Chapter 13
The Luminescent Solar Concentrator:
Advances, Optimization, and Outlook

Rahul Bose
Imperial College London, UK

Keith W. J. Barnham
Imperial College London, UK

Amanda J. Chatten
Imperial College London, UK

ABSTRACT

Luminescent Solar Concentrators (LSCs) offer a way of making Photovoltaic (PV) systems more attractive through reduced energy costs, the possibility of application in cloudy regions, and improved building integration. LSCs collect light over a large area and concentrate it, both spatially and spectrally, onto solar cells at the edges of the device, such that the total cell area required to generate a specific power is reduced. Since the solar cells constitute the more expensive component in the system, this leads to cost reductions. Unlike conventional geometric concentrators, LSCs do not require solar tracking and can collect diffuse as well as direct sunlight. The current research challenges lie in increasing the efficiency of the LSC and extending it to larger areas to make it commercially viable. In this chapter, the authors outline the mode of operation of the LSC, with particular regard to cost considerations and device geometry. They then review recent approaches aiming to increase device efficiency and, finally, introduce their versatile raytrace approach to modeling the LSC. The model is utilised here to investigate tapered LSC designs and rationalise the optimal geometry and configuration for planar LSCs.

DOI: 10.4018/978-1-4666-1927-2.ch013

1. INTRODUCTION

In light of the world's ever-growing energy demands (OECD, 2009) and the urge to reduce greenhouse gases, the development of sustainable energy is a pressing task for science. As a renewable energy technology Photovoltaics (PV) is likely to play a key role in our future energy mix (MacKay, 2009). Indeed currently about a quarter of the world's population still lives without electricity (World Bank, 2008). Climate change and energy independence aside, renewable energy seems the only long term, sustainable solution to the world's growing energy need and diminishing resources.

The point at which electricity from renewable sources is cost-competitive with conventional electricity from the grid is called grid-parity. Grid-parity has not yet been achieved for PV, but, since solar irradiation does not vary notably from year to year, technological development and economies of scale continuously drive the efficiency of PV up and the cost down. Given that two thirds of conventional electricity is globally generated by fossil fuels (IEA, 2009) with obviously finite supplies we can expect a rise in the cost of conventional electricity that will ultimately favour renewable sources. The aim of the Luminescent Solar Concentrator (LSC) is to accelerate the process of making PV more cost-effective, by boosting the power conversion of solar cells with the use of a relatively inexpensive, versatile concentrator. It is a planar low-concentration device employing luminescent centres such as dyes or nanocrystals and is particularly well suited to Building Integrated Photovoltaics (BIPV).

The LSC can collect direct as well as indirect diffuse light and, unlike geometrical concentrators, does not require tracking. Costing more than the solar cells, tracking is the highest single expenditure in conventional concentrator PV systems (Extance, 2010). The non-tracking approach of LSCs alleviates space, cost, and maintenance requirements, allowing for a different range of applications. The LSC outputs a narrow, red-shifted spectrum, which can be matched to the PV cell absorption. This way the light coupled into the cell is converted more efficiently. Because thermalisation happens in the LSC, unwanted heating of the cell can be avoided. The LSC is versatile in that they can be designed semi-transparent or coloured and also flexible. By reducing the amount of solar cells required, the LSC could help make photovoltaic energy generation more viable.

In the next section, the operation of the LSC is explained in terms of its light-capture and waveguiding properties. Efficiency limits and cost considerations are detailed and alternative geometries are reviewed.

2. PRINCIPLES OF THE LSC

There are two main principles that govern the luminescent solar concentrator: light capture and waveguiding. A typical LSC as depicted in Figure 1 consists of a transparent plate doped with luminescent centres. Incident light is absorbed by these centres and re-radiated. Due to the difference in refractive index between the plate and the surrounding air a large fraction of the luminescent radiation is trapped within the plate by Total Internal Reflection (TIR). The trapped luminescence is wave-guided to the plate edges where it is converted by PV cells. Ideally, the output is in a narrow spectrum that is matched to the cells. The geometric ratio between the top surface and the edges leads to the concentration.

2.1. Light Capture

Light impinging on the surface of an LSC is either reflected or transmitted into the LSC. The LSC is a dielectric waveguide and as such has a refractive index n that is higher than that of its surrounding, i.e. higher than 1 in the case of air. Light is therefore refracted into the LSC at an angle closer to the surface normal according to Snell's