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PRODUCTION STATUS OF GaAs/Ge SOLAR CELLS AND PANELS

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GaAs/Ge solar cells with lot average efficiencies in excess of 18.0% have been produced by MOCVD growth techniques. A description of the cell, its performance and the production facility are given. Production GaAs/Ge cells of this type were recently assembled into circuits and bonded to aluminum honeycomb panels to be used as the solar array for the British UOSAT-F program.

INTRODUCTION

GaAs/Ge solar cells are in demand for applications involving spacecraft solar arrays which require increasingly higher power outputs per unit area but have no capacity for growth due to limitations on the array envelope. GaAs is grown onto a germanium wafer by metallo-organic chemical vapor deposition (MOCVD) techniques. The use of germanium as a growth substrate instead of gallium arsenide, enables solar cells to be manufactured which are robust enough to survive the assembly processes and handling required to produce solar arrays.

To meet this demand for high efficiency, rugged GaAs/Ge solar cells, Spectrolab has recently commissioned a new production facility which is able to fabricate solar cells in excess of 18.0% efficiency in a range of sizes varying from 2cm x 2cm to 6cm x 6cm. To date this facility has processed over 2000 4.5cm x 4.5cm wafers and produced material from which single junction GaAs/Ge, wrapthrough GaAs/Ge and dual junction GaAs/Ge solar cells have been fabricated. These cell types are presently being integrated into solar cell circuits for use on military and scientific research programs.

Earlier this year single junction GaAs/Ge cells of dimension 2cm x 4cm were produced and assembled into the UOSAT-F solar array. This effort is noteworthy on many counts. The program was completed in an extremely short time frame - 3 months; the bare cell lot average efficiency was 18.3% with a maximum of 19.7% the delivered solar array had an average circuit efficiency of 18.2% with a maximum of 18.6%.

In the following sections, a description of the solar cell design is given, including some unique features devised to increase cell stability at high temperatures. The new Spectrolab facility is described with its projected capacity for mass production of GaAs/Ge solar cells. Cell performance distributions from different programs are shown and finally, a description of the design and build of the UOSAT-F solar array is given including acceptance test performance data of the completed array.

MOCVD MANUFACTURING FACILITY

Spectrolab has established a high volume MOCVD manufacturing facility, currently occupying 7000 sq. ft. with room for expansion to 30,000 sq. ft. This area presently houses 3 MOCVD barrel reactors, each of which has produced GaAs solar cells of over 20% at AM0, 28°C efficiency.

Currently, the problem with large scale barrel MOCVD reactors is that gas depletion, which occurs as the source gases traverse the wafer, results in large variations in layer thickness and doping uniformity which ultimately translate to reduced yield and radiation hardness.

Based on this fact, and the need for improved uniformity to meet the more stringent needs of advanced solar cells such as $GaInP_2$/GaAs or AlGaAs/GaAs tandem cells, our strategy has been to pursue the development of improved, MOCVD systems to replace the conventional barrel design. Delivery of the first reactor is scheduled for delivery in the second quarter of 1992 with commissioning completed by the third quarter of 1992. Additional systems will be added to meet the needs of the market as it matures.

Our MOCVD strategy is also driven by the need for substantial cost reduction and the ability to provide an enabling technology for larger area GaAs/Ge solar cells up to 8cm x 8cm in size. The reactor is therefore being designed with 4" diameter wafer capability to provide a growth option for Air Force programs currently utilizing large area silicon cells or as a possible growth option for Space Station Freedom. Alternatively up to six 2cm x 4cm cells can be laser scribed from a 4" wafer, substantially reducing the cost of smaller area cells below current levels. Further cost reduction will also be possible through a three-fold reduction in cycle time thus substantially increasing the reactor throughput.

CELL DESCRIPTION

The cross section of the GaAs/Ge cell is shown in Figure 1.

The starting wafer upon which the active GaAs layers are grown is 7 mils thick, 4.5cm x 4.5cm n-type Ge, chem-mechanically polished on the front side and chemically etched on the backside. The wafer is doped to 5E17 cm^{-3} with Sb and oriented several degrees off <100> toward the nearest <111> plane.

MOCVD growth of GaAs is performed at low pressure. Growth conditions have been optimized to ensure electrical performance uniformity of ± 3% between the top and bottom rows.

The n-type GaAs buffer is between 2 to 6 microns thick and is doped to 5E18 cm^{-3} with Si. It is grown using a specific nucleation/growth procedure designed to minimize the diffusion of Ga into the wafer, thus assuring the elimination of an active Ge junction.

The base is typically 2 to 3 microns thick and is doped to nominally 2E17 cm^{-3} with Si.

The p-type emitter is doped to between 2 and 4E18 cm^{-3} with Zn and is typically 0.5 microns thick. The thickness is controlled using SPC to ensure radiation hardness which is known to be a strong function of emitter thickness.

An $Al_{0.85}Ga_{0.15}As$ window serves to passivate the surface of the emitter by providing an optically transparent heteroface at the cell surface. It is typically 500 A thick and is heavily doped to 2E18 cm^{-3} with Zn.

The dual antireflection (AR) coating used is Ta_2O_5/Al_2O_3. The window surface is specially treated prior to AR coating to guarantee subsequent environmental stability.

A noteworthy feature of the cell design is the front contact GaAs cap structure. This provides a very effective barrier against metal diffusion into the sensitive junction region. Cells manufactured at Spectrolab with this type of contact have shown thermal stability up to 550°C for several minutes duration and for over 500 hours at 350°C. The GaAs cap is typically 0.3 to 0.5 microns thick and is heavily doped (>1E19 cm^{-3}) with Zn to allow good ohmic contact to be achieved between the grid and the front of the cell. It also allows higher efficiencies to be achieved, compared to other designs, since it reduces the recombination velocity beneath the contact, allowing higher Voc to be achieved.

Both front and back silver contact layers are typically 5 microns thick and are weldable using Ag or Ag/Kovar interconnects without degrading cell performance.

CELL PERFORMANCE

Spectrolab has processed approximately 2000 Ge wafers on its manufacturing line into cell sizes from 2cm x 2cm, up to 6cm x 6cm. AM0 efficiencies exceeding 18% have been achieved for each cell type.

In Figure 2 we show the efficiency distribution of approximately 640 weldable 2cm x 4cm GaAs/Ge cells fabricated for the UOSAT-F flight program. The average efficiency was 18.3%. Representative cells, flown on the NASA Lewis Research Center Learjet under near ideal AM0 conditions confirmed the inactivity of the Ge wafer.**

In Table 1 we also show the efficiencies of thirty two 4cm x 4cm cells recently fabricated. The average AM0, 28°C efficiency was 18.3% with a best efficiency of 19.2%.

A limited number of 6cm x 6cm prototypes have also been made from 6.5cm x 6.5cm wafers. The IV curve of the best cell with an AM0 efficiency of 18.2% is shown in Figure 3. Further improvements in efficiency are expected by increasing the grid height to over 12 microns.

** The authors would like to thank David Brinker of NASA LeRC for assistance in performing the learjet measurement.

UOSAT-F

The UOSAT series of micro-satellites are built by the University of Surrey. Their primary goal is to provide a vehicle for research into satellite engineering topics at low cost. UOSAT-F is the fifth in the series and will fly an RAE Solar Cell Technology experiment, including indium phosphide and cleft GaAs cells for NASA-Lewis. The payload also includes a CCD Earth imaging camera.

The solar arrays are body mounted and fairly small area. To maximize power, therefore, GaAs is the material of choice for the array solar cells. The UOSAT-3 and -4 arrays were made by Mitsubishi and FIAR/CISE/EEV respectively. UOSAT-F provided an opportunity to fly an American GaAs/Ge solar array for the first time on an European satellite. Specifically it enabled Spectrolab to combine its skills as cell manufacturer and panel assembler to design build and test the array in an extremely short timeframe. UOSAT-F is scheduled for ARIANE launch in early May 1991.

UOSAT-F SOLAR PANEL ASSEMBLY

Cells taken from the distribution shown in Figure 2 were interconnected by means of welded silver-plated Kovar interconnects. Welding was chosen as the method of interconnection since earlier panel assembly experience had shown that solder wets GaAs and sometimes wicks under the interconnect and over the cell edge, thus shorting out the GaAs cell junction just below the surface. Attrition through the welding line was, as a result, less than 1%.

The cells were covered with 6 mil ceria doped microsheet and then interconnected into circuits of 42 cells series, 2 parallel.

The array consisted of three panels, each panel having two circuits bonded to it with CV 2568 silicone adhesive.

Each circuit was wired with 24 awg redundant wiring which were later connected directly into the spacecraft power system since the panels were body mounted.

The six circuits were tested on a LAPSS and found to have efficiencies varying from 17.9% to 18.6%.

The panel outputs at maximum power varied from 32.6 watts to 33.9 watts at 38 volts. The I-V curve for the latter is shown in Figure 4. The three completed panels are shown in Figure 5.

CONCLUSION

Spectrolab's MOCVD GaAs/Ge solar cells are now available in lot average efficiencies in excess of 18.0% in dimensions varying from 2cm x 2cm to 6.5cm x 6.5cm. Production capability is to be significantly increased with commissioning of a new, improved design reactor which will allow production of 8cm x 8cm cells.

Spectrolab's capability for integrating these cells into solar panels has been proven by the fabrication of the UOSAT array with circuit efficiencies as high as 18.6%.

Table 1 PERFORMANCE DISTRIBUTION OF 4cm x 4cm GaAs/Ge CELLS

Voc (mV)	Isc (mA)	Vmp (mV)	Imp (mA)	Pmp (mW)	Cff (%)	Eff (%)
1019	488	870	455	396	79.6	18.3
1013	474	874	444	389	80.9	18.0
1022	484	893	450	402	81.4	18.6
1018	468	873	444	387	81.3	17.9
1020	466	883	439	388	81.7	17.9
1025	468	896	444	398	83.0	18.4
1029	485	890	458	407	81.5	18.8
1020	465	888	435	386	81.5	17.8
1031	483	910	456	415	83.3	19.2
1025	455	893	438	391	83.9	18.1
1032	481	900	456	410	82.7	19.0
1031	484	894	443	396	79.4	18.3
1028	482	888	448	398	80.3	18.4
1031	490	892	463	413	81.7	19.1
1022	469	872	435	379	79.1	17.5
1026	469	886	433	384	79.7	17.7
1025	485	878	438	385	77.3	17.8
1027	478	894	444	397	80.9	18.3
1025	469	886	430	381	79.2	17.6
1028	475	902	449	405	83.0	18.7
1029	480	892	449	401	81.1	18.5
1031	488	892	467	417	82.8	19.2
1027	476	890	440	392	80.1	18.1
1031	468	904	447	404	83.7	18.7
1018	459	886	427	378	80.9	17.5
1023	478	900	448	403	82.5	18.6
1021	472	900	442	398	82.5	18.4
1023	471	898	439	394	81.9	18.2
1026	474	898	449	403	82.9	18.6
1026	483	891	444	396	80.0	18.3
1028	477	908	449	408	83.1	18.8
1025	470	900	436	392	81.5	18.1

Average Effy = 18.3

* AM0, 28 C

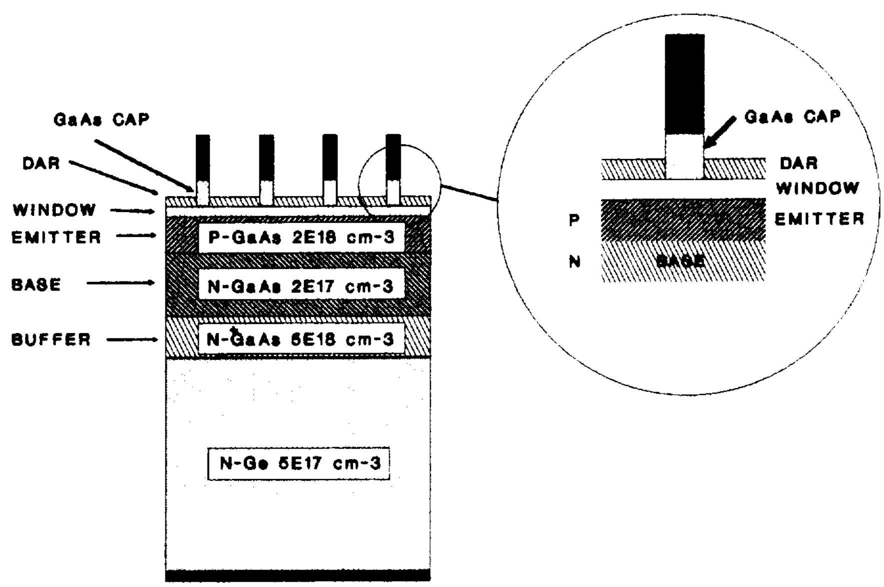
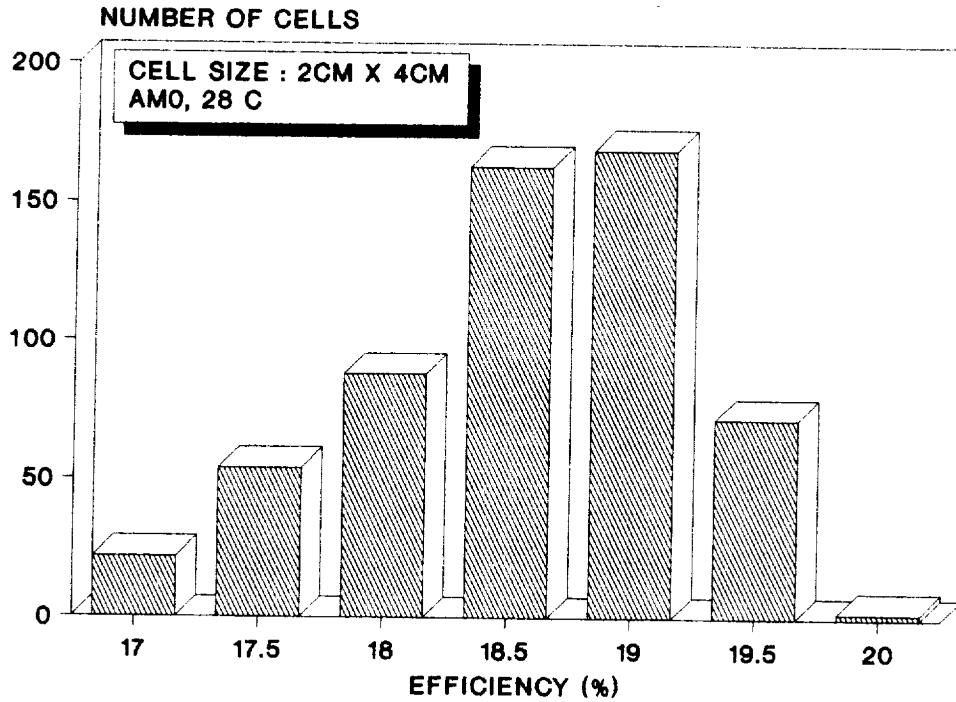


Figure 1 GaAs/Ge CELL CROSS-SECTION



640 CELLS › 16.5% (18.30% AVG)

Figure 2 EFFICIENCY DISTRIBUTION FOR UOSAT CELLS

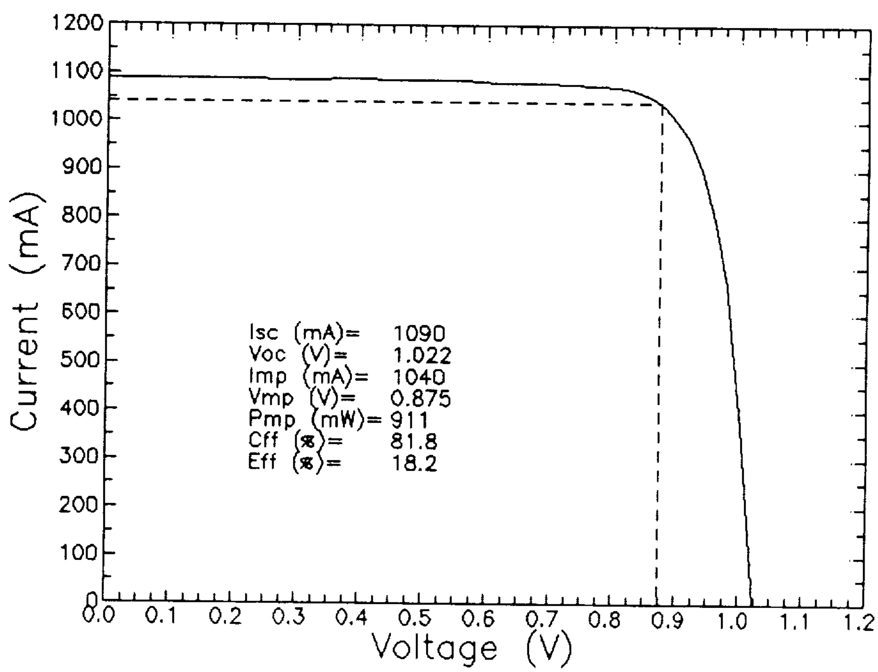


Figure 3 IV CURVE FOR 6.5cm x 6.5cm GaAs/Ge SOLAR CELL

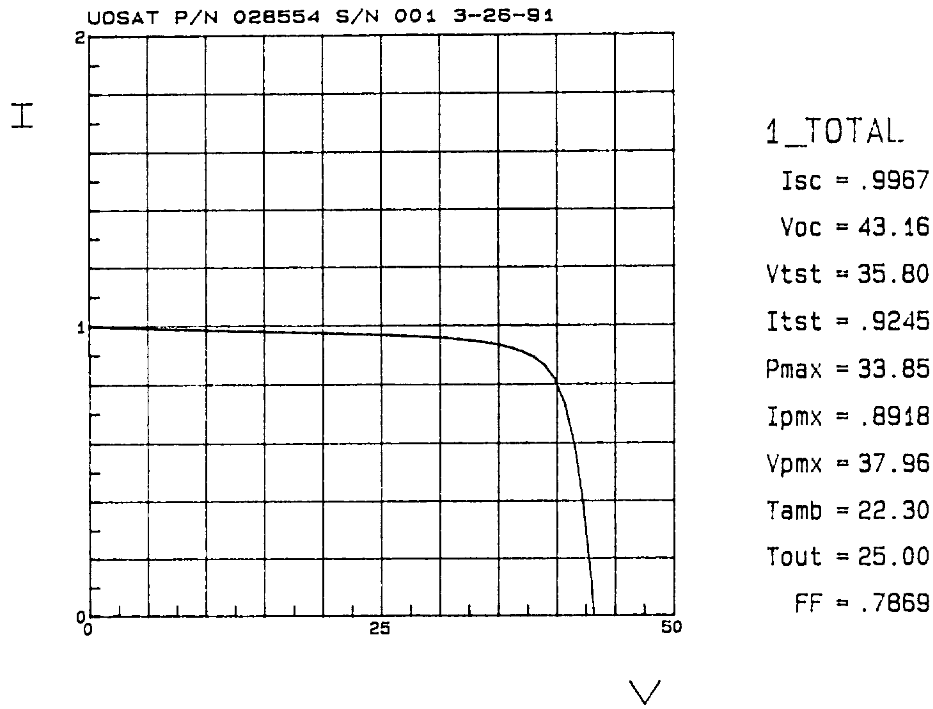


Figure 4 UOSAT PANEL POWER OUTPUT

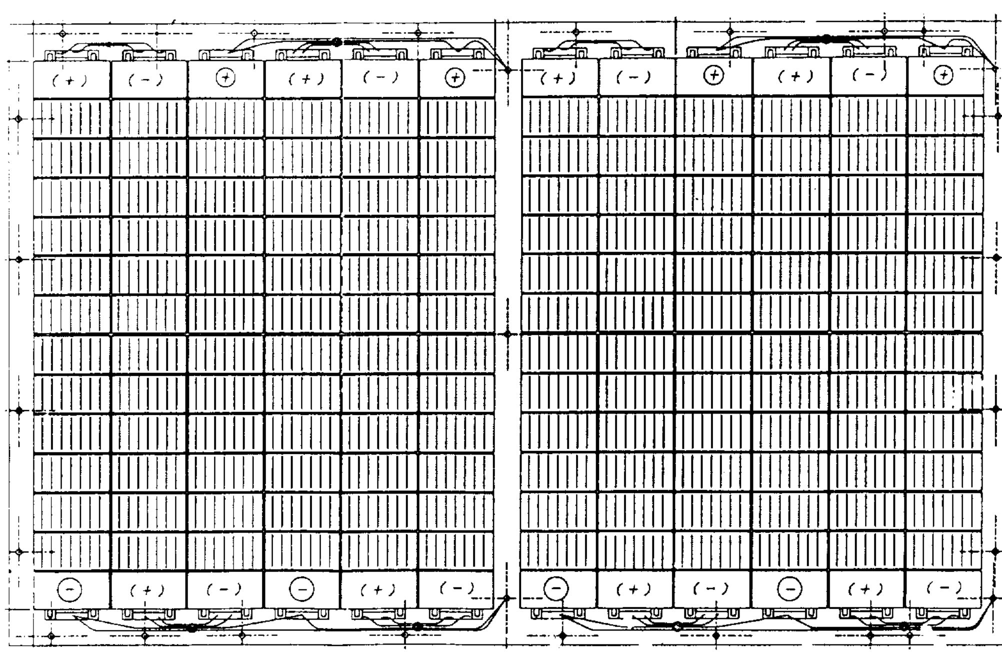


Figure 5 SCHEMATIC OF UOSAT PANEL LAYOUT