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Current Status of Silicon Solar Cell Technology

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SUMMARY

During the last five years, the efficiency of silicon solar cells has increased dramatically. In 1970, the average outer space efficiency of silicon solar cells was 10.5%. In 1975, laboratory cells have reached efficiencies above 15% and production cells are in the 13% range. Most of the increased output has resulted from increased short-circuit current, with only minor increases in voltage being reported. The technologies leading to this increase focussed primarily on increased current output.

Short-circuit current can be increased by increasing the amount of light entering the cell and by increasing the collection of minority carriers generated by that light. Reduction of surface coverage by the grid pattern and use of optimized high refractive index coatings such as Ta_2O_5 or TiO_x lead to about 10% more current in the cover-glassed cell.

The most important advance in increasing the amount of light entering the cell came through surface texturizing using chemical etchants. The pyramidal surface structures which result yield two benefits. First, multiple reflections experienced by the incoming beam reduces the bare surface reflectivity to about 11%. Subsequent antireflection coating and a cover glassing leads to a reflectivity of only about 3%.

The second benefit arises because light is refracted as it enters the silicon and travels obliquely through the cell. Collection efficiency increases because light is absorbed closer to the junction. Also more infrared light is absorbed because the path length is greater than the silicon thickness and because the light is totally internally reflected from the smooth back surface.

The use of shallow junctions and the back surface field effect has also led to increased output. The former aids blue response, the latter increases red response due to increases in minority carrier lifetime. Incorporation of the back surface field also yields increased voltage in 10Ω-cm cells.

Device Performance and Production Status: Increased device performance results from inclusion of the above technologies into the cell. However, transition from the laboratory to cost effective production is difficult and represents a significant barrier to rapid introduction of new, marketable

solar cell devices. The Helios cell, in high volume production at Spectolab, has an average efficiency of 13%. The violet cell, nearing production by OCLI, has an efficiency of about 13.5%. The highest performance, 15.3%, is achieved by the CNR (COMSAT non-reflective) cell now in laboratory production at the COMSAT Laboratories. Most of the improved output in this cell comes from increased short-circuit current. The CNR cell has a quantum yield (electrons collected per incident photon) above 90% over most of the response region. Thus it appears that little further improvement in short-circuit current can be anticipated in the future.

Although developments to date have been significant and exciting, additional research and development opportunities exist. Efficiency increases can be expected and cost reductions by orders of magnitude can be predicted.

Open-Circuit Voltage: The last substantial barrier to achieving the maximum practical efficiency of about 19% is the open-circuit voltage. Although simple diode theory predicts an increasing voltage with decreasing resistivity, contrary results are obtained experimentally. It appears that a low emitter efficiency of the diffused region is the cause of poor voltages. Effects that may be acting to reduce the voltage include band gap narrowing, increased interband transition rates and defect clustering.

Technological approaches aimed at increasing cell voltage have examined alternate dopants, ion implantation and epitaxial structures. Epitaxial structures with voltages above 630 mV have been fabricated.

Short-Circuit Current: The one remaining research area related to current is determination of and reduction of cell surface recombination velocity.

Low Cost Technology: The final barrier to widespread use of solar cells is cost. The U.S. ERDA National Photovoltaic Program is clearly focussed on this target. Both automated, high rate cell production and new technologies appear to be required to meet stringent cost requirements of 10-50¢/watt arrays in 1985. A variety of low cost vacuum and non-vacuum technologies are currently being investigated for automated production. Also, recent work on the web dendrite ribbon silicon growth method is aimed at demonstrating the feasibility of continuous growth of 5 cm wide material. Cells of 12% AMO efficiency have been made on web dendrite material that was grown in the 1960's. The EFG ribbon growth technique has also shown improvements in crystallinity and materials properties. Lower cost, more efficient slicing techniques and the use of larger diameter silicon ingots are also being investigated.