(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 731 123 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
14.05.2014 Bulletin 2014/20

(51) Int Cl.:
H01J 35/18 *(2006.01)*

(21) Application number: **13187283.0**

(22) Date of filing: **03.10.2013**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **07.11.2012 US 201213670710**

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(54) **Variable radius taper X-ray window support structure**

(57) A support structure (10) for an x-ray window comprising a support frame (11) defining a perimeter (11p) and an aperture (11a), a plurality of ribs (12) extending across the aperture of the support frame and carried by the support frame, and openings 13) between the plurality of ribs. A rib taper region (12t) can extend from a central portion (12c) of the ribs to the support frame. The taper region can include a non-circular, arcuate pair of fillets (fig. 3,(33a), (33b)) on opposing sides of the ribs and an increasing of rib width from the central portion to the support frame.

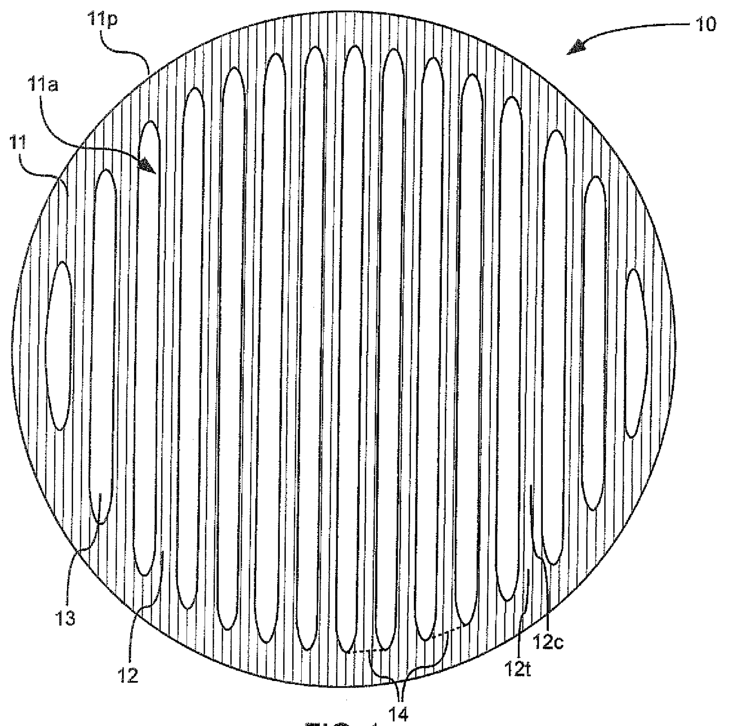

FIG. 1

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Description

CLAIM OF PRIORITY

[0001] Priority is claimed to US Nonprovisional Patent Application Serial Number 13/670,710, filed on November 7, 2012 the whole contents of which is herein incorporated by reference.

FIELD OF THE INVENTION

[0002] The present application is related generally to x-ray window support structures.

BACKGROUND

[0003] It is important for support members in support structures, such as x-ray window support structures, to be strong but also small in size. X-ray windows can include a thin film supported by the support structure, typically comprised of ribs supported by a frame. The support structure can be used to minimize sagging or breaking of the thin film. The support structure can interfere with the passage of x-rays and thus it can be desirable for ribs to be as thin or narrow as possible while still maintaining sufficient strength to support the thin film. The support structure and film are normally expected to be strong enough to withstand a differential pressure of around 1 atmosphere without sagging or breaking.

[0004] Such support structures can comprise a support frame defining a perimeter and an aperture, a plurality of ribs extending across the aperture of the support frame and carried by the support frame, and openings between the ribs. Stresses can occur at the junction of the ribs and the support frame. It can be important to reduce such stresses in order to avoid failure at this junction.

SUMMARY

[0005] It has been recognized that it would be advantageous to have a strong x-ray window support structure, and advantageous to minimize stresses at a junction of the ribs to the support frame. The present invention is directed to an x-ray window support structure that satisfies these needs. The support structure comprises a support frame defining a perimeter and an aperture, a plurality of ribs extending across the aperture of the support frame and carried by the support frame, and openings between the plurality of ribs. A rib taper region can extend from a central portion of the ribs to the support frame. The taper region can include a non-circular, arcuate pair of fillets on opposing sides of the ribs and an increasing of rib width from the central portion to the support frame.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006]

FIG. 1 is a schematic top view of an x-ray window support structure, in accordance with an embodiment of the present invention;
FIG. 2 is a schematic cross-sectional side view of an x-ray window, in accordance with an embodiment of the present invention;
FIG. 3 is a schematic top view of a portion of an x-ray window support structure, in accordance with an embodiment of the present invention;
FIG. 4 is a schematic top view of a portion of an x-ray window support structure, in accordance with an embodiment of the present invention;
FIG. 5 is a schematic top view of a portion of an x-ray window support structure, in accordance with an embodiment of the present invention;
FIG. 6 is a schematic top view of a portion of an x-ray window support structure, in accordance with an embodiment of the present invention; and
FIG. 7 is a schematic top view of a portion of an x-ray window support structure, in accordance with an embodiment of the present invention.

DEFINITIONS

[0007]

- As used herein, the term "carbon fiber" or "carbon fibers" means solid, substantially cylindrically shaped structures having a mass fraction of at least 85% carbon, a length of at least 5 micrometers and a diameter of at least 1 micrometer.

- As used herein, the term "directionally aligned," in referring to alignment of carbon fibers with ribs, means that the carbon fibers are substantially aligned with a longitudinal axis of the ribs and does not require the carbon fibers to be exactly aligned with a longitudinal axis of the ribs.
- As used herein, the term "rib" means a support member and can extend, linearly or with bends or curves, by itself or coupled with other ribs, across an aperture of a support frame.

DETAILED DESCRIPTION

[0008] As illustrated in FIG. 1, a support structure 10 for an x-ray window is shown comprising a support frame 11 defining a perimeter 11p and an aperture 11a, a plurality of ribs 12 extending across the aperture 11a of the support frame 11 and carried by the support frame 11, and openings 13 between the plurality of ribs 12. The ribs 12 can be attached or joined to the frame 11 at a junction 14. Typically, the ribs 12 and frame 11 are formed integrally from a single wafer or sheet of material, but they can be formed separately and attached together, such as with an adhesive.

[0009] Shown in FIG. 2 is an x-ray window 20 having tops of the ribs 12 terminating substantially in a common plane 16. A thin film 21 can be disposed over and can be attached to the ribs 12 and the support frame 11.

[0010] When the thickness t of the ribs 12 is sufficiently thin, stress on the rib material can become very large near the junction 14 of the ribs 12 with the support frame 11. A rib taper region 12t (shown in FIG. 1) may be used to reduce stress at this junction 14.

[0011] Shown in FIG. 3 is a section of a support structure 30. A rib taper region 12t can extend from a central portion 12c of the ribs 12 to the support frame 11. The taper region 12t can include a non-circular, arcuate pair of fillets 33a-b on opposing sides of the ribs 12. Non-circular, arcuate fillets 33 can allow for reduced stress, while also allowing ribs 12 to be spaced closer together. The taper region 12t can include an increasing of rib width W from the central portion 12c to the support frame 11 ($W_J > W_c$). Rib width W can continuously and smoothly increase, with no sharp angles or inflection points, from the central portion 12c to the support frame 11.

[0012] The support structures described herein may be further defined or quantified by the shape of the ribs, such as having a long length relative to an increase in rib width in the taper region 12t. The support structures described herein may also be defined or quantified by the shape of the openings 13 in the taper region 12t, such as a relationship of rib length in the taper region 12t to an opening width, a relationship of radius of curvature at a taper beginning to a radius of curvature at the support frame, or elliptical shaped openings. These definitions can be used to quantify the non-circular, arcuate shape of the fillets 33a-b of the taper region 12t.

[0013] As shown on support structures 30 and 40 in FIGs. 3-4, a location where the central portion 12c of the ribs 12 meets the taper region 12t defines a taper beginning T_b; a rib width at the taper beginning T_b defines a central rib width W_c; a rib width at a junction of the rib 12 with the support frame 11 defines a junction rib width W_J; and a straight line distance, parallel with a center of the rib 12, from the taper beginning T_b to the support frame 11 defines a taper length T_L. In one aspect, the central rib width W_c, the junction rib width W_J, and the taper length T_L can satisfy the equation: $1 < \frac{T_L}{W_J - W_c} < 3$. In another aspect, the central rib width W_c, the junction rib width W_J, and the taper length T_L can satisfy the equation: $1.4 < \frac{T_L}{W_J - W_c} < 2.2$. These equations can quantify a long length of the ribs 12 relative to an increase in rib width in the taper region 12t.

[0014] As shown on support structure 40 of FIG. 4, an opening 13 width at the taper beginning T_b defines a taper opening width O_w. The taper length T_L divided by the taper opening width O_w can be between 1 and 3 $\left(1 < \frac{T_L}{O_w} < 3\right)$ in one aspect, or between 1.4 and 2.2 $\left(1.4 < \frac{T_L}{O_w} < 2.2\right)$ in another aspect. These equations can quantify a long length of the ribs 12 in the taper region 12t relative to an opening width O_w at the taper beginning T_b.

[0015] As shown on support structure 50 of FIG. 5, a radius of curvature of the fillets 33 at the taper beginning T_b defines a central radius R_c and a radius of curvature of the fillets at a junction of the ribs 12 with the support frame 11 defines a junction radius R_J. The central radius R_c divided by the junction radius R_J can be between 10 and 100 $\left(10 < \frac{R_c}{R_J} < 100\right)$ in one aspect. The central radius R_c divided by the junction radius R_J can be between 20 and 50

$\left(20 < \frac{R_c}{R_J} < 50\right)$ in another aspect. These equations can quantify a large radius of curvature at the taper beginning T_b relative to a substantially smaller radius of curvature at a junction of the ribs 12 with the support frame 11, thus quantifying the non-circular, arcuate shape of the ribs 12.

[0016] The larger radius of curvature closer to the central portion 12c of the ribs 12 can result in reduced stress in the ribs, and thus greater rib strength and reduced risk of rib failure. The gradually and continually decreasing radius of curvature towards the junction 14 can allow ribs 12 to be packed closer together. Thus, if a larger spacing between ribs 12 is allowed, such as if a relatively strong film is used, then the central radius R_c divided by the junction radius R_J can be relatively smaller. If a smaller spacing between ribs 12 is allowed, such as if a thinner or relatively weaker film is used, then the central radius R_c divided by the junction radius R_J may need to be larger.

[0017] As shown on support structure 60 of FIG. 6, openings 13 can have a half-elliptical shape 61 between ribs in the taper region 12t. Eccentricity e of the half-elliptical shape can be between 0.90 and 0.99 (0.90<e<0.99) in one aspect, between 0.80 and 0.99 (0.80<e<0.99) in another aspect, between 0.93 and 0.98 (0.93<e<0.98) in another aspect, or between 0.75 and 0.90 (0.75<e<0.90) in another aspect. Eccentricity e is defined as: $= \sqrt{1 - \frac{b^2}{a^2}}$. These equations can quantify the shape of openings 13 in the taper region 12t.

[0018] In previous figures, ribs 12 were shown packed closely together, such that where the rib taper for one rib 12 ended at the support structure 11, a rib taper for another rib 12 began. As shown on support structure 70 of FIG. 7, ribs 12 can be spaced farther apart, such that there is a region of an inner perimeter 71 of the support structure in which there are no ribs, and no beginning of taper of ribs.

[0019] The central portion 12c of the ribs 12 can have a substantially constant width W, and ribs can be substantially parallel with each other, as is shown on support structure 10 in FIG. 1. A variable rib width in the central portion 12c, or non-parallel ribs, such as hexagonal or intersecting ribs, are also within the scope of this invention.

[0020] The ribs 12 and / or the support frame 11 can comprise low atomic number elements such as aluminum, beryllium, boron, carbon, fluorine, hydrogen, nitrogen, oxygen, and / or silicon. Use of such low atomic number elements can result in minimized x-ray spectrum contamination. The ribs 12 and / or the support frame 11 can comprise boron carbide, boron hydride, boron nitride, carbon fiber composite, carbon nanotube composite, kevlar, mylar, polyimide, polymer, silicon nitride, diamond, diamond-like carbon, graphitic carbon, pyrolytic graphite, and / or amorphous carbon. The openings 13, ribs 12, and support frame 11 can be formed by laser ablation. Manufacturing of the support structure from a carbon composite wafer is described in US Patent Application Serial Number 13/667,273, filed on November 2, 2012, and in US Patent Application Serial Number 13/453,066, filed on April 23, 2012, which are hereby incorporated herein by reference. If a carbon composite support structure is used, carbon fibers in the carbon composite can be directionally aligned with the ribs 12.

[0021] The film 21, described previously in the description of FIG. 2, can be configured to pass radiation therethrough. For example, the film 13 can be made of a material that has a low atomic number and can be thin, such as for example about 5 to 500 micrometers (μm). The film 13 can have sufficient strength to allow differential pressure of at least one atmosphere without breaking. The film 13 can be hermetic or air-tight. The film 13 can combine with one of the support structures described herein and a shell to form a hermetic enclosure.

[0022] The present invention will now be described by way of reference to the following clauses:

1. A support structure for an x-ray window, the support structure comprising:

    a) a support frame defining a perimeter and an aperture;
    b) a plurality of ribs extending across the aperture of the support frame and carried by the support frame;
    c) openings between the plurality of ribs;
    d) a rib taper region extending from a central portion of the ribs to the support frame;
    e) the taper region including a non-circular, arcuate pair of fillets on opposing sides of the ribs; and
    f) the taper region including an increasing of rib width from the central portion to the support frame.

2. The support structure of clause 1, wherein the support frame and the ribs comprise a carbon composite material including carbon fibers embedded in a matrix.

3. The support structure of clause 2, wherein the carbon fibers in the carbon composite are substantially aligned with the ribs.

4. The support structure of clause 2 or any one of the preceding clauses, wherein the openings, ribs, and support

frame were formed by laser ablation of a carbon composite wafer.

5. The support structure of clause 1 or any one of the preceding clauses, wherein the ribs comprise carbon, carbon fiber composite, silicon, boron carbide, or combinations thereof.

6. The support structure of clause 1 or any one of the preceding clauses, wherein:

a. a location where the central portion of the ribs meets the taper region defines a taper beginning;
b. a radius of curvature of the fillets at the taper beginning defines a central radius;
c. a radius of curvature of the fillets at a junction of the ribs with the support frame defines a junction radius; and
d. the central radius divided by the junction radius is between 10 and 100.

7. The support structure of clause 1 or any one of the preceding clauses, wherein the fillets include a larger radius of curvature closer to the central portion of the ribs and a smaller radius of curvature towards the support frame.

8. The support structure of clause 1 or any one of the preceding clauses, wherein openings at the taper region have a half-elliptical shape.

9. The support structure of clause 8, wherein the half-elliptical shape has an eccentricity of between 0.90 and 0.99.

10.The support structure of clause 8, wherein the half-elliptical shape has an eccentricity of between 0.80 and 0.99.

11.The support structure of clause 1 or any one of the preceding clauses, wherein:

a) a location where the central portion of the ribs meets the taper region defines a taper beginning;
b) a straight line distance, parallel with a center of the rib, from the taper beginning to the support frame defines a taper length;
c) an opening width at the taper beginning defines a taper opening width; and
d) the taper length divided by the taper opening width is between 1 and 3.

12.The support structure of clause 11, wherein the taper length divided by the taper opening width is between 1.4 and 2.2.

13.The support structure of clause 1 or any one of the preceding clauses, wherein:

a) a location where the central portion of the ribs meets the taper region defines a taper beginning;
b) a rib width at the taper beginning defines a central rib width;
c) a rib width at a junction of the rib with the support frame defines a junction rib width;
d) a straight line distance, parallel with a center of the rib, from the taper beginning to the support frame defines a taper length; and
e) the central rib width, the junction rib width, and the taper length satisfy the equation: $1 < \frac{\text{taper length}}{\text{junction rib width} - \text{central rib width}} < 3$.

14.The support structure of clause 13, wherein the central rib width, the junction rib width, and the taper length satisfy the equation: $1.4 < \frac{\text{taper length}}{\text{junction rib width} - \text{central rib width}} < 2.2$.

15.The support structure of clause 1 or any one of the preceding clauses, wherein the central portion of the ribs have a substantially constant width.

Claims

1. A support structure for an x-ray window, the support structure comprising:

a. a support frame defining a perimeter and an aperture;
b. a plurality of ribs extending across the aperture of the support frame and carried by the support frame;
c. openings between the plurality of ribs;
d. a rib taper region extending from a central portion of the ribs to the support frame;
e. the taper region including a non-circular, arcuate pair of fillets on opposing sides of the ribs; and
f. the taper region including an increasing of rib width from the central portion to the support frame.

2. The support structure of claim 1, wherein the support frame and the ribs comprise a carbon composite material including carbon fibers embedded in a matrix.

3. The support structure of claim 2, wherein carbon fibers in the carbon composite are substantially aligned with the ribs.

4. The support structure of claim 2, wherein the openings, ribs, and support frame were formed by laser ablation of a carbon composite wafer.

5. The support structure of claim 1, wherein the ribs comprise carbon, carbon fiber composite, silicon, boron carbide, or combinations thereof.

6. The support structure of claim 1, wherein:

a. a location where the central portion of the ribs meets the taper region defines a taper beginning;
b. a radius of curvature of the fillets at the taper beginning defines a central radius;
c. a radius of curvature of the fillets at a junction of the ribs with the support frame defines a junction radius; and
d. the central radius divided by the junction radius is between 10 and 100.

7. The support structure of claim 1, wherein the fillets include a larger radius of curvature closer to the central portion of the ribs and a smaller radius of curvature towards the support frame.

8. The support structure of claim 1, wherein openings at the taper region have a half-elliptical shape.

9. The support structure of claim 8, wherein the half-elliptical shape has an eccentricity of between 0.90 and 0.99.

10. The support structure of claim 8, wherein the half-elliptical shape has an eccentricity of between 0.80 and 0.99.

11. The support structure of claim 1, wherein:

a. a location where the central portion of the ribs meets the taper region defines a taper beginning;
b. a straight line distance, parallel with a center of the rib, from the taper beginning to the support frame defines a taper length;
c. an opening width at the taper beginning defines a taper opening width; and
d. the taper length divided by the taper opening width is between 1 and 3.

12. The support structure of claim 11, wherein the taper length divided by the taper opening width is between 1.4 and 2.2.

13. The support structure of claim 1, wherein:

a. a location where the central portion of the ribs meets the taper region defines a taper beginning;
b. a rib width at the taper beginning defines a central rib width;
c. a rib width at a junction of the rib with the support frame defines a junction rib width;
d. a straight line distance, parallel with a center of the rib, from the taper beginning to the support frame defines a taper length; and
e. the central rib width, the junction rib width, and the taper length satisfy the equation: $1 < \frac{\text{taper length}}{\text{junction rib width} - \text{central rib width}} < 3$.

14. The support structure of claim 13, wherein the central rib width, the junction rib width, and the taper length satisfy the equation: $$1.4 < \frac{\text{taper length}}{\text{junction rib width} - \text{central rib width}} < 2.2 \ .$$

15. The support structure of claim 1, wherein the central portion of the ribs have a substantially constant width.

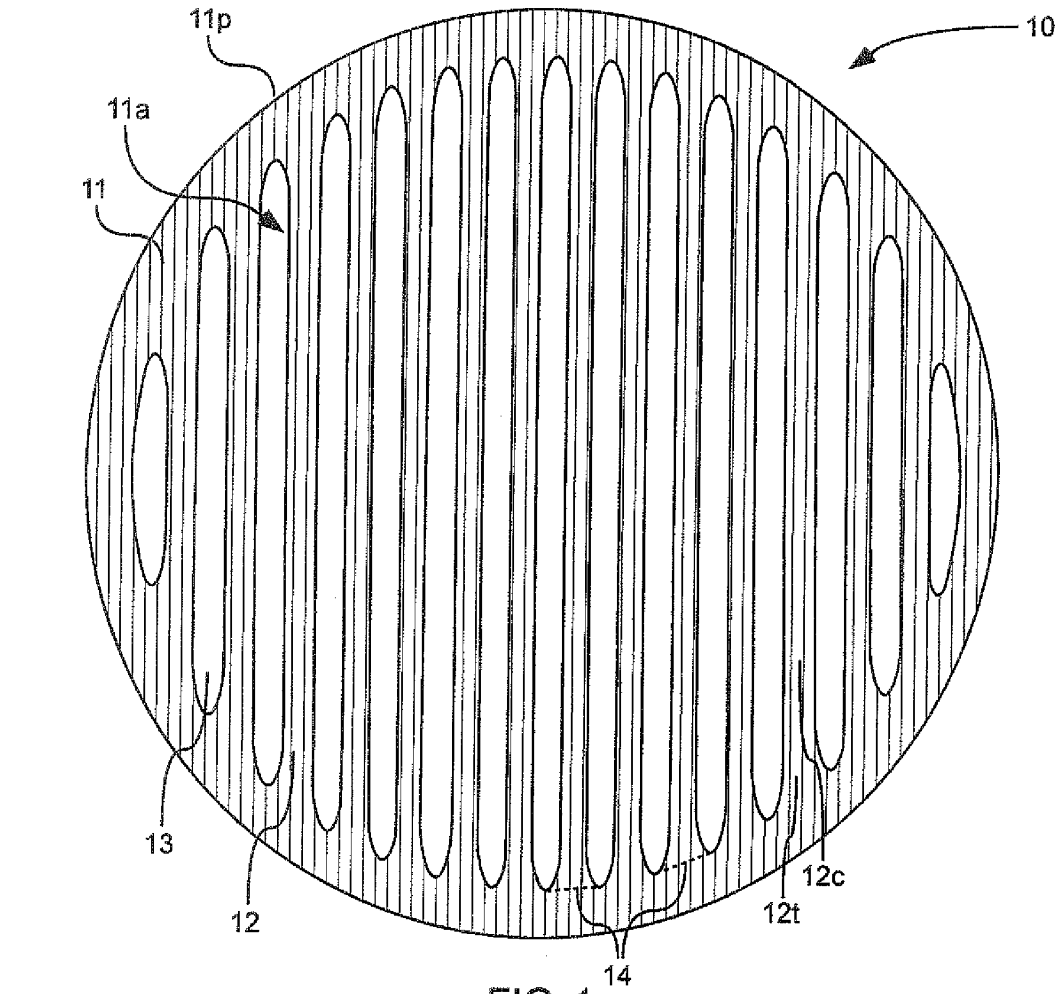

FIG. 1

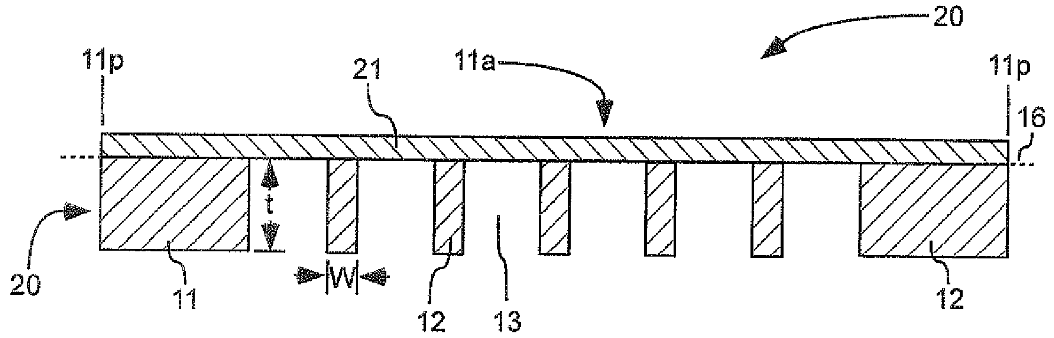

FIG. 2

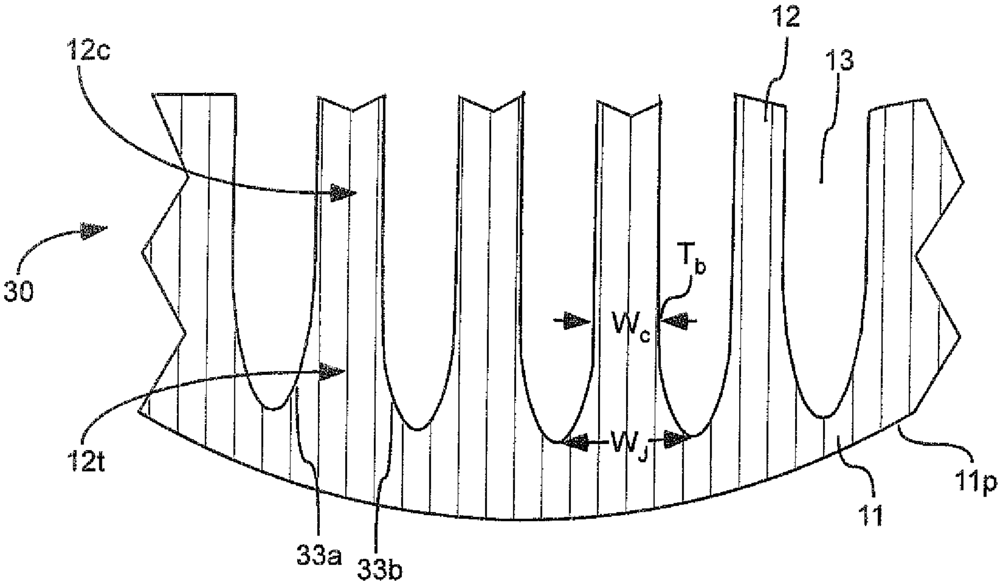
12c
12
13
30
T_b
W_c
12t
W_J
11p
11
33a
33b

FIG. 3

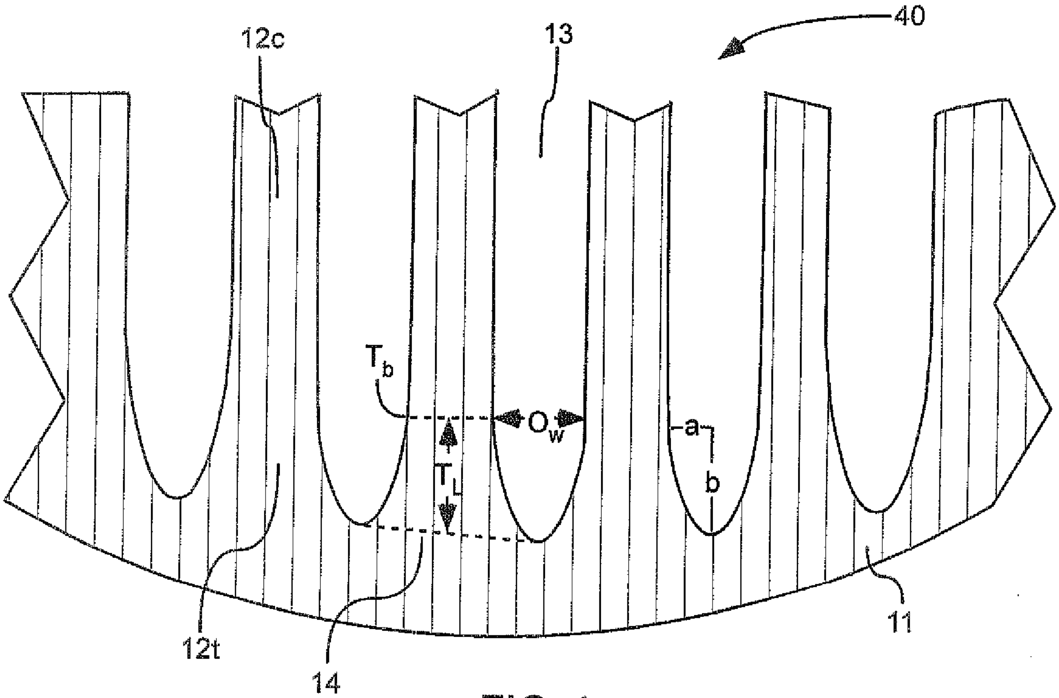
40
12c
13
T_b
O_w
a
b
T_L
12t
14
11

FIG. 4

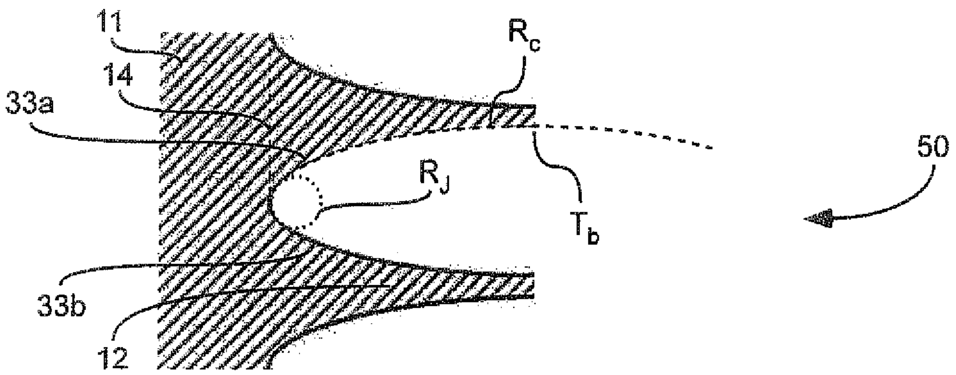

FIG. 5

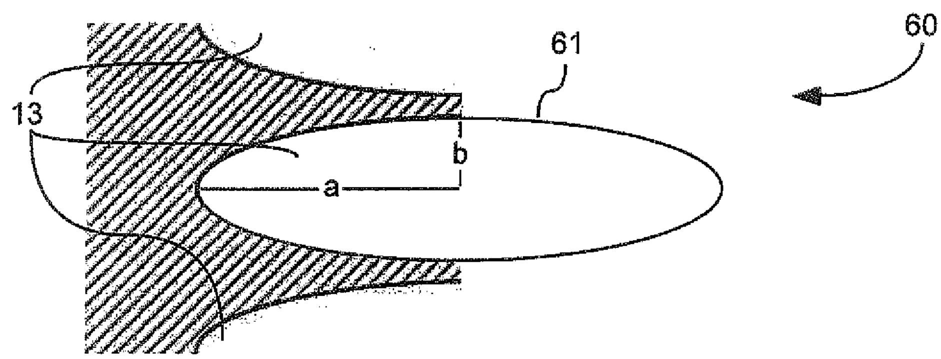

FIG. 6

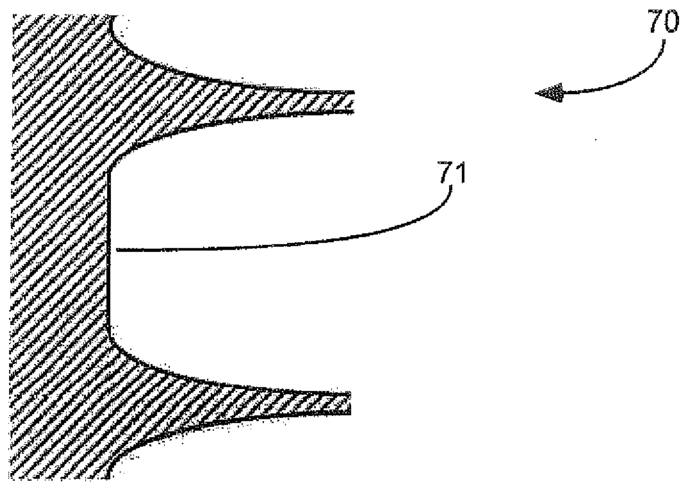

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 67071012 A **[0001]**
- US 66727312 A **[0020]**
- US 45306612 A **[0020]**