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METALLIZATION PROBLEMS WITH CONCENTRATOR CELLS

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INTRODUCTION

Cells used with concentrators have similar contact requirements to other cells, but operation at high intensity imposes more than the usual demands on the metallization.

Table 1 lists the overall contact requirements. We will discuss how concentrator cells can meet these requirements.

REDUCING RESISTIVE LOSSES

Since concentrator cells operate at high current density, any resistive losses are more severe.

Resistive Loss Model (See Reference 1* for previous references.)

- The procedure used to design concentrator cells is as follows (see Figure 1).
- 1) Select the intrinsic cell design best suited to the planned application -maximize collected current and voltage, minimize reflective and bulk resistance losses. These terms are derived from previous experience gained in optimizing the cell design.
 - 2) Select contacts with low contact resistance, and design a grid pattern using 3-7 below.
 - 3) The various resistive components (contact, front sheet, gridline, bulk) are analyzed as a network of resistors. This analysis generally uses parallel lines for rectangular or square cells, sometimes with the cell divided into quadrants; for circular cells, radial lines are used, often with increasing line density towards the outer edge (bus contact) of the cell.
 - 4) The resistive losses are computed, and transformed into power losses e.g. by taking their ratio to the internal impedance of the cell at the operating intensity X (this impedance = $0.9 V_{oc}/I_{sc}$). This impedance increases just less than linearly with X ($\sim 0.84X$ for $^X Si$, $^X 0.89X$ for $GaAs$), so that the relative percentage loss caused by resistive components increases at this same ratio. The shading loss does not vary with X , and is determined by the areal grid dimensions.
 - 5) The operating CFF of the cell under concentration is computed by subtracting the total resistive losses from an initial "ideal" CFF.
 - 6) The shading reduces the generated current density to the actual cell current density.

*P.A. Iles "A Survey of Grid Technology" to be published in Conference Rec. of 16th Photovoltaic Specialists Conference, 1982.

7) Grid line dimensions are selected within the best available state-of-the-art.

The rationale for grid design is to minimize shading losses (at low concentrations up to 10-20X), and then to gradually reduce the resistive losses more at higher concentrations (Reference 1). Figures 2 and 3 show the good agreement obtained between measured and calculated values. The slight improvement in the measured CFF can be explained by slight differences in the assumed and achieved gridline dimensions.

This agreement which has been repeated for many different cell designs, shows that the loss model analysis is valid (especially at low concentrations), even using the simpler lumped resistance assumptions. This adds confidence to use of the same model in designing grid (and busbar) configurations for large area cells, or for cells where low costs limit the choice of grid formation methods. For concentrator cells practical grid formation and deposition techniques have been developed, and generally require the use of photolithographic methods. Of course to obtain high concentrator system efficiency, it is essential to have high cell efficiency.

INCREASED OPERATING STRESSES

Items 5-7 in Table 1 are especially important under the increased operating stresses for concentrator cells. #5 is important, especially for terrestrial concentrator systems where severe temperature cycling (many times per day) is possible. It also increases the range of bonding methods and conditions which can be used. #6 is important because most concentrator cells operate hot (despite the use of cooling), and there may also be severe temperature gradients between the front and back surfaces of the cell.

Also cells may have to operate at high temperatures for extended periods (say 20 years), and it is considered that additional high temperature stability is required for concentrator cells. Some success has been achieved by using diffusion barriers to minimize interlayer movement; silicon concentrator cells with TiN barriers have survived heating above 600°C for long periods (½-1 hour) with little degradation, and this work continues.

The higher temperatures can also lead to accelerated corrosion rates (#8) when the cell is operating in the field; at present passivating layers (eg. Pd with Ti Ag) are used, but more testing is needed to show that this is not a severe operating problem.

The bonding of interconnects to concentrator cells (#7) involves the use of more massive interconnects (to reduce resistive losses), combined with larger bonding areas on the cells. The back surface must be well bonded to the substrate, to increase heat transfer.

CONCLUSIONS

Although there are some areas not completely resolved, the results obtained with concentrator cell contacts suggest that the resistive loss models used are satisfactory. The metallization behavior under the increased operating stresses supports the conclusion that for cells operating around one-sun levels, that some of the present metallization systems are adequate. More work is required however, when compromises are required between the metallization methods available, and the cost constraints of the cell or array processing methods.

Table 1. Cell Metallization Requirements

#	REQUIREMENT
1.	LOW CONTACT RESISTANCE TO SEMICONDUCTOR (N AND P).
2.	HIGH CONDUCTIVITY TO DECREASE RESISTIVE LOSSES.
3.	EASILY PATTERNED INTO GRIDS.
4.	MINIMUM CHANCE OF GRID ACTING AS FUSE.
5.	GOOD ADHESION
6.	GOOD HIGH TEMPERATURE STABILITY (UNDER SINTERING TO REDUCE CONTACT RESISTANCE, IMPROVE AR COATING, OR UNDER OPERATING CONDITIONS).
7.	EASILY BONDABLE (BY SOLDERING OR WELDING)
8.	MINIMUM CORROSION.
9.	SIMPLE METAL STACK.
10.	COMPATIBLE WITH CELL FEATURES (TEXTURING, SHALLOW xj).
11.	LOW COST (MATERIALS, DEPOSITION), EASILY APPLIED.
12.	LOW DENSITY TO REDUCE WEIGHT (SPACE-USE).
13.	THERMAL EXPANSION CLOSE TO SEMICONDUCTOR (ESPECIALLY ON BACK SURFACE).
14.	GOOD AT LOW TEMPERATURES (SPACE-CELLS).

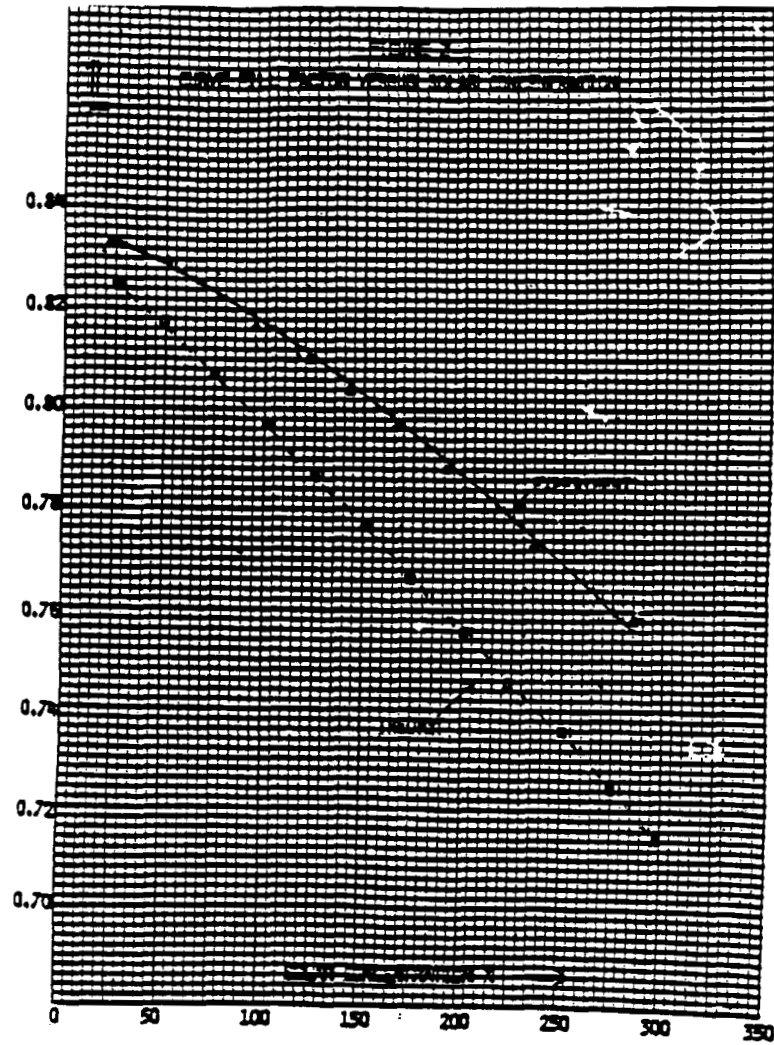
Figure 1. Resistive Loss Modeling

- SELECT J_{sc} , V_{oc} , CELL DIMENSIONS.
- SET-UP RESISTOR NETWORK.
- COMPUTE POWER LOSS COMPONENTS.
- MINIMIZE SUM OF RESISTIVE AND SHADING LOSSES.
- ESTIMATE OPERATING CFF, J_{sc} , V_{oc} AT VARIOUS INTENSITIES.
- SELECT OPTIMUM GRID PATTERN.

CONCLUDE GOOD AGREEMENT BETWEEN EXPERIMENT AND PREDICTIONS.
INFER THAT BASIC MODEL IS VALID AND CAN APPLY TO ONE-SUN
OPERATION, INCLUDING LARGE AREA CELLS.

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OF POOR QUALITY

Figure 2. Curve Fill Factor versus Solar Concentration



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Figure 3. Cell Efficiency versus Solar Concentration

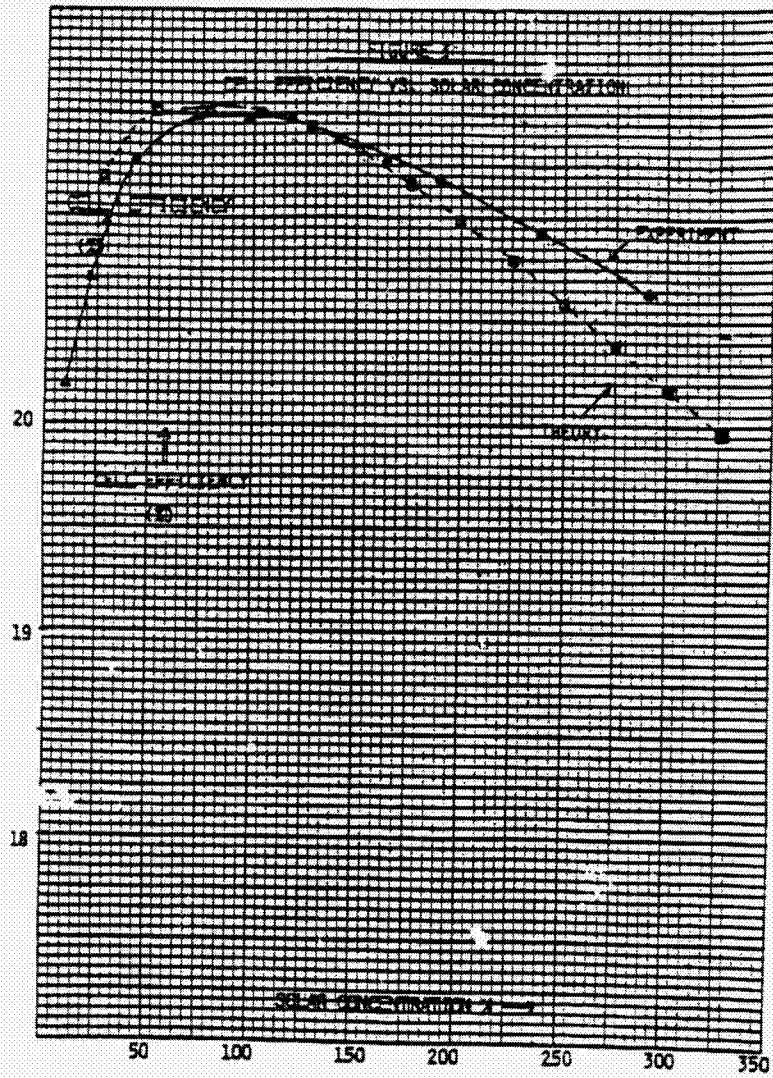


Figure 4. Increased Operating Stresses

- o ADHESION - FOR TEMPERATURE CYCLING, BONDING.
- o HIGH TEMPERATURE STABILITY
 - PROCESS SINTERING
 - OPERATING CONDITIONS
 - DECREASED CORROSION
- o TESTING DIFFUSION BARRIERS, SIMPLE STACKS AND PASSIVATING LAYERS.
- o BONDING
 - THICKER INTERCONNECTS
 - LARGER BONDING AREA
 - THERMAL CONTACT

Figure 5. Conclusions

- o RESISTIVE LOSS ANALYSIS IS VALID, SINCE CONCENTRATOR CELLS PROVIDE TEST UNDER VERY SEVERE CONDITIONS.
- o BEHAVIOR OF CONCENTRATOR CELLS UNDER ENHANCED OPERATING STRESSES SUGGESTS THAT HIGH COST CONTACT SYSTEMS HAVE PROMISE.
- o MORE WORK IS REQUIRED FOR LOW COST CONTACT SYSTEMS TO MEET MOST REQUIREMENTS EVEN AT ONE-SUN LEVELS.

DISCUSSION

WONG: Do you have any grid line patterns available here?

ILES: I don't have any here, you have to know what the concentrator intensity distribution is and what the size is; that's fairly obvious. They are all custom made, there is no such thing as a standard concentrator, there are several linear focus systems in various sizes and several point-focus, so that if you have an intensity and you have some idea of what the distribution is then we can find a pattern close to it. If you are just talking hypothetically we can send you a picture of a thing that looks very pretty with lots of lines on it, but if you have a Fresnel with a 100X lens, which may have a half-inch focused image, that's how we can design a cell with fairly precise dimensions.

BICKLER: Pete, is it true that the concentrator cells are shallow diffusion, slanted toward the blue response?

ILES: Yes, when you do the analysis, when you put the grids close together, the sheet resistance then becomes negligibly small.

BICKLER: Oh, I was going to say, it sounds like a paradox in that there is an advantage to over-shadowing, as you mentioned, in the metallization system to reduce the series resistance. I would assume you draw a parallel with the diffusion depth and that's a lack of transmission or analogous to a shadow, and well worth the --

ILES: That's true, but the scale of the two is so different -- it is typical to say 50X -- you are getting 3% or 4% shadowing and maybe 5% or 6% total resistive loss. If you go to 400X then you slide the shadow mask up to about 10% by putting more lines closer together. Putting the lines closer together is not to reduce the sheet resistance, it is to reduce the power through the grid lines. The grid lines are the more important resistor block.

CAMPBELL: Am I correct that the concentrator cells have a generally lower resistivity base than --

ILES: They generally are, particularly for high concentration, above about 50X or 100X, but they have been good; typically the ones that are made in the range of 0.1 to 0.3 or 0.4 ohm-cm, and have 10^{17} carriers per cubic meter, but there have been some quite good cells made with 1 ohm-cm, with high-quality material, and there have even been some made with 10 ohm-cm but they were thin, they were 2 mils thick, so that the bulk loss was reduced.

CAMPBELL: Other than putting this number into these equations, would this have any effect on the contact pattern?

ILES: No, there is a discrete bulk loss in the equation, even I can calculate that one, but apart from that, no problem, if you want to put it with a web you could easily calculate the pattern.

CAMPBELL: Are not a number of concentrator cells p on n?

ILES: Yes, the ones that Sandia made with great success are p on n; the ones that we make are n on p and p on n. There is a theoretical reason why p on n might be a little better as you go to higher intensities because the Dember effect is assisting you. No one has seen that yet; the resolution of all the other variables hasn't been good enough, but we also haven't seen conductivity modulation in either of them up to 1000X, which is also predicted by theory.