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Research and Development of Silicon Solar Cells for Low Solar Intensity and Low Temperature Applications

by P. Payne

December 29, 1970

Combined Quarterly Progress Report
and
Analysis Report

Prepared under Contract No. NAS2-5519

by

Heliotek, Division of Textron, Inc.
12500 Gladstone Avenue
Sylmar, California 91342

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AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

During this quarter crucible grown silicon was investigated to determine whether the short circuit current-temperature dependence of the low oxygen content float zone and Mon-X or Lopex type silicon could be duplicated with crucible grown silicon by varying the crystal growth parameters to minimize the oxygen concentration. Cells fabricated from this special ingot were compared to cells fabricated from a standard production grown ingot; no improvement in the short circuit current temperature characteristic was realized with the lower oxygen concentration crucible grown cells.

Investigation of the broken knee characteristic was oriented toward evaluating the effect of various edge treatments. The edge treatments included grinding the cell edges, applying a liquid glass film and heating to form a passivating layer, etching silicon slabs prior to slicing in order to reduce the mechanical damage at the cell edges, and mesa etching cells.

Grinding the cell edges in some cases completely eliminated the broken knee problem, however, in most cases, the broken knee effect was reduced considerably, but not eliminated. The results were similar with application of a glass film to the edges.

Etching the silicon slabs prior to slicing to remove additional mechanical damage did not eliminate the broken knee effect; however, it did reduce the occurrence and degree of the problem.

Cells which had been mesa etched to obtain low leakage currents were measured at low intensity and temperature. These cells exhibited exceptionally good performance due not only to the very low leakage currents, but also to the lower incidence of the broken knee effect.

The Analysis Report covering the entire program is included in this report.

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1.0 INTRODUCTION

The purpose of this program is to obtain a solar cell design optimized for operation at 5.0 mW/cm^2 solar intensity and -135°C, as encountered in a spacecraft mission to Jupiter. Originally this program was organized into Phase I, during which experiments were conducted to analyze and optimize the important solar cell variables, and Phase II during which 500 prototype cells would be fabricated using the procedures decided upon during Phase I. Phase I was completed in February 1970 and an analysis report was written which discussed the design variables selected. At that time the contract was modified to extend the Phase I experimental program and delay the fabrication of the 500 prototype cells for Phase II. A quarterly report in September 1970 covered work done on the Phase I extension. This combined quarterly report and analysis report includes a discussion of the work done during the last quarter of the Phase I extension as well as an analysis of the selected cell design. The selected cell design is based on the results of the last six months of work as well as the summary of the work discussed in the first analysis report.

As a result of the work done on this contract it has been shown that the wide range in solar efficiency at 5.0 mW/cm^2 solar intensity and -135°C that was exhibited by conventional solar cells was due to four major problems:

1. Metal semiconductor Schottky barrier formation
2. Variations in shunt resistance
3. A broken knee effect
4. Variations in the linearity of the short circuit current temperature dependence.

During this last quarter only the third and fourth problems were investigated with the major emphasis on the broken knee effect. Investigation of the variation in the linearity of the short circuit current as a function of temperature has shown that cells fabricated from float zone and Mon-X types of silicon which both have low oxygen contents, exhibited a short circuit current versus temperature dependence which consistently more closely approached a linear relationship (thus producing more power at low temperatures) than did cells fabricated from crucible grown silicon.

During this quarter crucible grown silicon with the growing parameters modified to minimize the oxygen concentration was used to fabricate cells to determine whether the short circuit current versus temperature characteristics obtained with float zone and Mon-X silicon cells could be duplicated with crucible grown silicon.

Investigation of the broken knee problem involved studying the effects of various cell processing procedures which, it was postulated, would change the edge characteristics of the solar cell.

The first portion of this report covers the work done this quarter while the cell design analysis section summarizes the entire experimental program.

2.0 ANALYSIS OF EXPERIMENTS PERFORMED DURING THIS QUARTER

2.1 TEMPERATURE EFFECTS ON SHORT CIRCUIT CURRENT

Investigation of 10 ohm cm N/P P+ cells for use at low temperature and low intensity has shown that the nonlinearity of short circuit current as a function of temperature can reduce cell output as much as 25%; a cell with potentially 15 to 17% efficiency might have only 13% efficiency due to low short circuit current at -135°C. This short circuit current effect occurs at both standard and low intensity.

Comparison of cells fabricated from crucible grown silicon (which up to this time had been used for all cells) to cells fabricated from float zone (low oxygen content and high dislocation count) and Mon-X (low oxygen content and low dislocation count) silicon showed that the float zone and Mon-X cells exhibited a short circuit current versus temperature dependence which more closely approached a linear relationship. More than 100 float zone and Mon-X cells have been fabricated and the largest deviation from the value extrapolated from a linear relationship has been 7%. Crucible grown cells typically have shown 7 to 25% deviation.

The two major differences between the Mon-X and float zone silicon and the crucible grown silicon was crystal orientation and oxygen content. The crystal orientation was < 100 > for the crucible grown silicon and < 111 > for the float zone and Mon-X silicon. The orientation was not likely to be the important variable, since occasional < 100 > orientation cells have exhibited a linear change in short circuit current as a function of temperature. The oxygen concentration, which is in the range of 10^{14} to 10^{15} atoms/cm^3 for float zone and Mon-X silicon and 10^{17} to 10^{18} atoms/cm^3 for crucible grown silicon, was an obvious parameter which was significantly different for the materials. Therefore it was assumed to be the important variable resulting in the improved linearity of the short circuit current versus temperature dependence of float zone and Mon-X cells. This is not incompatible with the occasional observation of this characteristic (good linearity) in crucible grown silicon cells since many crystal growth parameters affect oxygen concentration and it is likely that there is quite a large variation in the oxygen content of this type material.

If one was to select a material for making Jupiter type solar cells float zone and Mon-X silicon can certainly be used to obtain higher short circuit currents and efficiencies at low temperature; however, it was considered worthwhile to determine whether the low temperature improved short circuit current characteristic could be duplicated with crucible grown silicon. Although crucible grown silicon cannot be grown with the very low level oxygen concentration found in float zone silicon, the growth parameters can be modified to obtain approximately 10^{17} atoms/cm^3 rather than 10^{18} atoms/cm^3. Work done by Goss and Adington[1)] showed that reducing the crucible rotation from a range of 80 to 160 rpm to 10 rpm reduced the oxygen concentration by approximately a decade, from $\approx 10^{18}$ to 3×10^{17} atoms/cm^3. The oxygen concentration can also be reduced by growing a smaller diameter ingot. In order to investigate this a special ingot was grown with the low crucible rotation and a diameter of 1.25 to 1.50 inches rather than the 2.0 to 2.5".

When the ingot was cut the top, center and bottom sections were kept separate and identified so that any differences in cell characteristics as a function of position in the ingot could be observed, since each section should have a different amount of dissolved oxygen in it. For comparative purposes a standard production ingot was also cut, with top, center and bottom sections kept separate.

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1) Solid State Physics in Electronics and Telecommunications, Vol. 1, Semiconductors, Part 1, ed. M. Diserant and J. L. Michiels, Academic Press, London and New York, 1960, pp 35-37.

Solar cells made from each section of the ingot were measured at seven temperatures between 28 and -135°C in a tungsten light source (3.58 mW/cm^2 intensity). None of the sections from either ingot produced cells with an improved short circuit current versus temperature dependence. The cells from the standard production ingot (used as a control) showed a 12 to 28% deviation from the linearly extrapolated values. The cells from the top section of the lower oxygen content ingot showed 25 to 35% deviation and the cells from the middle sections 19 to 22% deviation from linearity. In the case of the cells fabricated from the bottom section of the ingot grown to minimize oxygen content, the short circuit current measured in a tungsten light source at 28°C was 40 to 50 mA rather than 110 to 120 mA and the short circuit current decreased sharply with temperature between 28 and-60°C rather than between -60 and -120°C which is the range in which the short circuit current usually deviates from a linear relationship. Since the growing parameters which were modified were the most significant ones with respect to altering the oxygen concentration, it was concluded that the oxygen concentration of crucible grown silicon could not be altered enough to improve the short circuit current versus temperature relationship.

2.2 BROKEN KNEE EFFECT EXPERIMENTS

This effect, which has been referred to by various names, including flat spots, broken knee and double slope, has been observed at low temperatures. It is observed primarily at low intensity; however if serious enough it is also present at high intensity. The effect acts like a leakage path which has a threshold voltage of .2 to .4V.

Experiments reported in the Heliotek September 15, 1970 Quarter Report indicated that the broken knee effect was associated primarily with the bar contact region of the solar cell. Since then one cell out of 15 measured after breaking has exhibited the broken knee on both the cell section with the bar contact and the cell section with only grid lines. In all other cases the section with only grid lines exhibited no broken knee, while the cell section with the bar contact had a broken knee which was more pronounced than that measured for the whole cell. The very pronounced difference between two sections of the same solar cells indicates that the problem was related to the contact even though the effect has been observed once in the uncontacted region. It might be either a metal-semiconductor-interface surface effect problem dependent on the relative size of the contact or an edge effect enhanced by the proximity of the contact. Since determination of or a solution to the problem, if it were a metal-semiconductor interface problem, would be somewhat difficult, the problem was attacked as if it were an edge problem. Various procedures for altering the surface states on the cell edges were used and their effects if any on the I-V characteristic curve were analyzed. They included etching the silicon slabs before slicing to reduce the mechanical damage on the edges of the slices, grinding cell edges after fabrication, application of a liquid glass film which was then heated to 400 to 600°C to form a passivating layer, and measurement of mesa etched cells.

It is well known that silicon is mechanically damaged during the cutting operations. In order to reduce the amount of damage which might still be present at the cell edges even after the prediffusion etch, an additional etch was used to remove 0.005 inch of silicon from all surfaces of silicon slabs prior their being sliced into blanks. Both Mon-X and crucible grown silicon slabs were processed in this manner and experimental Jupiter type solar cells were fabricated from the material. Measurement of the I-V characteristic curves at -135°C in both simulator and tungsten light sources showed that although the broken knee effect was not completely eliminated, the problem was reduced.

Only one out of six of the Mon-X cells had an efficiency of less than 13%. The other cells had outputs ranging from 13.8 to 15.2% (see Figure 1). Since previous groups of Mon-X cells have generally shown less than 50% yield of cells with efficiencies of 13% or more, this etching procedure is a worthwhile improvement.

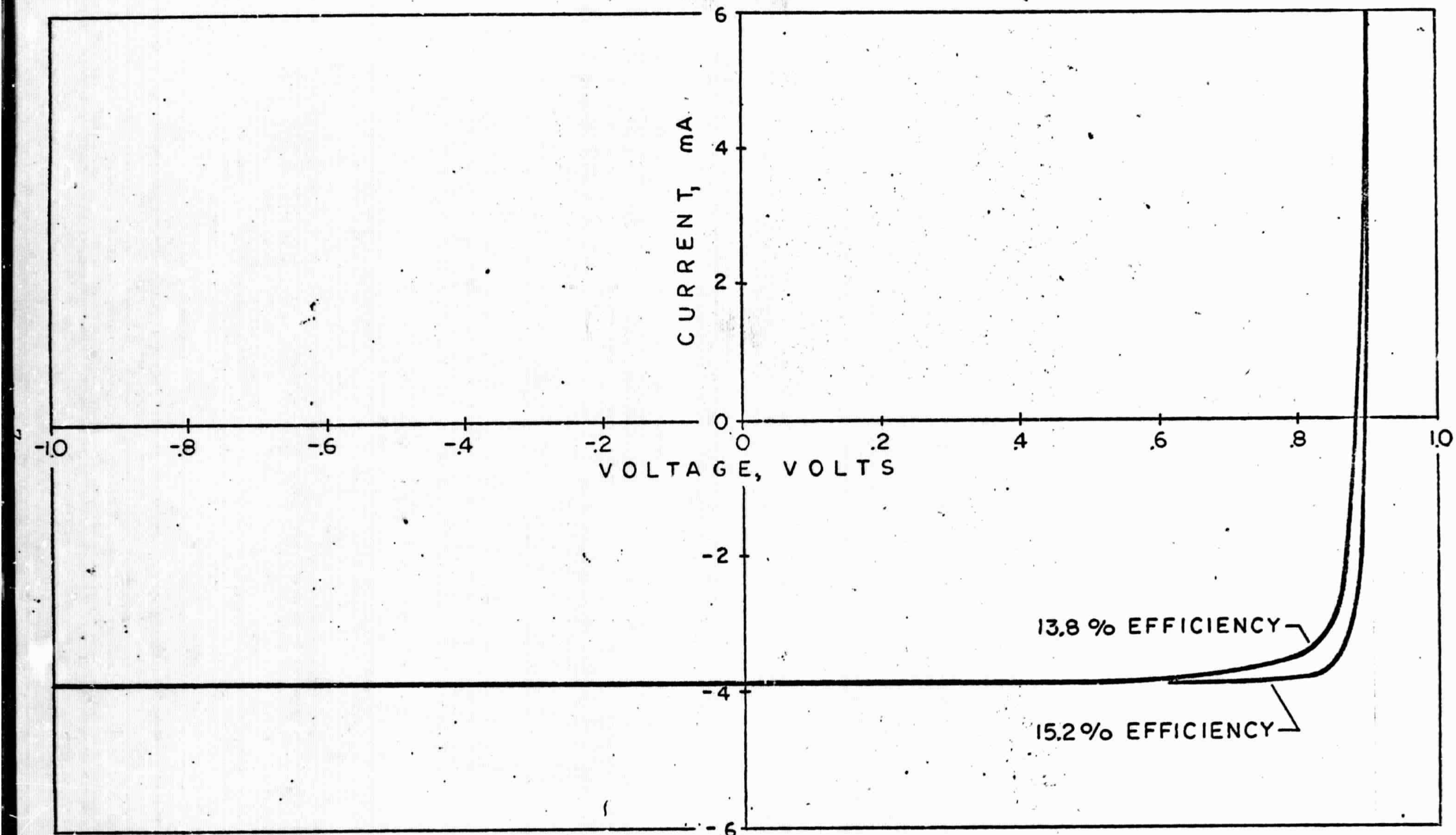

Figure 1. I-V Characteristic Curves of Mon-X Cells Measured at 5.0 mW/cm^2 Solar Intensity and -135°C.

Grinding the cell edges was also investigated for its effects upon the broken knee characteristics since this treatment should mechanically alter the surface states. Frequently the edges of cells with the broken knee characteristics show mechanical damage regions when inspected under a microscope (under 40 x magnification). Grinding the cell edges with 3M Co. #600 abrasive lapping paper to remove the damage regions produced varying results; (additional polishing on finer grit paper did not improve the cell characteristic curve).

Figure 2 shows curves measured at -135°C in a tungsten light source (3.58 mW/cm^2 intensity) before and after grinding the edges of a 1 x 2 cm cell (no AR coating). With this particular cell the extreme broken knee of the cell as fabricated was completely removed merely by grinding all four cell edges. This procedure, however, as a general rule did not always completely remove the problem; for the majority of the cells it merely reduced the problem. For example, figure 3 shows I-V characteristic curves (measured under the same conditions as those mentioned above) of a cell before and after grinding one edge and then four edges. Grinding just one edge which had a damaged region reduced the broken knee considerably, but it was still present. Grinding the other three edges did not produce any further improvement.

Figure 4 shows an even more extreme example of the broken knee. It was also reduced considerably, but not eliminated by grinding one of the edges. The other three edges were also ground, but no further improvement was observed.

A third technique investigated for its effects on the broken knee characteristics involved applying a suspension of glass in a liquid to the cell edges and then heating it to 400 to 600°C to harden it. This procedure did eliminate the broken knee effect on some of the cells on which the edges had been ground prior to application of the glass film. None of the cells with unground edges showed any significant improvement and the number of cell edges ground was found to affect the improvement. Figure 5 shows the effect of the glass layer after application to the same cell which was shown in Figure 4. The broken knee effect

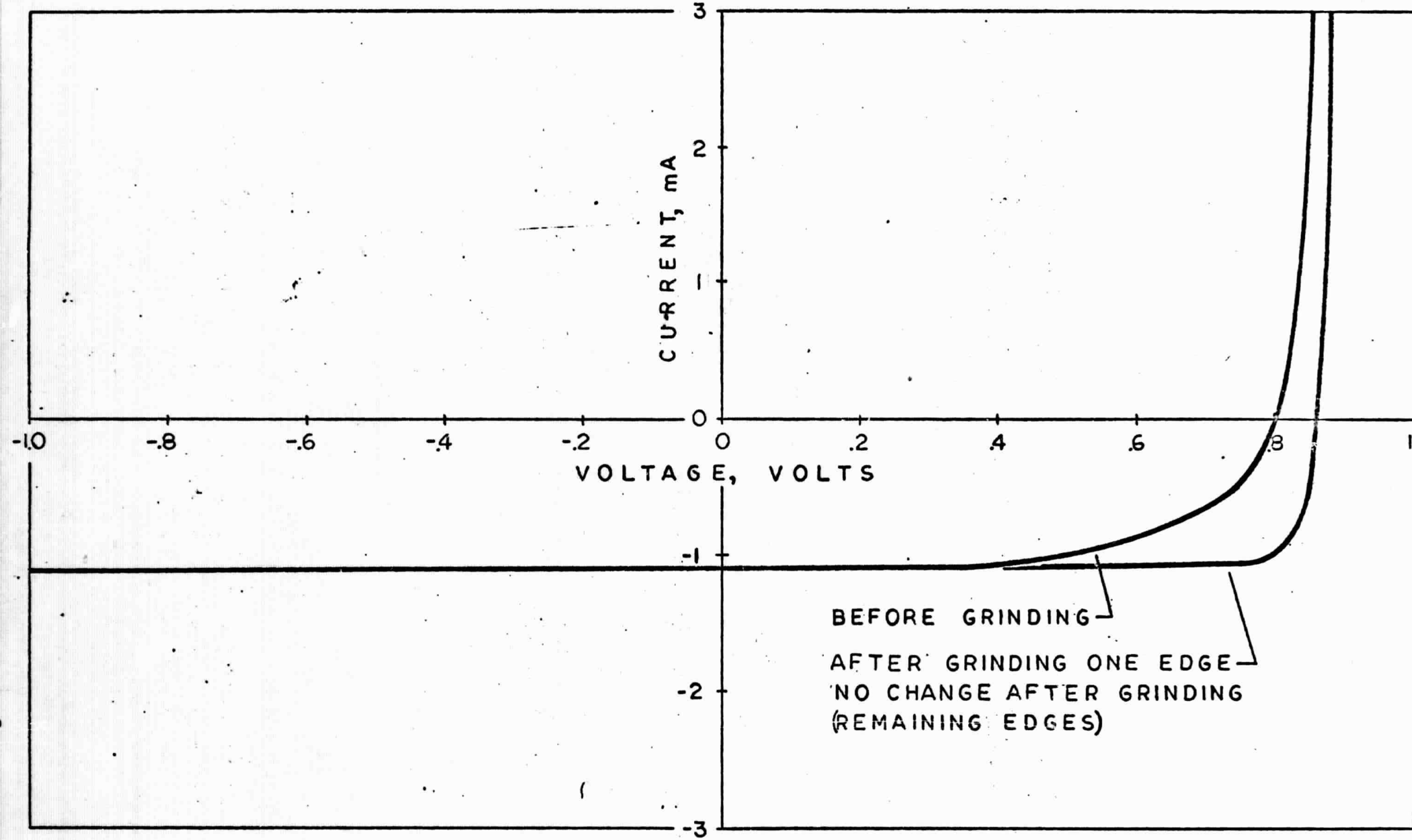

Figure 2. Effect of Grinding Cell Edges on Broken Knee Characteristic.
1 x 2 cm cell measured at -135°C in a tungsten light source
at 3.58 mW/cm^2 intensity.

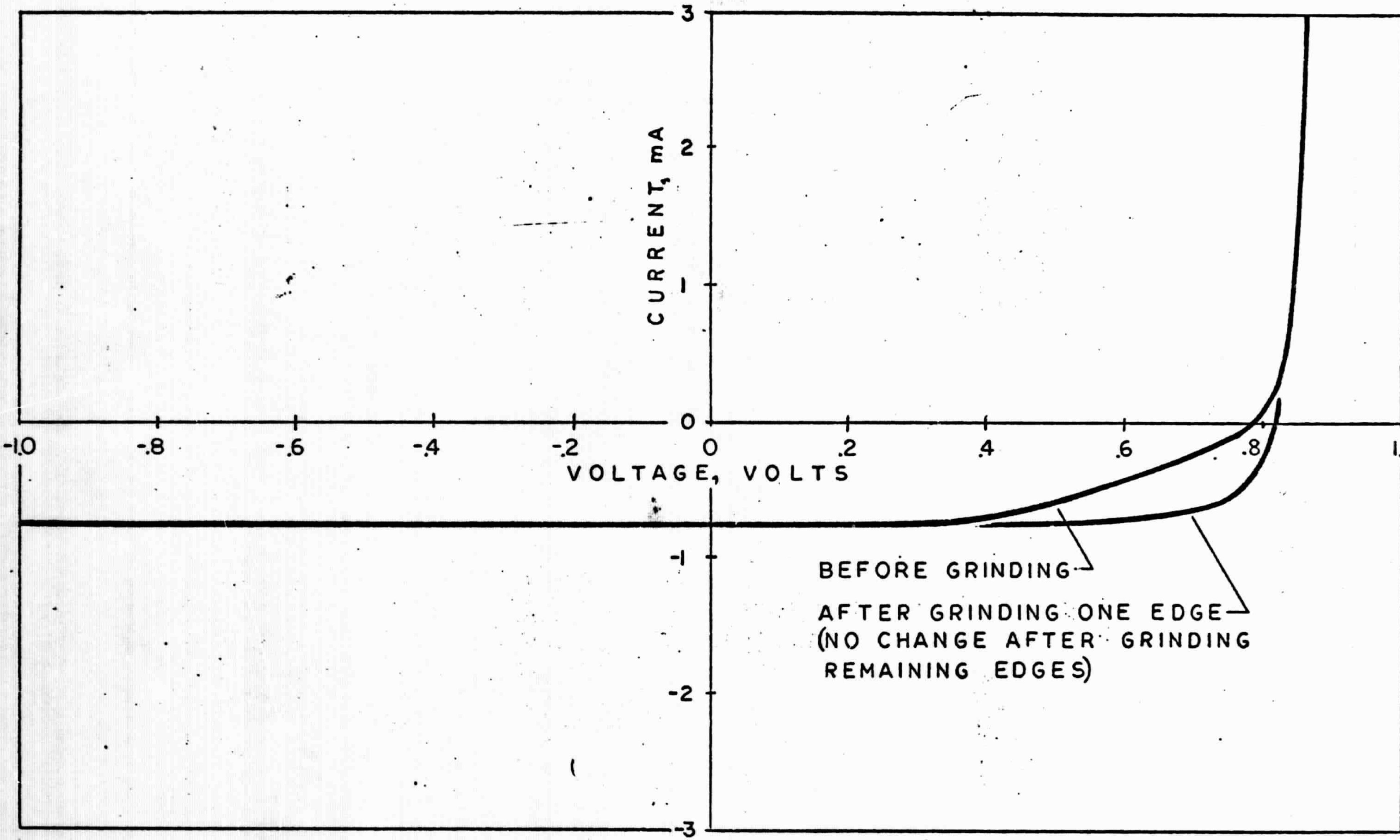

Figure 3. Effect of Grinding Cell Edges on Broken Knee Characteristic.
1 x 2 cm cell measured at -135°C in a tungsten light source
at 3.58 mW/cm^2 intensity.

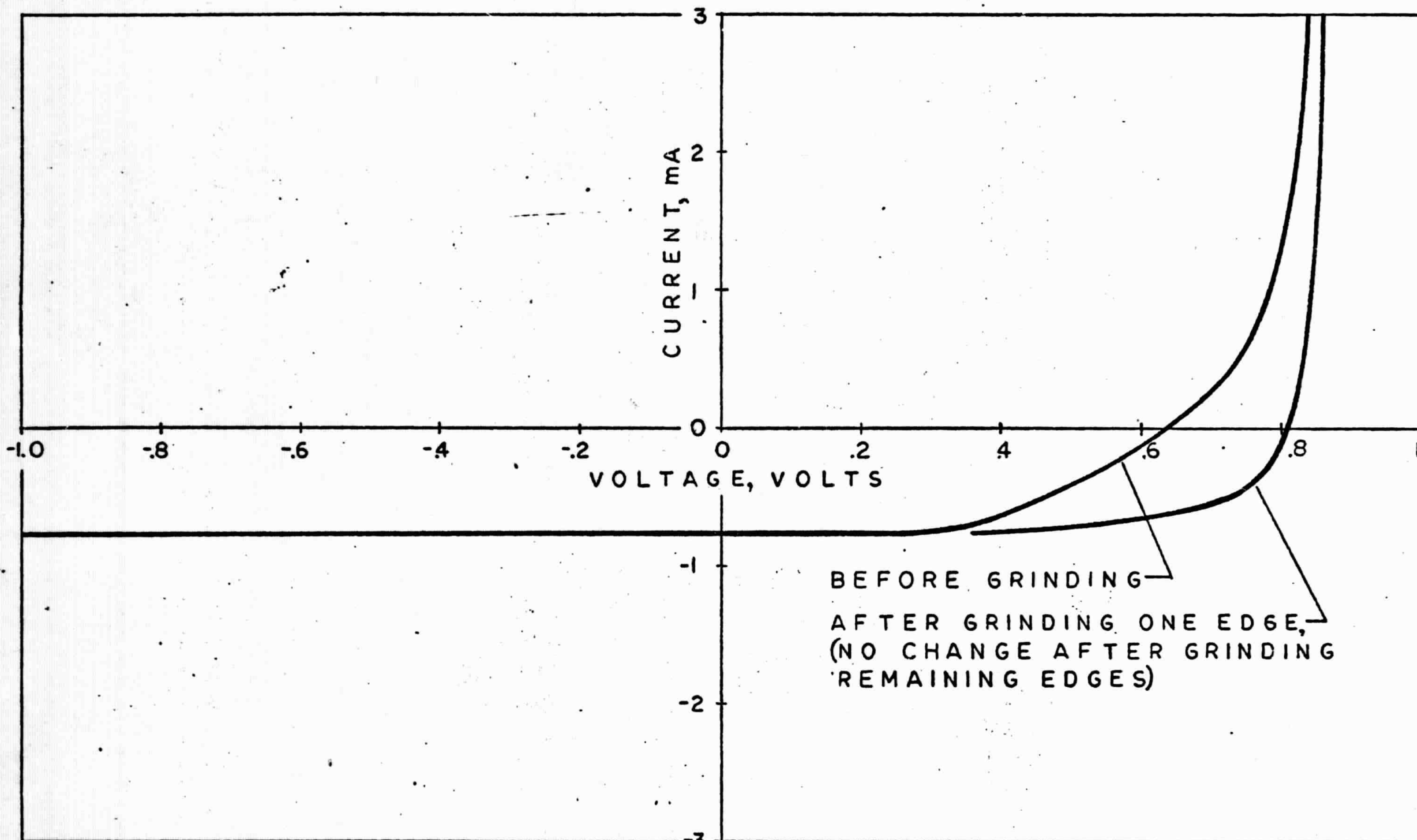

Figure 4. Effect of Grinding Cell Edges on Broken Knee Characteristic.
1 x 2 cm cell measured at -135°C in a tungsten light source
at 3.58 mW/cm^2 intensity.

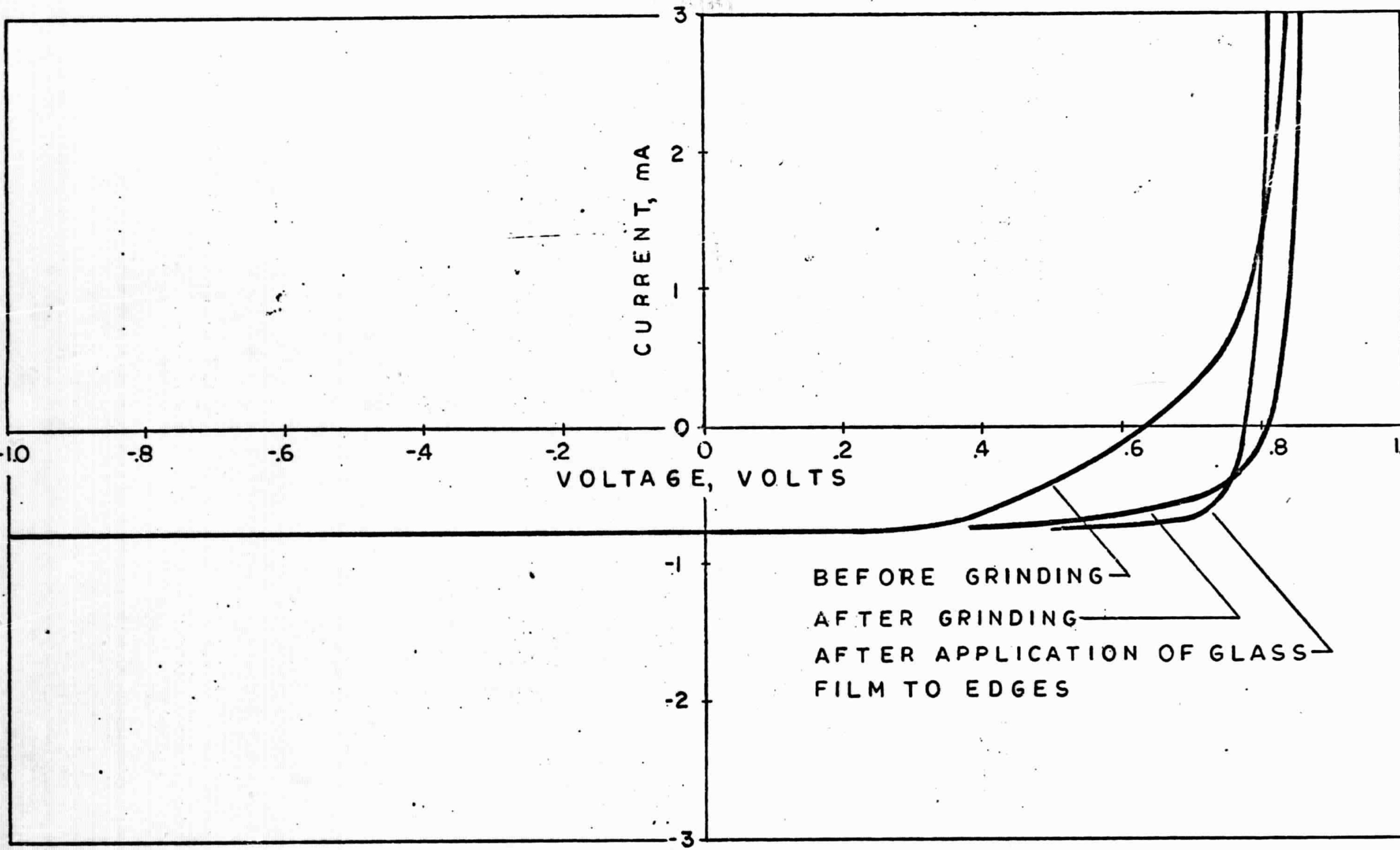

Figure 5. Effect of Applying Glass Film to Cell with Ground Edges.

1 x 2 cm cell measured at -135°C in a tungsten light source at 3.58 mW/cm^2 intensity.

which was reduced by grinding the cell edges was completely eliminated after application of the glass film. Although these results are not consistent, there obviously are surface state changes that are being made with these treatments.

Another process technique that was investigated as an approach for eliminating the effect of cell edge damage on the broken knee, was an etch of a portion of the front surface of the cell. This mesa etch is produced by masking all the cell surface except for a narrow region on the four edges of the surface. This technique moves the junction edge from the cell edge and minimizes the contamination which might otherwise occur at the junction edge. This technique has not been utilized to fabricate P^+ cells without a Schottky barrier, however, a number of conventional cells (without a P^+ region on the cell back surface) were fabricated with this mesa etching technique and measured. Even with the Schottky barrier present these cells did provide useful information on the broken knee probelm since broken knee break-down usually occurs at .3 to .4V and the Schottky barrier only affected the cell I-V characteristic curve beyond .6 to .65V. Measurement of these cells at -135°C in a tungsten light source (intensity of 3.58 mW/cm^2) indicated that mesa etching might be a valuable procedure to incorporate into the fabrication process for a Jupiter type cell. Only four out of sixteen devices measured exhibited a broken knee effect and in each case the effect was not as serious as is frequently seen with cells processed according to standard techniques being used for P^+ cells. These measurements as well as other edge altering techniques indicated that the broken knee effect is definitely associated with the edges of the solar cell. It also was evident that no one specific process is going to completely eliminate the problem. Rather, in addition to any particular process which may be used to reduce the occurrence and degree of the broken knee problem, it will require, very careful processing throughout the entire fabrication procedure.

2.3 TEST PROCEDURE

Since testing at -135°C and 5.0 mW/cm^2 solar intensity of every cell fabricated would be a time consuming procedure, any technique to streamline the procedure is desirable. The following is a discussion of two simple measurements which could be used to separate solar cells into an efficiency range at -135°C and 5 mW/cm^2. Measurement of cells in the dark as well as at 5 mW/cm^2 at -135°C has shown that the dark forward I-V characteristic curve duplicates the shape of the low intensity I-V characteristic curve (see Figure 6). This means that a measurement of the dark forward I-V characteristic at a convenient temperature such as liquid nitrogen temperature could be used to eliminate cells with excessively high current at maximum power voltage (approximately .8V) due to either a high leakage current or a broken knee. A low temperature dark measurement combined with a 28°C, 140 mW/cm^2 solar simulator measurement of the short circuit current would be sufficient to eliminate poor cells and predict that the good cells had efficiencies in a particular range as long as float zone type of silicon was used, since the short circuit current temperature coefficient of float zone cells is predictable within a certain range.

If however, the actual efficiency of cells were required, measurements at -135°C and 5 mW/cm^2 solar intensity would be necessary, but at this point, time would not be wasted in the measurement of poor cells since they would have already been eliminated by the first two measurements.

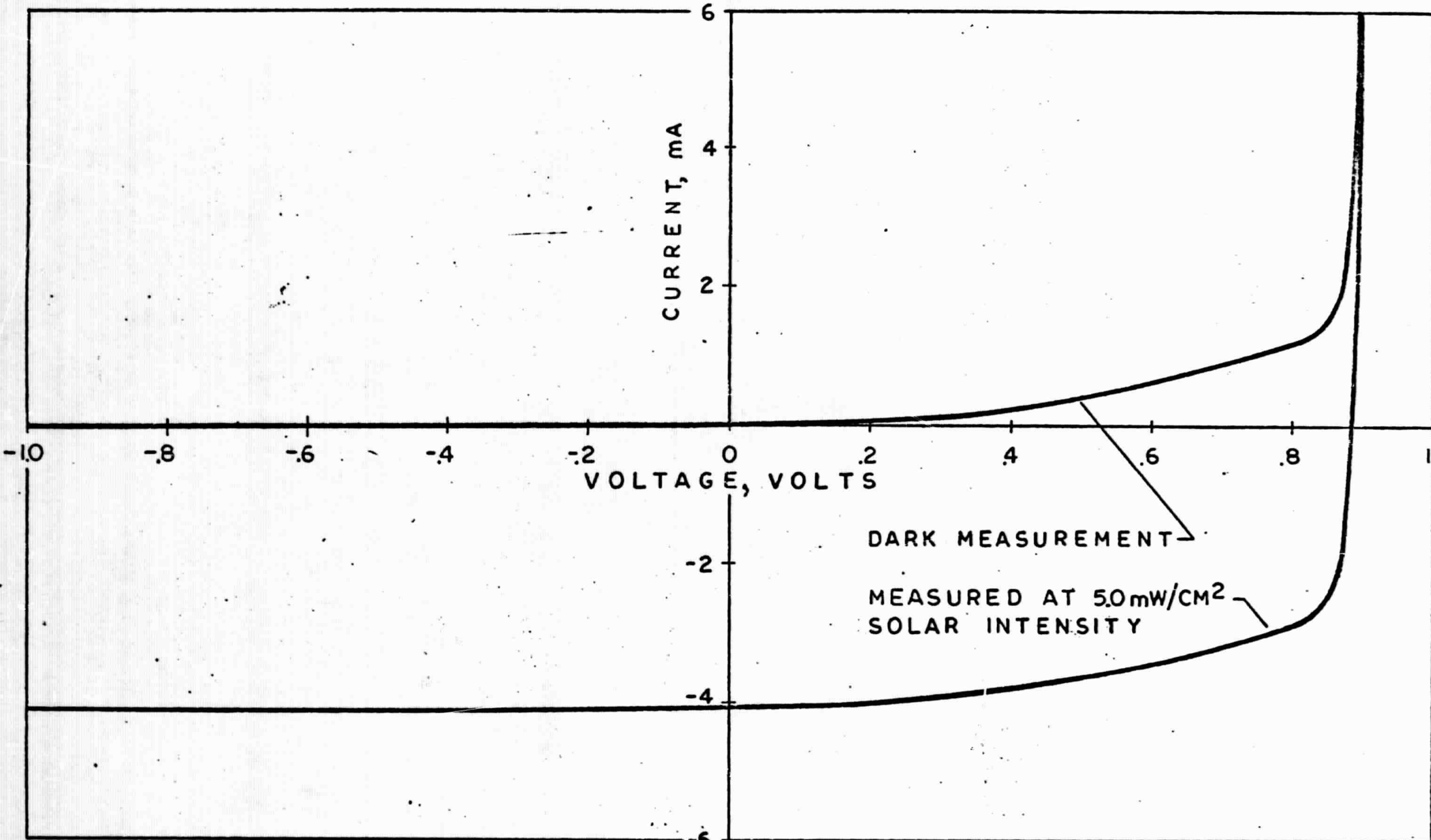

Figure 6. Comparison of Dark and Low Intensity Measurements

3.0 ANALYSIS OF OVERALL CELL DESIGN

This section discusses the cell design selected for operation at 50 mW/cm^2 solar intensity and -135°C. The selection is based upon all the work performed during Phase I (which was discussed in the first analysis report) and the Phase I extension. The topics discussed and the format is based upon items as they were listed in the Nasa/Ames work statement.

Some of the areas of study and analysis were discussed in detail in the first analysis report and, consequently, are only summarized in this analysis section.

3.1 SILICON PROPERTIES

An N/P solar cell fabricated from single crystal silicon with low oxygen concentration and low dislocation density will be used. The base region will be boron doped. The boron concentration will be approximately 10^{15} A/cm^3, i.e., 10 ohm cm resistivity. Selection of this concentration is based upon measurements performed by Heliotek which indicate that although 2 ohm cm cells (approximately 7×10^{15} A/cm^3 background concentration) are 30 to 50 millivolts higher in open circuit voltage at standard temperature and intensity, at Jupiter conditions they offer no advantage in open circuit voltage or efficiency (Figure 7).

3.2 DIFFUSION PROCESS

A standard phosphorus diffusion will be used to produce a P-N junction. Experiments showed that 0.5 and 1.0 micron junction depths gave the best results with respect to short circuit current for Jupiter conditions. Since the leakage current at .7V for the cells with the 1.0 micron junction depth was 20 to 25% lower than for cells with the 0.5 micron junction depth, 1.0 micron was selected as the optimum junction depth.

3.3 CELL THICKNESS

As specified by NASA Ames, the maximum average cell thickness will be 0.010".

3.4 CONTACT MATERIALS AND PROCESS OF CONTACT APPLICATION

Standard titanium-silver contacts will be used. In addition a P$^+$ region will be formed on the back of the cell by the evaporation of aluminum prior

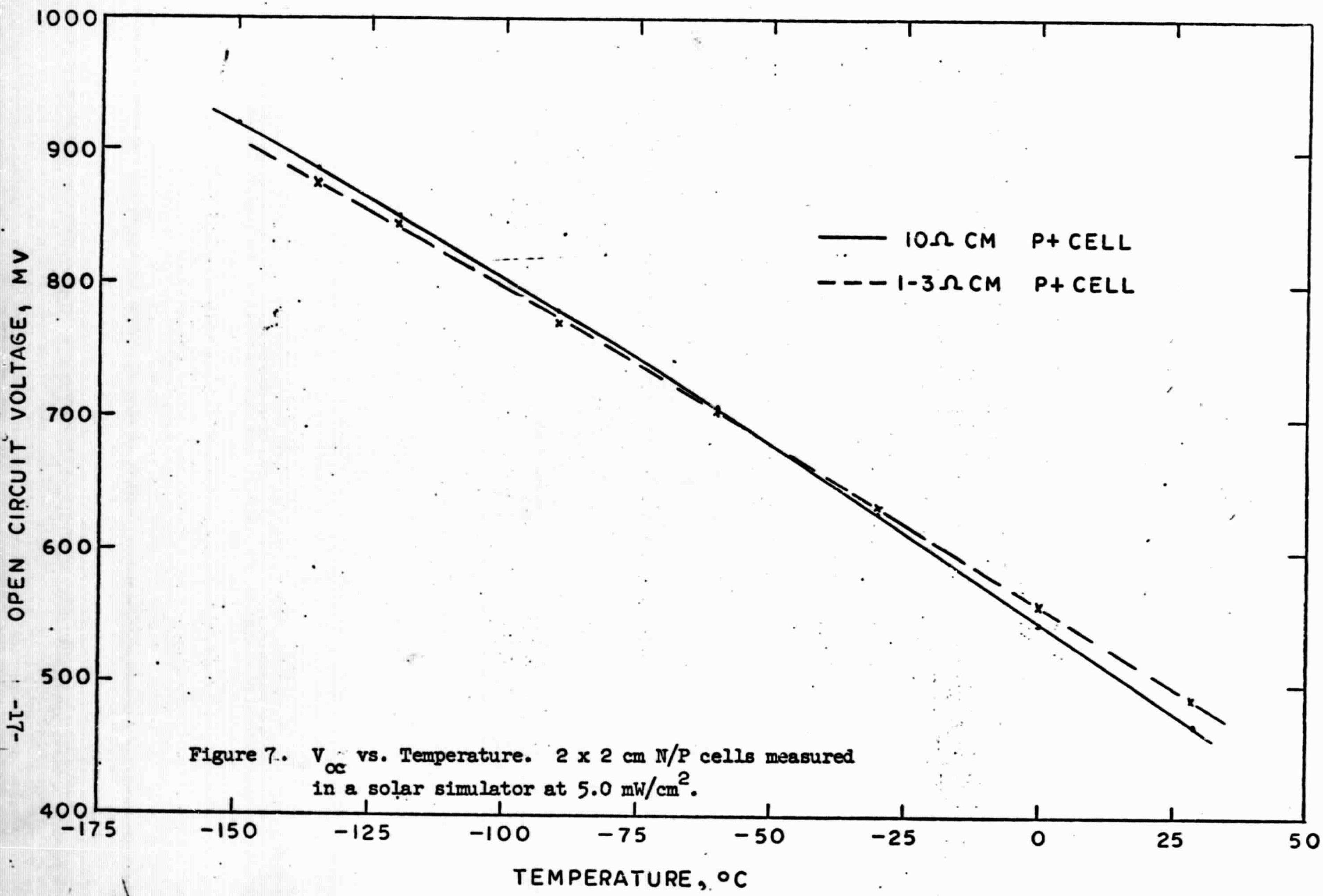

Figure 7. V_{oc} vs. Temperature. 2 x 2 cm N/P cells measured in a solar simulator at 5.0 mW/cm^2.

to evaporation of titanium-silver contacts. This procedure is being used in order to eliminate a Schottky type barrier which is usually present in standard N/P production cells at low temperatures. Use of a P^+ region increases the open circuit voltage at low temperatures (Figure 8) and also improves the curve factor. In selecting the contacting procedures two basic methods were investigated: 1) a two-step evaporation with alloying of the aluminum prior to evaporation of the titanium-silver; and 2) a one-step evaporation where aluminum, titanium and silver are all evaporated and the aluminum is alloyed in the titanium-silver contact sintering operation (performed at 605°C). Comparison of cells from the one-step and two-step evaporations showed that the high efficiency cells in each group had similar outputs, however there were more reject cells from the two-step evaporation due to I-V characteristic curves at low intensity and low temperature as shown in Figure 9 . This type of low temperature and low intensity performance was typical of cells which also exhibited a very significant broken knee at high intensity and -135°C. Since the broken knee effect did seem to be more serious in the cells from the two-step evaporations, the one-step evaporation was selected for application of the aluminum and the titanium-silver contacts.

Pull tests, (i.e. wire soldered to the contact and pulled perpendicular to the cell surface until failure) were performed to determine the mechanical strength of the contacts. Table I shows the data obtained for one-step and two-step evaporated contacts. All the front contacts withstood more than 500 grams. The majority of the back contacts also withstood 500 grams.

On both cells with less than 500 grams pull strength, a second pull test was performed and in all cases this repeat test resulted in strength greater than 500 grams.

3.5 CONTACT PATTERN AND GRID WIDTH

The contact will consist of a bar with six grid lines. Both two and six grid lines have been used and at low intensity two grid lines are sufficient for obtaining an I-V characteristic with a good curve factor.

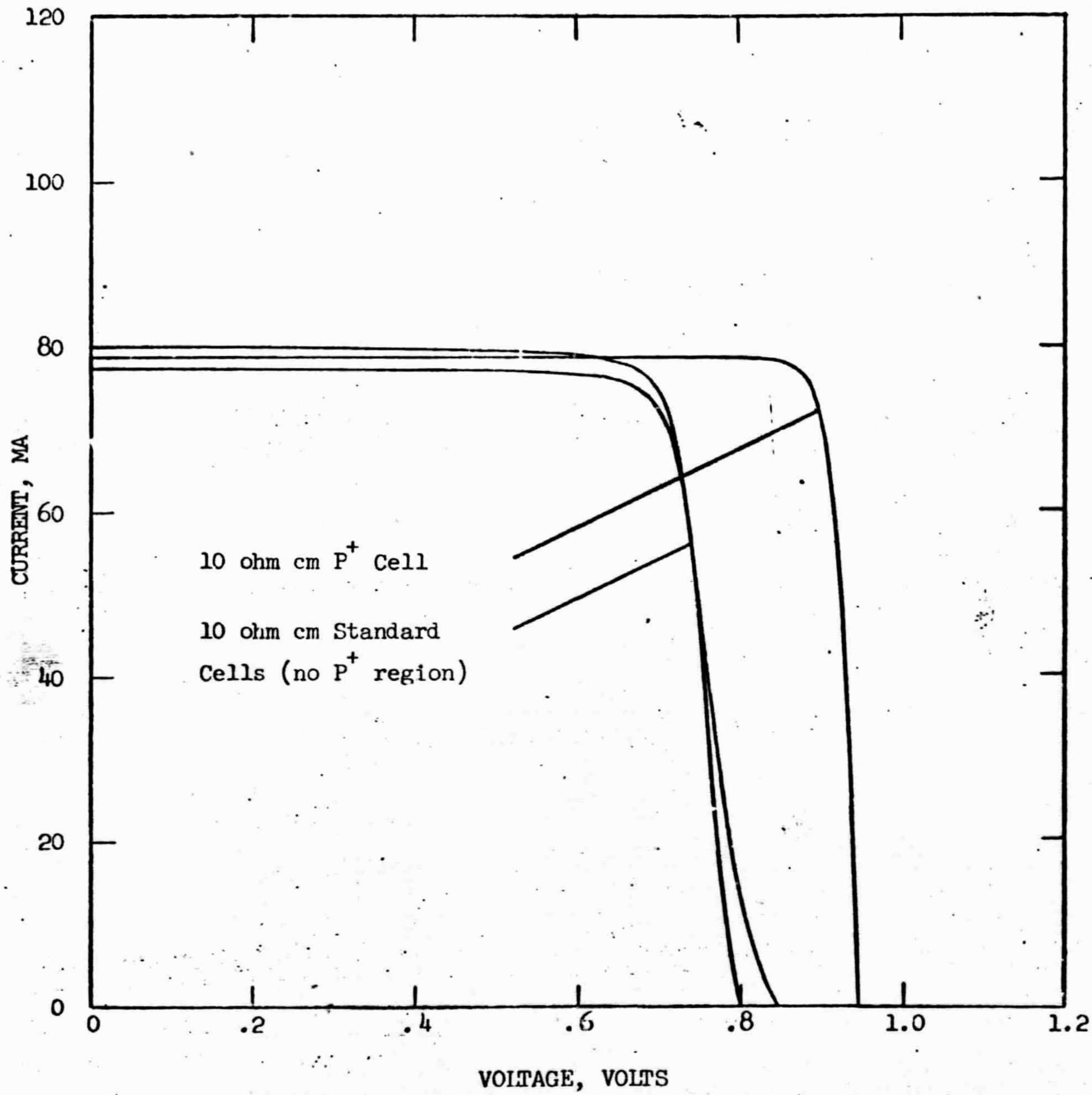

Figure 8. Comparison of 10 ohm cm P^+ Cell to Standard 10 ohm cm Cell. Measured in 100 mW/cm^2 tungsten light at -135°C.

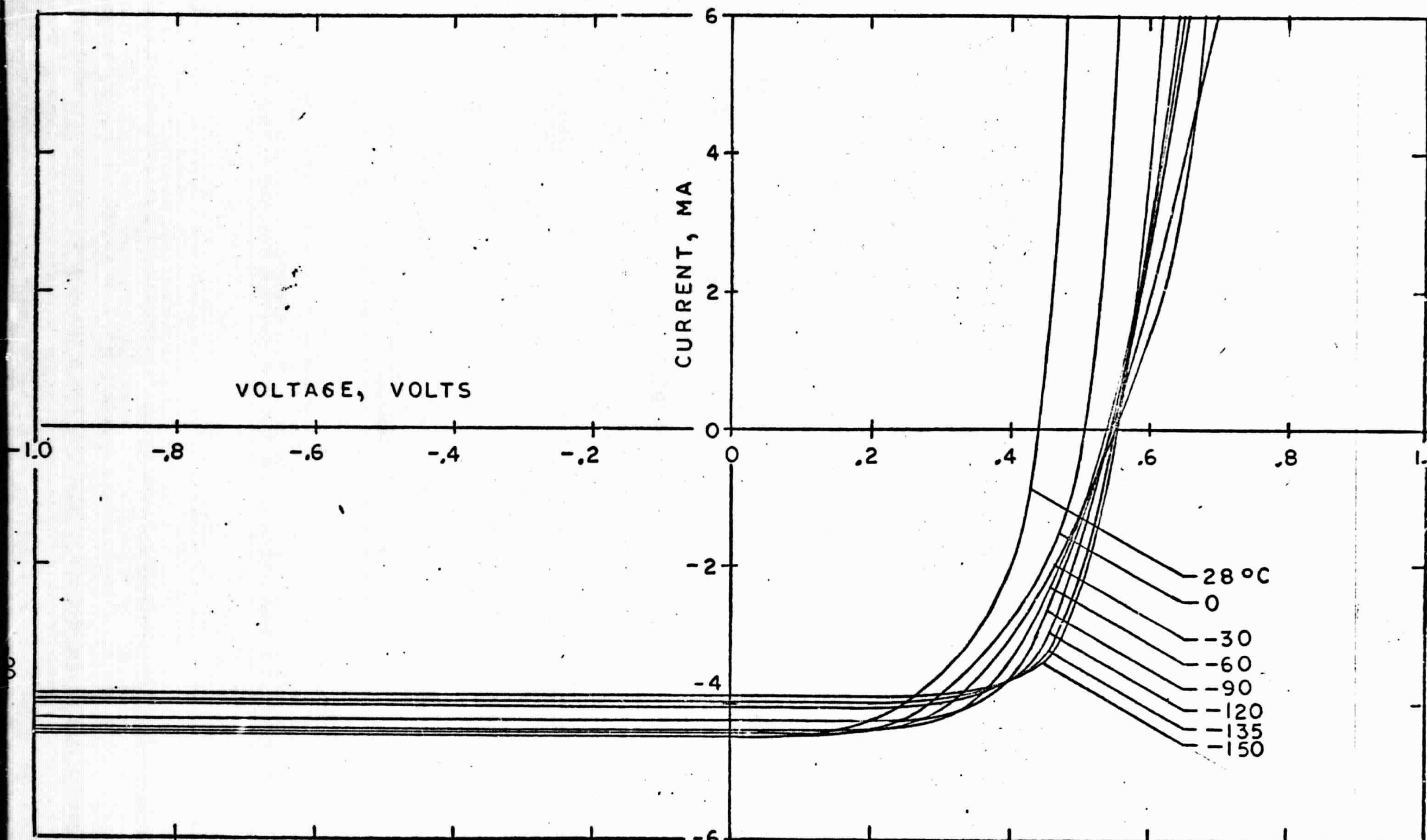

Figure 9. I-V Characteristic Curves at 5.0 mW/cm^2 of P+ Cell with Extreme Broken Knee

TABLE 1

Pull Test - 10 ohm cm N/P Cells with P+ Contact

Two-Step Evaporation

Cell No.	Front Grams Pulled	Back Grams Pulled
24-1	800	1000
24-2	1000	1000
24-3	600	1000
24-4	900	1000
24-5	1000	450 - 700
24-6	1000	500 - 700
24-7	600	1000
24-8	1000	1000
24-9	1000	250 - 700
24-10	1000	1000

One-Step Evaporation

Cell No.	Front Grams Pulled	Back Grams Pulled
26-1	1000	500 - 750
26-2	1000	750
26-3	1000	1000
26-4	1000	550

Approximately 2% is gained in active area by using two grids instead of six grids, however, use of two grids would restrict the use of these cells to a low intensity application. If a six grid contact were applied then cells which at low temperature showed a high leakage current in the forward direction at .8V or a broken knee effect could be used for 1 AU applications.

An isolated contact configuration is being used in order to reduce the possibility of metal extending over the cell edge and shunting the cell.

3.6 CELL ACTIVE SURFACE FINISH AND ANTIREFLECTION COATING

No investigations were done in this area. It is planned that the standard chemical polish etch and silicon monoxide antireflection coating will be used. The only precaution necessary will be to remove enough silicon in the etch so as to remove all surface damage since residual surface damage results in high dark reverse currents and once the cell is made with this defect there is no procedure which can be used to improve the shunt resistance as is the case where metal is evaporated across cell edges and can be etched off afterward. An additional etch will be used on the silicon slabs prior to slicing the silicon into cells, to reduce the amount of mechanical damage which might occur at the cell edges.

3.7 POWER OUTPUT

The solar cell design is to be optimized for power output at Jupiter. The minimum design goal value of average cell efficiency is 12.8% at -135°C as specified by NASA/Ames. The P+ region will be incorporated into the cell design in order to eliminate metal semiconductor Schottky barrier formation as a factor in reduced cell efficiency. An isolated contact configuration will be utilized to minimize leakage current. A 1.0 micron junction depth and a one-step application of aluminum and titanium-silver contacts were found to be superior to a 0.5 micron junction depth and a two-step application of aluminum and titanium-silver. In addition, cells will be fabricated from Mon-X or Lopex type silicon (low oxygen content and low dislocation count) rather than crucible grown silicon since the

Mon-X and Lopex type silicon cells all exhibited a more linear dependence of short circuit [illegible] on temperature. The maximum [illegible] of the short circuit current of float zone or Mon-X cells from the linearly extrapolated value has been [illegible]%, whereas, 7% has been the minimum value observed for crucible grown cells with a maximum being approximately 25% (Figure 10).

The broken knee problem has not been complete solved; however, several procedures have been investigated which minimize the problem. One of these procedures involves etching the silicon slabs prior to slicing into blanks. This reduces the amount of mechanical damage which might be at the cell edges. This process is not difficult and is easily incorporated as a procuedure in the fabrication of these cells. Mesa etching is another procedure which might be considered for use in fabricating [illegible] cells for low light levels and low temperature applications. Mesa etching is used to obtain cells with extremely low dark reverse currents and cells which have been fabricated using this procedure have been measured and have shown a lower incidence of the broken knee effect. Incorporation of this process into the cell fabrication would be more involved and should probably only be considered if further work showed the process to be highly successful in eliminating the broken knee effect.

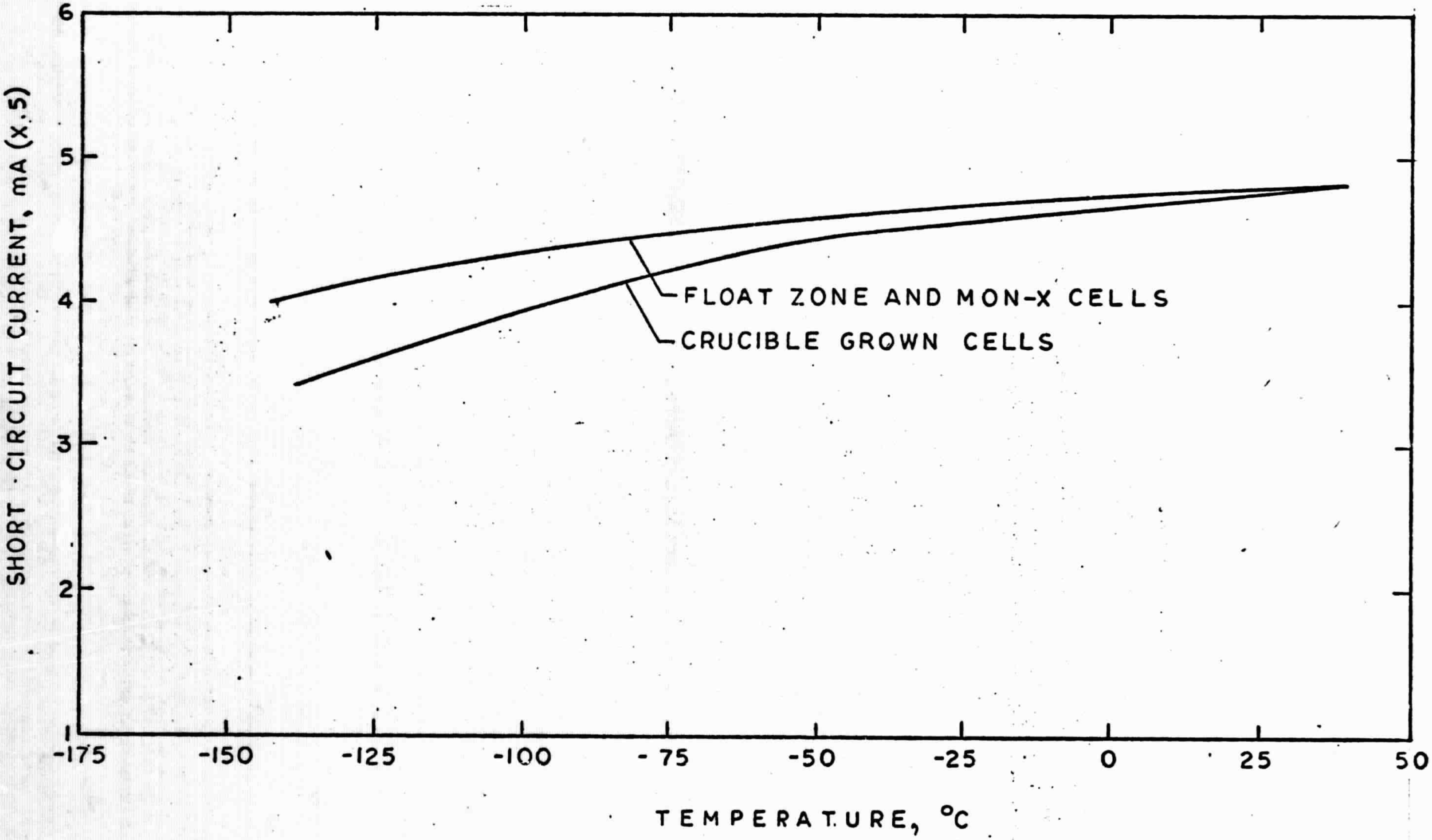

Figure 10. I_{sc} Vs. Temperature for Mon-X, Float Zone, and Crucible Grown 10 ohm cm N/P P+ Cells. Cells measured in solar simulator at 5.0 mW/cm^2.

3.8 VOLTAGE-CURRENT CURVE

At -135°C and 5.0 mW/cm^2 the cells with good power outputs have correspondingly good fill factors - .74 - .89. Those with broken knees and low efficiencies have lower fill factors.

3.9 ENVIRONMENTAL EFFECTS

In an accelerated humidity test (65°C, 95% relative humidity) P+ cells with approximately 0.5 mils of solder withstand 60 hours exposure with no degradation. Heliotek's experience with standard N/P cells has shown that if cells can withstand 3 days at 65°C, 95% relative humidity, they will also be able to withstand 30 days at 45°C and 90% relative humidity. Using this as a basis, (since the 30 day test was not performed) the Jupiter cells are not expected to degrade after 30 days at 45°C, 90% relative humidity.

3.10 MAGNETIC CHARACTERISTICS

Aluminum, the only new material used, has no magnetic properties, therefore, the P+ cell for Jupiter, like standard solar cells, should have no magnetic properties.

3.11 WEIGHT

The average cell weight will be .300 grams which corresponds to an average thickness of .010". With this thickness average cell efficiencies of 13% can be obtained.

3.12 SIZE

Larger area cells would reduce cost, testing, and handling, however, they have not been investigated during this program since this is a minor change in cell design and only the more significant variables were able to be investigated. Therefore 2 x 2 cm cells will be used.

3.13 COVER GLASS

As specified by NASA/Ames 0.006" fused silica coverglasses will be used for the Jupiter cell design.

3.14 INTERCONNECT FEASIBILITY

Cells will have the contacts covered with a thin layer (about 0.5 mil) of solder to provide humidity resistance. Standard techniques can be used for interconnections and as demonstrated by the pull test data presented in Section 2.4, the contacts will endure state-of-the-art pull-strength tests.

3.15 RELIABILITY PREDICTION ESTIMATE

The limited environmentals tests, contact pull tests and measurements performed indicate that the cell design selected meet the requirements specified for standard production space qualified N/P cells. Therefore, the reliability of this Jupiter cell design should in all respects be comparable to current production cells.

4.0 SUMMARY OF DESIGN SELECTED

The solar cell design selected from this study to be fabricated for a Jupiter mission will have the following characteristics and will utilize the fabrication procedures described. A Lopex or Mon-X type silicon, 10 ohm cm N/P cell with a boron doped base region and a phosphorous diffused 1 micron deep junction will be used. In addition to the conventional prediffusion etch which removes approximately 5 mils from the cell edges, an additional etch will be used prior to cell slicing when the silicon is in slab form to remove an additional 5 to 10 mils from each surface.

An aluminum and titanium-silver contact will be applied in a one-step evaporation to form a P+ contact on the back of the cells. A six grid configuration with an isolated contact has been selected for the front contact. The contacts will be sintered and solder covered (approximately 0.5 mils thick) using standard production procedures. Since processing procedures are available to minimize the broken knee problem, and all other problems affecting cell efficiency at low intensity and low temperature have been solved, the efficiency of these cells is expected to range from 13 to 16.5%.