

## RADIATION DAMAGE WORKSHOP REPORT

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### INTRODUCTION

The discussions were held to aspects concerned with Si and GaAs solar cell technologies. It was agreed that the multi-bandgap cell research is premature for radiation damage discussions since the materials used in such devices are not well characterized in terms of solar cell parameters (diffusion lengths, defects, growth methods, etc.). Some radiation damage work in the AlGaAs cell in GaAs cell is proceeding and will be included in the next HERD Conference.

### WORKSHOP CONCLUSIONS/RECOMMENDATIONS

Three general categories were considered for the Si and GaAs cells - namely, Starting Material, Cell Design/Geometry and Cell Processing/Fabrication. The results and recommendations of the discussion are summarized below:

#### Silicon

Starting Material - Purity of the starting material was concluded to be a fruitful area of research. It was emphasized that carbon and oxygen be held to as low as possible. In fact, a suggestion was made to purposely reduce all impurities by many zone processes of already high purity poly-silicon and then to make a final single crystal pass during which boron in one case and gallium in another would be introduced to achieve the desirable conductivities. The ingots would then be processed into solar cells for evaluation. However, it was understood that the true purity of these materials would not be known because of severe limitations on present diagnostic sensitivity - again for carbon and oxygen in particular. Thus, increased sensitivity of diagnostic methods was considered a very crucial matter in the discussions with the recommendation that emphasis be placed on improving such techniques at least by an order of magnitude. Basic research on defect formation interactions and annealing mechanisms was considered important in light of achieving low temperature anneal of radiation induced defects (below 200°C). The SUNY (Corbett) work is addressing this issue but more work is needed to determine the effect of high purity material on defect formations interactions and anneal. Tied to the subject of defect dynamics is synergistic effects and it was concluded that combined proton and electron effects testing should be conducted with samples provided to SUNY. It was recommended that B and Ga be investigated on a comparison basis to determine advantages/disadvantages of these dopants in high purity materials. In summary, the following recommendations resulted:

- (a) Reduce impurities - specifically O and C
- (b) Increase sensitivity of O and C detection
- (c) Conduct basic research on defect formation, interactions and anneal mechanisms
- (d) Include in (c) synergistic electron and proton effects
- (e) Continue research comparing B and Ga dopants in high purity material
- (f) Emphasize in all research achievement of annealing of defects at temperatures <200°C.

Cell Design/Geometry - For very high power-to-weight ratios at end-of-life, the thin cell and a thinned version of the vertical junction cell have promise. It was concluded that emphasis continue on both these structures with the addition of a thin cell with a drift field placed thereon very similar to the Westinghouse drift field cells of the mid to late sixties. Also, P-I-N structures offer the potential for very high radiation resistance in a thin geometry. Not enough work has been accomplished in the P-I-N structure and more is needed. The vertical junction structure may be very beneficial if the "tilt" is used. More research into this aspect of the VJ cell is needed. All of these cell concepts require input from the high purity material efforts to make a final judgement of which geometry is best suited for high end-of-life efficiency and low mass/cell design. In summary, the following recommendations were made:

- (a) Continue thin cell development with and without drift fields
- (b) Continue vertical junction cell work with further investigation of the "tilt" advantage
- (c) Continue the P-I-N effort - definitely need more radiation damage characterization on this device.

Cell Fabrication/Processing - Discussions were somewhat inconclusive in this area since not enough data has been generated. The discussions led to the conclusion that experiments should be conducted to decide on the advantages/disadvantages of P/N junction formation using N<sup>+</sup> diffusions and N<sup>+</sup> ion implantations. Radiation effects on rear contacts for low intensity, low temperature applications need further study. In summary:

- (a) Determine relative merits of diffusion and implantation for P/N junction formation with respect to radiation damage.
- (b) Place some effort on radiation effects to back contacts for low temperature, low intensity cell applications.

## Gallium Arsenide

Starting/Grown Materials - Purity and crystallinity were considered important for GaAs cells from the point of view of high end-of-life. The substrates now available are very suspect of containing fastdiffusers that move into the LPE or MO-CVD grow photovoltaic layers. These impurities can tie to Ga and/or As vacancies as well as interstitial Ga and As atoms. It is not known at this point how serious the problem is. Crystalline quality also may play a major role (dislocations, etc.) since these defects will propogate into upper layers during growth and can become active during radiation exposure. It was concluded that emphasis should be placed on comparisons of very pure defect-free substrate material and conventional substrate material. The grown layers also require purity and crystalline quality. It was not clear that a real problem exists for the grown layers since those persons engaged in GaAs cell technology routinely check their source melt or gas materials for electronic grade purity. Although very good and more consistent quality GaAs cells are being made, it was concluded that variations on dopant species and concentration levels could potentially yield considerable gains over present cells in end-of-life efficiency; these aspects deserve high emphasis. As for annealing of damage, the basic mechanisms need considerable attention. The parameters such as damage coefficients, carrier removal rates, etc., have yet to be determined in GaAs cell materials, especially as functions of dopant species and levels. In summary, the following recommendations were made:

- (a) Role of substrate quality in relation to radiation damage must be determined
- (b) Increase emphasis on effects of purity, crystallinity and dopants in grown layers on performance with respect to radiation damage
- (c) Radiation induced defects and their kinetics must be determined
- (d) As for silicon, increased diagnostic sensitivity is a must for GaAs material purity evaluations
- (e) Along with (b) and (c), basic studies must commence to define damage introduction and recovery processes as related to temperature effects
- (f) A systematic study of annealing with a goal of 100% recovery at temperatures below 200°C, for fluences up to  $1 \times 10^{16}$  of 1MeV electrons
- (g) Determine electron and proton damage equivalences in conjunction with variations of dopant species and concentration levels.

Cell Design/Geometry - This area of discussion concerned P/N versus N/P structures. It was concluded that research as discussed above, was needed to determine the relative merits of the various dopant types and levels. Such data will influence GaAs cell design (thin P layer?, thin N layer?, etc.). Thus, the recommendation concerning cell design and geometry was:

Perform modelling of GaAs cell structures as data becomes available to determine alternates to present designs.

Cell Fabrication/Processing - This discussion was limited to aspects of LPE and MO-CVD cell processing (processed induced defects) in relation to radiation damage. There is little data available to support any interrelation of process/fabrication and radiation damage. The recommendation was to:

(a) Examine LPE and MO-CVD growth processes in relation to radiation damage, but perform pre and post irradiation characterizations (DLTS for example) to make comparisons

(b) Perform (a) above in light of dopant species and levels.

#### OVERALL SUMMARY

In general, it was concluded that diagnostic sensitivities and material purities were basic to making significant gains in end-of-life performance and thermal annealability. Further, GaAs material characterization is so sketchy that a well defined program to evaluate such material for solar cell application is needed to maximize GaAs cell technology benefits.

#### PARTICIPANTS

The participants in this session were:

Cliff Swartz - NASA Lewis RC

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Al Scheimine - Solarex

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