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(71) Applicant: **3M INNOVATIVE PROPERTIES COMPANY** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(72) Inventors; and
(71) Applicants : **SHIRK, Ryan C.** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). **CARPENTER, Barry S.** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). **REDINGER, David H.** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). **SCHNOBRICH, Scott M.** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(74) Agents: **KNECHT, Harold C., III** et al.; 3M Center, Office of Intellectual Property Counsel, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

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(54) **Title**: FUEL INJECTORS WITH NON-COINED THREE-DIMENSIONAL NOZZLE INLET FACE

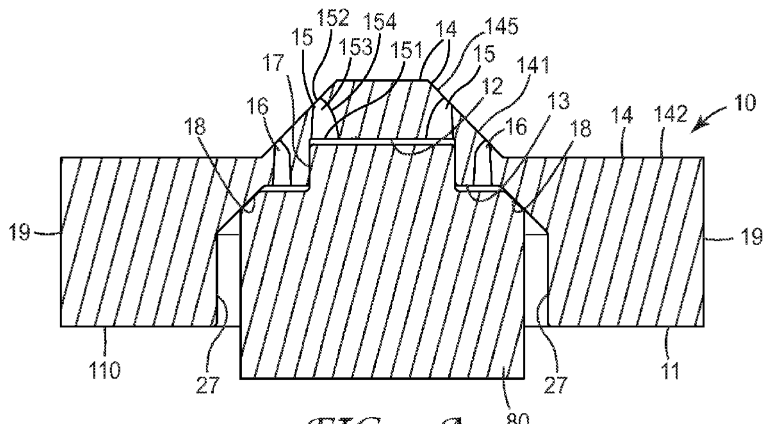

FIG. 3A

(57) **Abstract**: Nozzles and method of making the same are disclosed. The disclosed nozzles have a non-coined three-dimensional inlet face and an outlet face opposite the inlet face. The nozzles may have one or more nozzle through-holes extending from the inlet face to the outlet face. Fuel injectors containing the nozzle are also disclosed. Methods of making and using nozzles and fuel injectors are further disclosed.

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FUEL INJECTORS WITH NON-COINED THREE-DIMENSIONAL NOZZLE INLET FACE

FIELD OF THE INVENTION

This invention generally relates to nozzles suitable for use in a fuel injector for an internal combustion engine. The invention is further applicable to fuel injectors incorporating such nozzles. This invention also relates to methods of making such nozzles, as well as methods of making fuel injectors incorporating such nozzles. The invention further relates to methods of using nozzles and fuel injectors in vehicles.

BACKGROUND

There are three basic types of fuel injector systems. Those that use port fuel injection (PFI), gasoline direct injection (GDI), and direct injection (DI). While PFI and GDI use gasoline as the fuel, DI uses diesel fuel. Efforts continue to further develop fuel injector nozzles and fuel injection systems containing the same so as to potentially increase fuel efficiency and reduce hazardous emissions of internal combustion engines, as well as reduce the overall energy requirements of a vehicle comprising an internal combustion engine.

SUMMARY OF THE INVENTION

The present invention is directed to fuel injector nozzles. In one exemplary embodiment, the fuel injector nozzle comprises: a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface; an outlet face opposite the inlet face; and one or more first nozzle through-holes and one or more second nozzle through-holes, with each first nozzle through-hole comprising at least one inlet opening on the first inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, and each second nozzle through-hole comprising at least one inlet opening on the second inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, wherein the first inlet surface is not coplanar with the second inlet surface.

In another exemplary embodiment, the fuel injector nozzle comprises: a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface; an outlet face opposite the inlet face; and one or more first nozzle through-holes and one or more second nozzle through-holes, with each first nozzle through-hole comprising at least one inlet opening on the first inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, and each second nozzle through-hole comprising at least one inlet opening on the second inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, wherein a perpendicular wall portion of the inlet face separates the first inlet surface and the second inlet surface.

The present invention is further directed to fuel injectors. In one exemplary embodiment, the fuel injector comprises any one of the herein-disclosed nozzles of the present invention.

The present invention is even further directed to fuel injection systems. In one exemplary embodiment, the fuel injection system comprises any one of the herein-disclosed nozzles or fuel injectors of the present invention.

In another exemplary embodiment, the fuel injection system of the present invention comprises a fuel injection system of a vehicle, wherein the fuel injection system comprises: (I) a nozzle comprising a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface; an outlet face opposite the inlet face; and one or more first nozzle through-holes and one or more second nozzle through-holes, with each first nozzle through-hole comprising at least one inlet opening on the first inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, and each second nozzle through-hole comprising at least one inlet opening on the second inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, wherein the first inlet surface is not coplanar with the second inlet surface; and (II) a fuel injector valve having a fuel injector valve contact surface; wherein the fuel injection system provides at least three levels of fluid flow through the nozzle depending on a position of the fuel injector valve relative to the nozzle. The at least three levels of fluid flow through the nozzle may comprise (1) no fluid flow; (2) partial fluid flow, wherein fluid flows through the one or more second nozzle through-holes; and (3) full fluid flow, wherein fluid flows through the one or more first nozzle through-holes and the one or more second nozzle through-holes.

The present invention is also directed to methods of making nozzles. In one exemplary embodiment, the method of making a nozzle of the present invention comprises making any of the herein-described nozzles.

In another exemplary embodiment, the method of making a nozzle of the present invention comprises: forming a nozzle comprising a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface; an outlet face opposite the inlet face; and one or more first nozzle through-holes and one or more second nozzle through-holes, with each first nozzle through-hole comprising at least one inlet opening on the first inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, and each second nozzle through-hole comprising at least one inlet opening on the second inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, wherein the first inlet surface is not coplanar with the second inlet surface.

In another exemplary embodiment, the method of making a nozzle of the present invention comprises: forming a nozzle comprising a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface; an outlet face opposite the inlet face; and one or more first nozzle through-holes and one or more second nozzle through-holes, with each first nozzle through-hole comprising at least one inlet opening on the first inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, and each second nozzle through-hole comprising at least one inlet opening on the second inlet surface connected to at least one outlet opening on the outlet face by a cavity defined by an interior surface, wherein a perpendicular wall portion of the inlet face separates (i) at least one inlet opening of the one or more first nozzle through-holes from (ii) at least one inlet opening of the one or more second nozzle through-holes.

The present invention is also directed to methods of making fuel injectors. In one exemplary embodiment, the method of making a fuel injector comprises incorporating any one of the herein-described nozzles into the fuel injector.

The present invention is also directed to methods of making fuel injection systems of a vehicle. In one exemplary embodiment, the method of making a fuel injection system of a vehicle comprises incorporating any one of the herein-described nozzles or fuel injectors into the fuel injection system.

BRIEF DESCRIPTION OF DRAWINGS

The invention may be more completely understood and appreciated in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. **1** is a side view of an exemplary nozzle of the present invention;

FIG. **2** is a perspective view of an exemplary fuel injector valve suitable for use with the exemplary nozzle shown in FIG. **1**;

FIG. **3A** is a cross-sectional view of the exemplary nozzle shown in FIG. **1** and the exemplary fuel injector valve shown in FIG. **2** when in a “fully closed” position;

FIG. **3B** is a cross-sectional view of the exemplary nozzle shown in FIG. **1** and the exemplary fuel injector valve shown in FIG. **2** when in a “partially open” position;

FIG. **3C** is a cross-sectional view of the exemplary nozzle shown in FIG. **1** and the exemplary fuel injector valve shown in FIG. **2** when in a “fully open” position;

FIG. **4A** is a perspective view of another exemplary nozzle of the present invention;

FIG. **4B** is a top view of the exemplary nozzle shown in FIG. **4A**;

FIG. **4C** is a cross-sectional view of the exemplary nozzle shown in FIG. **4A** with an exemplary fuel injector valve positioned along an inlet face of the exemplary nozzle in a “fully closed” position;

FIG. **5** is a cross-sectional view of another exemplary nozzle of the present invention;

FIG. **6** is a cross-sectional view of another exemplary nozzle of the present invention;

FIG. **7** is a cross-sectional view of an exemplary fuel injector system of the present invention utilizing an exemplary nozzle of the present invention, wherein the nozzle comprises one or more inlet face features that reduce a SAC volume of the fuel injector system;

FIG. **8** is a schematic of an exemplary fuel injector system of the present invention;

FIG. **9** is a cross-sectional view of another exemplary nozzle of the present invention;

FIG. **10** is a cross-sectional view of another exemplary nozzle of the present invention;

FIG. **11** is a schematic of an exemplary vehicle comprising a fuel injector system of the present invention;

FIG. **12** is a cross-sectional view of an exemplary method step wherein nozzle material is removed from a nozzle using a contacting tool;

FIG. **13** is a perspective view of an exemplary contacting tool suitable for use in the material removal step shown in FIG. **12**;

FIGS. **14a-e** depict cross-sectional views of exemplary contacting tool suitable for use in the material removal step shown in FIG. **12**;

FIGS. **15a-e** depict cross-sectional views of exemplary outlet surface features formed using the contacting tools shown in FIGS. **14a-e**; and

FIG. **16** is a perspective view of another exemplary contacting tool suitable for use in the material removal step shown in FIG. **12**.

In the specification, a same reference numeral used in multiple figures refers to the same or similar elements having the same or similar properties and functionalities.

DETAILED DESCRIPTION

The disclosed nozzles represent improvements to nozzles disclosed in (1) International Patent Application Publication WO2011/014607, which published on February 03, 2011, and (2) International Patent Application Serial No. US2012/023624 (3M Docket No. 67266WO003 entitled "Nozzle and Method of Making Same") filed on February 2, 2012, the subject matter and disclosure of both of which are herein incorporated by reference in their entirety. The disclosed nozzles provide one or more advantages over prior nozzles as discussed herein. For example, the disclosed nozzles can advantageously be incorporated into fuel injector systems to improve fuel efficiency. The disclosed nozzles can be fabricated using multiphoton, such as two photon, processes like those disclosed in International Patent Application Publication WO2011/014607 and International Patent Application Serial No. US2012/023624. In particular, multiphoton processes can be used to fabricate various microstructures, which can at least include one or more hole forming features. Such hole forming features can, in turn, be used as molds to fabricate holes for use in nozzles or other applications.

It should be understood that the term “nozzle” may have a number of different meanings in the art. In some specific references, the term nozzle has a broad definition. For example, U.S. Patent Publication No. 2009/0308953 A1 (Palestrant et al.), discloses an “atomizing nozzle” which includes a number of elements, including an occluder chamber 50. This differs from the understanding and definition of nozzle put forth herewith. For example, the nozzle of the current description would correspond generally to the orifice insert 24 of Palestrant et al. In general, the nozzle of the current description can be understood as the final tapered portion of an atomizing spray system from which the spray is ultimately emitted, see e.g., Merriam Webster’s dictionary definition of nozzle (“a short tube with a taper or constriction used (as on a hose) to speed up or direct a flow of fluid.” Further understanding may be gained by reference to U.S. Patent No. 5,716,009 (Ogihara et al.) issued to Nippondenso Co., Ltd. (Kariya, Japan). In this reference, again, fluid injection “nozzle” is defined broadly as the multi-piece valve element 10 (“fuel injection valve 10 acting as fluid injection nozzle. . .” – see col. 4, lines 26-27 of Ogihara et al.). The current definition and understanding of the term “nozzle” as used herein would relate, e.g., to first and second orifice plates 130 and 132 and potentially sleeve 138 (see Figs. 14 and 15 of Ogihara et al.), for example, which are located immediately proximate the fuel spray. A similar understanding of the term “nozzle” to that described herein is used in U.S. Patent No. 5,127,156 (Yokoyama et al.) to Hitachi, Ltd. (Ibaraki, Japan). There, the nozzle 10 is defined separately from elements of the attached and integrated structure, such as “swirler” 12 (see Fig. 1(II)). The above-defined understanding should be understood when the term “nozzle” is referred to throughout the remainder of the description and claims.

The disclosed nozzles include one or more nozzle through-holes strategically incorporated into the nozzle structure. The one or more nozzle through-holes provide one or more of the following properties to the nozzle: (1) the ability to provide variable fluid flow through the nozzle (e.g., by opening or closing off one or more one or more nozzle through-holes), (2) the ability to provide multi-directional fluid flow relative to an outlet face of the nozzle, and (3) the ability to provide multi-directional off-axis fluid flow relative to a central normal line extending perpendicularly through the nozzle outlet face.

FIGS. **1** and **3A**-**3C** depict various views of an exemplary nozzle **10** of the present invention. As shown in FIGS. **1** and **3A**-**3C**, nozzle **10** comprises a non-coined three-dimensional inlet face **11** comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**. As used herein, the term “non-coined” refers to inlet face **11** of nozzle **10** not being formed by a deformation process like, for example, a coining or stamping operation. As discussed further below, inlet face **11** of nozzle **10** may be formed by, for example, a deposition/molding process such as a two-photon polymerization/molding process.

Each first nozzle through-hole **15** comprises at least one inlet opening **151** on first inlet surface **12** connected to at least one outlet opening **152** on outlet face **14** by a cavity **153** defined by an interior surface **154**. Each second nozzle through-hole **16** comprises at least one inlet opening **161** on second inlet surface **13** connected to at least one outlet opening **162** on outlet face **14** by a cavity **163** defined by an interior surface **164**.

As shown in FIGS. **1** and **3A**-**3C**, first inlet surface **12** is not coplanar with second inlet surface **13**. As used herein, the term "coplanar" is used to describe continuous or discontinuous surface portions that fall within a given plane, the given plane having no or some curvature within the plane (i.e., the continuous or discontinuous surface portions fall within a non-curved plane or within a curved surface; the term coplanar as used herein encompasses two portions (continuous or discontinuous portions) of a curved surface). In addition to not being coplanar, first inlet surface **12** may be parallel with second inlet surface **13** as shown in FIGS. **1** and **3A**-**3C**.

Although each of first inlet surface **12** and second inlet surface **13** are shown in FIGS. **1** and **3A**-**3C** as being substantially flat (i.e., having no curvature), it should be noted that each of first inlet surface **12** and second inlet surface **13** may independently have a radius of curvature within the inlet surface portion. Typically, when present, first inlet surface **12** and second inlet surface **13** each independently have a radius of curvature of up to about 4 m (or any radius of curvature up to 4 m, typically greater than 10 μm and any value or range of values between 10 μm and 4 m, in increments of 1.0 μm).

As shown in FIGS. **1** and **3A**-**3C**, first inlet surface **12** is separated from second inlet surface **13** by a perpendicular wall portion **17** of said inlet face **11**. As further shown in FIGS. **1** and **3A**-**3C**, one or more inlet openings **151** on first inlet surface **12** are separated from one or more inlet openings **161** on second inlet surface **13** by perpendicular wall portion **17**.

As shown in FIGS. **2** and **3A**-**3C**, nozzle **10** may be used in combination with an exemplary fuel injector valve **80**. Fuel injector valve **80** comprises a fuel injector valve contact surface **81**, at least a portion of which is operatively adapted (e.g., dimensioned, configured or otherwise designed) and sized to extend along perpendicular wall portion **17** of inlet face **11**. Fuel injector valve **80** further comprises a fuel injector valve sealing surface **82**, at least a portion of which is operatively adapted (e.g., dimensioned, configured or otherwise designed) and sized to contact and seal with second valve sealing surface **18** of inlet face **11**.

Fuel injector valve **80** is movable within nozzle **10** so as to selectively open or close one or more inlet openings **151** on first inlet surface **12** and one or more inlet openings **161** on second inlet surface **13**. FIG. **3A** provides a cross-sectional view of nozzle **10** and fuel injector valve **80** in a "fully closed" position, wherein all of inlet openings **151** on first inlet surface **12** and inlet openings **161** on second inlet surface **13** are closed (i.e., no fluid flow). FIG. **3B** provides a cross-sectional view of nozzle **10** and fuel injector valve **80** when in a "partially open" position, wherein inlet openings **151** on first inlet surface **12** are closed (i.e., no fluid flow) and inlet openings **161** on second inlet surface **13** are open (i.e., to allow fluid flow). FIG. **3C** provides a cross-sectional view of nozzle **10** and fuel injector valve **80** in a "fully open" position, wherein all of inlet openings **151** on first inlet surface **12** and inlet openings **161** on second inlet surface **13** are open (i.e., to allow fluid flow).

FIGS. **4A-4C** provide various views of another nozzle **10** of the present invention. As shown in FIGS. **4A-4C**, outlet openings **152** and **162** of nozzle **10** are not positioned along the same surface, but instead are positioned along two separate outlet surfaces of inlet face **14**. In particular, outlet openings **152** are positioned along a first outlet surface **141** (i.e., in this embodiment, also referred to herein as an uppermost outlet surface **141**) and outlet openings **162** of nozzle **10** are positioned along a second outlet surface **142** (i.e., in this embodiment, also referred to herein as a lowermost outlet surface **142**).

As shown in FIGS. **5-6**, nozzles **10** of the present invention may further comprise a number of optional, additional features. Suitable optional, additional features include, but are not limited to, one or more overlapping outlet surface portions **149**, one or more anti-coking microstructures **150** positioned along any portion of outlet face **14**, and one or more fluid impingement structures along any portion of outlet face **14**.

As shown in FIGS. **1** and **3A-6**, nozzles **10** of the present invention may comprise nozzle through-holes **15** and **16**, wherein each nozzle through-hole **15/16** independently comprises the following features: (i) an inlet opening **151/161** shape, (ii) an outlet opening **152/163** shape, and (iii) an internal surface **154** profile that may include one or more curved sections **157**, one or more linear sections **158**, or a combination of one or more curved sections **157** and one or more linear sections **158**. Selection of these features for each independent nozzle through-hole **15/16** enables nozzle **10** to provide (1) substantially equal fluid flow through nozzle through-holes **15/16**, (2) variable fluid flow through nozzle through-holes **15/16** (i.e., fluid flow that is not the same from one nozzle through-holes **15/16** to another), (3) single- or multi-directional fluid streams exiting nozzle through-holes **15/16**, (4) linear and/or curved fluid streams exiting nozzle through-holes **15/16**, and (5) parallel and/or divergent and/or parallel followed by divergent fluid streams exiting nozzle through-holes **15/16**.

In some embodiments, at least one of nozzle through-holes **15/16** has an inlet opening **151/161** axis of flow, a cavity **153/163** axis of flow and an outlet opening **152/162** axis of flow, and at least one axis of flow is different from at least one other axis of flow. As used herein, the "axis of flow" is defined as the central axis of a stream of fuel as the fuel flows into, through or out of nozzle through-hole **15/16**. In the case of a nozzle through-hole **15/16** having multiple inlet openings **151/161**, multiple outlet openings **152/162** or both, the nozzle through-hole **15/16** can have a different axis of flow corresponding to each of the multiple openings **151/152/161/162**.

In some embodiments, inlet opening **151/161** axis of flow may be different from outlet opening **152/162** axis of flow. In other embodiments, each of inlet opening **151/161** axis of flow, cavity **153/163** axis of flow and outlet opening **152/162** axis of flow are different from one another. In other embodiments, nozzle through-hole **15/16** has a cavity **153/163** that is operatively adapted (e.g., dimensioned, configured or otherwise designed) such that fuel flowing therethrough has an axis of flow that is curved.

Examples of factors that contribute to such differences in axis of flow may include, but are not be limited to, any combination of: (1) a different angle between (i) cavity **153/163** and (ii) inlet face **11** and/or outlet face **14**, (2) inlet openings **151/161** and/or cavities **153/163** and/or outlet openings **152/162** not being aligned or parallel to each other, or aligned along different directions, or parallel but not aligned, or intersecting but not aligned, and/or (3) any other conceivable geometric relationship two or three non-aligned line segments could have.

The disclosed nozzles **10** may comprise (or consist essentially of or consist of) any one of the disclosed nozzle features or any combination of two or more of the disclosed nozzle features. In addition, although not shown in the figures and/or described in detail herein, the nozzles **10** of the present invention may further comprise one or more nozzle features disclosed in (1) U.S. Provisional Patent Application Serial No. 61/678,475 (3M Docket No. 69909US002 entitled "GDI Fuel Injectors with Non-Coined Three-Dimensional Nozzle Outlet Face") filed on August 01, 2012, (2) U.S. Provisional Patent Application Serial No. 61/678,356 (3M Docket No. 69910US002 entitled "Targeting of Fuel Output by Off-Axis Directing of Nozzle Output Streams") filed on August 01, 2012, (3) U.S. Provisional Patent Application Serial No. 61/678,330 (3M Docket No. 69911US002 entitled "Fuel Injector Nozzles with at Least One Multiple Inlet Port and/or Multiple Outlet Port") filed on August 01, 2012, and (4) U.S. Provisional Patent Application Serial No. 61/678,305 (3M Docket No. 69912US002 entitled "Fuel Injectors with Improved Coefficient of Fuel Discharge") filed on August 01, 2012, the subject matter and disclosure of each of which is herein incorporated by reference in its entirety.

The disclosed nozzles **10** may be formed using any method as long as the resulting inlet face **11** of the nozzle **10** has inlet face **11** features as described herein. Although the methods of making nozzles **10** of the present invention are not limited to the methods disclosed in International Patent Application Serial No. US2012/023624, nozzles **10** of the present invention may be formed using the methods as disclosed in International Patent Application Serial No. US2012/023624. See, in particular, the method steps described in reference to FIGS. **1A-1M** of International Patent Application Serial No. US2012/023624.

<u>Additional Embodiments</u>

<u>Nozzle Embodiments</u>

1. A fuel injector nozzle **10** comprising: a non-coined three-dimensional inlet face **11**

comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite said inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**, with each said first nozzle through-hole **15** comprising at least one inlet opening **151** on said first inlet surface **12** connected to at least one outlet opening **152** on said outlet face **14** by a cavity **153** defined by an interior surface **154**, and each said second nozzle through-hole **16** comprising at least one inlet opening **161** on said second inlet surface **13** connected to at least one outlet opening **162** on said outlet face **14** by a cavity **163** defined by an interior surface **164**, wherein said first inlet surface **12** is not coplanar with said second inlet surface **13**. First inlet surface **12** is typically parallel with second inlet surface **13**, but not coplanar with second inlet surface **13**. See, embodiment 4 below. In some embodiments, a majority (i.e., greater than 50% and up to 100%) of an overall length of first inlet surface **12** is parallel with a majority (i.e., greater than 50% and up to 100%) of an overall length of second inlet surface **13**, while in other embodiments, only a portion (i.e., less than 50%) of an overall length of first inlet surface **12** is parallel with a portion (i.e., less than 50%) of an overall length of second inlet surface **13**.

2. The nozzle **10** of embodiment 1, wherein said inlet face **11** further comprises a first valve sealing surface **17** between said first inlet surface **12** and said second inlet surface **13**, with said first valve sealing surface **17** being configured or otherwise operatively adapted (e.g., dimensioned, configured or otherwise designed) to seal with a fuel injector valve **80** so as to allow a fuel (or fluid) (not shown) to pass through said second nozzle through-holes **16** but not said first nozzle through-holes **15**.

3. The nozzle **10** of embodiment 1 or 2, wherein said inlet face **11** further comprises a second valve sealing surface **18** being configured or otherwise operatively adapted (e.g., dimensioned, configured or otherwise designed) to seal with a fuel injector valve **80** so as to prevent a fuel (not shown) from passing through said second nozzle through-holes **16**.

4. The nozzle **10** of any one of embodiments 1 to 3, wherein said first inlet surface **12** and said second inlet surface **13** are exactly or generally parallel to each other.

5. The nozzle **10** of any one of embodiments 2 to 4, wherein said first valve sealing surface **17** is configured or otherwise operatively adapted (e.g., dimensioned, configured or otherwise designed) to seal with an exterior sealing surface **81** of a fuel injector valve **80** so as to prevent a fuel (not shown) from passing through said one or more first nozzle through-holes **15**.

6. The nozzle **10** of any one of embodiments 2 to 5, wherein said first valve sealing surface **17** is exactly or generally perpendicular to at least one of said first inlet surface **12** and said second inlet surface **13**.

7. The nozzle **10** of any one of embodiments 1 to 6, wherein said outlet face **14** comprises a first outlet surface **141** and a second outlet surface **142**, with each outlet opening **152** of said one or more first nozzle through-holes **15** being on said first outlet surface **141**, each outlet opening **162** of said

one or more second nozzle through-holes **16** being on said second outlet surface **142**, and said first outlet surface **141** is not coplanar with said second outlet surface **142**.

8. The nozzle **10** of embodiment 7, wherein said first outlet surface **141** and said second outlet surface **142** are exactly or generally parallel to each other.

9. The nozzle **10** of any one of embodiments 1 to 6, wherein said outlet face **14** comprises a first outlet surface **145** and a second outlet surface **142**, with said first outlet surface **145** being disposed at an acute angle to said second outlet surface **142**, and each outlet opening **152/162** being on said first outlet surface **145**.

10. A fuel injector nozzle **10** comprising: a non-coined three-dimensional inlet face **11** comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite said inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**, with each said first nozzle through-hole **15** comprising at least one inlet opening **151** on said first inlet surface **12** connected to at least one outlet opening **152** on said outlet face **13** by a cavity **153** defined by an interior surface **154**, and each said second nozzle through-hole **16** comprising at least one inlet opening **161** on said second inlet surface **13** connected to at least one outlet opening **162** on said outlet face **13** by a cavity **163** defined by an interior surface **164**, wherein a perpendicular wall portion **17** of said inlet face **11** separates said first inlet surface **12** and said second inlet surface **13**.

11. The nozzle **10** of any one of embodiments 1 to 10, wherein along said inlet face **11** between an outer periphery **19** of said nozzle **10** and a nozzle central axis **20** extending along a normal line perpendicular to said outer periphery **19**, said inlet face **11** comprises at least two perpendicular wall portions **17/27** of said inlet face **11** separated from one another by an intermediate wall portion **13/18** of said inlet face **11**.

12. The nozzle **10** of embodiment 11, wherein said at least two perpendicular wall portions **17/27** of said inlet face **11** comprise two concentrically-oriented perpendicular wall portions **17/27** of said inlet face **11**.

13. The nozzle **10** of any one of embodiments 10 to 12, wherein each perpendicular wall portion **17/27** has a circular cross-sectional configuration (or square, or triangular, or star-shaped, or any other polygon shape) as viewed along a nozzle central axis **20** extending along a normal line perpendicular to an outer periphery **19** of said nozzle **10**.

14. The nozzle **10** of any one of embodiments 10 to 13, wherein each perpendicular wall portion **17/27** of said inlet face **11** is substantially parallel to a nozzle central axis **20** extending along a normal line perpendicular to an outer periphery **19** of said nozzle **10**.

15. The nozzle **10** of any one of embodiments 11 to 14, wherein said intermediate wall portion **13/18** of said inlet face **11** comprises a first valve sealing surface **18**.

16. The nozzle **10** of any one of embodiments 1 to 15, wherein (i) an outer perimeter portion **110** of said inlet face **11** is within an inlet face plane **111**, (ii) an outer perimeter portion **140** of said outlet

face **14** is within an outlet face plane **144**, and (iii) said inlet face plane **111** is substantially parallel to said outlet face plane **140**.

17. The nozzle **10** of any one of embodiments 1 to 16, wherein (i) an outer perimeter portion **110** of said inlet face **11** is within an inlet face plane **111**, (ii) an outer perimeter portion **142** of said outlet face **14** is within an outlet face plane **144**, (iii) said inlet face plane **111** is substantially parallel to said outlet face plane **144**, and (iv) at least a portion of said outlet face **141/145** is above said outlet face plane **144**.

18. The nozzle **10** of any one of embodiments 1 to 17, wherein (i) an outer perimeter portion **110** of said inlet face **11** is within an inlet face plane **111**, (ii) an outer perimeter portion **142** of said outlet face **14** is within an outlet face plane **144**, (iii) said inlet face plane **111** is substantially parallel to said outlet face plane **144**, (iv) at least a portion of said outlet face **141/145** is above said outlet face plane **144**, and (v) a vertically-extending portion **145** of said outlet face **14** separates a lower planar portion **142** of said outlet face **14**, within said outlet face plane **144**, from an uppermost portion **141** of said outlet face **14**.

19. The nozzle **10** of any one of embodiments 1 to 18, wherein said inlet face **11** comprises (i) an outer perimeter portion **110** of said inlet face **11** is within an inlet face plane **111**, (ii) an outer perpendicular wall portion **27** extending upward from said outer perimeter portion **110** within said inlet face plane **111**, (iii) an intermediate wall portion **13/18** extending from said outer perpendicular wall portion **27**, at least a portion of said intermediate wall portion **13/18** representing said second inlet surface **13**, (iv) an inner perpendicular wall portion **17** extending upward from said intermediate wall portion **13/18**, and (v) an uppermost portion **12**, at least a portion of said uppermost portion **12** representing said first inlet surface **12**.

20. The nozzle **10** of any one of embodiments 1 to 19, wherein said first inlet surface **12** has a first surface radius of curvature of greater than about 10 μm (or any radius of curvature up to about 4 m, or any value or range of values between 10 μm and 4 m, in increments of 1.0 μm).

21. The nozzle **10** of any one of embodiments 1 to 20, wherein said second inlet surface **13** has a second surface radius of curvature of greater than about 10 μm (or any radius of curvature up to about 4 m, or any value or range of values between 10 μm and 4 m, in increments of 1.0 μm).

22. The nozzle **10** of any one of embodiments 1 to 19, wherein said first inlet surface **12** of said inlet face **11** has a relatively flat surface profile.

23. The nozzle **10** of embodiment 19 or 22, wherein said first inlet surface **12** of said inlet face **11** is within an uppermost inlet surface plane **121**, said uppermost inlet surface plane **121** being substantially parallel to said inlet face plane **111**.

24. The nozzle **10** of any one of embodiments 1 to 23, wherein said first inlet surface **12** of said inlet face **11** is below a lowermost portion **142** of said outlet face **14**.

25. The nozzle **10** of any one of embodiments 1 to 23, wherein at least a portion of said first inlet

surface **12** of said inlet face **11** is above at least a portion of said outlet face **14**.

26. The nozzle **10** of any one of embodiments 11 to 25, wherein at least a portion of said intermediate wall portion **13/18** of said inlet face **11** has a relatively flat surface profile, said portion comprising said second inlet surface **13**.

27. The nozzle **10** of embodiment 26, wherein said portion of said intermediate wall portion **13/18** is within an intermediate inlet surface plane **131**, said intermediate inlet surface plane **131** being substantially parallel to said inlet face plane **111**.

28. The nozzle **10** of embodiment 26 or 27, wherein said portion of said intermediate wall portion **13/18** is below said outlet face **14**.

29. The nozzle **10** of embodiment 26 or 27, wherein said portion of said intermediate wall portion **13/18** is above at least a portion of said outlet face **14**.

30. The nozzle **10** of any one of embodiments 1 to 29, wherein at least one outlet opening **152/162** is positioned along a lower planar portion **142** of said outlet face **14**.

31. The nozzle **10** of any one of embodiments 1 to 30, wherein at least one outlet opening **152/162** is positioned along a vertically-extending portion **145** of said outlet face **14**.

32. The nozzle **10** of any one of embodiments 1 to 31, wherein at least one outlet opening **152/162** is positioned along an uppermost portion **141** of said outlet face **14**.

33. The nozzle **10** of embodiment 31 or 32, wherein said vertically-extending portion **145** of said outlet face **14** forms (i) a first angle **P** with said lower planar portion **142** of said outlet face **14** ranging from about 90° to less than about 165° (or any angle or range of angle values between 90° and 165° in increments of 1°), and (ii) a second angle **Q** with said uppermost portion **141** of said outlet face **14** of from about 90° to less than about 165° (or any angle or range of angle values between 90° and 165° in increments of 1°).

34. The nozzle **10** of any one of embodiments 31 to 33, wherein said vertically-extending portion **145** of said outlet face **14** forms (i) a first angle **P** with said lower planar portion **142** of said outlet surface **14** ranging from about 90° to about 135° (or any angle or range of angle values between 90° and 135° in increments of 1°), and (ii) a second angle **Q** with said uppermost portion **141** of said outlet face **14** of about 90° to about 135° (or any angle or range of angle values between 90° and 135° in increments of 1°).

35. The nozzle **10** of any one of any one of embodiments 31 to 34, wherein said vertically-extending portion **145** of said outlet face **14** forms (i) a first angle **P** with said lower planar portion **142** of said outlet face **14** of about 135°, and (ii) a second angle **Q** with said uppermost portion **141** of said outlet face **14** of about 135°.

36. The nozzle **10** of any one of any one of embodiments 31 to 34, wherein said vertically-extending portion **145** of said outlet face **14** forms (i) a first angle **P** with said lower planar portion **142** of said outlet face **14** of about 90°, and (ii) a second angle **Q** with said uppermost portion **141** of

said outlet face **14** of from about 90°.

37. The nozzle **10** of any one of embodiments 31 to 36, wherein said vertically-extending portion **145** of said outlet face **14** comprises a relatively flat surface **146** (i.e., no curve) between said lower planar portion **142** of said outlet face **14** and said uppermost portion **141** of said outlet face **14**.

38. The nozzle **10** of any one of embodiments 31 to 37, wherein said vertically-extending portion **145** of said outlet face **14** has a cylindrical or truncated cone surface profile extending between said lower planar portion **141** of said outlet face **14** and said uppermost portion **141** of said outlet face **14**.

39. The nozzle **10** of any one of embodiments 1 to 38, wherein (a) at least one outlet opening **152** of said first nozzle through-holes **15** is positioned along a lower planar portion **142** of said outlet face **14**, and (b) at least one outlet opening **162** of said second nozzle through-holes **16** is positioned along said lower planar portion **141** of said outlet face **14**.

40. The nozzle **10** of any one of embodiments 1 to 38, wherein (a) at least one outlet opening **152** of said first nozzle through-holes **15** is positioned along a vertically-extending portion **145** of said outlet face **14**, and (b) at least one outlet opening **162** of said one or more second nozzle through-holes **16** is positioned along a lower planar portion **142** of said outlet face **14**.

41. The nozzle **10** of any one of embodiments 1 to 38, wherein (a) at least one outlet opening **152** of said one or more first nozzle through-holes **15** is positioned along a vertically-extending portion **145** of said outlet face **14**, and (b) at least one outlet opening **162** of said one or more second nozzle through-holes **16** is positioned along said vertically-extending portion **145** of said outlet face **14**.

42. The nozzle **10** of embodiment 41, wherein said at least one outlet opening **152** of said one or more first nozzle through-holes **15** is positioned along an upper portion **147** of said vertically-extending portion **145** of said outlet face **14**, and said at least one outlet opening **162** of said one or more second nozzle through-holes **16** is positioned along a lower portion **148** of said vertically-extending portion **145** of said outlet face **14**.

43. The nozzle **10** of any one of embodiments 1 to 38, wherein (a) at least one outlet opening **152** of said one or more first nozzle through-holes **15** is positioned along an uppermost portion **141** of said outlet face **14**, and (b) at least one outlet opening **162** of said one or more second nozzle through-holes **16** is positioned along a lower planar portion **142** of said outlet face **14**.

44. The nozzle **10** of embodiment 43, wherein said at least one outlet opening **162** of said one or more second nozzle through-holes **16** is positioned so as to direct fluid (not shown) exiting said at least one outlet opening **162** towards said vertically-extending portion **145** of said outlet face **14** so as to contact said vertically-extending portion **145**.

45. The nozzle **10** of any one of embodiments 1 to 44, wherein (1) each of said one or more first nozzle through-holes **15** has a first internal surface profile extending directly from a first nozzle inlet opening **151** to a first nozzle outlet opening **152** and a second internal surface profile extending directly from the first nozzle inlet opening **151** to the first nozzle outlet opening **152**, said second

internal surface profile of said first nozzle through-hole **15** being (i) on an opposite side of a first nozzle cavity **153** from said first internal surface profile of each said first nozzle through-hole **15** and (ii) closer to a central normal line **20** perpendicular to an outer periphery **19** of said nozzle **10**; (2) each of said one or more second nozzle through-holes **16** has a first internal surface profile extending directly from a second nozzle inlet opening **161** to a second nozzle outlet opening **162** and a second internal surface profile extending directly from the second nozzle inlet opening **161** to the second nozzle outlet opening **162**, said second internal surface profile of each said second nozzle through-hole **16** being (i) on an opposite side of a second nozzle cavity **163** from said first internal surface profile of said second nozzle through-hole **16** and (ii) closer to the central normal line **20** perpendicular to the outer periphery **19** of said nozzle **10**; and (3) each of said first internal surface profile of said first nozzle through-hole **15**, said second internal surface profile of said first nozzle through-hole **15**, said first internal surface profile of said second nozzle through-hole **16** and said second internal surface profile of said second nozzle through-hole **16** is independently either has a surface profile with or without curvature.

46. The nozzle **10** of embodiment 45, wherein said first internal surface portion of said first nozzle through-hole **15** has a relatively flat surface profile (extending directly from inlet opening **151** to outlet opening **152**), and said second internal surface portion of said first nozzle through-hole **15** has a curved surface profile (extending directly from inlet opening **151** to outlet opening **152**).

47. The nozzle **10** of embodiment 45, wherein said first internal surface portion of said first nozzle through-hole **15** has a surface profile with a first degree of curvature (extending directly from inlet opening **151** to outlet opening **152**), said second internal surface portion of said first nozzle through-hole **15** has a surface profile with a second degree of curvature (extending directly from inlet opening **151** to outlet opening **152**), and said second degree of curvature is greater than said first degree of curvature.

48. The nozzle **10** of any one of embodiments 45 to 47, wherein said first internal surface portion of said second nozzle through-hole **16** has a relatively flat surface profile (extending directly from inlet opening **151** to outlet opening **152**), and said second internal surface portion of said second nozzle through-hole **16** has a relatively flat surface profile (extending directly from inlet opening **151** to outlet opening **152**).

49. The nozzle **10** of any one of embodiments 45 to 47, wherein said first internal surface portion of said second nozzle through-hole **16** has a relatively flat surface profile (extending directly from inlet opening **151** to outlet opening **152**), and said second internal surface portion of said second nozzle through-hole **16** has a curved surface profile (extending directly from inlet opening **151** to outlet opening **152**).

50. The nozzle **10** of any one of embodiments 45 to 47, wherein said first internal surface portion of said second nozzle through-hole **16** has a surface profile with a first degree of curvature (extending

directly from inlet opening **151** to outlet opening **152**), said second internal surface portion of said second nozzle through-hole **16** has a surface profile with a second degree of curvature (extending directly from inlet opening **151** to outlet opening **152**), and said second degree of curvature is greater than said first degree of curvature.

51. The nozzle **10** of any one of embodiments 45 to 47, wherein said second internal surface portion of said second nozzle through-hole **16** has a relatively flat surface profile (extending directly from inlet opening **151** to outlet opening **152**), and said first internal surface portion of said second nozzle through-hole **16** has a curved surface profile (extending directly from inlet opening **151** to outlet opening **152**).

52. The nozzle **10** of any one of embodiments 45 to 47, wherein said first internal surface portion of said second nozzle through-hole **16** has a surface profile with a first degree of curvature (extending directly from inlet opening **151** to outlet opening **152**), said second internal surface portion of said second nozzle through-hole **16** has a surface profile with a second degree of curvature (extending directly from inlet opening **151** to outlet opening **152**), and said first degree of curvature is greater than said second degree of curvature.

53. The nozzle **10** of any one of embodiments 1 to 52, wherein each of (i) said one or more first nozzle through-holes **15** and (ii) said one or more second nozzle through-holes **16** independently comprises two or more nozzle through-holes (or any number or range of numbers of nozzle through-holes greater than two in increments of 1).

54. The nozzle **10** of any one of embodiments 1 to 53, wherein each of (i) said one or more first nozzle through-holes **15** and (ii) said one or more second nozzle through-holes **16** independently comprises from about 4 to about 24 nozzle through-holes (or any number or range of numbers between 4 and 24 in increments of 1).

55. The nozzle **10** of any one of embodiments 1 to 54, wherein said nozzle **10** comprises one or more overlapping outer surface portions **149** (see, FIG. **5**) along said outlet face **14**.

56. The nozzle **10** of any one of embodiments 1 to 55, wherein said outlet face **14** further comprises anti-coking nanostructures **150** thereon.

57. The nozzle **10** of embodiment 56, wherein said anti-coking nanostructures **150** are present along one or more portions of said outlet face **14**, said one or more portions of said outlet face **14** comprising (i) an upper surface **141** of one or more overlapping outer surface portions **149** of said outlet face **14**, when present, (ii) a lower planar portion **142** of said outlet face **10**, (iii) an uppermost portion **141** of said outlet face **14**, (iv) a vertically-extending portion **145** of said outlet face **14** between said lower planar portion **142** of said outlet face **14** and said uppermost portion **141** of said outlet face **14**, or (v) any combination of (i) to (iv).

58. The nozzle **10** of any one of embodiments 1 to 57, wherein at least one inlet opening **151/161** and at least one outlet opening **152/162** of at least one nozzle through-hole **15/16** have a similar shape.

59. The nozzle **10** of any one of embodiments 1 to 58, wherein at least one inlet opening **151/161** and at least one outlet opening **152/162** of at least one nozzle through-hole **15/16** have a different shape.

60. The nozzle **10** of any one of embodiments 1 to 59, wherein said nozzle **10** further comprises an inlet surface with one or more inlet face features **118** that extend into a ball valve outlet region **210** of a fuel injector system **100** to further reduce a SAC volume of the fuel injector system **100** when said nozzle **10** is placed in contact with a ball valve **212** outlet (also referred to herein as fuel injector tip **209**) of the fuel injector system **100**. It can be desirable, in addition or alternatively, for the inlet surface of the nozzle to match, preferably so as to mate and/or seal with, the outer surface of the ball valve. "SAC volume" is defined as a volume of space between an inlet face of a fuel injector nozzle (i.e., inlet face **11** of nozzle **10**) and an outer surface **211** of a ball valve **212** of a fuel injector system **100**. See, for example, FIG. **7** of the present invention.

Typically, the SAC volume is represented by a volume of space outlined by a line extending between fuel injector tips **209** and outer surface **211** of a ball valve **212** of a fuel injector system **100** given that most nozzles, including most embodiments of nozzle **10**, do not comprise any inlet face features **118** that extend into a ball valve outlet region **210**; however, as shown in FIG. **7** of the present invention, in some embodiments, nozzle **10** does comprise inlet face features **118** that extend into a ball valve outlet region **210**). In some embodiments, the SAC volume of a given fuel injector **101** can be reduced up to about 50% or more (or any percent up to 50% in increments of 1%).

61. The nozzle **10** of embodiment 55, wherein a portion of said inlet face **110** is within an inlet face plane **111** and extends along an outer perimeter of said inlet face **11**, and said one or more inlet face features **118** comprise a tubular-shaped member **118** having an outer circular side wall **1181** that abuts or is positioned adjacent to an inner side wall surface **213** of the ball valve outlet region **210**.

62. The nozzle **10** of any one of embodiments 1 to 61, wherein said nozzle **10** further comprises one or more fluid impingement members **1519** positioned along said outlet face **14**.

63. The nozzle of embodiment 62, wherein said one or more fluid impingement members **1519** are present along one or more portions of said outlet face **14**, said one or more portions of said outlet face **14** comprising (i) a surface **159/159'** of one or more overlapping outer surface portions **149** of said outlet face **14**, when present, (ii) a lower planar portion **142** of said outlet face **14**, (iii) an uppermost portion **141** of said outlet face **14**, (iv) a vertically-extending portion **145** of said outlet face **14** between said lower planar portion **142** of said outlet face **14** and said uppermost portion **141** of said outlet face **14**, or (v) any combination of (i) to (iv).

64. The nozzle **10** of any one of embodiments 1 to 63, wherein each inlet opening **151/161** has a diameter of less than about 400 microns (or less than about 300 microns, or less than about 200 microns, or less than about 160 microns, or less than about 100 microns) (or any diameter between about 10 microns and 400 microns in increments of 1.0 micron, e.g., 10, 11, 12, etc. microns).

65. The nozzle **10** of any one of embodiments 1 to 64, wherein each outlet opening **152**/**162** has a diameter of less than about 400 microns (or less than about 300 microns, or less than about 200 microns, or less than about 100 microns, or less than about 50 microns, or less than about 20 microns) (or any diameter between about 10 microns and 400 microns in increments of 1.0 micron, e.g., 10, 11, 12, etc. microns).

66. The nozzle **10** of any one of embodiments 1 to 65, wherein the nozzle **10** comprises a metallic material, an inorganic non-metallic material (e.g., a ceramic), or a combination thereof.

67. The nozzle **10** of any one of embodiments 1 to 66, wherein the nozzle **10** comprises a ceramic selected from the group comprising silica, zirconia, alumina, titania, or oxides of yttrium, strontium, barium, hafnium, niobium, tantalum, tungsten, bismuth, molybdenum, tin, zinc, lanthanide elements having atomic numbers ranging from 57 to 71, cerium and combinations thereof.

68. The nozzle **10** of any one of embodiments 1 to 67, wherein the nozzle **10** comprises a monolithic structure. As used herein, the term "monolithic" refers to a nozzle having a single, integrally formed structure, as oppose to multiple parts or components being combined with one another to form a nozzle.

69. The nozzle **10** of any one of embodiments 1 to 68 in combination with a fuel injector valve **80**, said fuel injector valve **80** having a fuel injector valve contact surface **81**, at least a portion of which is operatively adapted (e.g., dimensioned, configured or otherwise designed) and sized to extend along a perpendicular wall **17** of said inlet face **11** that is closest to a nozzle plate central axis **20** extending along a normal line perpendicular to an outer periphery **19** of said nozzle **10**.

<u>Fuel Injector Embodiments</u>

70. A fuel injector **101** comprising the nozzle **10** of any one of embodiments 1 to 69.

<u>Fuel Injector Systems Embodiments</u>

71. A fuel injection system **100** of a vehicle **200** comprising the fuel injector **101** of embodiment 70.

72. A fuel injection system **100** of a vehicle **200** comprising: a nozzle **10** comprising a non-coined three-dimensional inlet face **11** comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite said inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**, with each said first nozzle through-hole **15** comprising at least one inlet opening **151** on said first inlet surface **12** connected to at least one outlet opening **152** on said outlet face **14** by a cavity **153** defined by an interior surface **154**, and each said second nozzle through-hole **16** comprising at least one inlet opening **161** on said second inlet surface **13** connected to at least one outlet opening **162** on said outlet face **14** by a cavity **163** defined by an interior surface **164**, wherein said first inlet surface **12** is not coplanar with said second inlet surface **13**; and a fuel injector valve **80** having a fuel injector valve contact surface **81**; wherein said fuel injection system

100 provides at least three levels of fluid flow through said nozzle **10** depending on a position of said fuel injector valve **80** relative to said nozzle **10**.

73. The fuel injection system **100** of embodiment 72, wherein said nozzle **10** comprises the nozzle **10** of any one of embodiments 1 to 69.

74. The fuel injection system **100** of embodiment 72 or 73, further comprising a device **214** (e.g., a solenoid valve) that controls a position of said fuel injector valve **80** relative to said nozzle **10**.

75. The fuel injection system **100** of any one of embodiments 72 to 74, wherein the at least three levels of fluid flow through said nozzle **10** comprise (1) no fluid flow; (2) partial fluid flow, wherein fluid flows through said one or more second nozzle through-holes **16**; and (3) full fluid flow, wherein fluid flows through said one or more first nozzle through-holes **15** and said one or more second nozzle through-holes **16**.

Methods of Making Nozzles Embodiments

76. A method of making the nozzle **10** of any one of embodiments 1 to 69.

77. A method of making a fuel injector nozzle **10**, said method comprising: forming a nozzle **10** comprising a non-coined three-dimensional inlet face **11** comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite the inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**, with each first nozzle through-hole **15** comprising at least one inlet opening **151** on the first inlet surface **12** connected to at least one outlet opening **152** on the outlet face **14** by a cavity **153** defined by an interior surface **154**, and each second nozzle through-hole **16** comprising at least one inlet opening **161** on the second inlet surface **13** connected to at least one outlet opening **162** on the outlet face **14** by a cavity **163** defined by an interior surface **164**, wherein the first inlet surface **12** is not coplanar with the second inlet surface **13**.

78. A method of making a fuel injector nozzle **10**, said method comprising: forming a nozzle **10** comprising a non-coined three-dimensional inlet face **11** comprising a first inlet surface **12** and a second inlet surface **13**; an outlet face **14** opposite the inlet face **11**; and one or more first nozzle through-holes **15** and one or more second nozzle through-holes **16**, with each first nozzle through-hole **15** comprising at least one inlet opening **151** on the first inlet surface **12** connected to at least one outlet opening **152** on the outlet face **14** by a cavity **153** defined by an interior surface **154**, and each second nozzle through-hole **16** comprising at least one inlet opening **161** on the second inlet surface **13** connected to at least one outlet opening **162** on the outlet face **14** by a cavity **163** defined by an interior surface **164**, wherein a perpendicular wall portion **17** of the inlet face **11** separates (i) at least one inlet opening **151** of the one or more first nozzle through-holes **15** from (ii) at least one inlet opening **161** of the one or more second nozzle through-holes **16**.

79. The method of embodiment 77 or 78, wherein said step of forming the inlet face **11** comprises forming two concentrically-oriented perpendicular wall portions **17/27** along the inlet face **11**.

80. The method of embodiment 79, wherein each perpendicular wall portion **17/27** has a circular

cross-sectional configuration (or square, or triangular, or oval, or star, or any other polygon shape) as viewed along a nozzle plate central axis **20** extending along a normal line perpendicular to an outer periphery **19** of the nozzle **10**.

81. The method of embodiment 79 or 80, wherein each perpendicular wall portion **17/27** of the inlet face **11** is substantially parallel to a nozzle central axis **20** extending along a normal line perpendicular to an outer periphery **19** of the nozzle **10**.

82. The method of any one of embodiments 77 to 81, wherein (i) an outer periphery portion **110** of the inlet face **11** is within an inlet face plane **111**, (ii) an outer periphery portion **142** of an outlet face **14** of the nozzle **10** is within an outlet face plane **144**, and (iii) the inlet face plane **111** is substantially parallel to the outlet face plane **144**.

83. The method of any one of embodiments 77 to 82, wherein (i) an outer periphery portion **110** of the inlet face **11** is within an inlet face plane **111**, (ii) an outer periphery portion **142** of an outlet face **14** of the nozzle **10** is within an outlet face plane **144**, (iii) the inlet face plane **111** is substantially parallel to the outlet face plane **144**, and (iv) at least a portion of the outlet face **145/141** is above the outlet face plane **144**.

84. The method of any one of embodiments 77 to 83, wherein (i) an outer periphery portion **110** of the inlet face **11** is within an inlet face plane **111**, (ii) an outer periphery portion **142** of an outlet face **14** of the nozzle **10** is within an outlet face plane **144**, (iii) the inlet face plane **111** is substantially parallel to the outlet face plane **144**, (iv) at least a portion of the outlet face **145/141** is above the outlet face plane **144**, and (v) a vertically-extending portion **145** of the outlet face **14** separates a lower planar portion **142** of the outlet face **14** within the outlet face plane **144**, from an uppermost portion **141** of the outlet face **14**.

85. The method of any one of embodiments 77 to 84, wherein the inlet face **11** comprises (i) an outer periphery portion **110** within an inlet face plane **111** and adjacent an outer periphery **19** of the nozzle **10**, (ii) an outer perpendicular wall portion **27** extending upward from the outer periphery portion **110** of the inlet face **11** within the inlet face plane **111**, (iii) an intermediate wall portion **18/13** extending from the outer perpendicular wall portion **27** of the inlet face **11**, at least a portion of which comprises the second inlet surface **13**, (iv) an inner perpendicular wall portion **17** of the inlet face **11** extending upward from the intermediate wall portion **18/13**, and (v) an uppermost portion **12** of the inlet face **11**, at least a portion of which comprises the first inlet surface **12**.

86. The method of embodiment 85, wherein the uppermost portion **12** of the inlet face **11** has a relatively flat surface profile.

87. The method of embodiment 85 or 86, wherein the uppermost portion **12** of the inlet face **11** is within an uppermost inlet face plane **121**, the uppermost inlet face plane **121** being substantially parallel to the inlet face plane **111**.

88. The method of any one of embodiments 77 to 87, wherein at least a portion of an intermediate

wall portion **18/13** of the inlet face **11** that extends between perpendicular wall portions **27/17** of the inlet face **11** has a relatively flat surface profile.

89. The method of embodiment 88, wherein the portion of the intermediate wall portion **18/13** is within an intermediate inlet face plane **131**, and the intermediate inlet face plane **131** is substantially parallel to an inlet face plane **111**.

90. The method of any one of embodiments 77 to 89, wherein said step of forming the nozzle **10** comprises forming at least one outlet opening **152/162** along a lower planar portion **142** of the outlet face **14**.

91. The method of any one of embodiments 77 to 90, wherein said step of forming the nozzle **10** comprises forming at least one outlet opening **152/162** along a vertically-extending portion **145** of the outlet face **14**.

92. The method of any one of embodiments 77 to 91, wherein said step of forming the nozzle **10** comprises forming at least one outlet opening **152/162** along an uppermost portion **141** of the outlet face **14**.

93. The method of any one of embodiments 77 to 92, further comprising: forming a three-dimensional outlet face **14** on the nozzle **10**.

94. The method of any one of embodiments 77 to 93, further comprising: forming a three-dimensional outlet face **14** on the nozzle **10**, the three-dimensional outlet face **14** having a cylindrical or truncated cone surface profile (i.e., surface **145**) extending between a lower planar portion **141** of the outlet face **14** and an uppermost portion **141** of the outlet face **14**.

95. The method of any one of embodiments 77 to 94, wherein said step of forming the nozzle **10** comprises forming (a) at least one outlet opening **162** of the one or more second nozzle through-holes **16** along a lower planar portion **141** of the outlet face **14**, and (b) at least one outlet opening **152** of the one or more first nozzle through-holes **15** along the lower planar portion **141** of the outlet surface **14**.

96. The method of any one of embodiments 77 to 94, wherein said step of forming the nozzle **10** comprises forming (a) at least one outlet opening **162** of the one or more second nozzle through-holes **16** along a lower planar portion **141** of the outlet face **14**, and (b) at least one outlet opening **152** of the one or more first nozzle through-holes **15** along a vertically-extending portion **145** of the outlet face **14**.

97. The method of any one of embodiments 77 to 94, wherein said step of forming the nozzle **10** comprises forming (a) at least one outlet opening **162** of the one or more second nozzle through-holes **16** along a vertically-extending portion **145** of the outlet surface **14**, and (b) at least one outlet opening **152** of the one or more first nozzle through-holes **15** along the vertically-extending portion **145** of the outlet surface **14**.

98. The method of embodiment 97, wherein the at least one outlet opening **162** of the one or more second nozzle through-holes **16** is positioned along a lower portion **148** of the vertically-extending

portion **145** of the outlet face **14**, and the at least one outlet opening **152** of the one or more first nozzle through-holes **15** is positioned along an upper portion **147** of the vertically-extending portion **145** of the outlet face **14**.

99. The method of any one of embodiments 77 to 94, wherein said step of forming the nozzle **10** comprises forming (a) at least one outlet opening **162** of the one or more second nozzle through-holes **16** along a lower planar portion **141** of the outlet face **14**, and (b) at least one outlet opening **152** of the one or more first nozzle through-holes **15** along an uppermost portion **141** of the outlet face **14**.

100. The method of embodiment 99, wherein the at least one outlet opening **162** of the one or more second nozzle through-holes **16** is positioned so as to direct fluid (not shown) exiting the at least one outlet opening **162** towards the vertically-extending portion **145** of the outlet face **14** so as to contact the vertically-extending portion **145** of the outlet face **14**.

101. The method of any one of embodiments 77 to 100, wherein said step of forming the nozzle **10** comprises forming one or more nozzle through-holes **15/16** that independently comprise two or more outlet openings **152/162**.

102. The method of embodiment 101, wherein the two or more outlet openings **152/162** comprises from about 2 to about 24 outlet openings **152/162** (or any number or range of numbers between 2 and 24 in increments of 1).

103. The method of any one of embodiments 77 to 102, wherein said step of forming the nozzle **10** comprises forming one or more nozzle through-holes **15/16** having multiple cavity passages **153'/163'** extending along a length of the cavity **153/163**. See, for example, FIG. **9**, which depicts individual nozzle through-holes **15/16** comprising (i) single inlet openings **151/161**, (ii) multiple outlet openings **152/162**, and (iii) multiple cavity passages **153'/163'** extending along a length of cavity **153/163**. As shown in FIG. **10**, in other embodiments, individual nozzle through-holes **15/16** comprise (i) multiple inlet openings **151/161**, (ii) single outlet openings **152/162**, and (iii) multiple cavity passages **153'/163'** extending along a length of cavity **153/163**.

104. The method of any one of embodiments 77 to 103, wherein said step of forming the nozzle **10** comprises forming two or more nozzle through-holes **15/16** in each of (i) the one or more first nozzle through-holes **15** and (ii) the one or more second nozzle through-holes **16**.

105. The method of embodiment 104, wherein the two or more nozzle through-holes **15/16** of (i) the one or more first nozzle through-holes **15** and (ii) the one or more second nozzle through-holes **15** each independently comprise from about 4 to about 24 nozzle through-holes **15/16** (or any number or range of numbers between 4 and 24 in increments of 1).

106. The method of any one of embodiments 77 to 105, said method further comprising: forming one or more overlapping outer surface portions **149** along the outlet face **14** of the nozzle **10**.

107. The method of any one of embodiments 77 to 106, said method further comprising: forming anti-coking nanostructures **150** along one or more portions of the outlet face **14** of the nozzle **10**, the

one or more portions of the outlet face **14** comprising (i) an upper surface **141** of one or more overlapping outer surface portions **149** of the outlet face **14**, when present, (ii) a lower planar portion **142** of the outlet face **14**, (iii) an uppermost portion **141** of the outlet face **14**, (iv) a vertically-extending portion **145** of the outlet face **14** between the lower planar portion **142** of the outlet face **14** and the uppermost portion **141** of the outlet face **14**, or (v) any combination of (i) to (iv).

108. The method of any one of embodiments 77 to 107, said method further comprising: forming one or more fluid impingement members **1519** positioned along one or more portions of the outlet face **14** of the nozzle **10**, the one or more portions of the outlet face **14** comprising (i) a surface **141/159** of one or more overlapping outer surface portions **149** of the outlet face **14**, when present, (ii) a lower planar portion **142** of the outlet face **14**, (iii) an uppermost portion **141** of the outlet face **14**, (iv) a vertically-extending portion **145** of the outlet face **14** between the lower planar portion **142** of the outlet face **14** and the uppermost portion **141** of the outlet face **14**, or (v) any combination of (i) to (iv).

109. The method of any one of embodiments 77 to 108, further comprising: removing material from a side surface of a nozzle **10** so as to form one or more outlet face features **149/150/151** along the outlet face **14** of the nozzle **10**.

110. The method of embodiment 109, wherein said removing step comprises contacting the nozzle **10** with a contacting surface **701** (i.e., a lead contacting surface **701** along an outer surface **702**) of a tool **700**, the contacting surface **701** of the tool **700** providing at least one of the following outlet face features: (1) an overlapping outer surface profile **159/159'** for each overlapping outer surface portion **149**, when present, (2) at least one vertically-extending wall portion **145** along the outer face **14**, (3) one or more impingement members **151**, (4) anti-coking structures **150**, and (5) one or more outlet openings **152/162**.

111. The method of embodiment 109 or 110, wherein said removing step comprises removing material from the nozzle **10** with a surface **701** of a tool **700**, the surface **701** of the tool **700** comprising a single continuous surface (e.g., an arc-shaped surface) having a circular cross-sectional configuration (e.g., tool **701** shown in FIGS. **12-13**). The tool **700** can be the type, for example, that contacts and abrasively removes nozzle material, or it can be the type that removes material without actual contact (e.g., the electrode of an electric discharge machine or EDM). As shown in FIGS. **14-16**, tool **700** may have any desired cross-sectional configuration as shown in FIGS. **14a-e**, which results in various outlet surface **14** features including, but not limited to, a desired overlapping outer surface profile **159/159'** for a given overlapping outer surface portion **149** as shown in FIGS. **15a-e**, anti-coking microstructures **150** (as shown in FIG. **5**), impingement members **1519** as shown in FIG. **6**, and other outlet face **14** surface undulations (not shown). In some embodiments, tool **700** may be rotated along its axis, $\mathbf{r_a}$, to further provide surface features to outlet face **14** (e.g., when tool **700** has a star-shaped cross-sectional configuration, as shown in FIG. **14e**, and is rotated along is axis while

removing material from nozzle **10**, so as to result in an outlet face **14** features shown in FIG. **15e**). Further, tool **700** have further comprise one or more tool surface features **704** that may be used (either with or without rotation along its axis, $\mathbf{r_a}$) to further provide outlet face **14** features on nozzle **10**.

112. The method of embodiment 109 or 110, wherein said removing step comprises contacting the nozzle **10** with a contacting surface **701** of a tool **700**, the contacting surface **701** of the tool **700** comprising a wedge-shaped member **700** having a wedge edge **701** (as shown in FIG. **14b**) that initially contacts the nozzle **10**.

113. The method of embodiment 109 or 110, wherein said removing step comprises contacting the nozzle **10** with a contacting surface **701** of a tool **700**, the contacting surface **701** of the tool **700** comprising three or more connected surfaces **701** (e.g., tool **700** shown in FIGS. **14c**-**e**) so as to form (i) an upper overlapping outer surface portion **159**, (ii) a lower overlapping outer surface portion **145**, and (iii) one or more intermediate outer surface portions **159'** connecting the upper and lower overlapping outer surface portions **159/145** along the nozzle **10**.

114. The method of any one of embodiments 109 to 113, wherein said removing step further comprises forming one or more outlet openings **152/162** of one or more nozzle through-holes **15/16**.

115. The method of any one of embodiments 109 to 114, wherein said removing step comprises an electric discharge machining (EDM) step.

116. The method of any one of embodiments 109 to 115, wherein said removing step comprises a wire-EDM step.

117. The method of any one of embodiments 109 to 115, wherein said removing step comprises a sinker-EDM step.

118. The method of any one of embodiments 77 to 117, wherein said step of forming nozzle **10** comprises: fabricating a nozzle forming microstructured pattern used to form a nozzle pre-form; applying a nozzle-forming material over the nozzle forming microstructured pattern comprising one or more nozzle hole forming features; separating the nozzle-forming material from the nozzle forming microstructured pattern to provide the nozzle **10**; and removing material, as needed, from the nozzle **10** to form one or more nozzle through-holes **15/16**. See, for example, FIGS. **1A**-**1M** and the description thereof in International Patent Application Serial No. US2012/023624.

119. The method of embodiment 118, wherein said fabricating step comprises a two-photon polymerization step. For a description of a two-photon polymerization step suitable for forming nozzle **10** of the present invention, see FIGS. **1A**-**1M** and the description thereof in International Patent Application Serial No. US2012/023624.

<u>Methods of Making Fuel Injection Systems Embodiments</u>

120. A method of forming a fuel injection system **100** of a vehicle **200**, said method comprising incorporating the nozzle **10** of any one of embodiments 1 to 68 into the fuel injection system **100**.

<u>Nozzle Pre-Form Embodiments</u>

121. A nozzle pre-form suitable for forming the nozzle **10** of any one of embodiments 1 to 68. See, for example, other nozzle pre-forms and how the nozzle pre-forms are utilized to form nozzles in FIGS. **1A**-**1M** and the description thereof in International Patent Application Serial No. US2012/023624.

Microstructured Pattern Embodiments

122. A microstructured pattern suitable for forming the nozzle **10** of any one of embodiments 1 to 68. See, for example, other microstructured patterns and how the microstructured patterns are utilized to form nozzles in FIGS. **1A**-**1M** and the description thereof in International Patent Application Serial No. US2012/023624.

In any of the above embodiments, nozzle **10** may comprise a nozzle plate **10** having a substantially flat configuration typically with at least a portion of inlet face **11** substantially parallel to at least a portion of outlet face **14**.

It can be desirable for the thickness of a fuel injector nozzle **10** to be at least about 100 μm, preferably greater than about 200 μm; and less than about 3 mm, preferably less than about 1 mm, more preferably less than about 500 μm (or any thickness or thickness range between about 100 μm and 3 mm in increments of 1 μm). As shown in various figures, it can be desirable for the nozzles to have a thickness that is thinner in an inner region of the nozzle plate and thicker around the perimeter of the nozzle plate. For faster fuel spray breakup it can be desirable to decrease the thickness of the nozzle plate. Such a decrease, however, would likely produce a higher turbulence level at the nozzle outlet, which may result in the fuel spray breaking up quicker. As the thickness of the nozzle plate decreases, however, it becomes more difficult to maintain the rigidity or flatness of the nozzle plate during subsequent fabrication (e.g., machining) processes. The pressure upstream of the nozzle inlet in the fuel injector (especially with the higher pressures of a GDI systems) can also cause premature failure or unintended deflection of a nozzle plate that is too thin. In addition, as the nozzle plate thickness is decreased, it becomes increasingly difficult to produce a high quality weld (e.g,. laser weld) of the nozzle plate onto the injector body. By making the inner region thinner and the perimeter thicker, the inventive nozzle be operatively adapted (e.g., dimensioned, configured or otherwise designed) so as to strike a balance of the above needs.

Further, although not shown in the figures, any of the herein-described nozzles **10** may further comprise one or more alignment surface features that enable (1) alignment of nozzle **10** (i.e., in the x-y plane) relative to a fuel injector **101** and (2) rotational alignment/orientation of nozzle **10** (i.e., a proper rotational position within the x-y plane) relative to a fuel injector **101**. The one or more alignment surface features aid in positioning nozzle **10** and nozzle through-holes **15** therein so as to be accurately and precisely directed at one or more target location $\mathbf{l_t}$ as discussed above. The one or more alignment surface features on nozzle **10** may be present along inlet face **11**, outlet face **14**, periphery **19**, or any combination of inlet face **11**, outlet face **14** and periphery **19**. Further, the one or more alignment surface features on nozzle **10** may comprise, but are not limited to, a visual marking, an indentation within nozzle **10**, a raised surface portion along nozzle **10**, or any combination of such alignment surface features.

It should be understood that although the above-described nozzles, nozzle plates, fuel injectors, fuel injector systems, and methods are described as “comprising” one or more components, features or steps, the above-described nozzles, nozzle plates, fuel injectors, fuel injector systems, and methods may “comprise,” “consists of,” or “consist essentially of” any of the above-described components and/or features and/or steps of the nozzles, nozzle plates, fuel injectors, fuel injector systems, and methods. Consequently, where the present invention, or a portion thereof, has been described with an open-ended term such as “comprising,” it should be readily understood that (unless otherwise stated) the description of the present invention, or the portion thereof, should also be interpreted to describe the present invention, or a portion thereof, using the terms “consisting essentially of” or “consisting of” or variations thereof as discussed below.

As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” “contains”, “containing,” “characterized by” or any other variation thereof, are intended to encompass a non-exclusive inclusion, subject to any limitation explicitly indicated otherwise, of the recited components. For example, a nozzle, nozzle plate, fuel injector, fuel injector system, and/or method that “comprises” a list of elements (e.g., components or features or steps) is not necessarily limited to only those elements (or components or features or steps), but may include other elements (or components or features or steps) not expressly listed or inherent to the nozzle, nozzle plate, fuel injector, fuel injector system, and/or method.

As used herein, the transitional phrases “consists of” and “consisting of” exclude any element, step, or component not specified. For example, “consists of” or “consisting of” used in a claim would limit the claim to the components, materials or steps specifically recited in the claim except for impurities ordinarily associated therewith (i.e., impurities within a given component). When the phrase “consists of” or “consisting of” appears in a clause of the body of a claim, rather than immediately following the preamble, the phrase “consists of” or “consisting of” limits only the elements (or components or steps) set forth in that clause; other elements (or components) are not excluded from the claim as a whole.

As used herein, the transitional phrases “consists essentially of” and “consisting essentially of” are used to define a nozzle, nozzle plate, fuel injector, fuel injector system, and/or method that includes materials, steps, features, components, or elements, in addition to those literally disclosed, provided that these additional materials, steps, features, components, or elements do not materially affect the basic and novel characteristic(s) of the claimed invention. The term “consisting essentially of” occupies a middle ground between “comprising” and “consisting of”.

Further, it should be understood that the herein-described nozzles, nozzle plates, fuel injectors, fuel injector systems, and/or methods may comprise, consist essentially of, or consist of any of the herein-described components and features, as shown in the figures with or without any additional feature(s) not shown in the figures. In other words, in some embodiments, the nozzles, nozzle plates, fuel injectors, fuel injector systems, and/or methods of the present invention may have any additional feature that is not specifically shown in the figures. In some embodiments, the nozzles, nozzle plates, fuel injectors, fuel injector systems, and/or methods of the present invention do not have any additional features other than those (i.e., some or all) shown in the figures, and such additional features, not shown in the figures, are specifically excluded from the nozzles, nozzle plates, fuel injectors, fuel injector systems, and/or methods.

The present invention is further illustrated by the following examples, which are not to be construed in any way as imposing limitations upon the scope thereof. On the contrary, it is to be clearly understood that resort may be had to various other embodiments, modifications, and equivalents thereof which, after reading the description herein, may suggest themselves to those skilled in the art without departing from the spirit of the present invention and/or the scope of the appended claims.

EXAMPLE 1

Nozzles, similar to exemplary nozzles **10** as shown in FIGS. **1**, **3A**-**7** and **9**-**10**, were prepared for use in fuel injector systems, similar to fuel injector system **100**.

From the above disclosure of the general principles of the present invention and the preceding detailed description, those skilled in this art will readily comprehend the various modifications, re-arrangements and substitutions to which the present invention is susceptible, as well as the various advantages and benefits the present invention may provide. Therefore, the scope of the invention should be limited only by the following claims and equivalents thereof. In addition, it is understood to be within the scope of the present invention that the disclosed and claimed nozzles may be useful in other applications (i.e., not as fuel injector nozzles). Therefore, the scope of the invention may be broadened to include the use of the claimed and disclosed structures for such other applications.

What is claimed is:

1. A fuel injector nozzle comprising:

a non-coined three-dimensional inlet face comprising a first inlet surface and a second inlet surface;

an outlet face opposite said inlet face; and

one or more first nozzle through-holes and one or more second nozzle through-holes, with each said first nozzle through-hole comprising at least one inlet opening on said first inlet surface connected to at least one outlet opening on said outlet face by a cavity defined by an interior surface, and each said second nozzle through-hole comprising at least one inlet opening on said second inlet surface connected to at least one outlet opening on said outlet face by a cavity defined by an interior surface,

wherein said first inlet surface is not coplanar with said second inlet surface.

2. The nozzle of claim 1, wherein said inlet face further comprises a first valve sealing surface between said first inlet surface and said second inlet surface, with said first valve sealing surface being operatively adapted to seal with a fuel injector valve so as to allow a fuel to pass through said second nozzle through-holes but not said first nozzle through-holes.

3. The nozzle of claim 1 or 2, wherein said inlet face further comprises a second valve sealing surface being operatively adapted to seal with a fuel injector valve so as to prevent a fuel from passing through said second nozzle through-holes.

4. The nozzle of any one of claims 1 to 3, wherein said first inlet surface and said second inlet surface are parallel to each other.

5. The nozzle of any one of claims 2 to 4, wherein said first valve sealing surface is operatively adapted to seal with an exterior sealing surface of a fuel injector valve so as to prevent a fuel from passing through said one or more first nozzle through-holes .

6. The nozzle of any one of claims 2 to 5, wherein said first valve sealing surface is perpendicular to at least one of said first inlet surface and said second inlet surface.

7. The nozzle of any one of claims 1 to 6, wherein said outlet face comprises a first outlet surface and a second outlet surface, with each outlet opening of said one or more first nozzle through-holes being on said first outlet surface, each outlet opening of said one or more second nozzle

through-holes being on said second outlet surface, and said first outlet surface is not coplanar with said second outlet surface.

8. The nozzle of claim 7, wherein said first outlet surface and said second outlet surface are parallel to each other.

9. The nozzle of any one of claims 1 to 6, wherein said outlet face comprises a first outlet surface and a second outlet surface, with said first outlet surface being disposed at an acute angle to said second outlet surface, and each outlet opening being on said first outlet surface.

10. The nozzle of any one of claims 1 to 9, wherein said inlet face comprises (i) an outer perimeter portion of said inlet face, (ii) an outer perpendicular wall portion of said inlet face extending upward from said outer perimeter portion, (iii) an intermediate wall portion extending from said outer perpendicular wall portion, at least a portion of said intermediate wall portion representing said second inlet surface, (iv) an inner perpendicular wall portion extending upward from said intermediate wall portion, and (v) an uppermost portion, at least a portion of said uppermost portion representing said first inlet surface.

11. The nozzle of any one of claims 1 to 10, wherein each of (i) said one or more first nozzle through-holes and (ii) said one or more second nozzle through-holes independently comprises two or more nozzle through-holes.

12. A fuel injector comprising the nozzle of any one of claims 1 to 10.

13. A fuel injection system of a vehicle comprising the fuel injector of claim 12 and a fuel injector valve having a fuel injector valve contact surface;

wherein said fuel injection system provides at least three levels of fluid flow through said nozzle depending on a position of said fuel injector valve relative to said nozzle.

14. The fuel injection system of claim 13, wherein the at least three levels of fluid flow through said nozzle comprise (1) no fluid flow; (2) partial fluid flow, wherein fluid flows through said one or more second nozzle through-holes; and (3) full fluid flow, wherein fluid flows through said one or more first nozzle through-holes and said one or more second nozzle through-holes.

15. A method of making the nozzle of any one of claims 1 to 10.

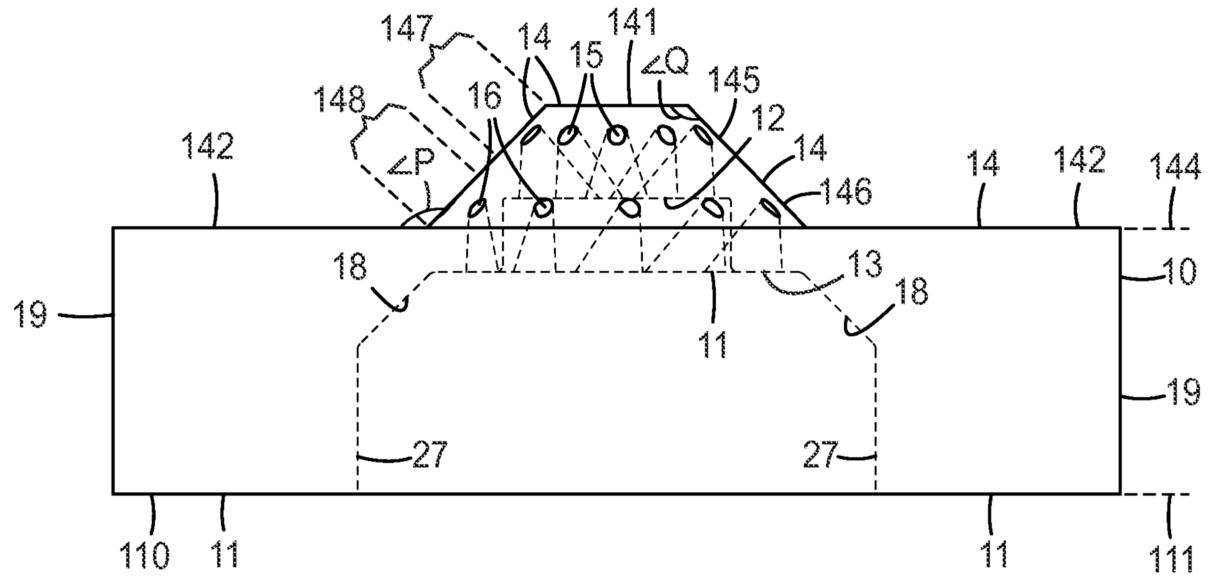
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FIG. 1

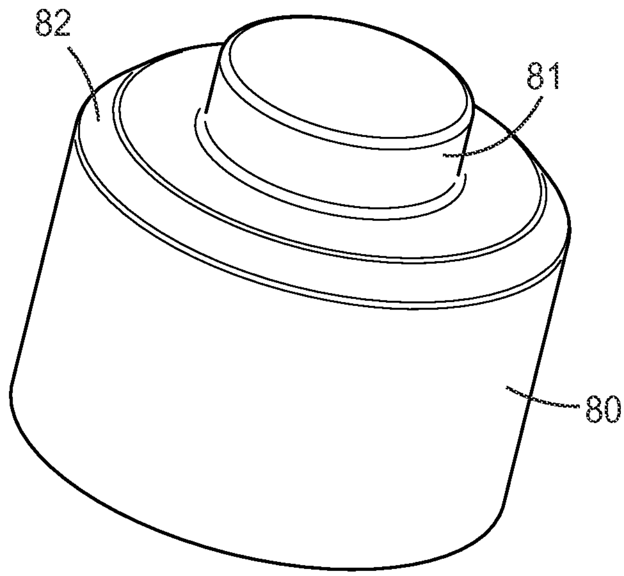
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FIG. 2

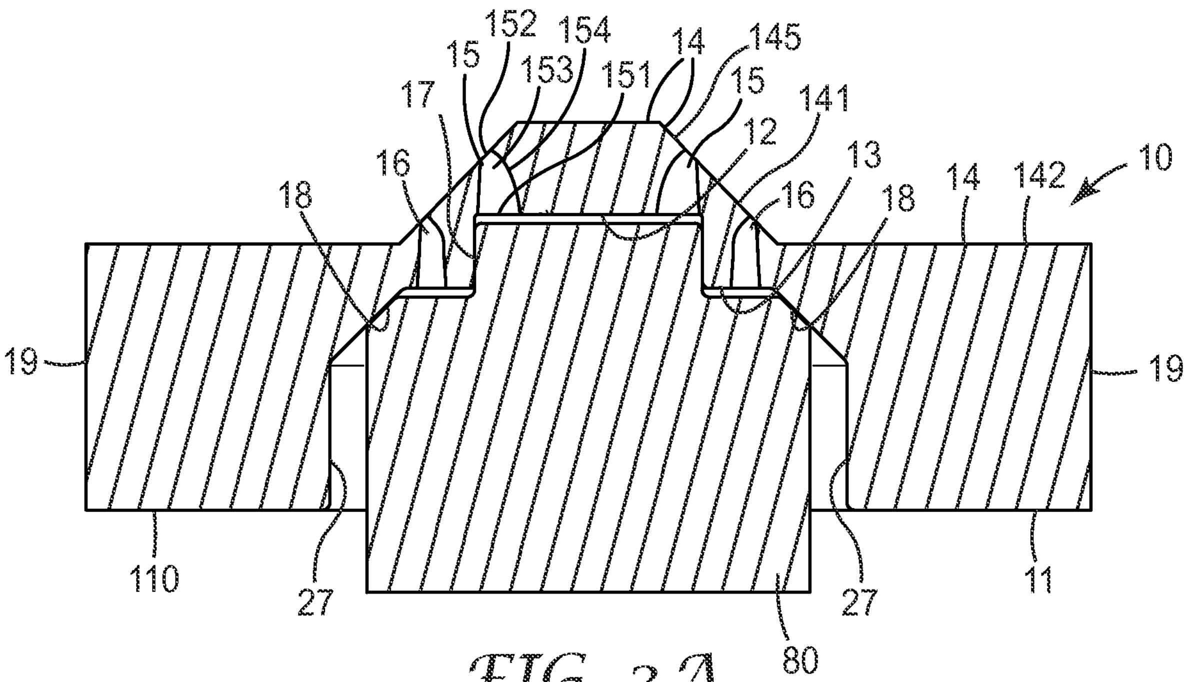
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FIG. 3A

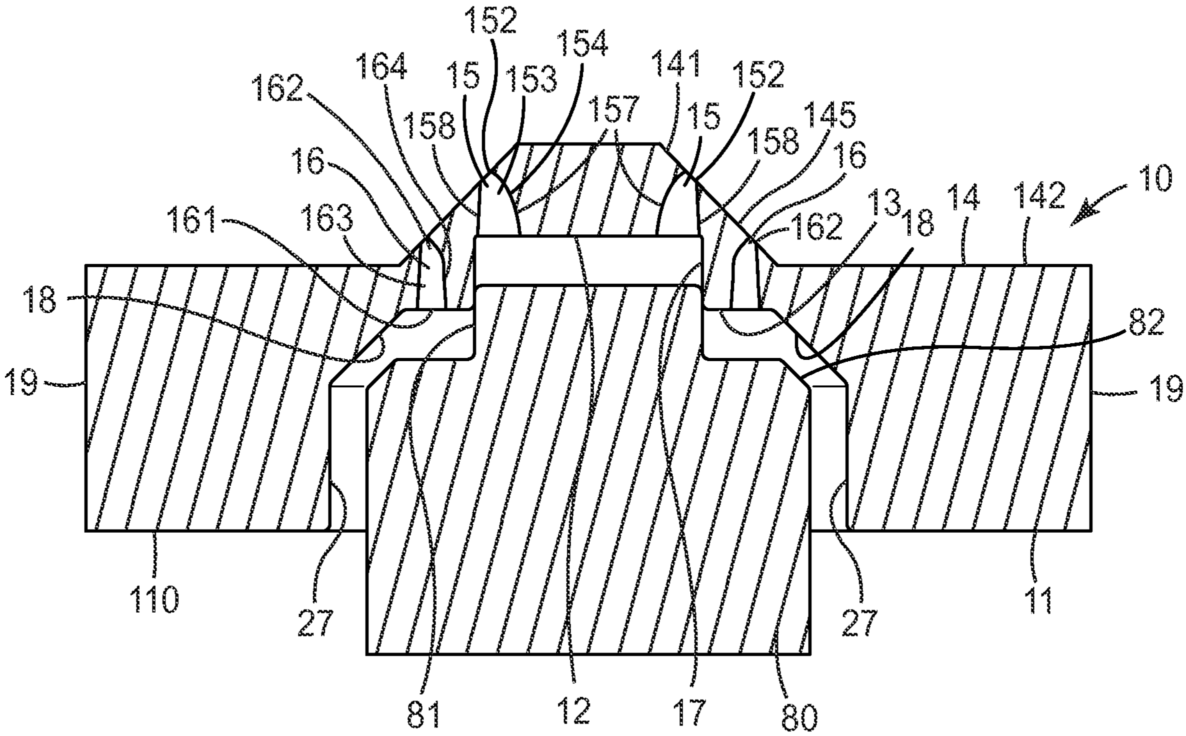
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FIG. 3B

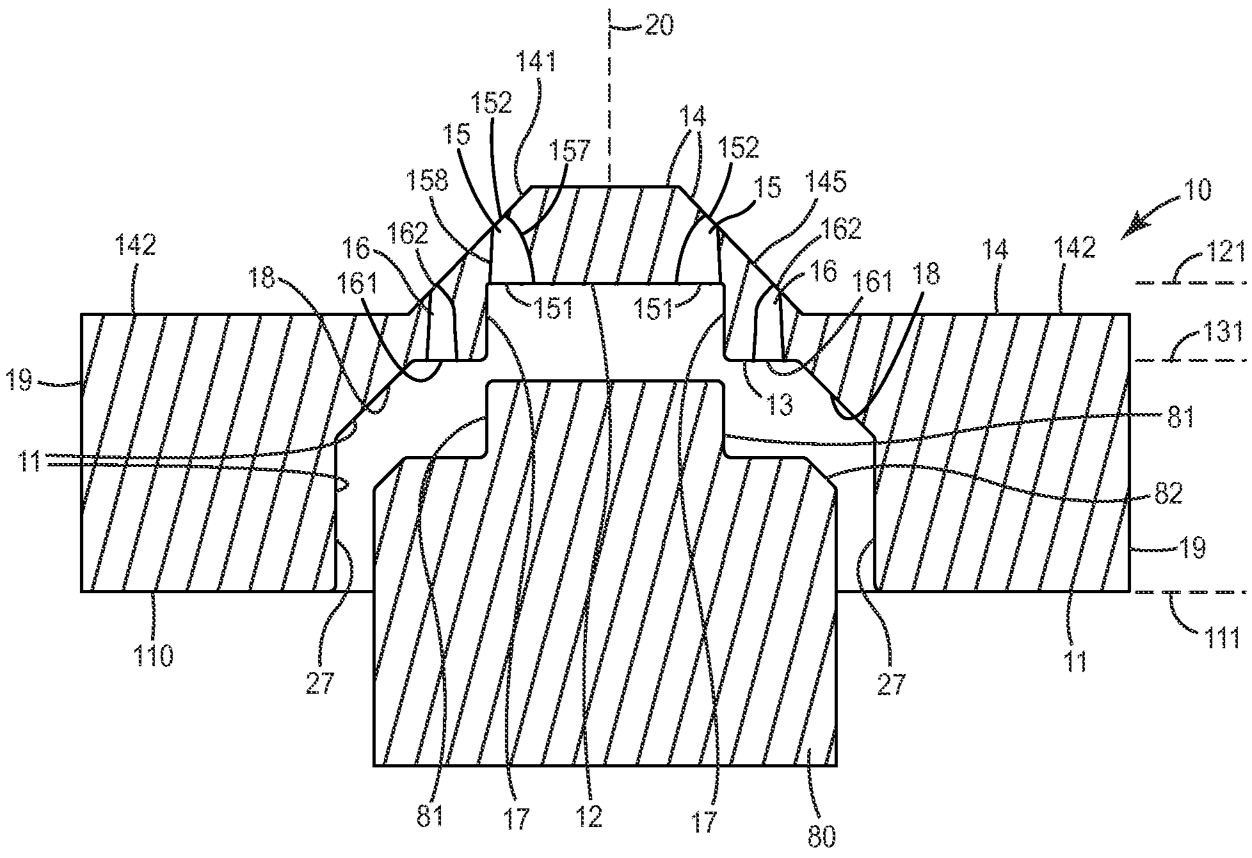
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FIG. 3C

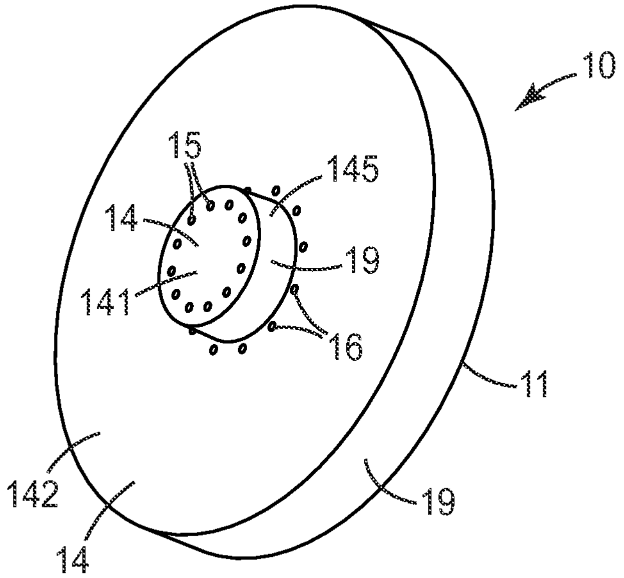

FIG. 4A

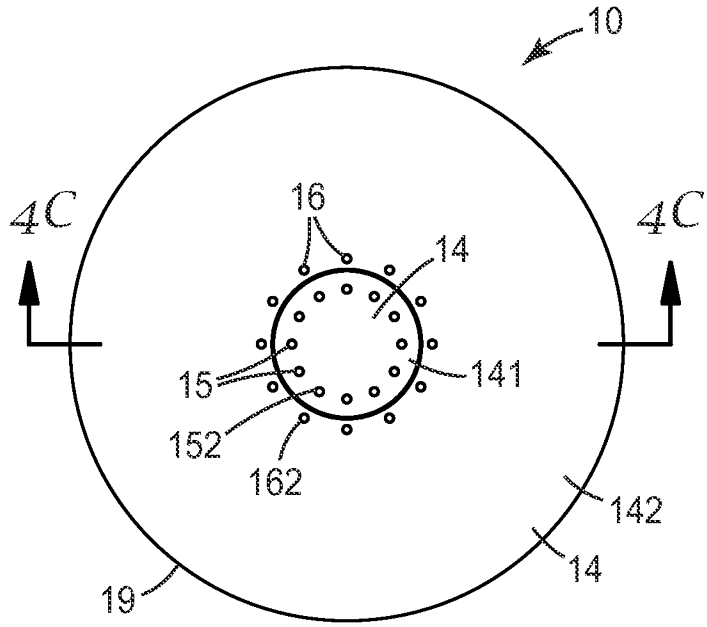

FIG. 4B

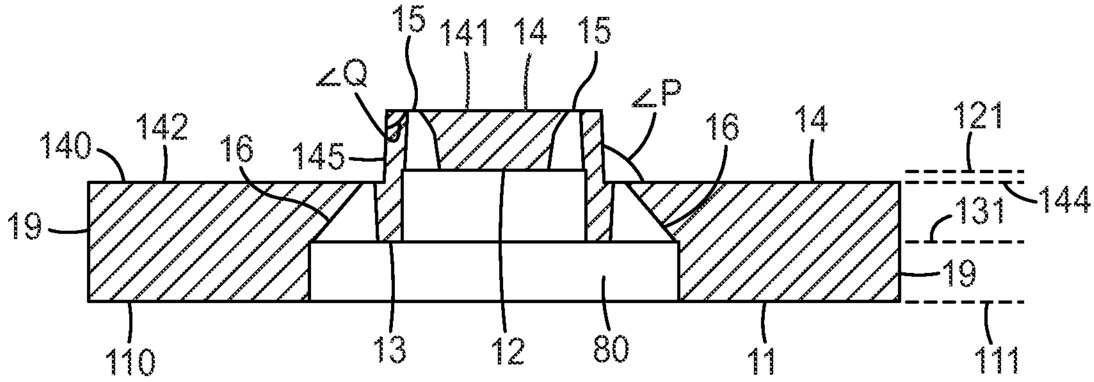

FIG. 4C

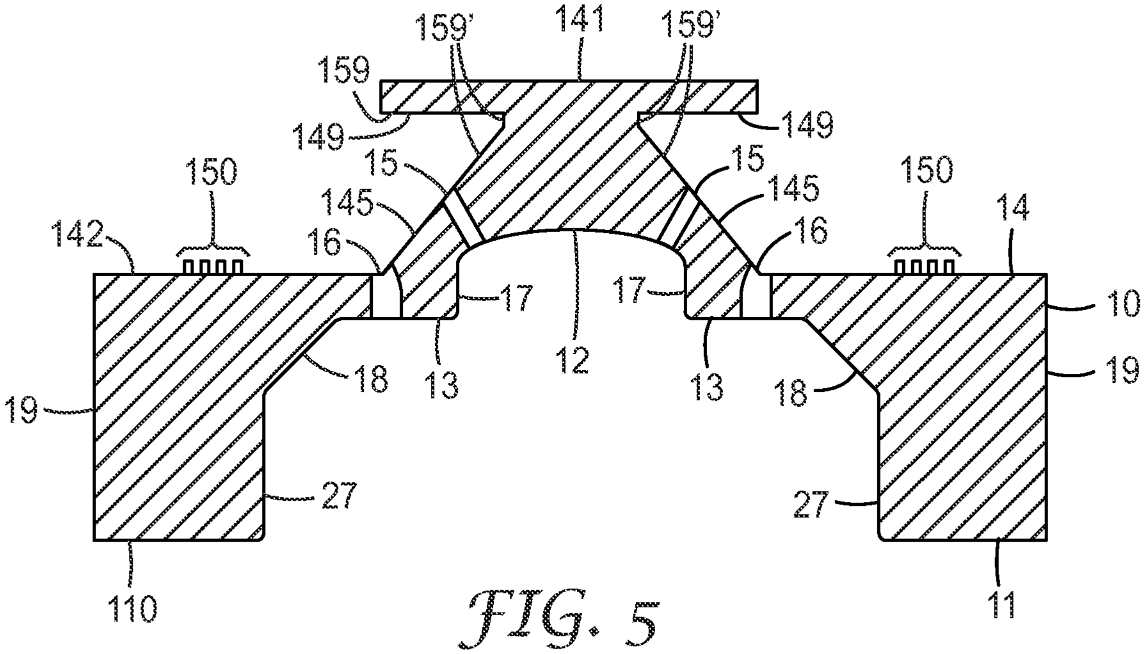
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FIG. 5

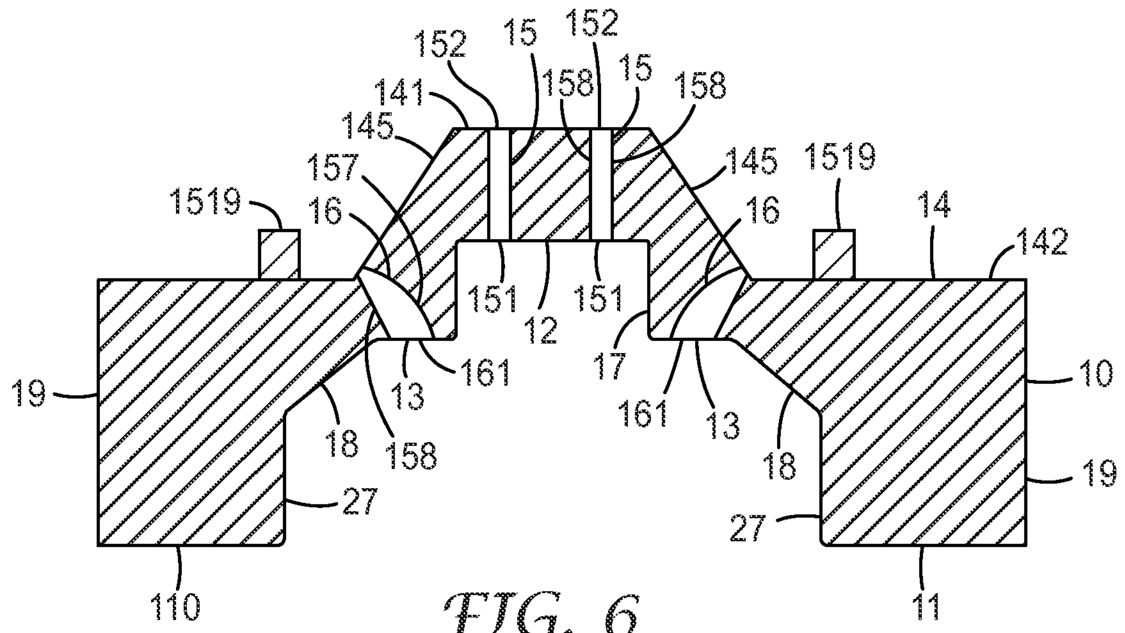
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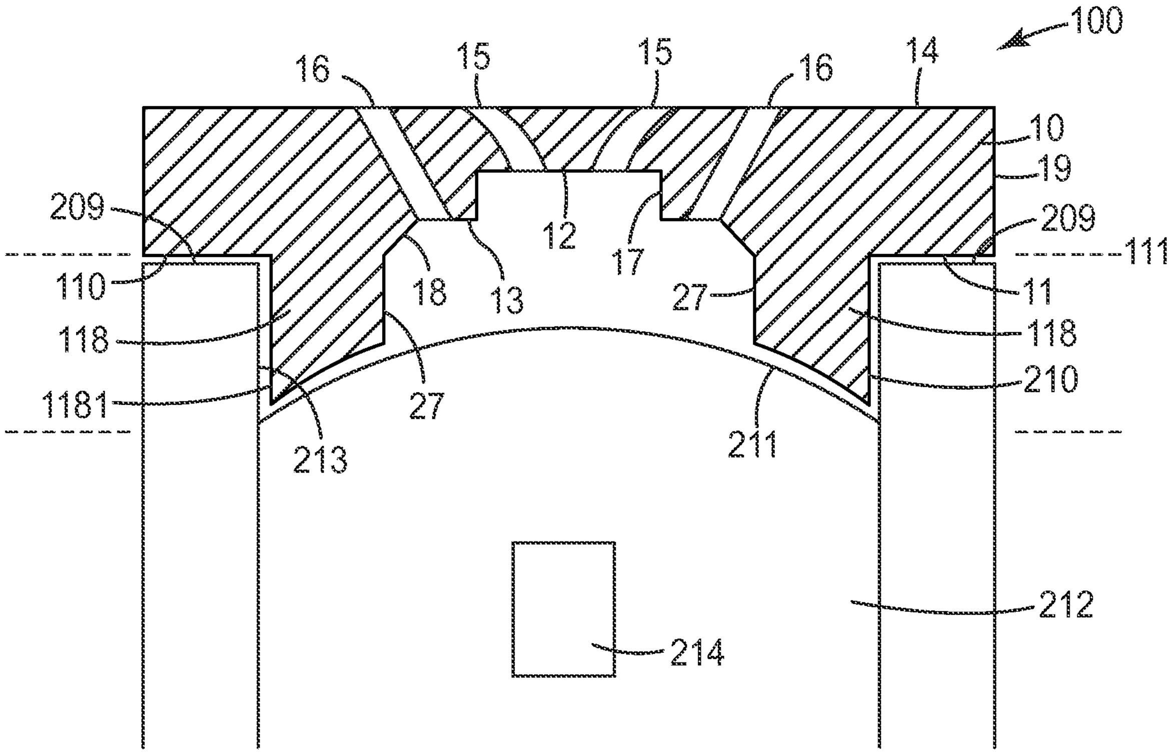
FIG. 6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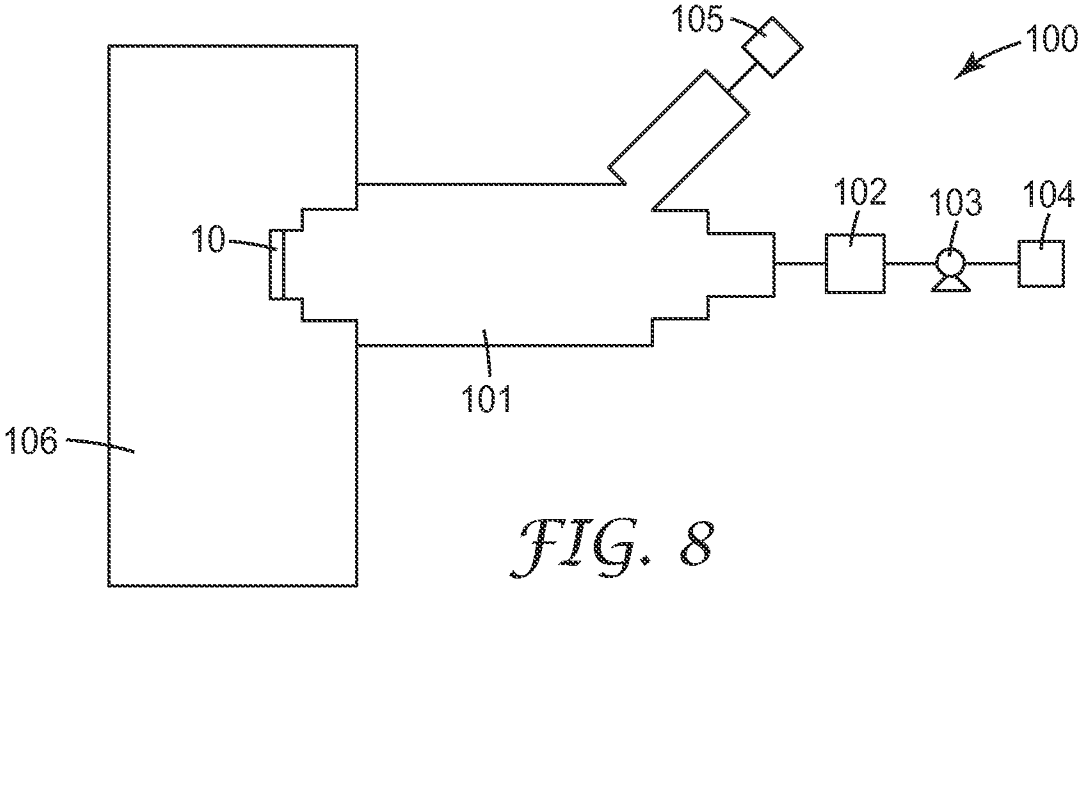
212
214

FIG. 7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104
10
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106

FIG. 8

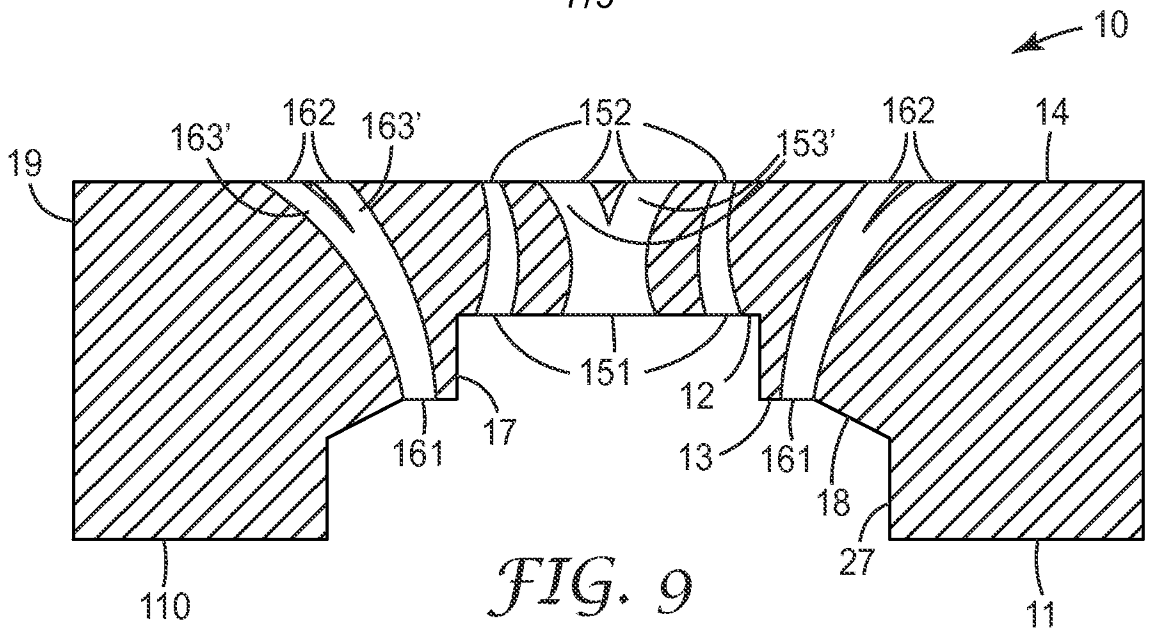

FIG. 9

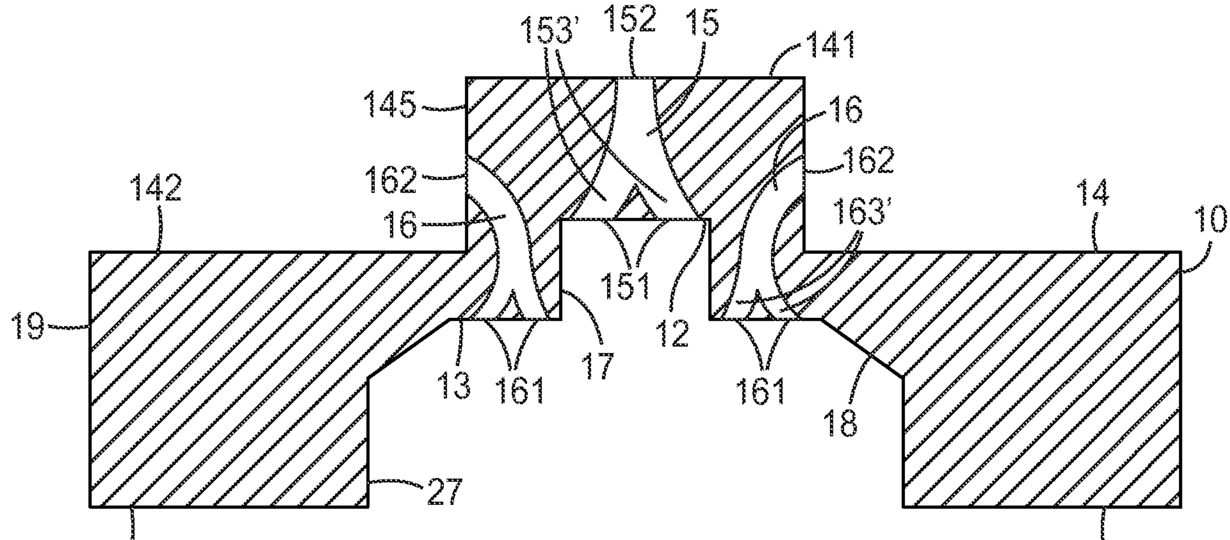

FIG. 10

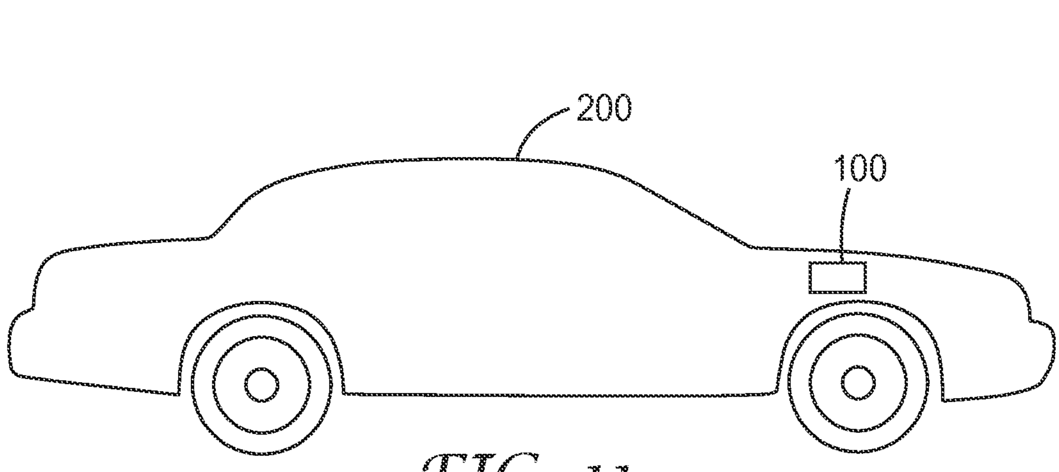

FIG. 11

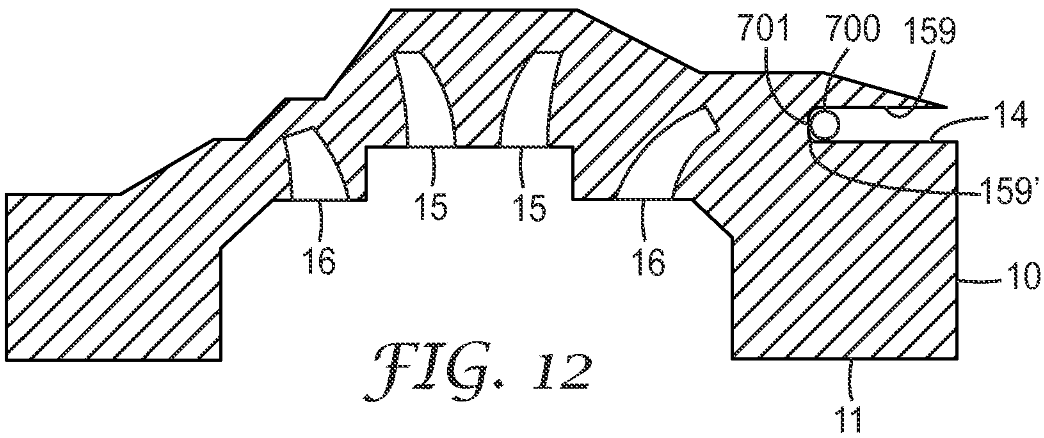

FIG. 12

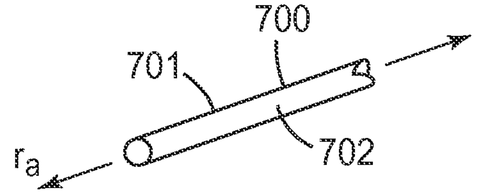

FIG. 13

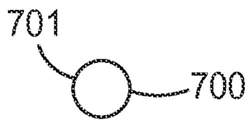

FIG. 14a

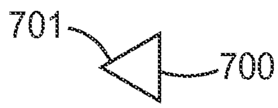

FIG. 14b

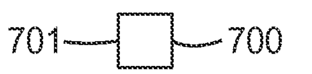

FIG. 14c

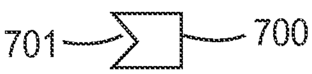

FIG. 14d

FIG. 14e

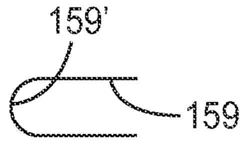

FIG. 15a

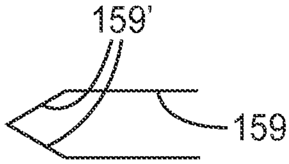

FIG. 15b

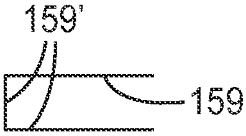

FIG. 15c

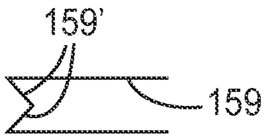

FIG. 15d

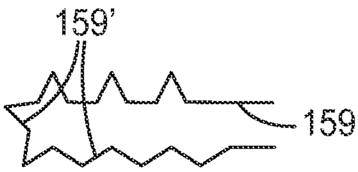

FIG. 15e

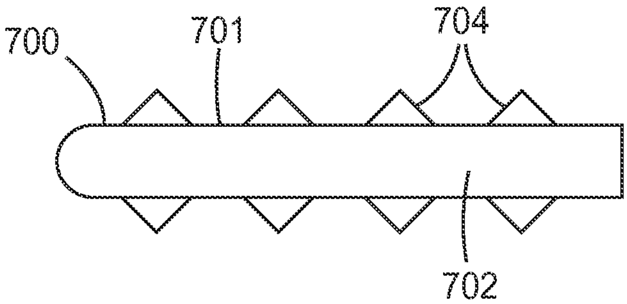

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/053178

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M61/18 F02M45/08
ADD.

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)
F02M

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2006 000243 A1 (DENSO CORP [JP]) 30 November 2006 (2006-11-30) abstract; figures 2,18 claim 1 claim 9 claim 10 paragraph [0101] - paragraph [0103] paragraph [0001] paragraph [0098] paragraph [0105] -----	1-5,9, 10,12-15
X	EP 1 995 448 A1 (TOYOTA MOTOR CO LTD [JP]) 26 November 2008 (2008-11-26) abstract; figure 1 claim 1 paragraph [0032] - paragraph [0034] ----- -/--	1-3,5,6, 10,12-15

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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"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

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Date of the actual completion of the international search	Date of mailing of the international search report
11 November 2013	18/11/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Barunovic, Robert

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No
PCT/US2013/053178

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 2008/120086 A2 (TOYOTA MOTOR CO LTD [JP]; DENSO CORP [JP]; OKUMURA FUMIHIRO [JP]; WATA) 9 October 2008 (2008-10-09) abstract; figures 4,8 claim 1 claim 6 claim 12 paragraph [0035] - paragraph [0036] paragraph [0033] paragraph [0031] paragraph [0002] paragraph [0011] ----- -/--	1-5, 11-15

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International application No
PCT/US2013/053178

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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