Renewable and Sustainable Energy Reviews 40 (2014) 214–223

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Physical principles of losses in thin film solar cells and efficiency enhancement methods

Meena Dhankhar, Om Pal Singh, V.N. Singh*

CSIR – National Physical Laboratory, Dr. K.S. Krishanan Marg, New Delhi 110012, India

ARTICLE INFO

Article history:
Received 4 September 2013
Received in revised form
15 April 2014
Accepted 19 July 2014

Keywords:
Thin film solar cell
Efficiency enhancement methods
Losses in a solar cell

ABSTRACT

Although there are individual reports on the efficiency enhancement methods in the form of news articles, highlights and research papers in the literature; there is no article mentioning all the methods used for enhancing the efficiency of a thin film solar cell. This article is focused on discussing the physical principles of losses in a thin film solar cell and the methods used for enhancing the efficiency. The article begins with a general outline about the thin film solar cell, its advantages, material requirements and its characteristics. Various losses in solar cell and how to overcome them in order to improve the efficiency of solar cell are discussed. Some novel methods used for enhancing the efficiency of thin solar cell are also discussed. Towards end, summary of some other parameters which can add to the efficiency of solar cell are described.

Contents

1. Introduction . . . 215
 1.1. Advantages and limitations of a photovoltaic cell . . . 215
 1.2. Theory of solar cell . . . 215
 1.3. Parameters of a solar cell . . . 215
 1.4. Shockley–Quisser limit . . . 216
 1.5. Different generations of solar cells . . . 216
2. Requirements of photovoltaic materials . . . 216
 2.1. Optical properties . . . 216
  2.1.1. Band gap . . . 216
  2.1.2. Absorption coefficient . . . 216
  2.1.3. Refractive index . . . 217
 2.2. Carrier concentration . . . 217
 2.3. Transport properties . . . 217
3. Thin film solar cells . . . 217
 3.1. Advantages . . . 217
 3.2. Basic requirements of thin film solar cell . . . 217
 3.3. Different types of thin film solar cells . . . 217
4. Losses in a solar cell . . . 217
 4.1. Optical losses . . . 217
  4.1.1. Non-absorption . . . 218
  4.1.2. Thermalization . . . 218
  4.1.3. Reflection loss . . . 218
  4.1.4. Transmission loss . . . 218
  4.1.5. Area loss . . . 218
 4.2. Collection losses . . . 218
 4.3. Resistance losses . . . 218

* Corresponding author. Tel.: +91 1145608562; fax: +91 1145609310.
E-mail address: singhvn@nplindia.org (V.N. Singh).

http://dx.doi.org/10.1016/j.rser.2014.07.163
1364-0321/

4.4. Metal/semiconductor contacts . . . 218
5. Light trapping techniques . . . 218
5.1. Antireflection coating (ARC) . . . 218
5.2. Surface texturing . . . 219
5.3. Back surface field (Bragg's reflector) . . . 219
5.4. Selective emitter structure . . . 220
5.5. Surface passivation . . . 220
5.6. Absorber material thickness . . . 220
5.7. Resonant dielectric structure . . . 220
5.8. Structure . . . 220
5.9. Metallic nanoparticles (plasmonic effect) . . . 220
5.10. Fishnet structure for a-Si:H thin film solar cell . . . 221
5.11. Electron reflector . . . 221
6. Other parameters affecting the efficiency of solar cell . . . 221
7. Conclusions . . . 222
Acknowledgements . . . 222
References . . . 222

1. Introduction

Earth receives more solar energy in an hour than we consume in an entire year. Covering 0.16% of the earth's surface with 10% efficient cells would provide electricity more than the current total energy demand of the planet. Solar photovoltaic (PV) works on the principle of photoelectric effect. It involves direct conversion of sunlight into electricity. The photovoltaic effect was first discovered by a French physicist A.E. Becquerel in 1839 [1,2]. The first solar power generation was shown by Chapin, Fuller and Pearson of Bell labs in 1954 [3]

1.1. *Advantages and limitations of a photovoltaic cell*

Solar cell has both advantages and limitations based on their availability, operation and principle. Some of the advantages are; being environmentally friendly, no noise, no moving parts, no emissions, no use of fuels and water, minimal maintenance requirements, long lifetime (up to 30 years), electricity is generated wherever there is light (solar or artificial), PV operates even in cloudy conditions, modular "custom-made" energy can be sized for any application from a watch to a multi-megawatt power plant. Some of the disadvantages are: PV cannot operate without light (no output at night), lower output in unfavourable weather, use of toxic materials in some solar cell, high initial costs that overshadow the low maintenance costs and lack of fuel costs, large area is needed for large scale applications. PV generates direct current and therefore special DC appliances or inverters are needed. For off-grid applications energy storage is needed [4].

1.2. *Theory of solar cell*

When the energy of an incoming photon is equal to or greater than the band gap of the material, the photon is absorbed by the material and it excites an electron into the conduction band. A hole is left behind and another electron from valence band moves to this position leaving behind a hole. In this way hole moves through the lattice. Thus it can be said that absorbed photon creates electron–hole pair. When p and n type materials are brought together, diffusion of carriers take place and charges build up on either side of junction and create an electric field. The p–n junction formed helps in separating these electron–hole pair. It acts like a semipermeable membrane and allows only one type of carrier to pass through it. On the n-type semiconductor side it allows only electrons to pass through it, while transport of holes (which are minority carriers) is due to recombination. Similarly p-type semiconductor side allows only holes to pass through it and transport of electron takes place by recombination.

Thus, three steps are involved in generating electricity from light: (i) absorption of photons, resulting in generation of electron–hole pairs, (ii) separation of carriers by the internal electric field created by p–n junction and collection at the electrodes resulting in potential difference and current in the external circuit, and (iii) potential difference at the electrodes of a p–n junction resulting in injection and recombination of carrier's which are the causes of losses [4,5].

Although the efficiency of solar cell is improving day by day, still there is a large gap between the theoretically predicted limit and the actual achieved efficiency. Improvement in the efficiency of solar cell even by few per cent makes a lot of difference in the watts per cent cost. Various factors, such as; spectral distribution, temperature and resistive load influence the electrical power output of solar cell and factors such as reflection, thermodynamics, charge carrier generation and conduction influence the conversion efficiency of a solar cell.

1.3. *Parameters of a solar cell*

Double diode model is used to define the parameters of the solar cell. The double diode model has the limitations that it gives erroneous results when applied to high efficiency solar cells. In actual devices the recombination becomes a complex function of carrier concentration, resulting in ideality factor and the saturation current varying with voltage. Still, for the sake of simplicity we have used the double diode mode to define the parameters. The equivalent circuit of solar cell is shown in Fig. 1 [6] and parameters of a solar cell are shown in Fig. 2 [7].

The current in the external circuit I can be written as, $I = I_L - I_D$, where I_L is the photocurrent and I_D is the diode (dark) current and

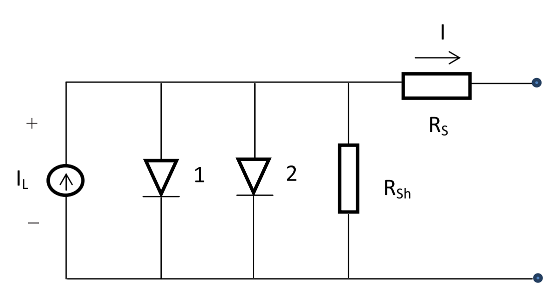

Fig. 1. Equivalent circuit of a solar cell.