RESULTS OF THE AIR FORCE HIGH EFFICIENCY CASCADED MULTIPLE BANDGAP SOLAR CELL PROGRAMS

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SUMMARY

The III-V semiconductor materials system that was selected for continued cascade cell development in Phase II by both contractors was the AlGaAs cell-on-GaAs cell structure (ref. 1). The progress made by the contractors since October 1979 has been considerable. However, the tunnel junction used as transparent ohmic contact between the top cell and the bottom cell continues to be the central difficulty in achieving the program objective of 25% AMO efficiency at 25°C. During the tunnel junction and top cell developments within the last year, it became apparent that the AlGaAs cell has potential for independent development as a single junction converter and is a logical extension of the present GaAs heteroface technology.

INTRODUCTION

Air Force space missions will require power systems in the two to ten kilowatt range during the 1980's with expansion to two hundred kilowatts by the year 2000. Super-imposed on these power systems will be requirements for survival to various hostile environments as well as the normal space environment. Cascade cell development is critical to both near term and far term earth orbit missions. The main parameters that will drive the cascade cell development are watts/kilogram and cost/watt, both at mission end-of-life. Factors that strongly influence these parameters are cell conversion efficiency, cell weight (along with array blanket weight) and high cell yield in mass production. Air Force sponsorship of research development in these areas will receive very high priority.

This paper presents results of the cascade cell developments supported by the Air Force and discusses approaches to achieve high power-to-weight and low cost-to-power ratios.

AIR FORCE CASCADE CELL DEVELOPMENT - PRESENT STATUS

The objective of the Air Force cascaded cell research and development is to fabricate and demonstrate solar cells with greater than 25% AMO conversion efficiency at one-sun and at 25°C. Based on results of research conducted in Phase I, it became clear that a near term payoff could be made if the AlGaAs cell-on-GaAs cell structure was pursued in Phase II. This system is not the optimum one but certainly has potential for reaching the stated objective with reduced difficulties in fabrication. The most significant advantages for this material selection are (a) lattice matching between AlGaAs and GaAs is essentially ideal, (b) the use of a single AR coating, such as Ta_2O_5, is expected to be consistent with high conversion efficiency, (c) the contact metallization system for the top cell (and window) is fairly well developed and (d) the technology used to fabricate this structure can be extended to a three cell stack for further efficiency gains. This latter advantage, however, would require considerable trickery or cleverness since there are a limited number of lattice matched systems available (Ge or a GaAs on Ge or Si cell). However, a development of the understanding and the use of "super lattices" can relieve lattice matching problems and thus provide for a wide range of materials for a botton cell of a three cell stack.

Both liquid phase epitaxy (LEP) and chemical vapor deposition by breakdown of metal-organic compounds (MO-CVD) are being investigated. The LPE efforts are being accomplished at Research Triangle Institute and the MO-CVD work is ongoing at Rockwell International.

RESEARCH TRIANGLE INSTITUTE

The difficulties encountered in the development of the four original semiconductor materials systems (GaInP on GaInAs, AlGaAs on GaInAs, AlGaAsSb on GaInAs and AlGaAsSb on GaAsSb) led to the decision to explore a special case of the second system wherein no indium is in the bottom cell. RTI has successfully demonstrated complete cascade structure with conversion efficiencies of greater than 15% AMO without an AR coating. Problems do remain with device area uniformity and control of the P dopant (Be) in the tunnel junction. RTI is now modelling the structure to determine the optimum aluminum composition in relation to the AMO spectrum, AR coating(s) and minority carrier diffusion lengths that are considered realistic based on available data. The modelling data will be used to guide the cell development to achieve the program objective (ref. 2). Since details of the AlGaAs on GaAs system development by RTI are presented elsewhere in this conference, the reader is referred to that paper (ref. 3).

ROCKWELL INTERNATIONAL (RI)

The four systems pursued by RI in Phase I were based on the AlGaAs/GaAs system with emphasis on MO-CVD material growth. These systems are discussed in some detail in reference (1). Many problems were encountered with these systems in Phase I and it was decided to pursue the AlGaAs cell on GaAs structure using MO-CVD with some effort directed at molecular beam epitaxy (MBE). The most serious problem encountered (and still remains) is control of the P dopant in the very highly doped tunnel junction during subsequent AlGaAs top cell growth. Since there is no available Be-organic compound suitable for CVD growth, RI chose to grow tunnel junction using MBE grown layers comprised of GaAs N+:Sn on GaAs P+Be (see Figure 1). If the GaAs tunnel layers can be made very thin, absorption of photons usable in the bottom cell will be negligible. Another advantage is that the transfer of the structure from the MBE apparatus to the MO-CVD system does not present severe oxygen related problems as would be encountered if the tunnel were grown with AlGaAs in the MBE reactor. The bottom GaAs cell has posed no problems; in fact, the MO-CVD grown GaAs bottom cell has been measured by RI to be nominally 20% efficient AMO.

The current status of the RI effort can be summarized as follows: The AlGaAs top cell suffers severe losses from interface states for MO-CVD growths, however, the MO-CVD method has considerable promise in low temperature, low pressure growths and if a Be-organic can be synthesized (attempts will be made by RI), then complete cascade cell growth in one reactor system is feasible. The tunnel junctions (GaAs material) have been demonstrated to be reliably grown and grown very thin (≈200Å). Growth of quality AlGaAs top cell material on the MBE tunnel remains to be accomplished. The GaAs MO-CVD cells are viewed as no development problem. As for a completed stacked structure, the optimum configuration (at least forGaAs MBE tunnels) has been defined and voltage addition has been consistent and repetitively demonstrated. However, because mismatches of generated current in the top and bottom cells, reasonably efficient cascade structures have yet to be demonstrated.

SPIN-OFF TECHNOLOGY

As a result of the AlGaAs top cell development, it was recognized that a single junction in the AlGaAs material can be superior to the present GaAs heteroface structure. The advantages of this approach are: (a) it is possible to select the proper Al composition in order to achieve better bandgap matching to the AMO spectrum, (b) if minority carrier lifetimes can be adequately controlled, then a diode factor of near unity at the maximum power point is feasible, (c) placement of the AlGaAs-GaAs heteroface will be moved far away from the P/N junction resulting in improved voltage performance over that expected with increased bandgap but nearness to interface recombination, (d) simplified AR coatings are possible, (e) well developed electrical contacting can be employed, and (f) the cell concept can be pursued with relative ease using existing AlGaAs LPE and MO-CVD growth technologies. The Air Force is planning development of this cell type as a logical extension of the GaAs heteroface cell. With proper support, this sturcture could be introduced into manufacturing technology development and brought into inventory in the very near term (three to four years).

CONCLUDING REMARKS

RTI has been fairly successful with the LPE growth AlGaAs on GaAs structure. However, the device area has been limited by the LPE reactor design and large area LPE growth of cascade cells remain to be demonstrated. RI has encountered difficulty in fabricating a complete cascade structure of reasonable conversion efficiency (at least as good as silicon cells). But in the long term, MO-CVD growth of the complete structure by employing low temperature and low pressure or with a Be-organic (to resolve the P dopant problem) is very attractive from the points of view of mass production and large area. The Air Force is planning to continue emphasis on the AlGaAs on GaAs structure for use in the late 1980's. Both LPE and MO-CVD will be considered as likely mass production candidates until one approach shows clear superiority over the other in terms of yield and cost. Plans for three cell stacks have been defined for the 1980's and independent development of the three cell system will be pursued.

The AlGaAs homojunction cell will be pursued for the near term with the intention of using it by the mid 1980's. Also, independent research to develop the so called galicon substrate will be conducted. Reasonable results have already been achieved under joint Air Force and NASA sponsorship at the Jet Propulsion Laboratory (JPL) (ref. 4).

REFERENCES

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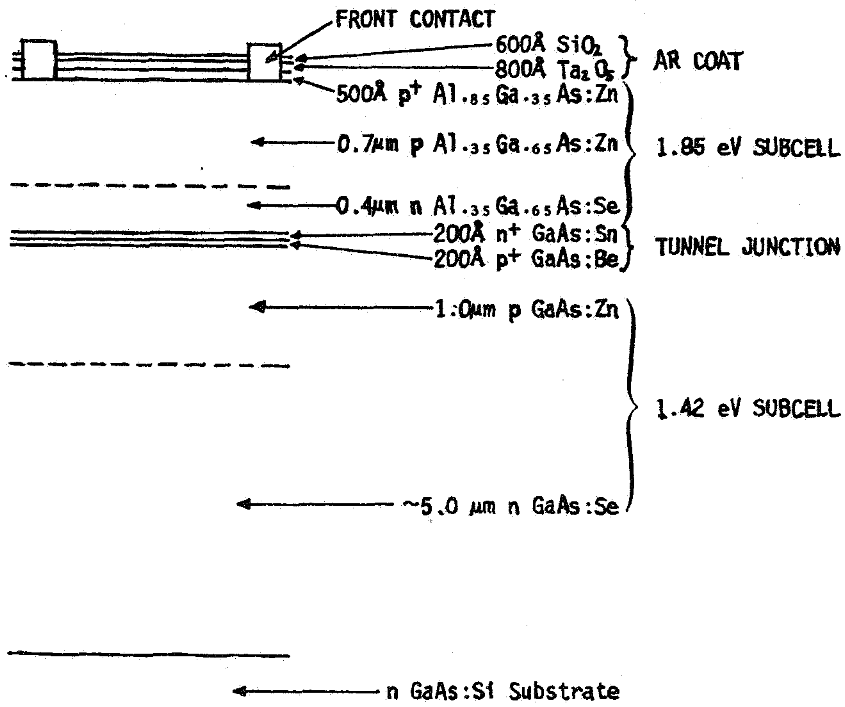

- MOCVD-GROWN ALGAAs AND GAAs SUBCELLS
- MBE-GROWN GAAs TUNNEL JUNCTION
- TWO LAYER AR COATING

FIGURE 1 ROCKWELL'S BASELINE CONFIGURATION OF THE TWO-CELL CASCADE STACK.