

ELECTROMAGNETIC RADIATION COLLECTOR

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates generally to electromagnetic radiation collection.

5 Related Art

[0002] The collection and concentration of electromagnetic (EM) radiation is well known. Radio waves are typically collected and concentrated using parabolic dishes. Solar radiation is collected and concentrated using parabolic mirrors or lenses. The former devices suffer from requiring a relatively
10 high height-to-collection area ratio and the latter being expensive, heavy and fragile. Both these types of device also suffer from the requirement to track the source in order to function properly.

BRIEF SUMMARY OF THE INVENTION

[0003] The invention seeks to overcome at least some of the
15 deficiencies in the prior art by providing an EM radiation collection and concentration device which can cover a large area, have a low profile, have no requirement to track the source and be constructed so as to be relatively light and inexpensive.

[0004] There is a pressing need to be able to generate energy from
20 renewable energy sources. Solar energy is one such resource which has potential to be exploited. Conventional devices for collecting radiant energy to generate energy in a useful form suffer from a high capital cost and/or the inability to

generate high enough temperatures to be useful for many applications. The invention seeks to overcome these deficiencies in the prior art by providing a radiant energy concentration device that can gather energy from a relatively large area and concentrate it onto a small target area. The device is relatively inexpensive to produce, can be light in construction and has the potential to generate high target temperatures or, in the case of conversion to electricity by photovoltaic cells, require only a small area of cells, thus saving cost.

[0005] The invention is directed to a device that can cover relatively large collections areas at relatively low cost, does not necessarily require materials of particular refractive index, can be made of light construction and can concentrate the radiation onto a single target area.

[0006] The invention is capable of being less massive and having a lower profile than prior art concentration devices. It is also capable of having high concentration factors. It is suitable in any application where it is desired to collect and concentrate EM radiation, with particular utility in the collection and concentration of solar radiation. In the case of solar radiation, a device in accordance with the invention can be used in conjunction with photovoltaic cells or to heat a fluid to harness the solar energy for a desired purpose. In the case of radio frequency radiation, the subject device could be used to collect, focus and tune the radiation.

[0007] An example of the device has an assembly of channeling areas that are used to collect and concentrate the incident EM radiation. Also disclosed are methods for manufacturing the subject devices.

[0008] Particular embodiments of the invention provide an electromagnetic radiation collector having a concentration chamber for collecting and concentrating electromagnetic radiation and directing it to a target, the concentration chamber having at least one inlet opening, the inlet opening having
5 a cross-sectional area. The collector also has a channeling area having an entry end for receiving the electromagnetic radiation, the entry end having a cross-sectional area, an exit end adjacent to the inlet opening of the concentration chamber, and at least one reflective wall between the entry end and the exit end. The cross-sectional area of the inlet opening is smaller than the cross-sectional
10 area of the entry end of the channeling area.

[0009] Other embodiments of the invention provide a method of collecting electromagnetic radiation. The method includes channeling electromagnetic radiation in a channeling area, the channeling area having an entry end for receiving the electromagnetic radiation, an exit end, and at least one
15 reflective wall between the entry end and the exit end, the entry end having a cross-sectional area; collecting and concentrating the electromagnetic radiation in a concentration chamber, the concentration chamber having at least one inlet opening adjacent the exit end of the channeling area, the inlet opening having a cross-sectional area; and directing the collected and concentrated electromagnetic
20 radiation to a target. The cross-sectional area of the inlet opening is smaller than the cross-sectional area of the entry end of the channeling area.

[00010] Still other embodiments of the invention provide an electromagnetic radiation collector that has a tapering element having an entry end for receiving electromagnetic radiation, the entry end having a central axis along a

first direction, and a cross-sectional area perpendicular to the first direction; an exit end having a central axis along a second direction, and a cross-sectional area perpendicular to the second direction; and a wall connecting the entry end to the exit end, the wall being capable of channeling the electromagnetic radiation

5 received by the entry end to the exit end. The cross-sectional area of the entry end is larger than the cross-sectional area of the exit end, and the second direction is not parallel to the first direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[00011] The foregoing and other features and advantages of the

10 invention will be apparent from the following, more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings wherein like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements.

[00012] Figure 1 shows an example of a first embodiment of the

15 invention;

[00013] Figure 2 shows an example of a second embodiment of the invention;

[00014] Figure 3 shows an example of a third embodiment of the invention;

20 [00015] Figure 4 shows a cross-sectional view of fourth embodiment of the invention;

[00016] Figure 5 shows a cross-sectional view of fifth embodiment of the invention;

[00017] Figure 6 shows a sixth embodiment of the invention; and

[00018] Figure 7 shows a seventh embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[00019] An exemplary embodiment of the invention is shown in the
5 drawings and described herein.

[00020] An example of a device in accordance with the invention has an
assembly of channeling areas wherein the EM radiation can be internally reflected
within the channeling areas. The channeling areas are constructed such that at
least some of the EM radiation that enters a broad end of the channeling areas will
10 be steered within the channeling areas to exit a narrow end of the channeling areas
at a direction different to that which it entered. The broad ends of the channeling
areas are assembled to form a surface that is herein termed the collection surface.
EM radiation falls on the collection surface and enters the broad ends of the
channeling areas. The EM radiation is reflected from the walls of the channeling
15 areas so as to be directed to exit from the narrow end of the channeling areas.
This is achieved by ensuring that at each reflection point the angle of incidence of
the EM radiation to the reflecting surface is less than 90° . A method for ensuring
that this is the case for a wide arc of angles of the EM radiation incident on the
collection surface is to shape the channeling areas such that they are much longer
20 than they are broad at their broad end. This provides, in some embodiments, a
small angle of taper of the walls of the channeling area thus fulfilling the
reflection angle requirements for a broader range of incident EM radiation angles.
The ratio of length of the channeling area to the breadth of its broad end should

desirably be between 2 and 1000, more preferably between 5 and 100, and most preferably between 10 and 50. Figure 1 shows an example of a single channeling area and a typical path 20 that EM radiation might take within the area.

[00021] The channeling areas can be made of solid material that is capable of transmitting the EM radiation that is to be collected and concentrated and with walls that reflect the EM radiation back into the channeling area. In another embodiment of the invention, the channeling areas are formed as cavities, where the walls of the cavities are capable of reflecting the EM radiation back into the cavity.

10 [00022] In one embodiment of the invention, the narrow ends of an assembly of channeling areas are gathered together into an area that is smaller than the area of the broad ends of assembled channeling areas. In such an example, the EM radiation collected over the broad ends area is concentrated into the narrow ends area. An example of this embodiment is shown in Figure 2.

15 [00023] In a particular embodiment of the invention, the narrow ends of the channeling areas open into a concentration chamber which serves to further concentrate the radiation exiting from the narrow ends of the channeling areas. The narrow ends of the channeling areas open onto one face of the concentration chamber wherein the faces of the concentration chamber are capable of reflecting the EM radiation. At least one, and preferably only one, of the faces of the concentration chamber is transmissive to or absorptive of the EM radiation with all other faces being reflective of the EM radiation. The face of the concentration chamber that is transmissive or absorptive, termed herein the exit port, is the port
20 though which the concentrated EM radiation can exit the device or be absorbed

and utilized in the desired manner. In one embodiment, a target that utilizes the EM radiation is placed at the exit port. The narrow ends of the channeling areas opening into the concentration chamber are configured such that the EM radiation exiting the narrow ends of the channeling areas is directed toward the exit port, either directly or via one or more reflections from the reflective faces of the concentration chamber. An example of such a configuration is given in Figure 3, which shows a schematic cross-section of a portion of the device. In Figure 3, the device 100 has channeling areas 120 having broad ends 130 and narrow ends 140. A concentration chamber 200 has entry ports 210 and an exit port 220. Also shown in Figure 3 is an indicative path 22 that a beam of EM radiation might take through the device. In an alternative embodiment, the concentration chamber 200 may have an additional exit port 230 at its other end such that any EM radiation which is reflected toward that end of the concentration chamber could also be utilized. This could add somewhat to the cost of the device but could serve to increase its efficiency.

[00024] In order that the EM radiation entering the concentration chamber is directed toward the exit port, while also providing a device with a low profile, it is desirable to steer the EM radiation within the channeling areas such that the direction normal to the plane of the narrow end of the channeling areas different from the direction normal to the collection surface. One way to achieve this is to curve the channeling areas as shown, for example, in Figure 3. In a particular embodiment, the angle of curvature of the channeling areas is approximately equal along their length to enhance the manufacturability of the device, however this is not necessary for the device to function.

[00025] In some embodiments of the invention, the channeling areas are tapered in only one dimension, that is they take the form of tapered slots. In other embodiments, the channeling areas are tapered in two dimensions so that they take the form of tapered rods, where the rods can be of any cross-sectional shape that is suitable for packing together at high density. Examples of such shapes are circles, squares, rectangles, triangles and other multi-sided polygons.

[00026] When the channeling areas take the form of tapered rods, to aid in accommodating the curvature of the rods, maintain a high packing density for the broad ends of the channeling areas and enhance the strength of an assembly of the channeling areas, the channeling areas can be assembled such that each channeling area is staggered relative to its neighbors. In a particular embodiment of this aspect of the invention, rows of channeling areas are assembled such that the channeling areas in each row are offset from the row in front such that the narrow end of each channeling area is between the narrow ends of the neighboring channeling areas in the rows immediately in front of and behind the subject row. By assembling the channeling areas in this way it is possible for the narrow end of each channeling area to curve into the space between the neighboring channeling areas in the row in front of it. This allows the channeling areas to be curved while maintaining high packing density of the broad ends of the channeling areas.

[00027] It is desirable to maintain a high packing density of the broad ends of the channeling areas at the collecting surface so that the highest fraction of the EM radiation incident on the collecting surface enters a channeling area and is not reflected back.

[00028] In one embodiment of the invention, the channeling areas are

circular in cross-section and the broad ends are assembled in a packing arrangement as is shown in Figure 4, where a top view of the assembled rows of the broad ends of the circular channeling areas are shown offset from one another.

- 5 Triangles are superimposed on the view to show the relationship of the centers of the circular ends. This arrangement increases packing density and allows space for the channeling areas to be curved as disclosed above. With this arrangement, a maximum fraction of $\pi/2\sqrt{3}$ (approx. 90%) of the incident radiation is collected.

In a particular embodiment of this aspect of the invention, channeling areas with a
10 square or rectangular cross-section are used. A top view of this arrangement is shown in Figure 5. With this shape of channeling area, the broad ends of the channeling areas can be packed such that close to 100% of the incident radiation enters the channeling areas and is thus collected. Note that in the embodiment shown in Figure 5 it is possible, but not necessary, for the channeling areas to be
15 of rectangular cross-section down their full length. For example, the channeling areas may be square or rectangular at the collecting surface but then transition to a circular area as we move down the channeling area toward its tip.

[00029] Devices in accordance with the invention are useful in applications where EM radiation concentration devices have been used in the prior
20 art, in particular solar radiation and radio frequency radiation. Examples of such uses particularly relevant to the collection and concentration of solar radiation are to heat fluid circulating through a tube or pipe, to generate electricity directly using photovoltaic cells or to produce hydrogen from water. Note that the invention has particular utility in the application of producing electricity using

photovoltaic cells as it allows the light to be collected from an extended area using the relatively inexpensive device of the invention and concentrate it on to a relatively small area of the relatively expensive photovoltaic cells. This potentially allows electricity to be generated at lower capital cost. Also, this

5 device addresses deficiencies in the conventional art when attempting to use a concentrator with photovoltaic cells. Apart from expense and weight, the conventional devices suffer from relatively low concentration factors of typically less than 10 and the problem of the photovoltaic cells overheating and becoming less efficient. The invention can have high concentration factors. For example, for

10 a panel according to the embodiment shown in Figure 3 that is two meters long with an exit port normal to the axis of its length, running the full width of the panel and 2 mm high, the calculated concentration factor is 1000. Also, for an embodiment as shown in Figure 3, the photovoltaic cells would be placed adjacent to and facing the exit port, such that the back of the panel of photovoltaic cells is

15 in free space rather than against a surface such as a roof as would usually be the case in the conventional art. In this configuration, the back of the panel of photovoltaic cells is thus easily accessible to cooling means such as finned heat-sinks, pads onto which water could be dripped and evaporated by ambient air currents, or other cooling devices.

20 [00030] A low profile collector and concentrator is most desirable in applications for radio frequency (RF) radiation. In these applications, the device could be used to focus the RF radiation onto an RF receiver. Also, by careful choice of the dimensions of the channeling areas, the subject device could be used to tune the collected RF radiation to a frequency that can be received more easily

by a receiver. For example, the device can be used to tune the RF radiation to a higher frequency, which requires a smaller and more easily implemented receiver.

[00031] The subject devices can be made by any suitable method. The channeling areas can be solid elements transmissive of light and made from materials such as polymers or glass. For these solid elements, the walls of the elements can be coated with a reflective material or the refractive index of the material can be such that in most cases the incident angle of the EM to be reflected to the wall of the element exceeds the critical angle so that total internal reflection occurs. This embodiment has potential advantages in ease of fabrication but can also tend to be heavy. This embodiment could be constructed by manufacturing many elements and assembling them into arrays as disclosed above. The broad ends can be clamped or otherwise held together and, in the case of the embodiment shown in Figure 3, the narrow ends can be set so that they are mounted in and penetrate a plate that forms the upper surface of the concentration chamber.

[00032] A particular embodiment is one where the channeling areas are cavities formed in a monolithic block made of metal or polymer material. This may be somewhat harder to fabricate but will be lighter. A method of manufacturing this embodiment is to form an assembly of curved elements, for example tapered elements, from a malleable material such as copper or nickel. The assembly can be one of individual elements or of rows of elements formed into combs where each tapered element is a "tooth" of the comb. Each comb forms a row or portion of a row of the elements and the "teeth" of the combs of successive rows in the assembly are staggered to give the arrangements shown in

Figures 4 or 5. Before being assembled into an array, the elements can be straight or already curved. If the elements are straight, a bar can be passed over the assembly of the narrow ends of the elements as a convenient method of introducing the desired curvature. The assembled elements can be held in their assembly by being clamped into a frame or other similar device. The curved assembled elements, in conjunction with side walls and, if applicable, a top and/or base, can then be used as a mold for the final monolithic shape. The shape with the desired assembly of cavities can be molded by any applicable method. It may be cast by pouring polymer into the mold and letting it set or by injection molding techniques. In this process it is desirable to first coat the mold with a suitable release agent to facilitate removal of the mold elements from the cast shape. After the cast shape is set the mold elements can be removed. This can most easily be achieved by first removing the cast shape from the mold side walls, top and/or base then unclamping the assembly of elements and removing them separately or in groups as is most convenient and practical. Note that in most cases the elements will need to be straightened somewhat to be withdrawn from the cavities so it is desirable that the material from which the tapered elements are made be malleable so that it can undergo the straightening process without breaking or distorting the shape of the cavity from which it is being withdrawn. This process results in a cast shape that contains an assembly of densely packed curved, light guiding cavities, wherein the broad ends of the cavities all open onto one face of the shape and the narrow ends of the cavities all open on to a different face of the shape.

[00033] If the shape is not cast from an intrinsically reflective material such as metal or metal filled polymer, then the external faces of the shape and/or the walls of the cavities can be coated with a reflective layer. For polymer material this is most easily achieved with an electroless metal deposition process such as electroless chrome or nickel deposition. A further transparent coating could be applied over the reflective coating if desired to protect the reflective coating. The molded and coated shape can then be assembled into a collector and concentration device by mounting the shape in a box with a reflective internal base surface when the face of the shape into which the narrow ends open is spaced apart from the reflective base of the box. The base of the box and the lower face of the shape then form the top and base of the concentration chamber, where at the end of the box to which the narrow ends of the cavities are directed is the opening or transmissive portion which serves as the exit port. A sheet of transmissive material such as glass or clear polymer sheet can be placed over the assembled array of broad ends of the cavities that forms the collecting surface in order to facilitate cleaning and prevent dust, dirt or water from entering the cavities.

[00034] An alternative method for collecting the EM radiation to inject it into the concentration chamber is to use a series of mirrors that focus the light into a series of spots or slots in the top of the concentration chamber. In the case of a slot, the optimal mirror shape is parabolic in the plane of the slot and normal to it. In the case of spots, the mirror is optimally a parabolic dish. The slots or spots are arranged to be at the focal line or point of the mirror such that EM radiation reflected off the mirror is substantially concentrated into the openings in the top of the concentration chamber. To allow for different angles of EM

radiation incident on the mirrors, the mirrors can be rotated about their focal line or point such that the focus of the light remains co-incident with the openings in the concentration chamber. A control mechanism can perform the rotation whereby a signal, which could be the output from the EM radiation target or from
5 a separate sensor, is monitored and the rotation of the mirrors performed so as to maximize the amount of EM radiation impacting the target.

[00035] In another aspect of the invention, the concentration chamber can be designed so that the lower face of the concentration chamber slopes from the non-target end of the concentration chamber to the target end, with the slope
10 being such that the target end has a larger height than the non-target end. This assists in minimizing the number of reflections that are required in the concentration chamber before the EM radiation impinges on the target.

[00036] In another aspect, the openings in the top of the concentration chamber can be designed such that on the edge of the opening furthest from the
15 target a flap is attached that hangs down into the concentration chamber. This flap helps to deflect the EM radiation entering the concentration chamber to shallower angles such that it is more likely to impinge on the target with a reduced number of reflections in the concentration chamber and helps to prevent light that has entered the concentration chamber from being lost through the other openings in
20 the top of the concentration chamber. The openings in the top of the concentration chamber can be gaps in a solid element or alternatively they can be areas of an integral solid element that are transparent to the EM radiation, with other areas of the element being reflective of the EM radiation. For example, the top of the concentration chamber can be a glass or polymer sheet which is selectively coated

with a reflective coating in areas other than those forming the openings to the concentration chamber. In this embodiment, the flaps could still be flaps of material protruding into the concentration chamber or they could be formed as the back surface of a bulge in the top of the concentration chamber where the back
5 surface of the bulge is coated or otherwise made reflective, and the front surface (that closer to the target end of the concentration chamber) is transmissive of the EM radiation.

[00037] Figure 6 is a cross-section schematic which depicts these aspects. In this example, a device 300 has focusing mirrors 310, slots or spots 320
10 onto which the EM radiation is focused, flaps 340 on the back edge of the slots or spots 320, a target 350 for the EM radiation and a sloped lower face 360 of the concentration chamber 330 that helps to direct the EM radiation toward the target 350. In order to allow for different incident angles of EM radiation onto the mirrors 310, the mirrors 310 can be made to rotate around their focal points or
15 focal lines. Alternatively, the whole device can be rotated such that the EM radiation presents a constant incident angle to the mirrors 310 or a combination of rotation of the whole device with rotation of the individual mirrors 310.

[00038] A potential limitation of the embodiment shown in Figure 6 is that the rotation of the parabolic mirrors in an counter-clockwise direction (as
20 drawn in Figure 6) can be limited if the bottom of the mirrors collide with the top of the concentration chamber. The effect of this limitation is that the range of angles of light incident on the parabolic mirrors can be limited. Specifically, in some configurations light at some angle greater than normal to the plane of the mirror tops cannot be focused onto the entry points to the concentration chamber

as it cannot be made to intersect with the concave parabolic surface of a mirror.

To overcome, or at least ameliorate this limitation, the back surface of the mirror structures can be formed so as to reflect light incident at angles past the normal onto the concave surface of the parabolic mirror behind it at the correct angle such

5 that the light is then focused onto an entry point to the concentration chamber. In

this aspect, the back surface is preferably a flat mirror, at least over the portion upon which light incident at the past normal angles to be focused impinges. That is, the required portion of the back reflective surface of the mirror structure is at a constant angle relative to the incident light angle. The mirror structures can be

10 rotated in a clockwise direction (as drawn in Figure 6) to ensure that light at different incident angles past the normal are focused onto an entry point to the concentration chamber, once they have been reflected from the concave parabolic surface of the preceding mirror structure. In an alternate embodiment, to ameliorate this limitation the parabolic mirrors can be placed closer together, thus

15 decreasing somewhat the cross-section of the entry area for each channel. This allows the base of the parabolic mirrors to be raised, so as to increase the gap between the base of the parabolic mirror and the top of the concentration chamber, while still ensuring that all EM radiation that enters the channelling area through the entry area impinges on the concave surface of the parabolic mirror. The

20 increased gap between the base of the parabolic mirrors and the top of the concentration chamber allows the mirrors to be rotated further in a counter-clockwise direction (as drawn in Figures 5 and 6) such that a larger range of angles of radiation incident on the entry to the channelling area can be directed toward the exit of the channelling area.

- [00039] Figure 7 is a cross-section schematic which shows such a variation of the example shown in Figure 6. In this variation, focusing mirror 310 that have a back side adjacent to a slot or spot 320, have a rear reflecting surface 370 that reflects EM radiation (an example of which is depicted by light ray 400) onto one of the focusing mirrors 310. Reflecting surfaces 370 can increase the amount of EM radiation that eventually gets directed into slots or spots 320. Similarly, the upper outside surfaces of concentration chamber 330 can be shaped to reflect EM radiation onto reflecting surfaces 370 and/or focusing mirrors 310 in order to capture even more EM radiation.
- 10 [00040] The invention is not limited to the above-described exemplary embodiments. It will be apparent, based on this disclosure, to one of ordinary skill in the art that many changes and modifications can be made to the invention without departing from the spirit and scope thereof.

CLAIMS

1. An electromagnetic radiation concentrator system comprising:

a plurality of parabolic reflective louvers, the louvers being arranged in a parallel array, wherein each louver is positioned to reflect and concentrate incoming radiation to at least one receiving element positioned to receive the concentrated radiation.
2. The system of Claim 1, each louver having a concave front face, wherein the front faces are oriented in a same direction.
3. The system of Claim 1, wherein the electromagnetic radiation comprises light.
4. The system of Claim 1, wherein the receiving element is an opening into a concentration chamber.
5. The system of Claim 1, each of the louvers having a focal line, wherein the louvers are configured such that each louver is rotatable about its own focal line.
6. The system of Claim 5, wherein rotation of the louvers is coordinated.
7. The system of Claim 6, wherein rotation of the louvers is adapted to permit concentration of the radiation at the collector during a period of time in which a source of the radiation is in motion with respect to the concentrator system.
8. An electromagnetic radiation concentrator system comprising:

a plurality of tapered reflective channels arranged in an array to capture and concentrate incoming electromagnetic radiation, wherein each channel comprises an inlet, an outlet, a transit length, and a reflective inner surface, wherein the transit length is at least five times as great as a breadth of the inlet, and wherein each channel is curved along its transit length such that the outlets of the channels converge in an area smaller than an area of an equal number of inlets, such that the convergence of the outlets causes that no incoming radiation can exit the concentrator system without being reflected at least once along the transit length, and wherein radiation exiting the outlet is concentrated as compared with radiation entering the inlet.