United States Patent

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[54] TRANSPIRATION-COOLED DEVICES

10 Claims, 3 Drawing Figs.

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60/39.66, 239/127.1
[51] **Int. Cl.** **F02k 11/02,**
B64d 33/08
[50] **Field of Search** 60/258,
265, 260, 39.66; 239/127.3

[56] **References Cited**

UNITED STATES PATENTS

2,705,399	4/1955	Allen	60/39.66
2,926,490	3/1960	Eaton	60/267
3,115,746	12/1963	Hsia	60/265
3,153,320	10/1964	Prosser	239/127.3
3,289,405	12/1966	Eng	60/39.74
3,309,026	3/1967	Loprete	60/266

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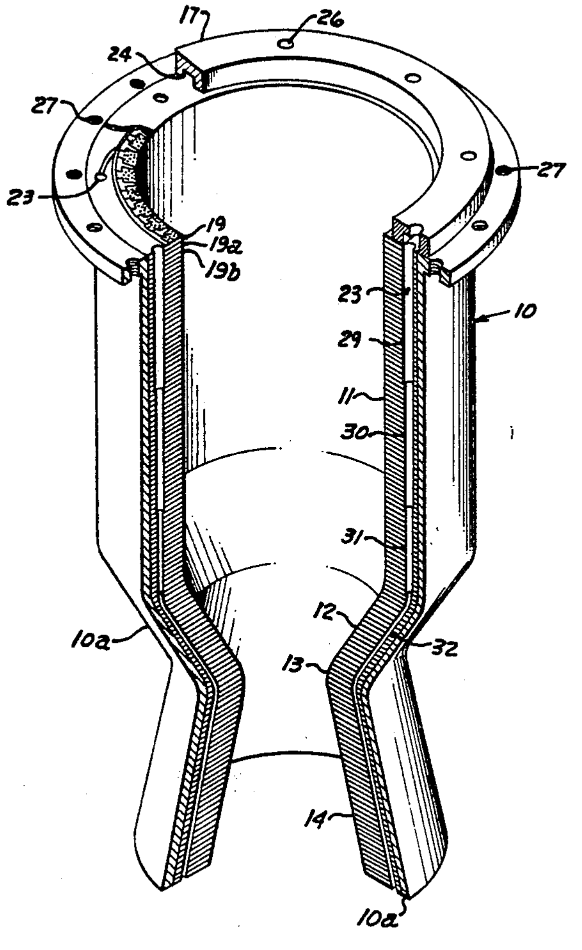
ABSTRACT: This invention relates to transpiration cooling and particularly to transpiration cooling of devices subjected to heat flux above the capabilities of the material forming the device, such as thrust chambers for rockets.

According to the present invention, a device to be cooled by transpiration cooling has a wall constructed of a plurality of discrete wafers, each having planar surfaces and edge surfaces. A controlled pattern of flow passages is formed on one or both planar surfaces of each wafer, each flow passage terminating at an end surface of the wafer. The wafers are joined together in a stack to form a unitary structure. The passage terminating edge surfaces together form the wall surface of the device, and the wall surface resembles a porous wall. The wafers are thin enough to give excellent wafer-to-coolant heat transfer area.

Transpiration cooling is accomplished by permitting coolant to flow through the passages in such a manner that heat input into the wall of the device is efficiently transferred to the coolant within the wall. This enables the coolant to reach the maximum limiting temperature of the wall material before it is introduced onto the wall surface, thus fully exploiting the cooling capacity of the coolant.

According to an optional but desirable feature of this invention, the flow passages in the wafers are divided into discrete groups, thereby allowing isolation of areas where coolant boiling might occur. Restrictor passages are provided to each group of passages so that the flow resistance into each group of passages is independent of the heat transfer on the surface of the device.



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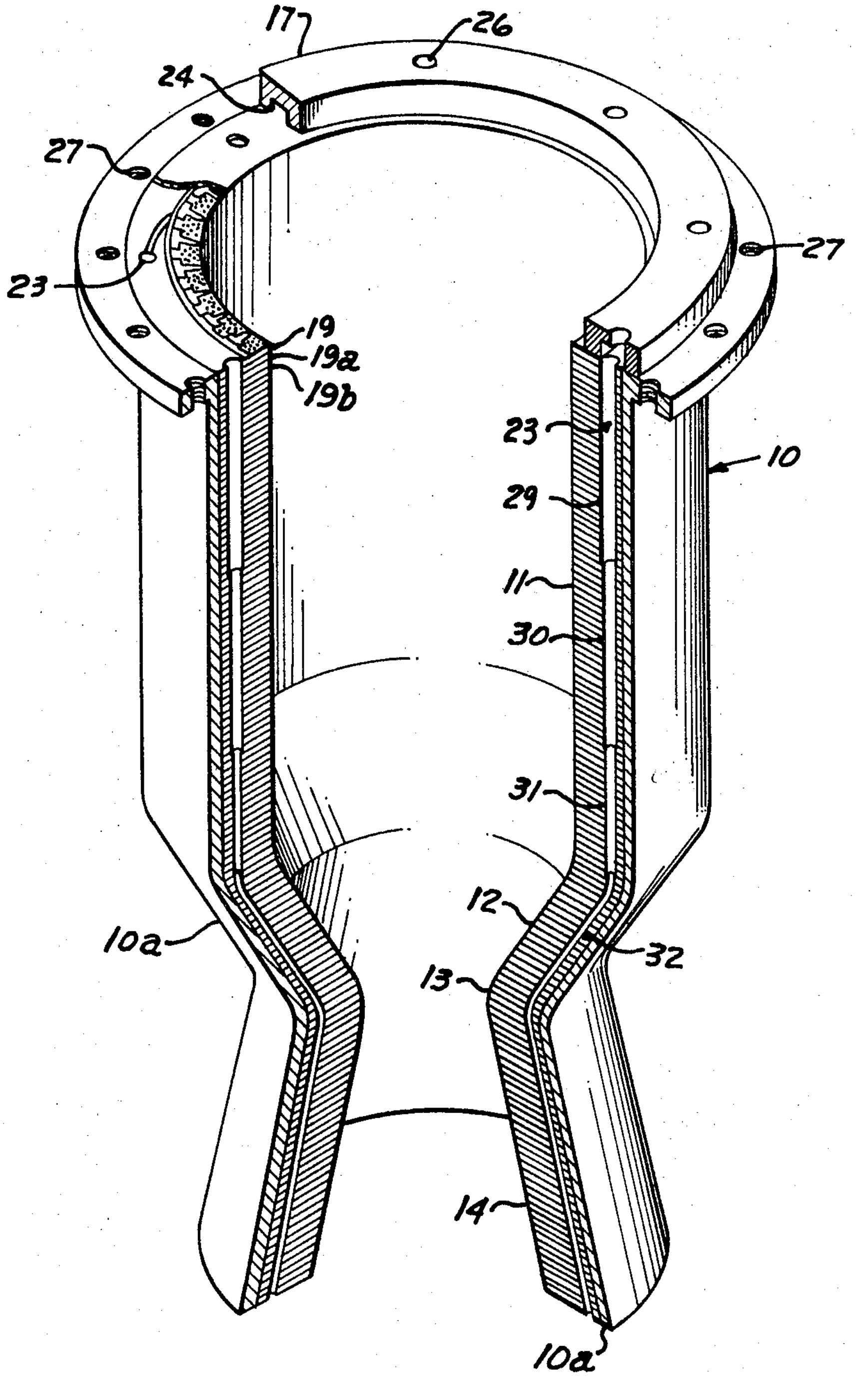

FIG. — 1

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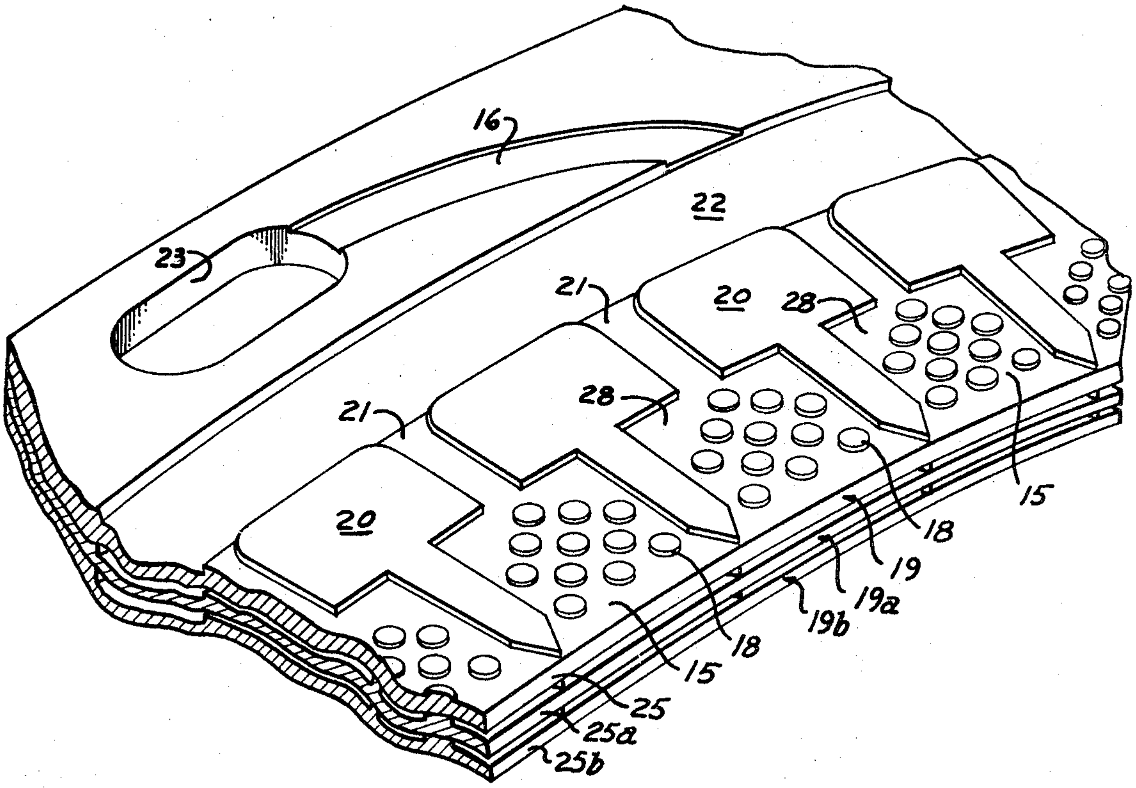

FIG. — 2

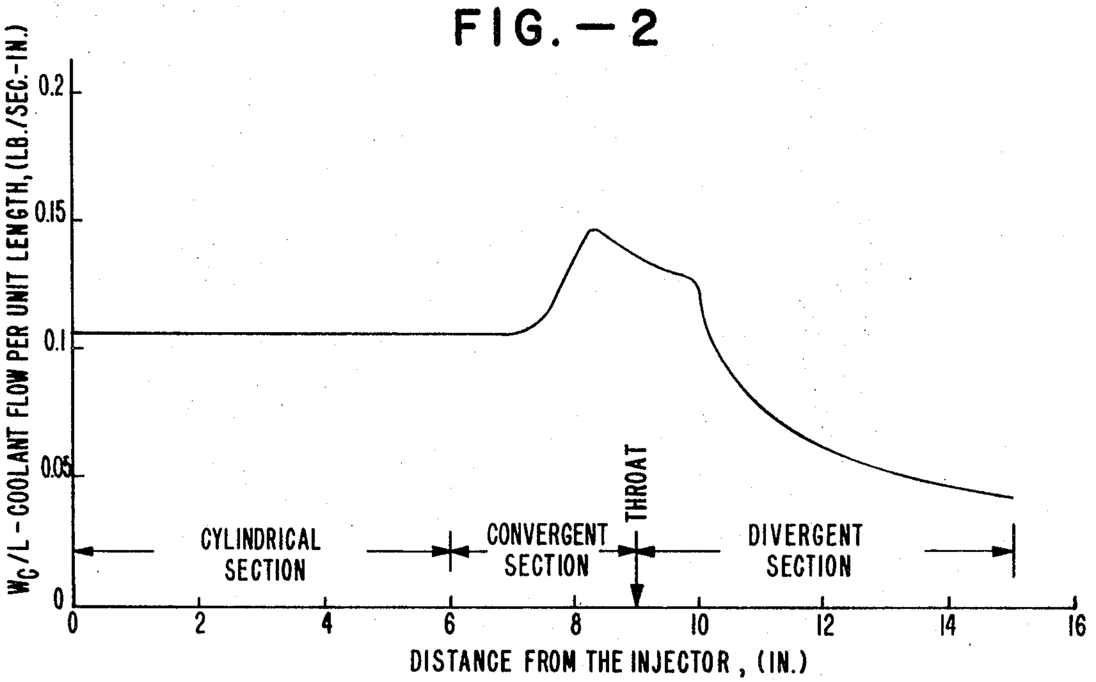

FIG. — 3

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TRANSPIRATION-COOLED DEVICES

This invention relates to transpiration cooling and particularly to transpiration cooling of devices subjected to heat flux above the capabilities of the material forming the device, such as rocket thrust chambers.

Devices, such as thrust chambers, cooled with conventional techniques, are susceptible to wall failures due to erosion in regions where the heat transfer conditions are unusually severe. Local melting or erosion of a small area of the surface of the chamber can cause a complete failure of the chamber wall since high-pressure coolant within a coolant tube will erupt through the failure opening.

Transpiration cooling has been recognized to be an effective method of cooling chambers under severe heat transfer operating conditions; that is, chambers operating under high pressures and high heat fluxes. Transpiration cooling is basically a process whereby a surface device, vessel, wall, container or the like in contact with heat energy at a temperature above the capabilities of the material forming the surface, is kept cool by the flow of a coolant fluid through the material toward the heat source.

Prior to the present invention, practical application of transpiration cooling has not been accomplished with any degree of success. Difficulties in fabricating complex shapes, coolant flow control problems, and porosity nonuniformities, have been major stumbling blocks to the successful development of transpiration-cooled devices. In addition, those devices constructed with conventional porous materials have been subject to "hot spot instability." Hot spot instability is a phenomenon in which an overheated region is deprived of coolant and the overheated region grows in size and intensity. Hot spot instability occurs because the hydraulic resistance of a conventional porous wall increases as the wall temperature rises due to the decreasing coolant density. Thus, when a region overheats, the coolant circumvents it due to its higher hydraulic resistance and the hot spot, now partially deprived of coolant, partially becomes hotter. Furthermore, conventional porous materials, being permeable in all directions, have the inherent limitation of being susceptible to the flow of hot combustion gases through the porous material, especially when utilized in a high-pressure gradient region of a throat.

The present invention overcomes the foregoing disadvantages of prior known techniques in that wafers or plates having passages to permit coolant flow are used; the wafers being thin enough to provide intimate thermal contact between the metal and the coolant within the wall. This enables the coolant to approach the maximum limiting temperatures of the wall material before it is introduced onto the chamber surface. In this manner, the cooling capability of the fluid is completely exploited and the coolant flow may be minimized. Furthermore, because with this invention the coolant passages are not random but discrete, they can be designed such that the coolant is brought to the heated surface in a great multiplicity of hydraulically isolated parallel passages. By designing these passages such that their area of major hydraulic resistance is some distance removed from the heated surface, their hydraulic resistance is made essentially independent of the surface heat flux. This uncouples the coolant flow from the surface temperature and substantially eliminates hot spot instability.

It is an object of the present invention to provide a transpiration cooling system for a device, such as a thrust chamber for a rocket.

Another object of the present invention is to provide a wafer design which makes possible the use of thin wafers having passages for coolant flow for transpiration cooling of devices.

According to the present invention, a device to be cooled by transpiration cooling has a wall constructed of a plurality of discrete wafers, each having planar surfaces and edge surfaces. A controlled pattern of flow passages is formed in one planar surface of each wafer, each flow passage terminating at an end surface of the wafer. The wafers are joined together in a stack to form a unitary structure. The passage terminating edge surfaces together form the wall surface of the device. Each wafer is sufficiently thin so that the resulting large number of wafers in the structure result in large coolant-to-wafer contact areas and provide excellent thermal communication between the coolant and wafers.

According to an optional but desirable feature of the present invention, the flow passages in the wafer are divided into groups, each group being in an individual flow compartment.

The present invention offers significant advantages over conventional cooling techniques in the following respects:

1. Precise flow control.—Control of the flow of the coolant in the lateral direction can be accurately maintained by varying the depth or length of the passage through the wafer, and providing internal manifold sizes conforming to the flow desired. If desired, the flow can easily be varied circumferentially over the surface of the chamber to accommodate nonuniform combustion conditions.

2. Failure protection.—The wafer-type transpiration-cooled design is not susceptible to failure caused by high-pressure coolant erupting through a failure opening in the chamber wall, since no high-pressure coolant is necessary in the high-temperature area of the chamber wall. Furthermore, localized overheating will not result in hot spot instability because the local coolant flow is uncoupled from the surface heat flux through the use of hydraulically isolated parallel coolant flow passages which have their hydraulic resistance significantly removed from the heated surface.

3. Cooling effectiveness.—By permitting excellent thermal communication between the metal of the wall and the coolant at all points within the wall, the cooling capability of the coolant is completely exploited and the cooling efficiency is maximized.

4. Fabrication simplicity.—Due to the basic simplicity and repetitious nature of the design, the same technology can be applied to rocket engines of all sizes. Building of micromotors can be accomplished with the same techniques employed in construction of huge multimillion-pound boosters. In addition, larger chambers can be fabricated by using a number of smaller easily constructed modules.

The above and other features of this invention will be more fully understood from the following detailed description and the accompanying drawings, in which:

FIG. 1 is a perspective view, partly in cutaway cross section, showing a thrust chamber according to a presently preferred embodiment of the present invention;

FIG. 2 is a perspective view, partly cut away, of a plurality of wafers stacked together to form a portion of the thrust chamber illustrated in FIG. 1; and

FIG. 3 is a graphical illustration of the coolant flow rate distribution in the thrust chamber illustrated in FIG. 1.

Referring now to the drawings, and particularly to FIGS. 1 and 2, there is illustrated a thrust chamber **10** having a cylindrical section **11** and an exhaust nozzle comprising a convergent section **12**, a throat **13** and a divergent section **14**. The inside face of the thrust chamber resembles a porous wall, containing many thousands of small openings or holes **15** which are in the order of several thousandths of an inch across and arranged in a precise, predetermined pattern. Holes **15** have hydraulic diameters within the range of 0.0005 inch to 0.020 inch; a typical size being 0.004 inch. Each hole is in fluid communication with a manifold **17** by means of a precisely controlled metering passage **16** which accurately meters the coolant flow to the holes. The term "hydraulic diameter" as used herein means four times the cross-sectional area divided by the wetted perimeter. The term "wetted perimeter" as used herein means the size of the perimeter of the passage actually wetted by fluid, which for purposes of this invention is the actual perimeter size.

The thrust chamber **10** is made of a stack of a large number of thin wafers **19** whose inner and outer peripheries are cylinders which define the inside and outside diameters of the chamber. The wafers are housed within housing **10*a*** which forms an outer shell for the thrust chamber and defines the outer diameter of the chamber.

Holes **15** are formed between islands **18** on each wafer **19**; the islands also serving as separators between adjacent wafers and being an integral part of the flow pattern on the wafer surface. Each wafer **19** is between 0.001 and 0.050 inches in thickness, 0.007 inch being typical although other thicknesses may be employed dependent upon the application.

Flow restrictors **20** having shapes approximating T-shaped islands, are formed as an integral part of each wafer **18**, and form passages **21** between the broadest section of the restrictors. Preferably separation between adjacent flow restrictors is such that passages **21** have a hydraulic diameter of the order between 0.0005 inch and 0.010 inch, a typical hydraulic diameter being 0.002 inch. As a result of the small hydraulic diameter of these passages, the flow through them will be substantially laminar.

The narrow portion between adjacent restrictors **20** forms a flared passage or flow channel **28** which provides a low-resistance flow path in the region where the flow will be subjected to influence of heat transfer conditions on the face of the thrust chamber. This flared passage makes the total flow resistance of each path relatively insensitive to heat transfer on the face of the thrust chamber.

A distribution plenum **22** is formed in each wafer **19** so that the flow of coolant from manifold header passage **23** is permitted to flow through metering passage **16**, plenum **22**, passages **21** and to holes **15**. Header passages **23** are in fluid communication with passage **24** of manifold **17**.

The individual wafers **19** may be formed any one of several different ways. One method known to those skilled in the art is photoetching. With photoetching, a thin metal sheet is imprinted with an acid resistant ink which outlines all the flow passages. The sheet is then immersed in an acid bath which etches out the flow paths at a precisely known, predetermined rate. Several depths of etch can be obtained on a single sheet of stock by repeating the above process with different patterns. In this way, it is possible to make distribution plenum **22** considerably deeper than passages **21** or metering passages **16** to obtain the proper distribution and pressure drop characteristics. It should be pointed out however, that it may be possible to form the individual wafers by embossing them or by electroplating areas to form raised areas rather than etching out the depressed areas.

Other means include, but are not limited to, the utilization of the crude etching process in forming all the passages with the exception of the metering passage **16** and flow restrictor passage **21**, which are later provided by a scribing process similar to that used in preparing defraction gratings. Grooving of channels can also be obtained by conventional indentation processes or forming rolls. These methods are likewise well known to those skilled in the art.

The completed wafers **19** are then stacked together to form the entire thrust chamber **10**. For some applications it may be desirable to bond the wafers together in forming the thrust chamber. Bonding of the wafers **19** can be accomplished in several ways. One method is to electroplate to the thin sheet stock a thin flash of brazed material prior to applying acid-resistant ink. The wafers will then end up with a coating of brazing alloy on all surfaces which contact adjoining wafers, but with none in any passageway through which coolant flows. The entire thrust chamber **10** may then be placed in a furnace and brazed together.

Other methods which might be used for joining the wafers together are diffusion bonding, resistant welding, or simply applying some advanced bonding agent to the contacting surfaces.

When fully assembled, faces **25**, **25*a***, **25*b***, etc., form the inside surface of the thrust chamber **10**; thereby resembling a porous wall having many thousands of holes **15** on the inside face of the chamber. The face of each wafer is sized so as to provide proper dimensions for the thrust chamber upon assembly.

Manifold **17** is attached to the uppermost portion of the thrust chamber and is provided with passage **24** for distribution of coolant to the respective header passages **23**. Ports **26** are provided in manifold **17** for the introduction of coolant. By way of example, a coolant may be introduced into the injector (not shown) by means of fittings (not shown) and transmitted from the injector to the ports **26** of the thrust chamber. The injector is mounted to the thrust chamber at the end of cylindrical section **11** of the chamber and over manifold **17** to close that end of the chamber. By way of example, the injector may be attached to the chamber by mating bolts to suitable threaded receptacles **27** or the like.

FIG. **3** illustrates a typical coolant flow along the length of the thrust chamber from the injector to the nozzle opening at full thrust. In the graph of FIG. **3**, the coolant flow,

$$W_C/L$$

in pounds per second per unit length is plotted against the distance from the injector along the length of the thrust chamber. The flow rate ideally should be substantially constant throughout the cylindrical section and into the convergent section of the thrust chamber. The flow rate should increase in the vicinity of the throat because of the high heat flux there, and then decrease through the divergent section. Since coolant flow rate drops as the coolant flows along passage **23** from manifold **17** to the various wafers (due to the release of coolant through the wafer passages), passage **23** is preferably divided into successive increments **29**, **30**, **31** and **32**, each having successively smaller diameters so as to maintain a sufficient flow rate through the passage **23**. Increment **32** is of the smallest diameter and continues along the length of the thrust chamber through the vicinity of the convergent section, the throat, and the divergent section. By providing incrementally decreasing sizing of passage **23**, the volume of coolant in the chamber walls and hence the amount of coolant lost on shutdown is minimized.

As examples of suitable coolant for use with the present invention, a propellant such as N_2O_4, ClF_3 or gaseous or liquid hydrogen may be used. Inert coolant such as water may likewise be used.

In operation, coolant is introduced into passage **23** by way of manifold **17** and is permitted to flow through metering passages **16** to each distribution plenum **22**. As the coolant enters passages **21**, the coolant develops a laminar flow due to the small size of the hydraulic diameter of each passage **21**. The coolant then flows into the flared portion **28** and finally through holes **15** to the inside surface of the thrust chamber. Inside the flared portion **28** the coolant is heated and may vaporize before reaching the inside surface of the thrust chamber. Once the coolant has left the wall it is driven out the exhaust nozzle with other exhaust gases. If the coolant is a propellant it will react with the combustion gas and contribute to the performance of the thrust motor.

In the flared portion **28** of each wafer, the coolant remains in intimate thermal contact with the metal of the wall at all points within the wall. Thus, by the time that the coolant reaches holes **15**, and surface **25** of each wafer, the coolant temperature approaches the maximum limiting temperature of the wall material. The cooling capacity of the coolant is therefore effectively exploited and the coolant flow may be minimized.

Provision of the individual flow compartments between each flow restrictor **20** allows isolation of areas of coolant boiling, thus preventing hot spots from spreading and creating large areas on the surface where overheating may occur.

Control of the flow of the coolant into the chamber can be accurately maintained by accurately sizing the depth or length of the metering passages **16** through the wafer. Thus, the flow of coolant to each plenum **22** and thereby to the holes **15** is accurately controlled.

Flow passage **21** is set back from the edge surface **25** so that the flow resistance through passages **21** is independent of influence caused by local heat transfer at the edge surface.

As is well known, the thrust chamber operates by injecting propellant into the chamber from an injector, attached to the end of cylindrical section **11** over manifold **17**. The propellant is ignited by suitable ignition means, well known in the art. The heat generated by this process is dissipated by the transpiration cooling techniques as described hereinbefore.

The present invention thus provides transpiration cooling of devices subjected to heat flux above the capabilities of the material forming the device, such as thrust chambers for rockets. By permitting intimate thermal contact to be maintained between the coolant and all points within the wall, the cooling capacity of the coolant is effectively exploited and the cooling efficiency is held at a high level.

Due to the simplicity and repetitious nature of the design, devices of all sizes may be fabricated by using an appropriate number of easily constructed modules.

Although the transpiration-cooling techniques of this invention have been described in connection with rocket thrust chambers, it is to be understood that these techniques are fully applicable to other devices as well. For example, cooling of rocket injectors and afterburners may be accomplished in accordance with these techniques. Furthermore, the principles of this invention are fully applicable to fields of technology outside of the rocket field, for example, to furnaces and the like.

This invention is not to be limited by the embodiment shown in the drawings, and described in the description, which is given by way of example rather than of limitation but only in accordance with the scope of the appended claims.

What we claim is:

1. A device having a wall adapted to contact heat energy, said wall comprising a stack of a plurality of discrete wafers, each wafer having planar surfaces and edge surfaces; a controlled pattern of flow passages on a planar surface of each wafer, said flow passages terminating at an edge surface thereof, a plurality of flow separators in each flow passage forming a porous surface of said wall having a plurality of edge surface holes arranged in a pattern; delivery means for delivering coolant to said flow passages, said delivery means including metering passages on each wafer for metering coolant flow to edge surface holes; said wafers being sufficient thin as to permit thermal equilibrium between said wafers and the coolant within the flow passages, whereby the device is transpiration cooled by the coolant in the flow passages.

2. A device according to claim **1** wherein said edge surface holes are of a hydraulic diameter of substantially between 0.0005 inch and 0.020 inch.

3. A device according to claim **1** wherein the thickness of each wafer is substantially between 0.001 inch and 0.050 inch.

4. A device according to claim **1** further including flow restrictor passages set back from said edge surface, whereby coolant flow resistance through said restrictor passages will be independent of local heat transfer conditions at the edge surface.

5. A device according to claim **4** wherein said restrictor passages are of a hydraulic diameter of substantially between 0.0005 inch and 0.010 inch.

6. A device according to claim **4** wherein said restrictors further form flared passages between them, each flared passage containing a plurality of flow passages.

7. A rocket motor thrust chamber, comprising:

a combustion chamber adapted to receive propellant injection means at one end thereof,

exhaust nozzle means associated with said combustion chamber at the other end thereof,

said chamber having a wall comprising a stack of a plurality of discrete wafers, each wafer having planar surfaces and edge surfaces; a controlled pattern of flow passages on a planar surface of each wafer, said flow passages being adapted to receive coolant and terminating at an edge surface thereof;

a plurality of flow separators in each flow passage forming a porous surface of said wall having a plurality of edge surface holes arranged in a pattern; said wafers being sufficiently thin as to permit thermal equilibrium between said wafers and coolant within the flow passages, whereby the combustion chamber is transpiration cooled by coolant in the flow passages; and

delivery means for delivering coolant to said flow passages, said delivery means including metering passages on each wafer for metering coolant flow to the edge surface holes.

8. A device according to claim **7** wherein said delivery means comprises a coolant manifold, and a manifold header passage passing through each of said wafers, said header passage being a fluid communication with said manifold and said flow passages.

9. A device according to claim **7** wherein said nozzle means comprises a convergent section, a throat, and a divergent section.

10. A device according to claim **7** further including flow restrictor passages set back from said edge surface, whereby coolant flow resistance through said restrictor passages will be independent of local heat transfer conditions at the edge surface.