Development of Flexible Thin-Film Photovoltaic Arrays for Nanosat Applications

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Abstract. Space Industries has supported on-going internal development of a “Nanosat” spacecraft for a variety of missions. An essential part of any small spacecraft effort is an efficient power system. Amorphous thin-film silicon photovoltaics provide a mass efficiency greater than other photovoltaic systems.

In cooperation with the Microelectronics Research Center at Iowa State University, Space Industries has undertaken a development effort to assess the potential of utilizing amorphous thin-film silicon photovoltaics on small spacecraft. An overview of the development of a prototype unit will be presented along with results from ground testing. Projections for utilization of this technology in a flight system will also be presented.

Introduction

Most spacecraft utilize photovoltaics to generate electrical power for their subsystems and payloads. The electrical subsystem usually consists of solar arrays (and associated mechanisms), power control and distribution electronics, and storage batteries. Traditionally, these components have been designed and integrated on a mission unique basis and require extensive engineering analysis and testing.

The on-going development of thin-film electronics provides an opportunity for significant reduction in the mass and volume of spacecraft power systems. Developments include thin-film photovoltaics and thin-film batteries.

The development of thin-film electronics (including photovoltaics and batteries) allows the spacecraft designer to begin to consider a power system as a thin sheet that is adhered to the body of the spacecraft or deployed from a roll (similar to current flexible blanket solar arrays). This thin-film sheet would contain all of the necessary components - photovoltaics (on one side) with batteries and control electronics on the opposite side in a thickness that is less than current rigid solar cells.

While thin-film technologies have existed for several years, recent developments have improved efficiencies and have provided insight into how thin films will function in a space environment. Advances in thin film
solar cells have pushed efficiencies for amorphous silicon (a-Si) into the 8-9% range. Other thin-film solar cell technologies (CdTe, and CIS) have exhibited somewhat higher efficiencies (~10%) but the production of these technologies in large quantities is not as mature.

To date, however, there is very limited data on thin-film flight tests. Thin film a-Si solar modules from Solorex, ECD and Iowa Thin Film Technologies Inc., designed for terrestrial applications have been flown in orbit with various results. No devices designed directly for space use have been flown.

The Iowa State University Microelectronics Research Center, in cooperation with Iowa Thin Film Technologies Inc. and the State of Iowa, has developed thin-film amorphous silicon solar modules on flexible polyimide substrates. The modules are produced by a roll-to-roll manufacturing technique that results in very thin modules. With 1 mil thick substrates, the modules are capable of about 1 watt/gram. This provides a significant advantage over conventional solar modules. In addition, the modules can be attached directly on the satellite surface or rolled up and easily deployed in orbit.

**Development Plan**

In late 1996, Space Industries and Iowa State University undertook a program of developing thin-film photovoltaics for nanosat applications. Under this program, a series of laboratory tests would be conducted to develop a system that would be useable for a nano-spacecraft.

The first step focused on developing a power controller for interfacing with the thin-film array. While a thin-film photovoltaic array is similar to regular arrays there are a few key differences. Thin-film photovoltaics are fabricated as arrays, not as individual cells. The production process creates individual cells with all necessary interconnecting circuitry deposited in place as part of the fabrication process. This step eliminates the array assembly process required with conventional photovoltaic cells.

This development of a power controller would use traditional components and would allow the development of a controller that could be easily built and tested, and then transitioned into thin-film devices. This effort would also allow for characterizing differences between thin-film arrays and conventional photovoltaics.

Following laboratory demonstration of the controller and a test array, work would then begin to transition the power control element into thin-film circuitry. If possible, a flight experiment could also be conducted at this state of the development with an array that was specifically designed for the space environment.

While the circuitry was being developed into thin-film devices, work would also be undertaken to examine deployment methods and mechanisms.

**Current Work**

The thin film solar modules will be used in conjunction with a small controller to charge on-board storage batteries. This controller is also being developed by the Iowa State University Microelectronics Research Center. The prototype controller is controlled by a personal computer via the parallel port. This controller will consist of a multi chip module. The prototype of the solar cell controller circuit consists of:
1) a commercial battery charger control chip,
2) a commercial eight channel serial A/D converter,
3) a controller power supply,
4) a solar cell heater,
5) a battery discharge circuit, and
6) a battery temperature sensor.

Several elements of the system are monitored to determine the health of the battery, solar cell, and control system. The open circuit voltage and short circuit current of the solar cell provide a status of the condition and capabilities of the solar cell. Assuming the battery is adequately charged, the system would be capable of heating the solar cell to a specified temperature for system tests. The battery charger controller chip has a battery temperature input. The battery voltage will vary as a function of its temperature. Charge termination and shut down voltages are functions of temperature. This data would be used by the computer to give override commands to the charger chip if local control within the charger chip is inadequate for control of the battery charge function.

The A/D converter provides information on the current through the battery, the voltage and current capability of the solar cell, the temperature of the battery, and the voltage of the battery. A history of current into and out of the battery gives indication of the charge of the battery. The charge and the battery voltage versus temperature will be used to power the system when the battery charge is low and also gives an indication of the condition of the battery. The system has the capability to discharge the battery to minimize memory effects in the battery.

Since the battery might be discharged at some point, the controller and interface chip power supply operates from solar cell energy when it is active. This allows the system to come up to power when the solar cell is illuminated and the battery is discharged.

The twelve bit A/D converter includes an eight channel multiplexer enabling up to eight analog functions to be monitored with the converter. Digital control is passed directly from the computer to the controller for battery discharge, solar cell open circuit thermostat, and battery temperature sensor.

Figure 1. Controller Test Set-up Block Diagram
voltage, solar cell short circuit current, solar cell heating, and controller shut down commands.

A small multichip module is envisioned for the controller. Figure 1 shows a block diagram of the system. The multichip module would contain the controller chip and interface circuit.

The system described is currently undergoing test and evaluation at the Iowa State University Microelectronics Research Center. Initial results indicate that the controller design works well and that the array exhibits typical behavior.

**Future Work**

Future work will focus on how this laboratory system may be scaled for spacecraft applications. The lower conversion efficiency of thin-film arrays presents challenges to the spacecraft designer due to the large array area required. The large array area is offset by the very low mass of the array system.

Future efforts are also contingent on funding for the continuation of this work. Plans are underway to seek funding through the SBIR and STTR programs.

**References**


**Author Biographies**

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