EXPERIMENTAL AND THEORETICAL DESIGN FOR A NEW ARRAY MICRO-LENSES SILICON SOLAR CELL CONCENTRATOR

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ABSTRACT
In this paper, a new model for array of micro-lenses concentrator was designed. This concentrator consists of array of micro-lenses (MLA) to focus solar light on four rectangular slaps of photovoltaic Si solar cell. The design aim to reduce the cost of the concentrators by reduces the effective area of the high cost silicon material area and simplified the structure of the system. The solar cell with the MLA-concentrator adds energy conversion efficiency (11.98%) and reducing the total cost.

Keywords: solar cell, concentrator, ray tracing program, cell efficiency.

INTRODUCTION
Silicon-based photovoltaic (PV) convert less than 20% of incident sunlight into electrical energy. High-efficiency solar cells developed for the space industry have demonstrated more than 41% conversion efficiency by layering multiple semiconductor junctions that capture large portions of the solar spectrum [1]. Fabrication and material costs limit these cells to only a few square centimeters, making them impractical for flat-panel installations. Concentrator photovoltaic (CPV) incorporate large-area optics that collect and deposit energy onto small, efficient solar cells with the promise of reducing electricity-generation costs compared to silicon-based PV [2].

For CPV systems to be cost-effective, the complete cost of the optics, assembly and mechanical tracking must not exceed the cost savings gained from using small area PV cells. Solar ray tracing programs was used to find new types of solar lens concentrator to save the cost by reducing the area of PV cells [3].

High-flux concentrators typically consist of a large primary optic to focus sunlight and a secondary optical element for flux homogenization. A common design approach divides the upward-facing primary into several small apertures, each with its own individual secondary element and solar cell [4].

The energy issue has been gaining a lot of attention in many countries in recent years. Among the kinds of energies, the solar energy is one of the most interesting topics of them. In addition to the fabrication process and raw material, another focal point aims at solar concentrator. This paper shows a new and easy way to increase the solar energy efficiency. We utilize the micro-optics principle to design and fabricate a micro-lens array of the solar concentrator. With this concentrator, it can enhance the amount of focused sunlight on the solar cell so the optical absorption on the solar cell is not required), and it is easy to manufacture. The size is smaller than conventional concentrator, especially. The MLA-concentrator can decrease the reflection of light at oblique angles and increases the second reflection at the interface between concentrator and solar cell, which makes the sunlight uniform. This new-type MLA-concentrator is fabricated by using LIGA-like process, and then it is integrated to the solar cell for electricity generation. Most important, this kind of structure can be combined with all kinds of solar cell.

![Figure-1. Individual secondary optics requires multiple PV cells (a). Each lens concentrate on individual secondary optics (b) Replace the secondary optics by waveguide. Arrows indicate PV cell locations. [4].](image)

However, integrating hundreds of small PV cells all aligned to their respective optics leads to large-scale connectivity and cost concerns. A planer concentrator was investigated by replacing the secondary optics and their associated cell with a single waveguide connected to a shared PV cell [4].

In this paper, we investigate an alternative approach for planar concentration by replacing multiple nonimaging secondary optics and their associated PV cells with small rectangular slaps of PV silicon cell (see Figure-2) to reduce the number of mounting, alignment and electrical connection cost.
Concentrator geometry

The geometric concentration ratio is the ratio of input to output areas of the optical system [4]. Every lens array aperture forms a demagnetized image of the sun which subtends ± 0.26° [5]. The aberration-free solar image height was calculated using $2 \tan \theta$ where $f$ is the lens focal length and $\theta$ is the acceptance half-angle. Each lens element has its own two dimensional geometric concentration defined by [5].

$$C_{\text{Lens}} = \frac{1}{(2F^* \tan \Theta)^2} \quad (1)$$

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.

A ray tracing ZEMAX EE non-sequential analysis software [6] was used to design and optimize the efficiency of this micro-array optic concentrator. The analysis assumed spherical, plano-convex refractive lenses forming a focus on a slab of the PV. Lens aberrations, Encircled energy, illumination distribution on the PV cell and material absorption were included in optical efficiency calculations. Simulations used weighted AM1.5 sunlight from 0.4 to 1.06µm at ± 0.26° field angles.

The simulated design used PMMA lens material ($n=1.49$ lens array) [7]. The new rectangular concentrator consists of array of 22x12 micro-lenses along x and y direction, respectively (Figure-2) with total area 66x36 mm. Each individual lens has rectangular aperture with 3.0mm diameter, 2.6 mm radius of curvature, 2.0 mm thickness and PMMA material (refractive index=1.491). There is air gap between the array lenses and the solar cell of 1.1 mm. This array of micro-lenses was used to focus sun light onto four rectangular Si PV solar cell of dimension (6.4x60 mm for each), so the total effective cell area equal to 14.81cm². The distance between the slaps is 3.0 mm. (Figure-3). The total thickness of the concentrator didn't exceed 4 mm. Air thickness between lenses and slab cells was optimized to give a uniform illumination on all area of the silicon cell.

![Figure-2](Image 560 to 576)

**Figure-2.** New design of micro-lenses concentrator.

**Figure-3.** Slabs of Si solar cell.

**Figure-4.** Electrical diagram represent I-V characteristic measurements circuit.

### RESULTS AND CONCLUSIONS

Figure-4 represents the current-voltage characteristics curve for of PV cell with and without the new concentrators. This figure indicates the improvement in solar cell characteristics.
Table-1 shows the current short circuit $I_{sc}$, voltage open circuit $V_{oc}$, maximum output power $P_{max}$, full factor FF, and efficiency $\eta\%$ for PV without and with array concentrator. Also the improvement in efficiency $\Delta\eta\%$ is shown.

As table shows, the efficiency improved from 6.75\% to 8.7\% without and with the new concentrator respectively, i.e., there is $\Delta\eta = 11.98\%$ improvement in the efficiency of PV with concentrator. One concludes that there is an improvement in the system cost by reducing the high cost Si material.

Table-1. Performance parameters for PV without and with concentrator.

<table>
<thead>
<tr>
<th></th>
<th>Without concentrator</th>
<th>With concentrator</th>
<th>Improvement</th>
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<tbody>
<tr>
<td>$I_{sc}$ mA</td>
<td>88</td>
<td>110</td>
<td>25</td>
</tr>
<tr>
<td>$V_{oc}$ mV</td>
<td>1430</td>
<td>1497</td>
<td>4.6</td>
</tr>
<tr>
<td>$P_{max}$ mW</td>
<td>77000</td>
<td>99510</td>
<td>29.2</td>
</tr>
<tr>
<td>FF</td>
<td>125840</td>
<td>164670</td>
<td>30.85</td>
</tr>
<tr>
<td>$\eta%$</td>
<td>6.75</td>
<td>8.7</td>
<td>11.98</td>
</tr>
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ZEMAX-EE code is used to study the distribution of the energy on the solar cell slabs. And the results from this code gives that 62\% of the incident solar radiation is on the solar cell arranged as (13\%, 18.5\% , 13.7\% and 16.0\% on first, second, third and fourth slab respectively).

The illumination distribution also examined by using ZEMAX physical propagation properties, Figure-6 shows that the illumination distribution along x and y coordinates of the PV slaps has a mean illumination value 90\% of the total input illumination which indicate the good lens array concentrator design. Also Seidel aberrations were analyzed, the results show that the designed array lenses concentrator suffer from spherical aberration (0.0029\%) and total aberration variance 0.0045.

Figure-7 shows the amounts of energy accumulated on the cell. This figure indicates that the circle radius at 90\% of the accumulated energy is 1mm. which is smaller than the solar cell diameter (12 mm). One must satisfy the conditions placed on the FOV are: size of solar cell (one slab) must be imposed that the image length will not be larger than the pitch (the distance from one lens center to the adjacent lens center is known as the pitch) must be observed.
REFERENCES


