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POWERING THE FUTURE OF PHOTOVOLTAIC ARRAY DESIGN SPACE MISSIONS TECHNOLOGIES

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ABSTRACT

Improvements in performance and versatility are the main requirment in Space solar power systems to stay competitive for missions planned in the future. This paper describes an advanced array design based on the recently developed Greenhouse Gases Observing Satellite (GOSAT) oriented flatplate array. The advanced design incorporates the use of high efficiency InGaP(Indium Gallium Phosphide) on GaAs(Gallium Arsenide) on InGaAs(Indium Gallium Arsenide) triple junction solar cells that have BOL efficiencies of greater than 22%. Reflections off deployable flatplate shutters increase the sunlight concentration on the planar solar cell panels resulting in a 30% increase in power from the solar cells.

Each solar cell panel 4 x 4 mm^2 and 200 micro m in the cell and a BOL output power of 1667W at the operating temperature of 81°C. The full size array consisting of 2 wings with 3 panels/wing has a BOL output of 10.0 KW and a projected EOL (e.g., lx10^{15} e/ cm^2, 1 MeV) output of about 7.7 KW.

This advanced solar power structure provides a new approach for utilizing high efficiency multi bandgap solar cells in a retractable array configuration, thus providing higher efficiency and a more versatile operational design.

KEYWORDS: Concentrator cells, Inverted triple junction, Multi-junction solar cells, High efficiency.

BACKGROUND

Space solar power systems require improvements in performance and versatility to stay competitive for space missions. nowdays Most solar arrays contains silicon solar cells of an efficiency of about 14% on a rigid substrate. These arrays have typically the specific weights in the 15-20 W/Kg range. Lightweight flexible arrays such as the Hughes FRUSA or Lockheed SAFE designs demonstrated specific weights as high as 66 W/Kg and advanced SCARLET system is being configured for NASA's JPL New Millennium Deep Space One (DS1) spacecraft and is scheduled to launch in mid-1998.

Now there are new higher efficiency solar cells being developed and moved into production readiness, so improvements in array specific weights are available. Also there are new mission requirements that area being imposed on solar cell arrays which drive designers toward innovative array concepts. Specifically, there are needs for lighter weight, smaller area, larger power, concentrator and retractable array designs whatever the cost are. Some of these requirements are conflicting, such as providing more robust concentrator arrays at lower weight; however, there will always be a need to try to minimize weights of the concentrator designs.

Sharp achieved this latest breakthrough as a result of a research and development initiative promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO) on the theme of "R&D on Innovative Solar Cells" Measurement of the value of 36.9%, which sets a new record for the world's highest non-concentrating conversion efficiency, was confirmed at the National Institute of Advanced Industrial Science and Technology (AIST).

This paper describes the developing retractable rigid flatplate solar array which utilizes advanced high efficiency solar cells that is a subsystem in GOSAT and some power augmentation through concentrator shutters; thus providing a versatile baseline design for multimission requirements. This versatile array design, even, provides a good improvement in specific weight performance in most robust configuration and it can be modified for providing significant increases in performance for many missions by substituting ultra light weight semi-rigid substrates and less robust hardware. Consequently, this technology provides a baseline array design that can be sutable for a specific mission requirements and improve the specific weight performance.

SOLAR ARRAY DESIGN

The advanced retractable array design being reported in this paper is based on sharp flat plate array recently developed and commercialized by Hughes Aircraft Companyand most of the space crafts. The advanced design incorporates the use of high efficiency InGaP(Indium Gallium Phosphide) on GaAs(Gallium Arsenide) on InGaAs(Indium Gallium Arsenide) solar cells that have BOL efficiencies greater than 22%. Reflections off deployable flat-plate shutters increase the sunlight concentration on the planar solar cell panels resulting in a 30% increase in power from the solar cells. The efficiency as shown in figure 1 was validated by National Renewable Energy Laboratory (NREL) 302-suns concentration and with a cell surface area of 0.165cm2.

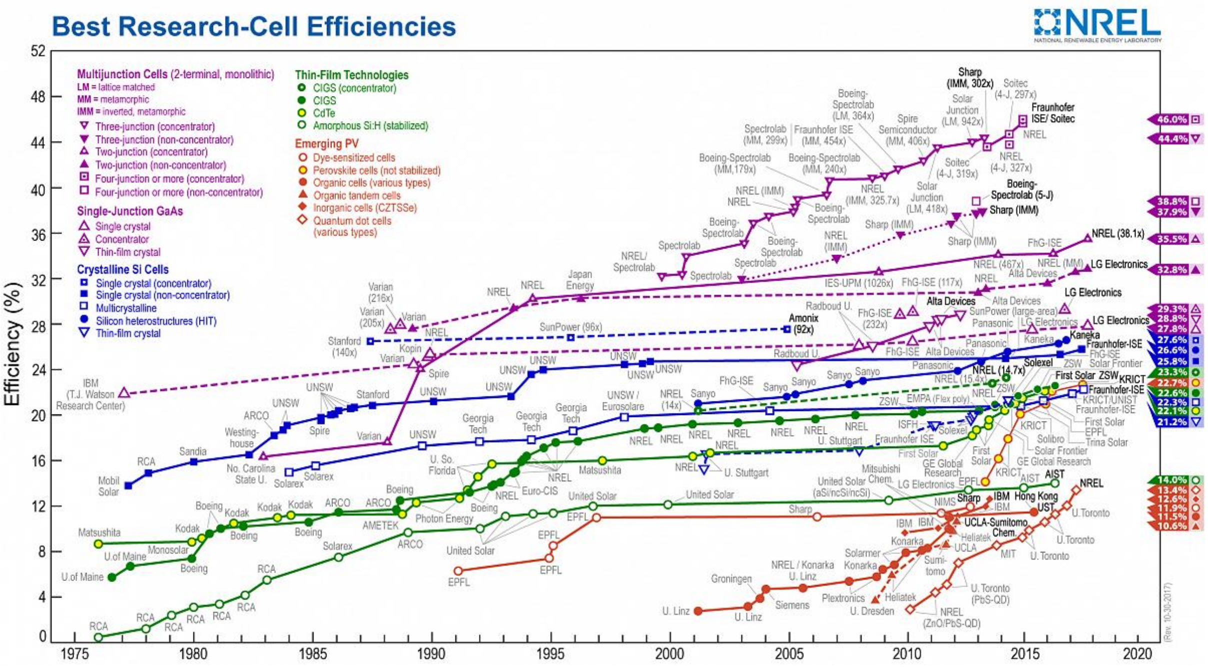

Figure 1: Sharp multijunction solar cell efficiency

Sharp and Germany's Fraunhofer Institute for Solar Energy Systems (ISE) are also part of an EU-Japanese project 'New Generation CPV' (www.ngcpv.org/) set up in June 2011 that is due to last 42 months up to the end of 2014. NGCPV has "the objective of approaching the 50% efficiency goal at cell level and 35% at module level". Sharp's cell uses three photo-absorption layers: indium gallium arsenide (InGaAs), gallium arsenide (GaAs), and indium gallium phosphide (InGaP) in an inverted metamorphic multi-junction (IMM) configuration. In the research, Sharp worked to expand the effective concentrator cell surface area and on improving the interface between concentrator cell and electrodes. The plan (Figure 2) is to use such cells in modules that combine many cells with Fresnel lens concentrators in fields of modules. Sharp began its development of solar cells for space applications in 1967, using single crystal silicon. The development of triple-junction compound semiconductor devices for the same purpose but with improvedn efficiency and durability, and reduced weight, began in 2000. Application of these cells began in 2005 with the small Riemei scientific satellite. The company has also developed triple-junction compound solar cells with 37.9%

conversion efficiency under 1-sun illumination for use in space, particularly in its work with the JAXA Japanese space agency.

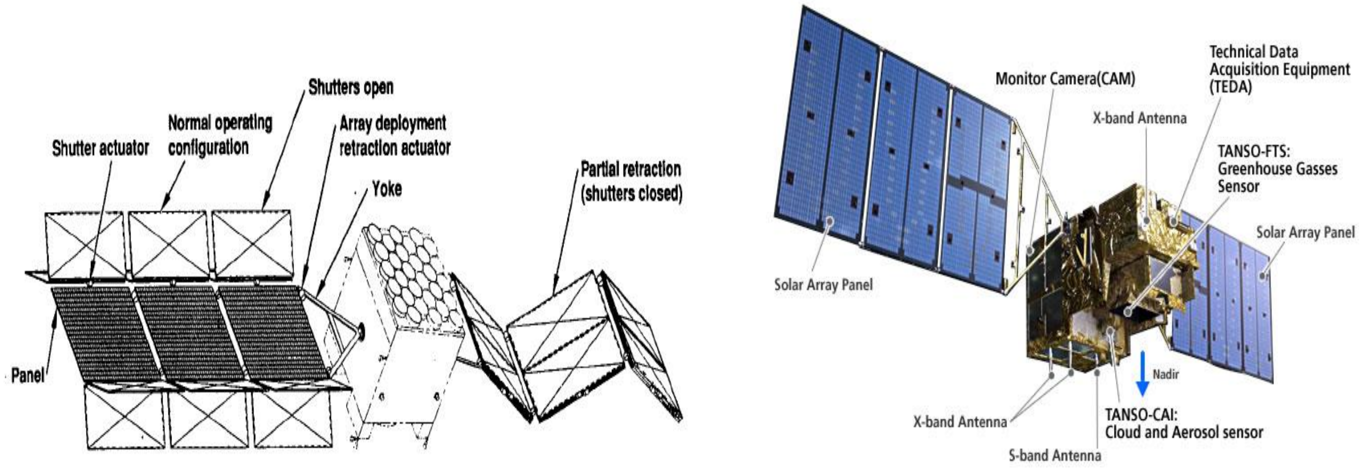

Figure 2: Sharp multijunction solar cells in modules

The advanced array in a partially and fully deployed configuration. Each solar cell panel 4 x 4 mm^2 and 200 micro m in the cell and a BOL output power of 1667W at the operating temperature of 81°C. The full size array consisting of 2 wings with 3 panels / wing has a BOL output of 10.0 KW and a projected EOL (e.g. , l x10^15 e/cm^2, 1 MeV) output of about 7.7 KW. providing a wide degree of versatility for in-orbit operations by deploying, retracting and relatching the array automatically in the orbit; increase the maneuverability and retrievability. Reliable mechanisms is designed for the deployment, retraction and latching operations. The shutter utilizes a combination stepping motor/cocked spring approach. Repeated deployment and retraction of the solar panels is completed with the use of four 250 in-pound stepper motors synchronized by use of different gearheads.

The solar cell panel/shutter stack occupies a volume 2.16×2.54 m^2.The three-panel, six-shutter stack is held in place during launch using a tensioning cable that holds the parts against snubbers. For deployment release, the tensioning cable is cut using redundant pyrotechnic cutters. Eight tiedowns are used to hold the three-panel stack and provide a panel launch configuration natural frequency of >19 Hz. concentration configuration and the associated mechanisms required to provide deployment and retraction functions. A yoke structure ties the solar array to a BAPTA solar drive mechanism installed on the spacecraft.

This drive mechanism provides the array pointing and electrical connection functions through slip ring mechanisms. The shutter mechanism utilizes a stepper motor/cocked spring actuator to deploy or retract because each solar cell panel has a stepper motor drive synchronized through the use of a gear reduction mechanism to deploy and retract the panels.. To open the shutter, the stepper motor rotates the shutter to the desired angle to provide optimum sunlight collection. Which in turn cocks the spring mechanism so that for retraction, the spring mechanism is simply uncocked and the shutter flies back to the closed position using a damping device to limit the closing velocity.

The solar cell array is laid out using nominal 4x4cm2 indium gallium arsenide (InGaAs), gallium arsenide (GaAs), and indium gallium phosphide (InGaP) in an inverted metamorphic multi-junction (IMM) configuration solar cells 0.010 cm thick. Sixty five solar cells are connected in series. Five of the series strings are connected in parallel to form a redundant circuit group. providing the Bypass diodes for every five cells in series to prevent damage to the solar cells due to shadowing or current generation mismatch. Ten of the circuit groups are connected in parallel to the panel bus. Redundant blocking diodes are connected in series with each of the circuit groups to prevent battery power from leaking through the solar cell array when not illuminated.

The 3250 solar cells on the panel in orbit at beginning-of-life (BOL) and at the operating temperature of 81°C provides a maximum power of 1667 watts at 60.0 volts. A three-panel wing thus provides a BOL power output of 5KW. After the equivalent of 1x10^15 e/cm2 fluence of 1 MeV electron radiation, the end of life (EOL) power output of a three-panel wing is predicted to be 3850W. A full two-wing array thus provides a BOL and EOL power output of l0 KW and 7.7KW respectively, table 1 represent The solar cell array performance that used in the system.

Cell size	4.00* 4.00 mm
Panel configuration	InGaP/GaAs/InGaAs
Isc	15.25 mA
Voc	3.014 V
Pmax	39.50 mW
Ipmax	14.74 mA
Vpmax	2.68 V
F.F	86.0 %
EFF	37.7 %
DTemp	25.0 C
MTemp	25.2 C
DIrr	100.0 mW/cm2
MIrr top	100.7 mW/cm2
MIrr middle	100.8 mW/cm2
MIrr bottom	99.5 mW/cm2

Table 1: sharp multijunction solar cells characteristics under AM1.5G (1-sun)

STRUCTURAL CONSIDERATIONS

Structural design was based on a combination of requirements related to the accommodations of launch loads, deploymenthetraction torque loads, and acceleration induced by the evasive actions of the spacecraft. In addition, the deployed natural frequency of the array had to be above a minimum acceptable associated with the operation of the spacecraft attitude control system. Launch loads mandate stowed array designs compatible with quasistatic loading levels in the 20 to 23g range and a stiffness compatible with a minimum 19Hz natural frequency for the stowed array. During normal operations in orbit, the array structure needs to provide a deployed natural frequency greater than 0.14Hz. As mentioned earlier, some missions being addressed require a robust design capable of withstanding high stresses resulting from mechanical and thermal environments. To meet these severe stresses, the baseline array design utilized a titanium honeycomb panel structure. Based on a launch load analysis, a one-inch thick panel with eight mil thick face sheets brazed onto a 3/8 inch cell honeycomb core meets the strength and stiffness requirements listed above. While the shutters are not active structural members of the array, they must be strong enough to survive launch loads and to avoid excessive deflections which could damage the array. The frames and blanket must not be allowed to contact the panels, either during launch or during retraction. Also, for the robust more versatile baseline design, shutters with rhodium plated titanium thermal blankets can be utilized to provide thermal shielding of the solar cells if desired. The shutter frame is made with 0.50 inch thick titanium honeycomb and will meet the stiffness requirements. Also, for the robust baseline design, redundant stepper motor actuators are used for both the shutters and the panels.

WEIGHT CONSIDERATION

Weights of all the components of a three-panel wing are shown in table 2 with total 397 lbs. for the robust baseline array design. Although this represents a much heavier design than required for most missions the BOL specific power of 12.6W/lb (27.8 W/Kg) represents an improvement over most similar robust designs. In order to investigate potential improved specific weights, three variations to this baseline design have been made; the associated weight changes and compared to the baseline design. In the first variation (Base/601), the titanium honeycomb substrate is replaced by a conventional with kevlar facesheet substrate. The double-sided shutters are replaced by a lighter weight single-sided shutter, and redundant motor actuator assemblies are replaced by single drive actuators. Motor drives for the shutters allow for retraction of the array. The resultant weight of a three-panel wing is reduced to 184 lbs. which represents a substantial increase in the BOL specific weight of 27.2 Whb (59.9 W/Kg). weight HS-601 substrate that has most of the aluminum honeycomb removed except for a grid pattern of one-inch wide ribs located on 12-inch centers.

Also, the shutter motor drives have been eliminated so retraction is not planned. This reduces the array weight substantially so that the 3-panel wing weight is reduced to 132 lbs. and operating temperature of the cells is decreased from 80°C to 70OC. This design results in a BOL specific weight of 39.2 W/lb (86.3 WKg). The second variation design utilizes a modified light- The third variation utilizes the same lightweight structure described above; however, the power output augmentation from the shutters is increased from 30% to 60% by increasing the size and optical efficiency of the reflectors. This results in a BOL specific weight of 50.9 W/lb (1 12.1 W/Kg) which represents a very attractive and advanced rigid solar cell array design.

Item	Base	Base/ 601	LTW T base	LTWT/ 301 * base	Qty	Weight, lb
Substrate	90	48	28	28	3	90
Cell assembly and harness	44	44	44	44	3	44
Hinges	9	9	8	8	18	9
Panel motor assembly	32	4	3	3	4	32
Shutters	66	12	12	12	12	66
Shutters motor assembly	48	24	-	-	12	48
Yoke	18	18	16	16	1	18
Thermal and ESD	10	10	9	9		10
Contingency	80	15	12	12		80
Total ,lb	379	184	132	132		397
Power prediction (on-orbit at 80 C (1E15 e/cm^2)						
BOL,W	5000	5000	5170	6721		
BOL,W/lb	12.6	27.2	39.2	50.9		
BOL,W/kg	27.8	59.9	86.3	112.1		
EOL,W	3850	3850	3981	5175		
EOL,w/lb	9.4	20.9	30.1	39.2		
EOL,W/kg	21.4	46.0	66.3	86.3		

Table 2: Sharp multijunction solar array wing (3 panel) design

CONCLUSIONS

This paper describes a baseline retractable sharp multijunction solar array design that is versatile specific power capabilities. Shutters are utilized to provide protective thermal shields; but at the same time are used to increase the array power by concentrating sunlight on the solar cells. Furthermore it is provided by retraction motors to increase maneuverability and operational freedom. The baseline design utilizes titanium construction so that very high temperatures can be experienced without structural or electrical degradation. The BOL specific power of about 28W/Kg is substantially higher than most other solar cell arrays.

This array design has the capability of being modified such that higher specific power values can be achieved as mission requirements change. The three design variations that described verify that BOL specific power values can be increased to 60,86, and 112 W/Kg respectively, thus providing a light flatplate solar array design capable of meeting various mission requirements of the future.

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