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UPDATE FOR THE STRETCHED LENS ARRAY SQUARERIGGER (SLASR) FOR SPACE

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Abstract

Over the past three years, the Stretched Lens Array SquareRigger (SLASR) has been tested and developed to a state of readiness for flight. The SLASR offers an unprecedented portfolio of performance metrics, including an areal power density of 300 - 400 W/m², specific power of 300 - 500 W/kg, and stowed power of 80 - 120 kW/m³. The larger values are for solar cell technology that will be available in 2008. In addition, the SLASR is scalable in array power over a range of 4 kW to 100's of kW's and more. Another significant advantage of this array is that the small cell circuits can be "super-insulated" and "super shielded" thus enabling high voltage (300 to 600 V) and excellent radiation hardness with low mass penalty. Finally, the small area cells use less semiconductor material leading to a solar array cost 66% to 75% lower per watt than a conventional planar array. These advantages lead to a modular, scalable design that can be mass produced at megawatt levels using existing fabrication capacities. This paper will describe those advantages in detail.

1. Introduction and Background

The team listed above has been developing refractive photovoltaic concentrator systems for producing space power from sunlight since the middle 1980's [1]. The first such technology developed and successfully flown in space was the point-focus mini-dome lens array, shown in Fig. 1. This array used mechanically stacked GaAs/GaSb cells from Boeing in the focal point of ENTECH's silicone mini-dome Fresnel lens concentrators. The lenses were coated with a multi-layer oxide coating to protect the silicone lens material from solar ultraviolet (UV) radiation and monatomic oxygen (AO). The

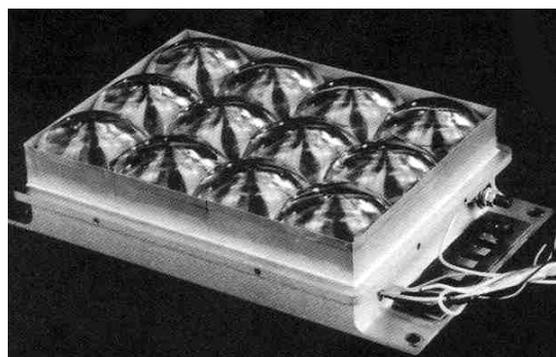


Figure 1: PASP-Plus mini-dome array

mini-dome lens array in Fig. 1 flew in 1994-95 on the NASA/USAF year-long PASP-Plus flight test in a very high-radiation elliptical orbit (363 km by 2,550 km at 70-degree inclination). Of the 12 advanced photovoltaic array types

included on PASP-Plus, the mini-dome lens provided the highest performance and the least degradation [2].

After the mini-dome lens array success, ENTECH, NASA, and other team members next developed the line-focus arched lens array, which evolved into the SCARLET array that performed flawlessly for the full thirty-eight-month mission on NASA's Deep Space 1 probe, shown in Fig. 2. SCARLET (acronym for Solar

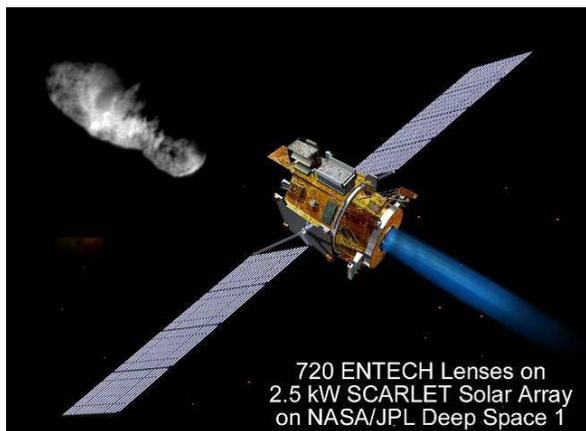


Figure 2: Scarlet array on NASA/JPL Deep Space 1 probe (1998-2001)

Concentrator Array using Refractive Linear Element Technology) employed silicone Fresnel lens material made by 3M using a high-speed continuous process. ENTECH laminated this silicone lens material to 75-micron-thick ceria-doped glass arches, which provided support and UV protection for the lenses. Monolithic triple-junction (GaInP/GaAs/Ge) cells were placed in the focal lines of the SCARLET lenses. The SCARLET array powered both the spacecraft and the ion engine on Deep Space 1 and performed as predicted on this highly successful mission [3].

Shortly after the SCARLET array delivery, ENTECH discovered a simpler approach to deploy and support the line-focus silicone lenses, thereby eliminating the fragile, bulky,

and expensive glass arches used on SCARLET. The new approach uses simple lengthwise tensioning of the lens material between end arches for lens deployment and support on orbit. Called the Stretched Lens Array (SLA), the new ultra-light concentrator array also enables a very compact stowage volume for launch [4]. The SLA is compatible with a variety of space array platforms, from small unfolding rigid-panel wings to large deployable flexible-blanket wings. Of all the platforms evaluated for SLA to



Figure 3: SLA/SR demonstration module

date, the lightest and most compact is ATK Space Systems' SquareRigger [5].

2. Stretched Lens Array/SquareRigger

The Stretched Lens Array on the Square Rigger platform offers an amazingly compact stowed volume and an extremely light-weight deployed platform for the flexible-blanket version of SLA for high-power space missions, as shown schematically in Fig. 4. For launch, SLASR's carbon composite structural tubes stow in a very compact volume, with the two folded and interleaved blankets of lenses and radiator sheets (containing the solar cell circuits) nested between the tubes. On orbit, the tubes automatically deploy to form rectangular "bay" structures, each about 2.5 m x 5.0 m in size.

After the bay tubular frame structure deploys and locks, the lens and radiator blankets are automatically pulled across the frame to form the deployed solar array. Recently, a full-scale SLASR bay has been fabricated and successfully deployed. Fig. 5 shows a front view of the deployed bay. The frame deploys in two minutes and the lens and radiator blanket takes 15 minutes. Both deployments are done with a single motor.

Multiple bays of the 2.5 m x 5.0 m size shown in Fig. 5 are employed to form large solar array wings for high-power space missions. Since each bay provides about 4 kW of power on orbit, two 12-bay wings will provide about 100 kW on orbit. For this 100 kW point design, the lens and radiator blankets comprise about 70% of the total wing-level mass, which corresponds to only 0.85 g/m² for this large array size.

3. SLASR Component Improvements

Over the past year, SLASR technology maturation work included the development of several

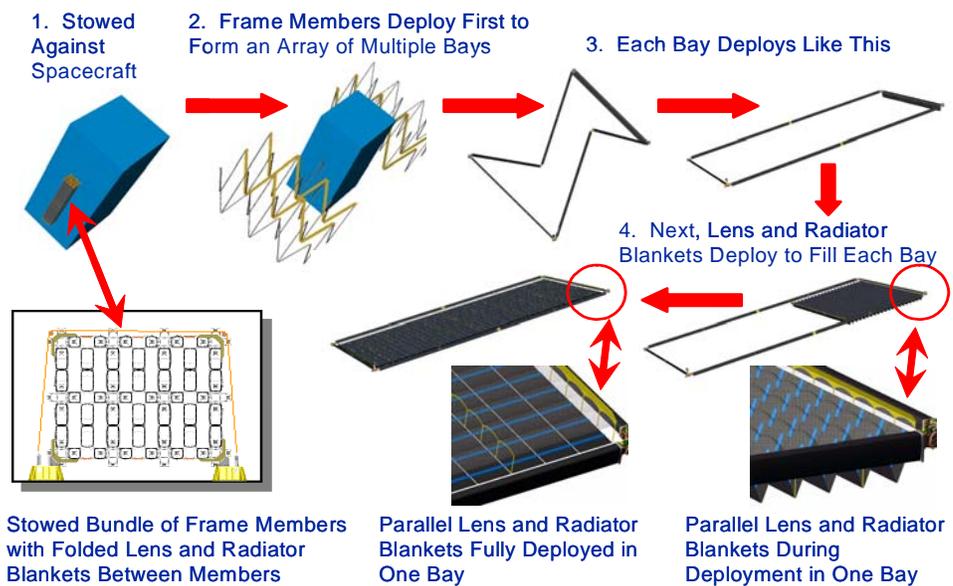


Figure 4: Stretched Lens Array SquareRigger (SLASR) schematic



Figure 5: 3.75 kW SLASR module

improved key components. First, a mission-tailorable protective coating for the silicone stretched lens has been developed. This coating can have a thickness over the range of 0.2 to 5.0 μm. In addition, an integral-diode, high efficiency multijunction multi-junction solar cell optimized for 8-suns irradiance has been produced.

The new lens coating work is based on the latest protective coating that very effectively blocks vacuum ultraviolet (VUV) wavelengths in space sunlight from reaching and possibly

damaging the silicone lens material beneath the coating. The graph in Fig. 6 shows the spectral transmittance of a coated silicone samples before and after more than 1,000 equivalent sun hours (ESH) of space sunlight VUV exposure. This thin lens coating will provide adequate lens protection for many missions (e.g., LEO, GEO,

or Deep Space). For very high radiation missions (e.g., belt flyers or space tugs flying between LEO and lunar orbit), a thicker coating is desirable to reduce the charged particle

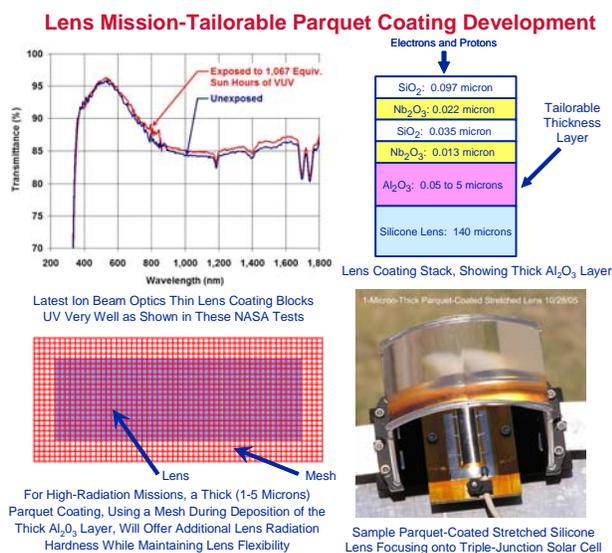


Figure 6: Mission-tailorable parquet lens coating.

radiation dose reaching the silicone lens. Dose-depth profile calculations show that a coating thickness up to 5 microns could be desirable for such missions. Such a thick coating will be relatively rigid, making it seem to be incompatible with the stretched lens approach. However, by using a parquet approach to the coating application, the thick coating can be separated into small regions, allowing the lens as a whole to remain flexible enough to stow and deploy as a stretched lens. The new process uses a mesh screen during coating application to provide the patterned parquet geometry, as shown in Fig. 6. The SLA module in Fig. 6 demonstrated the predicted performance for a 1-micron-thick parquet coating on a stretched lens focusing onto a triple-junction solar cell, showing the practicality of the new process.

Under previous Stretched Lens Array (SLA) development programs, the photovoltaic receiver used discrete bypass diodes to protect the multi-junction cells from reverse-bias

damage. These discrete diodes were relatively large, and were positioned alongside the solar cells, making the overall circuit about 2.0 cm wide, although the cells were only 1.2 cm wide, including busbars. The whole photovoltaic circuit (cells and diodes) must be well insulated, both above and below the circuit, to operate reliably at high voltage in space. To reduce the mass and complexity of the SLASR solar cell receiver, an integral-diode concentrator cell shown in Fig. 7 has been developed. To increase reliability and to minimize diode temperature excursions under bypass operation, redundant diodes are being used on the new cell. Two end tabs will be used to connect the back of the neighboring cell to both top bus bars of the SLASR concentrator cell, as well as closing the circuit between the tops of the diodes and the bus bars on the SLASR concentrator cell. The total photovoltaic receiver width is about 40% narrower for this approach than for prior SLA receiver approaches, reducing mass proportionally. While these new cells have not yet

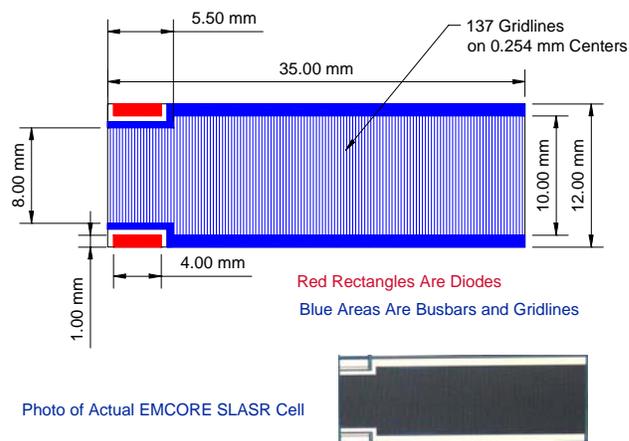


Figure 7: New, integral-diode concentrator cell.

been fully evaluated at 8 suns, one-sun data indicate that the new integral-diode cells should match earlier SLA cells with over 30% efficiency at 8 AM0 suns and 25 °C.

4. System Level Performance Metrics

The key performance parameters and system-level metrics for SLASR are revolutionary. The bottom-line areal power density, specific power, and stowed power are all unprecedented values, well above the current state of the art for space solar arrays of any kind. In addition, that this performance can be achieved at a significantly lower cost than conventional planar arrays can lead to a major change in spacecraft design.

Starting at the lens, its transmission has been measured at 92%. The latest multi-junction solar cells have an average efficiency of 30% at 25 °C. Thus the combined net lens/cell efficiency at 25 °C is 27.6% as confirmed by measurements made at high altitude. The cell temperature at GEO is predicted to be 71 °C – and this was confirmed on the SCARLET array on the Deep Space 1 mission. From measured temperature coefficients of the multi-junction solar cells, this temperature would decrease the cell output by 9%. Given the outer space solar intensity of 1366 W/m², (International Standard), the gross areal power density is 343 W/m². for a packing density of 90% the net areal SLA SquareRigger power density becomes **309 W/m²**! Based on the measured masses of components in the prototype module shown in figure 5, the wing mass density is 0.853 kg/m², which then leads to a SLASR net specific power of **362 W/kg**. Finally, again based on the prototype, the SLA SquareRigger stowed power density reaches an astounding value of **80 kW/m³**.

As noted above, this array can be produced at a cost between 1/3rd and 1/2 that of a planar array using the same solar cells. This comes about due to the much reduced quantity of III-V multi-junction solar cell material due to the small size of the cells. In addition, the small size of the cells can lead to a manufacturing cost reduction and yield increase due to the small size. For the usual wafers that are processed, 12 concentrator

cells come from an area where only two full size planar cells are produced. Thus a defect that would cause one large cell to be rejected (50% loss) would lead to only an 8% loss with the concentrator cells.

The lens material is made in volume at a low cost and the substrate on which the cells are mounted is a conventional carbon composite material that is in common use in space craft. Thus, this array is cost-effective, versatile, and has been shown to be durable in ground tests. All that is needed is a host satellite to fly with it.

5. Acknowledgement

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6. References

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