Lightweight Flexible Solar Array Experiment Summary

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Photovoltaic (PV**)** arrays are the primary sources of electrical power for geosynchronous and low-earth-orbiting satellites. The Lightweight Flexible Solar Array (LFSA) technology could, for some missions, provide higher power-to-weight ratios (specific energy) than conventional solar arrays, thus allowing a higher science payload mass fraction. Current solar array technologies provide specific energies in the range of 20-40 Watts/kg when the solar array deployment system and the solar array drive are considered. With further developments in the efficiency of thin-film solar cells, this technology could provide specific energies greater than 175 Watts/kg.

The LFSA technology is a lightweight PV solar array system. The unique new technology features of this solar array are the use of copper indium diselinide ($CuInSe_2$ or CIS) solar cells on a flexible, polyimide substrate and use of shape memory alloys (SMA) for the hinge and deployment system. Each of the two panels is approximately 5 in. wide by 18 in. long. The LFSA is deployed by heating the SMA hinges. Photographs of the LFSA hardware are shown in Figures 1 and 2.

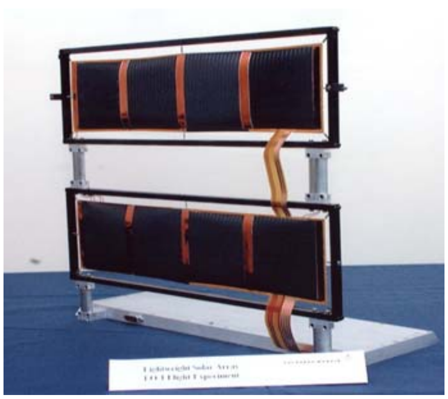

Figure 1. EO-1 LFSA Experiment

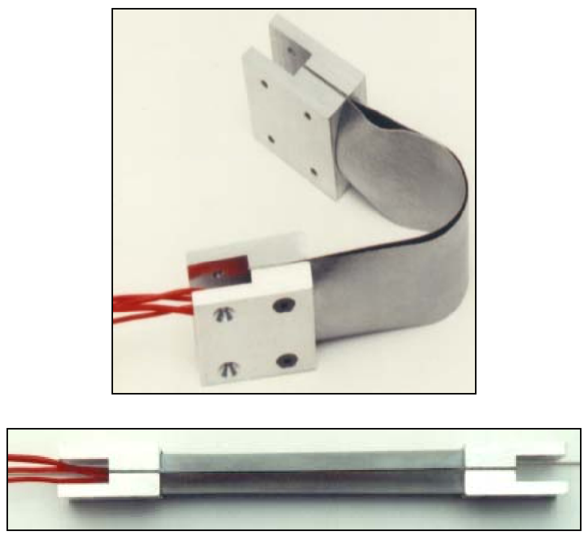

Figure 2. Shape-Memory Alloy Hinges, Stowed (Top), and Deployed (Bottom)

Silicon (Si), gallium arsenide on germanium (GaAs/Ge), and multi-junction (MJ) solar cells are technologies that involve crystal growth on a fragile wafer. The CIS thin-film solar cell technology is based on $CuInSe_2$ being vapor deposited on a flexible substrate that is substantially lighter than cells bonded to a rigid panel. The LFSA solar cell modules are 4 in. by 4 in. and each consists of 15 monolithically interconnected cells in series. The Air-Mass-Zero (AM0) module efficiency achieved for this size is approximately 2%. Higher efficiencies have been achieved on smaller areas.

Use of SMAs provides substantial weight savings over conventional hinges, deployment systems, and solar array drives. Therefore, a combination of these technologies could provide significant improvement in power-to-weight ratios. In addition, the SMA provides a shockless deployment environment and also is much safer to handle, integrate, and test than conventional pyro-based systems. Since it is also electrically resettable, the same device flies that is tested. The SMA deployment/hinge devices are significantly cheaper, simpler and, therefore, more reliable than current technology designs. A dual flexure concept was developed for integration on the Earth-Observing-1 (EO-1)/LFSA flight experiment. In this concept, the SMA strips are heat treated in the deployed ("hot") configuration and joined at the ends by metallic structural fittings. In the martensitic ("cold") state, the hinge is manually buckled and folded into the stowed configuration. Application of heat via internally bonded, flexible nichrome heaters transforms the SMA into the austenitic ("hot") state and causes the hinge to deploy. Once deployed power is turned off and the SMA is allowed to cool back to the low temperature martensitic phase. Although the martensite phase is "softer" than the high-temperature austenite phase, the very efficient section geometry in the deployed configuration allows the martensitic SMA hinge to support the lightweight solar array sections.

The validation objectives for the LFSA were twofold. The first objective was to demonstrate the release and controlled deployment of the CIS solar panels using the shape memory alloy release mechanism and hinges. The second objective was to monitor the photovoltaic performance of the CIS solar cells to assess their electrical output and degradation in the EO-1 orbital environment.

Ground test verification was employed for the EO-1 LFSA experiment. Primary testing included thermal (non-vacuum), vibration, acoustic, and thermal-vacuum cycling. This approach verified that the performance and functional attributes of the thin film PVs, deployment hinges, launch locks, current-voltage (I-V) measurement electronics, and structural components were completely satisfactory.

The on-orbit test validation phase started shortly after launch when the LFSA was deployed. The indicator switches and the panel temperature profiles indicated that the deployment was nominal. The elapsed time to deploy Panel 1 was between 30 and 40 seconds, whereas, the deployment time for Panel 2 was approximately one-half the time for Panel 1. The I-V output was initially consistent with ground-based electrical measurements of the CIS modules. However, about one month after launch, unexpected degradation in current output appeared. About four months after launch, a large step decrease in current output was observed. The observed on-orbit pattern of measured current output degradation is shown in Figure 3. No further current output flight data was acquired because the current had fallen to a point of being within the measurement noise level. After this degradation became evident, a rapid thermal cycling test in a nitrogen environment was performed on an engineering model of the LFSA at Lockheed Martin Astronautics. Final test results showed a similar degradation pattern that has been linked to excessive diffusion between PV contacts and the indium solder used to make the connection. Based on this, it has been concluded that the large decrease in current is due to progressive fracture of solder joints between the CIS modules and the flexible harness that carries current to the LFSA measurement electronics. Since this event, contact metallurgy practice for this application has been revised to include a diffusion barrier between the soldered top contact and the CIS absorber layer.

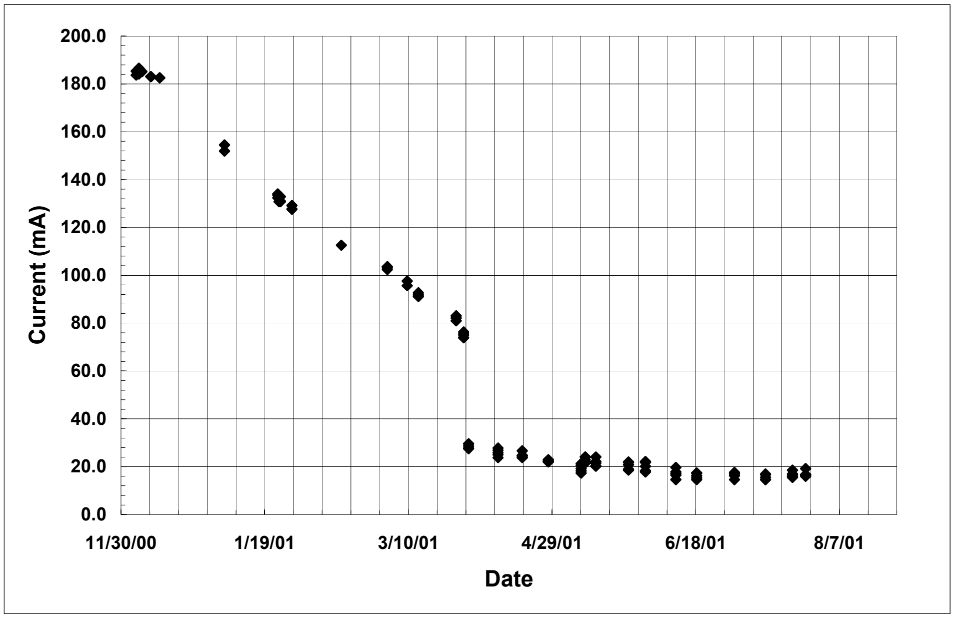

Figure 3. LFSA Current at 2 Volts vs. Time

The EO-1 experiment has demonstrated advanced technologies that have the potential to satisfy the specific system power goal of greater than 175 W/kg if the efficiency of thin-film solar cells improves to 10% or better. At present, large-area CIS does not approach this minimum when deposited on flexible substrates. Efficiency of thin-film PVs, aperture area, and the mass of the substrate remain key issues.

In conclusion, the ability to conduct a controlled deployment of the LFSA experiment using the shape memory alloy release and deployment system has been validated but work remains to be done in increasing the efficiency of CIS thin-film solar cells. Even though the PV performance of the CIS solar array assembly experienced a failure, the failure mechanism was identified and an advanced interconnect process has been developed for future use.