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# 2-dimensional mapping of power consumption due to series resistance evaluated by simulator for concentrator photovoltaic module

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## 1. Introduction

A super high efficiency multi-junction III-V based solar cell for concentrator photovoltaic (CPV) system has attracted increasing attention in recent years for their very high conversion efficiency [1]. It has reached conversion efficiencies of 41.1% at concentrations of 454 suns (454 kW/m2, AM1.5D ASTM G173-03) [2]. Under the concentration conditions, it is important to optimize the design of electrodes and cell structures, because the high density energy is emitted to the cell.

A total 3-dimensional (3D) simulator for concentrator photovoltaic (CPV) module was developed using a ray-trace and an equivalent circuit simulation [3]. By using this total 3D simulator, we can calculate the in-plane distribution of power consumption due to the each resistance component.

In this study, we analyzed the power loss at the electrode and top layer composed of *n*-AlInP window and *n*-InGaP emitter layers of the CPV cell, and the results were expressed by 2-dimensional mapping.

## 2. Simulator calculation and cell structure

We used an optical design software ZEMAX for ray-trace. A typical flat Fresnel lens (focal length = 150 mm) designed by ZEMAX was adopted as a first lens. As a secondary optical system, a homogenizer was installed. The geometrical concentration ratio was 597. The spectral irradiance used for the ray-trace simulation was AM1.5D (total power was 850 W/m$^2$). We carried out ray-trace in the wavelength range from 320 to 1700 nm. The power of this wavelength range was 94.6% in the total power.

A schematic diagram of 3D equivalent circuit model for InGaP/InGaAs/Ge triple-junction solar cell is shown in Fig. 1. In the 3D model, the same number of units as grid numbers were installed for every electrode, and units were connected with the lateral resistances each other. The top lateral resistance was composed of *n*-AlInP window and *n*-InGaP emitter layers. The each diode parameters were extracted from dark *I-V* characteristics of each single-junction solar cell (InGaP, InGaAs and Ge solar cell) using conventional equivalent circuit model [4, 5]. The calculations were carried out with a 3D equivalent circuit model using the simulation program with integrated circuit emphasis (SPICE).

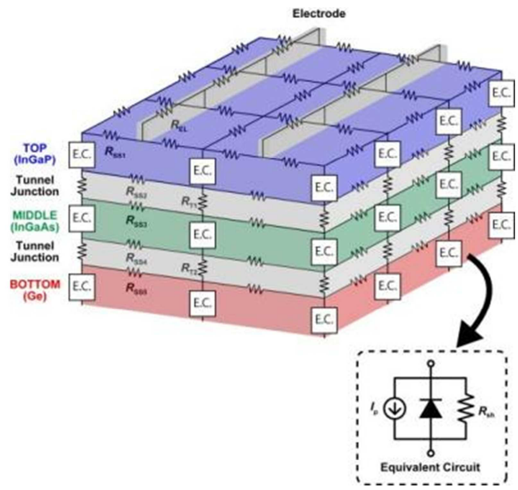


Fig. 1. Schematic diagram of 3-dimensional equivalent circuit model for triple junction solar cell.

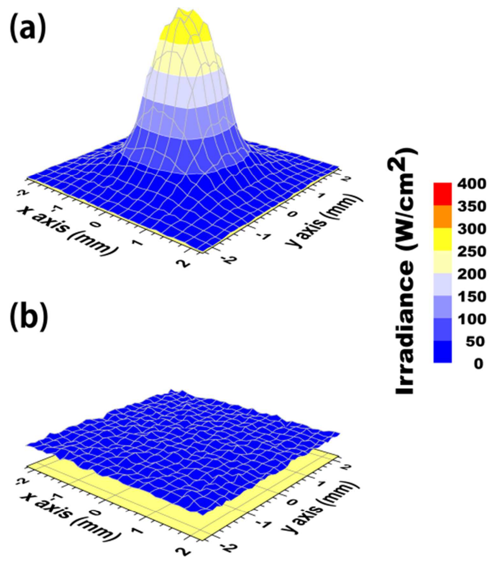


Fig. 2. The irradiance distributions for optical systems; (a) without and (b) with homogenizer.

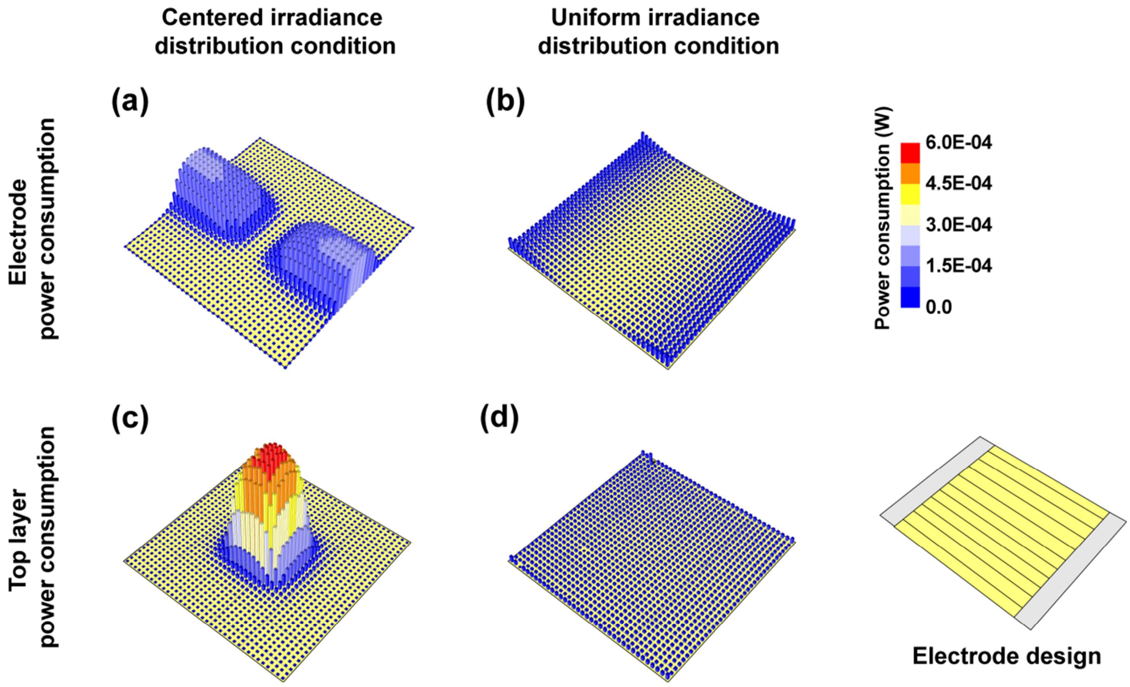

Fig. 3. 2D mapping of the power consumption due to the electrode resistance and top lateral resistance.

Super high efficiency InGaP/InGaAs/Ge triple-junction solar cell evaluated in this study was grown on a p-type Ge substrate using metalorganic chemical vapor deposition. An $In_{0.49}Ga_{0.51}P$ topsubcell, an $In_{0.01}Ga_{0.99}As$ middle subcell and Ge bottom subcell were all lattice-matched. The tunneling junctions consisted of *p*-AlGaAs/*n*-InGaP and *p*-GaAs/*n*-GaAs layers, respectively..

## 3. Results

The irradiance distributions for optical systems (a) without and (b) with homogenizer were shown in Fig. 2. In-plane distributions of photocurrent were calculated from the spectral response of the InGaP/InGaAs/Ge triple-junction solar cell and spectral irradiance distributions, and were applied to the 3D equivalent circuit calculations.

Figure 3 shows the 2D mapping of the power consumption due to the electrode resistance and top lateral resistance. The electrode design is also shown in Fig. 3. It is considered that the main components of series resistance are electrode resistance and top lateral resistance [6]. The bus electrodes were designed at the end of finger electrodes. In the case of the centered irradiance distribution (Fig.2 (a)), a large amount of power consumption was observed. On the other hand, in the case of uniform irradiance distribution (Fig. 2 (b)), the power consumption was reduced. Table I shows the total power consumption in each condition. The total power consumption was 179.2 mW for the centered irradiance distribution condition. By emitting the uniform irradiance distribution, total power consumption was greatly reduced.

Table I Total power consumption in each condition.

| | Centered irradiance distribution | Uniform irradiance distribution |
|---|---|---|
| Electrode | 42.4 mW | 10.1 mW |
| Top layer | 136.8 mW | 30.5 mW |

## 4. Conclusions

We analyzed a power consumption at electrode and top layer using 3D simulator. By emitting the uniform irradiance distribution, total power consumption was greatly reduced. This technique can be applied to the structural optimization of solar cells for concentration.


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