CHAPTER - V

PROPOSED WORK:
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5.1 Introduction

The exploitation of solar energy applying an innovative technology, based on focusing the sunlight on photovoltaic (PV) cells, appears to be very promising and competitive with respect to the present energy sources [1-3]. There are three ways in which the cell efficiency of solar cells may be improved by material dependence, better exploitation of the solar spectrum and harvesting of sun radiation. Present concentration Si solar cells are commonly of low base resistivity, in the range of 0.1Ω cm, commonly of type n^+p p^+. This type is a good structure for concentrations up to 500 suns.

Spectrum modification is a well researched topic in physics such as infrared quantum counter and phosphors [4]. It is also one of the third generation concepts suggested to over come the classical efficiency limit of silicon solar cells [5]. These concepts show extreme promise. While classical efficiency limit is currently estimated to be 29% [6], detailed-balance calculations shows that this could improve to approximately 37% [7,8] using spectrum modification at one sun. Enhancing optical absorption in the near infrared region is an important issue in order to achieve efficient solar cells with thin silicon wafers. Two methods are
commonly used, which are the texturisation of the wafer and the introduction of back surface reflectors.

5.2 Texturing in solar cells

Texturing solar cell surfaces to improve the cell performance has been attempted since 1960[9]. There are three major objectives to light trapping by texturing cells; (a) reducing the front surface reflectance, (b) increase the path length of the light through cell and (c) increase the amount of trapped light, reflected from the back surface, by total internal reflection at the front surface/air interface by making the incident angle greater than the critical angle. In the very first textured cells (1960), the primary goal was to reduce the front surface reflectance without applying antireflection coating[10]. Later (1974-1987), texturing was used to produce double bounces on the front surface and trap weakly absorbed long wavelength photons by total internal reflections[11]. The advantage of the textured surface are that the reflectivity of the textured surface is reduced for it to be the square of that of the smooth surface and that it traps the light inside the semiconductor. Sopori BL et.al.,[12] compared the effects of antireflection coating on the flat and textured surfaces of silicon solar cells.

Silicon solar panels can be made up of quantum heterostructures, eg. Carbon nanotubes or quantum dots, embedded in conductive polymers or mesoporous metal oxides. By varying the size of the quantum dots, the
cells can be tuned to absorb different wavelength. If the panels that absorb both visible and infrared spectrums are able to be manufactured, the panels may be able to achieve up to 60% efficiency.

5.3 Geometric Structure

In regular geometric structure two types of geometry is currently under investigation.

1. Pyramidal structure.

2. V-grooved structure.

a) Pyramidal structure: One geometric feature widely incorporated into commercial crystalline solar cells is the square based pyramid formed by intersecting (111) oriented crystallographic planes exposed by anisotropically etching silicon surfaces originally of (100) orientation. Studies have shown that some surface structure formed by intersecting (111) facets on x-Si yield a similar path length enhancement to that of the Lambertian cell[13]. The most promising that have been reported have been textured on both top and back surfaces, with perpendicularly oriented grooves[14] or random pyramids. A distinct advantage that perpendicular grooved and double sided pyramid textures have over single side untilted pyramids and Lambertian types is that around normal incidence they can completely block the escape of light rays reflected back on the top surface.
This feature is the main one that enables these double sided textures to enhance red absorption around normal incidence as well as Lambertien structure.

**b) V-groove structure:** The preferentially etched silicon substrate (with an original (111) surface orientation) have (110) -oriented grooves with (111) sides in serrated structures, or tetrahedral structures. Scheydecker et al.,[15] proposed a transparent V-grooved cover to reduce reflection losses by raising the imaginary average refractive index continuously with depth. Calculations and measurements for efficient combinations of smooth and structured covers and solar cell were presented. Recently, Brendel et al.,[16] proposed a thin poly crystalline silicon solar cells with glass super stratum having V-grooved surface for reducing reflections of incident light. In their calculations, V-groove of large tilt angle yields good light absorption, since the reflectivity at the front surface was reduced efficiently.

### 5.4 Photovoltaic concentrator system

The aim of concentrator technology is to improve the PV array performance per cost unit, by using concentrating optical components to increase the intensity of sunlight falling on the solar cell. By using concentration it is possible to decrease the area of solar cell material being used in a system and therefore to reduce the dependence of the PV industry
on the silicon stock limitations as well as reaching very high efficiencies, with sophisticated high cost cells.

There are wide verities of concentrator system types shown in Table (5.1). The classification of concentrator system according to the different technical solutions is,

- a) refractive concentrators (lenses)
- b) reflective concentrators (mirrors)
- c) Hybrid
- d) Luminescent
- e) Thermo photovoltaic
- f) Holographic

a) The optical refractive concentrators can be a Fresnel or classical lenses. Fresnel lenses are made by projecting the lens surfaces onto planar or curved sheets in such a way that the rays encounter the same slopes as in a conventional lens and therefore are similarly refracted. Planar microlens have more chromatic blur and when it arranged as lens array interference effect will be predominantly to reduce the focal performance. Fresnel lens has less weight and cost advantage compared with planar lenses. However, if a small cell size is used; classical lenses might be convenient because classical lenses of cylindrical nature are usually more efficient than Fresnel and planar lenses[17].
### Table (5.1). Characteristics of reference concentrators

<table>
<thead>
<tr>
<th>Reference concentrator</th>
<th>Optics</th>
<th>Cell Assembly</th>
<th>Cell type</th>
<th>Concentration Ratio</th>
<th>Cooling</th>
<th>Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point focus on single solar cell systems</td>
<td>Fresnel lens or conventional lens</td>
<td>One single cell or several cells with spectral beam splitting</td>
<td>Uni-Junction silicon or Uni-Junction III-V or Multi-Junction</td>
<td>50&lt;Xg&lt;500 for silicon cells &gt;500 for all other cells</td>
<td>Passive</td>
<td>Two-axis</td>
</tr>
<tr>
<td>Large area point focus systems</td>
<td>Big or medium size parabolic dish or central tower power plant</td>
<td>Parquet of cells</td>
<td>Uni-Junction silicon or Uni-Junction III-V or Multi-Junction</td>
<td>15&lt;Xg&lt;60 (without secondary) 60&lt;Xg&lt;300 (with secondary)</td>
<td>Active</td>
<td>Two-axis</td>
</tr>
<tr>
<td>Linear systems</td>
<td>Linear lens or Parabolic trough</td>
<td>Linear array of cells</td>
<td>Silicon or III-V(with 3D Secondary)</td>
<td>Passive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static systems</td>
<td>Non imaging devices</td>
<td>Usually linear array of cells</td>
<td>Silicon</td>
<td>1.5&lt;Xg&lt;10</td>
<td>Passive</td>
<td>No tracking</td>
</tr>
<tr>
<td>Compact mini point focus systems</td>
<td>Small lens or small parabolic dish or RXI device</td>
<td>One single cell</td>
<td>Uni-Junction silicon or Uni-Junction III-V or Multi-Junction</td>
<td>Xg&gt;800</td>
<td>Passive</td>
<td>Two-axis</td>
</tr>
</tbody>
</table>

b) Several reflector materials have been used for PV reflective concentrator. The two leading materials are silvered glass and various types of aluminized surfaces. The reflectivity of aluminium over the wavelength of interest of Si cells is 85%. New interfacial reflectors made of plastic films are promising high reflectivity materials for concentration.

c) A combination or refractive and reflective devices is also possible. One example of hybrid devices is RXI device.
d) Luminescent concentrators are a non-imaging optical device for collecting and concentrating light energy. It is essentially a planar optical matrix embedded with luminescent dye reflective on one side. Photon incident on the LC are absorbed by this dye at molecular level. These luminescent centers may then emit new photons, a large fraction of which are trapped within the LC and guided to its edges by total internal reflection.

e) A thermo photovoltaic device converts secondary thermal radiation, re-emitted by an absorber or heat source, into electricity. The device is designed for maximum efficiency at the wavelength of the secondary radiation.

f) The holographic concentrators allow realizing simultaneously concentration and spectral beam splitting by means of light diffraction effects to be carried out. Only the holograms made of photosensitive and highly transparent materials are able to achieve good transmission.

The optical characterization is aimed to verify the match between the performances of the realized lens samples and the theoretical features of the designed collectors. The methodology for optical characterization consists in the following measurements:

a) Test on the total collection efficiency of the cylindrical microlens
b) Energy distribution assessment in the image plane of the lens and uniformity estimation.

c) Identification of possible lack of uniformity in the lens performance and analysis of the light contributions pertaining to the different lens portions.

5.5 Light trapping Schemes

A number of approaches attempting to predict the performance of thin Si solar cells by theoretical modeling have been reported in literature (Stiebig et al., 1994, Leblanc et al., 1994, Hishikawa et al., 1997, 1999; Zenman et al., 2000, Krc et al, 2002,) the ray tracing of scattered photons is calculated up to the final absorption in any layer of solar cells or photon loss due to reflection into air.

Two types of schemes have been proposed to achieve light trapping in solar cells as schematically indicated in Figure (5.1). One type is based on randomizing the direction of light within the cell substrate as shown in Figure (5.1a). Once so randomized, only a small fraction of the light will lie with in the escape cone for refraction out of substrate surface from within. The rest is totally internally reflected giving rise to very effective light trapping[18]. The second type of scheme is based on regular geometrical structures[19], such as indicated in Figure (5.1b). The aim is to control the
direction of light within the substrate so that it is kept away from the escape cone associated with each surface for the maximum number of internal passes within the substrate.

![Diagram](a) (b)

Figure (5.1). Two different light trapping approaches (a) scheme based on internal randomization of light direction using a Lambertian surface (b) Geometrically based scheme.

5.6 Problem definition

Based on the literature survey, our problem focuses to improve the light trapping efficiency of V- grooved thin silicon solar cells by using cylindrical microlens array as concentrators applying ray tracing method. The systematic stages of approach to this problem as follows:
a) Theoretical study on focal performance of single and dual cylindrical microlenses using Boundary Element Method (BEM) under open and closed boundary conditions.

b) Design and optical characteristics study on focal performance of cylindrical microlens array are simulated using ZEMAX® software and its numerical results will be compared with theoretical findings.

c) Geometrical modeling of V-grooved thin silicon solar cells will be proposed by using cylindrical microlens array as photovoltaic concentrators. Reflectivity, axial distance, cell alignment and throughput will be calculated to find harvesting efficiency of solar cells and its numerical values compared with simulation results and reported values.
5.7 References


