THE GaAs SOLAR CELL RESEARCH AND DEVELOPMENT PROGRAMS OF THE AIR FORCE

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INTRODUCTION

GaAs has received much interest for space application photovoltaics due to its inherent advantages over silicon. Higher efficiencies, superior radiation hardness, and a greater temperature resistance are the major advantages of GaAs over Si. Present and future Air Force programs will look for ways of maximizing these advantages while minimizing disadvantages such as higher costs and weights. Currently, four programs in GaAs photovoltaics are underway and each program will be discussed in terms of its objective, approach and present status.

HIGH EFFICIENCY SOLAR PANEL (HESP) PHASE II GaAs

The HESP Phase II GaAs program is being performed by Hughes Aircraft Company (ref. 1). The program began in September 1977 and will conclude by October 1980. The objective of the program is the development of space qualified solar cells having a beginning-of-life (BOL) efficiency of 16%, at 25°C, under air mass zero (AMO) illumination. After 7 years in the synchronous orbit radiation environment, which is approximated by 3 x 10^{14} 1MEV electrons/cm^2 for laboratory simulation, these cells shall have an end-of-life (EOL) efficiency of 14%, at 25°C, under AMO illumination. Hardening the contacts and interconnects against laser and nuclear weapon effects and the development of weldable contacting and interconnecting techniques will also be considered. Also the fabrication methods developed from this program must be documented to provide a potential mass production capability.

The approach chosen was to use GaAs substrates grown through the Horizontal Bridgeman Growth Method. The cell is then fabricated using the liquid phase epitaxy (LEP) method (ref. 2).

The first step in this process, the Horizontal Bridgeman Growth of GaAs substrates, is being performed by a subcontractor, Crystal Specialties. This method is diagramed in figure 1. Gallium is placed in a quartz boat container, that is contained inside a three zone furnace. Support liners of boron nitride are placed on the sides and under the boat to provide support at high temperatures. A small amount of tellurium dopant is placed in the growth ampoule in front of the boat and a stoichiometric amount of arsenic is placed on the other end of the growth ampoule. The ampoule is evacuated and sealed. The gallium is heated to 1247°C, while the arsenic is heated to 600°C. The arsenic sublimes and reacts with the gallium forming a GaAs melt. The melt is slowly cooled to form a single crystal, n+ doped GaAs substrate. Ingots of 2x2 inch size have been produced using this method. The ingots are sawed, lapped and polished into wafers of 8 and 12 mil thickness. The thin wafers had a high rate of failure (62% rejects) compared to the thicker wafers (25% rejects), due mostly to handling problems. The acceptable wafers are shipped to Hughes for cell processing.

The wafers are processed into cells by infinite solution liquid phase epitaxy (LPE). As shown in figure 2, a molten solution of GaAs and dopants of Al, Be, or Sn is maintained at the growth temperature (750°C). While the wafers are lowered into the solution, the growth temperature is reduced a few degrees to initiate growth. Each growth run takes about one hour. The wafer holder has been modified to hold (8) 2x2 inch wafers therefore producing (64) 2x2cm cells in each batch.

The finished cell is shown in figure 3. The substrate is the 12 mil tellurium n+ doped wafer. The first layer grown by LPE is the Sn doped n-type buffer layer of 10 micron thickness. The next layer is the Be doped p-type window layer of the AlGaAs of .5 micron thickness. The junction is formed by diffusion of Be through the window layer into the buffer layer. The depth of this junction is critical to the radiation hardness of the cell. The cells developed by this program have .3 micron junction depths.

The upper p contact of AuZn is applied by sputtering through a 24 finger mechanical mask. The AuZn layer is an alloy of 85% Au and 15% Zn by weight and is about 2000Å in thickness. About 5 microns of silver is applied and the contact is sintered at 480°C.

The lower n contact of AuGeNi is applied by thermal evaporation. This alloy is 85% Au, 12% Ge and 1.5% Ni by weight and is also about 2000Å in thickness. A 5 micron silver overlay is applied.

A 750Å thickness anti-reflection (AR) coating of Ta_2O_5 is applied. A 12 mil thick fused silica coverglass with a second AR coating of MgF_2 is applied using Dow Corning DC 93-500 adhesive. The finished cell is 30 mils thick with a weight of 1.1 grams.

The program is near completion and the final report will be out in a few months. Based on results from the qualification testing most of the program objectives have been met. Specifically the goals for BOL and EOL efficiency have been met and were exceeded. The tests have demonstrated the superior radiation hardness and higher temperature capability of the GaAs cells compared to state-of-the-art silicon cells. The fabrication process has been documented and based on the success of this program is capable of a pilot line production if the need should arise.

The biggest disappointment of this program was a very high rate of failure of the welded back tabs. Thirty-three (33) percent of the back tabs failed the .55lb pull test, while only 8% of the front tabs failed. Each cell has 6 front contact tabs and 6 back contact tabs used to interconnect the cells. One broken tab does not prevent an electrical interconnection, in fact, the connection between cells can be carried by a single tab. Based on a 33% failure rate, the mathematical probability of all 6 rear tabs being broken at .55lbs pull strength is only 1 in a 1000. However, of the 24 cells tested, there were 2 which had all 6 rear tabs fail. This indicates that an abornally high rate of failures are occurring on certain cells. Furthermore most of the failures are occurring in a series of tabs located next to each other. This would indicate that contamination due to handling may be causing the welding problem. Further work will be required in this area and this will be scheduled into the GaAs panel program.

GaAs SOLAR CELL PANEL

The GaAs Solar Cell Panel program is being performed by Hughes Aircraft Company. The program began in October 1979 and will conclude by April 1983. The original objective of the program was to design and build a space qualified GaAs solar panel of at least 1.2 square meters with a five year EOL power density of $125 w/m^2$ at 27VDC. The plan was to build this panel to the requirements of the GPS Phase II spacecraft, however, that has been cancelled. The new objective is to design and build 3 panels and possibly fly as an experiment on another spacecraft. The new design parameters are dependent on the spacecraft and therefore have not yet been determined. These panels will utilize cell technology developed from the HESP Phase II program. At the present time Hughes is in the process of making cells for the program.

RIBBON GROWTH OF SINGLE CRYSTAL GaAs FOR SOLAR CELL APPLICATION

The GaAs ribbon growth program is being performed by Westinghouse Electric Corp (ref. 2). The work began in July 1978 and will conclude by July 1981. The objective of the program is to produce very thin layers of single crystal GaAs substrate material thru the dendritic web process. The success of this program will lead to a reduction in cost and weight of GaAs cells. The dendritic web techniques has been very successful for the growth of both Si and Ge crystals and it is hoped that this process can be useful in growth of GaAs crystals.

The general process of dendritic web growth is shown in figure 4. A dendrite seed having twin plane structure is lowered into molten GaAs at such a temperature that the seed neither melts nor nucleates growth. By slowly cooling the melt, a "button" shaped growth begins to form over the top of the seed. As the button is slowly pulled upward, two dendrites form columns that extend into the melt. Between these two dendritic columns a very thin film of liquid forms. This film freezes rapidly into a smooth single crystal surface producing excellent substrate material. This process was first used on GaAs by Westinghouse in 1964 under an AF contract. However, thermal control problems led to As vaporization and as a result, the quality of the web was poor. To correct these problems, a liquid encapsulation technique was developed using B_2O_3 which acts essentially like a cover over the liquid GaAs. The B_2O_3 encapsulation method has been thus far proven effective in trapping the vaporizing As. In addition, a computer heat flow analysis has been developed for this method and the computer indicates favorable results for dendritic web growth. Further developments will include growing larger width webs and the growth of n doped webs.

At present several 12 inch long, one centimeter wide ribbons have been grown using this technique. The thickness has varied considerably between the dendrites. Also, the ribbons contained multiple dendrites rather than one on each edge. It is suspected that this is a result of a larger than expected thermal gradient in the pull direction. In the remaining months of the program it is hoped that these problems can be resolved through finer control of the ribbon growth parameters.

THIN FILM GaAs SOLAR CELL RESEARCH

The Thin Film GaAs Solar Cell Research program is being performed by Howard University. It is a 6 month program which began in June 1980. The objective is to fabricate a Schottky barrier gallium-silicon oxide MIS solar cell with a BOL AMO efficiency of at least 12% at 25°C. EOL efficiency should not be degraded by more than 30% when irradiated at a fluence of $1x10^{16}$ electrons/cm^2 at 1MEV.

The Schottky barrier solar cells are majority carrier devices whose lifetimes are 5 orders of magnitude more radiation resistant than minority carrier devices. The major obstacle in the development of these cells has been finding a stable oxide. This program will fabricate Shottky barrier cells by using a spin-on gallium-silica oxide on GaAs.

At this time Howard University is in the process of optimizing both growth parameters and oxide thickness. Also some "spin-on" oxide layers were deposited onto the layers of GaAs that were grown by LPE. The thickness of these layers is presently unknown. In the next few months the Air Force expects some completed cells for delivery.

LOW COST GaAs SOLAR CELL DEVELOPMENT

The Low Cost GaAs Solar Cell Development Program is expected to begin in the near future. It is scheduled to be a 3 year program leading to a high efficiency, radiation hardened GaAs solar cell with a greater than 50% cost reduction at device level. This will be achieved by building the cell on a dendritic ribbon substrate. The approach to this program will be highly dependent on the GaAs Ribbon Growth Program mentioned earlier.

CONCLUSIONS

The five GaAs solar cell programs discussed are indicative of AF efforts to achieve the ultimate solar cell for space use. High efficency, low cost and weight cells that are hardened to both natural and man-made hazards is the goal of the AF solar cell program. GaAs shows much potential towards meeting those goals. Future developments will likely include thinner substrates thus reducing cost and weight; reducing the junction depth which may lead to an increased particle irradiation hardness; utilizing the higher temperature capability of GaAs to increase laser hardness; and increasing efficiency to over 20%. Successful completion of these objectives will undoubtedly lead to the operational use of GaAs in future AF space missions.

REFERENCES

1. High Efficiency Solar Panel, Phase II, Gallium Arsenide Interim Report by Hughes Aircraft Co., AFAPL-TR-79-2058.

2. Ribbon Growth of Single Crystal GaAs for Solar Cell Application by Westinghouse Electric Corp., AFAPL-TR-79-2094.

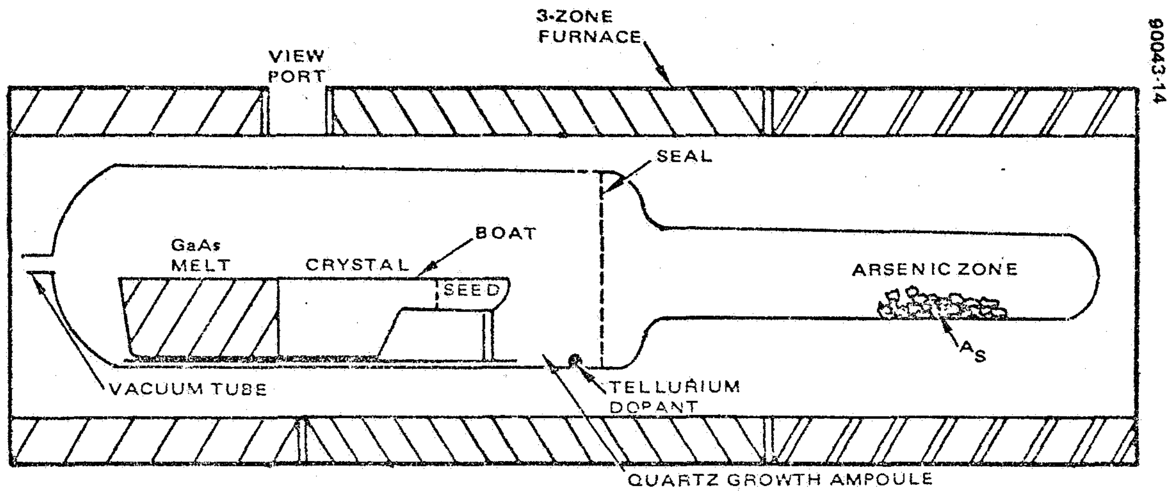

Figure 1 Horizontal Bridgman Growth.

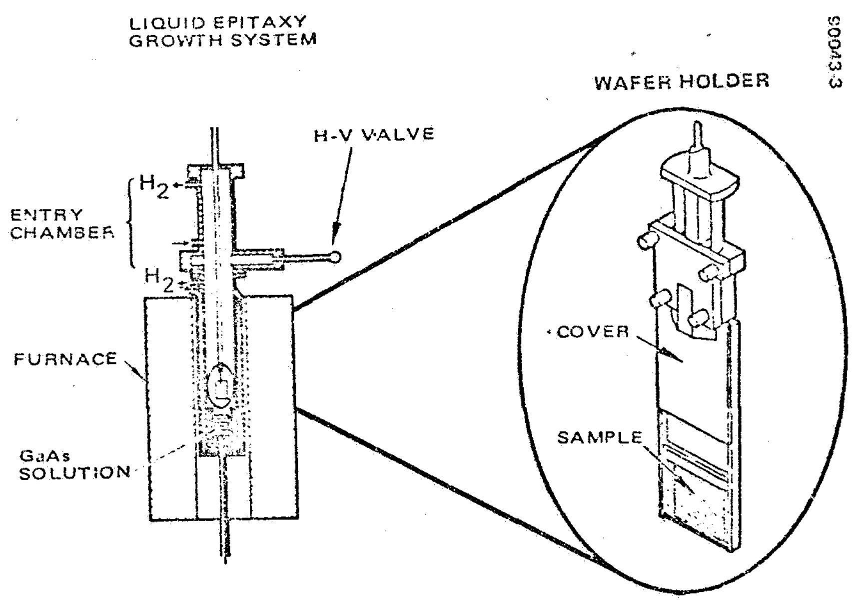

Figure 2. LPE fabrication of GaAs solar cells.

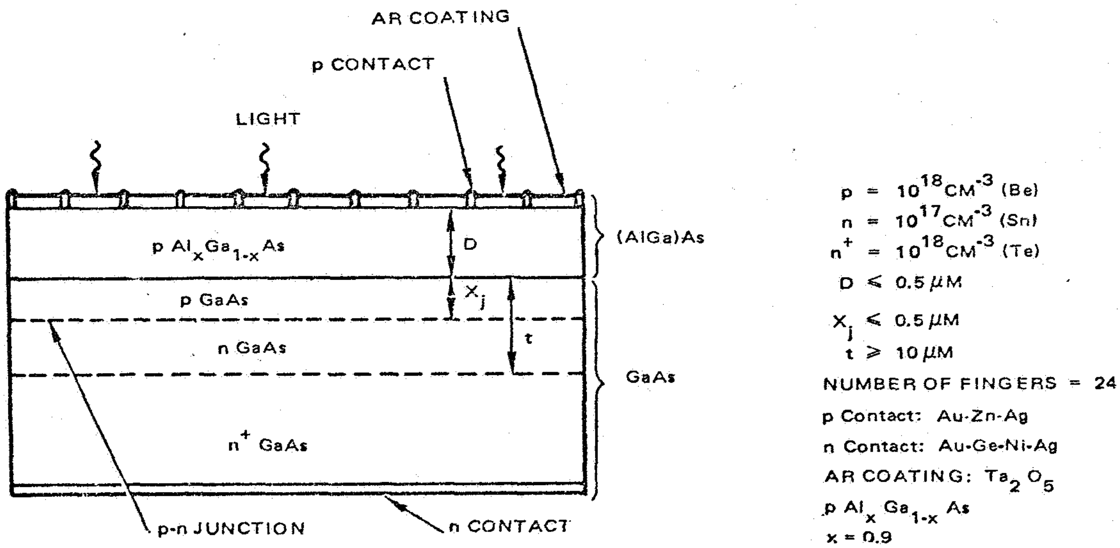

Figure 3 GaAs solar cell baseline design.

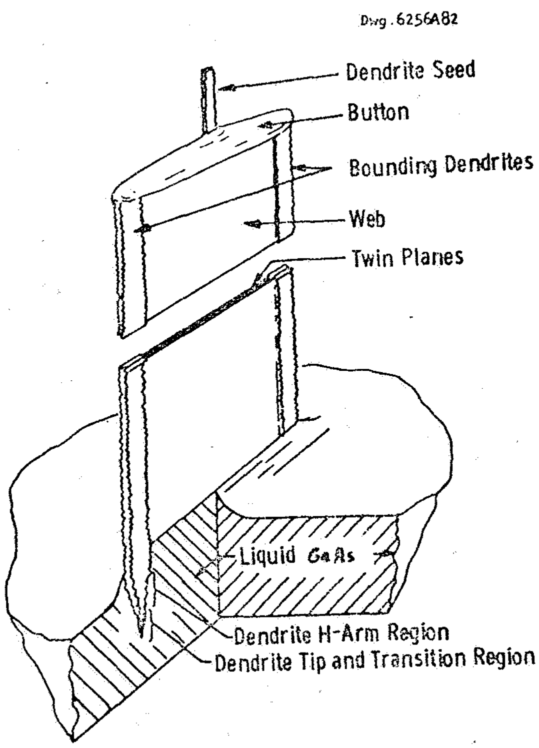

Fig. 4 – Schematic section of web growth

THE CLEFT PROCESS, A TECHNIQUE FOR PRODUCING EPITAXIAL FILMS ON REUSABLE SUBSTRATES*

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Using a new peeled film technique which we have named the CLEFT process we have grown single-crystal GaAs films by vapor-phase epitaxy on reusable GaAs substrates. A growth mask with narrow, widely-spaced stripe openings is first deposited on a single-crystal GaAs substrate with (110) orientation. The mask material is chosen to have low adhesion to GaAs. Epitaxial growth initiated within the openings is followed by lateral growth over the mask, which produces a continuous single-crystal GaAs film. The film is bonded to a secondary substrate and then mechanically cleaved from the GaAs substrate, leaving the surface of the latter in condition for repeating the procedure. In an initial demonstration of the CLEFT process, a solar cell with conversion efficiency of 15% at AM1 has been fabricated from a GaAs film only 8 μm thick mounted on a glass plate 300 μm thick. Because it can greatly reduce the quantity of bulk single-crystal material now being used in the fabrication of solar cells, the CLEFT process should permit a drastic reduction in cell cost without a significant reduction in efficiency. The CLEFT process should also be applicable to other semiconductors such as Si and InP.

* This work was supported by the Department of the Air Force.