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Spectral Splitting Optimization for Highly Efficient Hybrid Photovoltaic devices by using Na3AlF6, Y2O3 and TiO2 beam splitter

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Abstract— Spectral splitting optimization for efficient hybrid solar energy cell is studied by materials which are Na3AlF6, Y2O3, and TiO2. The Essential Macleod software is used to design this beamsplitter. Multilayer coating design consist of Na3AlF6 as low index material, Y2O3 as middle index material and TiO2 as high index material. The wavelength range of design is from 400nm to 2000nm with reference wavelength 700nm having incident angle 45 degree. Design consists of 56 alternating layers based on formula [LMHM]^14. Optimac refinement techniques is used to improve the design. It is concluded in the result that a good beam splitter is designed which transmits about 80% light in the spectrum range from 400nm to 975nm and reflect 77% light in the infrared region from 1000nm to 2000nm. The transmitted light is used for the solar cell and reflected light is used for thermoelectric generator.

Index Terms— Spectral Splitting, Essential Macleod, Photovoltaic, Beam splitter, Multilayer Coatings, Transmission, Reflection.

1 Introduction

Just after energy crisis the world seriously captured their attention for alternative energy sources rather than oil, gas, and coal. So many different renewable energy sources have been available since then. For instance, energy from wind, water and the sun has been found and created. These three, Energy sources do not pollute and are not harmful to the environment. While the sources such as fossil fuels, oil and coal pollute the environment. A lot of research has been taken place during the last 3 decades to enhance the efficiency of these clean energy sources, photovoltaic cells. Photovoltaic cells are made of materials that are semiconductors such as silicon (Si) Or Gallium Arsenide (GaAs) which converts solar energy coming from sun into electricity. These Semiconductors have a band gap of around 1.1-1.4 eV.[1]. It is possible to transform wavelengths between 400-1100 nm into electricity [2]. The wavelength greater than 1100nm is not converted into electricity because the energy of these waves is less then band gap of the material, it heats the solar cell and efficiency of solar cell decreases. To avoid the wastage of energy, the light of wavelength of greater than 1100nm is directed towards thermoelectric generator. In this way the wasted part of light can be used and increase the efficiency of solar cell.[3]. There are many kinds of techniques used for spectral splitting including beamsplitter, rugate filters, holographic concentrators etc. [4]. Several research works have been carried out on the hybrid solar system and some typical studies are listed as follows. Enok et al. [5] reported in a paper the design and optimization of spectral beamsplitting for hybrid thermoelectric concentrated solar energy devices. The beamsplitter divide the incident light into two parts one part is transmitted and other part is reflected. The thermoelectric generator is placed in the path of transmitted light and photovoltaic cell is in the way of reflected light. The beamsplitter is constructed through using SiO2 as low index material and Si3N4 as high index material. MgF2 is also used in initial design as facade layer and back layer, however due to losses cause by absorption this material remains omitted. Design consists of 20-200 layers of SiO2 and Si3N4 deposited on N-BK7 glass by sputtering process. The incident angle for the design is 45 degrees. However, the efficiency is found to only change slightly if the angle is varied from 350 to 550. It is concluded that micro crystalline photovoltaic cell has larger band gap than amorphous silicon photovoltaic cell. For this reason, amorphous silicon photovoltaic cell is best for this design having larger efficiency. K.P. Sibin et al. [6] reported in a paper design of a beamsplitter for photovoltaic thermoelectric hybrid system. For the photovoltaic-thermoelectric hybrid system, ITO / Ag / ITO spectral beam splitter coating has been designed and developed. The thicknesses of the ITO and Ag layers were changed to attain high visible transmittance, high NIR / IR reflectance, and best wavelength cut-off. The figure of merit outcomes revealed that the improved thickness of ITO and Ag layers are 60 and 21 nm, respectively. The improved multilayer IAI coatings display high transmittance in visible region which is about 88% as well as high reflectance of NIR / IR. To increase the transmittance, the chemical etching process was employed. Chemical etching on a single side glass substrate led to a nanoporous surface morphology that functions as antireflective coatings. Combined with the IAI multilayer system, this nano-porous

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morphology improves in transmission about 88% to 91%. The IAI multilayer optical cloud value for single-sided and for clear etched glass was found to be 1.30% and 0.45% respectively. The polarization and angular dependency results have shown that the multilayer IAI coatings are angular unresponsive up to 480 and display sensitive behavior to polarization as well. Ahmad Mojiri et.al.[7] reported Spectral beam splitting is a capable way to attain efficient solar energy conversion. Though spectral splitting gives high theoretical efficiencies, but at commercial level it is very difficult to obtain high efficiency.

Bauer et.al [8] In thermophotovoltaics it has been planned to use a filter between a light source and a long-wavelength photovoltaic (PV) cell that transmits thermal radiation in a narrow spectral window with high conversion efficiency in the PV cell. DeSandre et.al [9] It is also possible to combine PV cells and other systems changing radiation into heat, which is then converted into electricity in a consistent power plant. Goldsmith et.al [10] On the other hand the PV cell may be combined with a thermoelectric (TE) generator, where electricity is produced by heat.

In this paper the design and optimization of beamsplitter is discussed. Beam splitter is used to split incident light into two separate beams. Alternatively, a beam splitter may be used to merge two different beams into one beam. [11]. When the light coming from sun is directed towards a beam splitter by using lens or reflector, the beamsplitter split the incident light into two parts i.e., reflected part and transmitted part. The incident angle across the beamsplitter is chosen to 45 degrees. The visible light and near infrared light are reflected towards the solar cell which is good for solar cell application while the wavelength greater than 1100nm is directed towards thermoelectric generator, in this the efficiency of combined photovoltaic and thermoelectric system can be increased. Two different arrangements of beamsplitter use for efficient photovoltaic devices using a lens [Fig1(a)] or a reflector arrangement [Fig1(b)] are shown in figure 1.

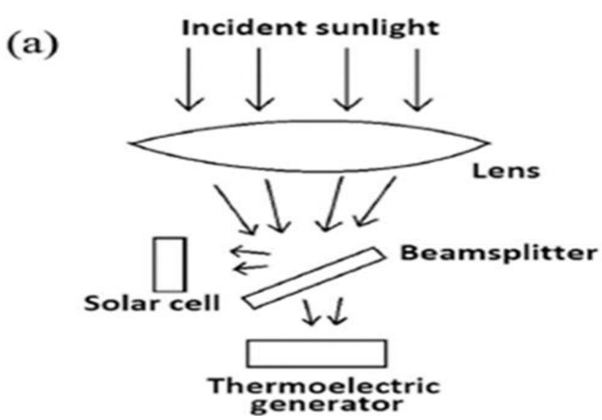

Figure 1(a) Schematic of TE-PV hybrid systems showing splitting of concentrated solar radiation by a spectrally selective beamsplitter. Concentration of solar radiation by a lens.[5]

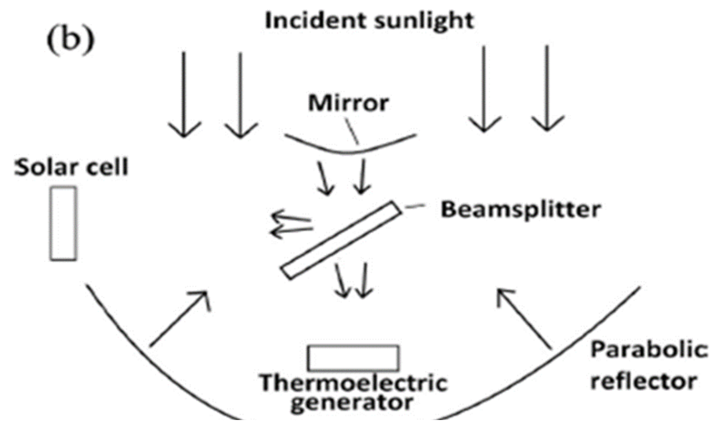

Figure 1(b) Schematic of TE-PV hybrid systems showing split-ting of concentrated solar radiation by a spectrally selective beamsplitter. Concentration of solar radia-tion by a reflector.[5]

For the beam splitter a multilayer thin film with alternating layer of Na_3AlF_6 taken as low index material, Y_2O_3 taken as medium index material and TiO_2 taken as high index material has been chosen, deposited on glass substrate. The paper is organized as follows in section 2 describes the procedure for initial beamsplitter design then optimization techniques are discussed to enhance the efficiency of the design. Then section 3 deals with results and at the end in section 4 conclusion is given.

2 DESIGNING OF BEAM SPLITTER

The working of beamsplitter to enhance the efficiency of solar cell is shown in figure 2. In this system the incident light coming from sun is incident on beam splitter, the beam splitter divides the incoming light into reflected portion and transmitted portion. The visible light and near infrared light are transmitted from the beam splitter but the infrared light is reflected from beam splitter.

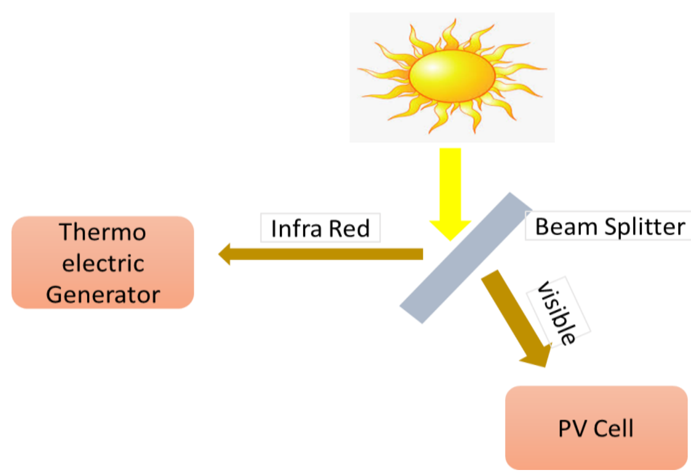

Figure 2 Schematic Diagram of Working of Beam Splitter

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The transmitted light is directed towards the solar cell and the reflected light is directed towards thermoelectric generator. To design a beam splitter, The Essential Macleod program is used. The Essential Macleod software includes all the important aspects for developing optical coatings and determining their performance. A broad variety of output parameters of a given type of coating with the normal transmission and reflectance amount, but also ellipsometric quantities, ultrafast, color and as a function of wavelength from the 0'th(zeroth) to the third derivative can be measured through this software. The results of arbitrary errors in the layers are determined. By using this software, one can optimize the existing designs to enhance the efficiency of them. One can also synthesize the given designs which arise with almost no other directions but the elements to be used and the desired output. It requires the layer density packing allocation.[12]. For the designing of beam splitter, Na3AlF6 as low index material, Y2O3 as middle index material and TiO2 as high index material are chosen. The wavelength range of the design is from 300nm to 2500nm with reference wavelength 700nm having incident angle450. The design consists of 56 alternating layers based on formula given as [LMHM]^14.

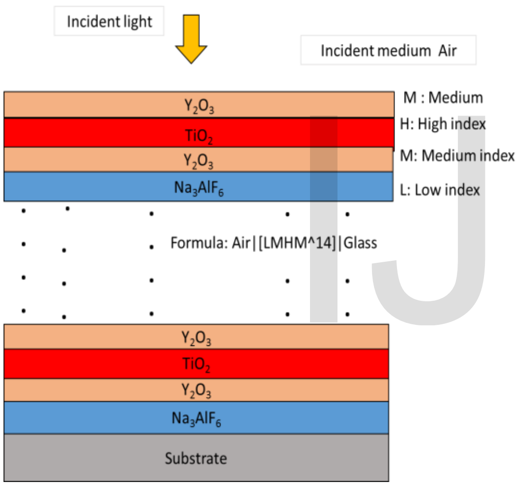

Figure 3 Schematic Diagram of Optical Coating

Schematic diagram of thin film coating is shown in the figure 3, which shows that the design begins by depositing first low index layer which is layer of Na3AlF6 on glass substrate. Then a layer of medium index material Y2O3 is deposited as shown in figure 3, after that a thin layer of high index material that is TiO2 is deposited then medium index material is deposited. The same sequence is repeated and until we have total 56 alternating layers.

3 Results

3.1 Results of Initial Design

This section contains the obtained results for the beam splitter used for PV cells. In figure 4 the transmittance curve of design at 45-degree incident angle with reference wavelength 570nm is shown. The reflectance plot of given design is also presented in figure 5. From figure 4 about 66% transmittance at 400nm is achieved. Maximum transmission is at 811nm which has value 99%. The average transmittance from 400nm to 900nm is 89%. it is also clear that there is also transmittance in the infrared region from 1100nm to 2000nm which is not required for photovoltaic application therefore it is necessary to optimize the design to remove the transmission in the infrared region.

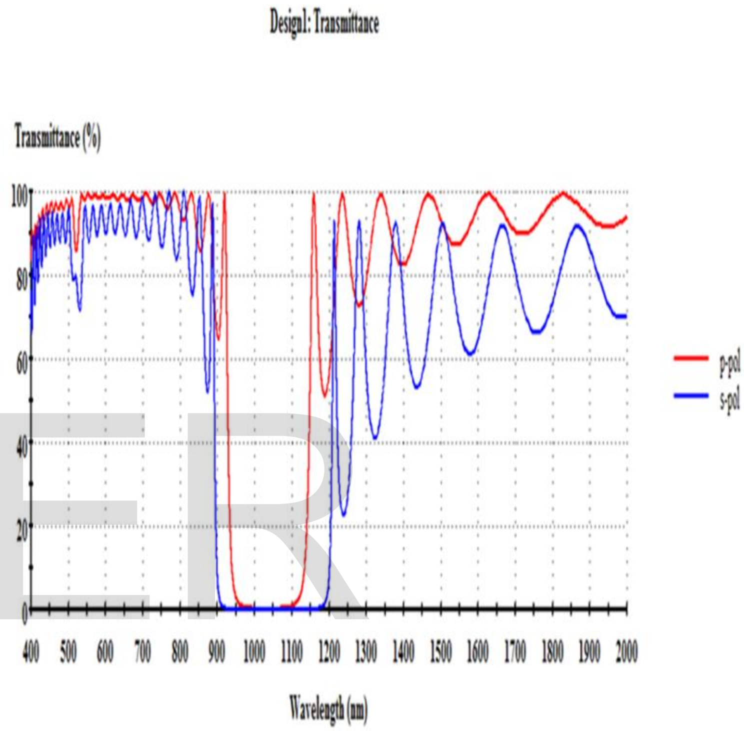

Figure 4 Transmittance plot of initial design

As the Photovoltaic cells are made of materials that are semiconductors such as silicon (Si) Or Gallium Arsenide (GaAs) which converts solar energy coming from sun into electricity. These Semiconductors have a band gap of around 1.1-1.4 eV.[1]. It is possible to transform wavelengths between 400-1100 nm into electricity [2]. The wavelength greater than 1100nm is not converted into electricity because the energy of these waves is less then band gap of the material, it heats the solar cell and efficiency of solar cell decreases. In order to avoid the wastage of energy, the light of wavelength of greater than 1100nm is directed towards thermoelectric generator. In this way the wasted part of light is also used and increase the efficiency of solar cell.[3]. In design there is also transmittance in the infrared region from 1100 to 2000nm which is not required, therefore there is need to optimize the initial design. There are many refinement techniques in Essential Macleod software, but here Optimac refinement technique is used. The results obtained from Optimac technique are presented here.

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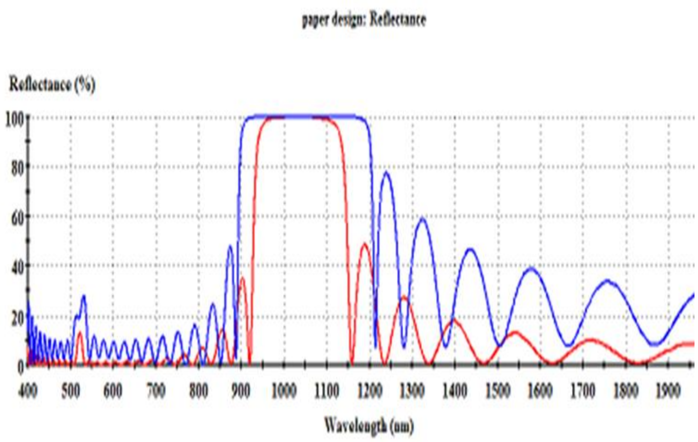

Figure 5 Reflectance plot of initial design

3.2 Results of Optimac Design

Figure 5 shows the transmittance curve of initial design after Optimac refinement at 45-degree incident angle with reference wavelength 570nm.Optimac design consist of 53 alternating layers based on initial design. From figure5 there is about 42% transmittance at 400nm. Maximum transmission at 790nm which has value 99.8%. The average transmittance from 400nm to 975nm is 80%. The average transmittance in the infrared region from 1000nm to 2000nm is only 4%.

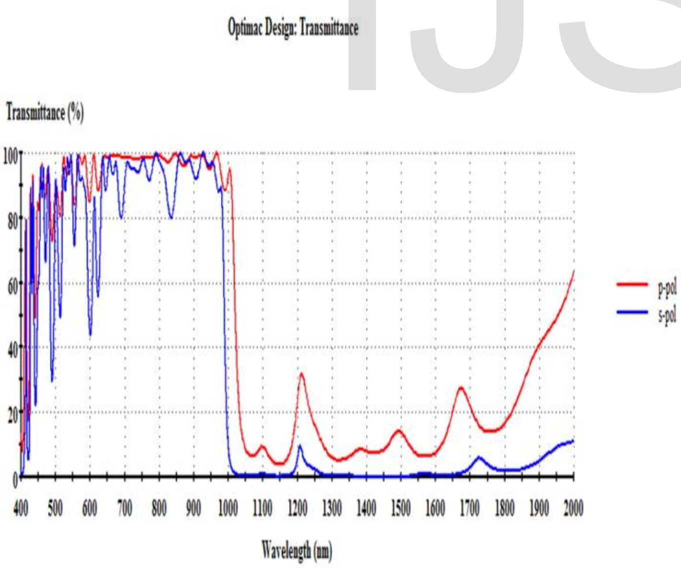

Figure 6 Transmission curve of design after optimac refinement

Similarly Figure 7 shows the reflectance curve of initial design from 1000nm to 2000nm after Optimac Refinement. Maximum Reflectance at 1036nm which has value 99%. The average reflectance from 1000nm to 2000nm is 80%. These 5 Transmittance Plot of Design after Optimac Refinement results show that there is about 80% transmittance in visible and near infrared region and about 77% reflectance in the infrared region. This beamsplitter can be used for the hybrid photovoltaic as well as thermoelectric application. The conclusion of this paper is presented below in section4.

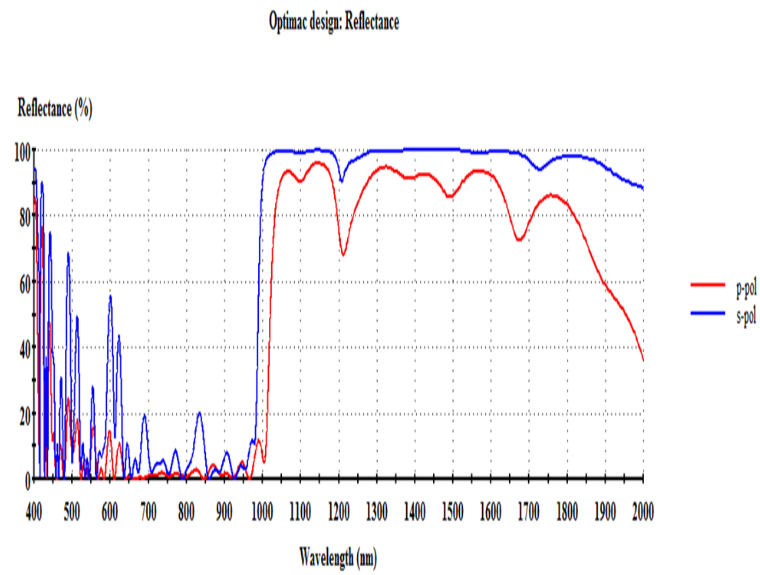

Figure 7 Reflectance curve of design after optimac refinement

4 CONCLUSION

In this paper Spectral splitting optimization for efficient hybrid solar energy cell is studied by using three materials which are Na3AlF6, Y2O3, and TiO2. Essential Macleod software is used to design this beamsplitter. Three multilayer coating design having Na3AlF6 as low index material, Y2O3 as middle index material and TiO2 as high index material is used. The wavelength range of the design is from 400nm to 2000nm with reference wavelength 570nm having incident angle 45-degree. Design consists of 56 alternating layers based on formula [LMHM]^14. Transmission and reflection in the visible region and in the infrared region have been studied. In initial design there is also transmittance in the infrared region from 1100 to 2000nm therefore initial design is optimized to remove the transmission in the infrared region. Initial design fails to give results according to demand therefore to obtain the desired design, Optimac refinement technique is used. Optimac refinement produced acceptable design for which an average value of transmittance in visible and NIR region is about 80% and average value of reflection infrared region from 1000nm to 2000nm is about 77%. The transmitted light is directed towards solar cell and reflected light is directed towards thermoelectric generator. beamsplitter transmit visible light to solar cell and reflect infrared light towards thermoelectric generator. In this way a beam splitter splits the incoming light and increase the efficiency of solar cell or photovoltaic cell, indeed it increase the overall efficiency of the combined thermoelectric and photovoltaic system.

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