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A comparison of performance of flat and bent photovoltaic luminescent solar concentrators

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Abstract

To employ new solar photovoltaic technologies in products and buildings, many systems need to be adapted. Inspired by the cylindrical shape, in this work we have evaluated the performance of luminescent solar concentrator photovoltaic (LSC-PV) elements with narrow PV cell strips that could be integrated in an outdoor lighting pole. Silicon photovoltaic (PV) cells were attached to the back of both flat and cylindrically bent PMMA lightguide sheets containing the dye Lumogen Red 305, and mirrors to non-covered edges of the light guides. The energy performance of these two elements was measured. The flat and bent LSC-PV elements were also simulated using optical modeling and the resulting performance parameters from simulations and experiments were compared. From simulations for a flat LSC-PV, the optical collection efficiency, concentration and electrical conversion efficiencies were found to be 18%, 1.8% and 2.8%, respectively, for a geometric gain of 10. For a bent LSC-PV shape, the respective values are 21%, 1.4% and 3.4% for a geometric gain of 6.7. Due to reduced sensitivity to the angular dependence of incoming irradiance it is expected that these bent LSC-PV elements would perform well on both sunny and cloudy days.

Keywords: Luminescent solar concentrators; Silicon PV; Product integrated PV; Solar-powered street lighting

1. Introduction

Solar energy harvesting using luminescent solar concentrator photovoltaic (LSC-PV) modules was originally proposed in the late 1970s (Goetzberger and Greubel, 1977; Weber and Lambe, 1976). In an LSC, sunlight penetrates the top surface of a lightguide made from inexpensive plastic or glass. The light is absorbed by luminescent materials, which are either embedded in the lightguide or applied in a separate layer on top and/or bottom of the lightguide. The luminescent materials can be organic fluorescent dyes, inorganic phosphors or quantum dots. The absorbed light is re-emitted at longer wavelengths, and a fraction of the re-emitted light is trapped in the higher refractive index lightguide by total internal reflection. The emitted light is guided to small PV cells attached to edges of the lightguide where it is converted into electricity. While the efficiency of

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the device compared with a bare solar cell array is modest, the LSC-PV is an attractive technology for use in consumer products or the built environment: the lightguide elements may be colorful and manufactured in a variety of sizes, the device performs well under both direct and indirect light, and could generally be employed anywhere plastic and are glass sheets are currently being used but now providing the element the additional function of electrical power generation (De Boer et al., 2012; Debije and Verbunt, 2012). In recent work on LSC-PVs, Philips Research has reported an efficiency of 4.2% for LSCs of $50 \times 50\ mm^2$ which is considered to be a record for Si-based LSCs (Desmet et al., 2012).

Considerable experience exists in product integrated photovoltaics (PIPV) (Reinders, 2012). In general it is assumed that to be able to use solar PV technologies in products or buildings, the PV cells often need to be adapted to the application (Reinders et al., 2013). Experiences with LSC-PV in a product context are limited and design issues with this PV technology may be different than with conventional solar cells in PIPV (Apostolou and Reinders, 2014). In particular, geometric modifications and efficiency (Bose et al., 2009; Chatten et al., 2011; Corrado et al., 2013; Inman et al., 2011; McIntosh et al., 2007; Pravettoni et al., 2009) play a role with regards to product-integrated LSC-PV. To evaluate these aspects (Viswanathan et al., 2012), this paper explores the effect of integration on the energy performance of LSC-PV in a light pole for outdoor lighting, like the one shown in Fig. 1, using both experiments and modeling. Due to the pole's cylindrical shape, we adjusted the conventional flat design of LSC-PV elements to a new structure.

Specifically, the PV cells have been moved from the edges to the back of a LSC-PV element (Corrado et al., 2013), which is a new location compared to conventional flat LSC-PV elements, mirrors have been placed on the non-covered edges, a diffuser reflective sheet made of micro cellular polyethylene terephthalate (MCPET) has been attached at the back of the LSC lightguide (in between the cells), and the shape has been altered from flat to a (half-)bent cylindrical LSC-PV. The device structure is illustrated by Fig. 2.

2. Experimental

As luminescent light guides we use 3 mm thick polymethylmethacrylate (PMMA) plates purchased from Evonik (PLEXIGLAS Fluorescent Bright Red 3C02 GT) containing approximately 200 ppm of the dye Lumogen F Red 305 (BASF) with absorbance >99% at 575 nm (and

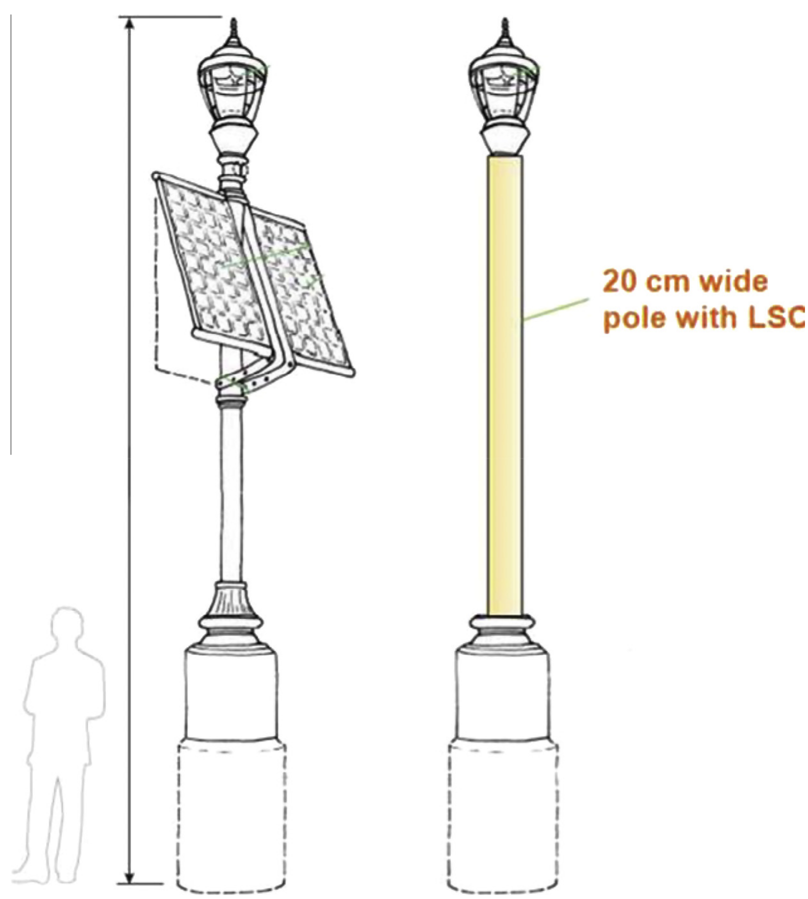

Fig. 1. Left: an existing solar street-lighting pole with conventional flat-plate PV modules, right: a street-lighting pole with integrated bent LSC-PV elements.