Available online at www.sciencedirect.com
ScienceDirect
Solar Energy Materials & Solar Cells 91 (2007) 597–608
Solar Energy Materials and Solar Cells
www.elsevier.com/locate/solmat

Design and fabrication of low concentrating second generation PRIDE concentrator

Tapas K. Mallick*, Philip C. Eames

School of Engineering, Warwick University, Coventry CV4 7AL, UK

Received 28 September 2006; accepted 27 November 2006
Available online 1 February 2007

Abstract

Prototype first generation Photovoltaic Facades of Reduced Costs Incorporating Devices with Optically Concentrating Elements (PRIDE) technology incorporating 3 and 9 mm wide single crystal silicon solar cells showed excellent power output compared to a similar non-concentrating system when it was characterized both indoors using a flash and continuous solar simulator. However, durability and instability of the dielectric material occurred in long-term characterisation when the concentrator was made by using casting technology. For large scale manufacturing process, durability, and to reduce the weight of the concentrator, second generation PRIDE design incorporated 6 mm wide "Saturn" solar cells at the absorber of dielectric concentrators. Injection moulding was used to manufacture 3 kWp of such PV concentrator module for building façade integration in Europe. Special design techniques and cost implications are implemented in this paper. A randomly selected PV concentrator was characterised at outdoors from twenty-four ($\approx$3 kWp) 2nd-G PRIDE manufactured concentrators. The initial PV concentrators achieved a power ratio of 2.01 when compared to a similar non-concentrating system. The solar to electrical conversion efficiency achieved for the PV panel was 10.2% when characterised outdoors. In large scale manufacturing process, cost reduction of 40% is achievable using this concentrator manufacturing technology.

Keywords: Acrylic; Injection moulding; Photovoltaic concentrator; Low concentration

1. Background and general concept

The increase of photovoltaic (PV) market growth and rapid expansion of silicon use into electronic market, has led to a shortage of silicon feedstock within past years [1] which is now tending to increase the cost of PV modules. The most common way to reduce the cost of PV output is to reduce the amount of silicon material used illuminating higher solar radiation intensity, maintaining its operating temperature and thus performances. This can be achieved by using the low cost dielectric material onto smaller solar cell area without loosing its system performances.

Flat plate static concentrator (FPSC) with optical efficiencies of 87.6% and 85.6% was reported for mono-facial and bi-facial photovoltaic concentrator with concentration ratios of 2 and 1.5, respectively [2]. For a bifacial photovoltaic concentrator made using 125×125 mm SOG wafers with concentration ratios of 2.0, the front and rear illumination efficiencies were 15% and 10.5%, respectively [3]. However the temperature effect on the concentrating solar cells is not reported for such concentrators. A three-dimensional ray trace analysis [4] illustrated that asymmetric concentrators are most suitable candidates for use in a building façade integration compared to their symmetric counterpart. Total internal reflection was used to design two asymmetric concentrators (1st-G PRIDE technology) that showed an optical efficiency of 81% for a wide range of solar incidence angles. It is reported that asymmetric concentrator maintained optical efficiencies of over 40% even for incidence angles outside its two-dimensional angular acceptance range [4]. Transmission losses was minimised by using a dielectric material with a low extinction coefficient and by minimising the path length for incident insolation. The basic optical configuration in the first generation PRIDE technology was developed by

*Corresponding author. Tel.: +44 2476523139.
E-mail addresses: t.mallick@warwick.ac.uk, tkmallick_uk@yahoo.com (T.K. Mallick), p.c.eames@warwick.ac.uk (P.C. Eames).

0927-0248/$ - see front matter
doi:10.1016/j.solmat.2006.11.016

consideration of the solar motion as seen from a South facing wall at the intended latitude of installation [4]. Prototype systems of 3 and 9 mm wide solar cells at the absorber with design geometrical concentration ratio of 2.45 were fabricated using casting technology. A PV concentrator of geometrical concentration ratio 2 with lens efficiency of 94% is reported to have average optical concentration ratio of 1.88 for direct insolation within $\pm 60^{\circ}$ and $\pm 25^{\circ}$ in the East–West and North–South at Australia [5]. A concentrating PV element made of $Cu(In,Ga)Se_2$ based solar modules, aluminium reflectors and insulation for building integration of concentration ratio of 3.0 have been reported for low concentration photovoltaic applications [6]. However, their experiment shows a maximum electric power increase of 1.9 times compared to its similar non-concentrating panels due to low optical efficiency of the concentrator. The fill factor decreased from 0.6 to 0.5 under concentrated light [6]. A static concentrator consists of vertical plate solar cells and white/transparent switchable bottom plate achieved a collector efficiency of 62% for a concentration ratio of 2.0 [7]. Design, fabrication method and outdoor experimental characterisation of low concentrating air filled asymmetric concentrator of geometrical concentration of 2.0 shows an effective power increase of 1.62 times to its non-concentrating counterpart [8,9]. Due to the rear aluminium plate of the concentrator the measured peak solar cell temperature was only 12° higher compared to the solar cell temperature at its identical place of the non-concentrating system which shows an effective usefulness of the low concentrating system.

The work presented in this paper details the design, manufacturing process of 3 kWp photovoltaic concentrator using the low cost acrylic material and electrical characterisation of a randomly selected PV concentrator module. The concentration ratio can be increased while maintaining acceptance of all of the direct and most of the diffuse solar radiation by using a transparent dielectric system. Refraction occurs at the aperture of the concentrator effectively reducing the incidence angle and thus allowing more incident radiation to be accepted and reach the PV. Materials such as acrylic and glass have refractive indices of approximately 1.49. For this design presented in Fig. 1 the untruncated system concentration ratio (aperture area/receiver area) was 4.46. The 81% truncated system with concentration of 2.45 has high optical efficiency for rays incident in the range from 0° to 66° from the perpendicular to the aperture surface [4]. Total internal reflection allows metallisation of the concentrator walls to be avoided which leads to minimisation of reflection losses (the majority of reflections at the dielectric air interface occur within the angle of total internal reflection). The geometrical and physical properties of the single trough asymmetric CPC is shown in Table 1. For a path length of 10.6 mm through a concentrator fabricated from a material with an extinction coefficient of $4\,m^{-1}$, 5.04% of incident insolation is absorbed during transmission. For a material with an extinction coefficient of $32\,m^{-1}$, a thickness of 6 mm will absorb 15% during transmission.

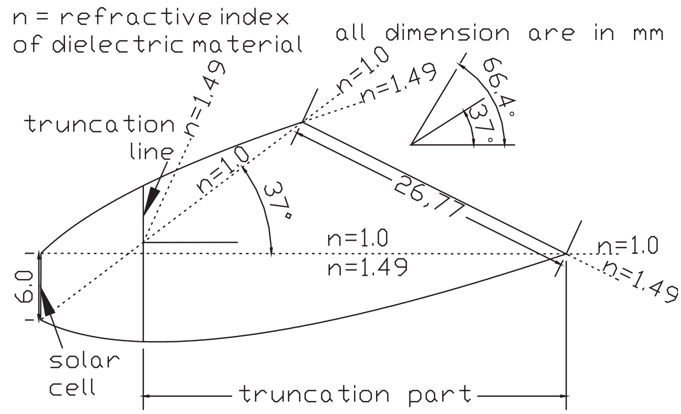

Fig. 1. An asymmetric CPC consisting of two different parabolas of acceptance angle 0° and 37°. The angular acceptance of the system is indicated on the figure for both the nondielectric mirror system ($n = 1$) and the dielectric system with a refractive index of 1.49.

Table 1
Geometrical properties of the single trough asymmetric CPC used to make the PV concentrator

	Untruncated	Truncated
Acceptance-half angles	66° and 0°	—
Absorber width (mm)	6.0	6.0
Aperture width (mm)	26.76	14.7
Length of upper parabola (mm)	49.0	26.7
Length of lower parabola (mm)	10.3	12.0
Depth of the concentrator (mm)	36.8	10.6
Area truncation (%)	81.0	—
Concentration ratio	4.46	2.45

2. Design of the asymmetric CPC

2.1. The concentrator trough

The 'SATURN' solar cells used to manufacture the second generation PRIDE concentrators were 6 mm wide and 116 mm long provided by BP Solar, Spain [10]. The grooves pitch of each solar cell was 1 mm and fourteen grooves were present in each busbar. The dimensions of the PRIDE system design, a truncated asymmetric compound parabolic concentrator (ACPC) is shown in Fig. 2. While concentration is reduced by truncating the full size PV system the optical efficiency increases due to both lower transmission losses and enhanced acceptance of diffuse solar radiation. Both weight and initial cost are reduced as less material is required. For a 6 mm wide absorber, the design allows concentration of 2.45 to be achieved with a concentrator that is only 10.6 mm deep.

2.2. The mould design

The design for the large area panel moulds developed to enable injection moulding to be used to produce the