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ASSESSMENT OF THE INTERNATIONAL WORKSHOP ON CdS SOLAR CELLS

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The National Science Foundation sponsored an International Workshop on CdS/Cu_2S solar cells and other abrupt heterojunctions held at the University of Delaware. Approximately 100 participants, including representatives of NSF, ERDA, NASA and EPRI, discussed during the three day workshop (April 30-May 2) critical questions relating to the performance, stability and economics of these cells with the aim to assess the current state of the art and future potential.

In three parallel sessions, general problems relating to the basic understanding of the cell operation, to material aspects of the cell and to manufacturing methods and cell engineering were discussed.

In a general meeting on the last day of the workshop, a synthesis was attempted in extensive discussions and summarized at a meeting of the Chairmen and Associate Chairmen after the formal adjournment of the workshop. Here it was agreed that the following statement summarized the principal outcome of the meeting. To the extent that there was a definable consensus, these points represent the principal areas of agreement.

Initial Performance and Possible Limits

Peak performances of 7-8.5% conversion efficiency have been demonstrated at room temperature. Peak values of short circuit currents of 25 mamp/cm^2, open circuit voltages of 0.53 volts and fill factors of 75% have been demonstrated. Most investigations show that the highest short circuit currents are obtained with close to stoichiometric Cu_2S.

The highest achievable short circuit current under 100 mwatts/cm^2 natural insolation is about 35 mamps/cm^2 for such cells, allowing 20% optical losses. The theoretical limit for the fill factor is agreed to be about 80%.

Two major approaches to increasing the open circuit voltage were agreed to; namely, recombination at interface states and modifying the band interconnect. A reasonable goal of 0.65 volts was projected and a theoretical upper limit of 0.86 volts was presented.

On the basis of the above individual parameters overall conversion efficiencies in excess of 15% are implied.

Cell Reliability

It was generally agreed that for terrestrial applications, degradation is not an obstacle to utilization of the CdS cell and lifetimes in excess of 20 years are achievable. A major contribution to observed degradation in the past was the result of inadequate protection from atmospheric constitutents. A major degradation mechanism is related to stoichiometry changes in the Cu_2S layer.

Economic Factors

There are at least two production techniques capable of producing economic CdS solar cells. Projected costs/watt were stated to be between 1 and 10 cents/peak watt using the techniques of sensitivity analysis. In order to achieve such projected costs a sufficient production yield of high efficiency cells is necessary. There are indications that such yields are achievable.

General Recommendations

It is recognized by the members of the workshop that the complexity of the heterojunction solar cells warrants a concerted research program with an over-critical mass to systematically approach and solve the key problems to further improvements.

Such improvements shall include an increase of conversion efficiency above 10%, a decrease in thickness of the CdS layer below 10μm, the development of an inexpensive grid and an inexpensive hermetic encapsulation. It must also include the achievement of a production yield in excess of 90% for high efficiency cells within one percentage point deviation. Finally, a life expectancy in excess of 20 years under actual operating conditions is desirable.

The current state of the art shows feasibility of achieving these goals. A great variety of cells have been fabricated using different techniques, electrodes and encapsulations and have demonstrated that cell efficiencies in excess of 5% can be achieved in various ways.

In order to accelerate further progress a systematic research program is recommended:

1. Substrates: A wide variety of substrates is currently used with success including glass, Mo, NiFe, Copper and Kapton with silver pyre. The parameters of influence to cell performance shall be identified and substrates shall be selected which are conducive to high efficient and economic cells.

2. Base Electrodes: Currently predominantly zinc is used but other materials such as Al, Pd-Ag-Ti and conducting glasses are known to produce ohmic contacts to CdS. Other materials and deposition methods shall be identified as ohmic contacts of sufficient conductance and, -for back wall cells - of sufficient optical transparency.

3. CdS Layer: It is know that CdS of different deposition and structure yields good CdS solar cells. Critical parameters shall be identified relating to structure, stoichiometry, doping and surface morphology to obtain high efficiency and stable cells. Alternative methods of deposition and treatments shall be investigated to economically produce such layers.

4. Cu_xS Layer: Evidence is obtained that Chalcocite with $X \geq 1.995$ deposited in a variety of ways yields cells with high collection efficiency. The range of permissible deviation from stoichiometry shall be identified with critical parameters relating to structure and doping to obtain highest collection efficiencies. Means for surface passivation and to stabilize the electrical parameters of the Cu_2S layer shall be investigated as well as alternative means of deposition and post-deposition treatments.

5. Top Electrode: Materials and means of attachment shall be identified to achieve stable ohmic contacts to Cu_2S which could replace the currently used gold.

   Low cost electrodes shall be developed with high collection efficiency (for front wall cells with high optical transparency).

6. Encapsulation: Materials or material combinations shall be identified which can combine antireflection coating with a hermetic sealing and possibly surface passivation. Inexpensive encapsulation techniques shall be developed.

7. Arrays: Critical parameters shall be identified for automatic array fabrication. Means to inexpensively produce and encapsulate such arrays shall be developed.

8. Alternative Heterojunctions: The investigation of alternative material combinations shall be continued and their potential shall be identified in comparison with the CdS/Cu_2 solar cell in respect to maximum possible efficiency, ease of fabrication, degradation mechanism and other relevant parameters influencing reliability and economics.

9. Cell Operation: Efforts shall be continued to improve the understanding of the physics of the cell operation.

10. Diagnostic Tools: Diagnostic tools shall be further developed to identify all essential parameters of the cell and to control reproducible manufacturing of all components of the cell.

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11. Life Testing: Meaningful accelerated life tests shall be developed and all newly developed cells shall be promptly submitted to such tests.

12. Documentation and Exchange of Information: All results shall be recorded with attention to ease of access and data retrieval. Close relation of the different parts of the program and swift exchange of information is emphasized.

In addition, systems analyses of the relation between initial cell costs, performance and useable lifetime shall be pursued to give guidance to cell research and development.

This workshop has served a useful function to assess the current state of the art and to provide guidance for future research. It is proposed to hold such workshops periodically.