US010385806B2

(12) **United States Patent**
McBain et al.

(10) **Patent No.: US 10,385,806 B2**
(45) **Date of Patent: Aug. 20, 2019**

(54) **SOLID PROPELLANT GRAIN**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 350 days.

(21) Appl. No.: **14/873,522**

(22) Filed: **Oct. 2, 2015**

(65) **Prior Publication Data**

US 2017/0096968 A1 Apr. 6, 2017

(51) **Int. Cl.**

F02K 9/26	(2006.01)
F02K 9/10	(2006.01)
C06B 45/00	(2006.01)
F02K 9/95	(2006.01)
C06B 45/18	(2006.01)
F02K 9/14	(2006.01)

(52) **U.S. Cl.**

CPC ***F02K 9/95*** (2013.01); ***C06B 45/00*** (2013.01); ***C06B 45/18*** (2013.01); ***F02K 9/10*** (2013.01); ***F02K 9/14*** (2013.01); ***F02K 9/26*** (2013.01); *F05D 2300/121* (2013.01); *F05D 2300/141* (2013.01); *F05D 2300/43* (2013.01); *F05D 2300/434* (2013.01); *F05D 2300/5024* (2013.01)

(58) **Field of Classification Search**

CPC F02K 9/08; F02K 9/10; F02K 9/12; F02K 9/26; F02K 9/95; C06B 45/00; C06B 45/12; C06B 45/18

USPC 102/285, 286, 287, 289, 291; 149/2, 3, 149/14, 108.2, 109.4

See application file for complete search history.

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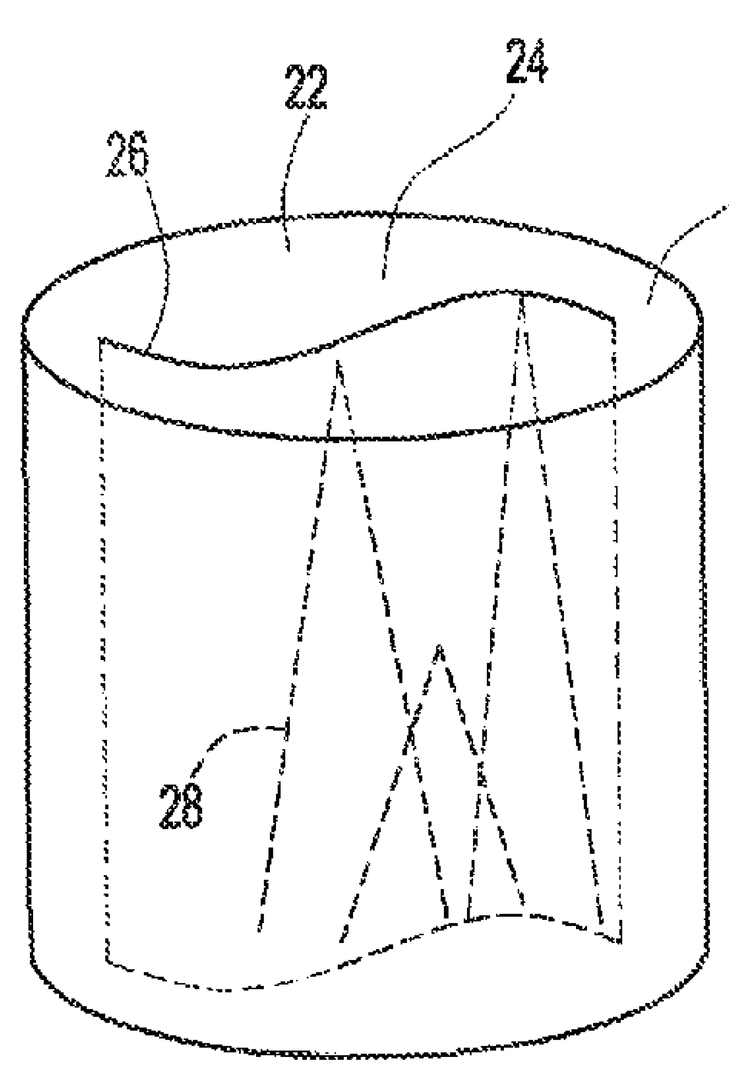
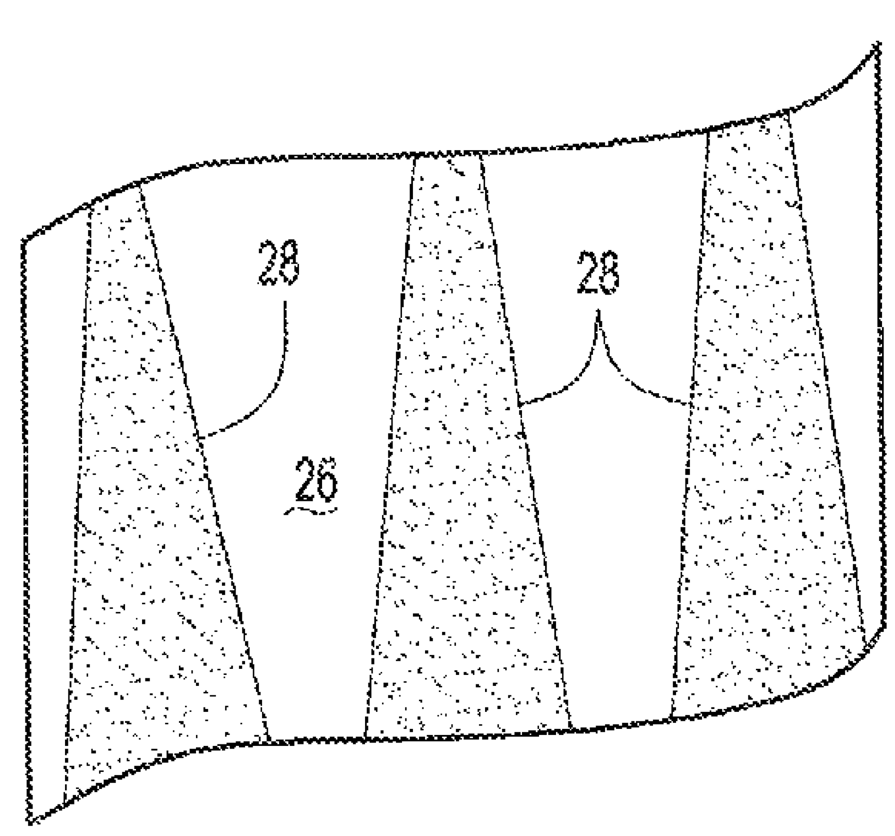
(57) **ABSTRACT**

A solid rocket propellant grain having rocket propellant and a membrane in contact with the rocket propellant. The membrane includes a highly heat conductive pattern which affects the propellant burning rate through localized conductive heat transfer from the combustion zone and into the uncombusted propellant. Different geometries for the thermally conductive pattern produce different combustion results.

20 Claims, 3 Drawing Sheets





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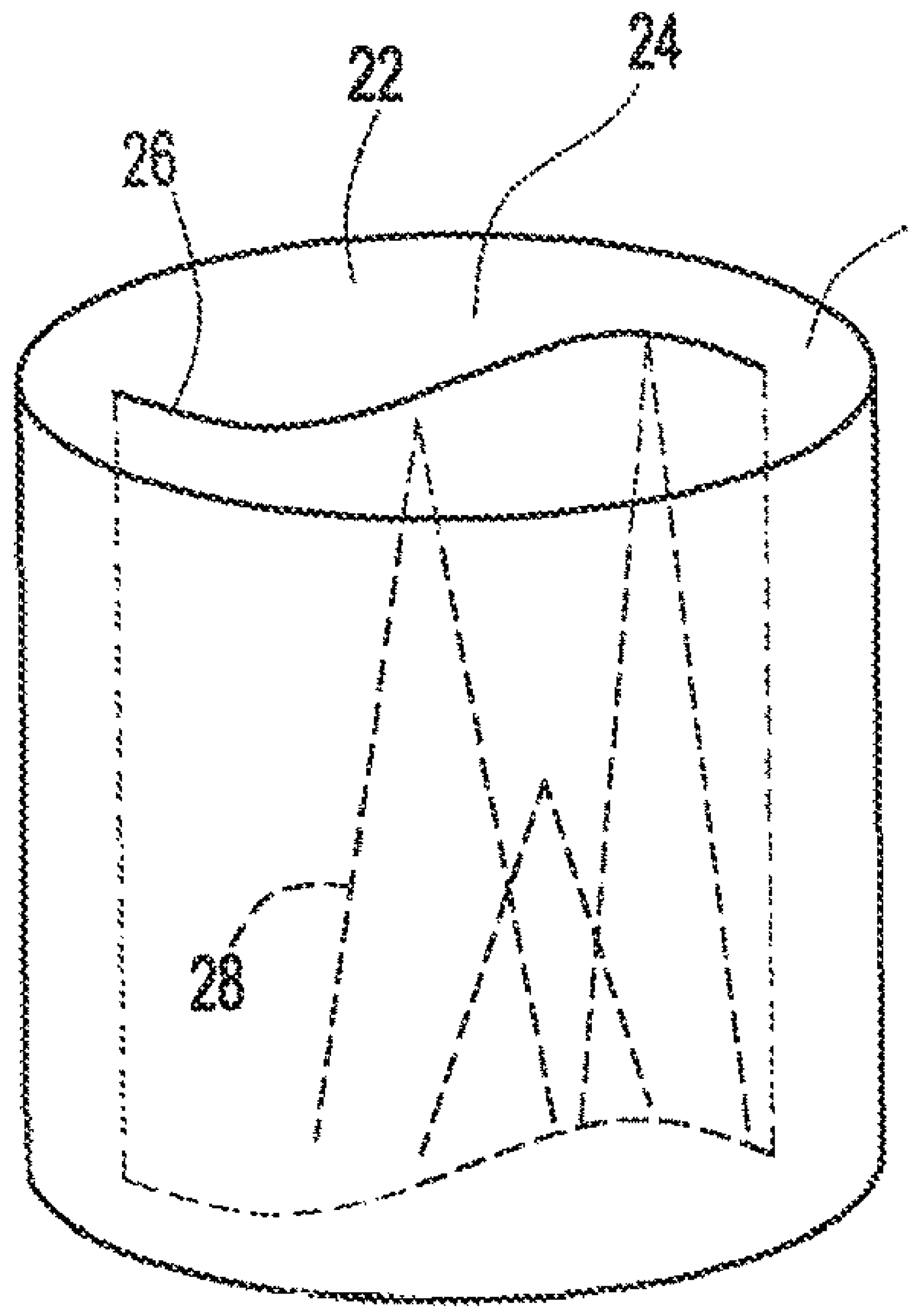

Fig-1

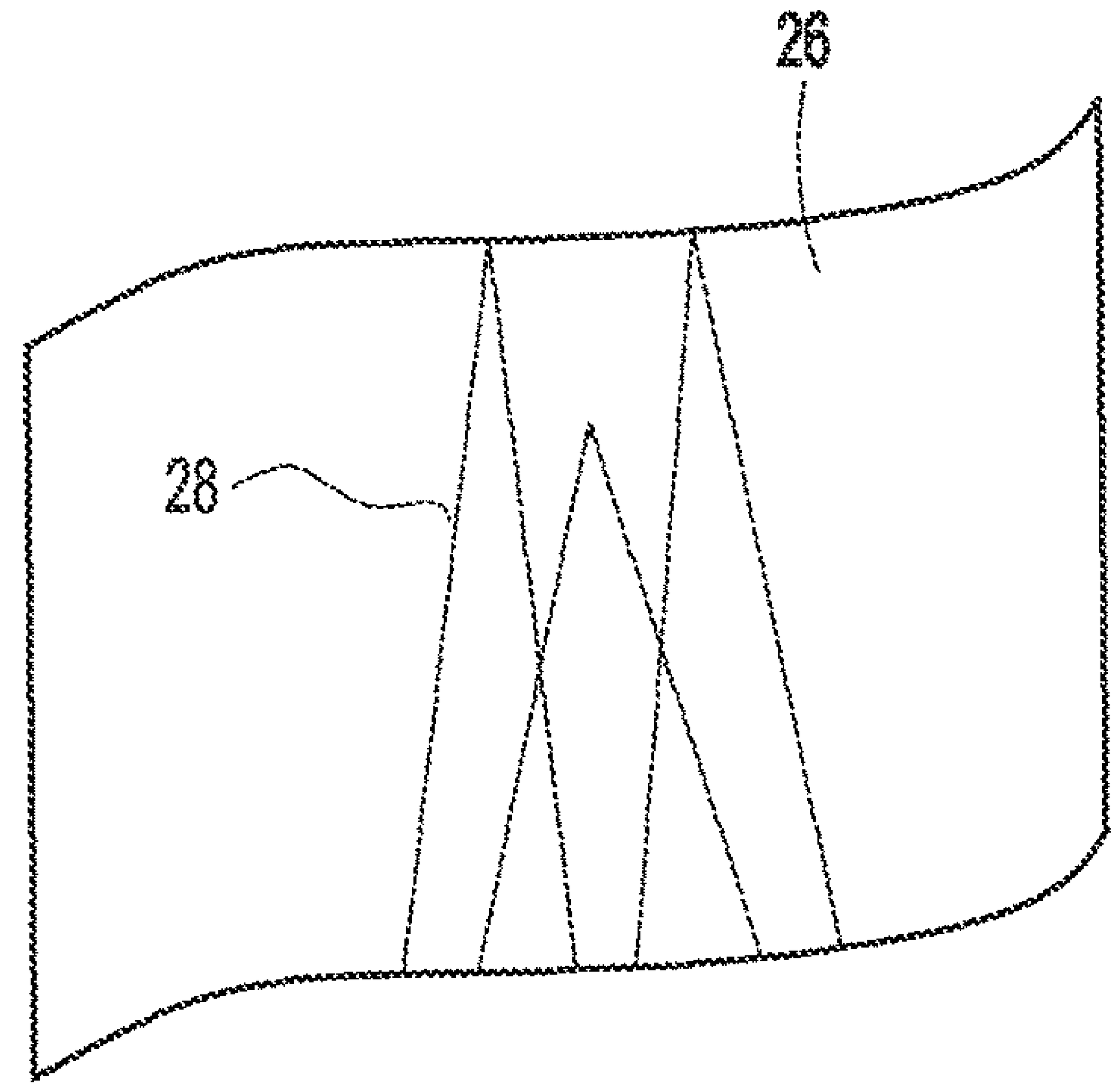

Fig-2

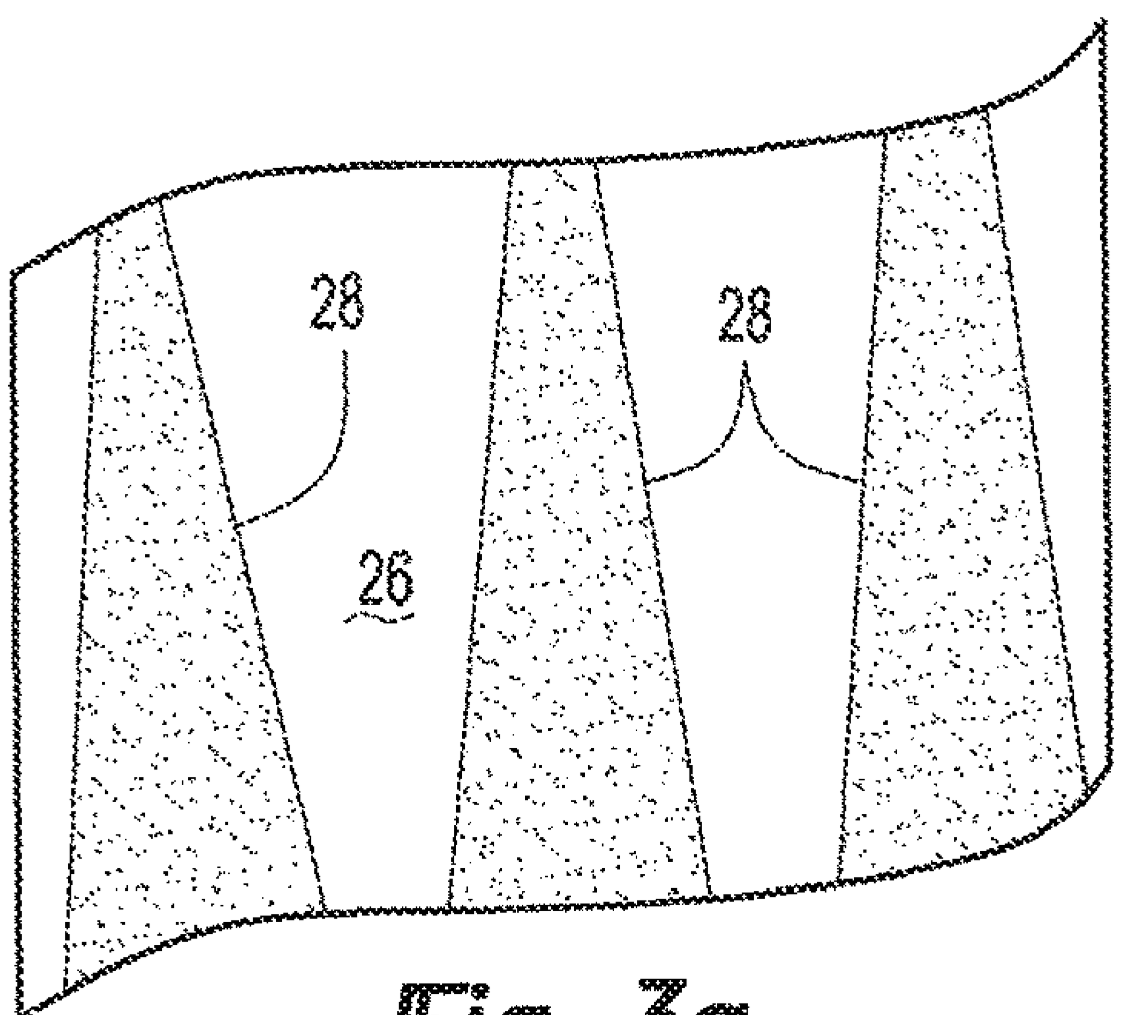

Fig-3a

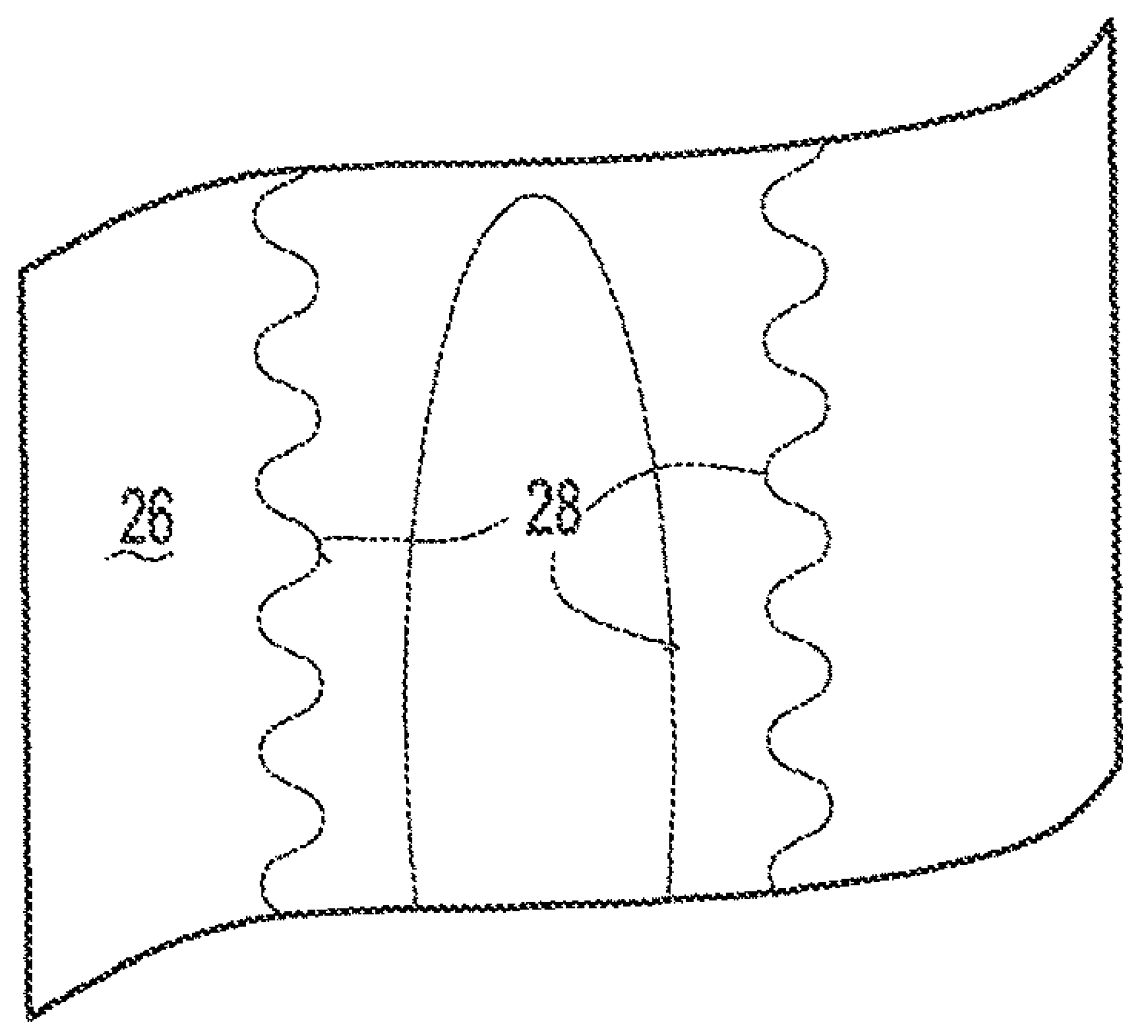

Fig-3b

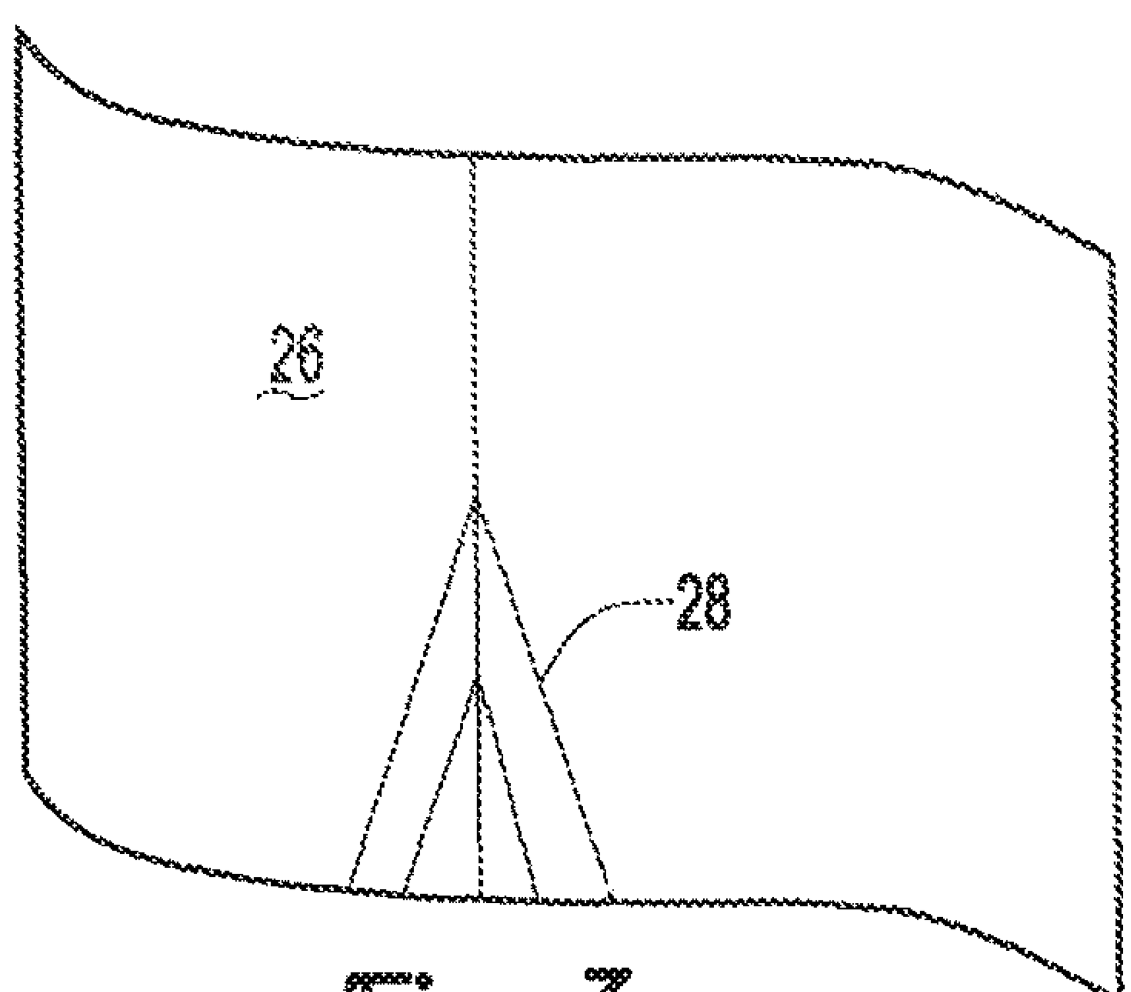

Fig-3c

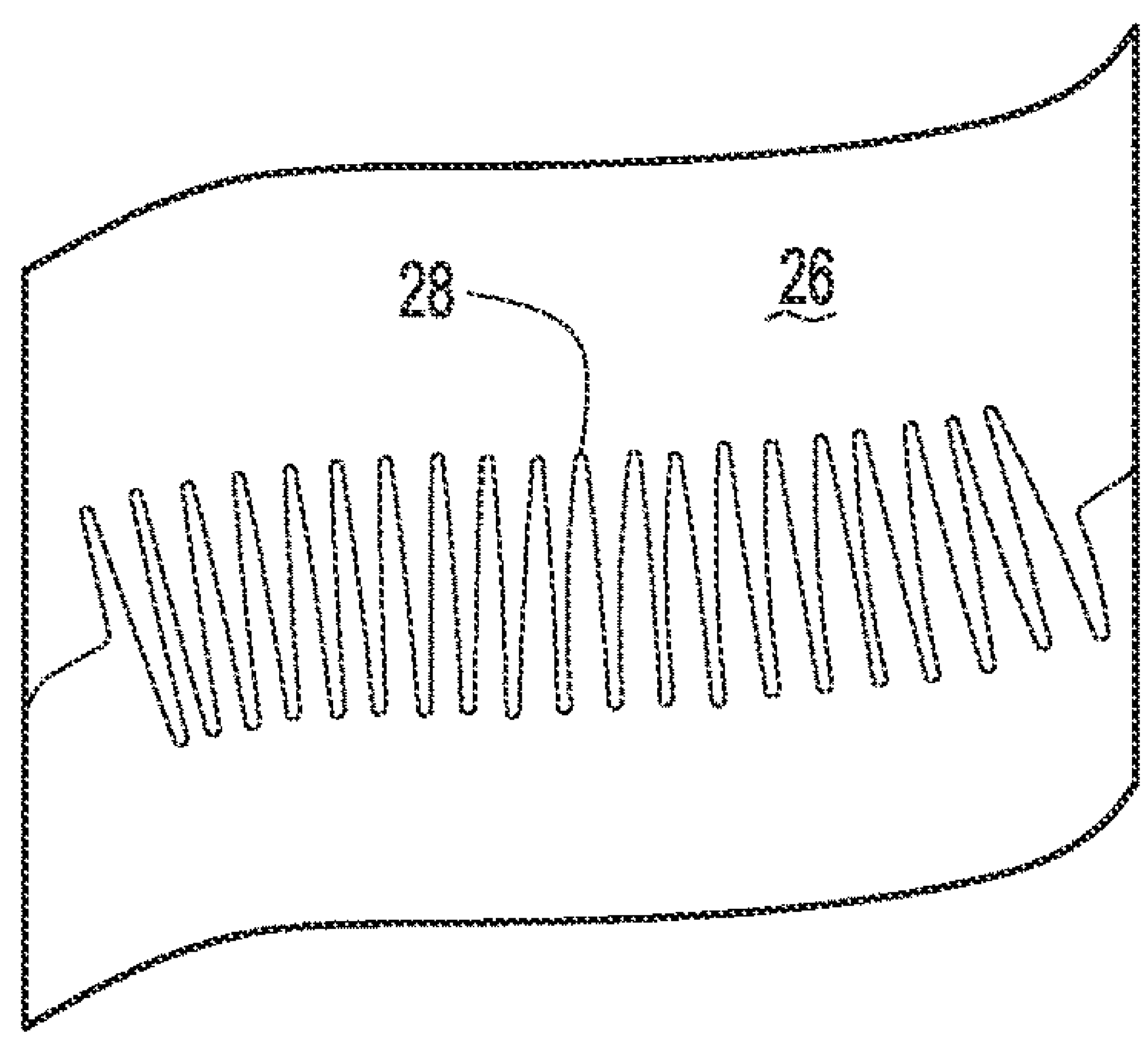

Fig-3d

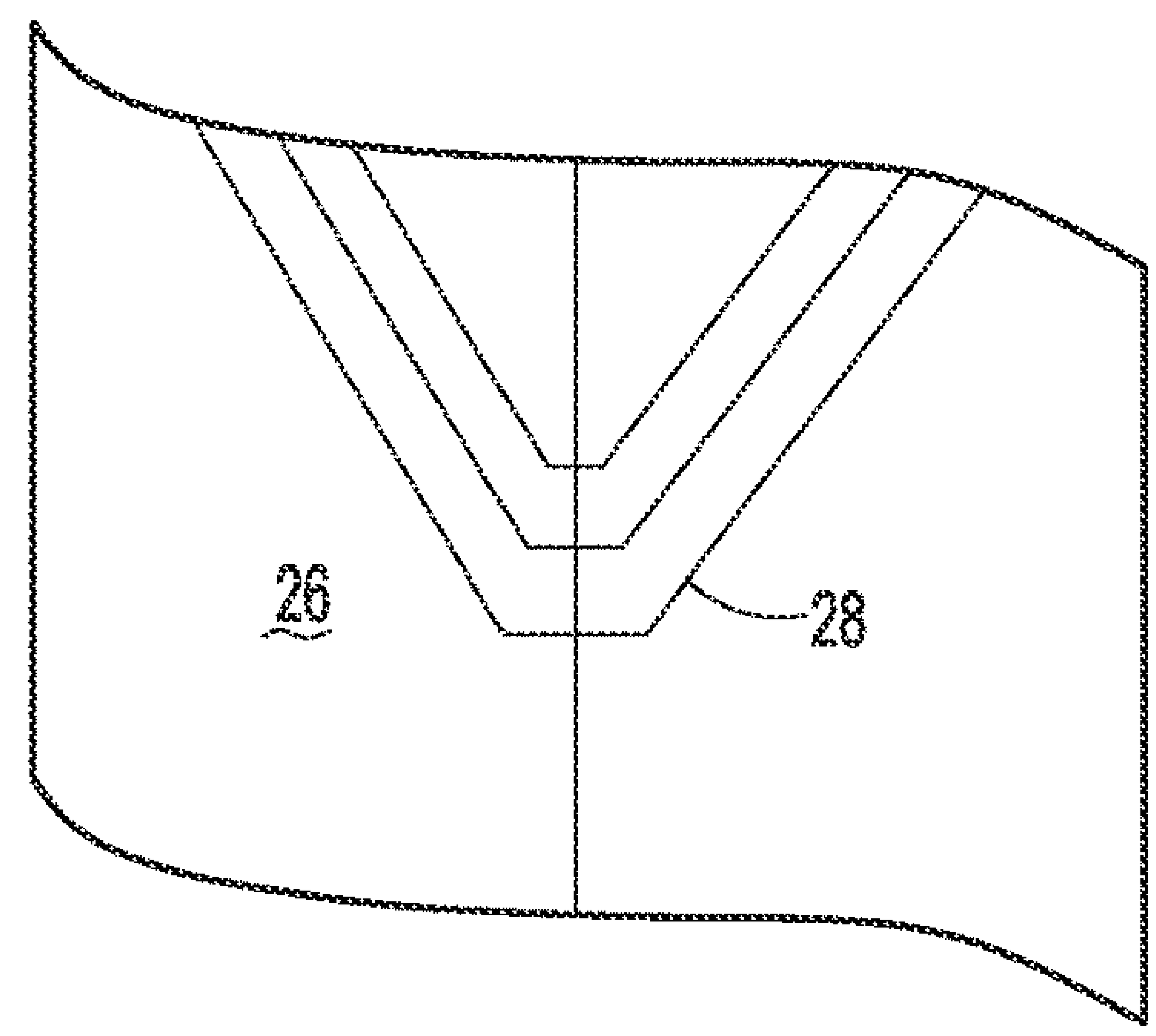

Fig-3e

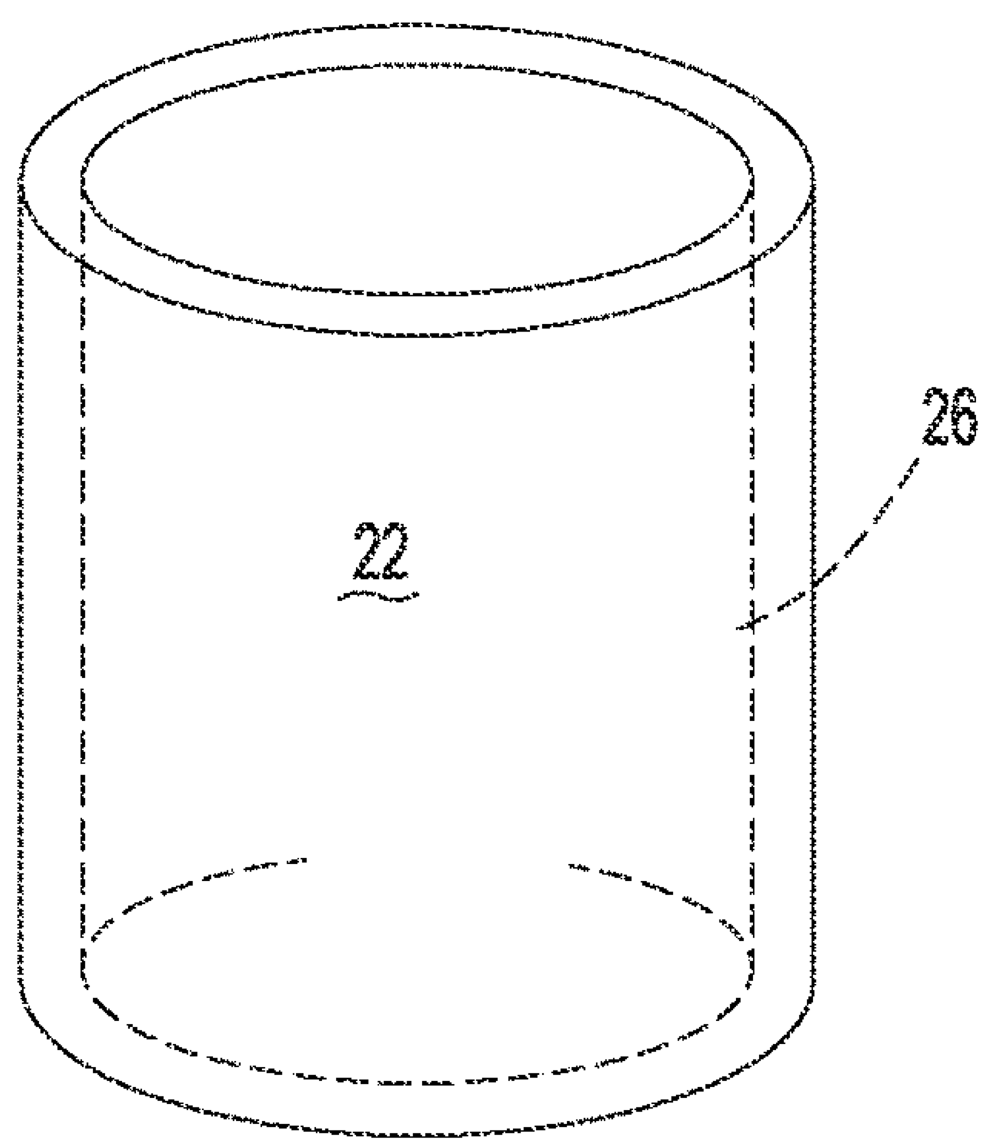

Fig-4a

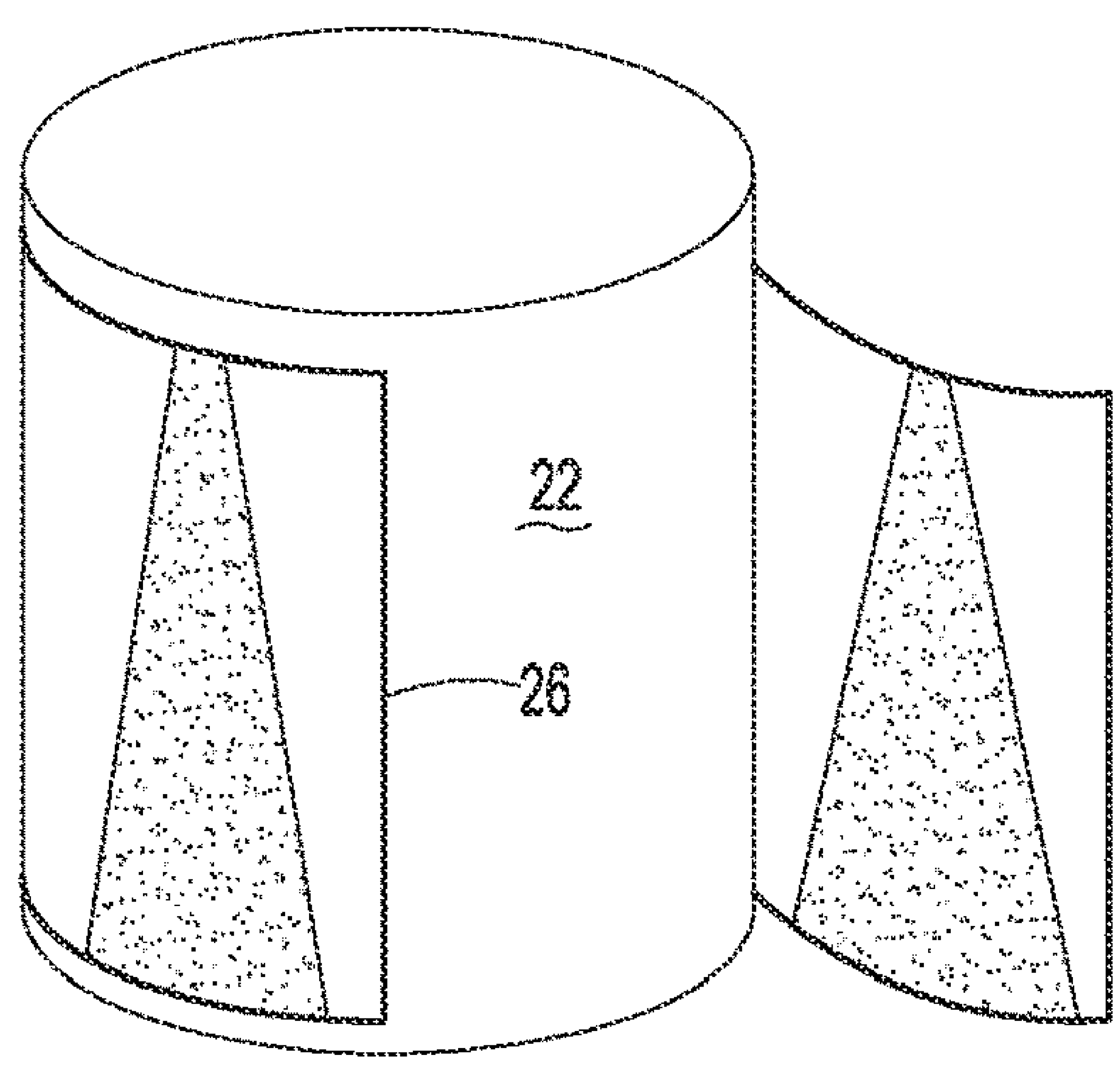

Fig-4b

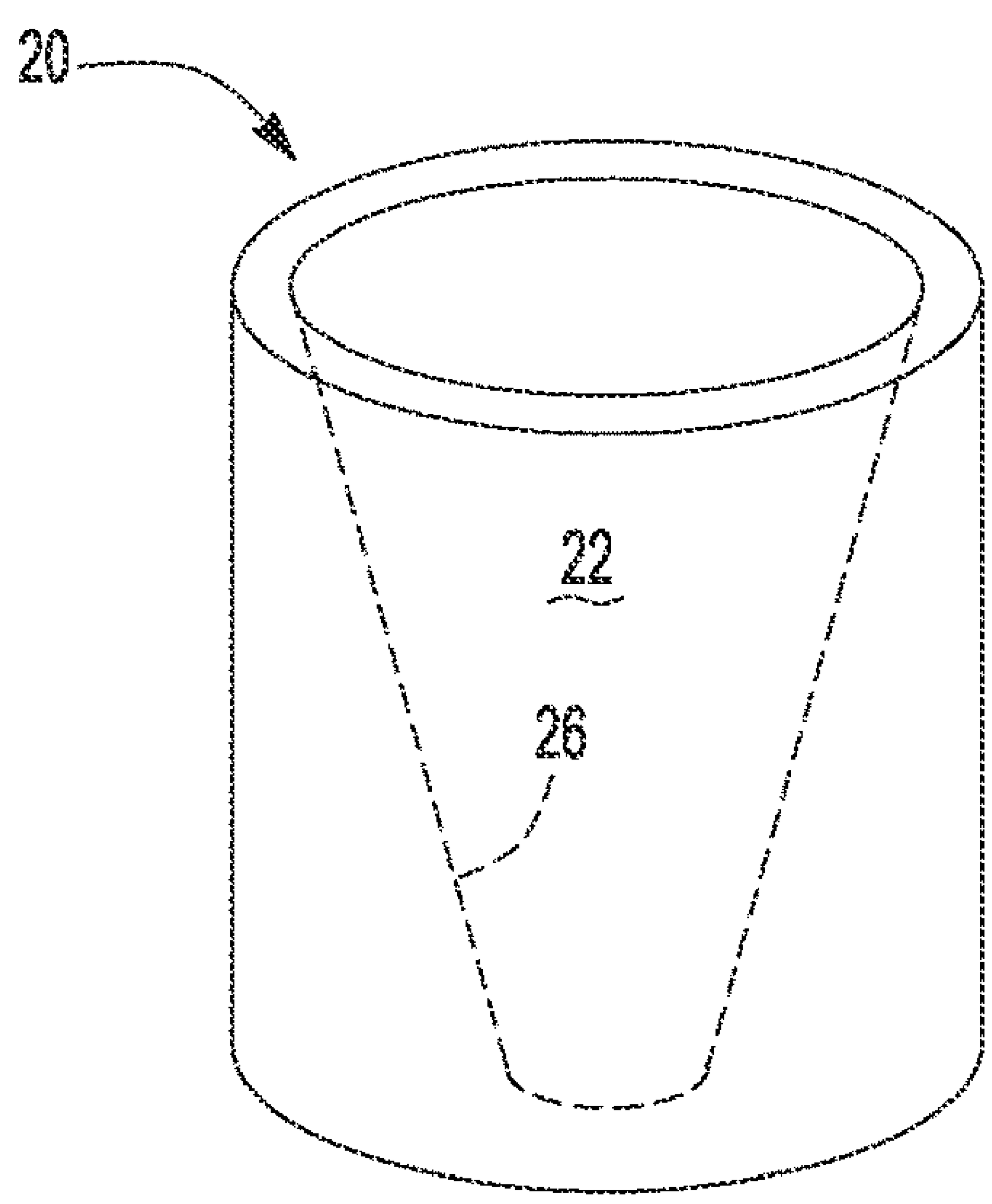

Fig-4c

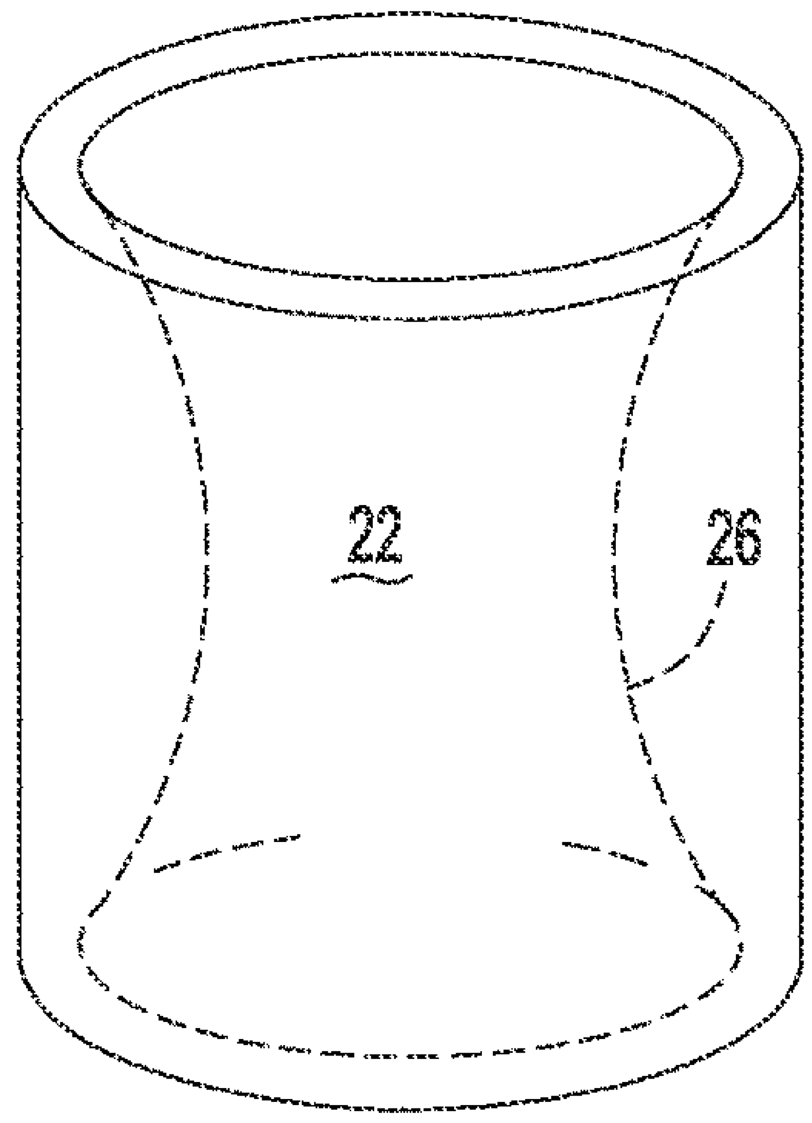

Fig-4d

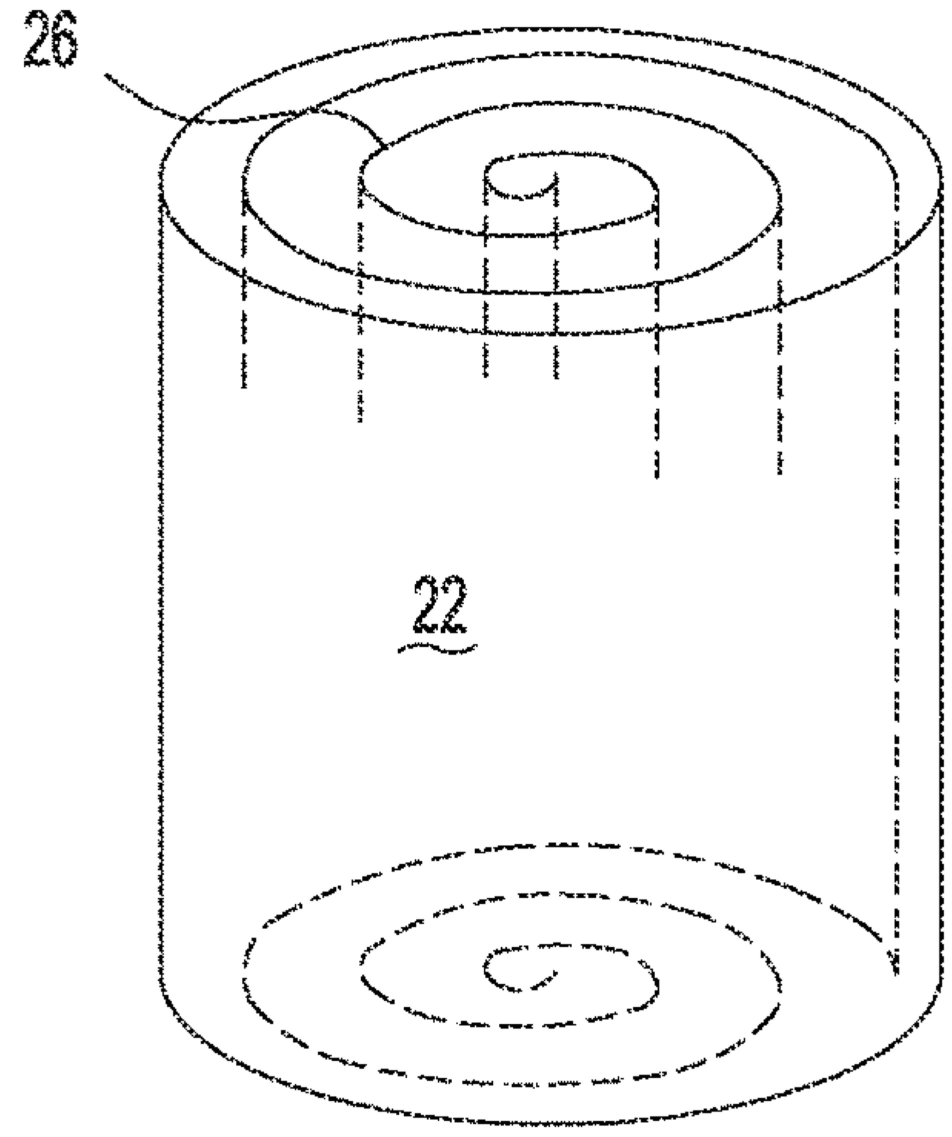

Fig-4e

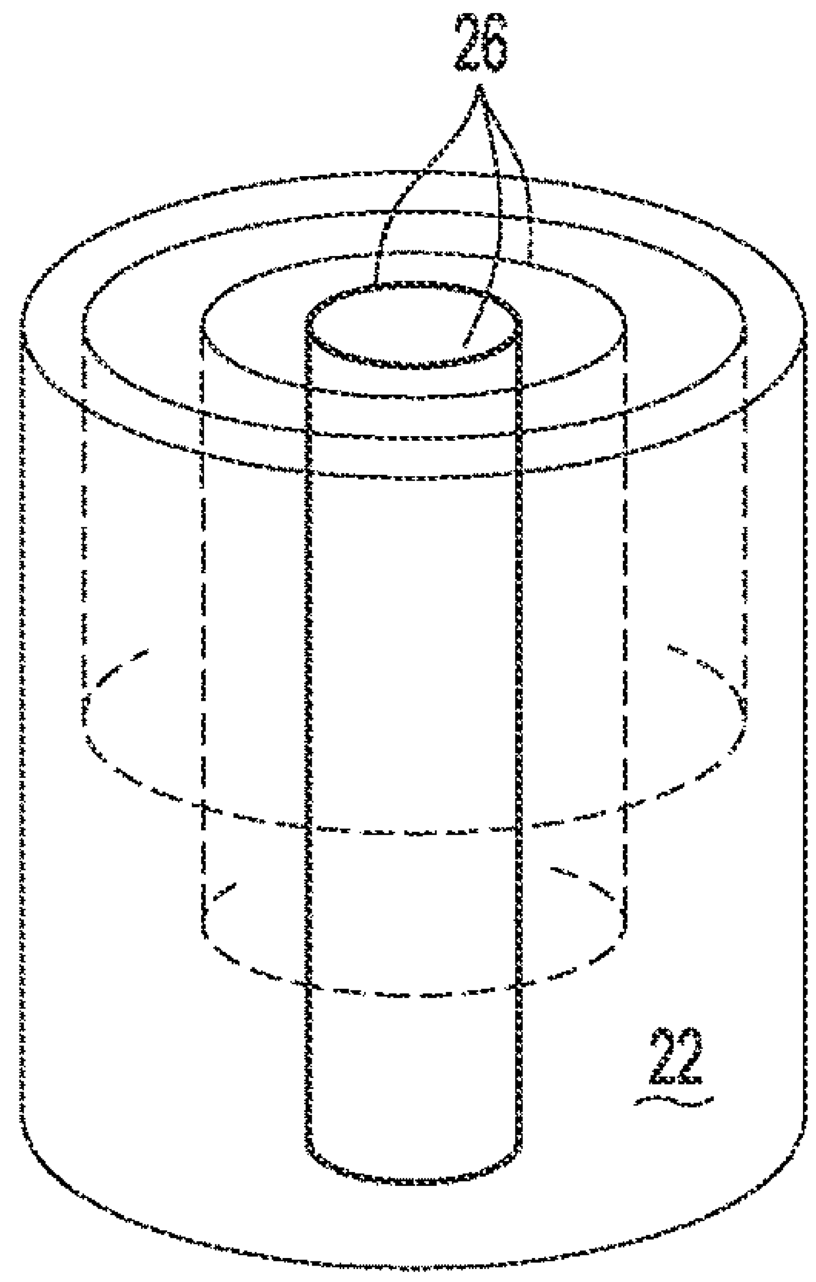

Fig-4f

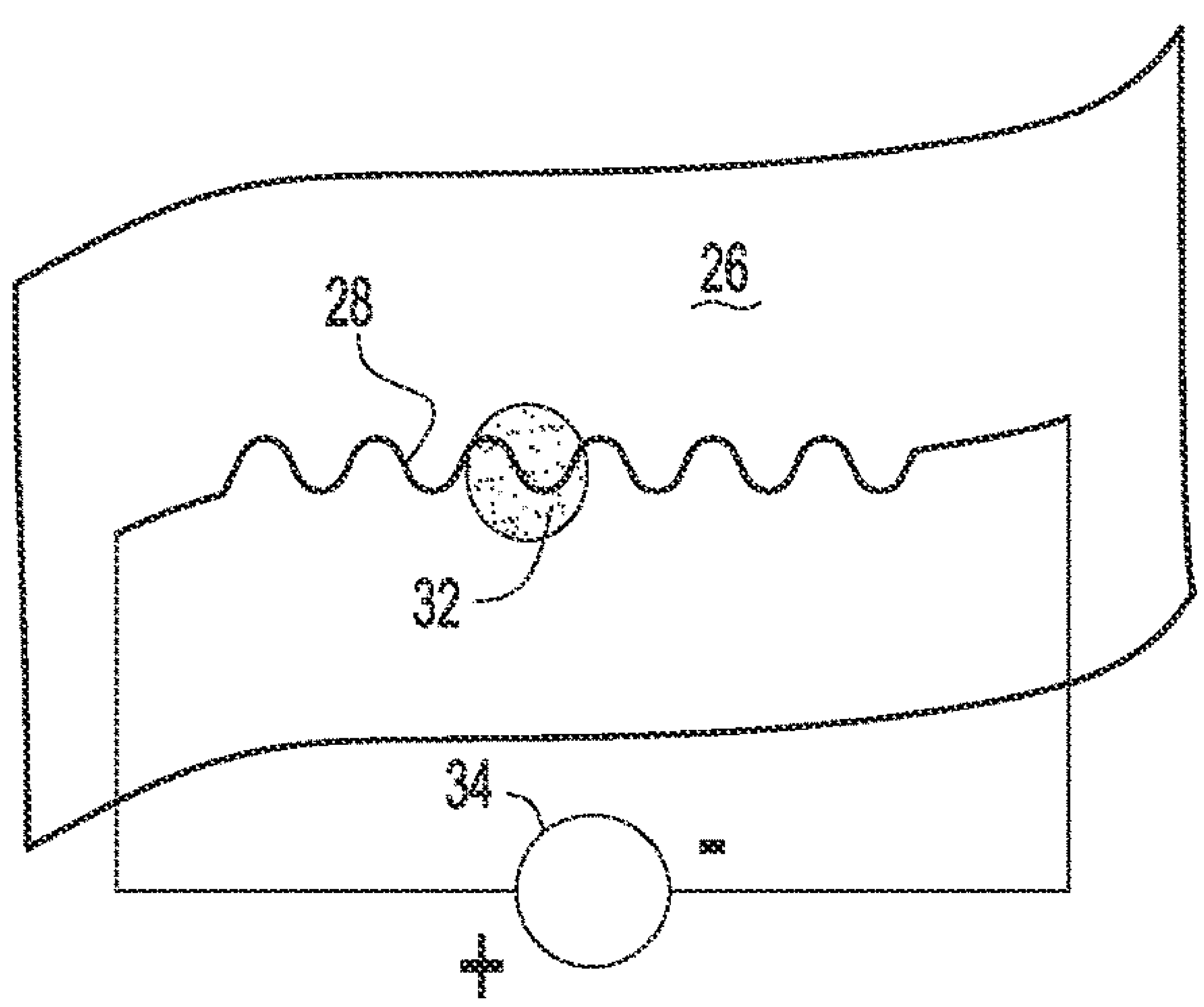

Fig-5

SOLID PROPELLANT GRAIN

GOVERNMENT INTEREST

The invention described herein may be manufactured, used, and licensed by or for the United States Government.

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates generally to a solid propellant grain.

II. Description of Related Art

Solid rocket propellants are used in many different rocket motors, especially for military applications. The solid propellant is ignited and creates a combustion zone on the propellant grain surface. The generated combustion gases create thrust via gas mass flow through the rocket nozzle, which provides propulsion for the solid rocket motor. Thrust over time ("thrust profile") is typically controlled by selection of desirable solid propellant burn rates and the geometry of the solid propellant grain. High thrust levels or complex thrust profiles usually require unique grain configurations such that the burning surface area coupled with propellant regression can achieve the desired gas mass flow. Achieving such grain surface areas requires internal passageways through the solid propellant, resulting in more free volume and less solid propellant within the confines of the combustion chamber. Such solid propellant grains result in low loading densities and reduced ranges.

One alternative is the end-burning solid propellant grain, where the propellant can fill virtually the entire combustion chamber. This has the highest loading density of any solid propellant grain, but also has the lowest initial surface area since just the flat end is exposed toward the rocket nozzle. Typical end-burning solid rocket motors result in long burn times but very low mass flow rate. Many rocket motors require much higher thrust levels to meet mission requirements.

Previously known attempts to increase the mass flow rate and thrust of end-burning solid rocket motors required embedding thermally conductive wires within the solid propellant, with one end of the wires in contact with initial burning surface. Thus, upon ignition of the rocket propellant, the heat from the combustion zone is thermally conducted by the wires into the rocket propellant, which creates localized conical combusting surface areas around the wires and results in increased mass flow and thrust. Thus the high loading density of the end-burning grain can achieve a greater thrust profile without a reduction in the mass of the total rocket propellant except, of course, for the minor mass of the embedded wires.

The previously known art of embedding thermally wires in solid propellant, however, is quite limited in the pattern of the embedded wires. The wires are usually straight, extending longitudinally through the rocket propellant, which was necessary since the propellant is cast into a mold of the desired shape of the propellant grain. Consequently, during solid propellant casting, the wires were maintained in a straight line under tension to assure the location and pattern of the embedded wires. Otherwise, if the wires drifted out of position then the overall performance of the rocket propellant could be jeopardized.

SUMMARY OF THE PRESENT INVENTION

The present invention provides a solid propellant grain which overcomes the above mentioned disadvantages of the previously known solid propellant grains.

In brief, the solid propellant grain of the present invention comprises a solid propellant that is formulated in the conventional fashion. The ingredients will vary, but any conventional rocket propellant may be used with the present construction.

Preferably, a membrane comprising of a flexible polymer will have a thermally conductive coating, such as a metallic foil, on one or both sides of the sheet. Thermally conductive pathways are etched into a desired pattern by removing portions of the metal foil using chemical etching, milling, or the preferred technique for the materials being used. The actual thermally conductive pattern may assume any of numerous forms dependent upon the propellant grain application.

Once the thermally conductive pattern is formed on the polymer sheet, the polymer sheet is positioned in the mold when the propellant is cast into its desired shape. The sheet may be embedded within the interior of the rocket propellant, used to surround the rocket propellant and, as needed, multiple flexible sheets may be embedded into a single propellant grain.

During the casting operation, the flexible sheets maintain the position of the thermally conductive pattern throughout the rocket propellant. Consequently, upon completion of casting of the rocket propellant into its mold, the position of the sheets, and thus the position of the thermally conductive patterns, is both established and known.

In operation, the thermally conductive patterns transfer heat from the combustion zone of the rocket propellant through the interior of the propellant grain thus increasing the rate of combustion. This, in turn, increases the mass flow rate from the combusting propellant grain thus providing greater propulsion for the rocket motor. Furthermore, since the flexible sheet consumes very little interior volume, the increase in the mass flow rate is obtained without a reduction of the actual mass of useful rocket propellant.

BRIEF DESCRIPTION OF THE DRAWING

A better understanding of the present invention will be had upon reference to the following detailed description when read in conjunction with the accompanying drawing, wherein like reference characters refer to like parts throughout the several views, and in which:

FIG. **1** is an elevational view illustrating a preferred embodiment of the present invention;

FIG. **2** is an elevational view illustrating a flexible membrane with an example thermally conductive pattern **28**;

FIGS. **3**A-**3**E are all elevational views of the membrane **26**, but illustrating different shapes for the thermally conductive pattern;

FIGS. **4**A-**4**F are all elevational views of solid propellant grains, but illustrating different methods of attaching or embedding the membrane to or within the rocket propellant; and

FIG. **5** is a view similar to FIG. **2**, but illustrating a modification thereof.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE PRESENT INVENTION

With reference first to FIGS. **1** and **2**, a propellant grain **20** is shown in FIG. **1** in the shape of an elongated cylinder. The propellant grain **20** includes a rocket propellant **22** composition which is cast into a desired shape for the propellant for a rocket by casting the rocket propellant **22** composition into an appropriately shaped mold. In FIG. **1**, for simplicity, the mold is cylindrical in shape.

The rocket propellant **22** may be of any conventional construction and fabricated in any conventional manner. Once positioned within a rocket, one face or one surface **24** is ignited to initiate the combustion of the propellant grain **20**.

With reference still to FIGS. **1** and **2**, a flexible membrane **26** is embedded within the rocket propellant **22**. This flexible membrane **26** is preferably constructed of a thin polymer sheet. Suggested polymer materials include, but are not limited to, polyesters, polyimides, or any other plastic materials that may be used to form the sheet **26**.

A thermally conductive pattern **28** is formed on the sheet **26**. This heat conductive pattern **28** can be formed from a metal foil, which typically exhibit highly thermally conductive properties. For example, the thermally conductive pattern **28** may be formed from silver, copper, aluminum, and so forth. In certain embodiments, the thermally conductive pattern **28** is symmetrical, in certain embodiments, the thermally conductive pattern **28** is symmetrical about the vertical axis of sheet **26**.

Thermally conductive pattern **28** can be formed on membrane **26** by applying a metal foil or other similar materials across one or both sides of the membrane **26** in any conventional fashion. The conductive layer on the membrane **26** is then etched, or otherwise patterned, to remove the unwanted portions and leave the heat conductive pattern **28** on the membrane **26**.

With reference now particularly to FIG. **1**, with the membrane **26** embedded in the solid rocket propellant **22**, the heat conductive pattern **28** extends towards the face **24** of the propellant grain **20**. Consequently, upon ignition of the face **24** of the propellant grain **20**, heat from the combustion transfers along the pattern **28** thus warming the rocket propellant **22** in the shape defined by the heat conductive pattern **28**. In this way, by proper design of the heat conductive pattern **28**, the shape of the combustion zone may be carefully controlled. For example, if desired, the combustion zone may be shaped into a plurality of conical combustion zones for the example of the heat combustion pattern **28** shown in FIG. **1**.

With reference now to FIGS. **3**A-**3**E, the shape of the heat conductive pattern **28** may assume any design desired. Furthermore, as shown in FIG. **3**A, the heat conductive pattern **28** may include large areas or merely in the shape of a thin wire as shown in FIGS. **3**B-**3**E. In order to transfer the heat from the combustion zone and to other areas of the rocket propellant, the thermally conductive pattern **28** should be in contact with the rocket propellant. However, the contact between the flexible membrane **26**, and thus the heat conductive pattern **28**, and the rocket propellant **20** may occur in any of several fashions.

For example, with reference now to FIGS. **4**A-**4**F, several different constructions for the position of the flexible membrane relative to the rocket propellant **22** are shown. For example, in FIG. **4**A, the membrane **26** with its heat conductive pattern **28** is embedded within the rocket propellant **22**. In FIG. **4**B, the flexible membrane **26** with its heat conductive pattern **28** is wrapped around the outside of the rocket propellant **22**. Thus, the heat from the combustion zone will be transferred along the outer periphery of the rocket propellant **22**.

In FIG. **4**C, the membrane **26** is in the shape of a cone embedded within the rocket propellant **22**. Thus, upon ignition of the rocket propellant **22**, the thermally conductive pattern on the membrane **26** will create a conical combustion zone for the propellant grain **20**.

In FIG. **4**D, the membrane **26** with its thermally conductive pattern **28** is in the shape of parabola which, upon ignition of the rocket propellant **22**, will exhibit its own characteristics. In FIG. **4**E, the flexible membrane **26** is in the shape of a spiral embedded within the rocket propellant **22**.

With reference now to FIG. **4**F, multiple flexible membranes **26**, each having their own thermally conductive pattern, may be in contact with the rocket propellant **22**. As shown in FIG. **4**, the plural flexible membranes **26** are in the shape of cylindrical tubes each having a different length, and each of which is embedded concentrically within the rocket propellant **22**.

With reference now to FIG. **5**, an example thermally conductive pattern **28** is shown attached to its associated flexible membrane **26**. Unlike the previously known heat conductive patterns, however, a bead igniter **32** has been deposited along the length of the thermally conductive pattern, in the example shown, in the center of the thermally conductive pattern. In operation, the bead igniter **32** may be ignited either from heat transfer from the combustion zone along the heat conductive pattern **28** and to the igniter **32**, or alternatively by conducting electric current from a voltage source **34** to the igniter **32** through the thermally conductive pattern **28**.

With reference to FIG. **5**, an example thermally conductive pattern **28** is shown attached to its associated flexible membrane **26**. An electric current from a voltage source **34** to the igniter **32** through the thermally conductive pattern **28** can be used to pre-warm the propellant grain **20** such that performance is identical despite colder ambient conditions.

Consequently, it can be seen that the flexible membrane **26** provides a support for the thermally conductive pattern during the casting operation of the rocket propellant. As such, the design of the thermally conductive pattern **28** is virtually unlimited thus allowing the rocket designer to achieve the desired thrust profile for a particular rocket.

Having described our invention, however, many modifications will become apparent to those skilled in the art to which it pertains without deviation from the spirit of the invention as defined by the scope of the appended claims.

We claim:

1. A solid propellant grain comprising:

a propellant having an interior,

a polymer sheet having at least one surface and having a thermally conductive pattern disposed on said at least one surface, said polymer sheet and said thermally conductive pattern being in contact with said propellant wherein said thermally conductive pattern transfers heat from a combustion zone through the interior of the propellant to increase the rate of combustion and provide greater propulsion, wherein said thermally conductive pattern comprises a metal.

2. The solid propellant grain of claim **1** wherein said polymer sheet is embedded in said propellant.

3. The solid propellant grain of claim **1** wherein said polymer sheet having said thermally conductive pattern is embedded in the propellant in the shape of a cone to create a conical combustion zone in the propellant.

4. The solid propellant grain of claim **1** wherein said polymer sheet having said thermally conductive pattern is embedded in the propellant in the shape of a parabola to create a parabolic combustion zone in the propellant.

5. The solid propellant grain of claim **1** wherein said polymer sheet having said thermally conductive pattern is embedded in the propellant in the shape of a spiral to create a spiral combustion zone in the propellant.

6. The solid propellant grain claim **1** wherein said polymer sheet is wrapped around the outside of said propellant such that heat from combustion will be transferred along the outer periphery of said propellant.

7. The solid propellant grain of claim **1** wherein said polymer sheet is flexible.

8. The solid propellant grain of claim **1** wherein said polymer sheet comprises a polyimide sheet.

9. The solid propellant grain of claim **1** wherein said polymer sheet comprises a polyester sheet.

10. The solid propellant grain of claim **1** wherein said polymer sheet and thermally conductive pattern comprises in total a metallic foil.

11. The solid propellant grain of claim **1** wherein said thermally conductive pattern is formed by etching a metallic foil on said sheet.

12. The solid propellant grain of claim **1** wherein said solid propellant grain comprises a plurality of polymer sheets, each polymer sheet having two surfaces and a thermally conductive pattern on at least one surface of said sheet.

13. The solid propellant grain of claim **1** wherein said heat conductive pattern is vertically oriented in said propellant.

14. The solid propellant grain of claim **1** wherein said sheet has a vertical axis and said heat conductive pattern is vertically oriented and symmetrical about the vertical axis of said sheet.

15. The solid propellant grain of **1** wherein said polymer sheet has a vertical axis and said heat conductive pattern is vertically oriented and symmetrical about the vertical axis of the polymer sheet and said propellant.

16. A rocket propellant grain comprising:

a rocket propellant grain having a vertical axis that aligns with a vertical axis of a rocket, and

a polymer sheet having at least one surface and having a heat conductive pattern disposed on said at least one surface wherein said heat conductive pattern is symmetric about a sheet axis and comprises a metal;

wherein said sheet axis aligns with the vertical axis of the rocket propellant grain and said heat conductive pattern being in contact with said rocket propellant grain such that the heat conductive pattern affects the rocket propellant grain burning rate though localized heat transfer from the combustion zone into the uncombusted rocket propellant grain.

17. A method of forming a solid propellant grain comprising:

forming a thermally conductive pattern comprising a metal on a polymer sheet,

positioning the polymer sheet in a mold such that said thermally conductive pattern is configured to transfer heat from a combustion zone through an interior of said solid propellant grain, and

casting propellant in the mold so that the polymer sheet is embedded within the propellant and the thermally conductive pattern on the polymer sheet is in contact with said propellant.

18. The method of forming a solid propellant grain of claim **17** wherein the thermally conductive pattern is formed symmetrically about a vertical axis of said polymer sheet.

19. A method of increasing the mass flow rate and thrust of an end-burning solid rocket motor, the method comprising:

forming a thermally conductive pattern comprising a metal on a polymer sheet,

positioning the polymer sheet in a mold such that said thermally conductive pattern is configured to transfer heat from a combustion zone through an interior of said solid propellant grain, and

casting propellant in the mold so that the polymer sheet is embedded within the propellant and the thermally conductive pattern on the polymer sheet is in contact with said propellant.

20. The method of increasing the mass flow rate and thrust of an end-burning solid rocket motor of claim **19** wherein the thermally conductive pattern is formed symmetrically about a vertical axis of said polymer sheet.

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