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Modeling the thermal absorption factor of photovoltaic/thermal combi-panels

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Abstract

In a photovoltaic/thermal combi-panel solar cells generate electricity while residual heat is extracted to be used for tap water heating or room heating. In such a panel the entire solar spectrum can be used in principle. Unfortunately long wavelength solar irradiance is poorly absorbed by the semiconductor material in standard solar cells. A computer model was developed to determine the thermal absorption factor of crystalline silicon solar cells. It was found that for a standard untextured solar cell with a silver back contact a relatively large amount of long wavelength irradiance is lost by reflection resulting in an absorption factor of only 74%. The model was then used to investigate ways to increase this absorption factor. One way is absorbing long wavelength irradiance in a second absorber behind a semi-transparent solar cell. According to the model this will increase the total absorption factor to 87%. The second way is to absorb irradiance in the back contact of the solar cell by using rough interfaces in combination with a non-standard metal as back contact. Theoretically the absorption factor can then be increased to 85%.

Keywords: Photovoltaic/thermal; Absorption factor; Solar cell; Optical model

1. Introduction

A photovoltaic cell has a typical efficiency of 5–20%. This means that the remaining 80–95% of the energy is available in the form of heat, in principle. In a photovoltaic/thermal (PVT) combi-panel one tries to collect this heat as good as possible [1]. Various PVT combi-panel designs were investigated by Zondag [2]. The simplest design is a so-called sheet-and-tube PVT combi-panel where the heat is collected by a copper sheet glued to the back of the encapsulated solar cells. The heat is transported by water flowing through a copper tube connected to the back of the sheet. An alternative design is the two-absorber PVT combi-panel where a second absorber is used behind semi-transparent solar cells. In this case the more practical heat-transporting medium is air flowing through a channel between cells and second absorber.

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Nomenclature

A	absorption factor (–)
d	thickness (m)
I	intensity (W m^{-2} sr^{-1})
k	extinction coefficient (–)
m	roughness coefficient (–)
N	complex refractive index (–)
n	real refractive index (–)
R	reflection factor (–)
r	reflectance (–)
T	transmission factor (–)
t	transmittance (–)
q	flux (W m^{-2})
Y	effective refractive index (–)

Greek symbols

α	absorption coefficient (m^{-1})
γ	distance to specular direction (rad)
η	modified refractive index (–)
θ	complex angle of refraction (–)
λ	wavelength (m)
τ	transmittance (–)
φ	real angle of refraction (–)

Subscripts

l	layer number
i	interface number
inc	incident
ref	reflected
λ	spectral

In Fig. 1 a schematic cross-section of a typical solar cell configuration is shown consisting of a glass cover (g), an encapsulant (e), a top grid (t), an anti-reflection coating (c), a semiconductor (s) and a metal back contact (m). Absorption in the semiconductor takes place only for photon energies above a certain threshold energy, called the bandgap energy. Long wavelength irradiance, with photon energies below this bandgap energy, is hardly absorbed at all. This implies that the absorption factor of the semiconductor is significantly lower than of a black absorber, which has an absorption factor of approximately 95%. Therefore a PVT combi-panel has a relatively low thermal efficiency. But this efficiency will increase significantly if the absorption of long wavelength irradiance is increased either at combi-panel or at cell level.

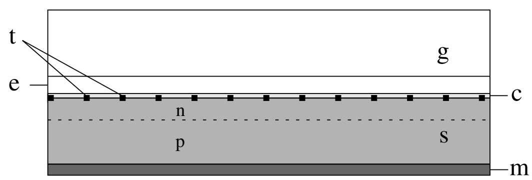

Fig. 1. A schematic cross-section of a typical encapsulated solar cell. g = glass, e = encapsulant, c = AR-coating, t = top grid, s = semiconductor, m = metal back contact.