International Symposium on Nonlinear Theory and its Applications
Xi’an, PRC, October 7–11, 2002

Approach to Improving the Energy Conversion Efficiency of Silicon Solar Cell by Using Prism

Manabu Kanazawa*^and**, Kosin Chamnongthai**, Noboru Morita* and Makoto Okuda*

*Department of Electrical Engineering
Nippon Institute of Technology
4-1 Gakuendai, Miyashiro, Minami-Saitama, Saitama
345-8501, Japan
Email: manabu_k@hotmail.com

** Department of Electronic and Telecommunication Engineering
King Mongkut’s University of Technology Thonburi,
Bangkok 10140, Thailand
Email: kosin.cha@kmutt.ac.th

Abstract

Recently since the infrared rays cause high temperature, the energy conversion efficiency of the silicon solar cell decreases [1]. To solve this problem, silicon solar cell for space was implemented by applying back surface reflector (BSR) behind the solar cell in order to reflect the infrared rays and suppress cell temperature rise [1]. Although this method is effective, it needs complicate manufacturing and can not be directly applied for existing silicon solar cells. The authors tried to improve the existing solar cells with IR cutoff filter in order to enhance the energy conversion efficiency in the same level as BSR. This paper proposes a method of using prism for searching the solar ray wavelength that generates maximum of energy conversion efficiency of silicon solar cell, then the appropriate IR cutoff filter can be produced.

1. Introduction

The countries in Southeast Asia and Africa that tend to increases the demand of electricity are located nearby the equator with high average temperature. The utilization of photovoltaic power generation seems to be greatly effective in these areas. However, recently since the infrared rays cause high temperature, the energy conversion efficiency of the silicon solar cell decreases. Typical temperature coefficient of a monocrystalline silicon cell is about −0.40 %/°C [2]. This is an important problem because it is larger than a coefficient of GaAs solar cells (from −0.2 %/°C to −0.25 %/°C) [3]. To solve this problem, the BSR is applied for the silicon cell as mentioned above or IR cutoff filter is utilized as a simpler method. The latter reflects rays of the wavelengths (above about 1100 nm) outside of the response band for the cell, since these rays cannot be useful generating electricity. Hence, It can be prevented temperature rise of the cell can be lowered [4]. It is likely that the value of 1100 nm for the silicon on the long wavelength side of transmission band is considered what the filter is applied for the polycrystalline silicon cell, and the monocrystalline cells differ in the spectral response slightly. Therefore the transmission band of the filter is not strictly optimized in order not to interfere with the spectral response of the cell.

In this paper, we propose an optical design which utilizes a prism for obtaining a suitable IR cutoff wavelength of the filter, because the prism can varies dispersion to search IR cutoff wavelength in order to obtain the peak efficiency of the solar cells.

2. Basic Idea

Fig. 1 shows geometry of a dispersing prism. Applying Snell’s law in this figure, total deviation of the incident ray can be written [5]:

$$\delta = \theta_{i1} + \sin^{-1}\left[(\sin\alpha)\left(n^2 - \sin^2\theta_{i1}\right)^{1/2} - \sin\theta_{i1}\cos\alpha\right] - \alpha \tag{1}$$

where θ_{i1} is the incident angle of the rays; n is the refractive index of the optical material, it is itself a function of frequency (see Fig. 2). The air outside the optical material is assumed to have refractive index 1. An optical design which utilizes the dependence on the wavelength of the deviation δ is proposed (see Fig. 3). It can be expected that this design can vary dispersion to search infrared cutoff wavelength in order to obtain the peak efficiency of energy conversion.

3. Design

In this study, an equilateral prism which has three equal 60° angles and three sides of length of 35 mm is used. The wavelength dependence of the refractive index for a material of the prism which is made of SF18 is shown in Fig. 2. The incident angle $\theta_{i1} = 60^\circ$ is selected in order to simplify calculation. In the design as shown in Fig. 3, an irradiation area to the cell can be obtain by calculating the interval between two rays which pass through an apex and another apex of the prism severally. However, some of rays which pass through the top of an apex in the prism cause deviation $\theta_t > 30^\circ$, for example $\theta_t = 31.08^\circ$ at wavelength 365 nm. Accordingly, some of the rays are deviated toward the left face of the prism, and θ_t increases as the wavelength decreases. To compensate a loss of irradiation to the cell the incident side of the prism need be shortened. For the original side A, a side which is shortened is defined as A′ and 365 nm is assumed to be the end of solar spectrum on the short wavelength side at AM-1.5. The above problem can be solved by selecting A′= 34.23 mm at wavelength 365 nm. Faces which are unnecessary for experimentation are covered with shields. The design is calculated on the assumption that a prism of size 35.0 × 35.0 mm and a solar cell of size 50 × 50 mm are selected.

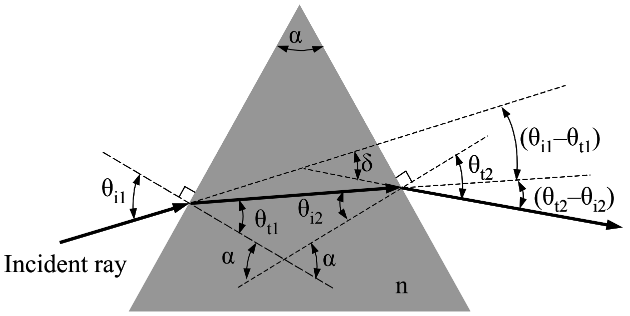

Fig. 1 Geometry of a dispersing prism.

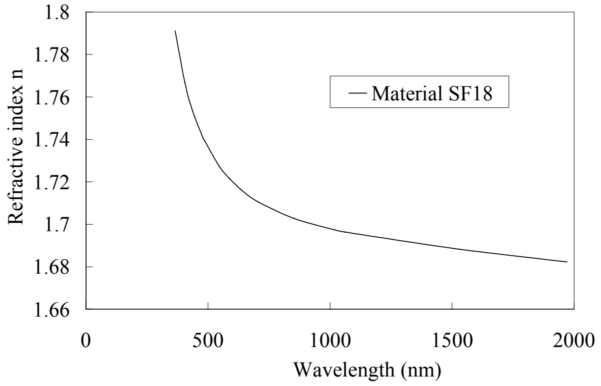

Fig. 2 The wavelength dependence of the refractive index for SF18.

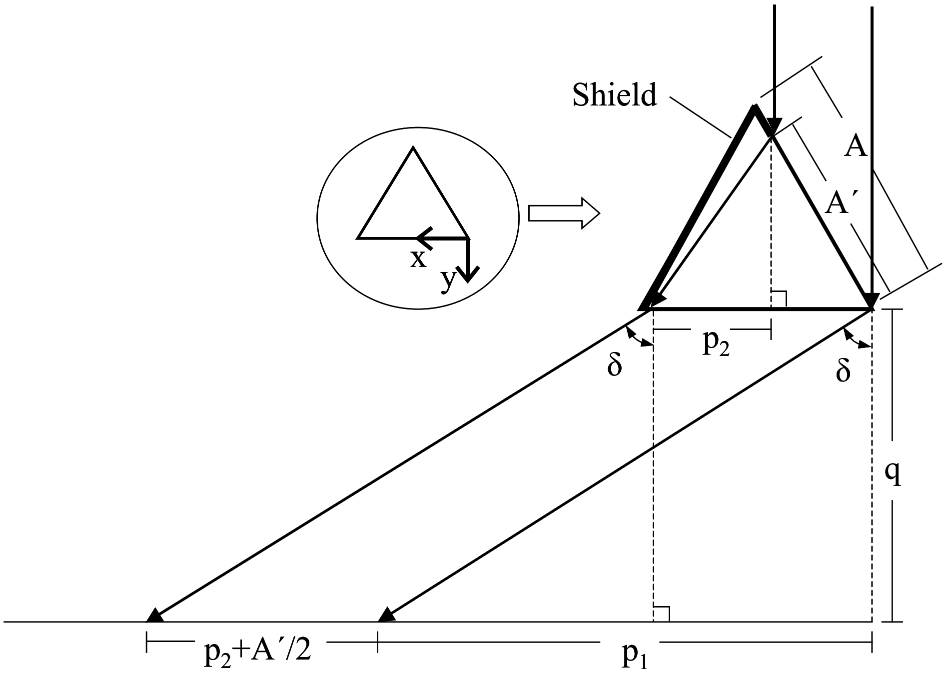

Fig. 3 Proposed design

3.1 Calculation Results

If rays which have irradiation range of the above interval pass through the nearest to the cell on the prism side, irradiation ratio which is the ratio of incident rays into prism to irradiated rays on the cell will be 0 %. Fig. 4 shows the relations between irradiation ratio and wavelength under the conditions that irradiation ratios at wavelength 3000 nm and 2000 nm are 0 % in either case. Positions (x, y) at wavelength 3000 nm and 2000 nm are (239.9 mm, 150 mm) and (245.1 mm, 150 mm) respectively, and 150 mm was selected for y.

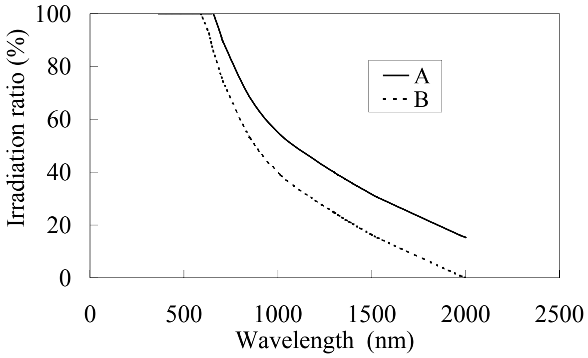

Fig. 4 The relations between irradiation and wavelength. A and B represent that irradiation ratios which will be 0 % at wavelength 3000 nm and 2000 nm respectively.

4. Discussion

It was found from the result that solar rays can be dispersed well by using prism and the irradiated rays on the cell can be varied in order to search continuously. However, in case of the conventional monocrystalline silicon cell the operational wavelength range is to 900 nm in the long wavelength side [6], thus the proposed method needs to be improved. On the other hand, the rays in the short wavelength side pass above the cell because the refractive index is larger than in the long wavelength side. For this problem, a method which reflects rays in the short wavelength side to the cell using a mirror can be proposed.

5. Conclusions

This paper presented an approach to improving the energy conversion efficiency of silicon solar cell by using prism. The unconvertible solar energy in the long wavelength side cannot be irradiated the cell by using dispersing prism. The characteristic of the irradiation ratio resembles a transmission characteristic of the filter, however it is not so sharp. Therefore the characteristic needs to be improved in practical use.

References

[1] Yoshihiro Hamakawa: “Photovoltaic Power Generation The Newest Technology and System”, CMC, p.28, p164, p.188, (2000), in Japanese

[2] D. E. Carlson, G. Lin and G. Ganguly: “Temperature Dependence of Amorphous Silicon Solar Cell PV Parameters”, 28th IEEE PVSC, 2000, pp. 707-712.

[3] William T. Beauchamp, Trudy Tuttle Hart, and Michael L. Sanders: “Blue/Red Reflecting Solar Cell Covers For GaAs Cells”, 23th IEEE PVSC, 1993, pp.1487-1490.

[4] W. T. Beauchamp, Bob McLean, and Mike Larro: “Qualification Test Results For Blue-Red Reflecting Solar Cell Covers and Other New Products For The Solar Power Market”, 24th IEEE PVSC, 1994, pp.2062-2065.

[5] Eugene Hecht: “Optics”, Addison-Wesley, pp.61-64, (1987)

[6] Roman Herschitz and Alex Bogorad: “Space Environmental Testing of Blue Red Reflecting Coverglasses for Gallium Arsenide and High Efficiency Silicon Solar Cells”, First IEEE WCPEC, 1994, pp.2189-2191.