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Design strategy and development of spherical silicon solar cell with semi-concentration reflector system

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Abstract

Structural and economical merits of a spherical silicon solar cell with semi-concentration reflector system have been discussed. The roles of the reflector system have been clarified; the reflector improves short-circuit current density and also open-circuit voltage by 4–6 times concentration to make a light irradiation area comparable to a p–n junction area. We have theoretically demonstrated that the spherical Si solar cell with semi-concentration reflector system can realize a performance comparable to that of conventional Si solar cells, with less amount of silicon material use.

Keywords: Spherical Si; Solar cell; Reflector

1. Introduction

Solar cells based on silicon spheres as a photovoltaic part have gathered much attention as a promising candidate for high performance with low-cost solar cells. Developments of spherical Si solar cells were initiated by Texas Instruments in 1980s [1], but the energy conversion efficiency was around 10% and its fabrication cost was not low: the essential requirements for solar cells, i.e., high efficiency with low cost, were not attained. In order to fulfill the requirements, we proposed the new type of a spherical Si solar cell with semi-concentration reflector system (we named our solar cell as S^3C) [2]. In this paper, the

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geometric influences of the spherical shape on solar cell performances are clarified. The unique features of the reflector system are then presented, along with the amount of Si material use and their solar cell performance.

Finally, the theoretical calculations on solar cell performances are shown on spherical Si solar cells, with and without the reflector, and a conventional flat Si solar cell.

2. Geometric influence of spherical shape

Solar cells with a spherical shape inherently have some demerits in short-circuit current density J_{sc} and open-circuit voltage V_{oc} if light concentrations are not applied. Here, the behaviors of J_{sc} and V_{oc} are discussed in the case without a reflector system.

2.1. Short-circuit current density

An incident angle θ of incident lights is always normal to a substrate ($\theta = 0°$) for the conventional flat solar cells. In contrast to this, the angles are not equal at different positions on a sphere, i.e., θ becomes larger from the center ($\theta = 0°$) to the edge ($\theta = 90°$) as shown in Fig. 1. This means that the reflectance at the edge part of a sphere is higher than that at the center part, because a higher incident angle gives a higher reflectance. The theoretical estimation of an attainable J_{sc} of a spherical Si solar cell can be obtained from the integration of a reflection over the sphere surface and standard solar energy spectrum as a function of wavelengths. Here, the cell area is defined as the projection area of a sphere. If internal quantum efficiencies in the wavelength range 300–1150 nm are assumed to be unity, J_{sc} of spherical Si solar cell without anti-reflective coating is calculated to be 26.2 mA/cm^2, while that of a conventional flat Si solar cell with a flat surface is 28.5 mA/cm^2. The 2.3 mA/cm^2 difference comes from the geometric difference between sphere and flat surfaces. The calculation indicates that J_{sc} of a spherical Si solar cell without a reflector is inherently low by around 10% compared to that of flat cells.

2.2. Open-circuit voltage

A p–n junction in a spherical Si solar cell is formed near the surface with a depth of less than 1 μm. In our case, the area of the p–n junction can be regarded to be equal to the surface area of the sphere because of the negligible p–n junction depth against the diameter of the sphere of 1 mm. When the above definition for the cell area is applied, the p–n junction area A_{pn} ($4\pi r^2$, where r indicates the radius of a sphere) is 4 times larger than the light irradiation area A_L (πr^2). In contrast to this, conventional flat Si solar cells have A_{pn} 1–2 times larger than A_L. The larger A_{pn}/A_L ratio increases a saturation current density J_0, dominant parameter in V_{oc}. The V_{oc} of a spherical solar cell is inherently lower than that of a flat solar cell, because a larger J_0 reduces V_{oc}. Typically, the V_{oc} difference between a spherical cell and a flat cell will be about 40–60 mV.

3. Concepts, merits, and performance analysis of S^{3}C

Fig. 2 shows the schematic images of S^{3}C. The diameter of a sphere is around 1 mm. The application of the reflector improves J_{sc} by collecting the reflection light near the edge of the sphere. The reflector with 4–6 times light concentration ratio, defined as the ratio of the