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**Guha et al.**

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(54) **METHOD OF CONCETRATING SOLAR ENERGY**

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

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This patent is subject to a terminal disclaimer.

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

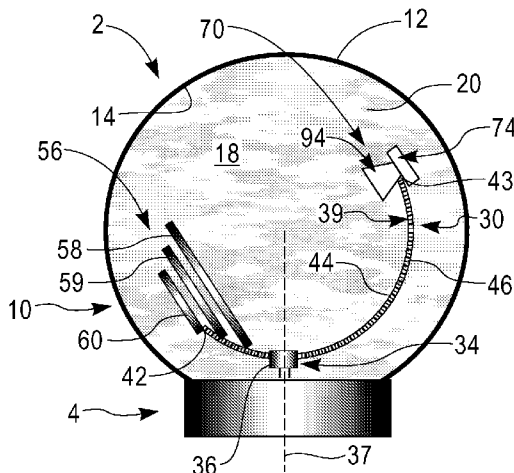
(57) **ABSTRACT**

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

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.

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

**10 Claims, 2 Drawing Sheets**



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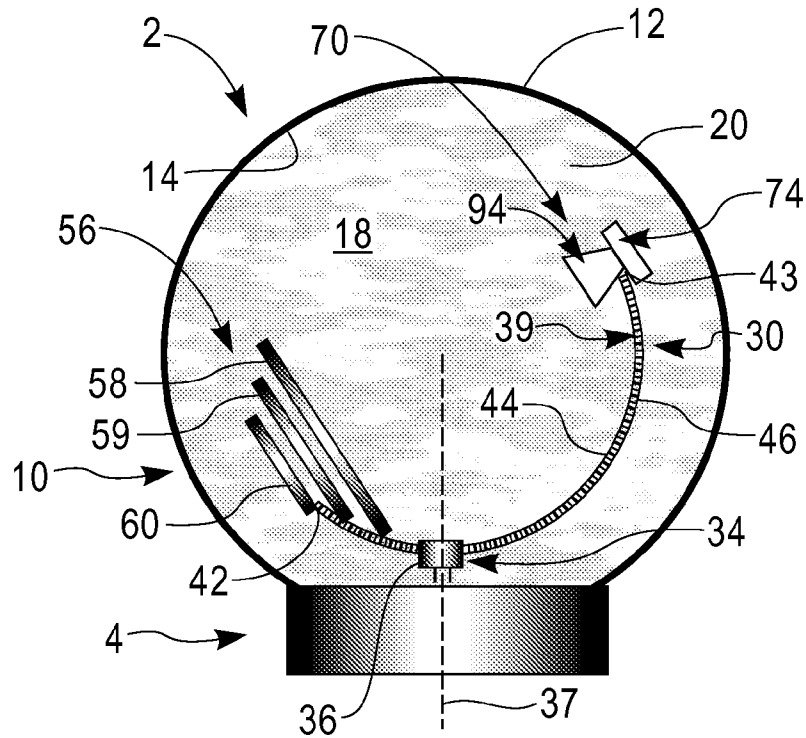


FIG. 1

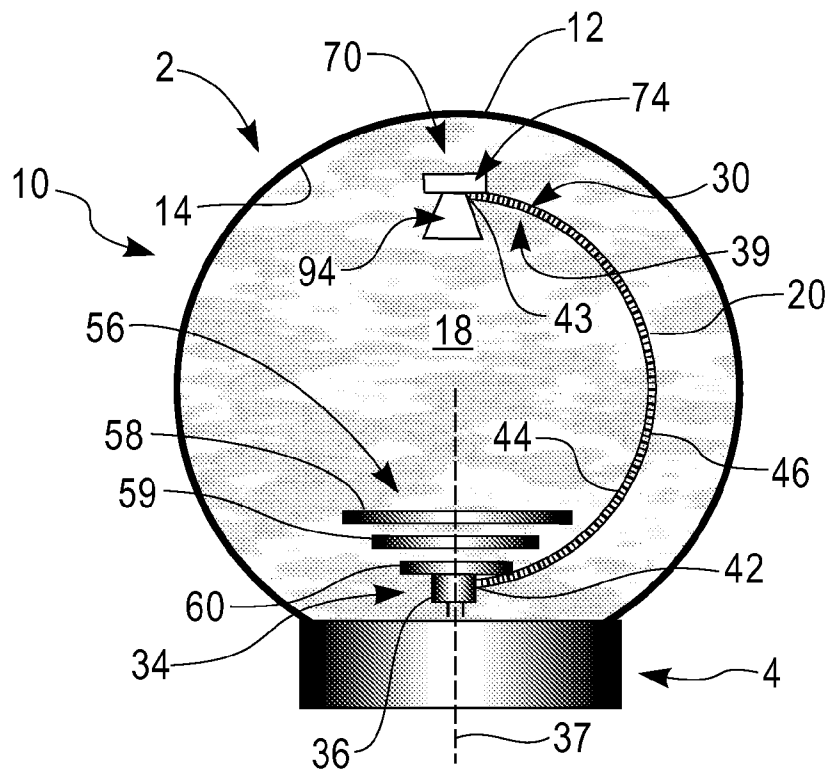


FIG. 2

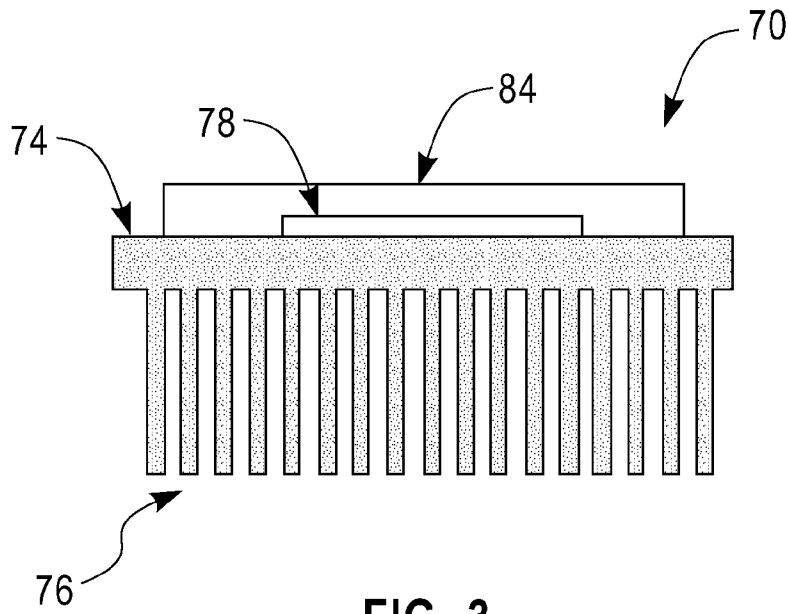


FIG. 3

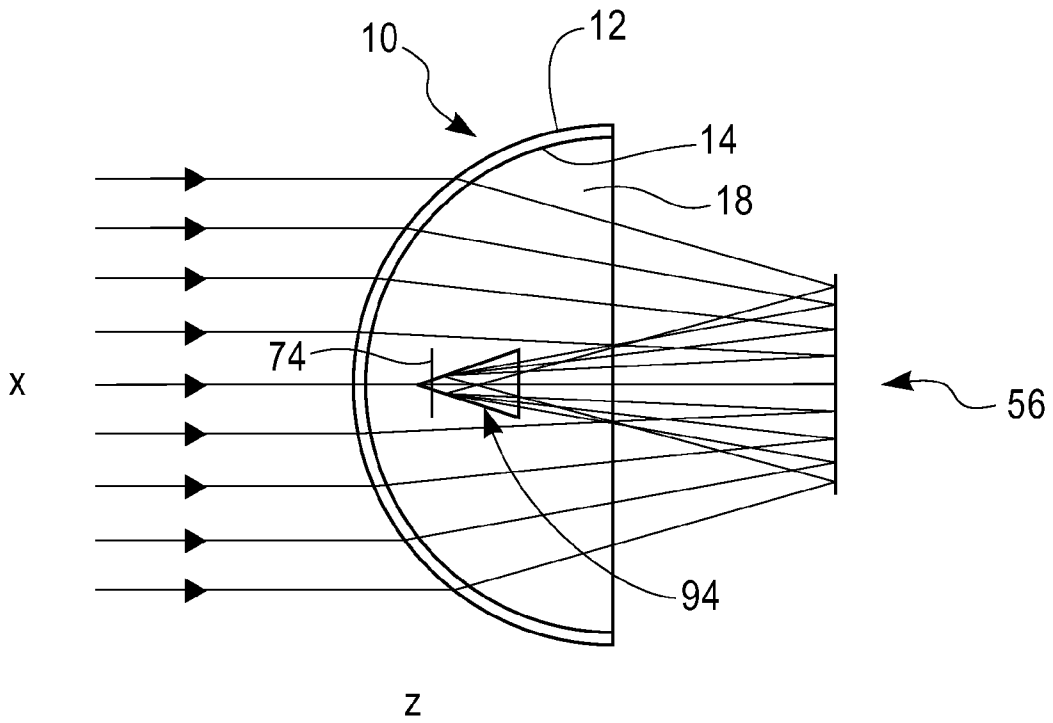


FIG. 4

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## METHOD OF CONCENTRATING 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

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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 through shell **10** to a level of about 2000 suns (200 watts/cm<sup>2</sup>) 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 or 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. 5

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. 10

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