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Design Of A 16-Cell Densely-Packed Receiver for High Concentrating Photovoltaic Applications

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Abstract

A novel densely packed receiver for concentrating photovoltaics has been designed to fit a 125× primary and a 4× secondary reflective optics. It can allocate 16 1cm^2-sized high concentrating solar cells and is expected to work at about 300 W_p, with a short-circuit current of 6.6 A and an open circuit voltage of 50.72 V. In the light of a preliminary thermal simulation, an aluminum-based insulated metal substrate has been use as baseplate. The original outline of the conductive copper layer has been developed to minimize the Joule losses, by reducing the number of interconnections between the cells in series. Slightly oversized Schottky diodes have been applied for bypassing purposes and the whole design fits the IPC-2221 requirements. A full-scale thermal simulation has been implemented to prove the reliability of an insulated metal substrate in CPV application, even if compared to the widely-used direct bonded copper board. The Joule heating phenomenon has been analytically calculated first, to understand the effect on the electrical power output, and then simulate, to predict the consequences on the thermal management of the board. The outcomes of the present research will be used to optimize the design of a novel actively cooled 144-cell receiver for high concentrating photovoltaic applications.

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Keywords: Solar energy, CPV, receiver, IMS, high concentration.

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1. Introduction

Photovoltaics represents the third most important renewable energy source in terms of globally installed capacity [1]. At the end of 2012, the global installed PV capacity reached 99 GW [2]. Since 1980, the photovoltaic market has grown by 37% per year [2] and, in 2011 and 2012, PV was the first electricity source for sizing of the new installations in Europe [1]. Even in front of such a remarkable development, the cost of the technology still represents a limit for the growth of the market [3,4]. The idea behind the Concentrating Photovoltaic (CPV) is to use refractive or reflective materials to focus the same irradiance on a smaller expensive semiconductor surface. In order to improve the efficiency of the system, multijunction cells are generally applied: these cells are made of more than one semiconductive layer. GaInP/GaAs/Ge cells represent the most common devices and have shown a record efficiency of 37.9% [6].

The increase in irradiance and reduction in volume lead to a rise in heat production. Considering an optical efficiency of 20% and a cell efficiency of 30%, a 500× system operating under Concentrating Standard Operating Conditions (DNI of 900 W/m2, [7]) is expected to produce about 25 W/cm2 of waste heat. Thermal management is a key issue for Concentrating Photovoltaic (CPV), since a drop in efficiency of about 0,035% per rise in Celsius degree is reported [5]. CPV plants exhibit even long-term degradation when working at high temperatures: they can safely work at any temperature below 80-100°C. Cooling is generally not required for concentration ratio below 5×, while is necessary in the other cases. Either active or passive cooling systems have be applied in different CPV systems [6,7].

In a CPV system, the receiver represent the element where the cells and the other surface mount components are place and in charge of heat and electrical power removal [8]. The choice of materials and components of the receiver plays a fundamental role both in the thermal management and in the cost of the product [9]. The receiver represents 20% of the cost of the whole CPV system, which includes the cooling system [10]. Printed Circuit Boards (PCB) are the most common board in electronic applications, due to their high flexibility and relatively low costs. PCBs are laminated material bonded with heat cured flame retardant epoxy resin and clad on either one or both sides with copper. Usually the laminated material is a low thermal conductive fiberglass, but it can be replaced with a metal baseplate: this case the thermal management of the system can be enhanced and the board is called Insulated Metal Substrate (IMS). The metal base works for mechanical support and for heat spreading: an electrical insulating film is placed between the base and the conductive layer. Aluminum is the material generally chosen as baseplate, due to its excellent thermal conductivity, light weight and relatively low cost [11]. IMSs have been developed to be used in LED (Light Emitting Diode) applications and show an heat transfer management similar to the one needed by the CPV technologies [12]. The CPV receiver manufacturers' interest on this technology is increasing [12–15]. In this light, Mabille et al. [13] demonstrated that, when exposed to accelerated aging tests, IM substrates behave as the Direct Bonded Copper (DBC) boards, the most used substrates in CPV applications [16–19]. The exploitation of IMS can positively affect both the thermal management and the cost of the CPV devices.

In this paper the design of a new 16-cell receiver for 500× CPV applications is presented. The copper pattern has been conceived to minimize the electrical resistivity and to make the prototype easily scalable. An aluminum based insulated metal substrate is considered as baseplate: a preliminary thermal simulation has been run before starting the work, to compare the performances of an IMS and a more expensive DBC. A full scale simulation, inclusive of the heat production due to the Ohm losses, has then been run to demonstrate the reliability of IMS in a densely packed high CPV system. The presented design can represent a step toward the required reduction in price of CPV systems and will be used to conceive a new 144-cell receiver.

Nomenclature

A	Conductor's cross section surface (m^2)
C_p	Heat capacity (J/kgK)
E	Electric field strenght (kg m/s^3A)
I	Electric current (A)
J	Current density (A/m^2)
l	Length of the conductor (m)