A SOLAR ARRAY MODULE FABRICATION PROCESS FOR HALE SOLAR ELECTRIC UAVS

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Abstract

We describe a fabrication process to manufacture high power to weight ratio flexible solar array modules for use on high altitude long endurance (HALE) solar electric unmanned air vehicles (UAVs). A span-loaded flying wing vehicle, known as the RAPTOR Pathfinder, is being employed as a flying test bed to expand the envelope of solar powered flight to high altitudes. It requires multiple light weight flexible solar array modules able to endure adverse environmental conditions. At high altitudes the solar UV flux is significantly enhanced relative to sea level, and extreme thermal variations occur. Our process involves first electrically interconnecting solar cells into an array followed by laminating them between top and bottom laminated layers into a solar array module. After careful evaluation of candidate polymers, fluoropolymer materials have been selected as the array laminate layers because of their inherent abilities to withstand the hostile conditions imposed by the environment.

Introduction

The RAPTOR Pathfinder solar electric airplane is serving as a technology integration platform to enable long endurance high altitude flight for weeks or months. The airplane has a 98 ft wingspan with an 8 ft chord, and was originally built and flown in 1983 by AeroVironment Inc. Flight altitudes exceeding 10,000 ft were achieved using Ag/Zn batteries as the power source. The flight envelope of the original aircraft has been expanded for high altitude flight through major upgrades to its structure and electric propulsion systems. In addition, the plane has been converted to solar electric powered flight by covering the upper wing skin with light weight flexible solar array modules. This paper describes the development of a light weight flexible solar array module fabrication process.

Solar Array Electrical Interconnection

Experiments conducted at LLNL have shown that solar cell interconnect soldering can cause solar cell breakages for thin (< 6 mil thick) silicon solar cells as well as leave undesired residue on the active surfaces. This is due, in part, to the 200°C temperature required for soldering, and the solder fluxes used to promote good adhesion. We have developed an interconnect soldering scheme that utilizes a conductive Ag surface mount solder cream. This cream is ideally suited manufacturing applications because it can be applied directly to the interconnect contact area, it is easy to use, it results in very low interconnect contact resistance, and after soldering no undesired residues remain after a simple isopropyl alcohol cleaning step.

The electrical interconnect on the first phase of solar modules used on Pathfinder employs copper strips 50 mils (0.050") wide by 3 mils (0.030") thick soldered to each solar cell using the Ag surface mount solder cream (ESP Solder Plus, Part # 6-GN63-500-A) consisting of a Sn-Pb silver with a mixture of bismuth, rosin, terpene, polyol and carboxylic acid. This highly viscous liquid paste is applied between the copper strips and the metal electrodes on the solar cells before soldering. After soldering, the cells are cleaned using isopropyl alcohol followed by de ionized water. This process is ideally suited for manufacturing because it is very inexpensive, fast, and easy to perform.

Electrical testing of finished solar array modules has shown that no degradation of the interconnects develops under high current testing. In addition, the contact resistance value is very low at $<10^{-5}$ ohm-cm^2.

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Solar Array Laminate Structure

The laminate structure consists of two fluoropolymer Halar™/silicone adhesive sandwiched layers that encapsulate the solar cells. The result is a hermetically sealed planar solar cell array laminate structure. The fluoropolymers are ideally suited for this application because they are: virtually chemically inert, highly transmissive in the visible spectrum, dimensionally stable at temperatures up to 200°C, highly abrasion resistant, and exhibit very little UV degradation. We have chosen very thin layers of each laminate in order to fabricate high power to weight ratio solar array modules. The Halar™ film is 25μm (1 mil), and the unsupported silicone adhesive film is 50μm (2 mils). Together they add up to 225gm/m^2 (0.046 lb/ft^2) for the top and bottom layers.

The films are obtained separately and then laminated together. The silicone adhesive comes sandwiched between two polyethylene (PE) release liners. One of the release liners is then removed and replaced by the Halar™. This forms the basis of our laminate structure as shown in Fig. 1.

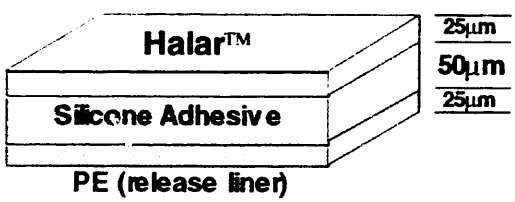

Fig. 1 - Laminate structure con. sting of Halar™ (25μm), an unsupported silicone adhesive (50μm), and a polyethylene (25μm) release liner.

Solar Array Laminate Process

The process involves laminating the electrically connected solar cells between the top and bottom Halar™/silicone adhesive layers. This encapsulates the silicon solar cells as shown in Fig. 2. The process is best described by illustration (Fig. 3). As the release liner is removed, the

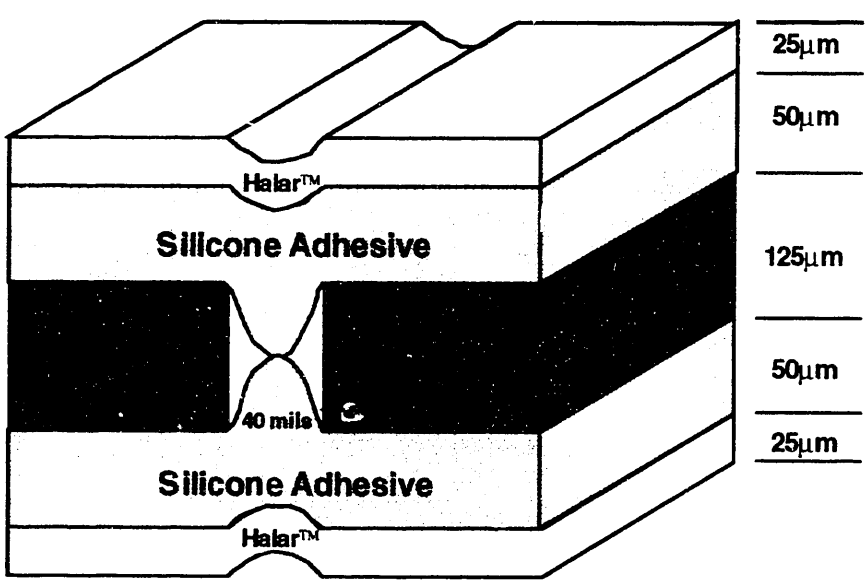

Fig. 2 - Solar array module structure with hermetically sealed solar cells. The solar cell thickness will vary from 100μm to 350μm depending on the type of cell used.

top and bottom laminate layers are fed between the laminating rollers. The electrically connected solar cells are then fed through the apparatus and hermetically sealed by the top and bottom laminate layers. The cells pass through the apparatus twice. The first pass is at room temperature

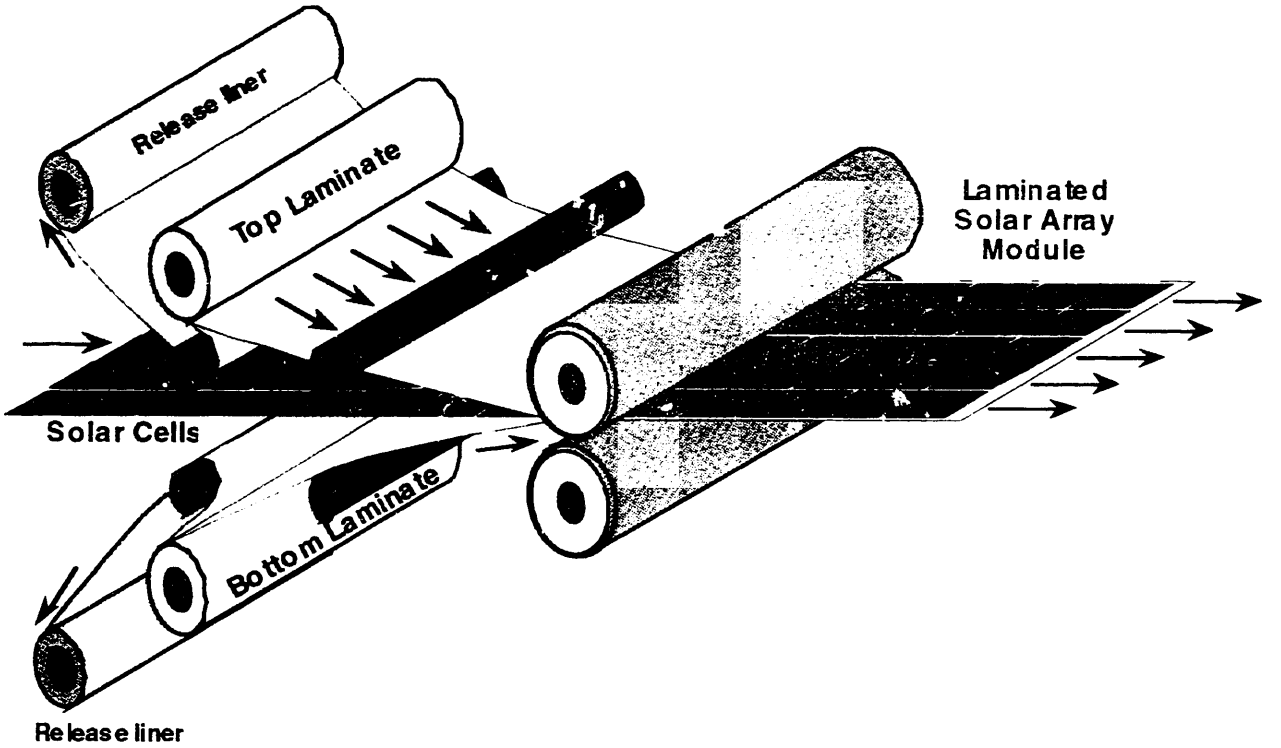

Fig. 3 - Schematic of array lamination process. As the release liner is removed, the top and bottom laminate layers are fed to the laminating rollers. The electrically connected solar cells are fed through to hermetically seal them into a solar array module.

and causes the solar cells to be laminated to the top and bottom layers. The second pass is at 140°F (60°C) and causes the silicone adhesive layers to reflow and hermetically seal the solar array module.

Summary

We have developed an array lamination process to fabricate high power to weight ratio solar array modules. This process involves first electrically interconnecting the solar cells with an inexpensive easy to use Ag solder paste, followed by laminating between two Halar™/silicone adhesive sandwiched layers. The finished product is a light weight, flexible, hermetically sealed solar array module.

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