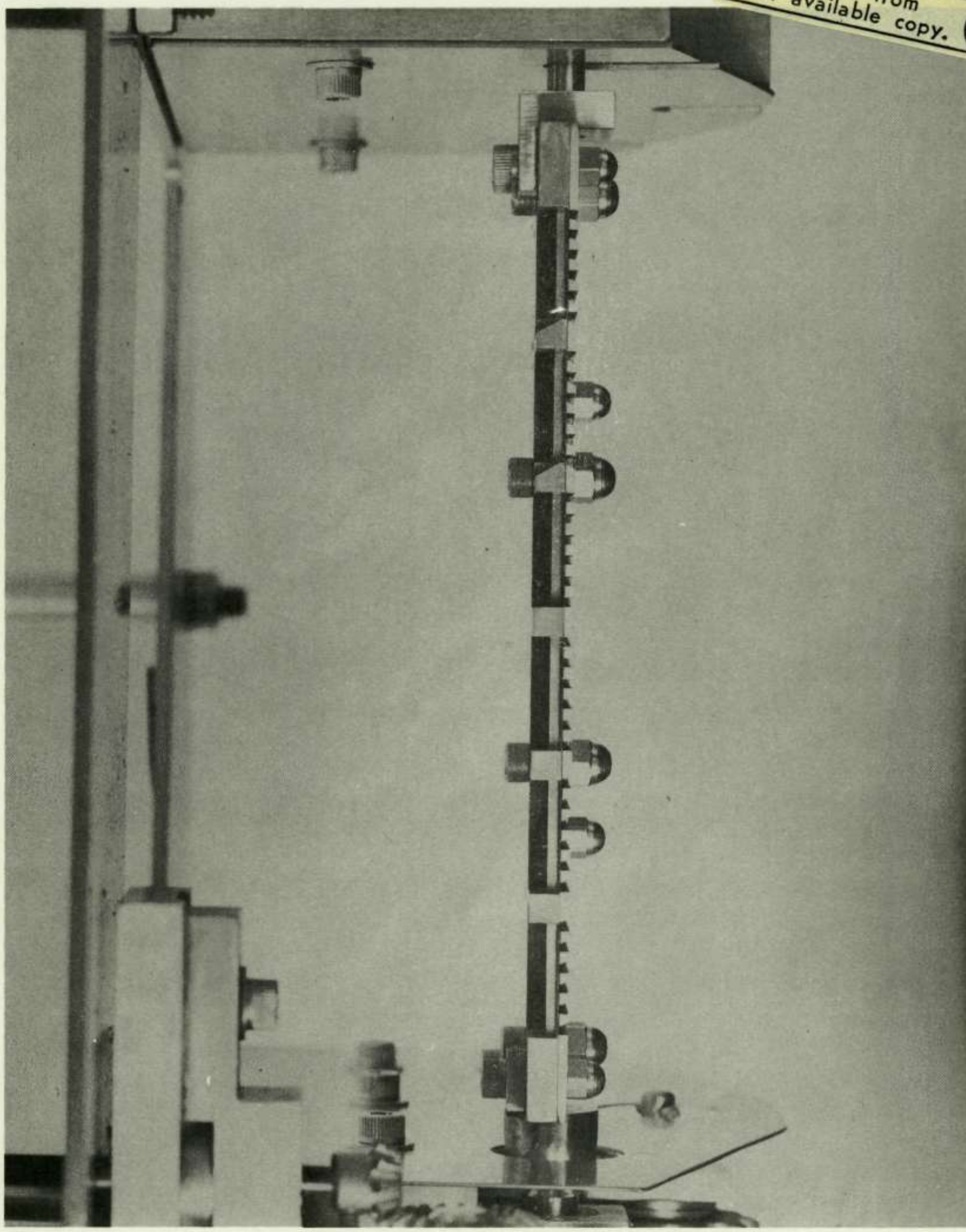

Figure 4 (c) - Design I Mask, Edge View

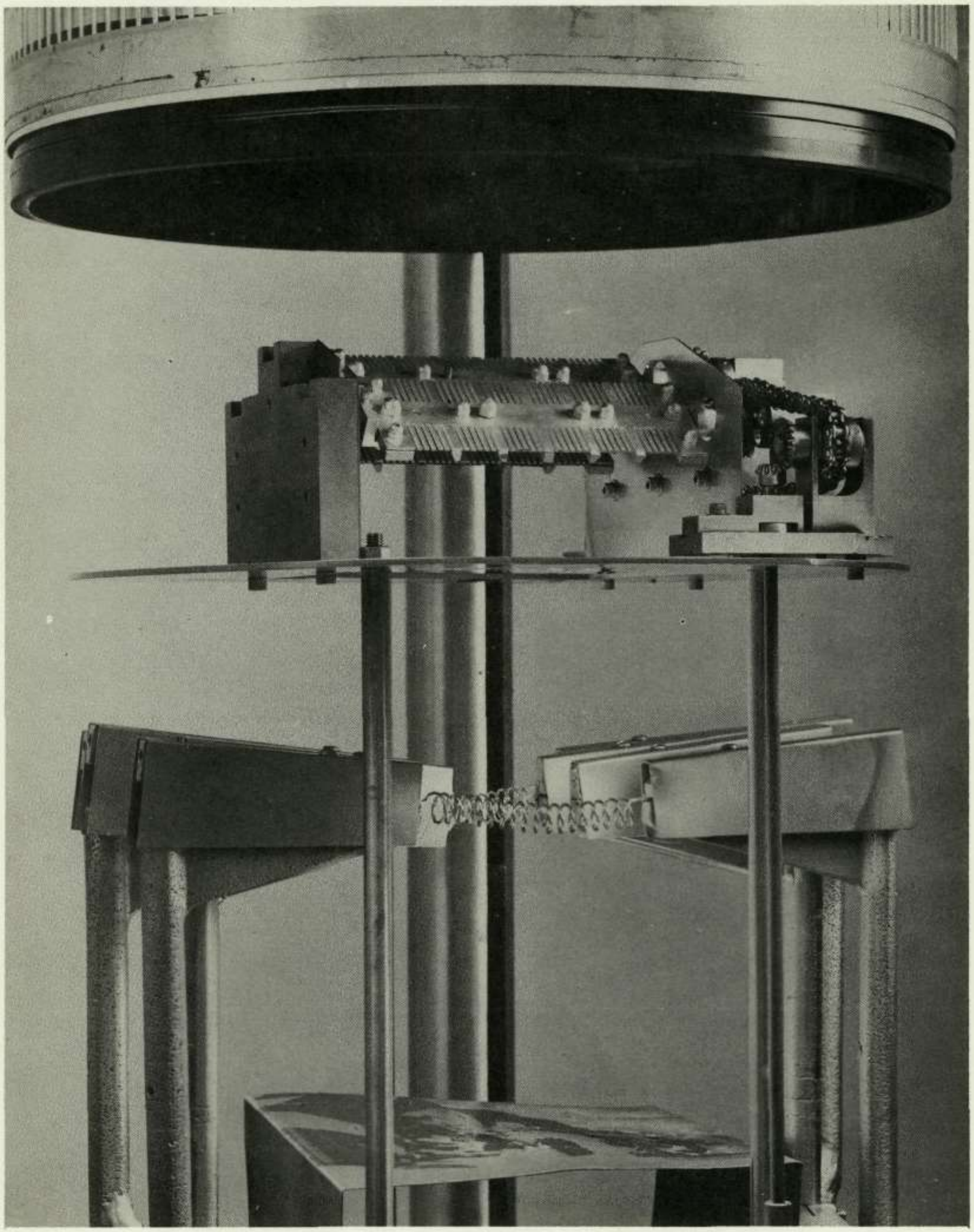

Figure 5 - View of Rotisserie for Design I and Design II Cells

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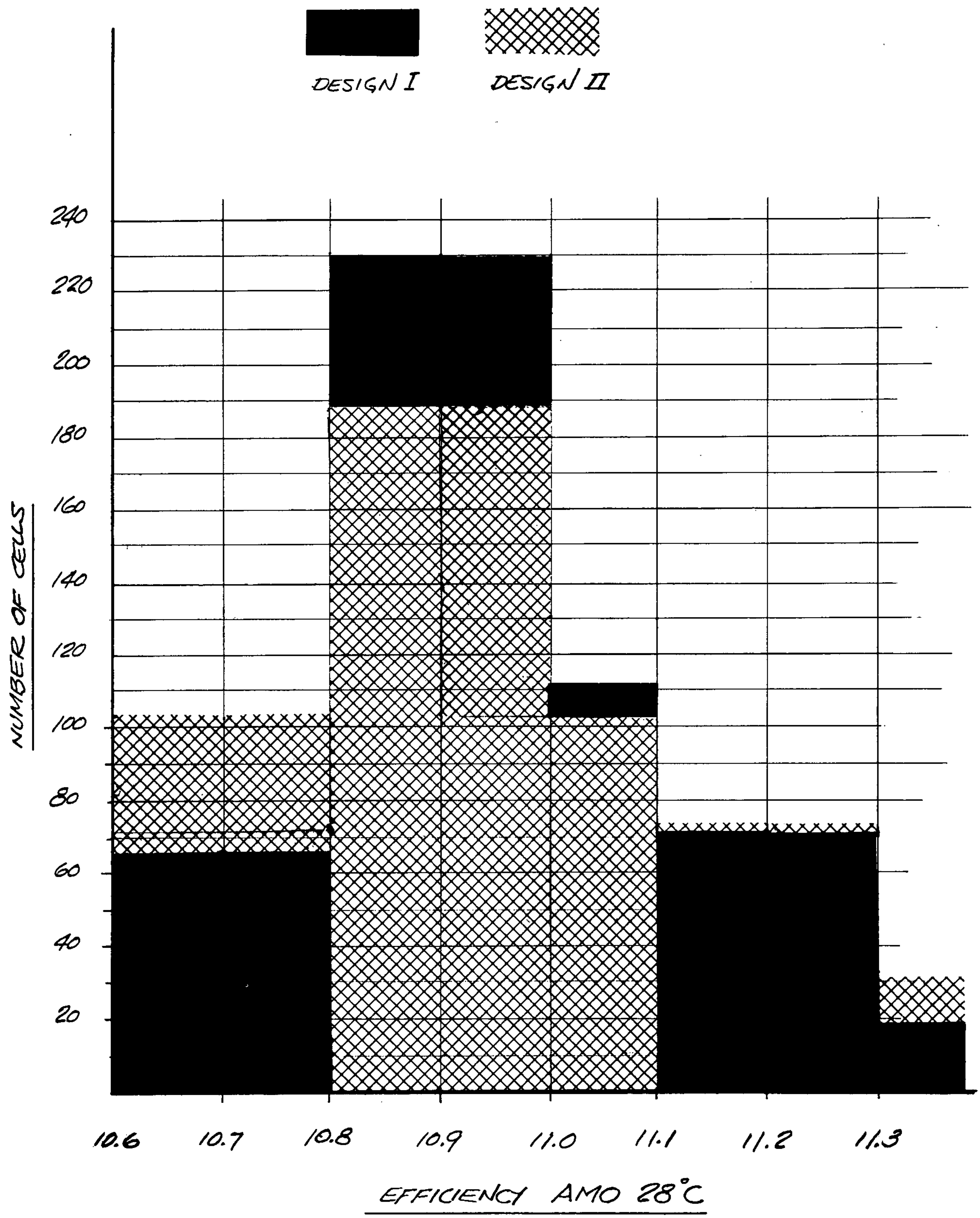

Figure 6 - Distribution of the 500 Design I and Design II Wraparound Cells

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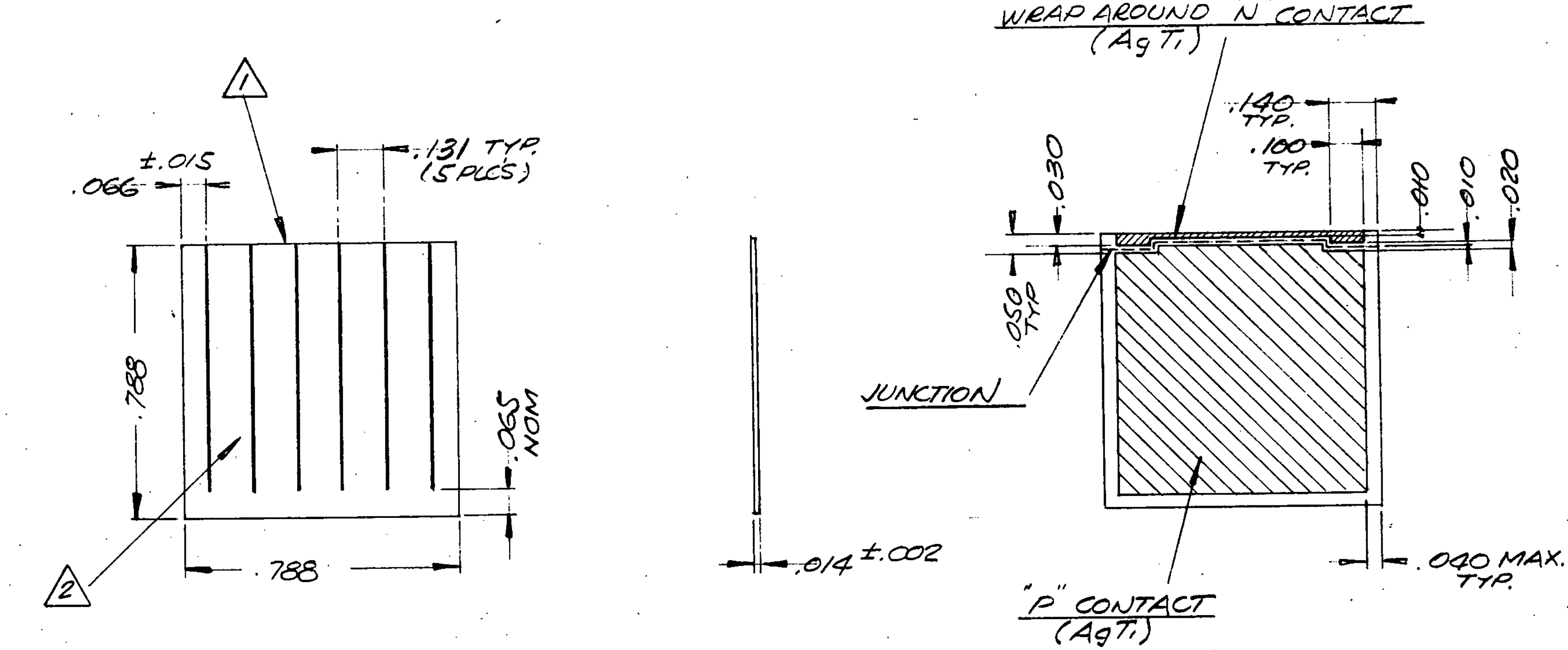

NOTES:

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2. ACTIVE AREA COVERED WITH SiO.
3. TOLER. UNLESS NOTED TO BE ±.005.
4. UNLESS NOTED ALL DIMENSIONS ARE IN INCHES

Figure 7 - Contact Configuration for Proposed Modified Design II Wraparound Cells

TABLE I

VALUES OF ELECTRICAL CHARACTERISTICS FOR WRAPAROUND SOLDERLESS CONTACT CELLS AND CONVENTIONAL BAR SOLDERLESS CELLS AT 28°C AND AMO

CELL TYPE	Isc (mA)	Voc (mV)	P_M (mW)	Eff. (%)	R_S (Ω)	C°.F. (%)
Conventional	144	550	57.8	10.6	.4	72.0
Design I	150	550	59.6	11.0	.55	72.0
Design II	150	545	59.6	11.0	.45	73.0

NOTE: (1) Based on total area; when the bar contact is not included the efficiency is 10.9%

(2) R_S (series resistance) was measured using the "Swanson" Method. (ref. IRE Trans. Military Electronics Vol. Mil-6, No. 1, 1962, pg.5)

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TABLE II

DISTRIBUTION OF THE 500 DESIGN I & 500 DESIGN II CELLS SHIPPED TO NASA - LEWIS*

Current (mA) @ 430 mV		P.Max. (mw)		Efficiency (%)		(%) Design I		(%) Design II	
From	To	From	To	From	To	%	No.	%	No.
134.5 -	136.4	57.8 -	58.7	10.6 -	10.8	13.2	66	20.8	104
136.5 -	138.4	58.7 -	59.6	10.8 -	11.0	46.5	232	37.5	187
138.5 -	140.4	59.6 -	60.4	11.0 -	11.1	22.5	112	20.8	104
140.5 -	142.4	60.4 -	61.3	11.1 -	11.3	14.2	71	14.4	72
142.5 -	above	61.3 -	above	11.3 -	above	3.8	19	6.6	33

*Data is based on 28°C AMO Solar Simulator Readings.
(Intensity = 135.3 mW/cm^2)

TABLE III

COMPARISON OF GRID RESISTANCES OF CONVENTIONAL BAR SOLDERLESS CONTACT CELLS TO WRAPAROUND SOLDERLESS CONTACT CELLS

CELL TYPE	THICKNESS OF Ag	MODE OF EVAP.	GRID RESISTANCE
Conventional	$3\frac{1}{2}\ \mu$	No Rotation	.7 Ω
Design I	$1\ \mu$	Rotation	2.1 Ω
Design I	$2\frac{1}{2}\ \mu$	Rotation	1.6 Ω
Design I	$4\ \mu$	Rotation	.8 Ω

NOTES:

(1) The grid resistances were measured using needle probe contacts and a Simpson Ohmmeter accurate to .01 Ω.

(2) Both the wraparound cells and the conventionals possessed grid widths of the order of .008".

(3) The probes contacted the grid at the end of the grid and at a distance approximately .650" from the end.

REFERENCES

Ref. 1: R. Gereth et al - "Silicon Solar Cell Technology of the Seventies". 8th Photovoltaic Specialists Conference Record, P. 352 (1970).