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Design And Production Of A 2.5 kWe Insulated Metal Substrate-Based Densely Packed CPV Assembly

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Abstract. The original design of a new 144-cell concentrating photovoltaic assembly is presented in this paper. It is conceived to work under 500 suns and to generate about 2.5 kW_e. An insulated metal substrate was selected as baseplate, in order to get the best compromise between costs and thermal performances. It is based on a 2mm thick aluminum plate, which is in charge of removing the heat as quick as possible. The copper pattern and thickness has been designed accordingly to the IPC Generic Standard on Printed Board Design and to the restrictions of fit a reflective 125x primary optics and a 4x secondary refractive optics. The original outline of the conductive copper layer has been developed to minimize Joule losses by reducing the number of interconnections between the cells in series. Multijunction solar cells and Schottky bypass diodes have been soldered onto the board as surface mounted components. All the fabrication processes are described. This board represents a novelty for the innovative pattern of the conductive layer, which can be easily adapted to be coupled with different optics geometries and to allocate a different number of cells. The use of an IMS as baseplate will give an experimental contribution to the debate about the exploitability of this kind of substrates in CPV. This board is being characterized indoor and outdoor: the results will be used to improve the design and the reliability of the future receivers.

Keywords: High concentration, Assembly, Thermal Management, Insulated Metal Substrate.
PACS: 88.40.-j

INTRODUCTION

The thermal management represents one of the most important issues for any CPV application. A 30%-efficient cell operating under Concentrating Standard Operating Conditions (DNI of 900 W/m^2) is expected to generate about 25 W/cm^2 of waste heat, if a transmissivity of 0.8 is accounted for the concentrating optics. If not rapidly removed, this energy leads to an increase in cell's temperature, which means a reduction in voltage and efficiency[1]. Along with the design of an optimal active or passive cooling system, the choice of materials and components of the assembly is a fundamental player in terms of thermal management's effectiveness. Commercial companies [2,3] generally use direct bonded copper (DBC) as baseplate for their assemblies. DBCs are a well-known technology, already used in electronic applications, which grants good performances in terms of both electrical conduction and thermal dissipation. On the other hand, Insulated Metal Substrates (IMS) are gaining the attention of the researchers, due to their lower cost and higher flexibility. IMS are composed of a copper circuitry bonded onto a metallic substrate trough a dielectric layer and have been developed by the LED industry. Recently Mabille et al. [4] have proven that IM substrates and Direct Bonded Copper (DBC) substrates behave similarly when exposed to accelerated aging tests. In a previous work, the thermal management of a IMS and a DBC was compared both in a single cell receiver scenario and in a densely packed case [5]. The outcomes of a three dimensional simulation showed a negligible difference in temperature at a steady state, when an adequate active cooler is applied.

In the present paper, the design and the development of a 2.5 kW_e, 144-cell receiver is presented. It has been built on an aluminum based insulated metal substrate and it was designed to work at 500 suns. The present work describes the geometry and the novelties of the receiver, conceived to reduce the cost of the CPV while keeping high thermal and electrical performances. All the assumptions made in the designing stage and the fabrications issues are reported in the paper.

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MATERIALS AND METHODS

The Insulated Metal Substrate

Aluminum based IMS has been chosen as baseplate. This kind of substrates offers high flexibility in terms of dimensions, choice of materials and pattern of the conductive layer. The IMS is based on a 2.003 mm thick 5052 aluminum layer and a 70µm-thick copper layer is bonded onto it through a 4.5 µm thick marble resin. Aluminum has been chosen due to its good thermal performances and its lower price than copper. The resin has a thermal conductivity of about 3 W/mK, which is slightly higher than that of other similar commercial thermal interface materials [6]. The 262.5x255.0 mm IMS was produced using a chemical etching process and then covered using a resistive layer to avoid the spreading of the solder. The sequence of the assembly's layers is represented in Fig. 1.

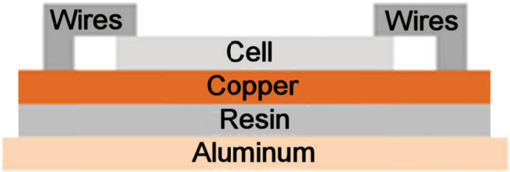

FIGURE 1. Cross sections of the CPV cell assembly

Surface-Mount Components

The Azurspace's 3C40 multijunction cells [7] have been used in this receiver. The three junctions correspond to GaInP, GaAs and Ge and efficiency up to 37.20% at 500× and 25°C is reported by the supplier. In the same conditions, a short circuit current of 6.587 and an open circuit voltage of 3.170 V are expected, while at the maximum power point an electrical output of 18.6 W is awaited. The cell has an active area which sizes 10 mm×10mm and the current flows from the back of the device to the two 0.45mm-width Au/Ag finished tabs placed on the front.

Taking into account the investigation presented by Vorster and van Dyk [8], one bypass diode per cell has been installed. Schottky diodes were chosen because of their low voltage drop which leads to lower losses and lower temperature while in bypass operation compared to the normal ones. The diodes have been oversized to reduce the risk of breakage [9]: 10A diodes have been considered to bypass an about 6.6 A current. The Vishay V10P45S Schottky diodes have been installed on the receiver, because of their good performances and limited dimensions.

An original paste mask was used to spread the Sn–3.2Ag–0.6Cu solder on the board. The components were then placed manually on the board, and the whole plate was finally placed in an automatic reflow oven at 217°C.

The Interconnectors

The interconnectors between the front contacts of the cells and the conductive layer have been realized using the wire bonding technology: 32 um-thick aluminum wires were installed on each side of the cells, as shown in Fig. 2. Aluminum grants high mechanical strength, can be processed at room temperature and it is cheaper than gold. 70 aluminum wires per cell were installed, in order to make the only thermal conduction able to remove all the Ohmic losses of the material.

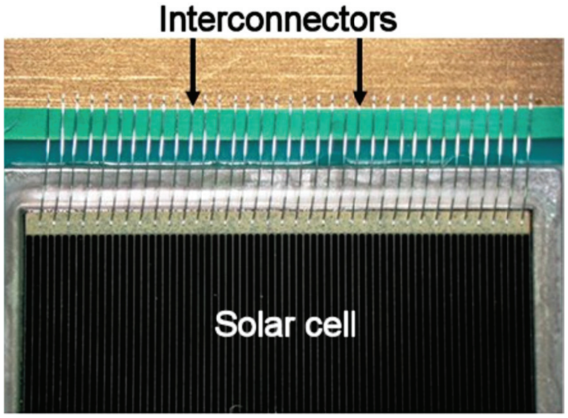

FIGURE 2. The aluminum wires bonded on a cell's front tab

DESIGN

The Conductive Layer

The original design of the pattern has no intermediate interconnections between the negative pads of adjacent cells: one shape of copper is used for both purposes. This let to reduce the number of interconnections, which are usually considered one of the weaknesses in electronic boards. In this light, the design has been optimized compared to that presented in [5]. The new design counts four shapes repeated in space: C1, C2, C3 and C4. They are represented in Fig. 3.

TABLE 1. Minimum width (in mm) accordingly to the IPC-2221 Standards, for ambient temperature of 25°C, depending on current and copper's temperature.

Current vs Temperature	28°C	29°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C
6.5870 A	4.16	3.5	3.05	1.57	1.15	0.94	0.80	0.71	0.64
3.2935 A	1.60	1.34	1.17	0.60	0.44	0.36	0.31	0.27	0.25

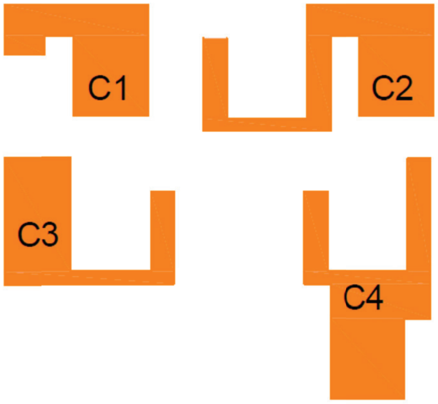

FIGURE 3. The four shapes of the conductor's pattern

In Fig. 5 the main differences between the old and the new pattern are highlighted: each change is marked with the same letter in both the designs. Firstly, C1 and C3, respectively placed at the positive (a) and the negative (b) pole of each series, have been modified to accommodate the terminal tabs. Secondly, C4 has been introduced to remove the need of interconnections between the end of two rows and, then, to reduce the Ohmic losses of the copper pattern (c). Furthermore, the gaps the conductive materials have been reduced (d) to gain space to extend the conductive area. Thanks to that, the minimum copper width (e) has been enlarged.

The design has been drawn up accordingly to the IPC-2221 Generic Standards on Printed Board Design to fit a 4x secondary. Coupling the secondary with a 125x primary optics raises the concentration to 500×. Table I shows the minimum width required for a 70µm-thick copper plate depending on the conductor's temperature and on the maximum current flowing into it. The copper layer allows the assembly to at any temperature 5°C above the ambient temperature: this is in the range of operating temperatures generally accepted for CPV[10]. Fig. 4 shows the flow of the current (a) and the density of current across a 4-cell pattern (b).

Arrangements Of The Cells In The Module

The cells have been connected in two series, to reduce the effect of the shadowing. When at least one cell is shadowed, all the other series-connected cells are affected: the intensity of the current they generate is delimited. On the other hand, a larger number of series would have decreased the output voltage and increased the sum of the output currents and, then, the Ohmic losses. In this way, a current of 6.440 A and a voltage of about 208 V from each couple of terminals can be achieved. Each series is expected then to produce about 1.25 kW$_e$.

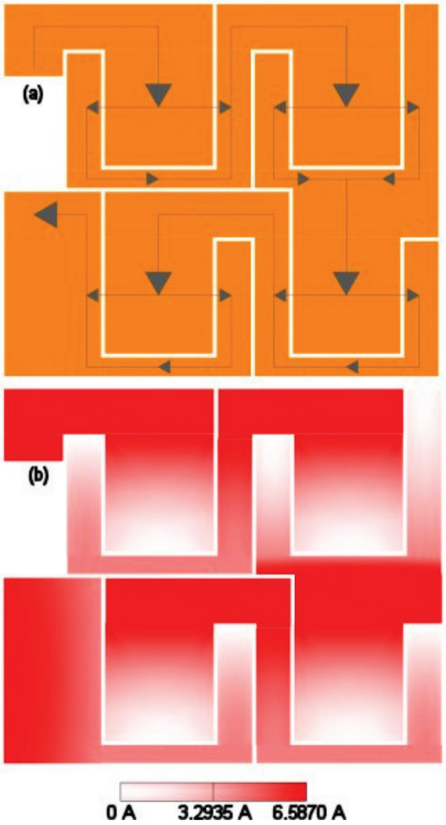

FIGURE 4. Current flow (a) and current density (b) across a 4-cell design

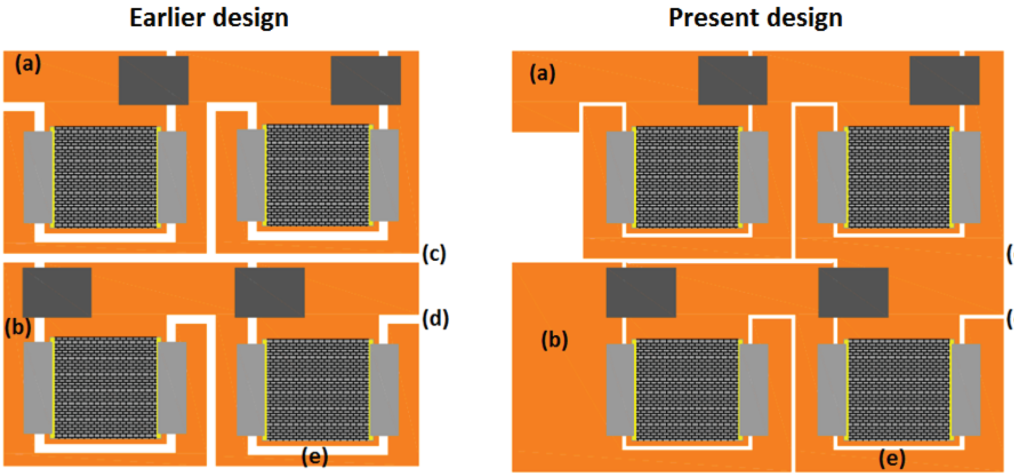

FIGURE 5. Particulars of the old and the new designs, respectively on the left and the right hand side. The differences are marked with letters from a to e.

CONCLUSIONS

A new high-performance 500× semi-densely packed receiver has been developed and is shown in Fig. 6. The geometry of all the components has been designed to fit the requirements of the Standards and to grant acceptable thermal management and electrical performances to the assembly. The shape of the electrically conductive layer has been designed to minimize the electrical resistances, by reducing the number of interconnections and to assure easy scalability to the structure. Aluminium wires have been used where interconnectors where needed, due to their flexibility and good performances in terms of electrical and thermal performances. A global power output of an electrical output of 2.5 kW_e is expected to be generated from the 144 solar cells. This assembly represents a novelty for the unique low-resistance design of the conductive layers.

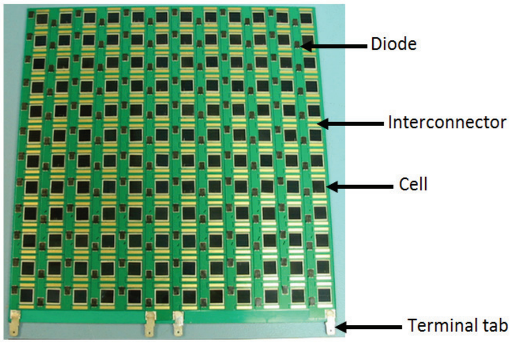

FIGURE 6. The full 144-cell board design.

ACKNOWLEDGMENTS

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