Development of Lithium Diffused
Radiation Resistant Solar Cells

Third Quarterly Report

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SUMMARY

As a result of the boron diffusion studies conducted during the first six months of this contract, two diffusion processes were selected for evaluation and comparison of the output, yield, and degree of stress produced during diffusion. These two processes were: 1) BCl_3 (no O_2) with a two minute boron deposition time, and 2) BCl_3 with O_2. Both diffusion processes meet the low stress requirement since neither cause bowed cells. The AMO output of the cells diffused in BCl_3 with O_2 were 25 to 28 mW, while the output of cells diffused with no O_2 using a short boron deposition time was 28 to 33 mW. The difference in output was primarily due to the cells diffused with O_2 having lower open circuit voltages (590 mV average rather than 615 mV) and higher series resistance (.5 to 1.0 ohms rather than .2 to .5 ohms). Silicon cut from the same ingot was used in the two different diffusions and, therefore, differences in output are free of any variations in material parameters. The reason for low open circuit voltages is uncertain; however, the high series resistance is partly due to the high sheet resistances (50 to 80 ohms/square compared to 15 to 22 ohms/square obtained in a BCl_3 diffusion with no O_2).

Investigating the influence of boron diffusion parameters upon lithium cell output showed that a two minute rather than eight minute boron deposition time increased lithium cell output as much as 4 mW. The AMO output of lithium cells subjected to the same lithium diffusion parameters was 24 to 27 mW when an eight minute boron deposition time was used and 28 to 32 mW when a two minute boron deposition time was used.

Investigations of the effect of sintering cells from the above experiments were also made. The AMO output of lithium cells sintered in a hydrogen atmosphere increased 1 to 4 mW as a result of increases in both short circuit current and open circuit voltage.

Lithium cells made from Lopex silicon were fabricated for Lot 11. The cells were subjected to a two minute boron deposition and sintering was included as a process step. The resulting AMO outputs ranged from 29 to 34 mW, which is equivalent to an efficiency range of 10.9 to 12.8%.

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1.0 INTRODUCTION

The goal of this contract is to investigate the effect of various process parameters on lithium doped solar cell performance. This program is a continuation of work done on JPL Contract 952547-Part I, and has been organized into five areas of study. The five basic areas include: P-N diffusion studies, material studies, lithium diffusion studies, special structure studies and contact studies.

The purpose of the P-N diffusion studies is to develop a boron diffusion which: 1) does not etch silicon, 2) will yield higher efficiency lithium cells due to reduced stresses and 3) can be used for larger area and thinner cells (also due to reduced stresses).

As part of the material studies, parameters such as oxygen content of crucible grown silicon will be investigated.

Lithium diffusion investigation will be performed in the following areas:

1) Diffusion profiles as a function of cell thickness for various diffusion times and temperatures will be analyzed.

2) Additional cells with lithium diffusions of eight hours at 325°C will be fabricated and studied to verify that the extremely high initial and recovered outputs can be made reproducibly with high yields.

3) The diffusion time at 325°C will be varied since eight hours does not seem to be optimum for float zone silicon.

4) Lithium evaporations will be investigated further in order to optimize the procedure and determine on a statistical basis cell output as a function of lithium application.

In the contact studies the performance of TiAg contacts on lithium cells in typical specification acceptance and qualification tests will be evaluated. The tests will include humidity testing of soldered cells, pull test before and after humidity tests, temperature cycling, and evaluation of the effects of solder and interconnecting on cell performance.

In addition to the experimental studies, 600 lithium doped solar cells will be fabricated for radiation testing and analysis by JPL.

During this quarter two hundred cells were fabricated using two different boron diffusion processes in order to determine which provided the best combination of low stress and high efficiency. The two diffusions used were: 1) $BC\ell_3$ (no O_2) with a two minute boron deposition time, and 2) $BC\ell_3$ with O_2 present in the carrier gas. The electrical characteristics, including power output, open circuit voltage, and series resistance were compared.

The effect of the short deposition time $BC\ell_3$ diffusion (no O_2) process on the output of lithium cells was also investigated. Good improvements in efficiency were achieved as a result of these studies. The improvements in AMO output observed for lithium doped cells (which increased from a range of 24 to 27 mW to a range of 28 to 32 mW) was far in excess of any improvements made on either 1 or 20 ohm cm P/N cells with no lithium.

2.0 TECHNICAL DISCUSSION

2.1 BORON DIFFUSION EVALUATION

The objective of the boron diffusion investigation during this contract has been to develop a boron diffusion process which could be used to diffuse large quantities ($\geq$ 100 blanks per diffusion) of stress-free high efficiency cells. As described in the Second Quarterly Report (January 1971) two processes have been investigated which produce low stress P/N cells: 1) a modification of the standard $BC\ell_3$ diffusion, involving reduction of the boron deposition time and 2) use of $BC\ell_3$ with O_2. During this quarter approximately 200 cells were diffused using the two processes in order to obtain a statistical comparison of output.

The cells used for this comparison were 0.012 to 0.015" thick with a resistivity of 0.2 to 1.2 ohm cm. Etched rather than lapped blanks were used since, unlike the standard $BC\ell_3$ diffusion, neither of these diffusion processes etch enough silicon to remove the surface damage present on a lapped blank. As shown in Figure 1, the AMO output of cells diffused in $BC\ell_3$ (no O_2) with a short deposition time, averages 3 to 4 mW higher than the output of the cells diffused in $BC\ell_3$ with O_2. This lower output of the cells diffused with O_2 present was primarily due to lower open circuit voltage and higher series resistance. The average open circuit voltage of the cells diffused with O_2 was 590 mV while the open circuit voltage of cells diffused without O_2 was 615 mV. The series resistance was measured on cells from each group. The series resistance of the cells diffused with O_2 was typically around .8 ohms while for the cells diffused with no O_2 the series resistance was around .3 ohms. Table I summarizes the electrical data on these two groups of cells.

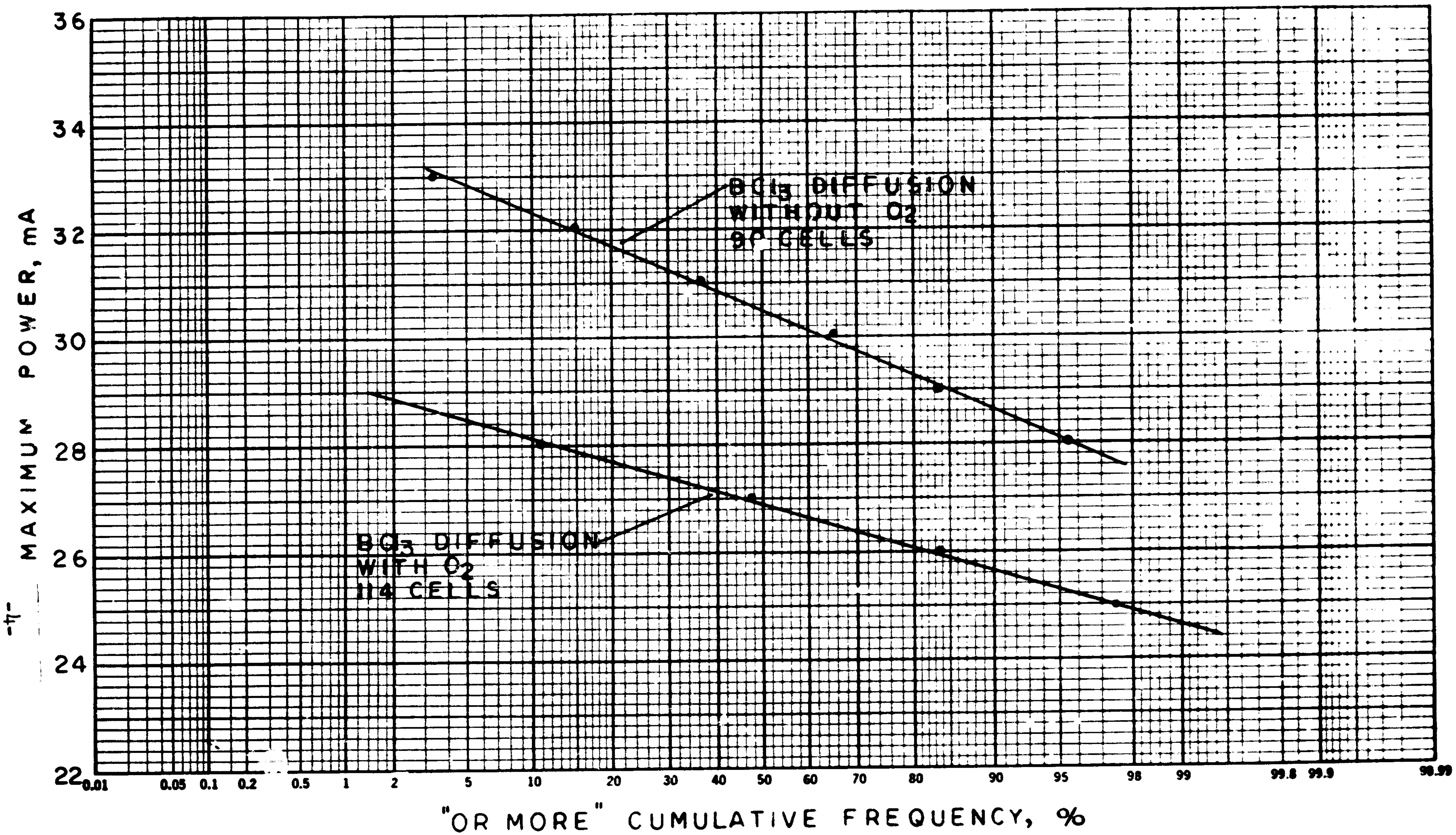

Figure 1. Maximum Power Distributions for 1 ohm cm P/N Cells Diffused with Two Different Boron Diffusion Techniques. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

TABLE I

Electrical Characteristics of 1 ohm cm P/N Cells

Description		BCl_3 (no O_2) 2 min. deposition	BCl_3 with O_2
AMO Output, mW	Range	28-33	25-28
	Median	30.5	26.9
V_{oc}, mV	Range	600-625	570-600
	Median	615	590
Series Resist.	Range	.2 - .5	.4 - 1.0
ohms	Median	.3	.8

At the present time, although neither of the two diffusions discussed can be used for diffusion of one hundred cells or more per diffusion, the BCl_3 diffusion with a short deposition time and without O_2 produces the best combination of low stress and high efficiency.

2.2 Effect of Boron Diffusion on Short Circuit Current

The BCl_3 (without O_2) diffusion with a 2 minute boron deposition time has also been used to diffuse 20 ohm cm Lopex and crucible grown cells. Results of these diffusions have indicated that diffusion studies should be performed to optimize diffusion parameters for 20 ohm cm material. The ratio of the short circuit current measured in a solar simulator (140 mW/cm^2) vs. a tungsten light source (100 mW/cm^2) was between 1.10 and 1.15 for the 1 ohm cm cells, while 20 ohm cm cells (including the lithium diffused cells) had simulator-tungsten ratios between 1.05 and 1.10. These ratios are lower than the 1.18 ratio typical of P/N cells and are due to tungsten short circuit currents which increased 15 to 30% while simulator short circuit currents increased only 10%. For example, a cell diffused with an eight minute boron deposition time having a tungsten short circuit current of 55 mA would typically have a simulator short circuit current of 65 mA, while a cell diffused with a two minute boron deposition time would have a short circuit current of 64 mA in tungsten and 70 mA in the simulator. Both the simulator and tungsten short circuit currents of the cell diffused with a two minute boron deposition time are higher, but the ratio is lower. A low simulator-tungsten ratio can be caused by a deep junction or an improperly matched antireflection coating. In this case the low ratio was probably due to a deep junction. This was verified by an experiment in which reduction of the diffusion time from 10 to 5 minutes resulted in simulator tungsten ratios of 1.13 to 1.15 for both the control cells (no lithium) and the lithium diffused cells. Additional work will be done to determine whether the diffusion time has been optimized to obtain the best simulator output for higher resistivity cells.

2.3 Boron Diffusion Effects on Lithium Cell Output

Investigation of the influence of a short boron deposition on the output of lithium doped cells showed that short circuit currents and outputs measured in a solar simulator (140 mW/cm^2 intensity) were improved approximately 10% and 15% respectively, when a boron deposition time of two rather than eight minutes was used.

Both crucible grown and Lopex silicon have been boron diffused with two and eight minute boron deposition times. Lithium cells fabricated from both materials have exhibited higher short circuit currents when the short boron deposition time is used. The short circuit current measured in a tungsten light source (100 mW/cm^2) exhibits a particularly large increase, from an average of 53 mA (obtained with the eight minute deposition time) to an average of 64 mA. Figures 2 and 3 show distributions of the short circuit current (measured in both solar simulator and tungsten light sources) of forty lithium cells fabricated from Lopex silicon. Twenty cells were boron diffused with an eight minute boron deposition and twenty with a two minute deposition. These distributions show that the two minute deposition results not only in higher short circuit current, but also more uniform short circuit currents. In fabricating Lopex lithium cells using five sets of lithium diffusion parameters (3 hours at 340°C, 7 hours at 340°C,

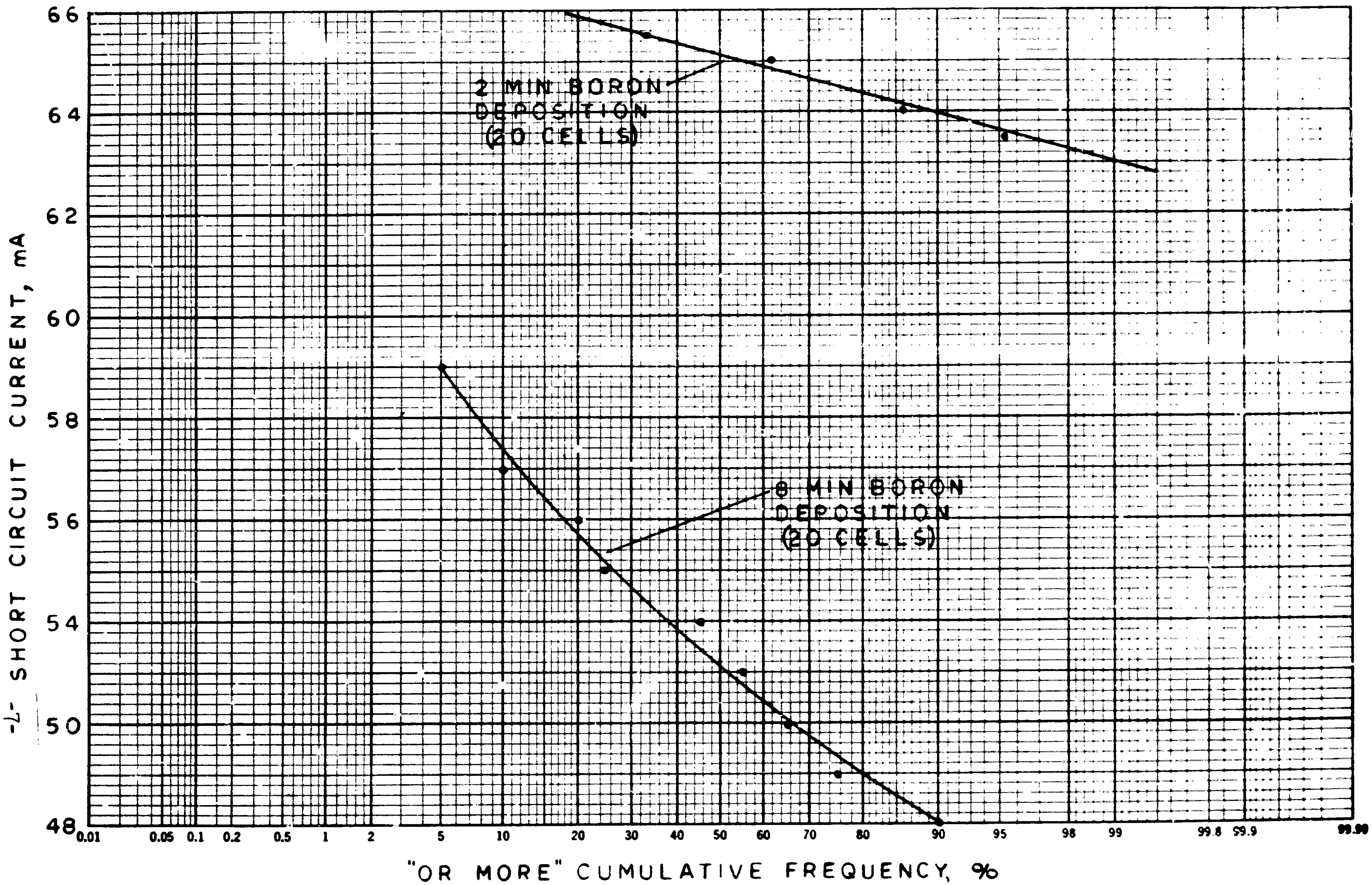

Figure 2. Comparison of Short Circuit Current of Lithium Cells as a Function of Boron Deposition Time. Measured at 25°C in a Tungsten Light Source (100 mW/cm^2 Intensity).

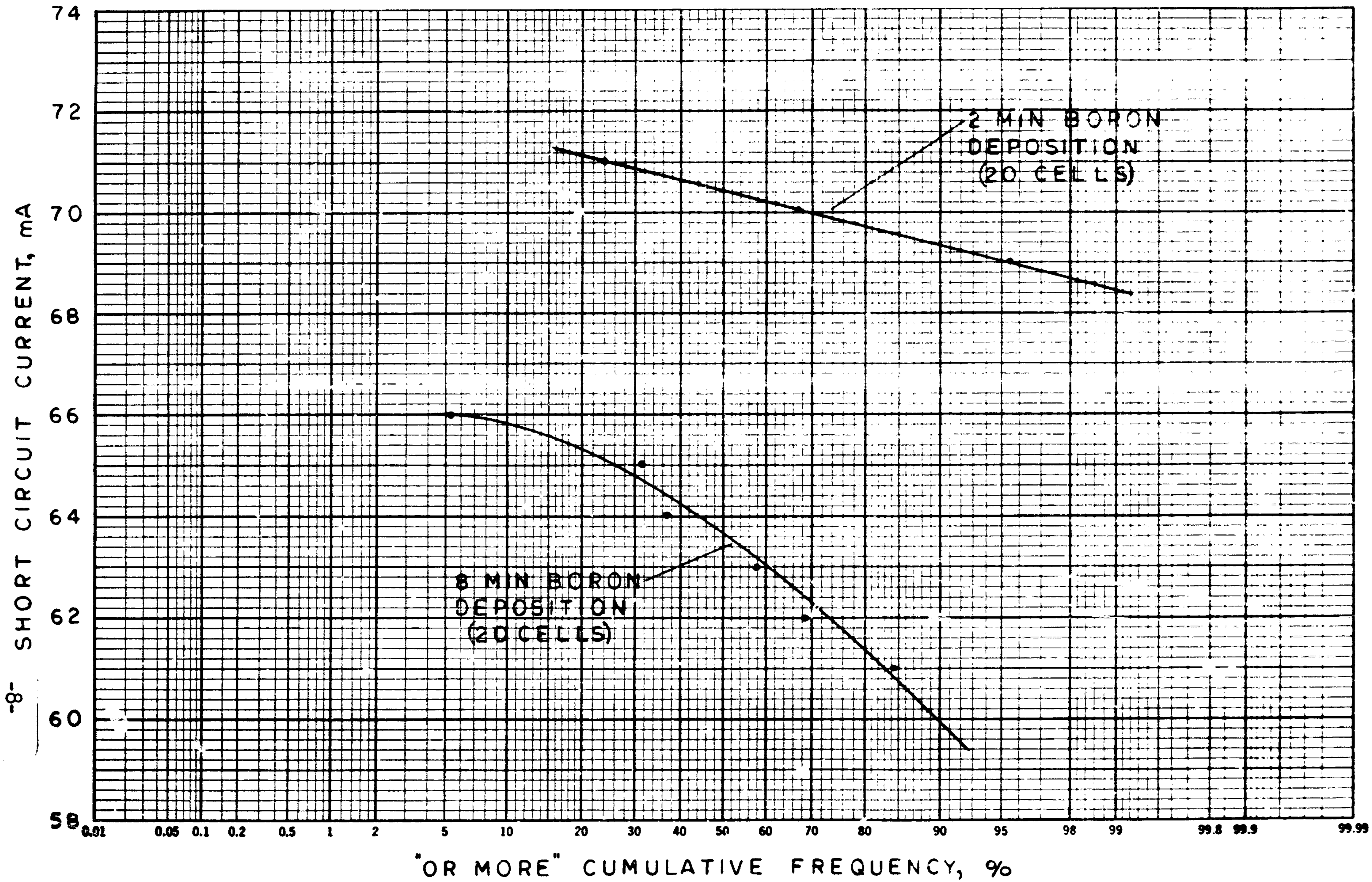

Figure 3. Comparison of Short Circuit Current of Lithium Cells as a Function of Boron Deposition Time. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

5 hours at 350°C, 3 hours at 360°C, and 7 hours at 360°C) the short circuit current typically ranged from 67 to 73 mA (Figure 4). This 6 mA spread in short circuit current is a considerable improvement over previous lithium cell lots delivered during Part 1 of this contract. Previous lots have exhibited short circuit ranges as high as 16 mA.

In addition to the higher short circuit currents obtained for lithium cells subjected to a 2 minute boron deposition, open circuit voltages as high as 615 mV were obtained; the highest open circuit voltage observed for cells diffused with an 8 minute boron deposition was 595 mV. The higher short circuit currents and open circuit voltages led to Lopex lithium cell AMO outputs ranging from 28.0 to 32.0 mW, rather than 24.0 to 28.0 mW as was obtained when an 8 minute boron deposition time was used.

Sintering was investigated to determine its effect upon the curve factor which for some cells was below 0.70. In most cases sintering improved the curve factor slightly; in addition, the short circuit current (measured at 140 mW/cm^2 in the solar simulator) of lithium cells subjected to a two minute boron deposition increased 3 to 5 mA. Typically improvements of 10 to 25 mV in open circuit voltage were also observed. These improvements in curve factor, open circuit voltage and short circuit current resulted in AMO outputs 1 to 4 mW higher than the unsintered cell output. Figure 5 shows I-V curves of a typical cell before and after sintering. Figure 6 shows the output distributions for 102 Lopex lithium cells before and after sintering. The cells after sintering averaged 2.5 mW higher output, which is equivalent to an improvement of one efficiency group.

Lithium cells which had been subjected to an 8 minute boron deposition were also sintered. Although the short circuit current of many of these cells increased as much as 7 mA with sintering, the outputs were still lower than lithium cells which had been diffused with a short boron deposition, since the outputs were so much lower prior to sintering.

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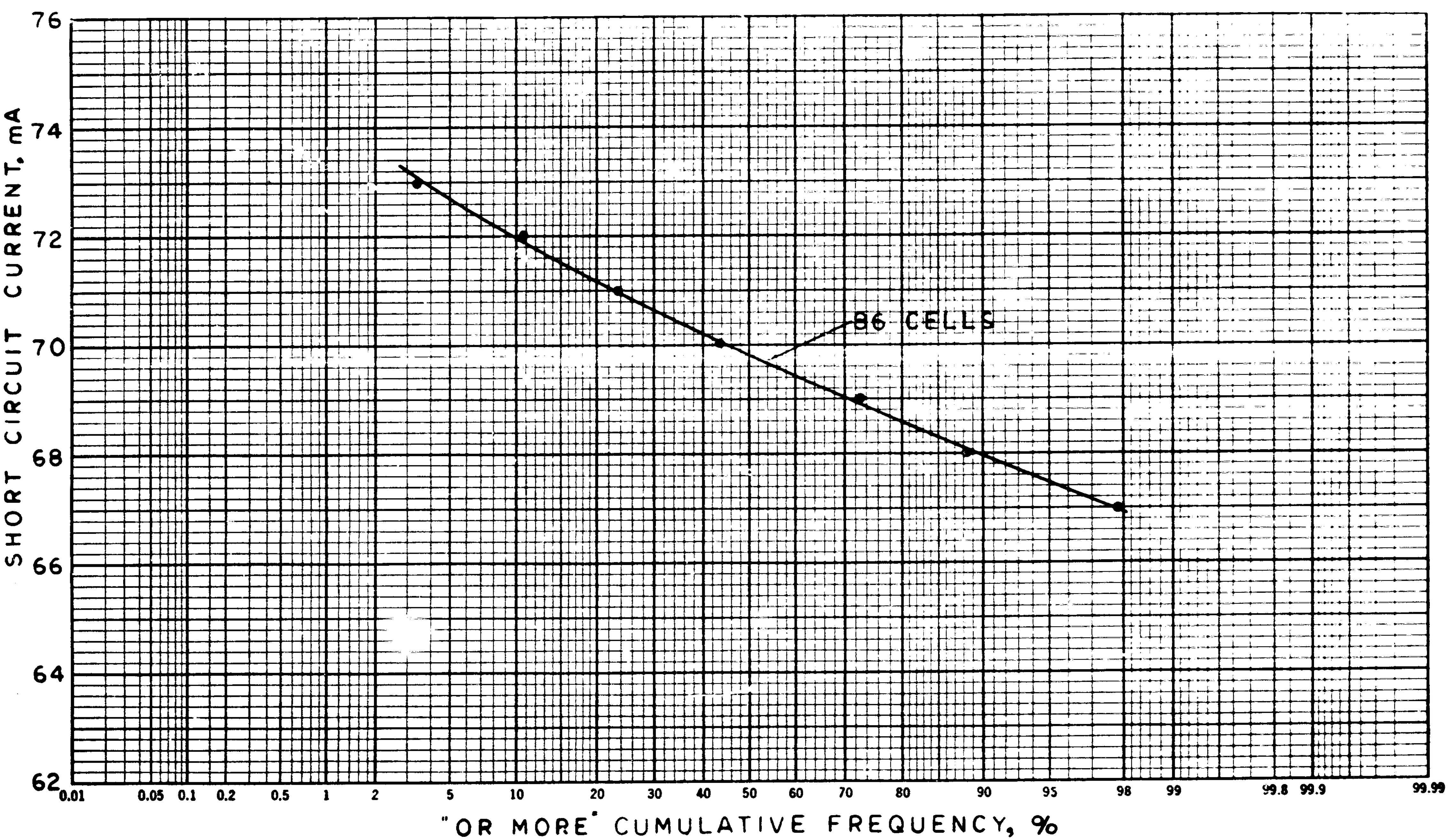

Figure 4. Short Circuit Current Distribution of Lithium Cells Diffused with a Two Minute Boron Deposition Time. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

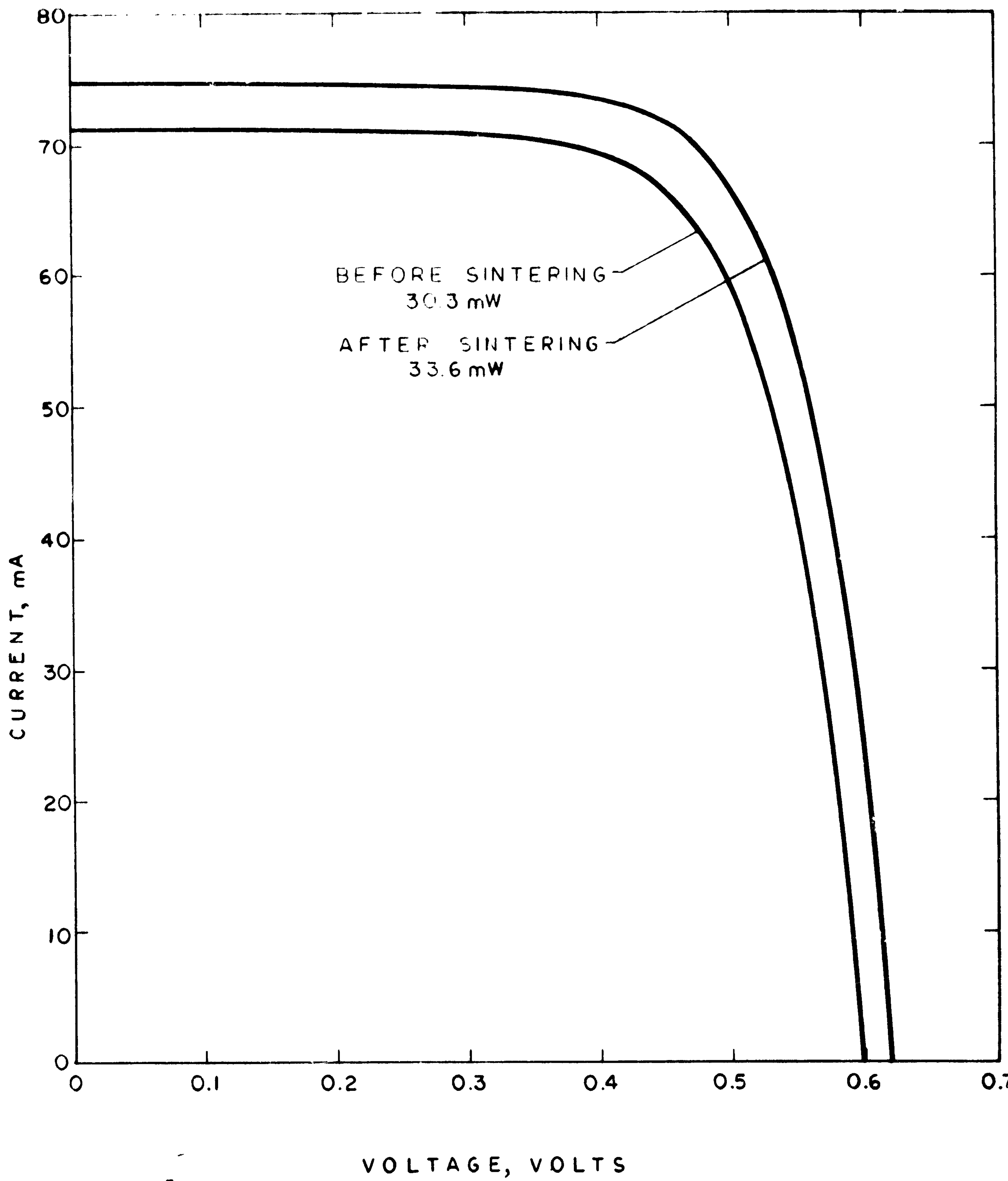

Figure 5. I-V Characteristics Curves of a Typical Lithium Cell Before and After Sintering. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

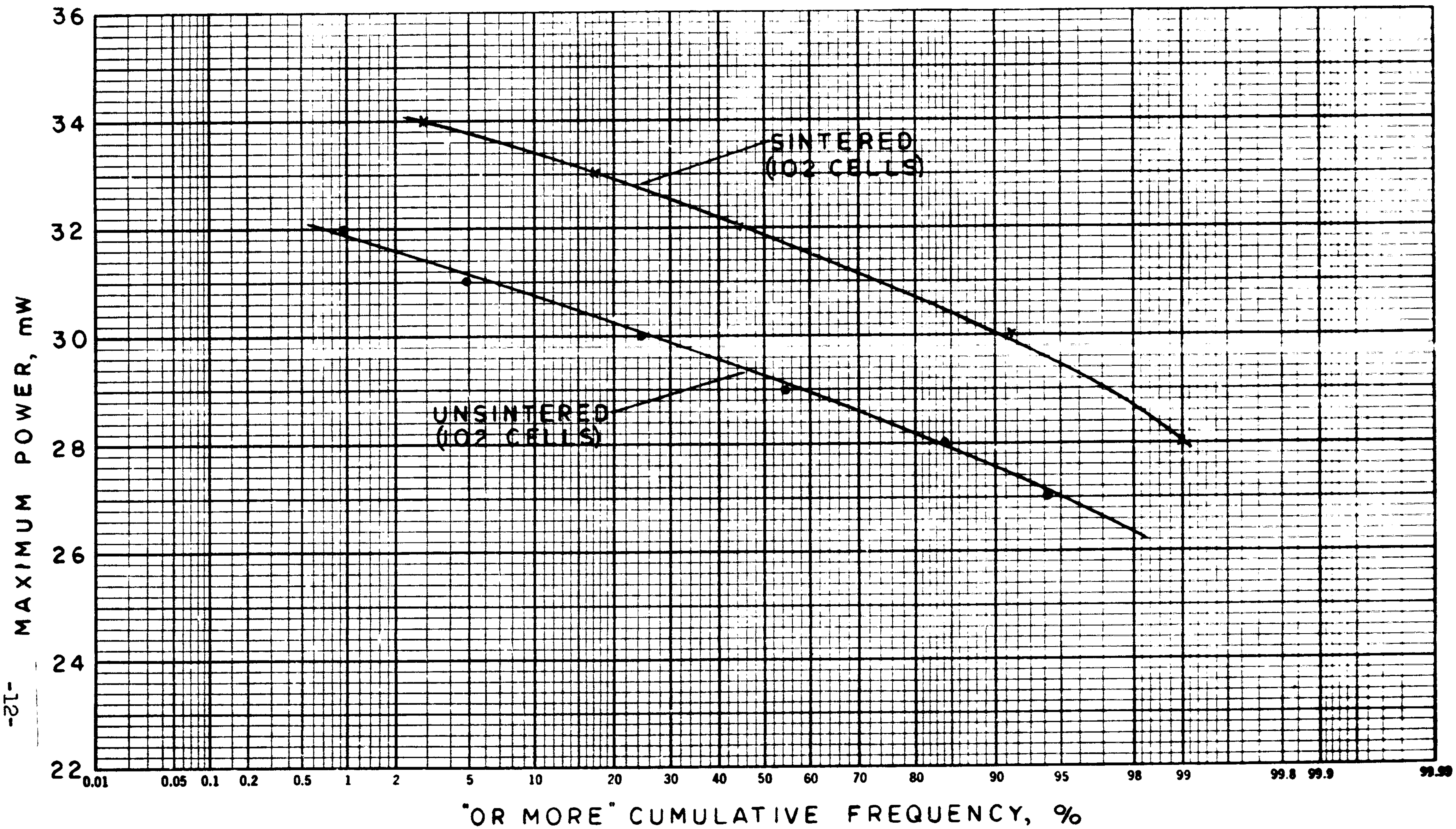

Figure 6. Comparison of Lithium Cell Output Before and After Sintering. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

2.4 Cells for Shipment to JPL

Cells for Lot 11 were fabricated from 20 ohm cm Lopex silicon. The following combinations of time and temperature were used for the lithium diffusions: 1) 3 hours at 340°C, 2) 7 hours at 340°C, 3) 3 hours at 360°C, and 4) 7 hours at 360°C.

The initial cells fabricated, which were lithium diffused three and seven hours at 340°C, had low AMO outputs, generally ranging from 24 to 27 mW. These cells were boron diffused with an eight minute deposition time. At the time of the Lot 11 fabrication period, experimental boron diffusions were being performed using a two minute boron deposition time on 1 ohm cm crucible grown silicon, so slices of Lopex silicon were included in these diffusions for comparison. Use of the two rather than eight minute boron deposition time resulted in lithium cell AMO outputs of 28 to 32 mW; consequently, the boron deposition time was changed to two minutes for cells in this lot. Sintering experiments being done at this time showed improvements in the short circuit current of 3 to 5 mA and in the output of 1 to 4 mA; consequently all the cells in Lot 11 were sintered in H_2 at 605°C. Figure 7 shows the maximum power distributions (after sintering) for the different groups of Lopex lithium cells. The various diffusion parameters produced similar AMO outputs with the outputs for all the groups ranging from 29 to 34 mW. This is equivalent to an efficiency range of 10.9 to 12.8%. The median efficiency is 11.9%. These efficiencies are the highest obtained on lithium cells thus far.

In Figure 8 the Lopex cells which make up each group in Figure 7 are treated as a single group and the AMO output is compared to a typical AMO output distribution of conventional 10 ohm cm N/P cells. The lithium cell output is 3 to 11% higher than the N/P cell output. Even if for some reason the sintering step is eliminated from the process the output is equal to or better than the 10 ohm cm N/P cells. Figure 9 compares I-V characteristic curves of a typical 10 ohm N/P cell and a typical lithium cell from this group of 105 lithium cells. These curves show that the high lithium doped cell output is due to short circuit currents as high as 10 ohm cm N/P cell currents and higher open circuit voltages.

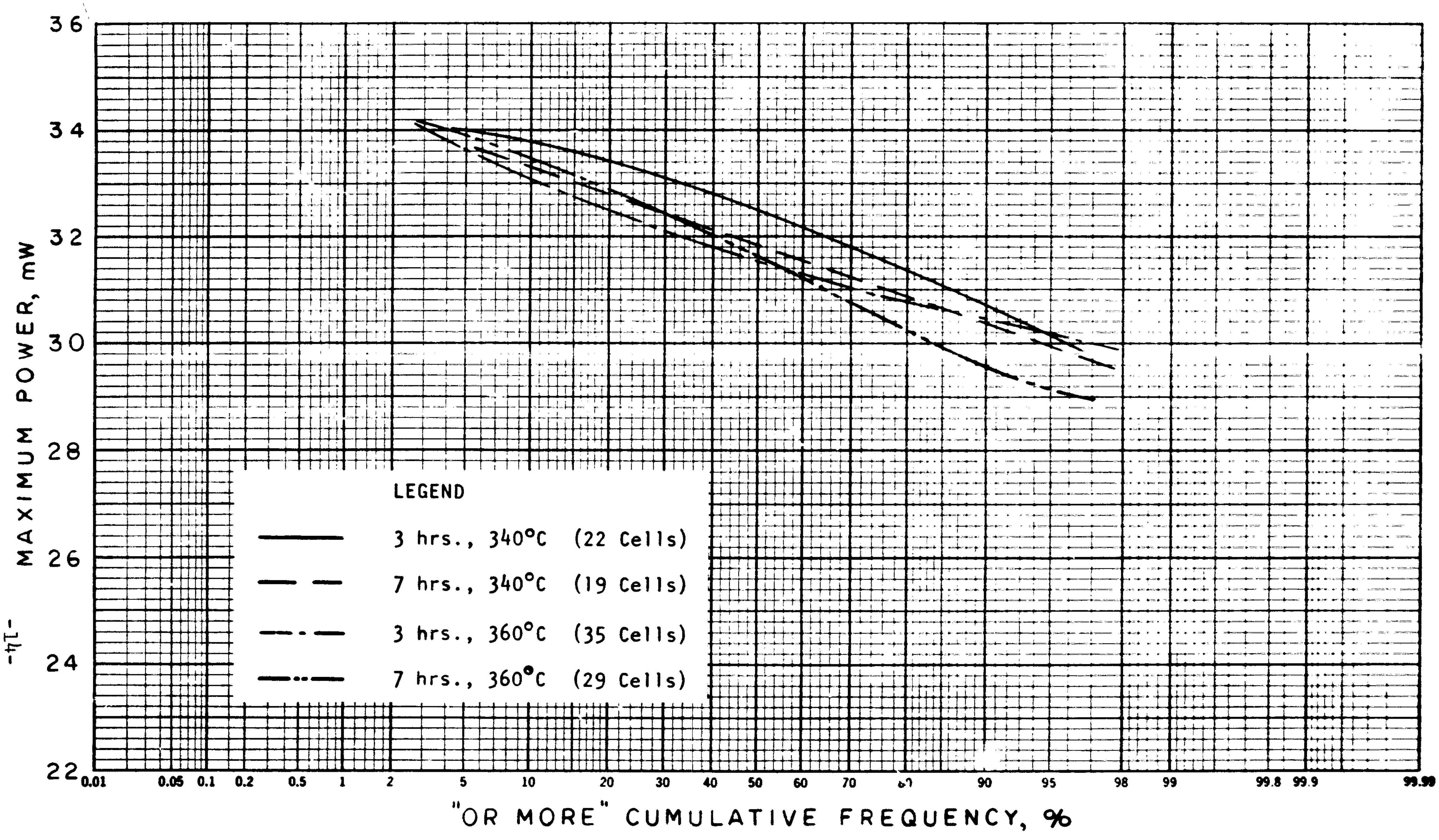

Figure 7. Maximum Power Distributions of Lopex Lithium Fabricated for Lot 11. Measured at 25°C in Solar Simulator (140 mW/cm^2).

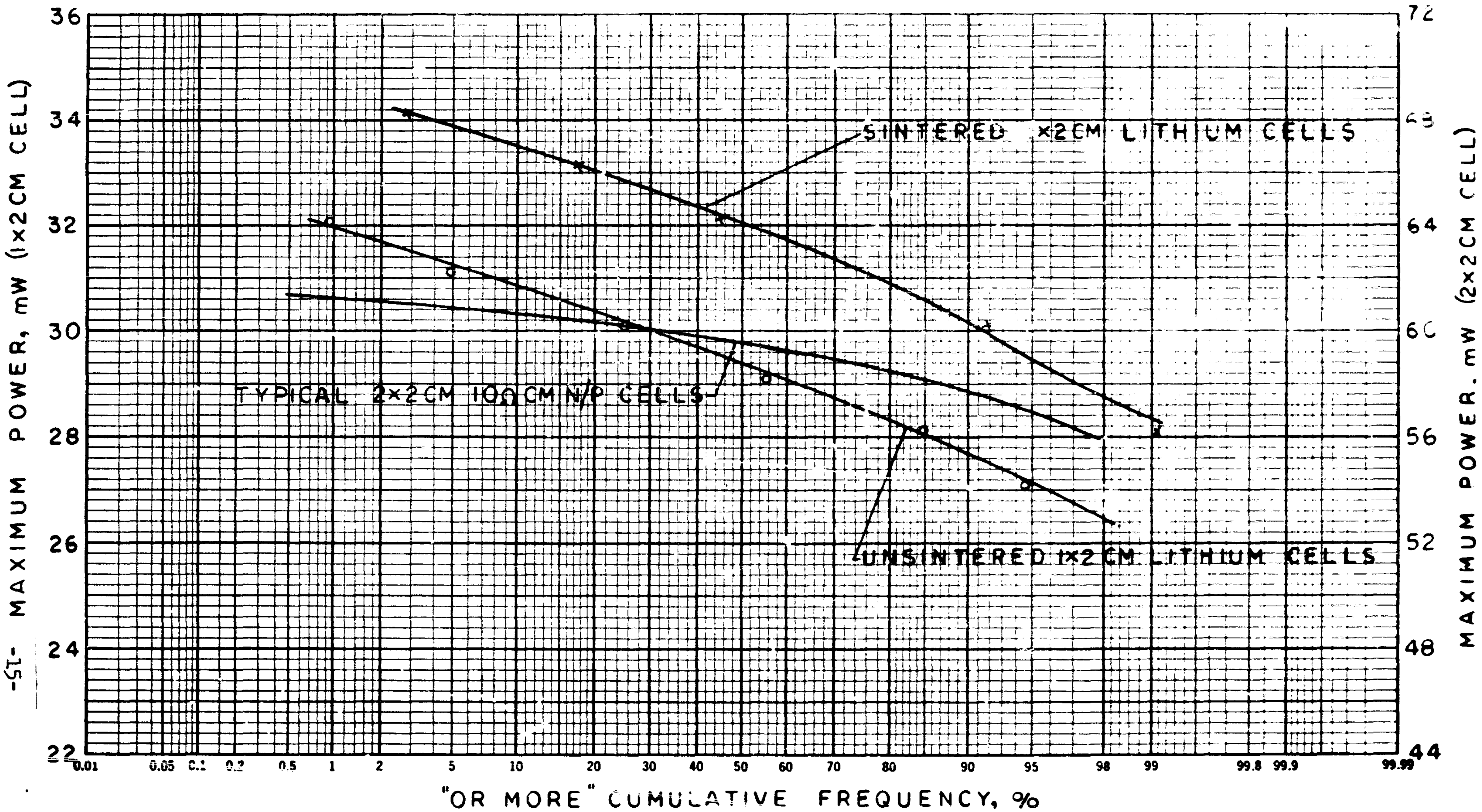

Figure 8. Comparison of Sintered and Unsintered Lopex Lithium Cell Output Distributions to a Typical 10 ohm cm N/P Cell Output Distribution. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

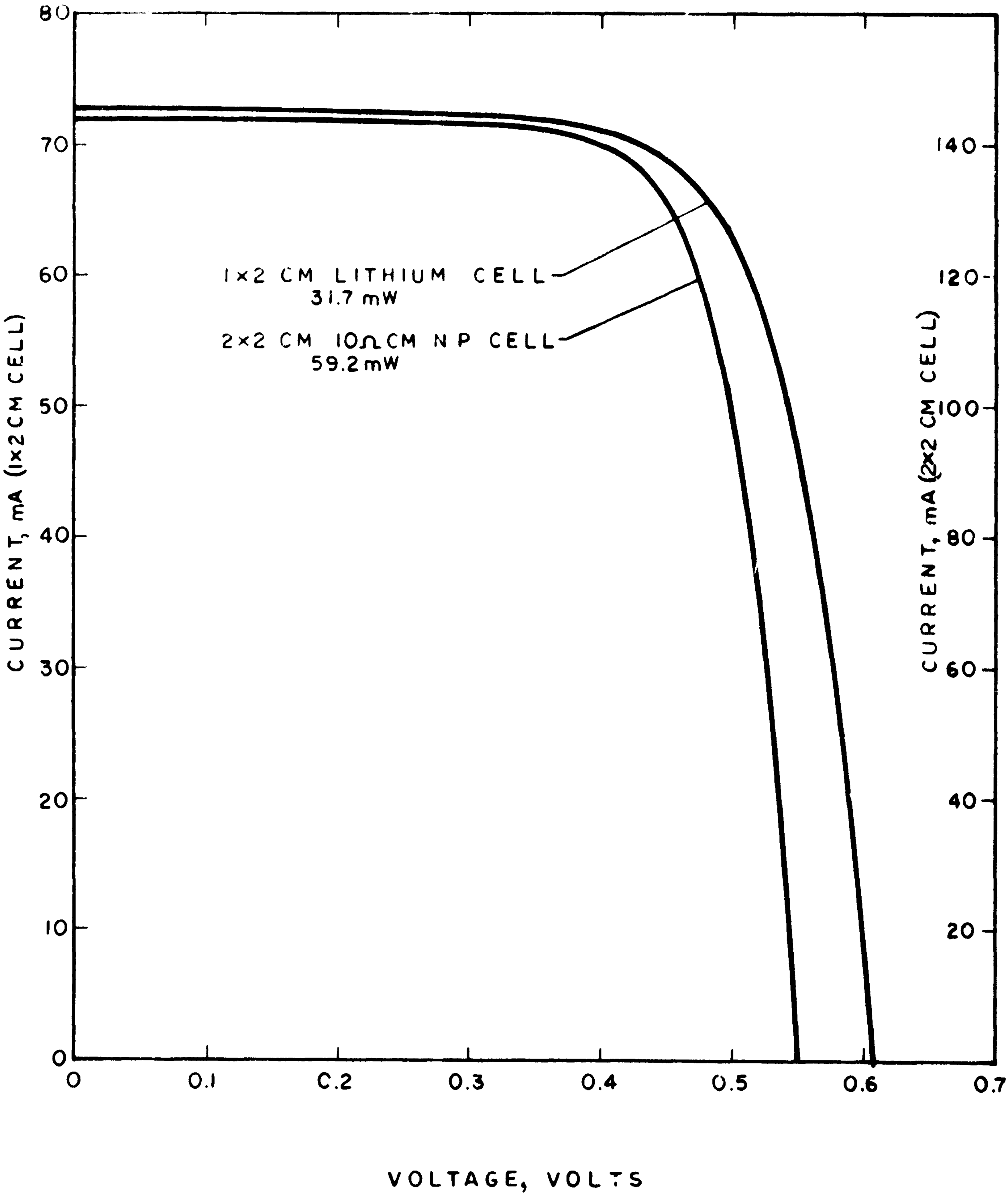

Figure 9. Typical 10 ohm cm N/P Cell vs. Typical Lopex Lithium Cell. Measured at 25°C in Solar Simulator (140 mW/cm^2 Intensity).

3.0 CONCLUSIONS

Both the $BC\ell_3$ diffusion with O_2 and the $BC\ell_3$ (no O_2) diffusion with a short boron deposition time produce low stress P/N cells; however, the $BC\ell_3$ (no O_2) diffusion with 2 minute deposition time produces superior AMO outputs, 28 to 33 mW vs. 23 to 28 mW.

Lithium cells can be fabricated with 10 to 15% higher outputs by using a two rather than eight minute boron deposition time. Combining this improvement with the 5 to 10% increase obtained by sintering has resulted in the highest lithium cell efficiencies (AMO) yet obtained, 10.9 to 12.8% for a group of 100 cells. The median efficiency for this group was 11.9%.