AIR FORCE DEVELOPMENT OF THIN GaAs SOLAR CELLS

Ken Masloski
Air Force Wright Aeronautical Laboratories
Wright Patterson Air Force Base, Ohio

INTRODUCTION

The advantages of gallium arsenide (GaAs) over silicon (Si) type solar cells are many and have been well documented. However, two major disadvantages are weight and cost. Several ideas have recently surfaced that, if successful, will diminish these disadvantages. The CLEFT peeled film technique introduced by John Fan at Massachusetts Institute of Technology and the galicon cell being developed at the Jet Propulsion Laboratory are two of the more promising approaches. Presently, the Air Force is funding a program with Varian Associates, reference 1, to develop low weight, low cost, high efficiency GaAs solar cells. This paper will summarize the work under this program entitled "Low Cost GaAs Solar Cell Development".

PROGRAM GOALS

The specific goals of this program are the development of GaAs solar cells with at least an 18% conversion efficiency at beginning-of-life (BOL) and at least 13.5% after 5×10^{15} (1 Mev) electrons/cm^2. The cost and weight goals are $300/watt and 550 watts/kg respectively, both at the cell level without a cover. These goals are considerably beyond the current state-of-the-art and represent a difficult but realizable challenge that must be attained to meet future power requirements of 25 kW and higher.

The only logical way to achieve such goals is to significantly reduce the cell thickness. Since the collection process in a GaAs cell takes place in the first few microns, theoretically such a cell could be made with a thickness on the order of 2 to 3 microns. However, thick substrates do provide physical strength to the cell so there are limits as to how thin cells can be fabricated before breakage becomes a very serious problem. In this program, the thickness goal was set at 50 microns or less. It is very unlikely the other goals will be met if the thickness exceeds 50 microns.

The $300/watt cost goal translates to slightly less than $30 per 2 x 2 cm^2 cell. It is not the intention of this program to fabricate cells at this cost, but to identify fabrication processes that could reduce GaAs cell costs to this level on a large quantity scale. While cell cost is important, it is secondary to the power to weight ratio.

VARIAN APPROACH

The approach chosen by Varian on this program is to first optimize a thick (~300μm)AlGaAs/GaAs structure using the organometallic vapor phase epitaxy (OM-VPE) growth method. The OM-VPE process allows superior control in the growth of the various cell layers. Techniques such as a graded junction and base plus a back surface field (BSF) are expected to increase efficiency. Any combination of these is possible with OM-VPE plus the option of growing n on p or p on n devices. The optimum structure will be identified through a combination of material growths and an advanced computer model.

Since currently existing GaAs computer models do not account for effects such as junction grading and base grading, a more advanced model is to be developed. The approach is to divide the cell into 50 or so thin layers with the doping, composition, mobility, etc., assumed constant in each. The layers are then coupled by their boundary conditions, and the solution to each layer is analytic in form. The model will be verified and modified to incorporate the results from the initial experimental material growths. It will then be used as an analytical aid in developing the optimum structure with further material growths verifying the results.

The optimized AlGaAs structure will be thinned via a stop etch technique which has been used in the production of photocathodes at Varian. The idea is to grow a thin AlGaAs stop etch layer on the substrate at an appropriate postion to get the desired thickness. The cell active layers are grown, front contacts are attached, an AR coating is formed, and the cell is then glass bonded. The substrate is then chemically etched away to the stop etch layer. The result is a thin glass bonded cell that must only be back contacted. An alternate approach is to simply polish the substrate to between 30 to 50 microns. Both methods will be employed and compared to determine the yield vs performance tradeoff.

The method may seem costly; however, a detailed study by Varian indicates otherwise. Also, a gallium recovery process would be possible in a large scale production facility. A cost study is planned toward the end of this program.

PROGRESS

Considerable progress has already been made in the first six months of the program. Most of the work has been fabricating and testing of various material growths to determine the optimum structure. While grading the doping level in the base and the use of a BSF have proved effective, the graded windows have reduced cell performance. Based on the spectral response curve, it appears the graded windows are absorbing too much blue. The best cell had a BSF and graded base. Work is now underway to determine the most optimum way to utilize these features.

The basic cell structure is shown in figure 1. It is an OM-CVD grown p on n GaAs solar cell. The n type base layer is linear graded from 7 x 10^{17} to 2 x 10^{18} Se atoms/cm^3. Earlier material growths indicate the base grading should begin within the first micron from the junction. This can be modeled analytically by computer if exponential grading is assumed, thereby providing a constant electric field in the base. It is felt a graded base will build a field to force minority carriers towards the junction thereby improving efficiency.

A BSF is formed by inserting a thin (1300Å) layer of AlGaAs within the base and 1-1.5 microns from the junction. The BSF can be modeled as a zero recombination velocity boundary condition to the base. The purpose of the BSF is to confine carriers in the base, so they can be collected rather than lost to the substrate.

The p type emitter layer thickness is 1000Å, 2000Å or 3000Å in selected samples. The dopant is 2 x 10^{18} zinc atoms/cm^3. The top window layer is approximately 1300Å in thickness and is a $Al_{.8}Ga_{.2}As$ composition doped with 1 x 10^{18} zinc atoms/cm^3.

The alternative n on p structure is currently being considered and several material growths are being fabricated. Because of the higher mobility of n-type GaAs, the n doped emitter layer can be made much thinner. The emitter layer thickness for the n on p device will be 400Å to 800Å in selected samples. The n on p structures will be carefully evaluated to determine if any advantages exist over p on n structures.

Thinning via the polish back method and the stop etch technique is scheduled to begin by early spring 1982.

BLANKET TECHNOLOGY

In the near future, the Air Force plans to combine the thin GaAs cell with other technologies to develop light weight, hardened solar blankets. The other technologies include adhesiveless covers such as the plasma Activated Source (PAS) integral covers and Electrostatic Bonding (ESB), high temperature contacts and welded interconnects to reduce the vulnerability to laser threats. The objective is the development of a blanket with a BOL power to mass ratio of 250 watts/kg and at least 200 watts/kg after 1 x 10^{15} (1 Mev) electrons/cm^2.

Using current technology with 200 micron thick Si cells, a blanket level power to mass ratio of 116 watts/kg at BOL and 85 watts/kg after 1 x 10^{15} (1 Mev) electrons/cm^2 is considered good, reference 2. Unfortunately, the current technology cannot meet the higher power requirements expected for the near future. Since covered cells account for three quarters or more of the total blanket weight, it is obvious that the blanket power to weight ratio goals can only be met with thin, high efficiency solar cells with low mass covers. Such cells combined with high temperature contacts, and welded interconnects can meet the power to weight goals and significantly increase the military hardness without incurring additional weight.

Using the following weight assumptions, the blanket level goals can be put into perspective with the successful development of the thin 2 mil GaAs cell.

.0279 g/cm^2	2 mil GaAs solar cell
.0670 g/cm^2	12 mil 7940 fused-silica
.0027 g/cm^2	1 mil DC-93-500 adhesive
.0099 g/cm^2	3 mil Kapton-Al blanket
.0042 g/cm^2	Aluminum interconnect weight
.1117 g/cm^2	Total blanket weight

Assuming an 18% BOL, 13.5% EOL efficient cell provides a blanket level power to weight ratio of 217 watts/kg BOL and 163 watts/kg EOL. It should be noted the major weight cost is in the coverslide. The cover provides significant attenuation of proton irradiation, and the amount of protection is directly related to the glass thickness. Tradeoffs between coverglass thickness and EOL efficiency must be made for each mission to optimize EOL power to weight ratios. Clearly these numbers indicate a need for low areal density covers that are effective against particulate irradiation.

CONCLUSIONS

The work being performed at Varian represents a relatively straight forward approach towards the development of thin, high efficiency GaAs solar cells. The Air Force has a very strong interest in the development of light weight space power systems. Eventually, the thin cell technology will be combined with other appropriate technologies towards the development of light weight, military hardened solar array blankets.

REFERENCES

1. Low Cost GaAs Solar Cell Development - Air Force Contract #F33615-81-C-2025, Varian Associates, Pala Alto CA, Principle Investigator - Peter Borden

2. High Voltage High Power Solar Power Systems Study - Air Force Contract #F33615-79-C-2042, Lockheed Missiles and Space Company, (interim presentation)

THICKNESS	
1500Å	P+ WINDOW $Al_{.8}Ga_{.2}As$
1000Å to 3000Å	P EMITTER (2×10^{18}) Zinc dopant
1-1.5μm	n BASE (7×10^{17} to 2×10^{18}) linear graded Se dopant
1300Å	BSF AlGaAs
.5μm	Buffer Layer
~300μm	n+ SUBSTRATE GaAs Sn dopant ($1 \times 10^{18}/cm^3$)

FIGURE 1 CELL STRUCTURE