DOE/ER/12149--T1

REQUEST FOR CONTINUATION OF AWARD

and

YEAR 1 PROGRESS REPORT

DOE AWARD DE-FG06-94ER1249

12149

A THERMOPHOTOVOLTAIC GENERATOR FOR USE IN A
LIGHTWEIGHT ELECTRIC CAR

SUBMITTED TO

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Technical Progress Report - May 1, 1995
A Thermophotovoltaic Generator for use in a Lightweight Electric Car

A. INTRODUCTION:

In the nine months since the start of this project significant progress toward the completion of the tasks scheduled in the first year has been made and in some cases exceeded. A number of unforeseen problems have been isolated and solved with redesign of components and specification of different materials. This project has been running concurrently with a Phase I DOE Green Car SBIR grant to JX Crystals in which WWU is the sub-contractor to do burner design, construction and testing. As a result of this concurrent project, the design of the single burner for the TPV8 which is nearing completion at this time, incorporates the improvements of the Phase I Green Car burner. ~~Table #1 shows the status of the tasks scheduled for the first nine months of the contract~~ and the current status *are shown*

Table 1

SCHEDULED TASK	SCHEDULED PROGRESS as per GRANT	CURRENT STATUS
Installation of Equip. - Sputtering Machine	Complete by April '95	Completed early. Sputtering Machine has been installed and operational since March '95.
- Mask aligner	Complete by April '95	Deleted. Due to bid for Sputtering Machine coming in at \$9,913.31 over budget this equipment was purchased with other funds by JX Crystals.
Cell Development	75% Complete by May 1st.	On schedule with the cells made in 1994 giving open circuit voltages as high as 0.52 V and fill factors as high as 0.84. Cells produced in March and April are being optimized for increased current.
Cell Fabrication	8% Complete by May 1st	On schedule. Since the installation of the sputtering machine 1995 cells have been fabricated. A new design for a larger cell is complete and production of this cell for the TPV8 single is underway.
Circuit Development	Complete by March 1st	Behind Schedule. Work was completed on 5 & 7 cell test circuits. Design for the 20 cell circuits for the TPV8 single cylinder is underway.
Cooling Channel	Complete by April 1st	On schedule. Preliminary design is complete.

SCHEDULED TASK	SCHEDULED PROGRESS as per GRANT	CURRENT STATUS
Receiver Fabrication	8% Complete by May 1st	Behind Schedule. Fabrication of receivers has been delayed until the installation of a CNC machine currently being purchased on the DoD award. They call for a repetitive machining process which can be made most efficiently on a CNC.
Filter Development	Complete by April 1st	Behind Schedule. Filter optimization is underway. 17 layer filter is designed and being tested.
Filter Fabrication	8% complete by April 1st	Behind Schedule. Waiting filter optimization.
Burner Development	75% complete by May 1st.	On schedule. Preliminary design is complete and fabrication of parts is 65% complete.
Regenerator Development	70% complete by May 1st	Ahead of schedule. Design, fabrication of parts is complete and assembly is underway.
Single cylinder design	60% complete by May 1st	Ahead of schedule. Preliminary design is complete and fabrication of parts is underway.
Fabrication	25% complete by May 1st	On schedule. Emitter is redesigned and fabrication of parts is underway

B. MODIFICATIONS TO TPV8 SINGLE CYLINDER DESIGN OUTLINED IN PROPOSAL

1. Recuperator/Regenerator (see figure 1)

The original design called for ten plates to circulate the air. The current design calls for 21 plates. In testing the Green Car SBIR Phase I burner it was discovered that recuperator efficiency was 65%. We are in the process of assembling a unit with double the number of plates which should improve efficiency to 85% for this component. The fan power requirement should not rise as we have located a centrifugal fan able to overcome twice the flow restriction at no increase in power requirement.

Under the current design the recuperator has been placed under the burner. This allows better balance with this larger heavier component underneath and the fuel flow does not run the length of the emitter. CH_4 had been pyrolysing in the fuel supply tube and coating it with carbon. The new design should prevent this and also provides a better site for cold start ignition.

Figure 1 - Redesign of TPV8 Single Cylinder - 4/22/95

As higher temperatures have been achieved it has become necessary to change the recuperator plates to a combination stainless steel and ceramic design.

2. Burner Modifications (see figure 1)

All the materials utilized in the current burner design have been changed from the original proposed design. The emitter is made from a combination of silicon carbide tube and plates. (see figure 2). This new design permits a more even temperature range along the length of the burner.. These plates with holes provide greater turbulent flow of the gas/air mixture. It is expected that higher temperatures will be achieved with the addition of plates inside the silicon carbide emitter tube. Ceramic cuffs have been added above and below the emitter to provide insulation for the area not exposed to PV cells. Better thermal coupling between combustion gases and the emitter tube is provided by increase in turbulence in up and down direction. An additional air flow passage has been added to provide greater circulation of the hot air to improve the cooling to the filters and cells. A ceramic diffuser was added to the top of the emitter tube to aid in providing a pressure rise and increased turbulence in the combustion zone.

Figure 2 - Silicon Carbon Spine Pieces

3. Receivers

New receivers have been designed and gold plated brass mirrors are going to be constructed to improve efficiency.

4. Cells: (see figure 3)

In 1994, we designed and fabricated our first GaSb thermophotovoltaic cells. These cells are 1.05 cm x 1.05 cm square with two contact pads on opposite sides. The cells are designed for use in receivers with side mirrors which funnel the IR down into the cells. The side mirrors shade the contact pads. The IR illuminated area is 0.85 cm wide and subtracting the grid area, the active area is 0.75 cm².

We built a photographic flash test station capable of testing these cells at short circuit currents up to 6 Amps. Testing these 1994 cells gave open circuit voltages as high as 0.52 V and fill factors as high as 0.84. These values are near theoretical limits. We then sent some of these cells to NASA Lewis for quantum efficiency measurements. The better cells had peak quantum efficiencies of only 74%.

In 1995, we have focused on two areas for cell improvement. We are increasing wafer throughput and we are optimizing our cell process to increase the cell quantum efficiencies

In order to increase cell currents, we have varied our diffusion parameters in order to vary the zinc concentration and depth profile in the cell emitter. A measure of the zinc concentration and junction depth is the p-layer sheet resistance. We have now established a good correlation between cell short circuit current as measured against a standard cell and p-layer sheet resistance. This correlation is shown in figure 4. As can be seen, lighter zinc doping gives higher cell currents and quantum efficiencies. The voltages and fill factors show no degradation over the sheet resistance range shown in figure 3. The cell shown in figure 1 had a current 1.2 times higher than a NASA 1994 reference cell with a peak quantum efficiency of 74%. We are sending some of these new cells to NASA Lewis for quantum efficiency measurements and we plan to decrease the zinc doping even further and evaluate the results.

Figure 3 GaSb TPV Cell - April, 1995

Figure 4. Short Circuit Current vs Emitter Sheet Resistance.

5. Circuits:

During the first four months of the project the circuit assembly system was developed to insure that production of circuit boards would keep up with cell production. The following fixtures were developed:

1. A width go/no go fixture which allows a quick check of the maximum width of the circuit board after the shearing process.
2. Flatness fixture to check the circuit board for warpage after shearing. This fixture is also used to flatten the cell jumper strips after cutting to shape.
3. A cooling plate to reduce the time between soldering steps in the circuit board assembly process.
4. A soldering fixture to allow accurate and quick positioning of the circuit board and the two jumper strips for soldering under the microscope in the hot bar bonder.
5. An extended column and optical fixture to optimize the microscope and bonder probe position to speed up the soldering process and enhance the quality of the soldering.
6. Adaptation of the X/Y stage to a microscope for close inspection of the solder joints to enhance quality.
7. A lead forming fixture to produce a very small, precise and repeatable "s" shaped bend in the jumper strips.

These fixtures enabled the assembly process for 5 and 7 cell strings to be reduced by 83% from 3 hours to 30 minutes per circuit board.

6. Filters:

Originally we planed to mount the filters at the edge of the mirror in front of the cells. The temperature in this zone has proved to be too high for filter efficiency. We are now experimenting with filters mounted directly on the cell in a cooler zone. The work outlined below was completed as part of the DOE Green Car Phase I. Final optimization is now underway on the 17 layer filter which will be used in the TPV8 single cylinder.

Two different dielectric filters were designed, a 9 layer and a 17 layer. These filters were designed to transmit as much energy as possible below 1.7 microns while reflecting as much energy as possible above 1.7 microns. We fabricated and measured our first 9 layer filters. Our filter work has been very instructive in terms of generator performance modeling. Two filter efficiencies are useful in characterizing a filter. We define a passband efficiency as simply the current produced in a cell with the filter divided by the current produced by the cell with no current. We also define a transmitted energy efficiency as the energy transmitted in the cell response band divided by the total energy transmitted. These two efficiencies will be important in our present more complete generator model.

Figure 4 shows the theoretical transmission spectra for the two dielectric filters of our design (9 layer and 17 layer filters), as well as the experimentally measured transmission for our first 9 layer filter. We plan to use the 17 layer filter. Note that this filter has a transmission window from 1.3 to 1.7 microns and that it reflects back the emitter energy very efficiently between 1.7 and 4 microns. Beyond 4 microns, it begins to transmit again.

Figure 4: Theoretical vs. Experimental IR Filter Transmission Spectra

C. BUDGET STATUS AS OF APRIL 30, 1995 AND ESTIMATED EXPENDITURES FOR REMAINING MONTHS OF THE AWARD.

As indicated on the summary report a number of items are projected to be slightly over the original amount budgeted. The sputter deposition system which was essential to increase production of the PV cells came in \$9,913.31 over budget. In order to absorb this amount without increasing the total award it was decided to eliminate the purchase of the mask aligner. JX Crystal has purchased the aligner needed from the company's funds. The other overages have been eliminated by decreasing the amounts allotted for small tools and instrumentation. This has been possible due to the concurrent running of the DOE Green Car Phase I subcontract from JX Crystals. A number of small tools and instruments which are used on both projects were purchased instead on that contract. Dr. Seal also reduced the amount of remuneration received from the contract in order to employ another engineer, Edward West for a month of part time work and to enable Gavin Campbell to work more hours than originally scheduled to keep the tasks on schedule.

Budget information removed