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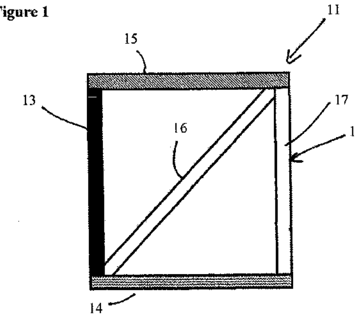
(54) Title: SI CELLS WITH III-V MULTIJUNCTION CELLS

Figure 1



(57) **Abstract**: A solar conversion assembly comprises: a) a type III-V multiple cell stack solar cell device b) a silicon solar cell device c) a band splitting device located relative to the type III-V solar cell device and the silicon solar cell device. The band splitting device splits light falling on the splitting device into a plurality of wavelength bands and directs a first of said bands to the type III-V solar cell device and the second of said bands to the silicon solar cell device.

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Si cells with III-V multijunction cells

Introduction

The present invention relates generally to the field of photovoltaics and in particular the invention provides structures for improved thermodynamic cycles for conversion of concentrated solar power.

Background

Low conversion efficiency of the traditional thermodynamic cycles has been one factor that has hampered practical application of concentrated solar power. The highest conversion efficiency to date is reported to be 31.3% for a Stirling engine coupled to a $64m^2$ (active area) dish on a freezing but very bright day in Albuquerque in January 2008. This was not a particularly large improvement on the previous record of 29.4% set 25 years earlier, suggesting that practical upper limits are being approached. Efficiencies of power tower, parabolic trough and linear Fresnel reflector approaches, generally based on the Rankine thermodynamic cycle, are appreciably lower with peak efficiency of 25%, 20% and 16% respectively the best expected in the near to medium term.

Quantum based thermodynamic cycles offer higher efficiency. In particular, it has been shown that the conversion efficiency for monochromatic light in a photovoltaic converter monotonically approaches 100% as the bandwidth and angular spread of incident light decreases and the intensity increases. The angular spread of sunlight from the sun's disc and the finite intensity of sunlight places a thermodynamic limit of 87% on sunlight conversion based on this strategy of dividing sunlight into monochromatic components. The recent spectacular rise in efficiency of monolithic tandem stacks of solar cells is testimony to this effect. Efficiency has increased spectacularly from 24% in 1990 to the most recent record of 41.6% efficiency established by Boeing/Spectrolab.

In recent times interest has increased in spectral splitting as a means to further enhance the efficiency of solar conversion beyond that possible from monolithic cell stacks. An efficiency of 42.7% measured by partitioning the solar spectrum and converting by 5 separate cells was recently reported earlier this year and more recently this figure has been extended to 43%. Complementing these cell results, a system efficiency of 36.5% has been independently confirmed for a small system based on this approach including additional system losses such as optical losses in the required concentrating lens and dichroic reflectors. This is already appreciably higher than the 31.3% result with traditional thermodynamic cycles, despite the obvious untapped potential.

Summary

The present invention provides a solar conversion assembly comprising:

a) a type III-V multiple cell stack solar cell device

b) a silicon solar cell device

c) a band splitting device located relative to the type III-V solar cell device and the silicon solar cell device to split light falling on the splitting device into a plurality of wavelength bands and directing a first of said bands to the type III-V solar cell device and the second of said bands to the silicon solar cell device.

The band splitting device will preferably split the spectrum about a wavelength in the range of 890-1100nm.

The solar conversion device is preferably also configured to constrain the angle of incidence of light on the type III-V solar cell device. The angular constraint may be achieved by providing an inlet port having an anti-reflection (AR) coating with a restricted angular response. The bandpass reflector may also have a restricted angular response.

The assembly will preferably comprise receiver sub-assembly containing the solar cell devices and band splitter and a light concentrating device, such as a reflective concentrator or transmissive lens system which concentrates and directs light falling onto the band splitting device in receiver the sub-assembly thereby also limiting the angular range of light rays entering the sub assembly. The degree of constraint will depend upon the disk diameter of the light concentrating system and the distance from the lens to the sub assembly containing the solar cells.

The solar conversion assembly may be modified by employing a band splitting device that is pivotable about a pivot axis to change an angle of incidence of light impinging on the band splitting device. In this case the band splitting device will preferably have a splitting characteristic which varies as the angle of incidence of the light impinging on the band splitting device varies. When the band splitting device is pivotable it may be independent of the semiconductor receivers. Alternatively the band splitting device may be located over a surface of one of the semiconductor receivers, whereby the receiver and band splitting device pivot together, in which case it may be a bandpass filter positioned on the receiving surface of the Silicon receiver.

The band splitting device may be a dichroic filter.

Brief description of the drawings

Embodiments of the invention will now be described with reference to the accompany drawings in which:

Figure 1 shows a "Power-cube" receiver design according to an embodiment of the present invention;

Figure 2 schematically illustrates a reflective concentrator and power cube according to an embodiment of the invention;

Figure 3 shows a "Power-cube" receiver design similar to that of Figure 1 in which the bandpass reflector is pivotable; and

Figure 4 shows a variation on the design of figure 3 in which a band pass filter/reflector is located over a surface of a semiconductor receiver and the respective semiconductor receiver is pivotable with the bandpass filter/reflector.

Detailed description of embodiments

Comparative studies frequently suggest cost advantages for concentrating solar power (CSP) system based on the power tower concept. The potential of the power tower approach with improved efficiency receivers has recently gained interest for those working in the area of concentrating solar power.

Compared to approaches with distributed receivers, the advantage of the power tower concept is that it allows for more sophisticated, potentially higher performance receivers. With the traditional thermodynamic cycles, this allows higher operating temperatures, although these introduce their own challenges in the thermally unstable environment that results. However, more advanced thermodynamic cycles only require high effective temperatures rather than actual temperature with consequent operational advantages.

Embodiments of the invention will harness the benefits of tandem III-V cell with those of silicon cells to achieve otherwise un-attainable efficiencies. These embodiments of the invention make use of spectrum splitting in combination with the power tower concept for higher efficiency conversion of concentrated solar power using a "power-cube" 11, shown schematically in Figure 1, capable of energy conversion efficiency above 40%, including all optical losses.

The design of the "Power-cube" receiver 11 seen in Figure 1, includes an inlet port 17, a Type III-V semiconductor receiver 13, a Silicon receiver 14 and a wide-band reflector 15 assembled in a cube with a bandpass (e.g. dichroic) reflector 16 positioned diagonally to separate the incoming light into two bands directed respectively to the

Type III-V semiconductor receiver 13 and the Silicon receiver 14. The inlet port 17 is provided with an Anti-reflection coating 18 to enhance the capture of light in the power cube 11. The AR coating 18 is provided with a restricted angular response to limit the angle of incidence of light on the Type III-V semiconductor receiver 13. Light enters the power cube through the inlet port 17 (and the AR coating 18) and strikes the diagonal bandpass reflector 16 which reflects lightwithin the passband frequencies and passes light outside the passband frequencies. The reflected light is redirected to the silicon cell 14 by the bandpass reflector 16 whereas the transmitted light passes to the Type III-V semiconductor receiver 13. Usual antireflection techniques will be used on the receivers 13 & 14 but there will be some stray light reflected from the surfaces of the receivers which will then be reflected from various surfaces inside the cube to different extents and some will be directed back to one of the receivers while some will escape through the inlet port and be lost.

A Solar System III-V receiver which recently achieved efficiencies above 40% for individual cells could conveniently form the Type III-V receiver 13 of Figure 1.

The power tower concept offers the potential for careful optimisation of the receiver to give maximum efficiency. Referring to Figure 2, this approach employs a reflector system 50 to concentrate solar energy 51 onto the inlet port 17 of the power cube 11. The power cube 11 achieves higher performance by complementing the III-V cell stack by the additional incorporation of much lower cost silicon cells that can increase performance by up to 6% absolute, and by constraining the system's angular response to improve the voltage of the III-V cells.

A recent Boeing/Spectralab 40.7% efficient 3-cell stack is described in the proceedings of the 51st Electronic Materials Conference, June, 2009 (Richard King) in which the I-V curve and device configuration of the Boeing/Spectralab device are described and in which the final output curve of this device is shown, together with that of the composite cells. Such a device would also be suitable for use in the present power cube design. In the power cube design a surplus 0.085A/W of the Ge cell (subcell 3) is deflected to a Si cell and converted at over 0.7V, which is typical of operation at high concentration, with a resulting combined efficiency boosted by at least 6% giving a finial value above 46%. This boost offsets losses at the system level allowing a big-boost in the performance of a practical solar converter to values above 40%. The dielectric-based bandpass reflector in Figure 1 is designed to reflect wavelengths in the circa 890-1100nm range to the silicon array shown.

The proceedings of the 51st Electronic Materials Conference, June, 2009 (Richard King) also graphically illustrates radiative efficiencies of III-V cells fabricated by Boeing/ Spectrolab, deduced from voltage. As shown in these radiative efficiency curves (lower red lines), some III-V cells have radiative efficiencies approaching 100%. Those within 60 mV of the lower dashed red line have radiative efficiency above 10%. Such cells will see a voltage improvement if their angular emission of light is restricted. This can be achieved by restricting the range of angles to which the cells respond. In the "power-cube", this is easily achieved by restricting the angular response of the AR coating of the inlet port 17 and/or of the bandpass reflector 16. Since the heliostat field directs light to the tower over a limited solid angle, reasonable gains can be expected as cell technology continues to mature. Restricting the angular acceptance angle to half would increase voltage/cell by 2-20 mV for radiative efficiencies above 10%.

The embodiment of Figure 1 is not optimal because the cells in the stack of cells which make up the Type III-V semiconductor receiver will be connected in series, as the spectral content of the sunlight entering the cube varies during the day, the mismatch of currents generated by the cells in the Type III-V semiconductor receiver will change causing a variable loss. Referring to Figure 3 an improved "Power-cube" receiver has a bandpass (e.g. dichroic) reflector 26 positioned diagonally to separate the incoming light into two bands directed respectively to the Type III-V semiconductor receiver 13 and the Silicon receiver 14 with the bandpass (e.g. dichroic) reflector 26 and the Silicon receiver 14 each pivotable about a pivot axis 21. By controlling the angle of incidence of the light impinging on the reflector as the spectral content of the light changes, the reflection/transmission properties of the bandpass reflector are shifted in a manner that compensates for the variable spectral content of the light during the day. This will decrease the spectral mismatch in the Type III-V cells and allow the maximum amount of light to be sent to the silicon cell increasing overall energy conversion efficiency over the day.

Otherwise the "Power-cube" receiver of Figure 3 is similar to that of Figure 1 and may be used in the system of Figure 2.

In another variation of the conversion assembly of Figures 1 and 3, the "freestanding" reflector 16, 26 can be replaced with a reflector 116 attached to the surface of one of the semiconductor receivers, in this case the silicon receiver 114. The design of the converter 111 seen in Figure 4, includes an inlet port 117, a Type III-V semiconductor receiver 113, a Silicon receiver 114 and a bandpass (dichroic) filter 116 positioned on the receiving surface of the Silicon receiver 114 and at an acute angle to the Type III-V semiconductor receiver 113. The AR coating 18 is provided with a restricted angular response to limit the angle of incidence of light on the Type III-V semiconductor receiver 113. Light enters the converter 111 through the inlet port 117 (and the AR coating 118) and strikes the diagonal bandpass filter/reflector 116 which passes light within the passband and reflects light ouside the passband frequency. The transmitted light is passed to the silicon receiver114 by the bandpass filter/reflector 116 whereas the reflected light is redirected to the Type III-V semiconductor receiver 113. Alternatively the positions of the silicon receiver 114 and Type III-V semiconductor receiver 113, in which case the transmission/reflection characteristic of the filter/reflector 116 must be inverted. Usual antireflection techniques will be used on the receivers 113 & 114. but there will be some stray light reflected from the surfaces of the receivers which will then be reflected from various surfaces inside the converter to different extents and some will be directed back to one of the receivers while some will escape through the 117 inlet port and be lost.

Other than the configuration of the reflector over one receiver, the Figure 4 converter is functionally is similar to that of Figure 3 and may be used in the system of Figure 2. While described with a bandpass filter 116 positioned over the silicon receiver 114, a bandpass reflector could equally be positioned over the Type III-V semiconductor receiver 113 and this pair pivoted together.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

CLAIMS:

1. A solar conversion assembly comprising:

a) a type III-V multiple cell stack solar cell device

b) a silicon solar cell device

c) a band splitting device located relative to the type III-V solar cell device and the silicon solar cell device to split light falling on the splitting device into a plurality of wavelength bands and directing a first of said bands to the type III-V solar cell device and the second of said bands to the silicon solar cell device.

2. The solar conversion assembly of claim 1 wherein the band splitting device splits the spectrum about a wavelength in the range of 890-1100nm.

3. The solar conversion assembly of claim 1 or 2 wherein an angle of incidence of light on the type III-V solar cell device is constrained by an angular response constraining device.

4. The solar conversion assembly of claim 3 wherein the angular constraining device is an inlet port having an anti-reflection (AR) coating with a restricted angular response.

5. solar conversion assembly of claim 1, 2, 3 or 4 wherein the bandpass reflector has a restricted angular response to light.

6. The solar conversion assembly of claim 1, 2, 3, 4 or 5 comprising

a) a receiver sub-assembly containing

i) the type III-V multiple cell stack solar cell device;

ii) the silicon solar cell device

iii) the band splitting device and

b) a light concentrating device.

7. The solar conversion assembly of claim 6 wherein the light concentrating device comprises a reflective concentrator which concentrates and directs light falling onto the band splitting device in receiver the sub-assembly to thereby also limit the angular range of light rays entering the sub assembly.

8. The solar conversion assembly of claim 6 wherein the light concentrating device comprises a transmissive lens system which concentrates and directs light falling onto the band splitting device in receiver the sub-assembly thereby also limiting the angular range of light rays entering the sub assembly.

9. The solar conversion assembly as claimed in any one of claims 1 to 8 wherein band splitting device is pivotable about a pivot axis to change an angle of incidence of light impinging on the band splitting device and the band splitting device has a splitting

characteristic which varies as the angle of incidence of the light impinging on the band splitting device varies.

10. The solar conversion assembly as claimed in any one of claims 1 to 9 wherein the band splitting device is located over a surface of one of the semiconductor receivers, whereby the receiver and band splitting device pivot together.

11. The solar conversion assembly as claimed in any one of claims 1 to 10 wherein band splitting device is a bandpass filter positioned on the receiving surface of the Silicon receiver.

12. The solar conversion assembly as claimed in any one of claims 1 to 11 wherein band splitting device is a dichroic filter.

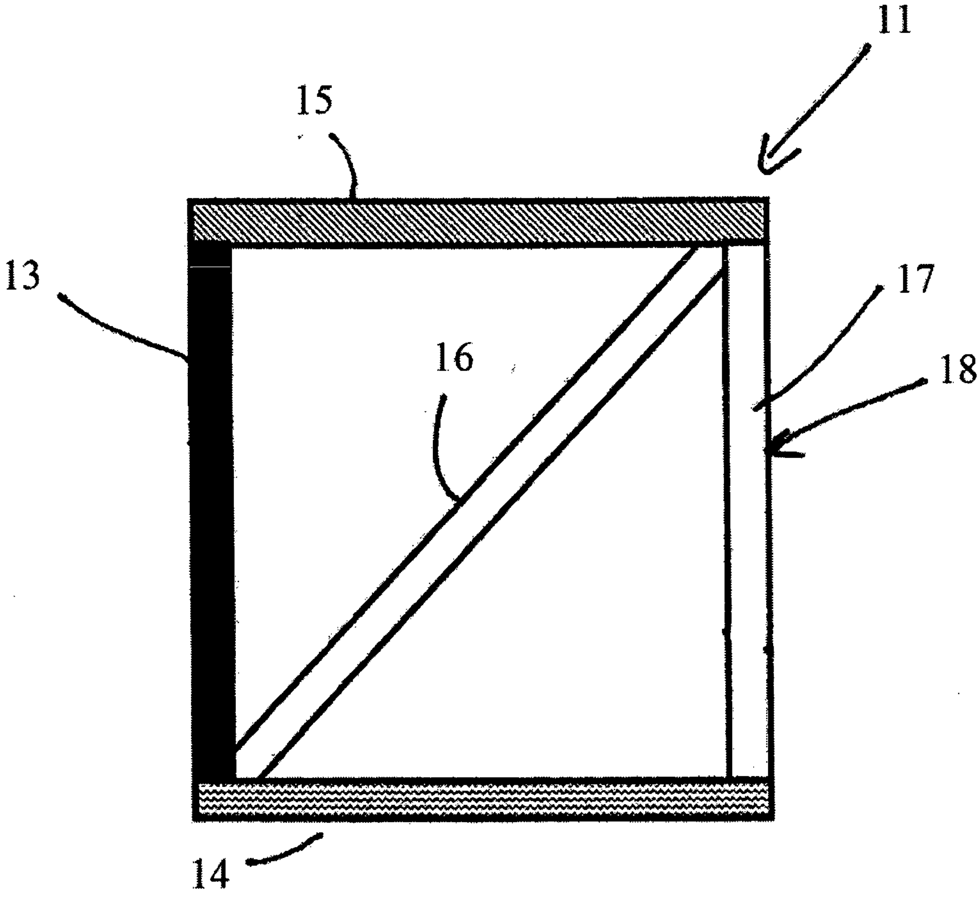

Figure 1

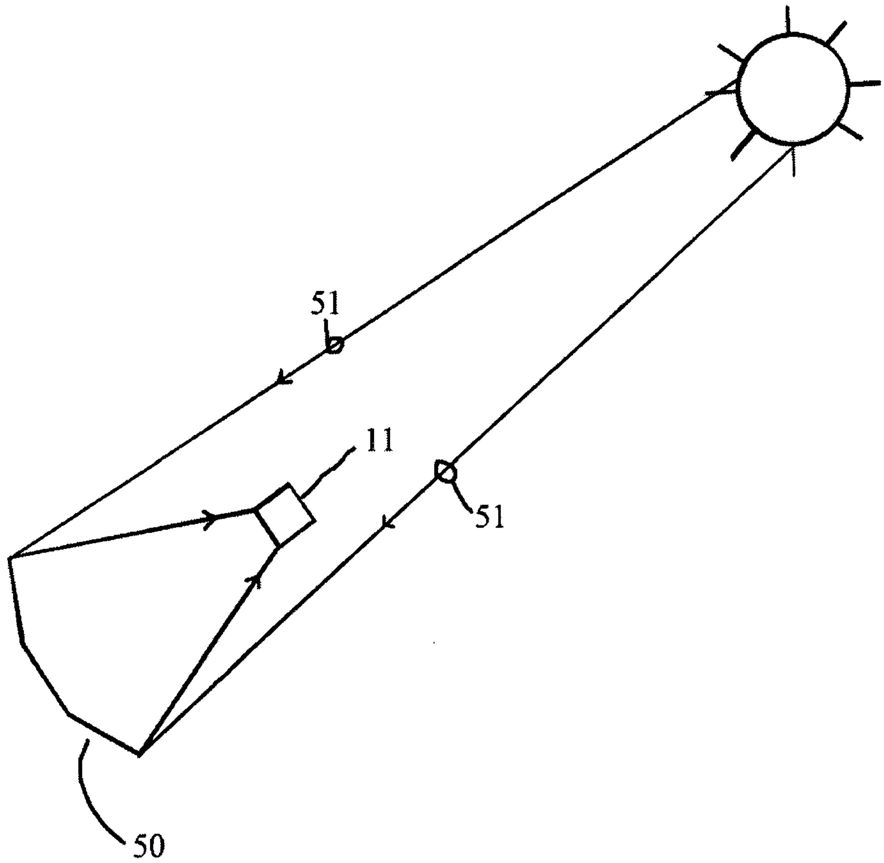

Figure 2

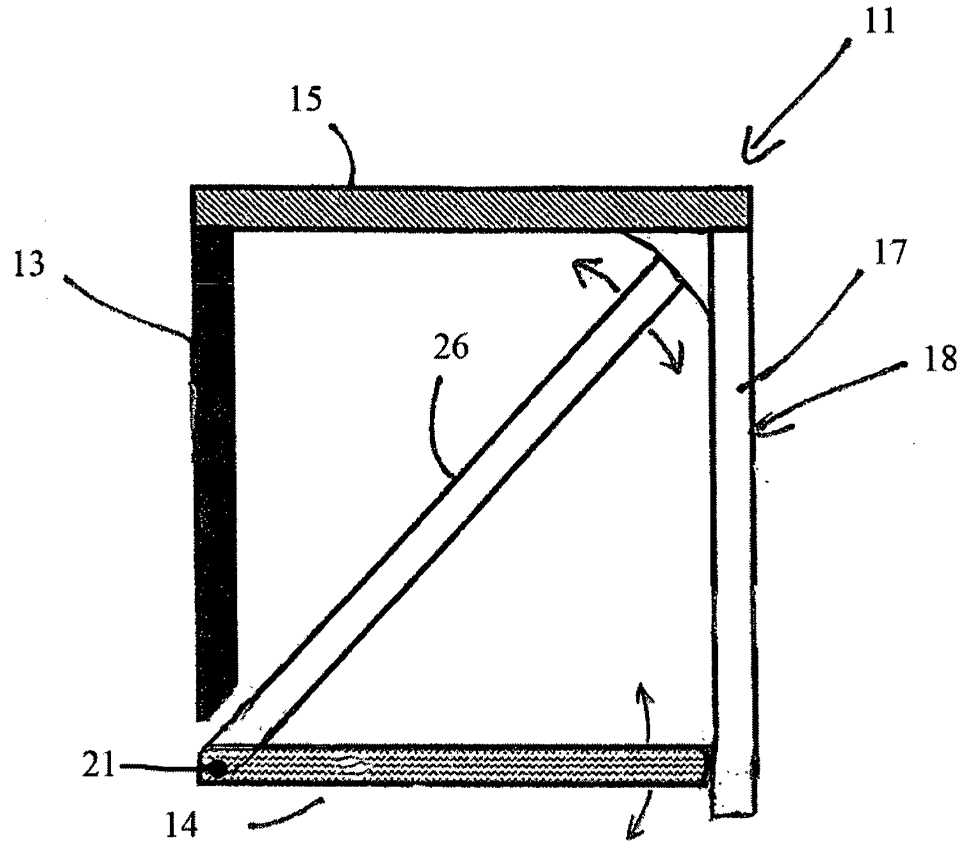

Figure 3

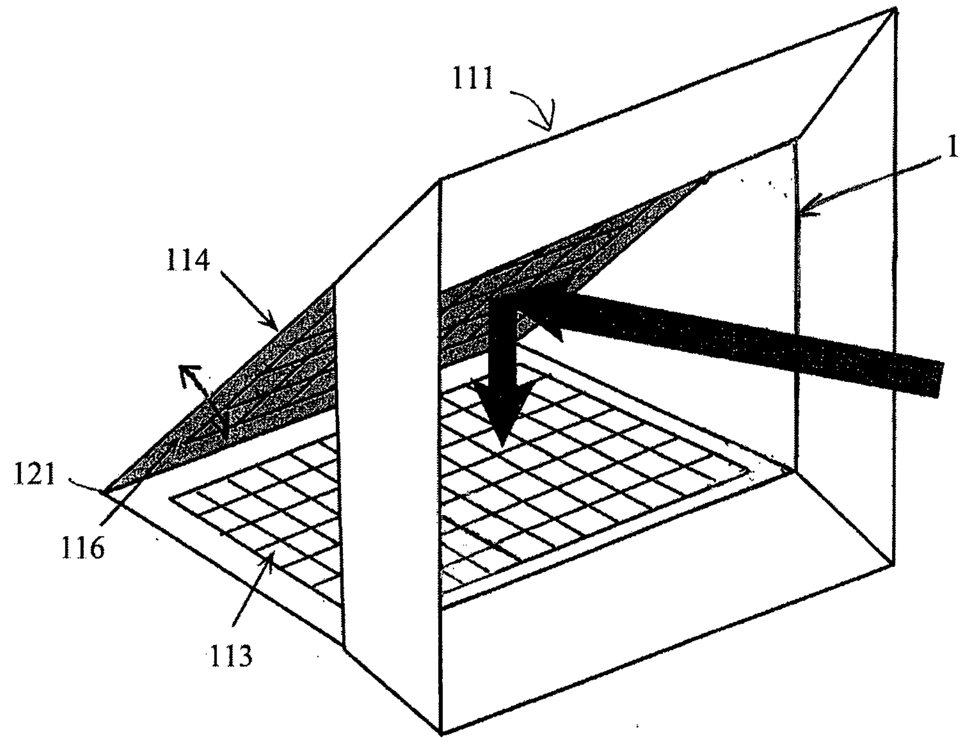

Figure 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2011/000146

A. CLASSIFICATION OF SUBJECT MATTER

INT. CL.

H01L 31/042 (2006.01)   ***H01L 31/052*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI & EPO – IPC & Keywords – photovoltaic, solar, cell, split, divide, segment, direct, filter, dichroic, wavelength, band and other like terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/032052 A2 (UNIVERSITY OF DELAWARE) 12 March 2009 Whole document especially pages 2-6	1-12
X	US 2009/0199889 A1 (WILLMOTT) 13 August 2009 Whole document especially Paragraphs 20-30	1-12
X	GB 1528527 A (STANDARD TELEPHONES AND CABLES LTD) 11 October 1978 Whole document especially Abstract	1

☐ Further documents are listed in the continuation of Box C   ☒ See patent family annex

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Date of the actual completion of the international search	Date of mailing of the international search report
12 June 2011	23 JUN 2011

Name and mailing address of the ISA/AU	Authorized officer
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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	2009032052	CN	101919065	EP	2183790	KR	20100066525
		US	2010078063				
US	2009199889	NONE					
GB	1528527	DE	2729322	FR	2395608		

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END OF ANNEX