CASE STUDY

UV22DC80-1 Space-Based Solar Power Harvesting

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Research documents the use of Master Bond UV22DC80-1 UV+heat (dual) curable epoxy in a prototype concentrator photovoltaic (PV) system. The theoretical design treatment seeks to address the challenges in creating high specific power, ultralight PV systems for use in harvesting space-based solar power (SSP). Weight-reduction is critical for space-based applications; launching the mass of the SSP system into orbit can be the largest contributor to operational cost.[1] As such, designing an ultralight system with high specific power is critical to making this sustainable energy technology feasible. In constructing the linear concentrating mirrors, Master Bond UV22DC80-1 was chosen for its key attributes of high temperature resistance, excellent dimensional stability, and compliance with NASA outgassing requirements. The epoxy serves a vital function in smoothing the rough surface of the carbon fiber reinforced polymer (CFRP) prior deposition of silver (Ag) in the construction of reflective specular mirror.

Application

Space-based solar power (SSP) generation has long been an alluring technological concept. The premise envisions many photovoltaic (PV) arrays located in geostationary orbit harvesting abundant solar energy and beaming it to earth via microwave transmission.[1] The lack of absorptive atmosphere and the improved ability to orient towards the sun enhances the theoretical efficiency and power generating capacity of SSP systems when compared with terrestrial solar power generation. At present, the weight and low specific power of flat plate design photovoltaics limits the economic feasibility of launching them into orbit. The authors explore a concentrator design that has the potential to increase the specific power to the target range of 1-10 kW/kg needed for cost effective solar-based power generation. The function of the adhesive encapsulant can be visualized in **Figure 1** for a wire bonded assembly. The die is physically bonded to the substrate often with a suitable die adhesive; the connections between the die contact pads and the underlying board circuitry is then made through the wire bonding process. This particular case sees the use of a dam to contain the uncured encapsulant adhesive prior to final cure. From this diagram it can be seen that the encapsulant effectively seals the chip and protects the fragile wire bonded connections between the chip and the board substrate. The encapsulant utilizes physical mass to seal and mechanically secure the assembly while distributing any mechanical stresses resulting from thermal mismatch of the components.

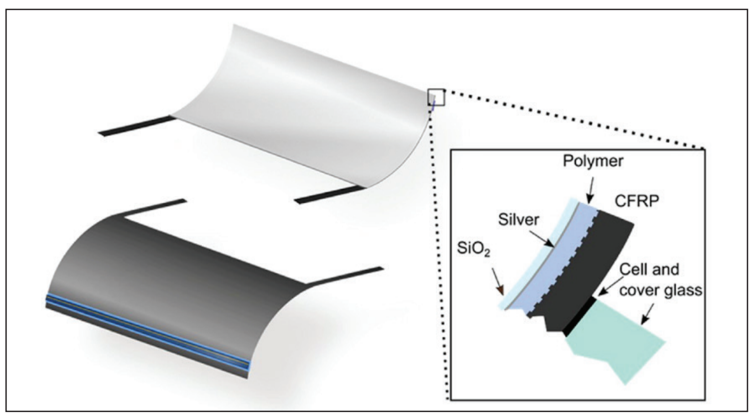

Figure 1. Schematic of linear concentrator design CFRP backbone is coated in a smoothing polymer (Master Bond UV22DC80-1), silver mirror, and high emissivity SiO_2 layers.[1]

The authors explore a concentrator design using a parabolic trough concentrator to reduce mass and increase cell efficiency. In addition to focusing the incident radiation, the reflector's backbone is comprised of carbon fiber reinforced polymer (CFRP) providing radiation shielding and heat dissipation. Thermal management is of key importance when designing robust and long-lived photovoltaics. High reliability and a long operating life are especially important for space-based photovoltaics due to the prohibitively high cost of delivering them to orbit. The CFRP has a high thermal emissivity and thermal conductivity allowing for efficient thermal management while providing a high specific power relative to the heavier flat plate designed PV's.

Details of the design prototype can be seen in **Figure 1**.[1] Fabrication of the reflector involves casting 3- or 4-ply CFRP sheets over a parabolic mold. To allow for a smooth surface necessary for the manufacture of a highly reflective mirror, a smoothing polymer was needed to coat the rough surface of the CFRP. Master Bond UV22DC80-1 UV dual-cure epoxy was coated onto the CFRP surface via drawdown and cured. The resultant smooth surface was then coated with 40 nm of silver and protected by a 10-20 nm overcoat of SiO_2. Material selection optimized for efficient optical reflection across the solar spectrum.

Theoretical calculations and simulations were then performed on the design; these included the optimization of cell architecture, reduction of the cell size, and the use of multilayer optical coatings to increase thermal emissivity of the concentrator surfaces.[1] The thickness and characteristics of the CFRP were optimized for heat transfer with the resulting specific power being calculated. Overheating of the cell leads to loss of efficiency and eventual degradation of the components making the thermal management of these devices critical. Construction of a physical prototype with the optimized characteristics was not presently feasible due to material limitations of commercially available plies of prepreg materials used in the construction of the CFRP.

Key Parameters and Requirements

Adhesive systems used for space-based applications must stand up to the harsh environments of space. The lack of atmosphere in space results in wide temperature swings, and the vacuum environment causes volatile, migratable components found in adhesives, encapsulants, gaskets, and other organic materials to outgas. Outgassing is especially damaging in the case of systems that have sensitive optics and mirror surfaces; condensation of these volatile components upon lenses and mirrors can greatly reduce the efficiency of these systems or render them inoperable. Concentrator PV's can provide great increases in performance; however, they rely upon sensitive mirrored reflectors to concentrate the solar energy upon the cells.[1] Designing a space-based system that utilizes concentrators then requires the utmost attention to the outgassing properties of any adhesive or encapsulant used in the construction of the device.

A historical encounter with this problem was seen in the 1990's with the Hughes/Boeing 702 spacecraft.[1] It utilized fold-out reflector panels which increased the photovoltaic array's power output by ~1.8x. However, the deployment of the reflectors increased the temperature of the panel significantly leading to outgassing from the adhesive encapsulant used. These volatile organic compounds then condensed on the reflective panels with UV radiation chemically degrading the components leading to darkening and loss of reflector performance. Since this event, scientists and engineers have been reluctant to utilize concentrator photovoltaics in space-based applications. To exploit the greater potential of concentrator PV's, the authors sought to address the two intrinsic challenges associated with space-based concentrator PVs: a superior design to enable ample thermal management and careful selection of any adhesives or encapsulants to minimize outgassing.

Master Bond UV22DC80-1 was carefully chosen as it exhibits several critical properties. This adhesive meets NASA low outgassing requirements for use in space while having excellent high temperature performance. The design criteria of the authors required an adhesive capable of handling temperatures of ~100°C; UV22DC80-1 readily meets these thermal requirements with a service temperature of -73°C to 177°C [-100°F to +350°F]. The mechanical properties of the adhesive are enhanced by the inclusion of nanosilica filler providing a relatively low coefficient of thermal expansion (CTE) as well as relatively high Shore D hardness and a tensile modulus > 400,000 psi at room temperature. UV curable systems often exhibit significant shrinkage upon curing; this can lead to residual stress at the interface and in extreme cases loss of adhesion. However, the nanosilica used in this specialty system, UV22DC80-1 leads to minimal shrinkage and provides a superior joint especially compared to commercially available UV curable systems. The inclusion of the nanosilica leads to improved mechanical properties without compromising the glass transition temperature (T_g) of > 125°C. It also meets the NASA low outgassing requirements, which was critical for the application.

In addition to the above properties, Master Bond UV22DC80-1 provides great versatility when used in fabricating and manufacturing components and prototypes. The product is a dual-curable epoxy; it cures when exposed to UV radiation as well as possessing a secondary thermal cure mechanism. The UV cure mechanism enables rapid fixturing as exposure to UV radiation will rapidly set the adhesive. Post thermal cure can then be employed to further increase the extent of polymerization, improve mechanical properties, and cure any regions of the adhesive that were shadowed out from exposure to the UV curing source. Thermal cure can be attained at temperatures as low as 80°C allowing for temperature sensitive substrates to be used in the device construction.

Results

After computational optimization of the design parameters, the authors found that the concentrator photovoltaic can potentially reach a specific power output that would prove feasible for space-based solar power generation. With a CFRP possessing the optimal thickness, and with the concentrators exhibiting optimal mirror and backside emissivity, the device could be capable of providing 4.1 kW/kg specific power. This fell within the target range of 1-10 kW/kg believed to be needed for cost efficient introduction to geostationary orbit. At present time, the commercially available prepreg materials are the limiting factor to constructing the optimal device. Existing materials and prototyping efforts have mirror thickness of ~140-180 μm whereas the optimal design parameters found by the authors would require a mirror thickness of 37 μm necessary to provide the specific power and thermal dissipation needed. The work is a significant contribution to the field, and it demonstrates that with future advancements in material science and fabrication, a space-based solar power generating system could prove feasible.

References

[1] Warmann, E. C., Espinet-Gonzalez, P, Vaidya, N., et al. *An ultralight concentrator photovoltaic system for space solar power harvesting.* Acta Astronautica 170 (2020), 443-451.