

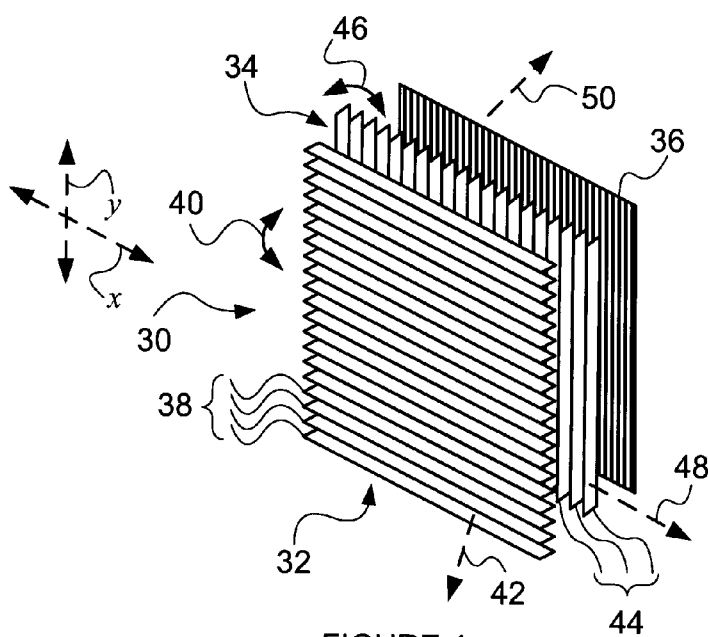


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- (71) Applicant (for all designated States except US): **THE UNIVERSITY OF BRITISH COLUMBIA** [CA/CA];  
c/o Industry Liaison Office, 103 - 6190 Agronomy Road,  
Vancouver, British Columbia V6T 1Z3 (CA).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **WHITEHEAD, Lorne A.** [CA/CA]; 2690 Balaclava Street, Vancouver, British Columbia V6K 4E2 (CA).
- (74) Agent: **WIGGS, Blake R.**; Oyen Wiggs Green & Mutala LLP, Suite 480 - The Station 601 West Cordova Street, Vancouver, British Columbia V6B 1G1 (CA).

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(54) Title: SUNLIGHT REDIRECTING MIRROR ARRAYS



(57) Abstract: Sunlight redirector (30) incorporates closely proximate mirror arrays (32, 34) having parallel, uniformly spaced, longitudinal mirror segments (38, 44). Prismatic sheet (36) is positioned behind and closely proximate second array (34). Segments (38) extend in first direction (x). Segments (44) extend in second direction (y) perpendicular to direction (x). Segments (38, 44) have normal vectors (42, 48). Segments (38) are interconnected for simultaneous pivotal movement (40), such that their normal vectors (42) remain parallel. Segments (44) are interconnected for simultaneous pivotal movement (46), such that their normal vectors (48) remain parallel. Arrays (32, 34) redirect incident light toward sheet (36), which redirects the light into a desired fixed direction, e.g. parallel to the sunlight redirector's normal vector (50). Segments (38, 44) may have inward and outward segments (60A, 60B) which can be adjustably positioned to maximize redirection of incident sunlight rays in a desired direction.



## SUNLIGHT REDIRECTING MIRROR ARRAYS

### Reference to Related Application

5 [0001] This application claims the benefit of United States provisional patent application serial no. 61/551,050 filed 25 October 2011.

### Technical Field

[0002] This disclosure pertains to mechanisms for redirecting light, particularly sunlight.

10

### Background

[0003] WO 2009/000070, which is incorporated herein by reference, describes a sunlight redirector in which longitudinally adjacent plane mirrors are pivotally interconnected by non-stretching linkages to form a columnar array (see Figure 1 hereof). The non-stretching linkages constrain movement of the mirrors such that their normal vectors remain parallel. Pivotal couplings (not shown in Figure 1 hereof, but see WO 2009/000070) permit movement of the mirrors with respect to two mutually perpendicular axes and prevent movement of the mirrors with respect to a third axis which is perpendicular to the other two axes. Actuators (not shown in Figure 1 hereof, but see WO 2009/000070) controllably move the mirrors to orient their normal vectors such that the mirrors reflect incident light in a desired direction. The actuators can be adaptively controlled to move the mirrors to track the sun, and thereby continually redirect sunlight into a specific direction, e.g. through a wall opening to illuminate the interior of a building.

[0004] Such mirror arrays are useful in building core daylight illumination systems, as explained in WO 2009/000070. It is desirable that such mirror arrays be thin, to facilitate mounting the arrays on or within building walls. A thin mirror array can be formed from a large number of small mirrors. However, a disadvantage of this approach is that the required number of mirrors increases in inverse proportion to the square of the thickness of the array, potentially prohibitively increasing the

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cost of constructing a suitably thin array. This disclosure addresses that disadvantage.

**[0005]** The foregoing examples of the related art and limitations related thereto are intended to be illustrative and not exclusive. Other  
5 limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

#### Brief Description of Drawings

**[0006]** Exemplary embodiments are illustrated in referenced figures  
10 of the drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

**[0007]** Figure 1 isometrically and schematically depicts a prior art mirror array as disclosed in WO 2009/000070.

**[0008]** Figure 2 is a front elevation depiction of a circularly rotatable  
15 mirror array having a plurality of longitudinal, pivotable mirrors.

**[0009]** Figures 3A, 3B and 3C are side elevation schematic depic-  
tions of several interconnected longitudinal mirror segments, respectively  
depicting positioning of the segments to achieve small, intermediate and  
large angular redirection of incident light rays.

**[0010]** Figure 4 isometrically depicts a rectangular mirror array  
20 having a first plurality of longitudinal, pivotable mirrors, a second plural-  
ity of longitudinal, pivotable mirrors which extend substantially perpendic-  
ular to the first plurality mirrors, and a prismatic sheet.

**[0011]** Figures 5A, 5B, 5C and 5D are side elevation schematic  
25 depictions of four pairs of longitudinal mirror segments; Figure 5A  
depicting substantially parallel alignment of the segments in each pair;  
Figure 5B depicting alignment of one segment in each pair in a direction  
substantially parallel to a dominant direction of incident sunlight rays;  
Figure 5C depicting alignment of the outward segments to direct incident  
30 light onto adjacent inward segments; and Figure 5D depicting alignment of  
the inward segments to direct incident light onto adjacent outward seg-  
ments.

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Description

**[0012]** Throughout the following description specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure.

Accordingly, the description and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

**[0013]** Figure 2 depicts a sunlight redirector 10 having a plurality of substantially parallel, uniformly spaced, longitudinal mirror segments 12. Segments 12 are interconnected (not shown) in a manner similar to that used to interconnect Venetian blind slats. A controller (not shown) coupled to one or more of segments 12 can be selectably actuated to simultaneously pivot all of segments 12, as indicated by double-headed arrow 14. Segments 12 can thus be pivotally adjusted, in the manner of a Venetian blind, such that their respective normal vectors 16 remain parallel. Segments 12 are of differing lengths, and are arranged such that sunlight redirector 10 has a circular front elevational shape as seen in Figure 2. Sunlight redirector 10 is rotatable about its normal vector 18, as indicated by double-headed arrow 20.

**[0014]** Sunlight redirector 10 can thus be rotated to track the sun's azimuthal motion relative to the array's normal vector 18, and segments 12 can be pivotally adjusted to compensate for changes in the sun's altitude, so that light rays reflected by segments 12 will be redirected in a desired, fixed direction, e.g. substantially parallel to normal vector 18 to facilitate redirection of light rays through a wall opening to illuminate the interior of a building.

**[0015]** Figures 3A, 3B and 3C illustrate a potential disadvantage of using sunlight redirector 10's segments 12 to redirect light—redirection efficiency depends on the desired redirection angle. Figure 3A depicts a small redirection angle situation in which the mirror segments (represented by solid lines) are nearly parallel to the incident light, so most rays (repre-

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sented by dashed lines) do not strike the mirrors and are therefore not redirected as desired. Figure 3B depicts an intermediate situation in which the mirror segments are obliquely angled relative to the incident light, with most rays striking the mirrors and being redirected as desired. Figure 3C depicts a situation in which the desired redirection angle is so large that the mirror segments are positioned at such a large oblique angle relative to the incident light that most rays which strike the mirrors are redirected onto an adjacent mirror, then further redirected away from the desired direction. The Figure 3A and 3C situations are problematic since it is desirable to redirect rays corresponding to a wide range of sun angles.

**[0016]** Another potential disadvantage of sunlight redirector 10 is possible increased complexity and cost in rotatably moving sunlight redirector 10 about normal vector 18. Figure 4 depicts a stationary sunlight redirector 30 which addresses the foregoing potential disadvantages.

**[0017]** Stationary sunlight redirector 30 has a first mirror array 32, a second mirror array 34 and a prismatic sheet 36. First mirror array 32 is formed of a first plurality of substantially parallel, uniformly spaced, longitudinal mirror segments 38. Segments 38 are mirrored on either one or both sides, depending on the expected range of directions of the incident sunlight; and are interconnected (not shown) in a manner similar to that used to interconnect Venetian blind slats. A controller (not shown) coupled to one or more of segments 38 can be selectably actuated to simultaneously pivot all of segments 38, as indicated by double-headed arrow 40. Segments 38 can thus be pivotally adjusted, in the manner of a Venetian blind, such that their respective normal vectors 42 remain parallel. Segments 38 are of equal lengths, and are arranged such that first mirror array 32 has a rectangular front elevational shape as seen in Figure 4.

**[0018]** Second mirror array 34 is formed of a second plurality of substantially parallel, uniformly spaced, longitudinal mirror segments 44. Segments 44 are mirrored on either one or both sides, depending on the expected range of directions of the incident sunlight; and are intercon-

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5 nected (not shown) in a manner similar to that used to interconnect Venetian blind slats. A controller (not shown) coupled to one or more of segments 44 can be selectably actuated to simultaneously pivot all of segments 44, as indicated by double-headed arrow 46. Segments 44 can thus be pivotally adjusted, in the manner of a Venetian blind, such that their respective normal vectors 48 remain parallel. Segments 44 are of substantially equal lengths, and are arranged such that second mirror array 34 has a rectangular front elevational shape as seen in Figure 4.

10 **[0019]** First mirror array 32 is positioned in front of and in close proximity to second mirror array 34 with mirror segments 38 extending in a first direction  $x$ , and mirror segments 44 extending in a second direction  $y$  which is substantially perpendicular to the first direction  $x$ . Prismatic sheet 36 is positioned behind and in close proximity to second mirror array 34.

15 **[0020]** First mirror array 32 can be pivotally adjusted to compensate for changes in the sun's altitude such that light rays reflected by segments 38 are redirected in a desired, fixed direction, e.g. toward prismatic sheet 36. Second mirror array 34 can be pivotally adjusted to compensate for changes in the sun's azimuth such that light rays reflected by segments 44 are also redirected in a desired, fixed direction, e.g. toward prismatic sheet 36.

20 **[0021]** Light rays redirected toward prismatic sheet 36 by either of first or second mirror arrays 32, 34 are refracted (i.e. redirected) by prismatic sheet 36 into a final desired fixed direction substantially parallel to the normal vector 50 of sunlight redirector 30. For example, the final desired fixed direction can be such that the rays are redirected through a wall opening to illuminate the interior of a building. Light rays redirected by first and second mirror arrays 32, 34 are efficiently redirected by prismatic sheet 36. Neither first mirror array 32 alone, nor second mirror array 34 alone, will efficiently redirect sunlight rays in situations where very little redirection is required. This corresponds to the disadvantage depicted in Figure 3A. Prismatic sheet 36 compensates by imparting further substantial redirection of the light rays in such situations, thus

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improving efficiency. For example, without prismatic sheet 36, sunlight redirection efficiency of an array mounted on a south wall would be very low while the sun is due south.

[0022] The side of prismatic sheet 36 facing toward second mirror array 34 may be flat. The opposite side of prismatic sheet 36 may bear a large plurality of vertically extending  $70^\circ$  internal whole angle isosceles triangle prisms. Sheet 36 can be formed of a transparent polymeric material such as polycarbonate (PC), polyethyleneterephthalate (PET), polymethyl methacrylate (PMMA), or a combination of PC, PET and/or PMMA. 2370 optical lighting film available from 3M, St. Paul, MN can be used to form sheet 36. The precise angle and size of the film's prisms is not highly critical—generally the desired characteristic is that light rays that are oriented roughly  $30^\circ$  (between  $10^\circ$  and  $50^\circ$ ) to the left or to the right of perpendicular will be efficiently refracted by the film into a direction which is substantially perpendicular to the macroscopic plane of sheet 36. Consequently, light rays redirected by first and second mirror arrays 32, 34 do not need to be perpendicular to sunlight redirector 30 as a whole—which in any case is a difficult constraint to satisfy at times near solar noon.

[0023] Although sheet 36 improves sunlight redirector 30's efficiency for problematic sun angles (e.g. at times near solar noon), it may not satisfactorily accommodate all desired light redirection angles. Furthermore, light refracted through sheet 36 may be redirected in slightly different directions, depending on the wavelength of the incident light. These disadvantages can be circumvented as discussed below in relation to Figures 5A—5D.

[0024] Figures 5A—5D each depict four pairs of longitudinal inward/outward mirror segments 60A, 60B; 62A, 62B; 64A, 64B; and 66A, 66B (represented by solid lines). Each mirror segment 12 in sunlight redirector 10 may be one such pair of inward/outward segments. Similarly, each mirror segment 38 and/or each mirror segment 44 in sunlight redirector 30 may be one such pair of inward/outward segments. Mirror

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segments 60A, 60B; 62A, 62B; 64A, 64B; and 66A, 66B are mirrored on both sides.

**[0025]** Outward segments 60B, 62B, 64B and 66B are adjustable with respect to inward segments 60A, 62A, 64A and 66A respectively. Figure 5A depicts adjustment to align the inward and outward segments in each pair substantially parallel to one another. Figure 5B depicts adjustment of the segments to align the outward segment in each pair in a direction which is substantially parallel to the dominant direction of incident sunlight rays (depicted as dashed arrows in Figures 5A—5D). Figure 5C depicts adjustment of the segments such that incident light rays are first reflected by the outward segments onto the adjacent inward segments, then further reflected in the desired direction by the inward segments. Figure 5D depicts adjustment of the segments such that incident light rays are first reflected by the inward segments onto the adjacent outward segments, then further reflected in the desired direction by the outward segments.

**[0026]** The different segment adjustment configurations depicted in Figures 5A—5D yield different light redirection efficiencies which depend on factors such as the segments' sizes and the incident light angle. The segments can be automatically selectably adjusted by a suitable control system to adopt any of the depicted adjustment configurations (or any desired intermediate adjustment configuration) in order to maximize light redirection efficiency at different times. Generally, the best choice at any particular time will be the adjustment configuration that minimizes total loss of useful light rays (i.e. light rays which pass through the sunlight redirector without being redirected are "lost" in the sense that they are not redirected into the desired direction). In all cases, the inward/outward mirror segments are adjustably positioned taking into account both the sunlight incidence angle and the desired direction into which the light rays are to be redirected. The required mirror segment positions can be readily determined for any selected sunlight incidence angle by well known ray trace analysis techniques. The so-determined mirror segment position data can be stored in a look-up table or emulated in various forms of open loop mathematical algorithms or feed-back-based closed loop algorithms, or

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some combination thereof. Such look-up table and algorithmic techniques are well known to persons skilled in the art. In some cases, the Figure 4 stationary sunlight redirector 30 can be formed without prismatic sheet 36, if mirror segments 38 and/or 44 are suitably formed of inward/outward  
5 segments as aforesaid.

**[0027]** The scope of the claims should not be limited by the preferred embodiments set forth herein, but should be given the broadest interpretation consistent with the description as a whole.

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## WHAT IS CLAIMED IS:

1. A sunlight redirector (10), comprising:  
a plurality of substantially parallel, uniformly spaced, longitudinal  
5 mirror segments (12);  
each one of the mirror segments having a normal vector (16);  
wherein the mirror segments are interconnected for simultaneous  
pivotal movement (14) of the segments, such that the mirror  
segments' normal vectors remain parallel; and  
10 the mirror array is rotatable (20) about a normal vector (18) of the  
array.
2. A sunlight redirector (10) as defined in claim 1, wherein:  
the mirror segments (12) are of differing lengths, and are arranged  
15 such that the mirror array is circular.
3. A sunlight redirector (10) as defined in claim 1, wherein the mirror  
segments (12) redirect incident light rays into a desired fixed  
direction substantially parallel to a normal vector of the sunlight  
20 redirector.
4. A sunlight redirector (30), comprising:  
a first mirror array (32) having a first plurality of substantially  
parallel, uniformly spaced, longitudinal mirror segments (38);  
25 a second mirror array (34) having a second plurality of substantially  
parallel, uniformly spaced, longitudinal mirror segments (44);  
and  
a prismatic sheet (36);  
wherein:  
30 the first mirror array (32) is positioned in front of and in close  
proximity to the second mirror array (34);  
the prismatic sheet (36) is positioned behind and in close  
proximity to the second mirror array (34);

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the first plurality of mirror segments (38) extend in a first direction (x); and

the second plurality of mirror segments (44) extend in a second direction (y) substantially perpendicular to the first direction (x).

5

5. A sunlight redirector (30) as defined in claim 4, wherein:  
each one of the first plurality of mirror segments (38) has a normal vector (42);

10 each one of the second plurality of mirror segments (44) has a normal vector (48);

the first plurality mirror segments (38) are interconnected for simultaneous pivotal movement (40) of the first plurality segments, such that the normal vectors (42) of the first plurality mirror segments remain parallel; and

15

the second plurality mirror segments (44) are interconnected for simultaneous pivotal movement (46) of the second plurality segments, such that the normal vectors (48) of the second plurality mirror segments remain parallel.

20

6. A sunlight redirector (30) as defined in claim 5, wherein:  
the first plurality mirror segments (38) are of substantially equal length and are arranged such that the first mirror array (32) is rectangular; and

25 the second plurality mirror segments (44) are of substantially equal length and are arranged such that the second mirror array (34) is rectangular.

7. A sunlight redirector (30) as defined in as defined in any one of claims 4-6, wherein:  
the first mirror array (32) redirects incident light rays toward the prismatic sheet (36);

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- the second mirror array (34) redirects incident light rays toward the prismatic sheet (36); and  
the prismatic sheet (36) redirects light rays into a desired fixed direction substantially parallel to a normal vector (50) of the  
5 sunlight redirector.
8. A sunlight redirector (30) as defined in claim 7, wherein the prismatic sheet (36):  
has a flat side facing toward the second mirror array (34); and  
10 has an opposite side bearing a large plurality of vertically extending 70° internal whole angle isosceles triangle prisms.
9. A sunlight redirector (30) as defined in claim 7, wherein the prismatic sheet (36) is formed of a transparent polymeric material  
15 such as polycarbonate (PC), polyethyleneterephthalate (PET), polymethyl methacrylate (PMMA), or a combination of PC, PET and/or PMMA.
10. A sunlight redirector (10; 30) as defined in as defined in any one of the preceding claims, wherein:  
20 at least some of the mirror segments (12; 38, 44) each further comprise an inward mirror segment (60A, 62A, 64A, 66A) and an outward mirror segment (60B, 62B, 64B, 66B); and the inward and outward mirror segments are adjustably positionable  
25 to maximize redirection of incident sunlight rays in a desired direction.
11. A sunlight redirector (30) as defined in claim 5, wherein:  
30 each one of the first plurality of mirror segments (38) further comprises an inward mirror segment (60A) and an outward mirror segment (60B);

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each one of the second plurality of mirror segments (44) further comprises an inward mirror segment (60A) and an outward mirror segment (60B);

each one of the outward mirror segments (60B) is adjustable  
5 between:

a first position in which each one of the outward mirror segments is substantially parallel to a corresponding one of the outward mirror segments; and

10 a second position in which each one of the outward mirror segments is substantially parallel to an incident sunlight direction.

12. A sunlight redirector (30), comprising:

15 a first mirror array (32) having a first plurality of substantially parallel, uniformly spaced, longitudinal mirror segments (38); and

a second mirror array (34) having a second plurality of substantially parallel, uniformly spaced, longitudinal mirror segments (44);  
wherein:

20 the first mirror array (32) is positioned in front of and in close proximity to the second mirror array (34);

the first plurality of mirror segments (38) extend in a first direction ( $x$ );

25 the second plurality of mirror segments (44) extend in a second direction ( $y$ ) substantially perpendicular to the first direction;

at least some of the mirror segments (38, 44) each further comprise an inward mirror segment (60A) and an outward mirror segment (60B); and

30 the inward and outward mirror segments (60A, 60B) are adjustably positionable to maximize redirection of incident sunlight rays in a desired direction.

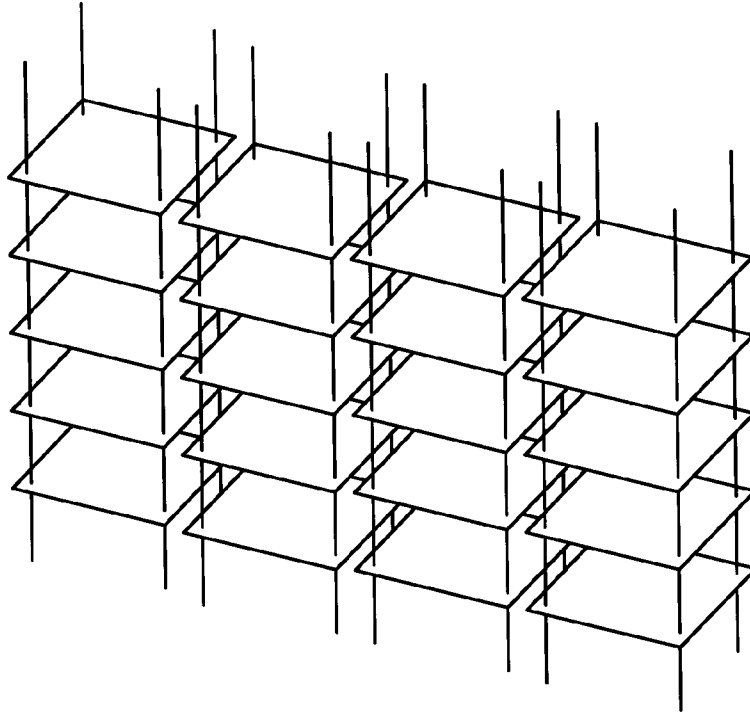


FIGURE 1 (PRIOR ART)

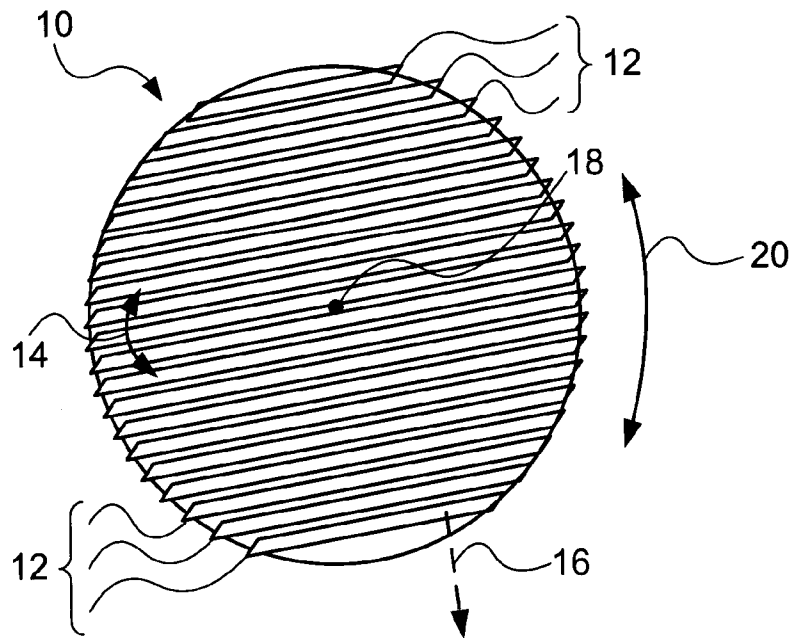


FIGURE 2

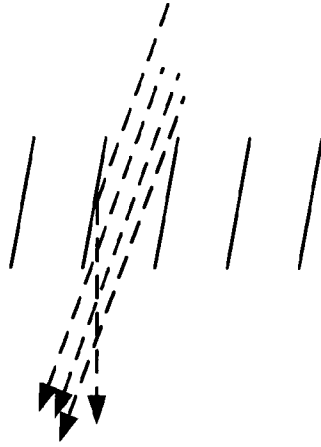


FIGURE 3A

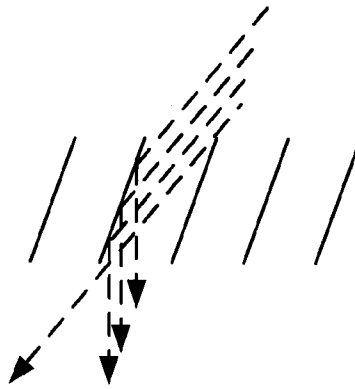


FIGURE 3B

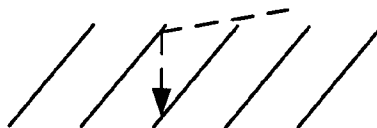


FIGURE 3C

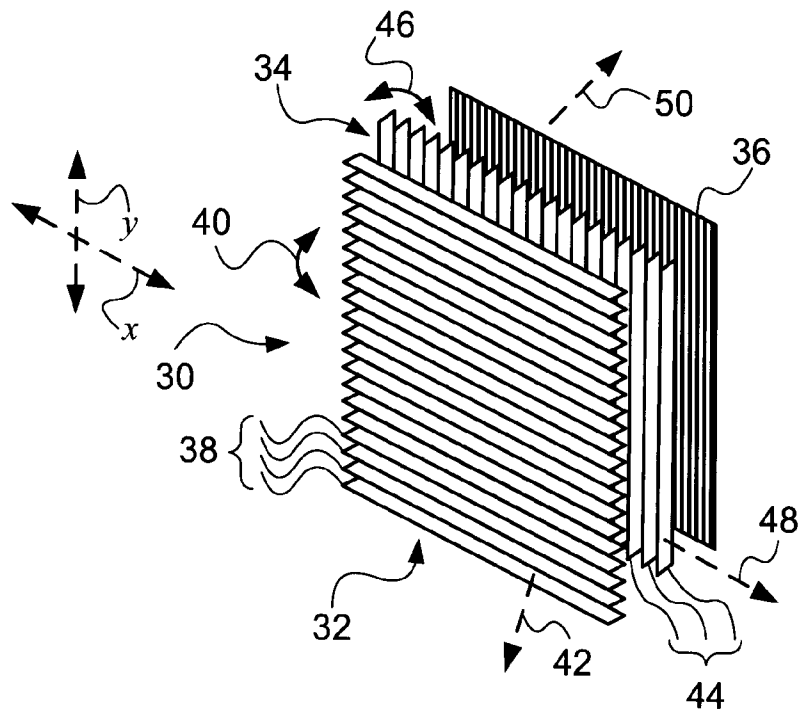


FIGURE 4

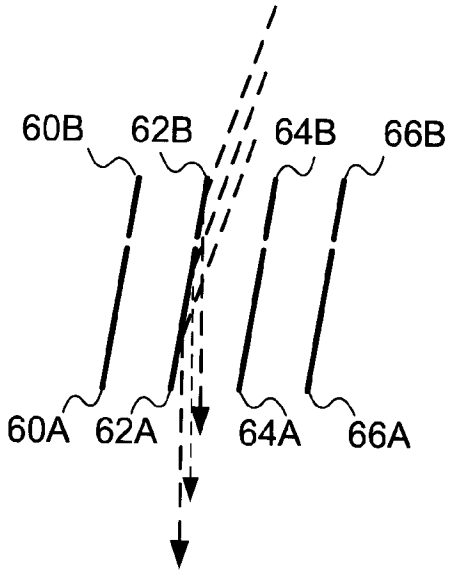


FIGURE 5A

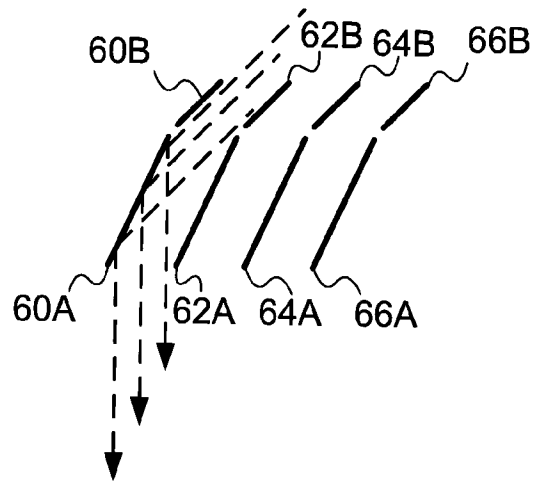


FIGURE 5B

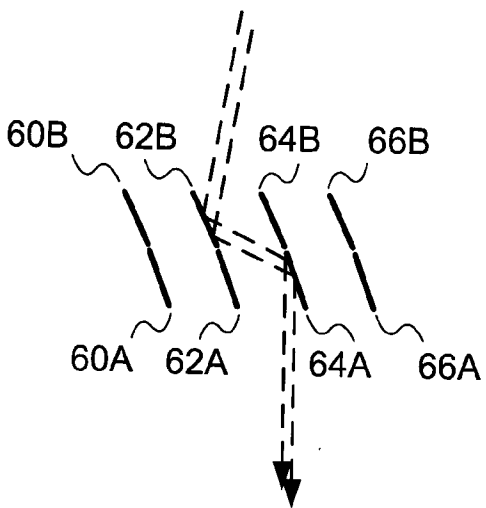


FIGURE 5C

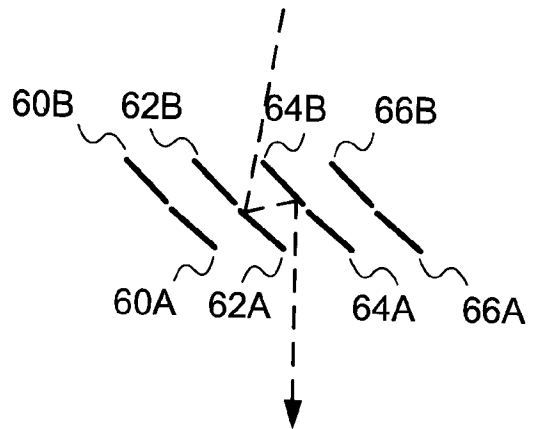


FIGURE 5D

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/CA2012/000854

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC: **F21S 11/00** (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)  
 IPC: **F21S 11/00** (2006.01)  
 According to International Patent Classification (IPC) or to both national classification and IPC

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)  
 Canadian Patents Database, Epodoc  
 Keywords: Prism, mirror, array, parallel, rotate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO2011/012301 (BARTENBACH) 3 February 2011 (03-02-2011)	1-3 and 10

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

* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 06 December 2012 (06-12-2012)	Date of mailing of the international search report 17 January 2013 (17-01-2013)
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Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Authorized officer <b>Simon Webster (819) 956-6135</b>
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.  
**PCT/CA2012/000854**

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO2011012301A1	03 February 2011 (03-02-2011)	DE102009039136A1 EA201200221A1 EP2470826A1 KR20120065324A US2012126098A1	03 February 2011 (03-02-2011) 30 August 2012 (30-08-2012) 04 July 2012 (04-07-2012) 20 June 2012 (20-06-2012) 24 May 2012 (24-05-2012)