Micro Optics in Solar Power Systems

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Abstract

The usage the a new type of micro optic concentrator that collects the sunlight from hundreds of small aperture lenses within a micro-lenses array and concentrates the sunlight on PV slices. A ray tracking has been performed by using ZEMAX-EE sequential analysis software to model and optimize the efficiency of the micro lenses-array concentrator.

A new model for array of lenses concentrator is designed and simulated. This concentrator consists of array of micro lenses to focus solar light on four rectangular slices of photovoltaic Si solar cell. The design aims to reduce the cost of the concentrators by reducing the effective area of the high cost silicon material area and simplifying the structure of the system. This design has high relative illumination efficiency and that indicate a good illumination distribution which improves solar cell efficiency. The results show that micro lenses array concentrator can works well over such a large range in acceptance angles and wavelengths, therefore; this concentrator does not needs to accurate to tracking sun through the daytime which simplifies the design and reduces the total cost of the system.

Keywords: Micro optic Concentrator, Illumination solar cell, ray Tracking.

المركزات البصرية المايكروية في تصميم الخلايا الشمسية

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الخلاصة

أستخدم نوعا جديدا من المركز البصري المايكروي الذي يجمع ضوء الشمس من مئات من العدسات ذات الفتحة الصغيرة خلال صف من العدسات المايكروية و يركز ضوء الشمس على الشرائح الفوتوضوئية.
تم تتبع الأشعة باستخدام زيماكس برنامج التحليل التسلسلي لتشكيل وتحسين كفاءة مركز العدسات المايكروية. تم تصميم ومحاكاة مركز شمسي متكون من صفوف من العدسات المايكروية التي تركز الإشعاع الشمسي على أربع شرائح مستطيلة من الخلايا السليكونية. التصميم يهدف إلى تقليل كلفة المركزات الشمسية من خلال تقليل مساحة المادة السليكونية باهظة الثمن وتبسيط التصميم الكلي. ويحتوي على كفاءة إضاءة نسبية عالية وذلك يدل على التوزيع الجيد للإضاءة الذي يحسن كفاءة الخلية الشمسية، لقد أظهرت النتائج بان مركز صفوف العدسات المايكروية يمكن أن يعمل بشكل جيد على مدى واسع من زوايا المجال والأطوال الموجية ، لذلك هذا المركز لا يحتاج بالضرورة إلى تتبع دقيق للشمس خلال النهار مما يبسط التصميم ويقلل كلفة النظام الكلية.

كلمات مفتاحية: المركز البصري المايكروي ، الخلايا الشمسية ، متعقب الضوء

1-Introduction

Optics of solar concentration typically consists of lenses or mirrors. One aim of solar concentrators is to reduce the cost of a solar power systems through reducing the amount of expensive semiconductor used in exchange for mechanics of tracking and optical concentrating components.
Solar trackers rotate the solar panel or solar concentrator so that direct normal incidence is maintained throughout the day.

As concentration increases, so does the required complexity and precision of the tracking mechanics.Therefore this increased precision results in a larger fraction of the total system cost in tracking[1].
In this research, we present an alternative to large scale two - axis mechanical trackers that relies on the unique geometry of an array micro - lenses concentrator . Silicon based photovoltaics (PVs) convert less than 20 % of incident sunlight into electrical energy.

High efficiency solar cells developed for the space industry have demonstrated more than 43% conversion efficiency by layering multi semiconductor junctions that capture large portions of solar spectrum[2]. For CPV systems, to be cost-effective, the complete cost of the optics, assembly and mechanical tracking must not exceed the cost saving gained from using small area PV cells.
Solar ray tracing programs are used to find new types of solar lens concentrator to save the cost by reducing the area of PV cells[3]. Figure(1) offers the Layout of micro-lenses array (12× 23) and explains that all micro-lenses focus sunlight onto PV slices that stuck along the 70 mm of array.

2- Concentrator Geometry

The geometric concentration ratio (C_{geo}) is defined as the ratio of input to output areas of the optical system.
For the micro lenses array concentrator, this ratio is simply the area of the lenses array divided by the output area of the lenses array, as seen in Eq.(1).

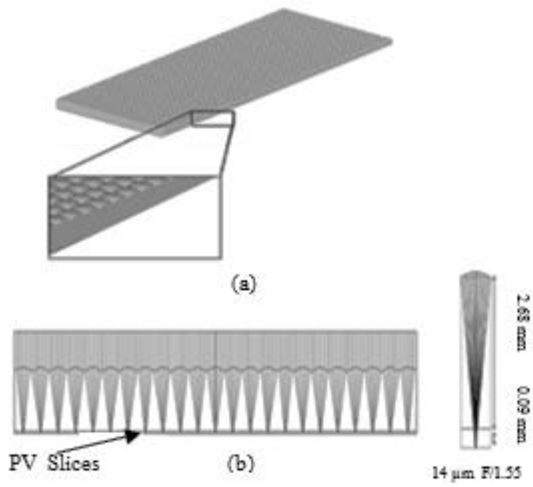


Figure (1): Layout of micro - lenses array concentrator (a)3Dimention (b)2Dimetion.

Optical efficiency (η) is the fraction of light which reaches the output aperture and principally includes Fresnel reflections and material absorption. Eq.(2) denotes the flux concentration (C_{flux}) as the product of the geometric concentration ratio and optical efficiency and indicates the concentration level presented at the PV cell, or represents irradiance distribution on the PV cell. Every lens in array aperture forms a demagnified image of the sun which subtends ± 0.26° [4]. The aberration-free solar image height has been calculated by using ($2f \tan\theta$) where (f) is the lens focal length and (θ) is the acceptance half - angle. Each lens element has its own two dimensional geometric concentration defined by Eq.(3)[5]. The lens aperture to image area is expressed in terms of the lens focal length to diameter ratio, or F-number (F/#), and acceptance half-angle (θ).

$$C_{geo} = \frac{\text{area of the lenses array}}{\text{output area of the lenses array}} \quad \ldots\ldots\ldots(1)$$

$$C_{flux} = \eta \times C_{geo} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$C_{lens} = \frac{1}{(2f/\#\tan\theta)2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Micro-lenses array provide concentration; in addition to that collects, homogenize and transports the energy to the (PV) cell.

3- System Optimization

A ray tracking has been performed using ZEMAX-EE sequential analysis software to model and optimize the efficiency of the micro lenses-array concentrator [6].

The analyses assume hemispherical plano convex , these refractive lenses form the homogenization rays on the solar cell. Lens aberrations, Fresnel reflections and material absorption are included in optical efficiency calculations of ZEMAX-EE program.
Simulation uses weighted (AM 1.5) and wavelength from (0.325-1.6) μm at ±0.26° field angles.

In each of the previous designs simulation we used a glass of type BK7 and in this design also ($n_d = 1.5168$, $\acute{\alpha} = 3\times10^{-6}\ \text{cm}^{-1}$) glass of lenslet array[7].The new rectangular concentrator consists of array of 12×23with total area (27.2× 81) mm^2 .
An individual lens with (1mm) radius and F/1.55 is used to focus sunlight onto four rectangular PV slices (6 mm × 70 mm) for each with total effective cell area equal to (16.8 cm^2) . The total thickness of the concentrator does not exceed (3 mm). Air thickness between lenses array and (PV) slices is optimized to gives a uniform illumination efficiency 100 % on all areas of the silicon cells at ± 0.26° field angles.

Air spaces between the lenses have fears. This problem can be solved by making of hexagonal lenses to lined compact (tightly). There are rays that do not appear in the scheme of the spot because of the extreme edges of micro-lenses array . Since that a spot area is bigger than cells area, the loss in the rays do not appear in the process of concentration .

4- Results and Discussion

4.1- Spot diagram of the design

The spot diagram shows a 12×23 array of lenses formed a grid of spots on the image plane (PV slices) as shown in fig.(2). The (276) spatially separate images for each object point.The design array of micro lenses makes each single lens in the array focused sunlight . It gives bright spot is independent of other so it has Airy pattern independent. It contains 84% of the energy of incident light on the lens. The remaining energy divided on the other rings, so these rings interfere with neighboring rings from the neighboring lenses and this process be homogeneous lighting and focusing on both[8].

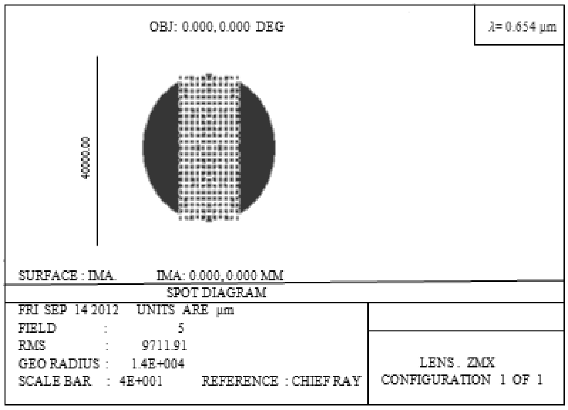


Figure (2): Spot diagram of 12×23 array of micro-lenses .

4.2- Surface sag

Fig. (3) (a ,b) shows the surface sag of the curvature and aperture of each lenslet in the array of (12 column) and (1 column) respectively.

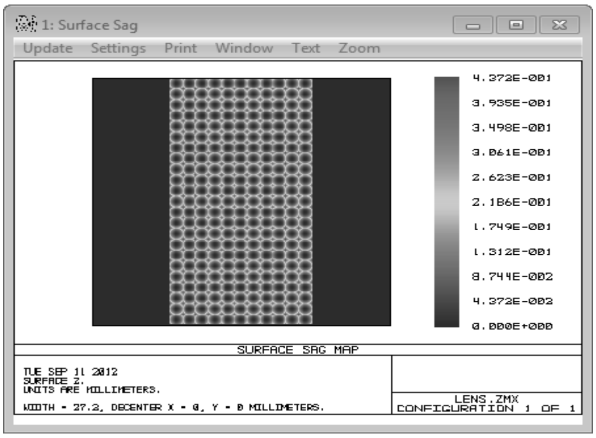


Figure (3-a).

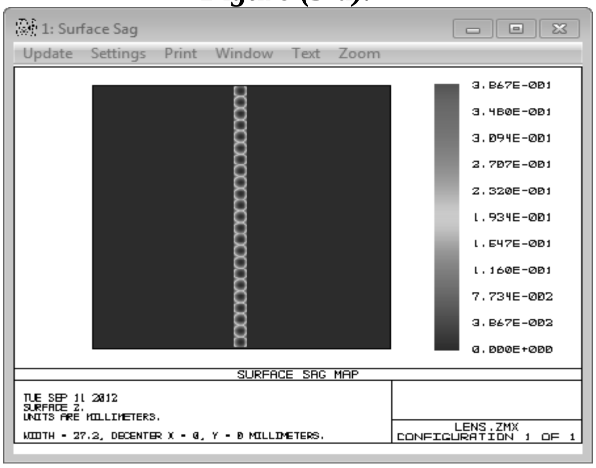


Figure (3-b).

RMS radius of this concentrator remains constant with wavelengths at the full field ± 0.26° , but it will change over ± 45°.

4.3-Encircled Energy

We find from fig.(4) that radius from center at (80 %) of total energy equal to (1.212×10^4 µm) and this equals to diameter (24.24 mm). This value is very suitable to dimensions of PV slices.
Diameter (24.24 mm) makes width of each single slice is (6mm) and the space between them is equal to (0.6mm) and the distance from array edge to slice is equal to(0.3mm).

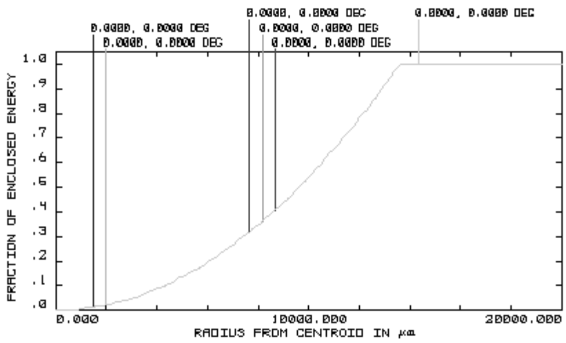


Figure (4): Encircled energy of micro-lenses array.

4.4-Reflection coefficient

Fig.(5) explain the relationship between the reflection coefficient (%) with incidence angles.The reflection coefficient is very low at incidence angles(0°–50°).
After that increases even 90°.This improves concentration ratio and reduces rays loss.

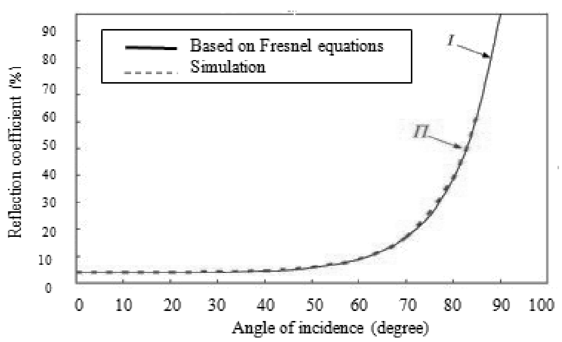
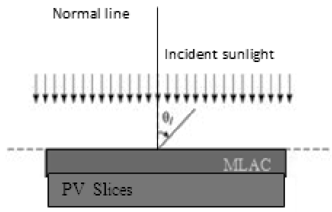


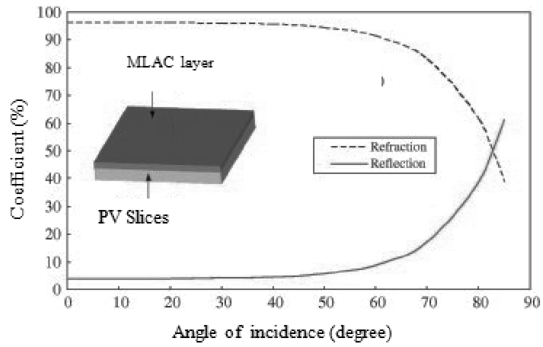
Figure (5) : The relationship between the reflection coefficient and angle of incidence.

4.5- Refraction coefficient

Micro-lens array concentrator (MLAC) is attached on the surface of a solar slices as shown in fig.(6-a). MLAC can reduce the opportunity of reflection as light arrives at the surface and therefore can increase the refraction coefficient as shown in fig.(6-b). As a result, the gain of photovoltaic power can be improved with the MLAC. Light is efficiently refracted by the MLAC and absorbed by the solar slices without the need of a solar tracking mechanism.
Optimization of geometrical parameters of MLAC such as contact angle and interspace (gap) between each micro-lens is designed by simulation.



(a)



(b)

Figure (6) : (a) A plain MLAC as the interface; (b) the coefficients of reflection and refraction for angles of incidence.

4.6- Illumination Distribution

The illumination distribution will be examined by using ZEMAX-EE physical propagation properties.

Fig. (7) shows that the illumination distribution along x and y coordinates of the PV slices has illumination value 100% of the total input illumination at field angles

± 0.26° which indicates the good lens array concentrator design .

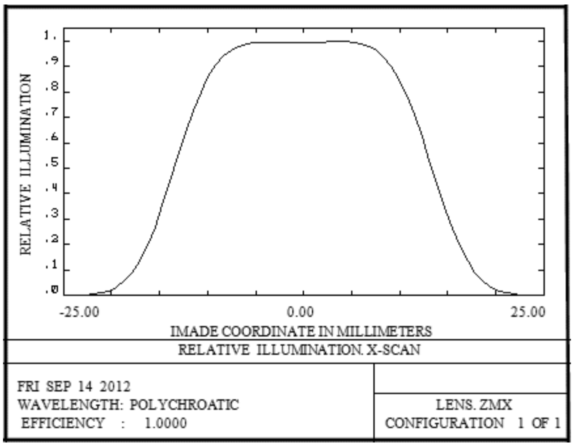


Figure (7)*:illumination distribution on the PV slices at field angles ± 0.26° .*

MLAC has good relative illumination at different field angles. Fig.(8) shows the relative illumination distribution of the wavelength with the field angles ± 80° on PV slices. We can conclude from fig. (8) that MLAC has high relative illumination efficiency and these figures indicate a good illumination distribution which improve solar cell efficiency.

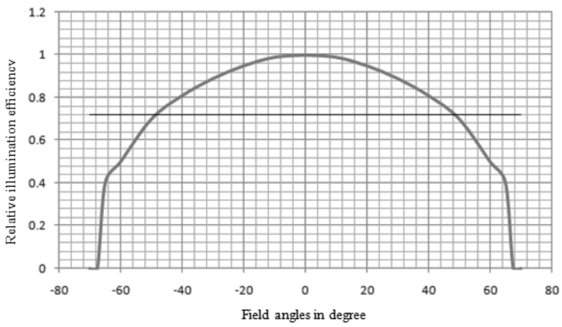


Figure (8) : illumination distribution on the PV slices at field angles ± 80°.

So these figures prove that MLAC can works well over such a large range in field angles and wavelengths. This concentrator does not needs accurate tracking to sun through the daytime.

5- Conclusions

1-Increase the concentration ratio of the sunlight on PV cell at field angles ± 60°.
2-An irradiance on PV cell is homogeneous
3-This concentrator can works well over such a large range in field angles (± 45°) and wavelength.
4-This concentrator has efficiency 100% relative illumination on PV cell.
5-It didn't needs to accurate tracking to sun through the daytime which simplifies the design and reduces the total cost of the system.

6-References

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