US008569616B2

(12) United States Patent
Guha et al.

(10) Patent No.: **US 8,569,616 B2**
(45) Date of Patent: ***Oct. 29, 2013**

(54) METHOD OF CONCETRATING SOLAR ENERGY

(75) Inventors: **Supratik Guha**, Yorktown Heights, NY (US); **Philip C. Hobbs**, Briarcliff Manor, NY (US); **Yves C. Martin**, Yorktown Heights, NY (US); **Robert L. Sandstrom**, Yorktown Heights, NY (US); **Theodore G. van Kessel**, Yorktown Heights, NY (US)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 124 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/237,386**

(22) Filed: **Sep. 20, 2011**

(65) **Prior Publication Data**

US 2012/0006318 A1 Jan. 12, 2012

Related U.S. Application Data

(62) Division of application No. 12/622,504, filed on Nov. 20, 2009, now Pat. No. 8,026,439.

(51) **Int. Cl.**
H01L 31/00 (2006.01)

(52) **U.S. Cl.**
USPC **136/256**

(58) **Field of Classification Search**
USPC 136/246
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,604,601	A	7/1952	Menzel
3,070,699	A	12/1962	Lehmann et al.
3,293,440	A	12/1966	Mueller
3,370,293	A	2/1968	Green
3,984,685	A	10/1976	Fletcher et al.
3,984,686	A	10/1976	Fletcher et al.
4,045,246	A	8/1977	Mlavsky et al.
4,081,289	A	3/1978	Campbell, III
4,086,485	A	4/1978	Kaplow et al.
4,107,521	A	8/1978	Winders

(Continued)

FOREIGN PATENT DOCUMENTS

DE	2749992	A1	5/1979
DE	4116894	A1	11/1992

(Continued)

OTHER PUBLICATIONS

Chia-Yen Lee et al., "Sun Tracking Systems: A Review," Sensors 2009, 9, 3875-3890.

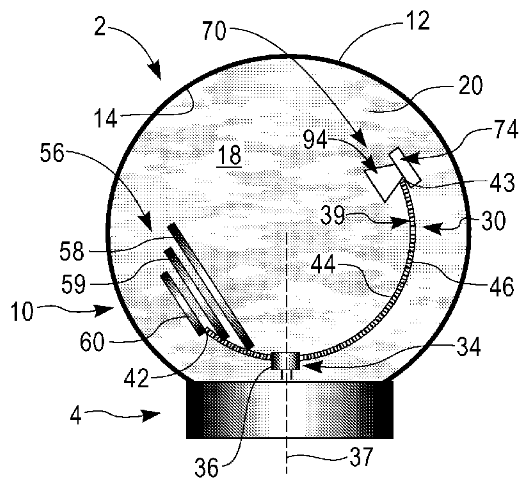
(Continued)

Primary Examiner — Jennifer Michener
Assistant Examiner — Shannon Gardner
(74) *Attorney, Agent, or Firm* — Cantor Colburn LLP; Vazken Alexanian

(57) **ABSTRACT**

A method of concentrating solar energy includes receiving solar energy through a surface of an optically clear shell, guiding the solar energy through a liquid contained in the optically clear shell, folding the solar energy back through the liquid toward a solar receiver, and shifting the solar receiver within the optically clear shell to track the sun, wherein the solar energy collected by the solar receiver is converted into electrical energy.

10 Claims, 2 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,146,785 A	3/1979	Neale	
4,200,472 A	4/1980	Chappell et al.	
4,223,214 A	9/1980	Dorian et al.	
4,225,781 A	9/1980	Hammons	
4,262,195 A	4/1981	White et al.	
4,278,829 A	7/1981	Powell	
4,586,488 A	5/1986	Noto	
4,592,129 A *	6/1986	Legge	438/72
4,687,923 A	8/1987	Bauck	
4,691,075 A	9/1987	Murphy	
4,730,602 A	3/1988	Posnansky et al.	
4,868,379 A	9/1989	West	
5,153,778 A	10/1992	Sasian-Alvarado	
5,483,060 A	1/1996	Sugiura et al.	
5,498,297 A	3/1996	O'Neill et al.	
5,593,544 A	1/1997	Fahlgren et al.	
5,593,549 A	1/1997	Stirbl et al.	
6,018,122 A	1/2000	Hibino et al.	
6,034,319 A	3/2000	Falbel	
6,127,620 A	10/2000	Tange et al.	
6,337,129 B1	1/2002	Watanabe et al.	
6,399,874 B1	6/2002	Olah	
6,465,725 B1	10/2002	Shibata et al.	
6,583,349 B2	6/2003	Tanaka	
6,689,949 B2	2/2004	Ortabasi	
6,696,637 B2	2/2004	Lawheed	
6,992,276 B2	1/2006	Blauvelt et al.	
7,148,465 B2	12/2006	Blauvelt et al.	
7,177,140 B2	2/2007	Clarke et al.	
7,208,674 B2	4/2007	Aylaian	
7,476,832 B2	1/2009	Vendig et al.	
7,847,228 B2	12/2010	Lin	
2001/0006066 A1	7/2001	Cherney et al.	
2004/0011395 A1	1/2004	Nicoletti et al.	
2005/0161581 A1	7/2005	Michiyama et al.	
2006/0041345 A1	2/2006	Metcalf	
2006/0225778 A1	10/2006	Brabec et al.	
2007/0051360 A1	3/2007	Rhee	
2007/0144574 A1	6/2007	Yada	
2007/0215199 A1	9/2007	Dold et al.	
2008/0017784 A1	1/2008	Hoot et al.	
2008/0128586 A1	6/2008	Johnson et al.	
2008/0138634 A1	6/2008	Morris et al.	
2008/0172256 A1	7/2008	Yekutiely	
2008/0308152 A1	12/2008	Grip	
2008/0314438 A1	12/2008	Tran et al.	
2009/0043253 A1	2/2009	Podaima	
2009/0056790 A1 *	3/2009	Tian et al.	136/246
2009/0084435 A1	4/2009	Guha et al.	
2009/0188488 A1	7/2009	Kraft et al.	
2009/0199846 A1	8/2009	Collins et al.	
2009/0229794 A1	9/2009	Schon	
2009/0308377 A1	12/2009	Kleinwaechter	
2010/0000518 A1	1/2010	Chen et al.	
2010/0023138 A1	1/2010	McDonald et al.	
2010/0031991 A1	2/2010	Mochizuki et al.	
2010/0095955 A1	4/2010	Carrasco Martinez	
2010/0101560 A1	4/2010	Olsson et al.	
2010/0180886 A1	7/2010	Chang	
2010/0192940 A1	8/2010	Yoon	
2010/0326427 A1	12/2010	Chen	

FOREIGN PATENT DOCUMENTS

DE	19801213	A1	7/1999
EP	0405678	A1	1/1991
EP	2105683	A	9/2009
JP	58018059	A	2/1983
JP	2291912	A	12/1990
JP	3256580	A	11/1991
JP	5052702	A	3/1993
JP	8095641	A	4/1996
WO	2008034423	A2	3/2008

OTHER PUBLICATIONS

International Search Report; International Application no. PCT/US2011/020654; International Filing Date: Jan. 10, 2011; Date of Mailing: Mar. 9, 2011.

International Search Report—Written Opinion; International Application No. PCT/US2011/020654; International Filing Date: Jan. 10, 2011; Date of Mailing: Mar. 9, 2011.

International Preliminary Report on Patentability for PCT Application No. PCT/US2011/020654, dated Jul. 26, 2012, pp. 1-7.

* cited by examiner

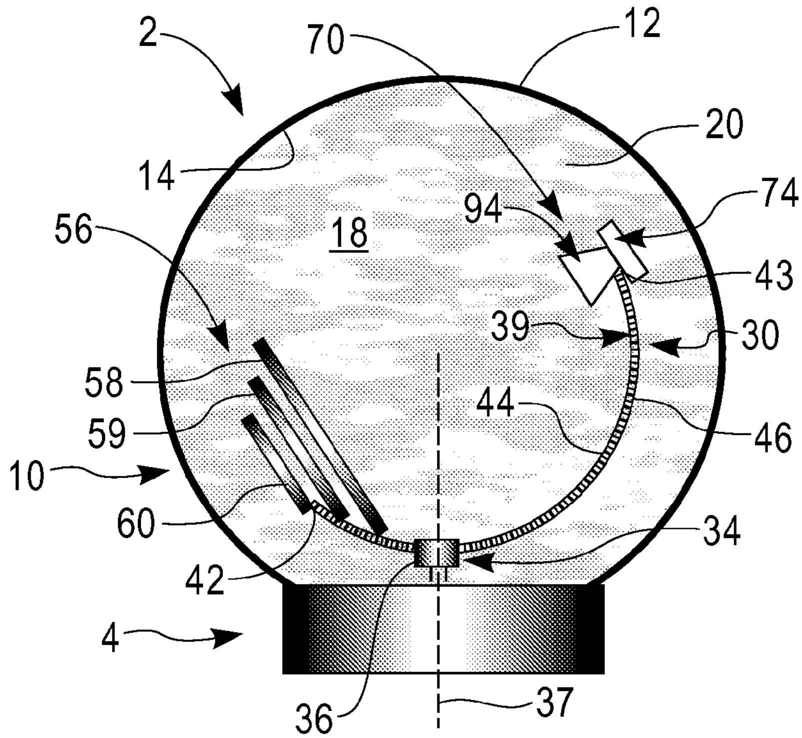

2
70
12
20
14
74
94
18
43
56
39
30
58
44
46
59
10
60
34
42
4
36
37

FIG. 1

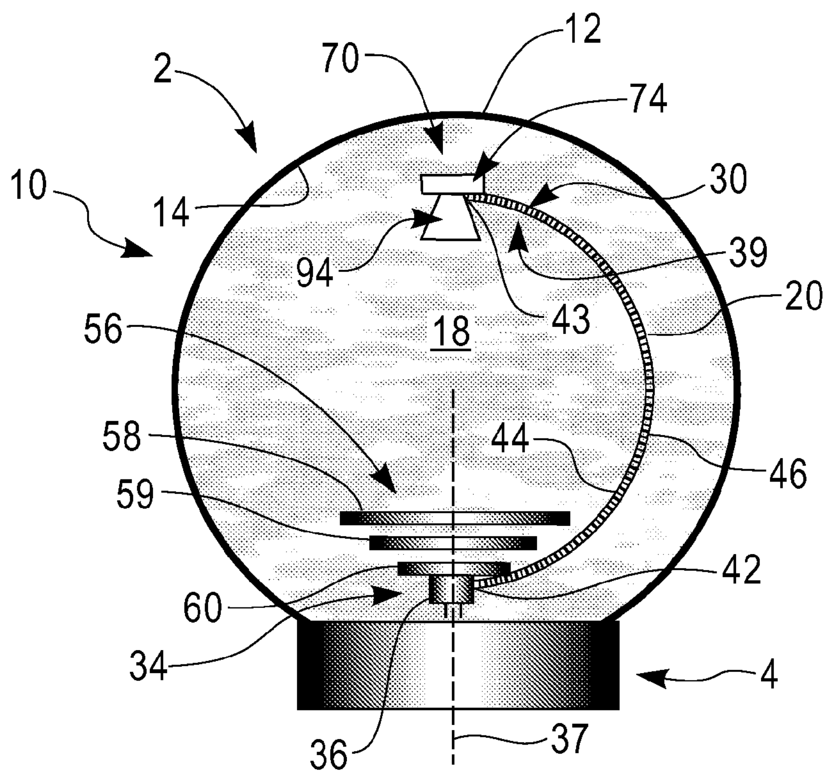

12
70
2
74
30
10
14
94
39
43
20
18
56
58
44
46
59
42
60
34
4
36
37

FIG. 2

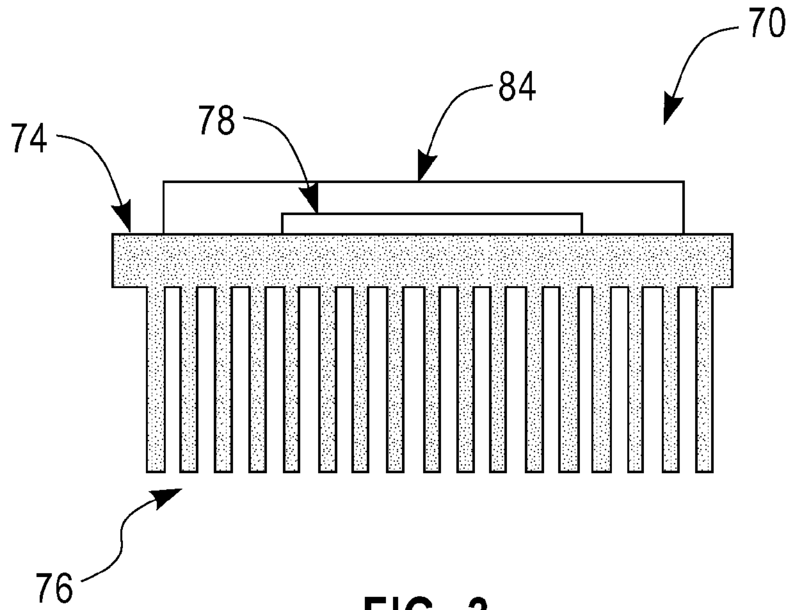


FIG. 3

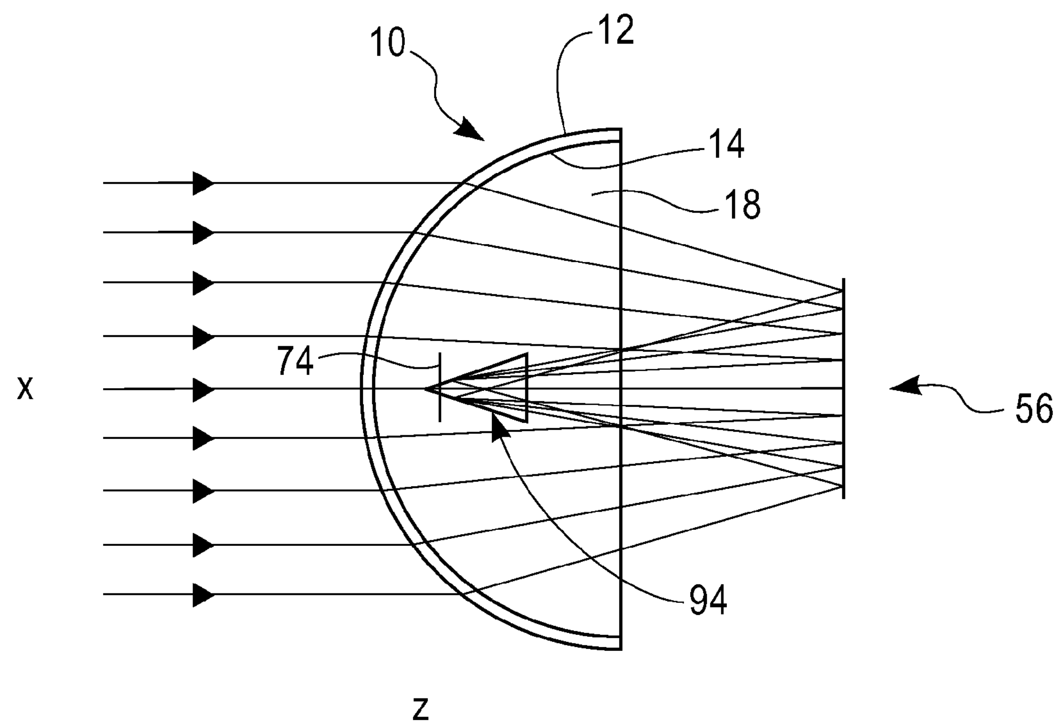


FIG. 4

METHOD OF CONCETRATING SOLAR ENERGY

CROSS REFERENCE TO RELATED APPLICATION

This application is a divisional of U.S. Pat. No. 8,026,439 filed Nov. 20, 2009, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND

The present invention relates to solar concentrators and, more particularly, to a solar concentrator including an optical tracking system.

Solar power systems fall generally into two categories: fixed position flat panels and tracking concentrator systems. Fixed position flat panel systems employ one or more stationary panels that are arranged in an area having an unobstructed view of the sun. As the earth rotates, the sun's rays move over the stationary panel(s) with varying degrees of intensity depending upon geographic location, the time of day and the time of the year. In contrast, solar concentrator systems collect, and focus the sun's rays onto one or more solar cells. Certain solar concentration systems employ tracking systems that follow the sun's path in order to enhance energy collection. Simply put, fixed position flat panels represent a passive solar collection system, while solar concentrator systems represent a more active energy collection system.

Solar concentrator systems utilizing photovoltaic cells typically operate at or below about 500 suns concentration. Operating at higher sun concentration levels creates cooling challenges. In order to address the cooling challenges, certain solar concentration systems employ liquid cooling systems such as found in U.S. Pat. No. 4,081,289. In the '289 patent, a sphere contains a liquid medium and a plurality of fixed solar panels. The sphere acts as a lens and the liquid as a focal and cooling medium. The liquid is circulated within the sphere to carry away heat generated by solar rays impacting the fixed solar cells. In addition to serving as a heat exchange medium, the liquid, in combination with the sphere, focuses the sun's rays toward the fixed solar cells. While effective as a cooling medium, the use of the sphere and liquid to focus light imparts significant limitations on energy collection. That is, the actual focal point of the light passing through the sphere and the liquid is outside of the sphere itself.

Solar concentrator systems allow the use of fewer semiconductor elements to produce a given amount of electric power. However, the use of fewer semiconductor elements results in a need for optics and a system for tracking the sun. At present, the additional cost associated with the necessary optics and tracking systems does not exceed the cost benefit of a reduced number of solar cells.

SUMMARY

According to one exemplary embodiment, a method of concentrating solar energy includes receiving solar energy through a surface of an optically clear shell, guiding the solar energy through a liquid contained in the optically clear shell, folding the solar energy back through the liquid toward a solar receiver, and shifting the solar receiver within the optically clear shell to track the sun, wherein the solar energy collected by the solar receiver is converted into electrical energy.

Additional features and advantages are realized through the techniques of the present invention. Other embodiments and aspects of the invention are described in detail herein and are considered a part of the claimed invention. For a better understanding of the invention with the advantages and the features, refer to the description and to the drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The forgoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is an elevational view of a solar concentrator including a solar collection system in accordance with an exemplary embodiment;

FIG. **2** is the solar concentrator showing the solar collection system shifting to track the sun;

FIG. **3** is an elevational view of a solar receiver portion of the solar collection system in accordance with an exemplary embodiment; and

FIG. **4** is a schematic view of the solar concentrator showing the solar collection system focusing solar rays onto the solar receiver in accordance with an exemplary embodiment.

DETAILED DESCRIPTION

With reference now to FIGS. **1** and **2**, a solar concentration system constructed in accordance with an exemplary embodiment, is indicated generally at **2**. Solar concentration system **2** includes a base member **4** that supports an optically clear shell **10**. Optically clear shell **10** includes an outer surface **12** having an anti reflective and/or anti-fouling coating such as polydimethylsiloxane (PDMS). Optically clear shell **10** includes an inner surface **14** that defines a hollow interior portion **18**. In accordance with an exemplary embodiment, hollow interior portion **14** is filled with a liquid **20** such as water. Of course other liquids such as glycol, alcohol, and the like can also be employed to prevent freezing or to adjust an optical index. Solar concentration system **2** is further shown to include a solar collection system **30** arranged within hollow interior portion **18**.

In accordance with an exemplary embodiment, solar collection system **30** includes a tracking system **34** having a base element **36** that is configured and disposed to rotate about an axis **37**. Tracking system **34** is further shown to include a support arm **39** that is operatively connected to base element **36** in a manner that will be detailed more fully below. Support arm **39** includes a first end **42** that extends to a second end **43** through an arcuate intermediate portion **44**. Intermediate portion **44** is provided with a plurality of gear teeth **46** that are configured and disposed to cooperate with a corresponding gear element (not shown) provided within base element **36**. In this manner, support arm **39** shifts between first end **42** and second end **43** relative to base element **36**. That is, tracking system **34** includes at least one of an alt/azimuth and an elevation drive system that aims solar collection system **30** toward the sun's position in the sky at a given time and in a particular geographic area such as shown in FIG. **2**. More specifically, tracking system **34** rotates about axis **37** and shifts support arm **39** between first and second ends **42** and **43** to position reflector member **56** relative to the sun.

In accordance with an exemplary embodiment, reflector member **56** is mounted to first end **42** of support arm **39**. Reflector member **56** includes a plurality of reflector surfaces **58**-**60** that are arranged in a stepped configuration. In accordance with one exemplary embodiment, reflective surfaces

58-60 are flat to reduce cost. Reflective surfaces 58-60 fold the optical path such that the focus is within optically clear shell 10. The use of multiple reflective surfaces aids in correcting spherical aberration, however, it should be understood that reflector member 56 could also include a single reflector that is formed, for example, to have a flat circular construction. Of course, it should be understood that reflector 56 can take on a variety of forms. That is, reflector member 56 could include one or more planer mirrors, convex mirrors, and/or concave mirrors depending upon the level of solar concentration desired. In any event, solar rays passing through optically clear shell 10 impact reflector member 56. Reflector member 56 folds the rays back towards a solar receiver system 70 mounted at second end 43 of support arm 39.

As best shown in FIG. 3, solar receiver system 70 includes a heat sink 74 having a plurality of fins 76. A solar receiver 78 is mounted to heat sink 74 and is encapsulated by a clear shell 84. Clear shell 84 provides a seal that protects solar receiver from liquid 20. In accordance with one aspect of an exemplary embodiment, clear shell 84 is formed from a plastic encapsulant such as or epoxy. In accordance with another aspect of an exemplary embodiment, clear shell 84 is formed having multiple layers formed from materials such as glass, acrylic, silicone and plastic. Solar receiver 78 takes the form of a photovoltaic cell that is configured and disposed to convert light energy to electrical energy. With this arrangement, the solar rays folded back from reflector member 56 impinge upon solar receiver 78. More specifically, the distortion produced by passing light through a sphere would locate the focal point of the solar energy at a point outside hollow interior portion 18. Reflector member 56 corrects for the distortion by folding the light back to a focal point within hollow interior portion 18, i.e., upon solar receiver 78 as shown in FIG. 4. Solar receiver 78 in turn produces an electrical output. In accordance with an exemplary embodiment, reflector member 56 concentrates the solar energy passing though shell 10 to a level of about 2000 suns (200 watts/cm^2) or more of incident light. This level of solar concentration produces a significant amount of heat that must be dissipated. Towards that end, the heat developed by the concentrated solar rays impinging upon solar receiver 78 is dissipated by heat sink 74. Heat sink 74 initiates a convective cooling effect through liquid 20 to lower temperatures at solar receiver 78.

As further shown in FIG. 1, solar receiver 70 includes a light cup 94, or reflective optic, that is positioned across solar receiver 78. Light cup 94 collects any stray solar rays that are folded back from reflector member 56 towards solar receiver 78 in order to achieve even higher energy conversion efficiencies. In place of light cup 94, a light pipe, or refractive optic, (not shown) having a substantially cylindrical cross-section is employed to gather stray light. The use of light cup 94 (reflective optic) or a light pipe (not shown) (refractive optic) improves collection efficiency in the presence of optical distortions and tracking errors (improved acceptance angle). In addition to improving collection efficiency, light cup 94 and/or the light pipe homogenize the gathered light with respect to solar receiver 74.

The low cost per watt is further enhanced by tracking system 34. That is, tracking system 34 represents a near zero mass within liquid 20 which decreasing costs associated with moving the various optical components. In addition, liquid 20 serves as a dampener. More specifically, liquid 20 acts to dampen the motion of tracking system 34 thereby limiting oscillations of the collection components, e.g., reflector member 56 and solar receiver 78. By minimizing oscillations of the collection components, the need for complicated correction algorithms is avoided. The stepped configuration of reflector member 56 further aids in damping. Finally, the use of a passive, convective, cooling system eliminates the need to complicated and costly fluid circulation systems.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one ore more other features, integers, steps, operations, element components, and/or groups thereof.

The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiment was chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated

While the preferred embodiment to the invention has been described, it will be understood that those skilled in the art, both now and in the future, may make various improvements and enhancements which fall within the scope of the claims which follow. These claims should be construed to maintain the proper protection for the invention first described.

What is claimed is:

1. A method of concentrating solar energy, the method comprising:

receiving solar energy through a surface of an optically clear shell;

guiding the solar energy through a liquid substantially filling the optically clear shell;

folding the solar energy back through the liquid toward a solar receiver; and

orienting the solar receiver through a tracking system arranged entirely within the optically clear shell to track the sun, wherein the solar energy collected by the solar receiver is converted into electrical energy.

2. The method of claim 1, further comprising:

collecting stray solar energy in a light cup mounted to the solar receiver; and

passing the stray solar energy from the light cup to the solar receiver.

3. The method of claim 2, further comprising: focusing the solar energy on the solar receiver.

4. The method of claim 1, further comprising: dissipating heat energy from the solar energy through the liquid in the optically clear shell.

5. The method of claim 4, further comprising: dissipating heat energy from the solar energy through a heat sink mounted to the solar receiver.

6. The method of claim 1, further comprising: tracking the sun with one of an azimuth drive system and an elevation drive system.

7. The method of claim **1**, wherein folding the solar energy back through the liquid comprises reflecting the solar energy off a stepped mirror arranged within the optically clear shell.

8. The method of claim **7**, wherein reflecting the solar energy off the stepped mirror includes reflecting the solar energy off of a curvilinear reflective surface.

9. The method of claim **7**, wherein reflecting the solar energy off the stepped mirror includes reflecting the solar energy off of a plurality of reflective surfaces.

10. The method of claim **1**, wherein receiving solar energy through the surface of the optically clear shell includes passing the solar energy through at least one of an anti-fouling coating and an anti-reflective coating provided on the optically clear shell.

* * * * *