



(51) International Patent Classification:

F24J 2/05 (2006.01) *F24J 2/24* (2006.01)
F16L 9/10 (2006.01) *F24J 2/26* (2006.01)
F16L 51/02 (2006.01)

(21) International Application Number:

PCT/US2017/043834

(22) International Filing Date:

26 July 2017 (26.07.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/366,796 26 July 2016 (26.07.2016) US

(71) Applicant: **THE TRUSTEES OF COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK**
[US/US]; 412 Low Memorial Library, 535 West 116th Street, New York, NY 10027 (US).

(72) Inventor: **CHEN, Julian, Chengjun**; 19 Denim Place, White Plains, NY 10603 (US).

(74) Agent: **GANGEMI, Anthony, P.**; Murtha Cullina LLP, One Century Tower, 265 Church Street, New Haven, CT 06510 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH,

(54) Title: PARTIAL ABSORPTION COATING FOR ALL-GLASS BOTTOMLESS SOLAR THERMAL ENERGY COLLECTORS

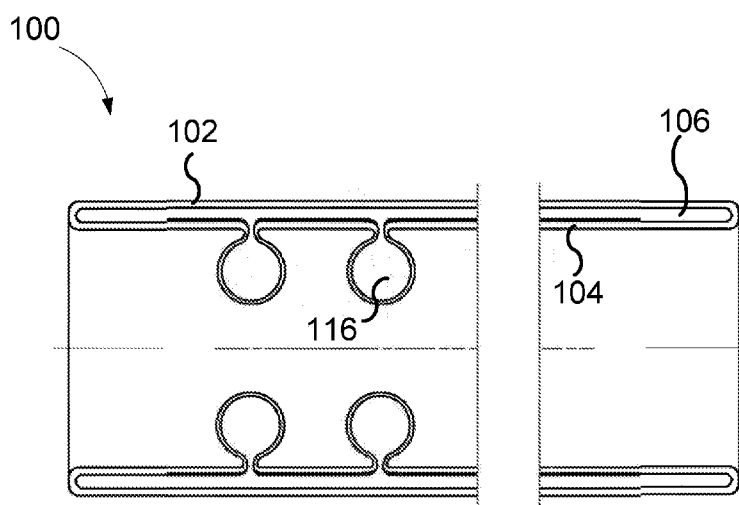


FIG. 1A

(57) Abstract: A bottomless solar thermal energy collector and method of making the same are disclosed. The solar thermal energy collector includes an inner translucent tube having a series of stress-relief grooves configured to reduce the stresses exerted due to temperature changes of the liquid located in the collector. The inner translucent tube also includes an absorptive coating disposed on an upper semicylinder of the tube and a reflective coating disposed on a lower semicylinder of the tube. An outer translucent tube is positioned around the inner translucent tube and a vacuum is disposed between them. The collector also includes collector-end regions where the diameter of the inner translucent tube decreases and the spacing between the inner translucent tube and the outer translucent tube increases. The grooves are created in the inner translucent tube by locally heating the tube, thinning the tube at the heated portion, reducing the tube's diameter at the heated portion, and then pushing the ends of the tube back towards each other.

GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

PARTIAL ABSORPTION COATING FOR ALL-GLASS BOTTOMLESS SOLAR THERMAL ENERGY COLLECTORS

CROSS REFERENCE TO RELATED APPLICATION(S)

- 5 **[0001]** This application claims the benefit of U.S. Provisional Application No. 62/366,796, filed July 26, 2016, which is incorporated by reference as if disclosed herein in its entirety.

BACKGROUND

- [0002]** Bottomless solar thermal energy collectors have a wide range of applications, including water heating, air heating, and various high-temperature solar thermal applications.
- 10 The design and manufacture of all-glass bottomless solar thermal energy collectors has been a holy grail of the solar energy industry for several decades. Because of the still-rather-high thermal expansion coefficient and extreme brittleness of borosilicate glass, to date attempts to make all-glass bottomless solar thermal energy collectors have failed. Successful mass-
- 15 production of all-glass bottomless solar thermal energy collectors would be a game changer of solar thermal energy applications.

[0003] Without wishing to be bound by theory, the maximum stress in a simple straight vacuum tube is:

$$\sigma = \frac{3Eh}{2H^2} \Delta L = \frac{3Eh}{2H^2} \alpha L \Delta T$$

- where E is the modulus of elasticity of borosilicate glass, h is the tube wall thickness, H is the spacing between inner and outer tubes, α is the thermal expansion coefficient of borosilicate
- 20 glass, L is the tube length, and ΔT is the temperature difference between the inside and the outside of the tube.

[0004] Assuming $H = 15$ mm, the maximum stress is shown in Table 1. As shown, the maximum stress well exceeds the ultimate stress of borosilicate glass, $\sigma_b = 69$ MPa. Therefore, the tube breaks.

Tube Length (L)	Temperature (ΔT)	Maximum Stress (σ)
1 meter	50°C	205 MPa
1 meter	100°C	410 MPa
2 meters	50°C	410 MPa
2 meters	100°C	820 MPa

Table 1

[0005] United States Patent Application No. 62/345,336, incorporated herein by reference in its entirety, disclosed an improved design of a tankless solar water heater using bottomless solar thermal energy collectors.

SUMMARY

[0006] Some embodiments of the disclosed subject matter are directed to a bottomless solar thermal energy collector having an inner translucent tube, an outer translucent tube, and a vacuum disposed therebetween, with a stress-relief groove on the inner translucent tube. In some embodiments, a plurality of stress-relief grooves are included on the inner translucent tube. In some embodiments, the groove extends circumferentially around the inner translucent tube and has a circular cross-section. In some embodiments, the collector also includes collector-end regions where the inner translucent tube has a reduced diameter and increased spacing between the inner translucent tube and the outer translucent tube. The various design features of the collector reduce the overall stress resulting from the heating of liquid within the collector, resulting in increased durability and operational lifetimes. Further, in some embodiments, reflective and absorptive coatings are disposed on the inner translucent tube. In some embodiments, the collector is composed of glass.

[0007] Some embodiments of the disclosed subject matter are directed to a method of making a bottomless solar thermal energy collector. In some embodiments, the inner translucent tube is heated in a first region to allow neighboring second and third regions to be pulled apart, elongating and thinning the first region. In some embodiments, the first region is then depressed to locally reduce the diameter of the inner translucent tube and produce a recess. In some

embodiments, the first region is depressed by a physical article. In some embodiments, the second and third regions are push back towards each other, which creates the groove having a cross-section. In some embodiments, the outer translucent tube is then positioned around the inner translucent tube.

5

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The drawings show embodiments of the disclosed subject matter for the purpose of illustrating the invention. However, it should be understood that the present application is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

10 [0009] FIG. 1 is a schematic drawing of a bottomless solar energy collector according to some embodiments of the present disclosure;

[0010] FIG. 2 is a schematic drawing of a bottomless solar energy collector according to some embodiments of the present disclosure;

[0011] FIG. 3 is a chart of a method of making a bottomless solar energy collector according to some embodiments of the present disclosure; and

15 [0012] FIGs. 4A-4D are a pictographically portrayed method of making a bottomless solar energy collector according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0013] Referring now to FIG. 1A, aspects of the disclosed subject matter include a solar thermal energy collector 100 including an outer translucent tube 102 and an inner translucent tube 104. In some embodiments, a vacuum 106 is disposed between outer translucent tube 102 and inner translucent tube 104. In some embodiments, collector 100 is bottomless, i.e., open at both ends. In some embodiments, collector 100 is open at one end and closed at an opposing end, i.e., a “dead-end” vacuum tube. In some embodiments, collector 100 is capable of maintaining a high vacuum. In some embodiments, outer translucent tube 102 and inner translucent tube 104 are substantially transparent to sunlight, that is, visible and near-infrared light. In some embodiments, outer translucent tube 102 and inner translucent tube 104 are composed of glass. In some embodiments, outer translucent tube 102 and inner translucent tube 104 are composed of high-quality glass (free from iron and other coloring elements). In some embodiments, inner translucent tube 104 is composed of a metal. In some embodiments,

outer translucent tube 102 and inner translucent tube 104 are composed of glass with a very low thermal expansion coefficient to avoid cracking under heat. In some embodiments, outer translucent tube 102 and inner translucent tube 104 are composed of borosilicate glass (with a commercial name of Pyrex).

5 **[0014]** Referring now to FIG. 1B, in some embodiments, bottomless solar thermal energy collector 100 includes collector-end regions 108. In some embodiments, collector-end regions 108 are disposed at opposing ends of an intermediate region 110. In some embodiments, collector-end regions 108 are characterized in that a diameter of inner translucent tube 104 has a reduced diameter relative to intermediate region 110. In some embodiments, collector-end
10 regions 108 are characterized in that a spacing 112 between outer translucent tube 102 and inner translucent tube 104 is also greater at collector-end regions 108 relative to intermediate region 110. In some embodiments, collector-end regions 108 have an extended reduced diameter portion 114 with a reduced diameter relative to outer translucent tube 102.

[0015] Since the maximum stress is inversely proportional to the square of the spacing H of
15 the translucent tube, by increasing the outer diameter D and reducing the diameter d of the outlet tube, spacing H can be greatly increased and maximum stress reduced. In FIG. 1, outer translucent tube 102 may have, for example, a diameter of 100 mm. By using collector-end regions 108 produced by, for example, reducing the diameter of inner translucent tube 104 from 100 mm to 30 mm, the spacing H is increased to 35 mm. Furthermore, the number of the
20 vertical planes 115 is increased from 2 to 4, and the maximum stress is correspondingly reduced.

[0016] Referring now to FIGs. 1A and 1B, in some embodiments, a groove 116 is disposed in inner translucent tube 104. Without wishing to be bound theory, grooves 116 are provided to relieve stress by allowing increased expansion and contraction of inner translucent tube 104 in response to changing temperatures. In some embodiments, groove 116 extends around a
25 circumference of inner translucent tube 104. In some embodiments, groove 116 has a circular cross-section. In some embodiments, groove 116 is a decreased thickness relative to the rest of inner translucent tube 104. In some embodiments, a plurality of grooves 116 are disposed in inner translucent tube 104. In some embodiments, plurality of grooves 116 are evenly distributed. In some embodiments, plurality of grooves 116 are separated from adjacent grooves
30 by about 100 mm. In some embodiments, plurality of grooves 116 are irregularly spaced.

[0017] Referring now to FIG. 2, inner translucent tube 104 includes an upper semicylinder 200 and a lower semicylinder 202. In some embodiments, an absorptive coating 204 and a reflective coating 206 on an outer surface 208 of the inner translucent tube. In some embodiments, reflective coating 206 is disposed over at least a portion of lower semicylinder 202. In some embodiments, reflective coating 206 is disposed over the entire lower semicylinder 202. In some embodiments, reflective coating 206 is composed of silver, gold, aluminum, copper, nickel, chromium, molybdenum, titanium, stainless steel, or combinations thereof. In some embodiments, absorptive coating 204 is disposed over at least a portion of upper semicylinder 200. In some embodiments, absorptive coating 204 is disposed over the entire upper semicylinder 200. In some embodiments, absorptive coating 204 is disposed over substantially the entire outer surface 208. In some embodiments, absorptive coating 204 is composed of aluminum nitride, germanium, graphite, chromium oxide, chromium nitride, copper oxide, lead sulfide, silver sulfide, or combinations thereof. In some embodiments, absorptive coating 204 is composed of two layers. In some embodiments, the bottom layer (immediately over the tube) is a reflective coating composed of metal. In some embodiments, the top layer is composed of a semiconductor. In some embodiments, absorptive coating 204 and reflective coating 206 are not included in groove 116. In some embodiments, absorptive coating 204 and reflective coating 206 are included in groove 116.

[0018] Referring to FIG. 3, aspects of the disclosed subject matter include a method 300 of making a bottomless solar thermal energy collector. In some embodiments, at 302, a wall of an inner translucent tube is treated in a first region between a second region and a third region so that the first region becomes more pliable. In some embodiments, the wall is treated 302 via a heating process. In some embodiments, at 304, the wall is thinned at the first region. In some embodiments, the wall is thinned 304 by increasing the distance between the second region and the third region, e.g., pulling the second region and third region apart using a lathe. In some embodiments, at 306, the diameter of the inner translucent tube is reduced at the first region. Reducing 306 the diameter of the inner translucent tube locally at the first region produces a recess in the inner translucent tube. In some embodiments, a diameter of the inner translucent tube is reduced 306 by displacing the wall with a physical article, e.g., a rod. In some embodiments, the physical article is composed of graphite. In some embodiments, at 308, a distance between the second region and the third region of the inner translucent tube is reduced. In some embodiments, the distance between the second region and the third region is reduced 308 by pushing the second region and the third region back towards each other, e.g.,

using a lathe. The result is groove 116 disposed in inner translucent tube 104 as shown in FIG. 1 and discussed above. In some embodiments, at 310, absorptive and reflective coatings are deposited on an outer surface of the inner translucent tube. In some embodiments, at 312, an outer translucent tube is disposed around the inner translucent tube and a vacuum disposed between the outer and inner translucent tubes.

[0019] In some embodiments, thinning 304, reducing 306, and reducing 308 are preceded by treatment 302 to make the inner translucent tube wall pliable. As discussed above, in some embodiments, treatment 302 is a heating process.

[0020] A pictographic portrayal of method 300 is shown in FIGs. 4A-4D. Referring to FIG. 4A, a wall 400 of inner translucent tube 104 is treated in a first region 402 between a second region 404 and a third region 406 so that the first region becomes more pliable. As discussed above, in some embodiments, wall 400 is treated via a heating process 408. Referring now to FIG. 4B, in some embodiments, wall 400 is thinned at first region 402. As discussed above, in some embodiments, wall 400 is thinned by increasing the distance 410 between second region 404 and third region 406, e.g., pulling the second region and third region apart. Referring now to FIG. 4C, in some embodiments, the diameter of inner translucent tube 104 is reduced at first region 402. Reducing the diameter of inner translucent tube 104 locally at first region 402 produces a recess 412 in the inner translucent tube. As discussed above, a diameter of inner translucent tube 104 is reduced by displacing wall 400 with a physical article 414, e.g., a rod. Referring to FIG. 4D, in some embodiments, a distance 410 between second region 404 and third region 406 of inner translucent tube 104 is reduced. As discussed above, distance 410 between second region 404 and third region 406 is reduced by pushing the second region and the third region back towards each other, e.g., using a lathe. The result is groove 116 disposed in inner translucent tube 104.

[0021] The systems and methods of the present disclosure advantageously allow for all-glass construction of a bottomless solar thermal energy collector through increased stress resistance. Without wishing to be bound by theory, the maximum stress for a vacuum tube with a single stress-relief groove is:

$$\sigma = \frac{Eh}{\pi\phi^2} \Delta L = \frac{Eh}{\pi\phi^2} \alpha L \Delta T$$

wherein ϕ is the diameter and h the thickness of the groove.

[0022] Assuming $\Phi = 20$ mm and $h = 1.0$ mm, the maximum stress is shown in following Table 2:

Tube Length	Temperature (ΔT)	Maximum Stress (σ)
1 meter	50°C	8 MPa
1 meter	100°C	16 MPa
2 meters	50°C	16 MPa
2 meters	100°C	32 MPa

Table 2

- 5 Therefore, the maximum stress can be much smaller than the stress limit of borosilicate glass, and the collector will display increased durability.

[0023] The use of collector-end regions is also advantageous for the building of complete systems. The size of pipes and associated components, e.g., gaskets, can be much smaller, and standard O-rings can be used. Finally, the absorptive and reflective coatings discussed above
 10 reduce radiation heat loss, and thus increase the efficiency of the collectors of the present disclosure. The hourly temperature drop of liquid at night may be as low as 0.12 K/hr, which is much better than a standard domestic hot-water tank, which is about 0.25 K/hr.

[0024] Although the disclosed subject matter has been described and illustrated with respect to embodiments thereof, it should be understood by those skilled in the art that features of the
 15 disclosed embodiments can be combined, rearranged, etc., to produce additional embodiments within the scope of the invention, and that various other changes, omissions, and additions may be made therein and thereto, without parting from the spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. A method of making a bottomless solar thermal energy collector comprising:

5 treating a wall of an inner glass tube in a first region between a second region and a third region;

thinning said wall at said first region;

reducing a diameter of said inner glass tube at said first region to introduce a recess between said second region and said third region;

reducing a distance between said second region and said third region; and

10 disposing an outer glass tube around said inner glass tube, and a vacuum between said outer glass tube and said inner glass tube.

2. The method according to claim 1, wherein treating a wall of an inner glass tube in a first region between a second region and a third region includes heating said wall of said inner glass tube in a first region between a second region and a third region.

- 15 3. The method according to claim 1, wherein thinning said wall at said first region includes increasing said distance between said second region and said third region.

4. The method according to claim 1, wherein reducing a diameter of said inner glass tube at said first region to introduce a recess between said second region and said third region includes depressing a portion of said first region with a physical article.

- 20 5. The method according to claim 4, wherein said physical article is composed of graphite.

6. The method according to claim 1, wherein reducing a distance between said second region and said third region includes heating said first region and pushing said second region and said third region back towards each other.

7. The method according to claim 1, further comprising depositing an absorptive coating and a
25 reflective coating on an outer surface of said inner glass tube.

8. The method according to claim 1, wherein disposing an outer glass tube around said inner glass tube includes:

reducing a diameter of said inner glass tube relative to a diameter of said outer glass tube to provide a collector-end region in said inner glass tube with an extended reduced diameter portion.

9. A bottomless solar thermal energy collector comprising:

an outer translucent tube;

an inner translucent tube;

a vacuum disposed between said outer translucent tube and said inner translucent tube;

and

at least one stress relief groove in said inner translucent tube.

10. The bottomless solar thermal energy collector according to claim 9, wherein said at least one stress relief groove has a circular cross-section.

11. The bottomless solar thermal energy collector according to claim 9, further comprising an absorptive coating and a reflective coating on an outer surface of said inner translucent tube.

12. The bottomless solar thermal energy collector according to claim 11, wherein said reflective coating is composed of silver, gold, aluminum, copper, nickel, chromium, molybdenum, titanium, stainless steel or combinations thereof.

13. The bottomless solar thermal energy collector according to claim 11, wherein said absorptive coating is composed of aluminum nitride, germanium, graphite, chromium oxide, chromium nitride, copper oxide, lead sulfide, silver sulfide, or combinations thereof.

14. The bottomless solar thermal energy collector according to claim 11, wherein said inner translucent tube includes an upper semicylinder and a lower semicylinder, and wherein said reflective coating is disposed on said lower semicylinder.

15. The bottomless solar thermal energy collector according to claim 11, wherein said inner translucent tube includes an upper semicylinder and a lower semicylinder, and wherein said absorptive coating is disposed on said upper semicylinder.

16. The bottomless solar thermal energy collector according to claim 9, wherein said inner translucent tube further comprises a collector-end region with an extended reduced diameter portion having a reduced diameter relative to said outer translucent tube.
17. The bottomless solar thermal energy collector according to claim 9, wherein said at least one stress relief groove is separated from an adjacent stress relief groove by about 100mm.
18. The bottomless solar thermal energy collector according to claim 9, wherein said inner translucent tube and said outer translucent tube are composed of glass.
19. A bottomless solar thermal energy collector comprising:
- an outer glass tube;
 - an inner glass tube;
 - a vacuum disposed between said inner glass tube and said outer glass tube;
 - collector-end regions disposed at opposing ends of an intermediate region of said outer glass tube and said inner glass tube, wherein said inner glass tube has a reduced diameter at said collector-end regions relative to said intermediate region, and a spacing between said outer glass tube and said inner glass tube is greater at said collector-end regions relative to said intermediate region; and
 - a plurality of grooves extending around a circumference of said inner glass tube, said plurality of grooves having a circular cross-section;
 - wherein an outer surface of said inner glass tube has a lower semicylinder and an upper semicylinder, said lower semicylinder having a reflective coating disposed thereon and said upper semicylinder having an absorptive coating disposed thereon.
20. The bottomless solar thermal energy collector according to claim 19, wherein said grooves are stress release grooves, and said stress relief grooves are separated from adjacent stress relief grooves by about 100mm.

1 / 5

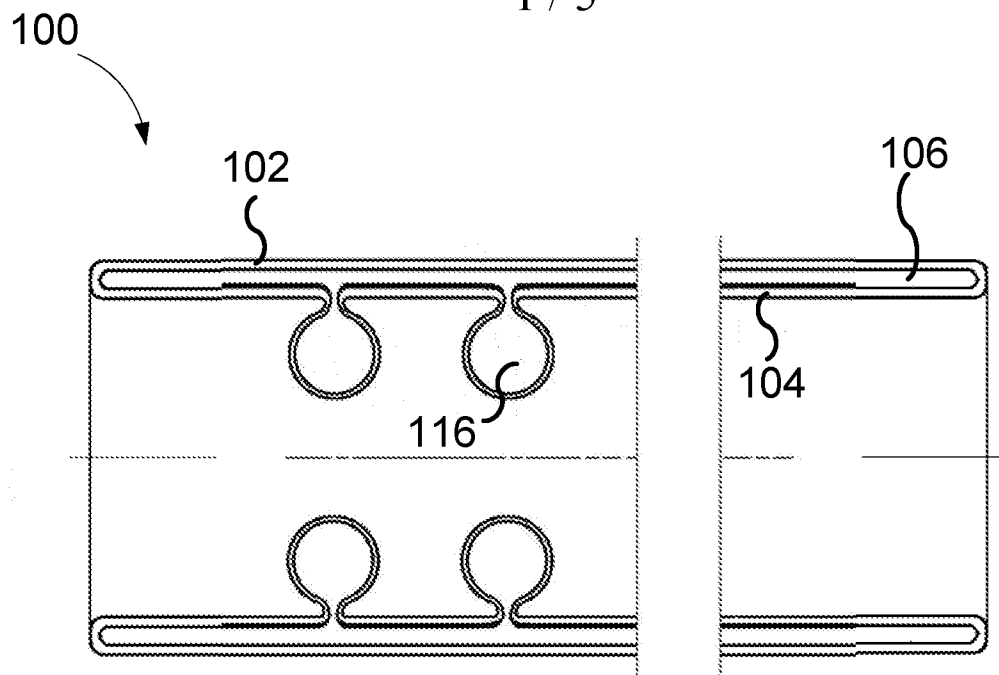


FIG. 1A

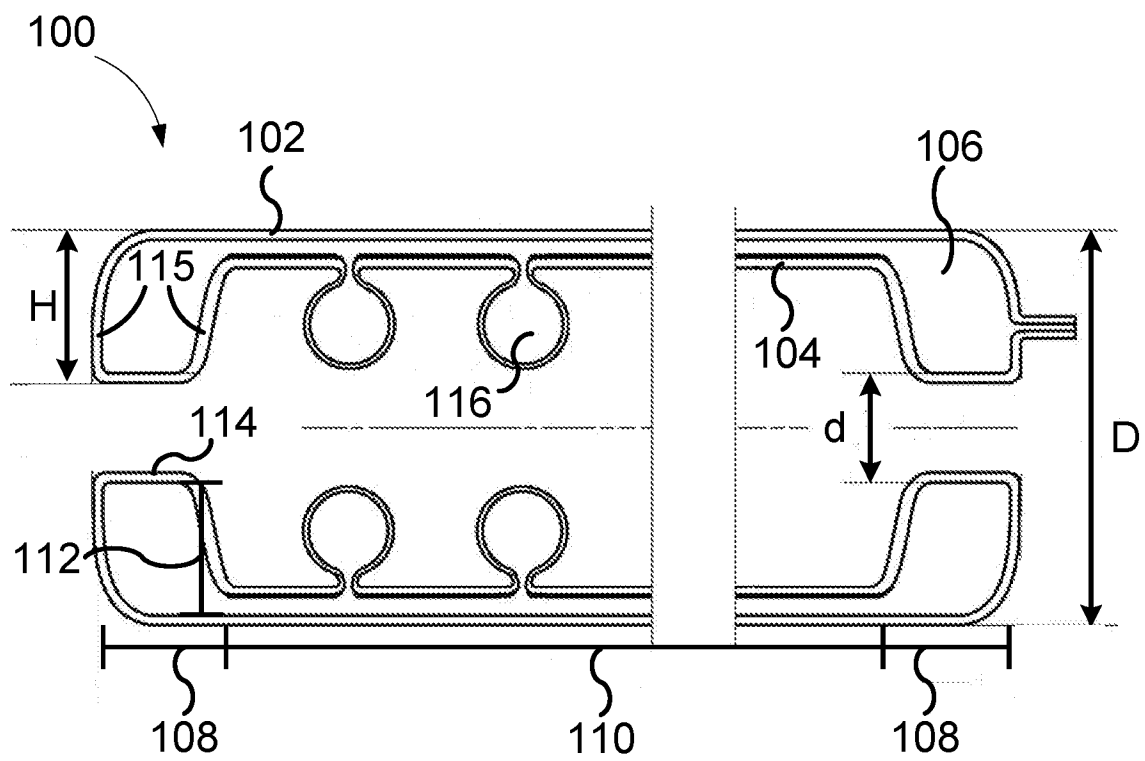


FIG. 1B

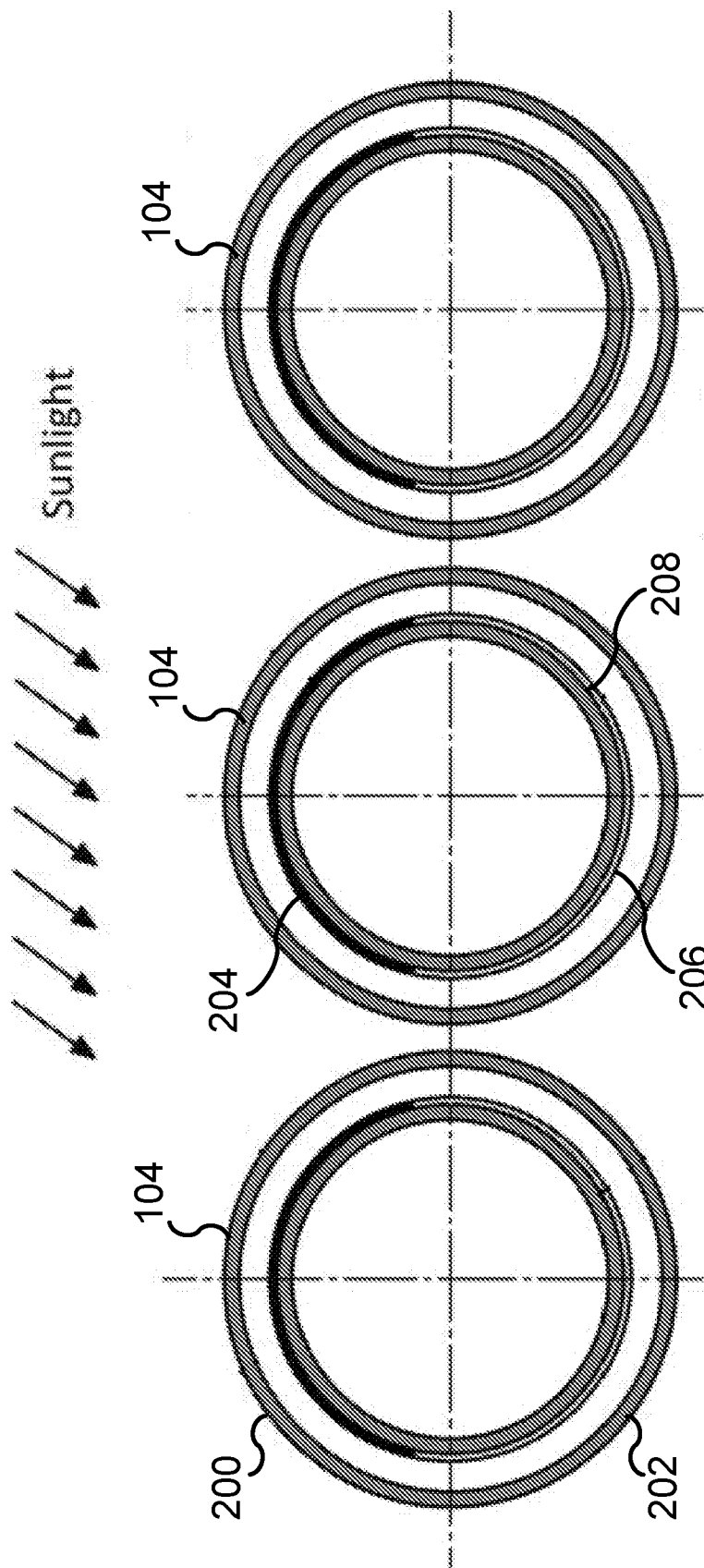


FIG. 2

3 / 5

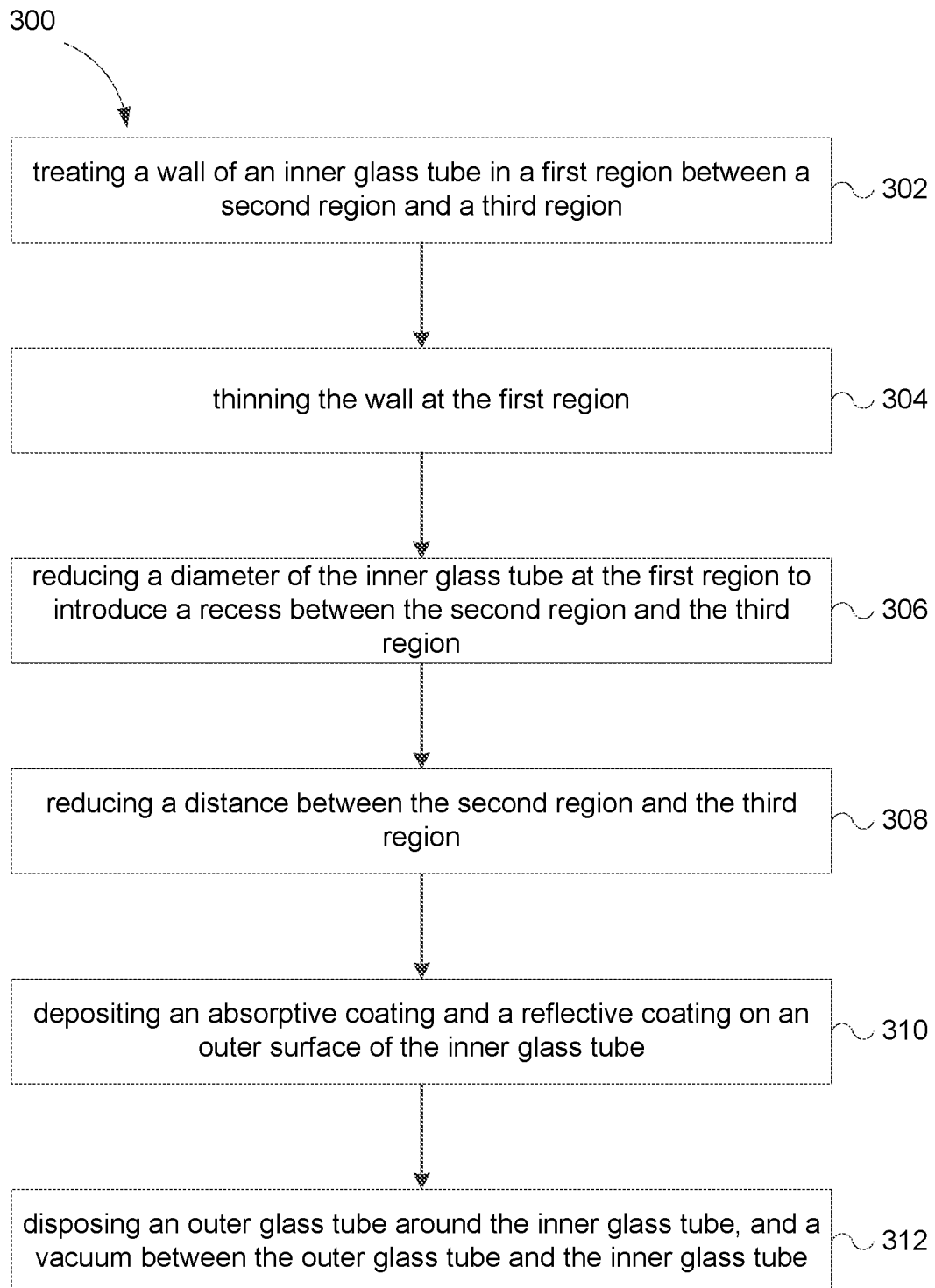


FIG. 3

4 / 5

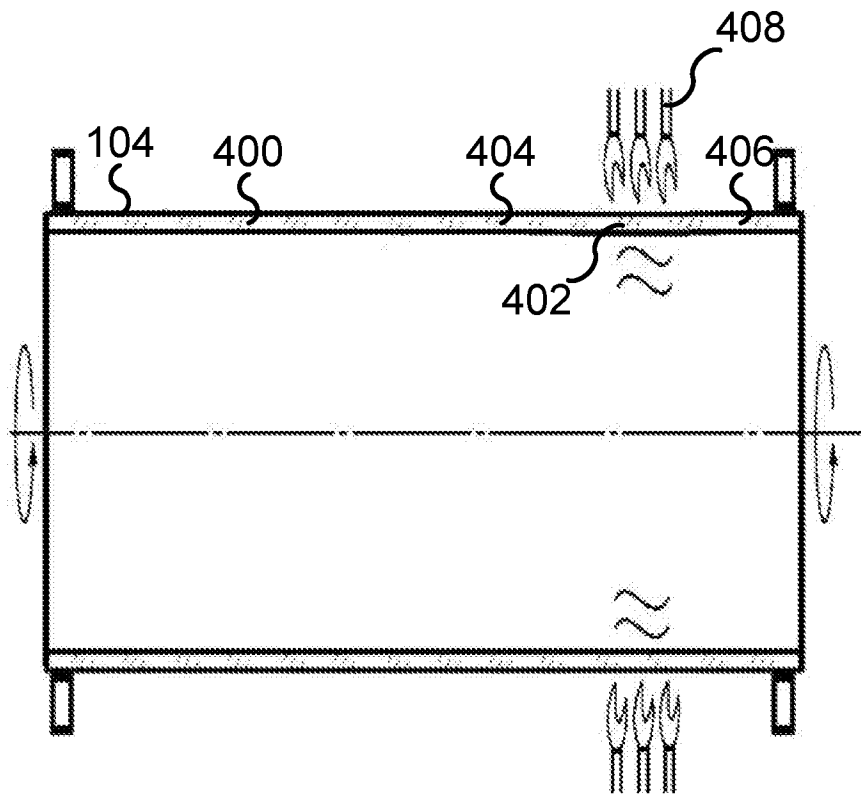


FIG. 4A

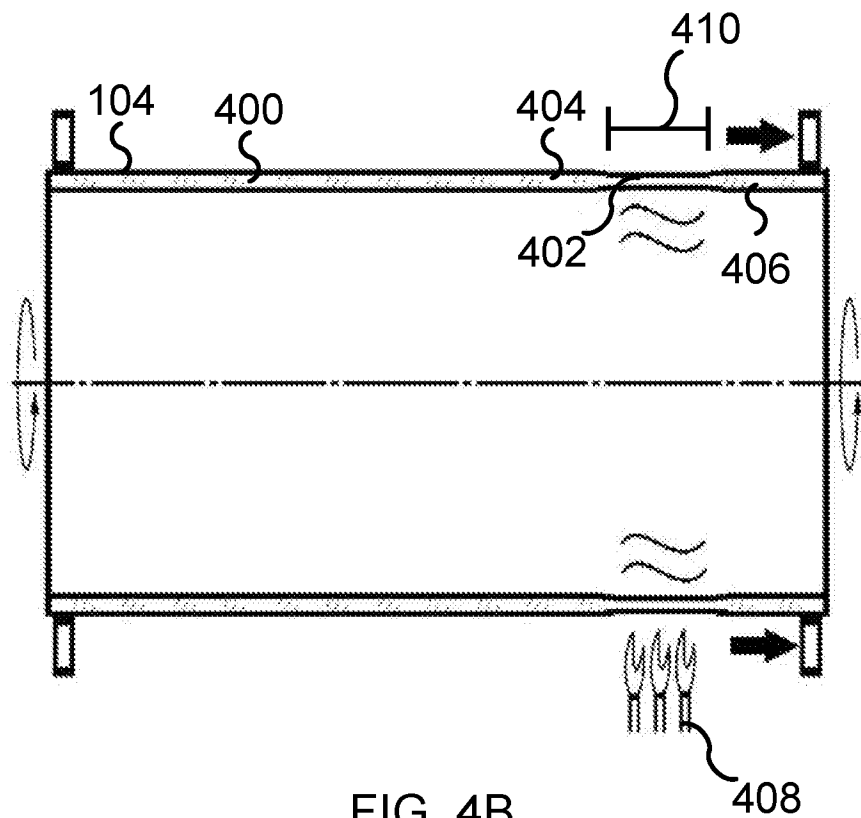


FIG. 4B

5 / 5

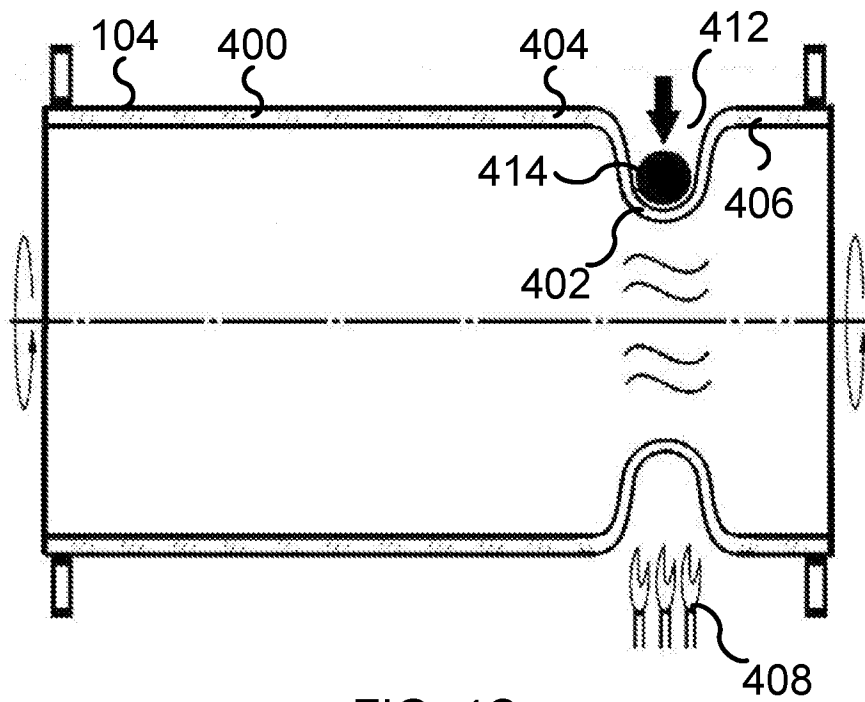


FIG. 4C

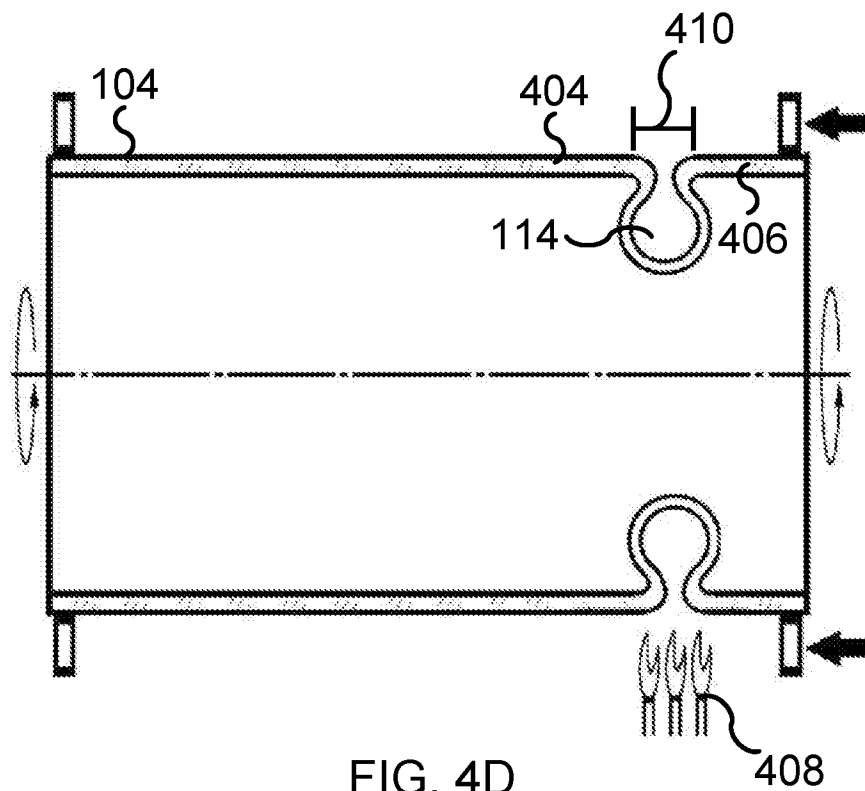


FIG. 4D

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/043834

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F24J 2/05; F16L 9/10; F16L 51/02; F24J 2/24; F24J 2/26 (2017.01)

CPC - F24J 2/055; F16L 51/02; F16L 51/024; F24J 2/24; F24J 2/26 (2017.08)

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)

See Search History document

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

USPC - 138/121; 165/82; 165/83 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 101256038 A (SOUTHEAST UNIVERSITY) 03 September 2008 (03.09.2008) machine translation	9, 10, 16-18
---		---
Y		11, 14, 15, 19, 20
Y	CN 103453682 A (WESTECH SOLAR CO LTD) 18 December 2013 (18.12.2013) machine translation	11, 14, 15, 19, 20
A	CN 103851809 A (LI ZI-QIANG et al) 11 June 2014 (11.06.2014) machine translation	1-20
A	CN 202024527 U (LOU ZHANGYUAN et al) 02 November 2011 (02.11.2011) machine translation	1-20

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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)

"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

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

18 September 2017

Date of mailing of the international search report

05 OCT 2017

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, VA 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774