Exploration of the horizontally staggered light guides for high concentration CPV applications

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Abstract: The material and processing costs are still the major drawbacks of the c-Si based photovoltaic (PV) technology. The wafer cost comprises up to 35-40% of the total module cost. New approaches and system designs are needed in order to reduce the share of the wafer cost in photovoltaic energy systems. Here we explore the horizontally staggered light guide solar optics for use in Concentrated Photovoltaic (CPV) applications. This optical system comprises a lens array system coupled to a horizontal light guide which directs the incoming light beam to its edge. We have designed and simulated this system using a commercial ray tracing software (Zemax). The system is more compact, thinner and more robust compared to the conventional CPV systems. Concentration levels as high as 1000x can easily be reached when the system is properly designed. With such a high concentration level, a good acceptance angle of $+-1$ degree is still be conserved. The analysis of the system reveals that the total optical efficiency of the system could be as high as %94.4 without any anti-reflection (AR) coating. Optical losses can be reduced by just accommodating a single layer AR coating on the initial lens array leading to a %96.5 optical efficiency. Thermal behavior of high concentration linear concentrator is also discussed and compared with a conventional point focus CPV system.

OCIS codes: (080.2740) Geometric optical design; (350.6050) Solar energy; (220.4298) Nonimaging optics; (220.1770) Concentrators.

References and links

1. G. Zubi, J. L. Bernal-Agustin, and G. V. Fracastoro, "High concentration photovoltaic systems applying III–V cells," Renew. Sustain. Energy Rev. **13**(9), 2645–2652 (2009).
2. J. Jaus, G. Peharz, A. Gombert, J. P. F. Rodriguez, F. Dimroth, F. Eltermann, O. Wolf, M. Passig, G. Siefer, A. Hakenjos, S. v. Riesen, and A. W. Bett, " Development of Flatcon® modules using secondary optics," in *Photovoltaic Specialists Conference (PVSC), 34th IEEE* (*2009*), 1931 - 1936.
3. J. H. Karp and J. E. Ford, "Planar micro-optic solar concentration using multiple imaging lenses into a common slab waveguide," Proc. SPIE **7407**, 74070D (2009).
4. J. H. Karp, E. J. Tremblay, and J. E. Ford, "Planar micro-optic solar concentrator," Opt. Express **18**(2), 1122–1133 (2010).
5. J. C. M. Anton, O. P. Ligero, D. V. Molini, E. B. Martinez, and S. J. Caparros, "Light collection and concentration system," Abengoa Solar New Technologies S.A, World Intellectual Property Organization, WO **2010/056405**, 20 (2010).
6. S. Ghosh and D. S. Schultz, "Compact optics for concentration, aggregation and illumination of light energy," Banyan Energy Inc., World Intellectual Property Organization, WO **2009/035986**, 19 (2009).
7. J. H. Karp, E. J. Tremblay, J. M. Hallas, and J. E. Ford, "Orthogonal and secondary concentration in planar micro-optic solar collectors," Opt. Express **19**(S4 Suppl 4), A673–A685 (2011).
8. D. Moore, G. R. Schmidt, and B. Unger, "Concentrated photovoltaic stepped planar light guide," in *International Optical Design Conference*, OSA Technical Digest (CD) (OSA, 2010), paper JMB46P.

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9. A. Cvetkovic, R. Mohedano, P. Zamora, P. Benítez, J. C. Miñano, J. Chaves, M. Hernandez, and J. Vilaplana, "Characterization of Fresnel-Köhler concentrator," Proceedings of the 25th European Photovoltaic Solar Energy Conference and Exhibition - EU PVSEC, (Valencia, Spain, 2010), 176–181.
10. C. Algora, "Determination of the optimum solar cell size" in *Concentrator Photovoltaics* (Springer, 2007), Chap. 5.

1. Introduction

Crystalline Si (c-Si) solar cells dominate the global photovoltaic market today. The cost of material and the cell processing for this technology is still the main obstacle in the widespread use of the PV systems converting the solar energy into the electricity. In order to overcome this major problem, new approaches and designs aiming to use of less semiconductor material are needed. One of the well known solutions to this problem is to collect the solar radiation from a large surface area and focus it onto a small solar cell using appropriate lenses. This approach has been successfully implemented in the Concentrating Photovoltaic (CPV) systems employing high efficiency multi-junction solar cells [1]. Although, the cost of electricity produced by these systems is comparable to the standard c-Si PV modules, technical and practical difficulties arising from the complex architecture and stringent optical tolerances make these CPV approaches less favorable than the other PV systems.

In a conventional CPV cell, point focus Fresnel lenses are generally used. In this design, the incident solar radiation falling on a large lens area is focused on a solar cell with dimensions of 1 mm^2 to several cm^2 depending on the preferences of the system designer. However, this design suffers from the inhomogenity of the light beam over the cell area, an additional secondary optics is needed to homogenize solar radiation and increase the tracking tolerance [2]. The optical tolerances and the complexity of the system get worse for smaller cell sizes for which the electrical connections and packaging requirements are already problematic. Another drawback of the conventional CPV systems is requirement of the large vertical distances to achieve very high concentration levels (> 500) while keeping large enough cell sizes. For example using f-1 optics and 1 cm cell size requires the distance between the lens and the cell to be greater than 40 cm for a 1000x concentration which is desirable in certain applications [1]. For a module having a large thickness, the mechanical construction should be made properly to meet the requirements for the stability and long term durability of the system.

In order to reduce complexity of CPV systems with a more robust construction, light guide solar concentration systems have been proposed [3]. In this approach, the incoming solar radiation is collected by several primary concentrators and directed to a single PV cell through a light guide vertically located with respect to direction of the solar radiation. Light guide solar concentrators can be divided into two main classes as "lossy and lossless" [4]. As the names indicate, lossy systems lose some of the collected solar radiation through injection points or directing surfaces [4]. Because of their architecture, they tend to have smaller loss if the tracking tolerance is made tighter. On the other hand, the lossless systems do not have geometrical decouple loss, while they still have some losses due to Fresnel reflections from boundaries and material absorption. In order to achieve a completely lossless system, a volume increase at injection points are necessary [4]. In some of the recent studies [5,6], the volume increase has been applied towards thickness direction resulting thicker light guide construction.

Many of the proposed light guide concentrators that implement linear exit ports have low concentration levels. For the lossless cases, this is a consequence of having long directing surfaces that couples well to line focus primary concentrators. To achieve high concentration in these systems, they need to be designed in circularly symmetric geometry with a point focus like circular exit port [5,6]. The lossy systems also need secondary concentration geometries to reach high concentration levels [7]. But similar to the lossless case, after applying secondary concentration features, the exit port of the light guide turns into small and discrete exit ports which resembles to the point focus systems. In order to overcome the

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problems encountered in previous concentration approaches, horizontally staggered light guides can be used. This kind of staggering does not increase the thickness of the light guide and this light guide well couples to the point focus primary concentrators [8]. This design has a potential for reaching high tracking tolerance with high concentration ratios while satisfying the cost effectiveness required by a CPV system.

In this paper, we investigate the effectiveness of the horizontally staggered design for very high concentration levels up to 1000x. D. Moore et al., have recently reported general structure and basic properties of this approach [8]. In this work, we present a detailed discussion and analysis of the horizontally staggered light guide system. We suggest side cut features to be used together with the end region concentrator geometry to reach a concentration level of 1000x. We also address the management of the heat accumulation on the cell surface especially at high concentration levels in comparison with the conventional point focus CPV systems.

2. Horizontally staggered light guide solar optics

2.1. Method of concentration

The concentrator investigated in this study is an arrangement of a lens array and a horizontal staggered light guide. As shown in Fig. 1, light guide stays below the primary concentrating lens array. Light directing surfaces, light transmitting media and the exit port of the concentrator are actually features of the horizontal light guide structure. A photovoltaic cell will be attached at the exit port of the optical concentrator to finalize the system. The components of the optical system, design parameters and their effects on the optical performance are discussed below in detail.

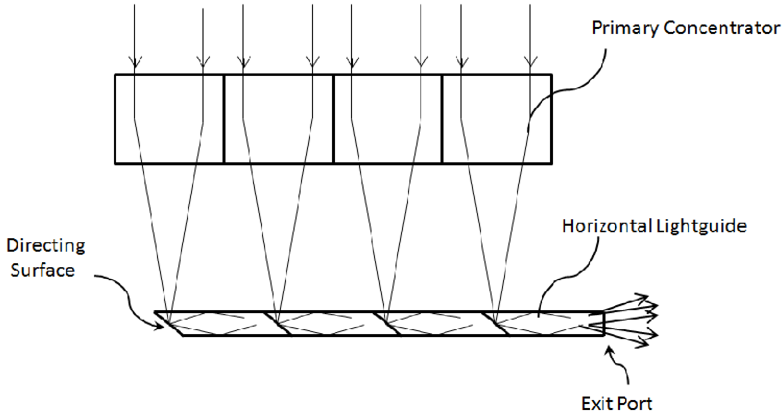

Fig. 1. Solar concentrator that using light guide.

2.2. Parts of the concentrator

2.2.1. Lens array

The primary concentrator array is focusing the light onto points of a rectangular grid. These focused points will be the injection points (acceptance region) of the light guide. The rectangular grid of the injection points is shown in Fig. 2(a).

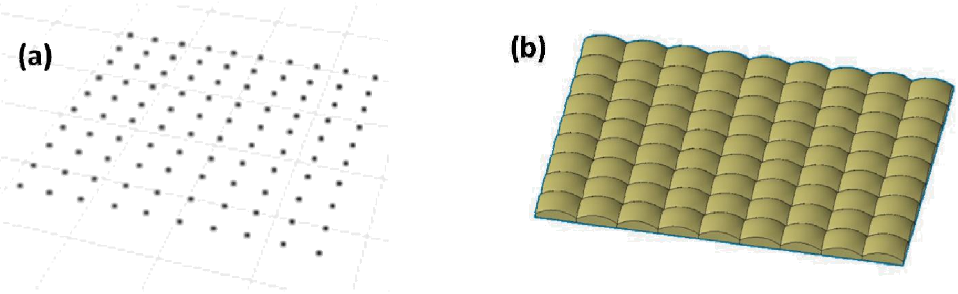

Fig. 2. Primary concentrator array, (a) Rectangular grid of focal points, (b) Lens array.

The primary concentrator array can be constructed from several different types of point focus concentrators such as fly eye lens array, array of Fresnel lenses, Compound Parabolic Concentrators (CPC), diffractive concentrators, Cassegrain systems or combinations of lenses and mirrors. In the optical design and simulations, ordinary simple lens array is chosen for simplicity as shown in Fig. 2(b). The primary concentrator focuses the incoming light onto the light directing surfaces which is a part of the light guide structure. Because the light directing surface is small, to achieve maximum acceptance angle the directing surface should be at the focus of the primary concentrator array where the beam width is the smallest.

The vertically staggered lossless light guide solar concentration systems are best coupled with line focus primary concentrators. These line focus primary optics squeeze the incoming collimated light only in one dimension, and if circularly symmetric form is not used, they are generally low concentration systems. In horizontally staggered light guides, instead of line focus lenses, point focus systems or specifically ordinary lentil type lenses can be used. These type of lenses squeeze the beam in two dimensions, and as a result, the diameter of the incoming beam is reduced. This has an important advantage compared to the line focus systems. If the line focus primary concentrator concentrates the light with a concentration of C, than the ordinary lentil type lenses approximately can give a concentration ratio of C^2. Because of this rule, horizontally staggered light guide solar optics can easily reach very high concentration values.

The focal length of the each focusing element in the primary concentrator array defines the main thickness of the total structure. The focal length also defines how big the sun image will be at the focus point, which is a design parameter for directing surfaces and also light guide thickness.

The aperture of the each lens element is also important together with the focal length. The f-number (focal length to aperture ratio) is a measure of the brightness of the image at the focus. If the f number gets smaller, than some light rays coming to the focus is too angled. This angle is an important parameter for the directing surface and should be properly designed to achieve Total Internal Reflection (TIR) at the directing surface and from the walls of the light guide structure. If the angle of the incident light gets excessively large, some of the incoming light rays will not satisfy the TIR conditions so decouple loss can be significant.

Excessively angled rays also cause optical path length elongation. If the rays move more in the material, depending on the material selection, internal absorption may cause significant transmission losses. These too angled rays also make too many TIR reflections from the surfaces of the light guide, resulting in more interaction with the optical surface irregularities such as surface roughness.

2.2.2. Low index media

In order to satisfy TIR condition inside the light guide, a low index region between the light guide and the lens array is compulsory. This low index medium can be an air gap in the

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simplest case or it can be a low index transparent material that fills the region between the light guide and the lens array.

Fresnel boundary reflections result from the refractive index changes at the boundaries. If the low index media between the light guide and lens array is properly selected, the Fresnel reflections can be minimized and increases the optical efficiency. The refractive index of this medium should be low enough to satisfy TIR in the light guide, while it should be high enough to reduce Fresnel reflection losses sourced from index differences.

Using low index materials instead of an air gap has some mechanical benefits such that the primary concentrator will support the light guide and no extra support structure is needed. On the other hand, the use of an air gap brings some design advantage in reaching very high concentration values. At higher concentration levels, the light traveling inside the light guide hits the boundaries with steeper angles. Therefore at the very high concentration regions such as the exit part of the light guide, it is beneficial to use an air gap as the low index medium. This approach is used in the simulated design to reach very high concentration levels.

2.2.3. Light guide

The light guide is responsible for transferring the light to the end of the concentrator. As illustrated in Fig. 3(a), it collects the light from different lenses and, when properly designed, gives extra concentration to the travelling photon beam. It is best visualized from the top view shown in Fig. 3(b).

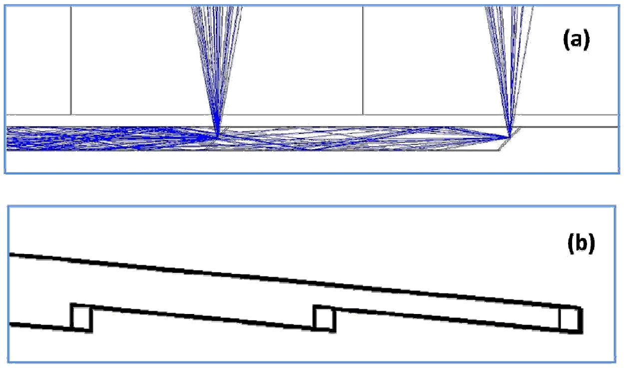

Fig. 3. Horizontally staggered light guide (a) Light guide collects light from different lenses. (b) Stepped structure of the light guide (top view).

The length of the light guide is restricted by several parameters. At a certain length, when new lenses are added to the system, adjacent light guides start to overlap. This overlapping prevents addition of new steps to the horizontal light guides and determines the concentration limits of the optical system.

Light directing surfaces reflect the light into the light guide with an angle such that reflection from the light guide surfaces satisfies the total internal reflection (TIR) condition. If the refractive index of the light guide material is high enough, no reflective surface coating is needed.

The absorption of the light guide is also important and it can significantly affect the final efficiency of the system. As the light travelling considerably longer distances inside the light guide, the absorption by the light guide material becomes important. Therefore, a low absorbing material should be used to fabricate the light guide of the system.

2.3. Further concentration methods inside the light guide

2.3.1. Side cutting surfaces

In order to reach higher concentration levels, the side of the light guide can be cut with specifically calculated surface orientations such that overlap of the adjacent light guides can be avoided. The surface compresses the light to a smaller volume and provides additional concentration as shown in Fig. 4(a).

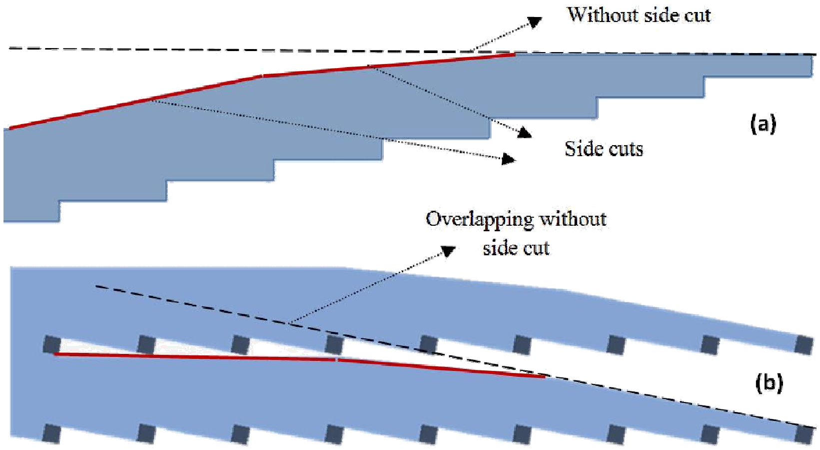

Fig. 4. Side cutting of light guides (a) Side cutting makes the exit port smaller and gives extra concentration. (b) Side cutting can postpone overlapping of adjacent light guides.

Side cutting can eliminate overlapping to some extent as shown in the Fig. 4(b). This side cutting gives extra concentration and therefore the light rays hitting to this surfaces start to move with steeper angles inside the light guide. After a certain length of the light guide the extra concentration surfaces cause the rays to move with excessively steeper angles and causes violation of TIR requirements inside the light guide. If a ray violates the TIR requirement, it starts to leak from the light guide and efficiency of the light guide reduces. Therefore the side cutting surfaces and the length of the light guide should be properly designed.

In our studies, to determine the side cutting geometry the ray that enters farthest from the end region and has the steepest horizontal angle is traced until it reaches to the exit port. The length of the light guide and the geometry of the side cut are iteratively determined to always preserve the TIR condition inside the light guide while keeping the length of the light guide as much as possible. Further study can suggest an equation or a generating algorithm to fully determine more effective side cutting geometries.

2.3.2. End cutting- final concentration region

In accordance with the concentration required at the end of the light guide, the end part of the light guide is designed to squeeze the light beam to a smaller region. This region can be either a separate part and then cemented to the light guide or be just the end geometry of the light guide. In the latter case, the end of the light guide can have a two dimensional conical or two dimensional Compound Parabolic Concentrator (CPC) type shape as shown in Fig. 5.

The CPC can further concentrate the light and reduce the PV area considerably. Concentration in the CPC geometry is defined by the input aperture and its acceptance angle. To collect all the light efficiently, the CPC input aperture should be equal or greater than the light guide output aperture.

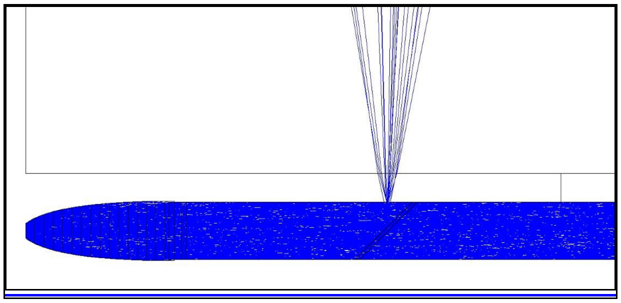

Fig. 5. End region of the light guide with a CPC type extra concentration element.

The concentrated light meets to the PV cell at the end of the final concentrator region. In most of the CPV applications, the image of the sun is generally circular while the PV cell is rectangular or square. This incompatibly prevents the optimum use of PV cell area because of the inhomogenous distribution of the light on the active PV cell area. However in the present light guide solar concentrator, the end geometry of the concentrator is rectangular which provides an excellent match with the rectangular PV cell geometries.

3. Concentrator simulations and performance

3.1. Input parameters

For the simulation of the solar concentrator, we have used the ZEMAX ray tracing software. The input parameters are adjusted to reach a 1000x geometric concentration and ± 1 degree of tracking tolerance. The wavelength range is selected to include visible and near infrared up to 1.1 microns.

In the designed system, one of the most common optical glass material, BK7 (nd: 1.516) is selected for the lenses and light guide structure. Lenses are aspheric lenses with a surface geometry of radius: 4.715 mm, conic constant: - 0,433 and a 5mm x 5mm square aperture. Thickness of the lens is selected to be 13.4 mm. Lens array has a MgF_2 AR coating of 150 nm on the out looking face. A low index medium with a 0.2 mm thickness and refractive index of 1.48 is inserted between the lens array and the light guide.

The light guide has a 0.4mm x 0.4mm step increase for every injection point and this branch increase is performed on a horizontal plane. The light guide has 45 degree reflective surfaces, which are assumed to be ideal reflectors.

A side cut and a CPC end region are added to the light guide to reach a high concentration level of 1000x. A side cut is realized with a one step straight line cut which is parallel to the virtual line passing from the injection surfaces. To prevent any overlapping with the adjacent light guides, width of the light guide is selected to be slightly smaller than the width of the primary lenses which is 5 mm. The width of the light guide is selected to be only 50 microns smaller than 5 mm to prevent touching of the adjacent light guides to each other.

A 2D CPC region is used as an end cut region and this CPC region is a solid structure that using the same material with the light guide which is BK7. All the reflections inside the CPC satisfy TIR. The exit port dimension and the acceptance angle fully define the 2D CPC geometry. The exit port has a 0.1 mm width and the acceptance angle is 14°.

In the simulation study, we used 20 lenses with corresponding reflective surfaces in the light guide. The total thickness of the structure is 14 mm and it is a very thin structure with respect to conventional CPV systems. The described geometry of the simulation is given as a graphical illustration in Fig. 6 and Fig. 7.

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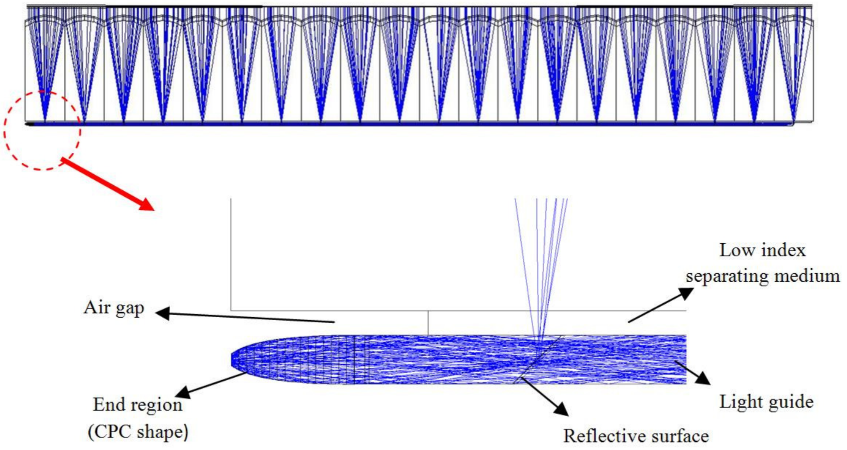

Fig. 6. Cross sectional view of the concentrator.

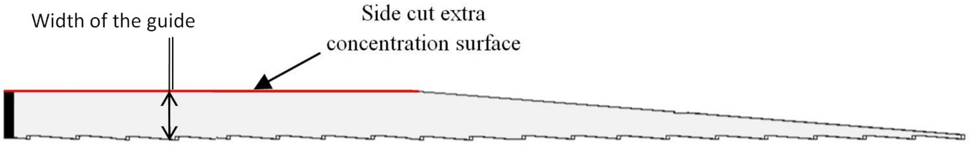

Fig. 7. Top view of the light guide with a single side cut extra concentration surface.

3.2. Simulation results

3.2.1. Optical efficiency

The optical efficiency, which is simply defined as the ratio of the output power to the input power, is a function of reflection and absorption losses. With the system parameters given above, the system efficiency is found to be 96.5% including absorption and reflection losses. If no AR coating is applied, then the total system efficiency drops to 94.4%.

The reflection losses occur at the boundaries where the light passes from one region to the other with different refractive indices. Although we assumed an AR coating on the surface of the lens array, the highest loss occurs here. The reflection loss is 2.1% from this region if all the wavelengths are assumed to have the equal weight. It is clear that a single layer AR coating is not sufficient to prevent boundary reflection because of broad wavelength distribution of the solar spectrum. By properly designing the AR coating with a multilayer structure, the reflection from the surface can be further reduced to below 1%. Because the refractive index change is very small at the boundaries, the total reflection loss at the two boundaries of the low index medium is 0.03%, which is not significant.

The absorption loss occurs in the lens material and inside the light guide because of the absorption in the BK7 glass. In our design the lens array and the light guide have absorption of 0.2% and 1.2% on the average, respectively. Absorption loss becomes important if the light guide is made longer to achieve thicker light exit regions.

The deviations from the ideal reflection condition at the 45 degree reflective surfaces can lead to reduction of the optical efficiency shown above. But the effect of the real reflective coating on the 45 degrees surfaces is very predictable. The effect of the non-ideality of the coating will be limited and real coatings will only alter the efficiency a few percent because every light ray is hitting to the reflective 45 degrees surfaces only once. Reflected rays will never encounter any of the other coated surfaces again. Therefore, after the first reflection the

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light rays will only exposes to the TIR reflections and this brings us that, the effect of the any selected reflective coating on the directing surfaces are easily predictable. The calculated ideal efficiency will be multiplied by the reflectivity of the coating to get the optical efficiency of the system with a selected realistic coating.

The possible varieties for the 45 degree reflecting surfaces should be addressed at this point. First, the surface reflectivity can be selected by accommodating several different reflecting surfaces such as silver, aluminum or dielectric mirror coatings. In these cases, the spectral variations in the reflectivity of these surfaces should be taken into account. Second, the reflective surface coating can be eliminated if a low absorption material with a high refractive index is chosen as the light guide material. With this higher index material, the light rays can make a TIR reflection from the 45 degree injection surfaces. Third, the 45 degree surface condition can be loosened. If the angle of the surface is changed than TIR can be satisfied in the directing surface without increasing the refractive index of the light guide. But this change will reduce the achievable concentration ratio and the simulations should be performed again to estimate the new concentration ratio.

3.2.2. Field of view (FOV)

FOV of the concentrator is defined as the angle where efficiency drops by %10. As the light guide gets thicker and the horizontal step is made larger, the focused light from the primary lens has more place to move without decoupling from the light guide. Therefore enlarging volumetric increase of light guide while keeping the primary concentrator size similar, gives better tracking tolerance. Increasing the acceptance angle reduces the concentration permanently. Decreasing tolerance to its half increases the concentration more than 4 times. In the simulated system we studied, simulations show that the FOV is more than $+-1$ degree as shown in Fig. 8. The angular size of the solar disc is not included in the simulations. This acceptance angle along with a 1000x concentration is not achievable with basic Fresnel lens and secondary optics combinations. This result demonstrates the advantage of the presented system in terms of concentration performance which is comparable with the sophisticated CPV optics such as Fresnel-Köhler concentrator [9].

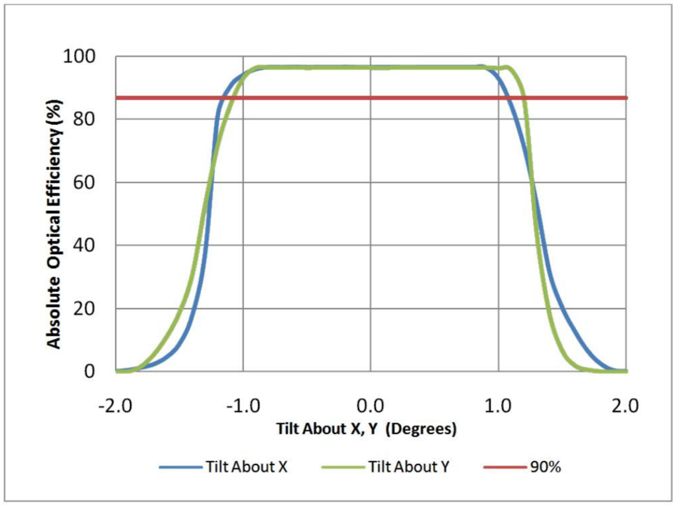

Fig. 8. Transmission efficiency vs. tilt angle.

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3.2.3. Concentration

Concentration is mainly a ratio of input and output apertures. The width of the input aperture is 100 mm and the width of the output aperture is 0.1 mm. The ratio of two dimension shows that system has a geometric concentration ratio of 1000x.

3.2.4. PV cell geometry

Exit port geometry of the light guide is a long thin strip. The small width of the exit port can be problematic because of increased assembly tolerances and small width cell sizes. It is possible to increase the small width of the exit port by putting several light guides on top of each other [8]. This method can increase the exit port width. But the dimensional increase will cause the elongation of the light guide too. Although the light guide utilizing low absorption materials and very smooth boundaries, too much elongation of the light guide can significantly degrade the optical transmission because of absorption and scattering losses.

Although 0.1 mm cell dimension required for 1000x concentration is small and it might bring some manufacturing difficulties, it is achievable with the GaAs based solar cell technology [10]. Moreover, this small width may be an advantage for extracting large current densities from the cell. A standard dicing and bonding machine should be able to fabricate such thin cell pieces and bond them to the edge of the light guide. If necessary, the width of the cell can be made slightly larger than the light guide exit to provide more tolerance in the bonding process. Cutting of cells with a small width from a wafer can waste more material in the dicing processes than the production of conventional CPV cells but ease of heat dissipation and a proper total system design with high concentration can still conserve the cost effectiveness required for CPV systems.

3.2.5. Thermal considerations

In the traditional point focus CPV applications cooling is a troublemaking issue at high concentration levels. Sophisticated active and passive coolers are needed to remove the heat generated by the focused sun light at high concentrations. The proposed concentrator has an important geometrical advantage for the cooling. Because the PV cell is spread to a line, the heat dissipation using a passive cooling plate could be easily integrated to the cell. Moreover, if an active cooling is selected for cooling, a simple water pipe touching to the back side of the PV cell would be sufficient to remove the heat accumulated in the cell.

A thermal simulation study was performed with the same parameters for line focus and point focus systems using a finite element software (Ansys Workbench) to get the steady state thermal behavior of the CPV structure and the maximum temperature of the cell. Both systems are assumed to have a 1000x concentration with a $500 W/m^2$ of the irradiance converted to heat on the photovoltaic surface. The irradiance is assumed to be uniform across the PV cell.

In both cases the area of the PV cell is selected to be 1 cm^2 for comparison. PV cell dimension of point focus system is 10mm x 10mm. The line focus system has a PV cell dimension of 0.32mm x 316mm. Both PV cells are touching to a 2 mm thick aluminum heat spreading sheet that has the same area as the collecting lenses (31.6cmx31.6cm). Considering a module with a front glass lens cover and a back aluminum cooling sheet, we assume that the heat accumulated on the cell leaves the system only from the back side of the module. In fact this is a worst case scenario and some of the heat will also dissipate from the top cover in reality. The heat is assumed to dissipate only from the bottom surface of the aluminum sheet via convection with a convection coefficient of $5 W/m^2$ C° and via radiative heat transfer with an emissivity of 1.0 to the ambient with an ambient temperature of 20 °C.

The simulation results are shown in Fig. 9. It is shown that heat transfer is much more superior in the line focus system than the point focus system. In the line focus system, heat is

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very well spreading on the heat dissipating aluminum sheet and promotes better passive cooling.

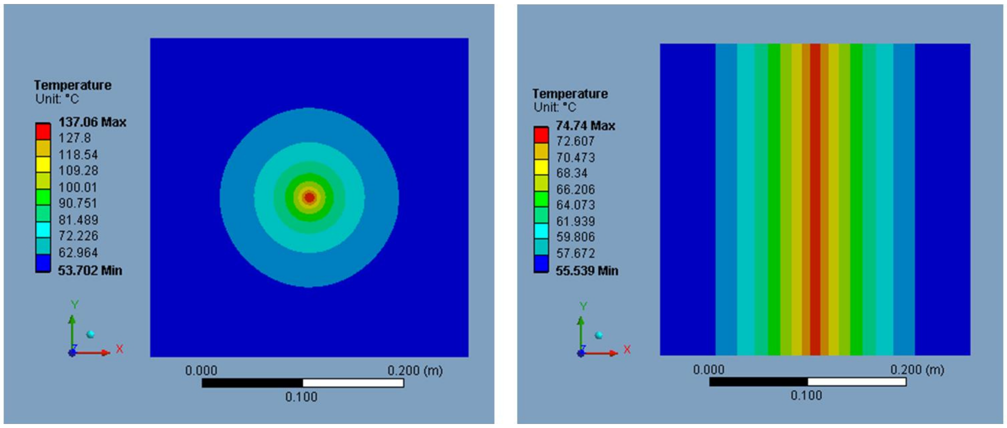

Fig. 9. Thermal simulation results of point focus and line focus systems.

The maximum temperature for the point focus system is found to be 137 °C. This value is too high for the solar cell operation and needs additional cooling means such as heat dissipation fins or active cooling systems. But for the line focus system, the maximum temperature on the cell is found to be 75 °C. This value is acceptable for high efficiency cells and therefore does not require any special cooling mechanisms. Thus, a passive cooling attachment like the one used in the simulation is sufficient to realize the high concentration light guide concentrator systems. Also, this maximum temperature is far below the critical temperature of plastic optics such as PMMA (<100°C), and low cost plastics can be used instead of glass as the light guide material.

4. Conclusion

The horizontally staggered light guide systems are shown to be very effective to collect and concentrate light with a compact geometry. Simulation results show that very high optical efficiency values are attainable with or without AR coating. This geometry of the optical concentrator can be adapted easily from low concentration to very high concentration applications. More than 1000x concentration is possible with a proper design of the extra concentration features and selecting appropriate materials. The rectangular and thin exit port of the system couples very well to the PV cells and passive heat dissipation is possible even at 1000x concentration level. The heat dissipation of this system is shown to be more effective than conventional point focus CPV systems.

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