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Thin Film Module Development

Theresa Jester
ARCO Solar, Inc.
Chatsworth, California

ARCO Solar, Inc. has developed and now produces a 5 watt thin film silicon photovoltaic module, the Genesis G100. As the first commercially available thin film product from ARCO Solar, the G100 module package incorporates excellent reliability, manufacturing ease, and consumer aesthetics.

This paper outlines the evolution of the Genesis module with emphasis on the design and construction of this commercial product.

The design of the Genesis G100 module was driven by several criteria, including environmental stability (both electrical and mechanical), consumer aesthetics, low materials costs, and manufacturing ease. The module circuitry is designed as a 12-volt battery charger, using monolithic patterning techniques on a glass superstrate. This patterning and interconnect method (Fig. 1) proves amenable to high volume, low cost production throughput, and the use of glass serves the dual role of handling ease and availability.

The mechanical design of the module centers on environmental stability. Packaging of the glass superstrate circuit must provide good resistance to thermal and humidity exposure along with hi-pot insulation and hailstone impact resistance. The options considered are given in Table I. ARCO Solar's reliability and manufacturing experience, based on production of over ten megawatts of photovoltaic modules and large-scale long-term field operations and testing, were employed to a high degree.

Ethylene vinyl acetate (EVA) was chosen as the pottant material for its excellent weatherability. An evolution of backsheet, framing, and termination techniques were built on this choice of EVA pottant.

We made direct use of materials and construction used in our Cz module products for the first thin film module prototype. The module design in Fig. 2 shows a glass/EVA/coated sheet metal laminate framed with anodized aluminum extrusions. Termination of this design was accomplished with two terminal posts protruding from the back of the laminate. Several problems emerged:

- o The metal frame and metal backsheet produced low hi-pot resistance when the thin film circuitry was carried close to the edge, resulting in an inefficient active area/module ratio.
- o The back side termination did not permit flush mounting after wire routing was installed.
- o For shipping considerations, the package was too heavy and bulky.

- o Aluminum extrusions were very costly for a square foot product.

The second design iteration improved with the use of a low profile side rail, as shown in Fig. 3. These roll-formed sheet metal rails framed a glass/EVA/glass laminate and provided flush mounting. Termination was accomplished by routing two wires along either side rail. Disadvantages to this design were:

- o From a customer's standpoint, the termination wires proved difficult to use.
- o The aesthetics needed improvement.

Our third prototype design approached the consumer aesthetics criteria with a glass/EVA/mirrored glass laminate framed with low profile roll-formed rails. The spade lug terminations were embedded in the side rails, offering a smooth product look. Two problems remained with this prototype:

- o Terminations would have saddled customers with the expenses of special tools purchases and of special employee training to prepare wires for module connections.
- o Difficulties in mounting this module were encountered.

A fourth prototype evolution progressed from discrete frame pieces to a one-piece rubber gasket. The glass/EVA/Tedlar-coated sheet metal laminate was terminated with a narrow printed circuit board onto which wires were soldered to exit the module frame. This one-piece frame approach provided manufacturing ease and improved termination options. Difficulties remaining to be solved were:

- o Poor adhesion of the rubber to the glass laminate allowed the rubber to pull away from the laminate.
- o Easy mounting holes were not designed into the frame.

The final commercial design of the Genesis G100 product made use of all of the strong points of the previous designs and added excellent consumer aesthetics as well as mounting ease for the customers. The design choices embodied in this module, and the rationale for each, are outlined in Table 2.

As shown in Figs. 4 and 5, the module is constructed from a glass/EVA/tempered glass laminate framed with a one-piece plastic frame. Termination is accomplished with a narrow printed circuit board laminated to the back sheet and a one-piece, two-conductor cable soldered to the board.

The physical and electrical characteristics of the final design are given in Table 3. The Genesis G100 module features mechanical and electrical environmental reliability, manufacturing and shipping ease, and consumer aesthetics, a package truly designed with pride by ARCO Solar to fulfill customer expectations.

Table I. Thin film module design options.

Pottants	Backsheets	Edge Seals	Frames	Terminations
EVA	Plastic	Tape	Injection molded plastic	J-box
PVB	Coated sheet metal	Gasket	Aluminum extrusions	Pigtail
Acrylic adhesives	Tempered glass	RTV	Roll-formed sheet metal	
Silicones			Gasket	

Table II. Thin film module design choices.

	Pottants	Backsheets	Edge Seals	Frames	Terminations
Choice	EVA	Tempered glass	RTV	Injection molded plastic	Pigtail
Reasons	Weatherable	Strength	Low cost	Low cost	Low cost
	Low cost	Low cost	Weatherable	Aesthetics	Weatherable insulation
	Vacuum lamination processing	Aesthetics	Easy application		
	Weatherable				
	Hi-pot/voltage isolation	Hi-pot/voltage isolation			

Table III. Characteristics of Genesis G100 commercial design.

Physical Parameters		Power Specifications	
Length	13.7" (34.7 cm)	Maximum Power (typical $\pm 10\%$)	5 Watts
Width	13.1" (33.3 cm)	Voltage at max power (typical)	14.5 Vts
Depth	0.5" (1.3 cm)	Current at max power (typical)	.35 Amps
Weight	3 lbs. (1.4 kg)	Open Circuit Voltage (typical)	20.8 Volts
Cable	16 AWG	Short Circuit Current (typical)	.435 Amps
Cable Length	5 ft. (1.5 m)		

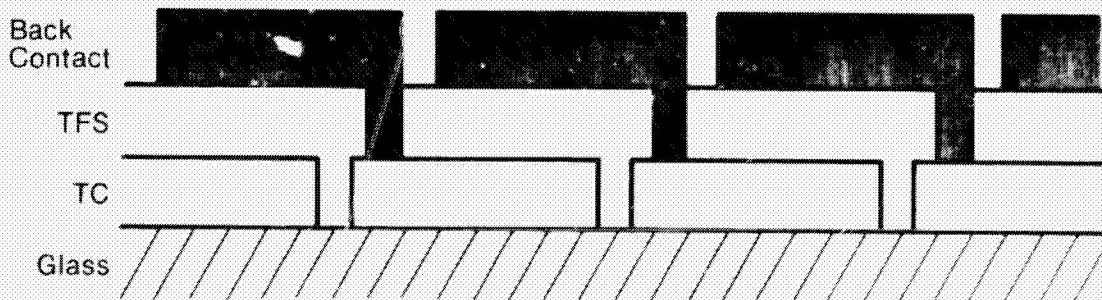


Fig. 1. Thin film module monolithic structure.

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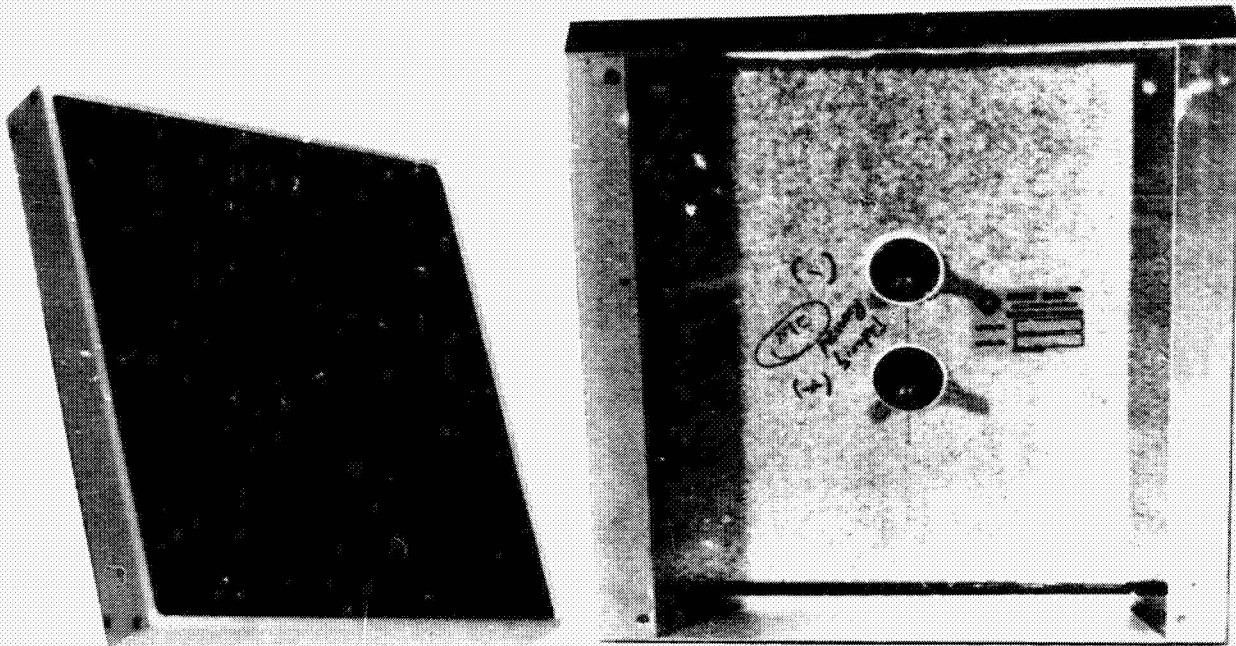


Fig. 2. Experimental packaging design based on Cz module design.

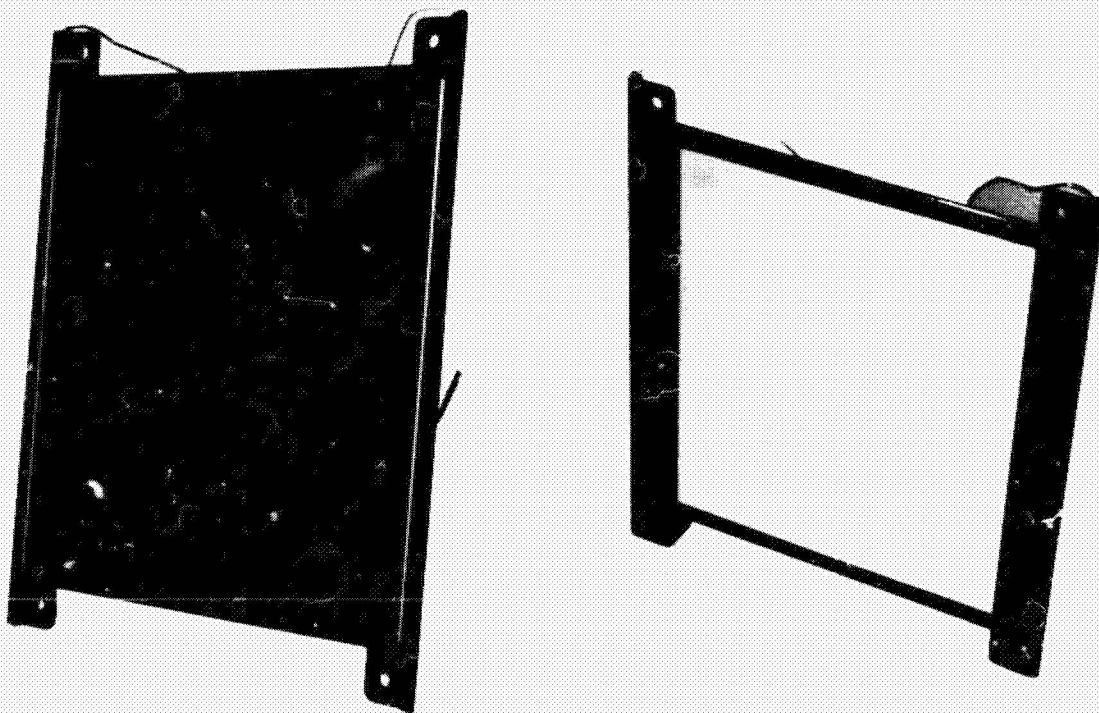


Fig. 3. Low-profile metal frame design.

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Fig. 4. Genesis G100 module.

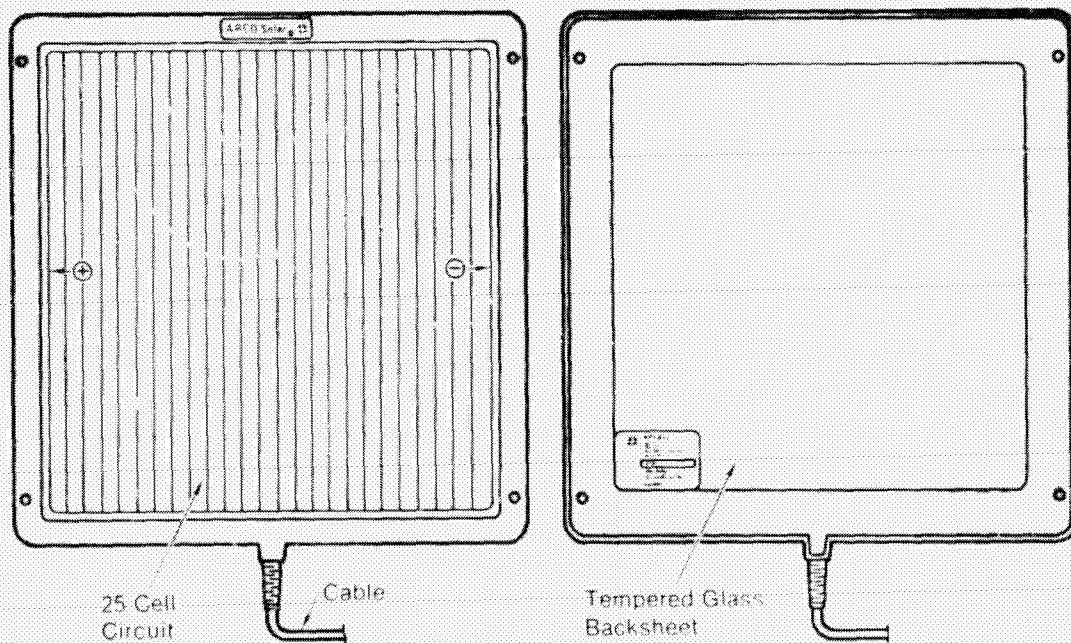


Fig. 5. Design details of commercial module.

DISCUSSION

VASEASHTA: Two things that I don't understand: No. 1, when I opened the module, beneath the IC board there was an epoxy, which I believe was still wet or sticky. Was there some technical consideration for that?

JESTER: Actually what we have done is, we coated that printed circuit board with RTV to keep any corrosion or moisture from attacking the contacts there, and it remains slightly tacky. But it should have been completely dry by the time you got it, unless you got one hot of the press -- did you come to ARCO and pick it out? It's for corrosion reasons that we coat that.

VASEASHTA: Second question, I also looked at the scribing. The tin oxide laser scribe looks thin, while the amorphous silicon looks kind of wide. It does not look like as if it is laser-scribed. If it is not proprietary, could you tell us the process?

JESTER: I really can't tell you that. But it is wider; you are right.

D'AIELLO: Two questions. One quick one: you mentioned the composition of the frame, or at least the trade name for it. Would you say that again?

JESTER: It's Rovel, and it's got some rubber in it for slight mechanical flexibility. It is a Dow product.

D'AIELLO: I assume the frame surface serves no mechanical function. Is it aesthetic?

JESTER: It is aesthetic, and it actually provides mounting. Most of the mechanics, though, come from that glass-glass package -- the mechanical strength. It is injection-molded high-temperature UV-stable material.

D'AIELLO: The question I really wanted to ask relates to the backing material. I noticed that in one earlier case you had mirrors and in the final case you have a glass backing, which is actually black. Two different cases for reflection of radiation, would you comment about that?

JESTER: Actually we went with black because aesthetically it looks very nice. It's just a painted material.

D'AIELLO: You don't attribute any thermal function to the back?

JESTER: Typically these modules are mounted flush on something -- there is not a lot of radiation possible.

BICKLER: I'm curious about your strain relief on the cable. It seems to me that if you mounted that in the same rectangular boss you have it tangential instead of coming out perpendicular, and you could place these modules next to each other. Is there a reason for that?

JESTER: Actually, since these were designed to be single-battery chargers, we did not worry too much about stacking them close together. You can stack in the other direction, of course, on an array. We actually include in this feed port some of the strain relief. There is some capture there.

ROYAL: With glass-on-glass, has putting that together been any trouble?

JESTER: Actually, it's been a very easy layup. It uses the vacuum lamination technique that we perfected out at our Camarillo facility. It really built on a lot of things that we knew about laminating. It's been very effective -- we don't get any bubbles. That's been real nice in that glass-glass package. It has been very resistant to humidity, of course, which has been a real plus.

ROYAL: You see no bubbles?

JESTER: Well, we actually haven't experienced a bubble problem. Actually, what we did is, in designing, we set the EVA processing temperature and pressures. When we first started out we had a problem with bubbles, but it had to do with the processing technique, so we have worked that out to where we have virtually 100% yield through lamination. Of course, as mentioned by someone else regarding edge-grinding, we found that treating the edge of the glass has made a difference in keeping that yield high. And that is a standard in tempering and in any kind of glass-handling plants. They treat the edges of their glass if they don't want any of these small fracture points to start a major crack. That has been real helpful in keeping our yields high in the lamination area.

LESK: A couple of questions. You didn't mention it, but I assume the 1-mm glass is also tempered?

JESTER: Actually, it is not. And how we obtained the good mechanical strength is, we get a very thin bond line between the thin glass and the 1/8 in. tempered back sheet. And in processing the EVA was one of the things we had to work out -- it's getting a real good mechanical couple by a thin bond line there.

LESK: So that's why it chipped on the steel ball test?

I have another question: 14 1/2 volts, if you are working with a system with a regulator, I thought was a little low for high-temperature applications. Are these designed primarily for systems without a regulator?

JESTER: That's right. We recommend not using a diode in installing these in a battery-charging system. They hook directly to the battery, and the leakage current on these modules at night is very low.

DE BLASIO: A couple of questions, one regarding the qualification of the modules. Are these Block V qualified?

JESTER: Actually, we have done internal testing to Block V and that testing has pointed, as we were developing the product, to areas that need improving. In fact, we have some modules we are starting to go through Ron's people to do some testing externally. We have been very successful in testing against Block V.

DE BLASIO: I was just curious, because if these were power-producing modules for residential application, I assume they will have to meet the UL and also the NEC requirements. Based on this morning's discussions, we have a double-insulated scenario relative to primary-secondary electrical insulation. Now I'm building up to the question: is the plastic acceptable in this case, where you have similar polymeric materials insulating an electrical conductor? Does that still provide you with a primary-secondary isolation?

JESTER: Maybe Russ can help me with the answer to that. The hi-pot on these, of course, is very good because there are no conductors.

DE BLASIO: I'm just bringing it up as a possibility: if you use similar materials, trying to protect or isolate from the electrical system, you will probably end up with a single layer of protection rather than a double layer. I think, with the plastic you get in the residential applications, you may get into that problem.

ROYAL: What are the commercial applications of Rovel?

GAY: The only UL-qualified hot tub uses Rovel. It is in standard use for fairly extreme conditions, chemicals, high temperatures, steam, and is able to meet the standards that you all have.

YERKES: You mentioned that you just put this on a battery and you don't need a diode at night. Is this because of amorphous material not being conductive in the dark? Is this a feature of amorphous modules that you are all finding, or is this just an ARCO Solar finding?

JESTER: I can't speak for the rest of the people making modules, but we have set up tests with modules and batteries and found that the leakage current at night is so low that you don't have to worry about that. Maybe some of the other manufacturers can answer that.

ROSS: The Coast Guard has done quite a bit of studying and has found that even crystalline-silicon modules generally do not require a diode relative to battery charging, and the reverse leakages are very, very low.

JESTER: We have measured numbers much less than a milliamp in reverse. If you look at that over tens of hours of darkness, it doesn't add up to very much. It is a negligible power loss for what you are putting in, even at low light levels. The module at low light levels still produces very high voltages. Our fill factor actually gets much better at low light levels because of the front conductor that everybody has mentioned. So at lower light levels it's a very good fill factor, and our voltage is retained, so even on a cloudy day we are going to be putting juice into the battery; we are not going to be feeding back.

ROYAL: You are charging 400 millimeters?

JESTER: That's right. In ratio to that, you look at the time. It's very small.

KNIAZZEK: Two questions. It was mentioned that the polymeric frame was good in high-temperature, active situations, and yet it seems that the bond is not totally integral between polymeric frame and glass, thus it is not a total water seal. That would imply that the EVA overhang was an inadequate moisture barrier. Is that the case?

JESTER: That's actually what we rely on for our moisture resistance of the laminate itself. And, like I mentioned, the RTV helps in our connection area. You are right that the frame is not where the hermetic seal comes from; it comes from the way we package the glass-glass in EVA.

KNIAZZEK: Another question. You mentioned that the pigtailed are soldered to a printed circuit-material. Could you comment on how the printed-circuit material is bonded to the active photovoltaic material?

JESTER: It's actually by ribbons, standard soldering to the part, and then to the printed circuit board.

KNIAZZEK: Standard soldering to the metallic-back contact? Would you comment on what that material is? The back contact?

JESTER: I would rather not.

ROYAL: As you went through the several design evolutions, were you running tests and if so, were you changing largely due to aesthetics, or was it because they did not pass Block V type tests? Is that what happened before you went to glass on glass?

JESTER: As I mentioned, all of our prototypes and design evolutions use the EVA glass front and metal or glass back, so that gave us our environmental seal. And the frame, that was the other issue. Of course, as Ron mentioned this morning, if you put products out and you have not tested them, that is not a real good position to be in. Of course we were testing as we went along.

D'AIELLO: Ed's (Royal) question brought another question to mind. None of your evolutions used standard ARCO backing, which is EVA Tedlar. Did you find something particular about this module that precluded that?

JESTER: Actually, we wanted to get more mechanical strength from the back sheet than our standard material provides.

D'AIELLO: It wasn't a function of the protection?

JESTER: No, not at all. In fact, EVA-Tedlar is the material on crystalline-silicon modules that passed Block V at JPL. So it is a very good material, and the mechanical strength is the reason that we went for the back sheet.

D'AIELLO: The question that I came up to ask really relates to the design with the 25 segments, and the specified 14 1/2 volt operation to charge batteries. My question relates to the voltage that you get out of a module versus the charging voltage. It seems that you are awfully close to the minimum required for charging batteries as they charge up. And if you were to lose a segment for some reason, your yield is impacted dramatically. I wondered why you didn't design it at a higher voltage for charging 12-volt batteries.

JESTER: The max power voltage when we first manufactured the module was higher than that. We have sized the power over that, so that as the product stabilizes it's at the specifications that we publish.

D'AIELLO: So what you are saying is the actual measured V_{max} will be higher than the 14 1/2 specified initially?

JESTER: Initially, and then as it stabilizes it becomes closer to what we specified.

D'AIELLO: What length of time do we expect it to take to stabilize?

JESTER: It will be about a month. Of course, it depends on the weather conditions and where it is installed. Like I said, we have oversized the initial power; we put out much more than 5 watts at the beginning.

D'AIELLO: So the 25 segments are giving you an operating voltage of well over 14 1/2, and you expect the voltage to drop because of fill factor degradation?

JESTER: As Chris Wronski has talked about, everybody is aware of it.

ARNETT: I just wanted to respond to, and add a point to, the gentleman's question about the EVA from Kodak. I just wanted to comment that the modules that we supply to Sacramento Municipal Utility District as part of their PV program use an encapsulation system that does not employ an edge seal, so if you have a glass-EVA in

the back-sheet laminate and it has been through Block V qualification -- we feel that the approach here, even though this frame does not provide a complete contiguous seal, is certainly an acceptable and durable lamination and encapsulation scheme for withstanding the humidity-freeze and other environments in Block V.

YERKES: I think a couple of questions have come up about this ARCO Genesis module. This thing is not designed to be a large SMUD array module; it was designed for a specific market where one module primarily is sold to self-regulate a charge on a 12-volt battery in a boat, or something like that, and therefore it is targeted at something not requiring those leads to fit 20 or 40 panels together. It has a big wide frame around it, and things that you wouldn't do if you were going for high efficiency, but it is going to sell.