

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-71729

NASA TM X-71729

(NASA-TM-X-71729) SUMMARY OF HIGH
EFFICIENCY SILICON SOLAR CELL MEETING HELD
AT NASA-LEWIS (NASA) 4 p HC \$3.25 CSCL 10B

N75-23681

Unclas
G3/20 21829

**SUMMARY OF HIGH EFFICIENCY SILICON
SOLAR CELL MEETING HELD AT NASA-LEWIS**

by Daniel T. Bernatowicz
Lewis Research Center
Cleveland, Ohio 44135



TECHNICAL PAPER to be presented at
Eleventh Photovoltaic Specialists Conference
sponsored by the Institute of Electrical and
Electronics Engineers
Phoenix, Arizona, May 6-8, 1975

SUMMARY OF HIGH EFFICIENCY SILICON SOLAR CELL MEETING

HELD AT NASA-LEWIS

by Daniel T. Bernatowicz
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

A High Efficiency Silicon Solar Cell Meeting was held at NASA-Lewis on November 14 and 15, 1974 to review progress, assess remaining problems, and outline directions for future work on raising solar cell efficiency. This paper presents the major recommendations and conclusions reached in the meeting.

INTRODUCTION

The NASA-Lewis Research Center has been conducting since 1971 a research and development program to raise the efficiency of silicon solar cells for space. This two-pronged program seeks early, significant increases in efficiency utilizing near-term technological advancements and efficiency increases to its practical limit (estimated in 1971 to be 18% AMO) through long range research. As a result of the Lewis program and others in government, private industry and universities significant advances have been made since 1971. Technological advances include the COMSAT violet and non-reflective cells and the Helios cell, and the research programs have yielded better understanding of the physical processes taking place within the cells. Therefore it was timely that a meeting be held to review progress, assess remaining problems, and outline directions for future work. A High Efficiency Silicon Solar Cell Meeting was held at the Lewis Research Center on November 14 and 15, 1974. Short formal presentations on recent progress provided a common basis of information for the subsequent discussion. Most of the information contained in these presentations will be covered in papers given at this Photovoltaics Specialists Conference. This paper will discuss the consensus of the participants in the High Efficiency Silicon Solar Cell Meeting on major directions to be taken to raise cell efficiency.

SUMMARY OF THE MEETING

About 35 representatives of government, industry, and university groups active in silicon materials research, photovoltaic research, and device development participated. The organizations represented are listed in figure 1.

Present State of the Art

The recent efficiency improvements were described and are summarized in figure 2. The Helios cell was in production at Spectrolab and could be supplied with a minimum efficiency of 12 to 13% (AMO). The Violet cell was reported to be nearing production at Centralab (now OCLI) and had an efficiency between 13.5 and 14% (AMO). The COMSAT Non-Reflective (CNR) cell was still made only in the laboratory at COMSAT. Although it had not been thoroughly optimized, an efficiency of 15% (AMO) was measured. Although these cells are different, they reflect several similar technological thrusts. All the cells have p⁺ backs, Ta₂O₅ antireflection coatings, shallower junctions, and thinner grid fingers. Conspicuous differences are the 20 ohm-cm resistivity in the Helios cell and the etched, low

reflection (textured) surface of the CNR cell. Discussions of these recent technology developments made clear the importance of production factors, such as integration of processes, yield, and cost, on the development of a marketable solar cell. Considerable process development, which may involve performance compromise, is involved in integrating new technologies into the commercial production of a solar cell.

Improvements in the Near Future

Further gains in efficiency are expected in the near future (2 to 3 years). These are expected to be extensions of recent improvements and process development:

- p⁺ Back (Back Surface Field)
- Better antireflection coatings
- Textured (non-reflective) surface
- Better junctions
- Thin structures
- Narrow grid fingers
- Adhesives or cover bonding methods that admit more blue light

The improved production cells in this period are expected to have a base resistivity in the range of 40-100 ohm-cm and to have a back surface field.

Directions for the Longer Term

Discussions of the longer range efficiency gains centered about research activities rather than process and technology development. Although the technological improvements were reducing the gap between achieved performance and the theoretical limit, it was agreed that further research was appropriate and necessary.

Several general areas of need, for an effective efficiency improvement program, were identified. These consisted of

- Better modeling of the solar cell, including detailed description of the structure and of the physical processes.
- Better techniques for making and interpreting lifetime and diffusion length measurements. Bulk and surface effects on these parameters should be separated.
- Better knowledge of the solar spectrum in space. Space tests on the Violet cell suggest that the blue end of the spectrum has been underestimated.
- Space tests for new solar cells on a timely basis.

There was an extended discussion on what was a reasonable efficiency goal. The maximum theoretical efficiency of 22% was not disputed, but it was agreed

that the goal should be the maximum practical efficiency, which would allow for such losses as reflection, shadowing, and series resistance. Some disagreement on these losses and junction losses, and further uncertainty due to the newly recognized band gap narrowing due to heavy doping, led to adoption of a range for the maximum efficiency. It was agreed that the maximum practical efficiency for silicon solar cells lay between 17 and 20% (AM0).

Although certain combinations of the technological thrusts listed earlier might yield a new device whose efficiency could approach this goal, it was agreed the main research path should continue to be on low resistivity silicon. The principal range of interest should be near 0.1 ohm-cm. Research on 0.1 ohm-cm silicon should investigate

- Lifetime as a function of dopant concentration, defects, processing procedures, and geometry.
- Band gap narrowing due to heavy doping.
- Dopants other than boron and various dopant profiles.
- Radiation damage and the effects of oxygen and carbon on radiation damage.

There was some concern that the reduction in lifetime, increase in recombination current, and increase in radiation damage as the doping level is increased may be due to the dopant itself rather than other impurities or defects due to processing. There might then be little potential for improvement of these parameters.

Since the meeting was concerned primarily with cells for space use, discussions were held on directions for radiation damage work to raise the end-of-life efficiency. The following devices and structures were identified as those that may be more tolerant to radiation damage and therefore deserve attention:

- Vertical multijunction cell.
- Thin cells and cells with very thin epitaxial layers.
- Cell with high resistivity base and a p^+ back surface field.
- GaAs cell, if the price of gallium can be reduced.

Although no specific deficiencies in radiation damage theory were identified, it was agreed that a larger store of basic information should be acquired. Research in the following areas should be conducted:

- Determination of the generation rate of primary defects by electrons and protons.
- Determination of the cross sections for the capture of primary defects by dopants and impurities.
- Search for getters for primary defects.
- Investigation of photon-induced degradation in silicon, especially float zone material.

MAJOR CONCLUSIONS OF THE ROUND TABLE DISCUSSION

The major conclusions reached in the round table discussion at the High Efficiency Silicon Solar Cell Meeting were as follows:

- The maximum practical efficiency of silicon solar cells is between 17 and 20% (AM0) and is still a reasonable goal.
- The long range R&D approach toward this goal should continue to focus on low resistivity (0.1 ohm-cm) silicon.
- Near term R&D should continue to focus on higher resistivity silicon, back surface fields, thinner grid fingers, and surface texturing to produce efficiency improvements.
- More research should be undertaken in radiation damage to raise end-of-life efficiency.
- Development of a production cell involves tradeoffs among fabricability, cost, and performance.

OBJECTIVE

- REVIEW PROGRESS IN RAISING EFFICIENCY
- ASSESS THE REMAINING PROBLEMS
- OUTLINE DIRECTIONS FOR FUTURE WORK

PARTICIPATING ORGANIZATIONS

| | | | |
|-------------|----------|----------|--------------------|
| CENTRALAB | HELIOTEK | MONSANTO | SIMULATION PHYSICS |
| COMSAT | HUGHES | MOTOROLA | SOLAREX |
| DOW CORNING | IBM | NORTHROP | TEXAS INSTRUMENTS |

UNIVERSITY

| | |
|-----------------|--------------|
| FLORIDA | PENNSYLVANIA |
| ILLINOIS | WAYNE STATE |
| N. CAROLINA ST. | BROWN |

GOVERNMENT

| | |
|-----------|------------|
| NASA-GSFC | JPL |
| NASA-HQ. | NSF |
| NASA-LaRC | NRL |
| NASA-LeRC | USAF-WPAFB |

CS-73683

Figure 1. High Efficiency Silicon Solar Cell Meeting Objective and Participating Organizations

| <u>DESCRIPTION</u> | <u>EFFICIENCY</u> | <u>STATUS</u> |
|--|-------------------|---------------------------|
| <u>HELIOS CELL</u> 20 Ω-CM P ⁺ BACK SHALLOW JUNCTION THIN GRID FINGERS Ta ₂ O ₅ | 12% TO 13% (AMO) | IN PRODUCTION |
| <u>VIOLET CELL</u> 2 Ω-CM P ⁺ BACK VERY SHALLOW JUNCTION VERY FINE GRID FINGERS Ta ₂ O ₅ | 13.5 TO 14% (AMO) | NEARING PRODUCTION |
| <u>COMSAT NON-REFLECTIVE CELL</u> ETCHED, LOW REFLECTION SURFACE OTHERWISE LIKE VIOLET CELL | 15% (AMO) | LABORATORY, NOT OPTIMIZED |

CS-73684

Figure 2. Summary of Present High Efficiency Solar Cells