Novel method and system for monitoring CPV cell and module temperature.

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Abstract

This paper outlines the concept of a novel system and method to monitor the temperature of a photovoltaic (PV) cell. PV cells in concentrator photovoltaic (CPV) systems in particular are subject to high thermal stress and accurate temperature monitoring will allow the introduction of thermal management strategies critical to maintaining efficient functioning and cell lifetime. The potential benefits of the manufacture of PV devices with integral temperature sensors and control for monitoring PV performance is outlined.

In terrestrial applications, solar cells are generally exposed to temperatures varying from 10˚C to 50˚C [1]. Concentration however raises the temperature of the cell and under high concentration solar cells may be exposed to temperatures in the range 250˚C to 650˚C [2]. Even under moderate concentration and a low DNI of less than 500Wm^2 cell temperatures have been found to exceed 80˚C during outdoor testing.

Discussion

The detrimental effect of excessive temperature on traditional silicon PV cells is well established and documented[3-6]. At higher temperatures the band gap of a semiconductor shrinks. This increases the equilibrium population of electrons and hence the dark saturation current density J_o. The reduced band gap also increases the photo-current, since lower energy photons can now be absorbed, but the increased dark current reduces V_{oc} faster than J_{sc} is increased, and a net reduction in efficiency results. (Figure 1)

The energy conversion efficiency of silicon solar cells normally falls by 4000-5000ppm for every degree centigrade increase in the operating temperature [7]. Gallium arsenide cells are less sensitive to increasing temperature with a fall of 1950-2640ppm for every degree centigrade increase in the operating temperature [8] and a temperature coefficient of performance approximately half that of silicon cells.

Current PV temperature measurement is usually performed with the use of single (or multiple) thermocouples placed on the underside of a photovoltaic module[9-10]. This can lead a large inaccuracy in the resulting measurements due to the large proximity difference between the encapsulated PV cell and the measuring device. The thermocouple may also require an external device such as a data logger, where the absolute temperature reading can then be obtained by combining the information of the known reference temperature and the difference of temperature between the probe tip and the tip reference (Figure 2),

Outline of System

The sensor device outlined consists of a junction diode formed on the surface of a cell; a metallic contact is deposited onto the cell during manufacture forming a Schottky barrier diode. The additional metal-semiconductor junction is formed by the evaporation of a metal contact with suitable work function. A wire is then bonded to the contact for connection to an external monitoring/control circuit. The reverse leakage current of the Schottky diode is temperature dependent and can be used as part of a feedback system to monitor and control the device temperature (Figure 3), either by controlling the movement of the module tracking so that the device is no longer in direct light or by switching in an active cooling device such as a fan if required.

The principle theory of the device is that as the temperature of a semiconductor increases so does the conductivity, due to carriers being liberated from the valence to the conduction band. For a metal, the resistance will increase, as conducting electrons are scattered by lattice vibrations. The operating temperature of the cell plays a key role in the photovoltaic conversion process, as the electrical efficiency and the resulting power output is virtually linearly dependent on the cell temperature (Figure 4).

Summary

An important feature of solar cells is their thermal behaviour. Thermal transport is important for safe and reliable operation of all electronic equipment, and is especially so in high-concentration PV devices. The thermal and thermo-mechanical issues associated with high solar flux and high temperatures are major hurdles in achieving high concentrations. Cells may experience both short-term efficiency loss and long term irreversible damage and degradation due to excessive temperatures.

Although it can be demonstrated that the temperature dependency of III-V semiconductors such as InGaP/InGaAs/Ge is less critical than that of silicon[11]. III-V cells are often used in concentrator systems as much reduced cell areas are required, offsetting the high cost inherent in the manufacture of these complex but highly efficient devices. As elevated temperatures inevitably reduce device lifetimes thermal management to keep cells from operating in excess of working temperature and to aid in reduction of thermal shock during cell cooling become attractive, as long term performance estimates are increased for a small increase in system cost - thereby decreasing the cost per peak watt.

Design considerations for CPV monitoring and resulting cooling systems should ideally include low and uniform cell temperatures, systems reliability and sufficient capacity for dealing with worst case scenarios and minimal power consumption by the system. Hence, CPV receivers must be designed to enable efficient thermal monitoring of the solar cells, while utilising compatible materials and processes to lower the thermal stresses.

References

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Figures

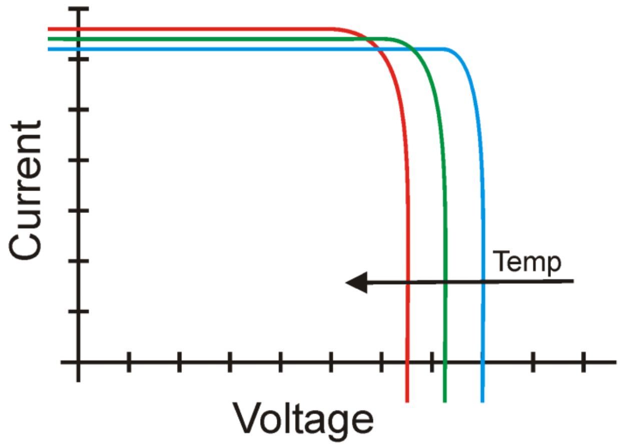

Fig 1. Effect of temperature on current-voltage curve

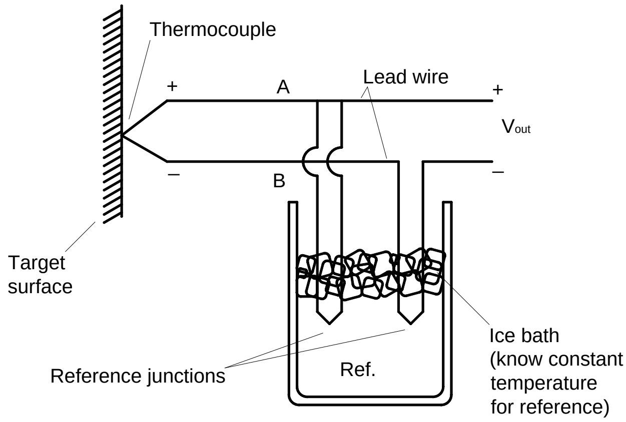

Fig 2. Typical thermocouple circuit

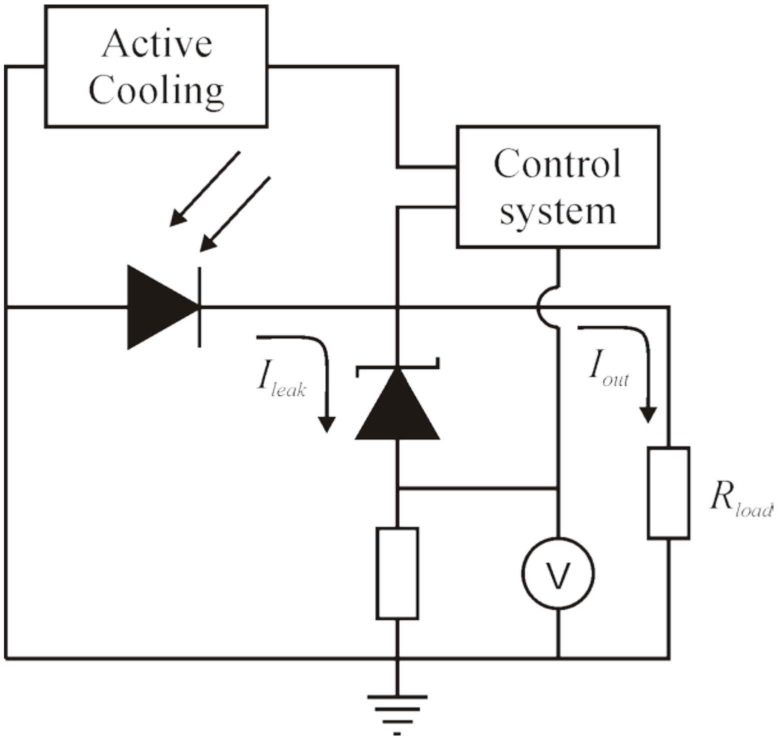

Fig 3. Schematic of device