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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 : **SCHNOBRICH, Scott M.** [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). **FIPP, Barbara A.** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). **NOVACK, James C.** [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). **SHIRK, Ryan C.** [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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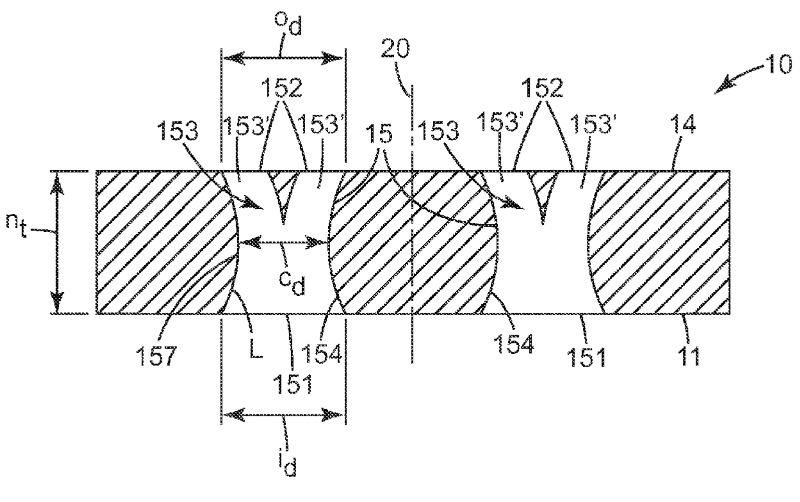
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) **Title**: FUEL INJECTOR NOZZLES WITH AT LEAST ONE MULTIPLE INLET PORT AND/OR MULTIPLE OUTLET PORT



(57) **Abstract**: Nozzles and method of making the same are disclosed. The disclosed nozzles have at least one nozzle through-hole therein, wherein the at least one nozzle through-hole has (i) a single inlet opening along an inlet face and multiple outlet openings along an outlet face or (ii) multiple inlet openings along an inlet face and a single outlet opening along an 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 INJECTOR NOZZLES WITH AT LEAST ONE MULTIPLE INLET PORT AND/OR MULTIPLE OUTLET PORT

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 an inlet face; an outlet face opposite the inlet face; and at least one nozzle through-hole comprising (i) a single inlet opening on the inlet face connected to multiple outlet openings on the outlet face by a cavity defined by an interior surface, or (ii) multiple inlet openings on the inlet face connected to a single outlet opening on the outlet face by a cavity defined by an interior 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 incorporated therein.

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 incorporated therein.

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 at least one nozzle through-hole within the fuel injector nozzle such that the at least one nozzle through-hole extends from an inlet face to an outlet face opposite the inlet face of the nozzle, the at least one nozzle through-hole comprising (i) a single inlet opening on the inlet face connected to multiple outlet openings on the outlet face by a cavity defined by an interior surface, or (ii) multiple inlet openings on the inlet face connected to a single outlet opening on the outlet face by a cavity defined by an interior surface.

The present invention is also directed to methods of making fuel injectors for use in an internal combustion engine of a vehicle. 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 further directed to methods of making fuel injection systems of an internal combustion 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.

The present invention is even further directed to methods of using fuel injection systems of an internal combustion vehicle. In one exemplary embodiment, the method of using a fuel injection system comprises: introducing two or more fuel components into a nozzle of a fuel injection system such that each fuel component independently enters separate inlet openings of a single nozzle through-hole and exits a single outlet opening of the single nozzle through-hole so as to mix the two or more fuel components from the two or more fuel reservoirs as the fuel components travel through the nozzle.

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 cross-sectional view of an exemplary nozzle of the present invention;

FIG. **2** is a cross-sectional view of another exemplary nozzle of the present invention;

FIG. **3** is a top view of an exemplary nozzle of the present invention;

FIG. **4** is a cross-sectional view of another exemplary nozzle of the present invention;

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

FIGS. **6**-**7** are perspective views of cavities of exemplary nozzle through-holes of the present invention;

FIGS. **8A**-**8C** are various views of an exemplary cavity of a nozzle through-hole of the present invention;

FIG. **9** is a schematic view of an exemplary fuel injection system of the present invention;

FIG. **10** is a schematic view of another exemplary fuel injection system of the present invention; and

FIG. **11** is a schematic view of another exemplary fuel injection system of the present invention.

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, wherein at least one nozzle through-hole comprises (i) a single inlet opening on an inlet face of the nozzle connected to multiple outlet openings on an outlet face of the nozzle by a cavity defined by an interior surface, or (ii) multiple inlet openings on the inlet face connected to a single outlet opening on the outlet face by a cavity defined by an interior surface. 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 a single nozzle through-hole or through multiple nozzle through-holes (e.g., the combination of increased fluid flow through one or more outlet openings and decreased fluid flow through other outlet openings of the same nozzle through-hole or of multiple nozzle through-holes) by selectively designing individual cavity passages (i.e., cavity passages **153'** discussed below) extending along a length of a given nozzle through-hole), (2) the ability to provide multi-directional fluid flow relative to an outlet face of the nozzle via a single nozzle through-hole or multiple nozzle through-holes, (3) the ability to provide multi-directional off-axis fluid flow relative to a central normal line extending perpendicularly through the nozzle outlet face via a single nozzle through-hole or multiple nozzle through-holes, and (4) the ability to mix two or more fuel components entering multiple inlet openings and exiting a single outlet opening of a single nozzle through-hole.

FIGS. **1-5** depict various views of exemplary fuel injector nozzles **10** of the present invention. As shown in FIG. **1**, exemplary fuel injector nozzle **10** comprises an inlet face **11**; an outlet face **14** opposite inlet face **11**; and at least one nozzle through-hole **15** comprising a single inlet opening **151** on inlet face **11** connected to multiple outlet openings **152** on outlet face **14** by a cavity **153** defined by an interior surface **154**. As shown in FIG. **2**, exemplary fuel injector nozzle **10** comprises inlet face **11**; outlet face **14** opposite inlet face **11**; and at least one nozzle through-hole **15** comprising multiple inlet openings **151** on inlet face **11** connected to a single outlet opening **151** on outlet face **14** by a cavity **153** defined by an interior surface **154**.

As shown in FIGS. **1-2**, nozzle through-holes **15** of exemplary nozzles **10** comprise multiple cavity passages **153'** extending along cavity **153**, wherein each cavity passage **153'** leads to one outlet opening **152** or extends from one inlet opening **151**.

As shown in FIGS. **3-4**, nozzles **10** of the present invention may comprise one or more arrays **28**, wherein each array **28** comprises one or more nozzle through-holes **15** and/or one or more nozzle through-holes **16**. As shown in FIG. **4**, each nozzle through-hole **16** comprises a single inlet opening **161** along inlet face **11** and a single outlet opening **162** along outlet face **14**.

As shown in FIG. **5**, exemplary 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 anti-coking microstructures **150** positioned along any portion of outlet face **14**, and one or more fluid impingement structures **1519** along any portion of outlet face **14**.

As shown in FIGS. **1-8C**, 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) one or more inlet openings **151/161**, each of which has its own independent shape and size, (ii) one or more outlet openings **152/163**, each of which has its own independent shape and size, (iii) an internal surface **154/164** 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**, and (iv) an internal surface **154** profile that may include two or more cavity passages **153'** extending from multiple inlet openings **151** and merging into a single cavity passage **153'** extending to a single outlet opening **152**, or a single cavity passages **153'** extending from a single inlet opening **151** and separating into two or more cavity passages **153'** extending to multiple outlet openings **152**. 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** (i.e., fluid flow that is essentially the same exiting each multiple outlet opening **152** of each of nozzle through-holes **15** and/or each outlet opening **162** of each of nozzle through-hole **16**), (2) variable fluid flow through any one nozzle through-hole **15** (i.e., fluid flow that is not the same exiting the multiple outlet openings **152** of a given nozzle through-hole **15**), (3) variable fluid flow through any two or more nozzle through-holes **15/16** (i.e., fluid flow that is not the same exiting the multiple outlet openings **152** of a given nozzle through-hole **15** and/or each outlet opening **162** of each of nozzle through-hole **16**), (4) single- or multi-directional fluid streams exiting a single nozzle through-hole **15**, multiple nozzle through-holes **15**, or any combination of nozzle through-holes **15/16**, (5) 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** having multiple inlet openings **151**, multiple outlet openings **152** or both, the nozzle through-hole **15** can have a different axis of flow corresponding to each of the multiple openings **151/152**.

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 (i.e., 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** that not being aligned or parallel to each other, or are aligned along different directions, or are parallel but not aligned, or are 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 (e.g., outlet face overlapping features **149**), (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 (e.g., specifically disclosed nozzle through-holes **15** and/or inlet face features **118** that reduce a SAC volume of a fuel injector), (3) 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 (e.g., specifically disclosed nozzle through-holes **15** having a relatively high coefficient of discharge (COD) value), and (4) U.S. Provisional Patent Application Serial No. 61/678,288 (3M Docket No. 69913US002 entitled "Fuel Injectors with Non-Coined Three-dimensional Nozzle Inlet Face") filed on August 01, 2012 (e.g., a non-coined three-dimensional inlet face **11**), 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 nozzle **10** has one or more nozzle through-holes **15** therein, and at least one nozzle through-hole **15** has (i) a single inlet opening **151** along an inlet face **11** and multiple outlet openings **152** along an outlet face **14** or (ii) multiple inlet openings **151** along an inlet face **11** and a single outlet opening **152** along an outlet face **14** as described herein. Although suitable 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 (e.g., using a multiphoton process, such as a two photon process) disclosed in International Patent Application Serial No. US2012/023624. See, for example, the method steps shown in FIGS. **1A**-**1M** and the description thereof in International Patent Application Serial No. US2012/023624.

<u>Additional Embodiments</u>

Nozzle Embodiments

1. A fuel injector nozzle **10** comprising: an inlet face **11**; an outlet face **14** opposite said inlet face **11**; and at least one nozzle through-hole **15** comprising (i) a single inlet opening **151** on said inlet face **11** connected to multiple outlet openings **152** on said outlet face **14** by a cavity **153** defined by an interior surface **154**, or (ii) multiple inlet openings **151** on said inlet face **11** connected to a single outlet opening **151** on said outlet face **14** by a cavity **153** defined by an interior surface **154**.

2. The nozzle **10** of embodiment 1, wherein said at least one nozzle through-hole **15** is a plurality of nozzle through-holes **15** comprising (i), (ii), or both (i) and (ii).

3. The nozzle **10** of embodiment 1 or 2, wherein said inlet face **11** and said outlet face **14** are substantially parallel.

4. The nozzle **10** of any one of embodiments 1 to 3, wherein said nozzle **10** is substantially flat.

5. The nozzle **10** of any one of embodiments 1 to 4, wherein said cavity **153** of each said nozzle through-hole **15** comprises multiple cavity passages **153'** extending along said cavity **153**, and each said cavity passage **153'** leads to one said outlet opening **152** or extends from one said inlet opening **151**.

6. The nozzle **10** of any one of embodiments 1 to 5, wherein said cavity **153** of each said nozzle through-hole **15** comprises multiple cavity passages **153'** extending greater than or equal to about 10% (or any fractional percent greater than 10% in increments of 1.0%) of a maximum overall length **L** of said cavity **153**. As used herein, the phrase "maximum overall length **L** of a given cavity **153**" represents the greatest distance extending from an inlet opening **151** to an outlet opening **152** of the given cavity **153**. As shown, for example, in FIG. **1**, length **L** of cavity **153** extends along curved surface portion **157** of nozzle **10**.

7. The nozzle **10** of embodiment 6, wherein said multiple cavity passages **153'** extend in the range of from about 10% to about 90% (or any percent or range therebetween in increments of 1.0%) of a maximum overall length **L** of said cavity **153**.

8. The nozzle **10** of any one of embodiments 5 to 7, wherein there are at least 4 of said cavity passages **153'** within each said nozzle through-hole **15**.

9. The nozzle **10** of any one of embodiments 5 to 7, wherein there are in the range of from 2 to 50, or any number or range therebetween in increments of 1 (e.g., from 3 to 20), of said cavity passages **153'** within each said nozzle through-hole **15**.

10. The nozzle **10** of any one of embodiments 1 to 9, wherein said at least one nozzle through-hole **15** comprises one inlet opening **151** and multiple outlet openings **152**.

11. The nozzle **10** of embodiment 10, wherein each said cavity passage **153'** leads to one said outlet opening **152** of said multiple outlet openings **152**.

12. The nozzle **10** of any one of embodiments 1 to 9, wherein said at least one nozzle through-hole **15** comprises multiple inlet openings **151** and one outlet opening **152**.

13. The nozzle **10** of embodiment 12, wherein each said cavity passage **153'** leads to one said inlet opening **151** of said multiple inlet openings **151**.

14. The nozzle **10** of any one of embodiments 1 to 11, wherein said at least one nozzle through-hole **15** comprises multiple outlet openings **152**, and each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid (not shown) flowing through said nozzle through-hole **15** forms multiple fluid streams that (1) substantially converge (i.e., some, most, all, or at least an otherwise commercially acceptable number of the streams converge) at generally or precisely one location a desired distance from the outlet face **14** of said nozzle **10**, (2) substantially diverge in multiple separate directions for a distance from the outlet face of said nozzle, (3) remain substantially parallel for a desired distance from the outlet face **14** of said nozzle **10**, or (4) any combination of (1), (2) and (3). As used herein, the phrase "substantially converge" refers to adjacent fluid streams that contact one another. The degree of contact between adjacent fluid streams may vary, but, at a minimum, the paths of the adjacent fluid streams overlap one another. As used herein, the phrase "substantially diverge" refers to fluid streams that move away from one another. For example, a nozzle through-hole **15** having a cavity **153** as shown in FIG. **6** produces four separate fluid streams (not shown) that are initially parallel with one another, but eventually converge to some extent a distance from outlet openings **152**. In contrast, a nozzle through-hole **15** having a cavity **153** as shown in FIG. **7** or FIG. **8A**-**8C** produces five separate fluid streams (not shown) that start to diverge from one another as soon as the fluid streams exit outlet openings **152**.

The distances at which a fuel stream, for each injector type (i.e., PFI, GDI, or DI), should break-up depend on a number of factors. For example, such a distance for a PFI type fuel injector system, the director plate port-to-port spacing, as well as the surface tension of the liquid fuel, can affect this distance. If the fuel stream breaks-up too far out from the nozzle, or if the individual stream velocities are too similar, the droplets may coalesce, which can have a negative effect on fuel efficiency. With the present invention, individual fuel stream speeds can be made substantially different, e.g., by changing the ratio of the inlet opening area to outlet opening area, for nozzle through-holes having larger inlet openings and smaller outlet openings.

If the goal is to have individual fuel streams converge at a point and break-up upon impact, than the distance to such a point would depend on the particulars (dimensions, configuration, and design) of the chosen internal combustion engine. In one example of a PFI application, it can be desirable for the fuel stream or spray to break-up right before the intake valve so as to allow the air coming into the combustion chamber (i.e., engine cylinder) to carry the small droplets of fuel with them into the cylinder. Smaller fuel droplets can more easily follow the flow path of the air, thus minimizing contact with portions (e.g., the back) of the valve. Allowing the fuel spray to break-up against the valve can cause carbon or coke buildup on internal surfaces. However, if the strategy is to use the back of the valve to breakup the spray, than it may be desirable to cause the fuel droplets to coalesce as soon as, or soon after, they exit the fuel injector nozzle. The coalescence of the fuel droplets can minimize momentum loss as the fuel spray travels through the air. Such reduction in momentum loss can result in the fuel droplets hitting the back of the intake valve with a higher momentum, which can cause a greater degree of fuel stream/spray break-up.

15. The nozzle **10** of embodiment 14, wherein each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid flowing through said nozzle through-hole **15** forms multiple fluid streams that remain substantially parallel for a desired distance from the outlet face **14** of said nozzle **10**.

16. The nozzle **10** of embodiment 15, wherein said fluid streams are substantially parallel with a nozzle central axis **20** extending along a normal line perpendicular to the outer face **14** of said nozzle **10**.

17. The nozzle **10** of embodiment 14, wherein each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid flowing through said nozzle through-hole **15** forms multiple fluid streams that substantially converge at about one location a desired distance from the outlet face **14** of said nozzle **10**.

18. The nozzle **10** of embodiment 14, wherein each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid flowing through said nozzle through-hole **15** forms multiple fluid streams that substantially diverge in multiple separate directions.

19. The nozzle **10** of embodiment 17 or 18, wherein said fluid streams are substantially off-axis relative to a nozzle central axis **20** extending along a normal line perpendicular to the outer face **14** of said nozzle **10**.

20. The nozzle **10** of embodiment 14, wherein each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid flowing through said nozzle through-hole **15** forms multiple fluid streams that (1) substantially converge at about one location a distance from the outlet face **14** of said nozzle **10**, (2) substantially diverge in multiple separate directions for a distance from the outlet face of said nozzle, and (3) remain substantially parallel for a desired distance from the outlet face **14** of said nozzle **10**.

21. The nozzle **10** of embodiment 20, wherein said fluid streams comprise streams that are substantially parallel with an off-axis relative to a nozzle central axis **20** extending along a normal line perpendicular to the outer face **14** of said nozzle **10**.

22. The nozzle **10** of any one of embodiments 1 to 21, wherein each said cavity passage **153'** leads to one said outlet opening **152** such that a fluid flowing through said at least one nozzle through-hole **15** forms fluid streams directed to two or more separate locations a desired distance from the outlet face **14** of said nozzle **10**.

Typical Distances for Fuel Stream Break-Up Upon Exiting a Nozzle Outlet Face

	Converging*		Diverging*		Parallel*	
	Min	Max	Min	Max	Min	Max
PFI	0.01 mm	400 mm	15 mm	100 mm	25 mm	400 mm
GDI	0.01 mm	150 mm	10 mm	150 mm	10 mm	200 mm
DI	0.01 mm	200 mm	10 mm	250 mm	10 mm	250 mm

* - Refers to the path followed by multiple fuel streams formed from multiple nozzle through-holes, multiple outlet openings of a single nozzle through-hole, or both.

23. The nozzle **10** of any one of embodiments 14 to 17 and 19 to 21, wherein the distance is in the range of from about 10 mm to about 400 mm (or any number or range therebetween in increments of 1.0 mm).

24. The nozzle **10** of any one of embodiments 14 to 17 and 19 to 21, wherein the distance is in the range of from about 0.01 mm to about 400 mm (or any number or range therebetween in increments of 0.01 mm).

25. The nozzle **10** of any one of embodiments 14, 18 to 20 and 22, wherein the distance is in the range of from about 10 mm to about 250 mm (or any number or range between about 0.01 mm and about 250 mm in increments of 0.01 mm).

26. The nozzle **10** of any one of embodiments 1 to 25, wherein said at least one nozzle through-hole **15** is a plurality of nozzle through-holes **15**.

27. The nozzle **10** of any one of embodiments 1 to 26, further comprising one or more arrays **28** of nozzle through-holes **15** for directing a fluid from said inlet face **11** to said outlet face **14**, wherein at least one of said one or more arrays **28** comprises said at least one nozzle through-hole **15**.

28. The nozzle **10** of any one of embodiments 1 to 27, further comprising one or more additional nozzle through-holes **16**, with each additional nozzle through-hole **16** comprising a single inlet opening **161** on said inlet face **11** connected to a single outlet opening **162** on said outlet face **14** by a cavity **163** defined by an interior surface **164**.

29. The nozzle **10** of any one of embodiments 1 to 28, wherein at least one said nozzle through-hole **15/16** is a curved nozzle through-hole **15/16** comprising an interior surface **154/164** with at least one curved portion **157** that is curved along a direction extending directly from an inlet opening **151/161** to an outlet opening **152/162**. When discussed herein, curved portion **157** or liner portion **158**, and/or any other surface portion form all or a part of a “curved surface profile” of internal surface **154** that extends directly from at least one inlet opening **151** to at least one outlet opening **152**. The “curved surface profile” can refer to (i) a shortest distance along internal surface **154** that extends directly from at least one inlet opening **151** to at least one outlet opening **152**, (ii) a longest distance along internal surface **154** that extends directly from at least one inlet opening **151** to at least one outlet opening **152**, or (iii) any other distance therebetween along internal surface **154** that extends

directly from at least one inlet opening **151** to at least one outlet opening **152**.

30. The nozzle **10** of embodiment 29, wherein said curved portion **157** extends directly along the interior surface **154/164** of said curved nozzle through-hole **15/16**, beginning proximate to an inlet opening **151/161** (i.e., extends directly in a direction from at least one inlet opening **151** to at least one outlet opening **152**).

31. The nozzle **10** of embodiment 30, wherein said curved portion **157** extends to at least one outlet opening **152/162** (i.e., extends directly in a direction from at least one inlet opening **151** to at least one outlet opening **152**).

32. The nozzle **10** of any one of embodiments 29 to 31, wherein the interior surface **154/164** of said curved nozzle through-hole **15/16** comprises a non-curved linear portion **158** on a side of said interior surface **154/164** opposite said curved portion **157**, with said linear portion **158** being non-curved along a direction extending directly from an inlet opening **151/161** to an outlet opening **152/162**.

33. The nozzle **10** of embodiment 32, wherein said linear portion **158** defines an obtuse angle **A** with a portion of the inlet face **11** of said nozzle **10**.

34. The nozzle **10** of embodiment 32 or 33, wherein said linear portion **158** extends to at least one outlet opening **152/162**.

35. The nozzle **10** of any one of embodiments 32 to 34, wherein the interior surface **154/164** of said curved nozzle through-hole **15/16** comprises another curved portion **157'** that is curved along a direction extending directly from an inlet opening **151/161** to an outlet opening **152/162**, with said other curved portion **157'** beginning proximate to an inlet opening **151/161** and ending where said linear portion **158** begins.

36. The nozzle **10** of embodiment 35, wherein said other curved portion **157'** is convex shaped.

37. The nozzle **10** of any one of embodiments 29 to 36, wherein said at least one curved portion **157** of the interior surface **154/164** of said curved nozzle through-hole **15/16** comprises two curved portions **157/157'** located on opposite sides of the cavity **153/163** of said curved nozzle through-hole **15/16** (i.e., each extends directly in a direction from at least one inlet opening **151** to at least one outlet opening **152**).

38. The nozzle **10** of embodiment 37, wherein one of said two curved portions **157/157'** has a convex shape and the other of said two curved portions **157/157'** has a concave shape (i.e., each extends directly in a direction from at least one inlet opening **151** to at least one outlet opening **152**).

39. The nozzle **10** of embodiment 37, wherein one of said two curved portions **157/157'** has a first convex shape and the other of said two curved portions **157/157'** has a second convex shape (i.e., each extends directly in a direction from at least one inlet opening **151** to at least one outlet opening **152**).

40. The nozzle **10** of any one of embodiments 29 to 39, wherein the inlet opening **151/161** of said

curved nozzle through-hole **15/16** has a periphery **151'/161'** defined by a convex shaped curved portion of the interior surface **154/164** of said curved nozzle through-hole **15/16**.

41. The nozzle **10** of any one of embodiments 1 to 40, wherein (a) said inlet opening **151** or said multiple inlet openings **151** of at least one nozzle through-hole **15** form an inlet opening pattern along said inlet face **11**, said inlet opening pattern having an inlet opening periphery and an inlet opening periphery diameter i_d, (b) said multiple outlet openings **152** or said outlet opening **152** of the at least one nozzle through-hole **15** form an outlet opening pattern along said outlet face **14**, said outlet opening pattern having an outlet opening periphery and an outlet opening periphery diameter o_d, with (i) said overall inlet opening periphery diameter i_d, (ii) said overall outlet opening periphery diameter o_d, or (iii) both of said overall inlet opening periphery diameter i_d and said overall outlet opening periphery diameter o_d being independently greater than a cavity diameter c_d along at least a portion of said cavity **153** of the at least one nozzle through-hole **15**.

42. The nozzle **10** of any one of embodiments 1 to 41, wherein (a) said inlet opening **151** or said multiple inlet openings **151** form an inlet opening pattern along said inlet face **11**, said inlet opening pattern having an inlet opening periphery and an inlet opening periphery diameter i_d, (b) said multiple outlet openings **152** or said outlet opening **152** form an outlet opening pattern along said outlet face **14**, said outlet opening pattern having an outlet opening periphery and an outlet opening periphery diameter o_d, with said outlet opening periphery diameter o_d being independently greater than a cavity diameter c_d along at least a portion of said cavity **153**.

43. The nozzle **10** of any one of embodiments 1 to 42, wherein (a) said inlet opening **151** or said multiple inlet openings **151** form an inlet opening pattern along said inlet face **11**, said inlet opening pattern having an inlet opening periphery and an inlet opening periphery diameter i_d, (b) said multiple outlet openings **152** or said outlet opening **152** form an outlet opening pattern along said outlet face **14**, said outlet opening pattern having an outlet opening periphery and an outlet opening periphery diameter o_d, with each of (i) said overall inlet opening periphery diameter i_d and (ii) said overall outlet opening periphery diameter o_d being independently greater than a cavity diameter c_d along at least a portion of said cavity **153**.

44. The nozzle **10** of any one of embodiments 5 to 43, wherein said cavity passages **153'** rotate within an x-y plane as said cavity passages **153'** extend through said nozzle **10**. See, for example, rotating cavity passages **153'** within cavity **153** shown in FIG. 7.

45. The nozzle **10** of any one of embodiments 1 to 44, wherein at least one inlet opening **151** and at least one outlet opening **152** for at least one nozzle through-hole **15** have a similar shape. It should be noted that a given nozzle through-hole **15** with multiple inlet openings **151** or multiple outlet openings **152** may comprise two or more inlet openings **151** or two or more outlet openings **152** having different opening diameters and/or opening shapes. Such an opening configuration produces individual fluid streams having different fluid velocities and droplet sizes from a single nozzle

through-hole **15**.

46. The nozzle **10** of any one of embodiments 1 to 45, wherein at least one inlet opening **151** and at least one outlet opening **152** for at least one nozzle through-hole **15** have a different shape.

47. The nozzle **10** of any one of embodiments 1 to 46, wherein each nozzle through-hole **15/16** has a total inlet opening area and a total outlet opening area, and said total inlet opening area is greater than said total outlet opening area.

48. The nozzle **10** of any one of embodiments 1 to 47, wherein said nozzle **10** has an overall ratio of total inlet opening area to total outlet opening area in the range of from greater than 1.0 to about 250 (or any number or range therebetween in increments of 0.1).

49. The nozzle **10** of any one of embodiments 1 to 47, wherein said nozzle **10** has an overall ratio of total inlet opening area to total outlet opening area ranging from about 0.0025 (e.g., 1 to 400) to about 400 (e.g., 400 to 1) (or any ratio or ratio range therebetween in increments of 0.0025 (ratio shown as fraction) or 1 to 1 (ratio shown as separate numbers)).

50. The nozzle **10** of any one of embodiments 1 to 49, wherein said nozzle **10** further comprises one or more outlet surface features **150/1519** extending along said outlet face **14**. Outlet surface features **150/1519** extending along outlet face **14** may include, but are not limited to, anti-coking microstructures **150** as shown in FIG. **5**, fluid impingement members **1519** as shown in FIG. **5**, or a combination thereof. Other suitable outlet surface features for use in the nozzles **10** of the present invention include, but are not limited to, overlapping outlet face structures **149** as disclosed in 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") referenced above.

51. The nozzle **10** of embodiment 50, wherein said one or more outlet surface features **1519** comprise one or more fluid impingement members **1519** positioned along said outer face **14**.

52. The nozzle **10** of any one of embodiments 1 to 51, 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). As used herein, the term “diameter” is used to describe a maximum distance across an inlet opening **151/161** (or an outlet opening **152/162**).

53. The nozzle **10** of any one of embodiments 1 to 52, 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).

54. The nozzle **10** of any one of embodiments 1 to 53, wherein the nozzle **10** comprises a metallic material, an inorganic non-metallic material (e.g., a ceramic), or a combination thereof.

55. The nozzle **10** of any one of embodiments 1 to 54, 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.

Fuel Injector Embodiments

56. A fuel injector **101** comprising a nozzle **10** according to any one of embodiments 1 to 55.

Fuel Injector System Embodiments

57. A fuel injection system **100** of a vehicle **200** comprising the fuel injector **101** of embodiment 56. As shown in FIG. **9**, exemplary fuel injector system **100** may comprise, *inter alia*, fuel injector **101**, fuel source/tank **104**, fuel pump **103**, fuel filter **102**, fuel injector electrical source **105**, and internal combustion engine **106**.

58. The fuel injection system **100** of embodiment 57, further comprising two or more fuel component reservoirs **104a**/**104b**, and tubing **108a**/**108b** extending between each fuel component reservoir **104a**/**104b** and a volume along said inlet face **11** of said nozzle **10**, said at least one nozzle through-hole **15** comprising multiple inlets **151a**/**151b** and a single outlet **152** so as to mix two or more fuel components (not shown) from said two or more fuel component reservoirs **104a**/**104b** as the fuel components travel through nozzle **10**. As shown in FIG. **10**, in addition to the two or more fuel component reservoirs **104a**/**104b** and tubing **108a**/**108b**, exemplary fuel injector system **100** may further comprise, *inter alia*, fuel injector **101**, fuel component pumps **104a**/**104b**, fuel component filters **102a**/**102b**, fuel injector electrical source **105**, and internal combustion engine **106**.

Methods of Making Nozzles Embodiments

59. A method of making the nozzle **10** of any one of embodiments 1 to 55.

60. A method of making a fuel injector nozzle **10**, said method comprising:
forming at least one nozzle through-hole **15** within the fuel injector nozzle **10** such that the at least one nozzle through-hole **15** extends from an inlet face **11** to an outlet face **14** opposite the inlet face **11** of the nozzle **10**, the at least one nozzle through-hole **15** comprising (i) a single inlet opening **151** on the inlet face **11** connected to multiple outlet openings **152** on the outlet face **14** by a cavity **152** defined by an interior surface **154**, or (ii) multiple inlet openings **151** on the inlet face **11** connected to a single outlet opening **152** on the outlet face **14** by a cavity **153** defined by an interior surface **154**.

61. The method of embodiment 60, said forming step comprising: applying a nozzle-forming material over a 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 a nozzle **10**; and removing material, as needed, from the nozzle **10** to form the at least one nozzle through-hole **15**. See, for example, the method steps shown in FIGS. **1A**-**1M** and the

description thereof in International Patent Application Serial No. US2012/023624.

62. The method of embodiment 61, wherein the nozzle forming microstructured pattern further comprises one or more planar control cavity forming features.

63. The method of embodiment 61 or 62, said forming step further comprising: providing a microstructured mold pattern defining at least a portion of a mold and comprising at least one replica nozzle hole; and molding a first material onto the microstructured mold pattern so as to form the nozzle forming microstructured pattern.

64. The method of embodiment 63, wherein the microstructured mold pattern comprises at least one fluid channel feature connecting at least one replica nozzle hole to (a) at least one other replica nozzle hole, (b) a portion of the mold beyond an outer periphery of the microstructured mold pattern, or (c) both (a) and (b).

65. The method of embodiment 63 or 64, wherein the first material comprises a material having a degree of elasticity.

66. The method of any one of embodiments 63 to 65, wherein the first material comprises polypropylene or polycarbonate. It should be noted that any of a number of moldable polymers may be used as the first material. Suitable moldable polymers include, but are not limited to, polycarbonate, liquid crystalline polymers (LCP), polyether ether ketone (PEEK), polypropylene (PP), thermoplastic elastomers (TPE) such as thermoplastic urethanes (TPU), fluoropolymers, polymer encapsulated metallic particles (e.g., such of those used in metal injection molding (MIM) and those described above.

67. The method of any one of embodiments 60 to 66, wherein the at least one nozzle through-hole **15** comprises a plurality of nozzle through-holes **15**.

68. The method of any one of embodiments 60 to 67, wherein said forming step further comprises: forming one or more additional nozzle through-holes **16** within the fuel injector nozzle **10** such that each additional nozzle through-hole **16** extends from the inlet face **11** to the outlet face **14** of the nozzle **10**, each additional nozzle through-hole **16** comprising (i) a single inlet opening **161** on the inlet face **11** connected to a single outlet opening **162** on the outlet face **14** by a cavity **163** defined by an interior surface **164**.

<u>Methods of Making Fuel Injector Embodiments</u>

69. A method of making a fuel injector **101**, said method comprising incorporating the nozzle **10** of any one of embodiments 1 to 55 into a fuel injector **101**.

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

70. A method of making a fuel injection system **100** of a vehicle **200**, said method comprising incorporating the fuel injector **101** of embodiment 69 into the fuel injection system **100**.

71. The method of embodiment 70, wherein the fuel injection system **100** comprises two intake valves **1062** per cylinder **1063**, and the at least one nozzle through-hole **15** independently directs fluid **1064** down corresponding throats of a split intake manifold **1065** towards the two intake valves **1062**. As shown in FIG. **11**, exemplary fuel injector system **100** may comprise, *inter alia*, fuel injector **101**, fuel source/tank **104**, fuel pump **103**, fuel filter **102**, fuel injector electrical source **105**, and internal combustion engine **106**. Internal combustion engine **106** further comprises combustion chamber **1061**.

Methods of Using Fuel Injection Systems Embodiments

72. A method of using the fuel injection system **100** of embodiment 58, said method comprising: introducing two or more fuel components (not shown) into the fuel injection system **100** such that each fuel component independently enters separate inlet openings **151** of a single nozzle through-hole **15** and exits a single outlet opening **152** of the single nozzle through-hole **15** so as to mix the two or more fuel components from the two or more fuel reservoirs **104a**/**104b** as the fuel components travel through the nozzle **10**.

Nozzle Pre-Form Embodiments

73. A nozzle pre-form suitable for forming the nozzle **10** of any one of embodiments 1 to 55. 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

74. A microstructured pattern suitable for forming the nozzle **10** of any one of embodiments 1 to 55. 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**.

Desirably, nozzles **10** of the present invention each independently comprise 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.

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 between about 100 μm and about 3 mm in increments of 1.0 μm).

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

The preparation of a nozzle plate begins with the design of its through-holes using conventional computer aided design software (CAD). A drawing of the intended design is prepared in which the individual through-hole has a single aperture or opening on one end and four individual apertures or openings on the other end. The cross-sectional split between the two ends (i.e., where one cavity splits into four) occurs at approximately 70 % of the through thickness. The design of the through-hole used in the nozzle plate of Example 1 is shown in Figure 6.

The nozzle plate of this example is designed using CAD layout software as an array of the aforementioned through-holes with a centrally positioned through-hole surrounded by additional through-holes arranged in concentric rings about the first to form a typical 2-dimensional hexagonal packing order of 37 through-holes.

The computer file containing both the through-hole design information and the positional information for through-holes within the nozzle plate array is used to execute the multi-photon exposure process within a photoresist layer, both of which are described in PCT/US2010/043628, which is incorporated herein in its entirety. Upon completion of the writing or exposure process the photoresist is “developed” by exposure to a solvent to wash away all photoresist material which was not exposed therefore not polymerized and is soluble. Once dried of any residual solvent a “master form” or “master” was obtained upon which solid forms in the shape designed as the through-holes remained.

As this example is made by a prototyping method this master form is used directly and a microstructured pattern was made electrically conductive by deposition of a thin layer of Silver applied via sputtering. This Silver-coated microstructured pattern is then electroplated with Nickel from a Nickel sulfamate solution so as to build up adequate material thickness from which the final nozzle plate will be formed.

Upon removal from the electroplating bath the Nickel plated side was subjected to an abrasive removal of material so as to remove enough material to expose the tips of the photoresist present in the microstructured features. The extent to which the material was removed was that necessary to provide openings which were of adequate size for the intended fluid mass flow rate desired of the nozzle plate, for example, to match that of a desired commercially available fuel injector.

This nozzle plate was attached to a commercially available fuel injector from which the original nozzle plate was carefully machined away. The nozzle plate of this example was carefully aligned such that the through-hole array was centered about the ball valve aperture and was laser welded onto the injector barrel to secure it to the injector. The excess material (i.e. the flange that extended beyond the barrel of the injector body) was machined away resulting in a fully functioning fuel injector. This injector was subjected to a series of tests including a leak test which ensured that the laser welding process had not distorted the ball valve seat in such a manner that the seal could not be formed and the injector leak.

<u>Results</u>

A fuel injector test bench available from ASNU Corporation Europe Limited (65-67 Glencoe Road, Bushey, WD23 3DP, United Kingdom) was used to collect mass flow rate information as a function of fluid supply pressure. Flo-Rite™ Fuel Injector FlowTest Fluid (1000-3FLO) recommended by ASNU for used with the equipment was used instead of gasoline. It is a hydrocarbon blend without the high flammability of gasoline and, thus for safety purposes, it is more suitable for usage in testing.

The fuel injector used with the nozzle plate of this example (Motorcraft Part Number 8S4Z9F593A) is manufactured by Robert Bosch GmbH and is suited for use in the 2.0 liter, in-line 4 cylinder Duratec™ engine manufactured by the Ford Motor Company. Results for a original equipment manufacturer's (OEM) part are provided for reference in Table 1 below.

Table 1 – results for nozzle plate (Example 1) as compared to original OEM nozzle plate

			Design		
			OEM	**Example #1**	units
Orifice count:		Inlet:	**4**	**37**	
		Outlet:	**4**	**148**	
Nozzle plate thickness:			**0.065**	**0.0119**	inch
Total Open Area (outlet):			**284956**	**200993**	um^2
Injector body:			**Motorcraft Part No. 8S4Z9F593A**		
Attachment Method:			**Laser Welding**		
Bench Testing (ASNU Testing)	Leak Test:		**PASS**	**PASS**	
	Flow Rate (static) @ pressures of:	2.0 bar:	**138.2**	**135.0**	grams/minute
		2.5 bar:	**157.9**	**154.4**	grams/minute
		3.0 bar:	**175.8**	**171.2**	grams/minute
		3.5 bar:	**190.1**	**187.5**	grams/minute
		4.0 bar:	**203.0**	**202.0**	grams/minute

The nozzle plate of this example has a higher count of smaller individual outlet holes and provides a comparable mass flow rate to the original equipment manufacture's (OEM) plate, and thereby, it is capable of distributing the fluid more uniformly over that area to which it is delivered. With smaller nozzle outlets produce smaller droplet sizes, which enables the fuel to be more highly atomized, resulting in a higher surface area, which has more exposure to oxygen in air and will burn more rapidly and completely than larger droplets. As a result fuel consumption and hydrocarbon emissions can be lowered.

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. 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:
an inlet face;
an outlet face opposite said inlet face; and
at least one nozzle through-hole comprising (i) a single inlet opening on said inlet face connected to multiple outlet openings on said outlet face by a cavity defined by an interior surface, or (ii) multiple inlet openings on said inlet face connected to a single outlet opening on said outlet face by a cavity defined by an interior surface.

2. The nozzle of claim 1, wherein said inlet face and said outlet face are substantially parallel.

3. The nozzle of claim 1 or 2, wherein said cavity of each said nozzle through-hole comprises multiple cavity passages extending along said cavity, and each said cavity passage leads to one said outlet opening or extends from one said inlet opening.

4. The nozzle of claim 3, wherein said multiple cavity passages extend in the range of from about 10% to about 90% of a maximum overall length of said cavity.

5. The nozzle of claim 3 or 4, wherein there are in the range of from 3 to 20 of said cavity passages within each said nozzle through-hole.

6. The nozzle of any one of claims 1 to 5, wherein said at least one nozzle through-hole comprises one inlet opening and multiple outlet openings.

7. The nozzle of any one of claims 1 to 5, wherein said at least one nozzle through-hole comprises multiple inlet openings and one outlet opening.

8. The nozzle of any one of claims 1 to 6, wherein said at least one nozzle through-hole comprises multiple outlet openings, and each cavity passage leads to one said outlet opening such that a fluid flowing through said nozzle through-hole forms multiple fluid streams that (1) substantially converge at one location a distance from the outlet face of said nozzle, (2) substantially diverge in multiple separate directions for a distance from the outlet face of said nozzle, (3) remain substantially parallel for a distance from the outlet face of said nozzle, or (4) any combination of (1), (2) and (3).

9. The nozzle of any one of claims 1 to 6 and 8, wherein each cavity passage leads to one said

outlet opening such that a fluid flowing through said at least one nozzle through-hole forms fluid streams directed to two or more separate locations a distance from the outlet face of said nozzle.

10. The nozzle of any one of claims 1 to 9, wherein said at least one nozzle through-hole is a plurality of nozzle through-holes.

11. The nozzle of any one of claims 1 to 10, further comprising one or more additional nozzle through-holes, with each additional nozzle through-hole comprising a single inlet opening on said inlet face connected to a single outlet opening on said outlet face by a cavity defined by an interior surface.

12. The nozzle of any one of claims 1 to 11, wherein at least one said nozzle through-hole is a curved nozzle through-hole comprising an interior surface with at least one curved portion that is curved along a direction from an inlet opening to an outlet opening.

13. A fuel injector comprising a nozzle according to any one of claims 1 to 12.

14. A fuel injection system of a vehicle comprising the fuel injector of claim 13.

15. A method of making the nozzle of any one of claims 1 to 12.

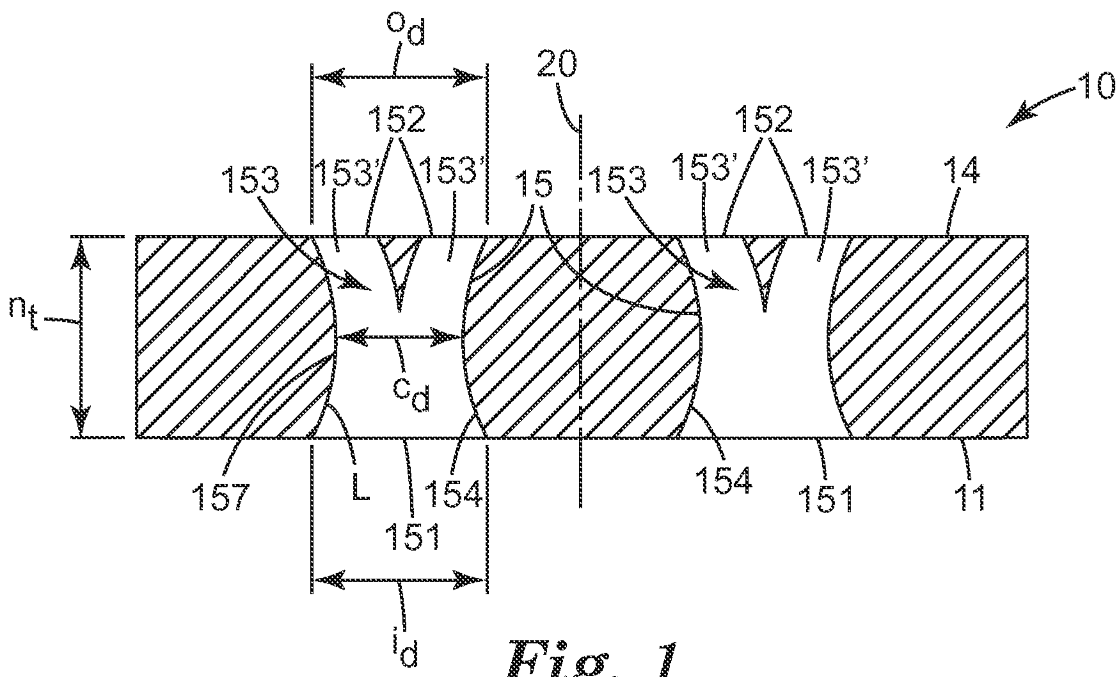

Fig. 1

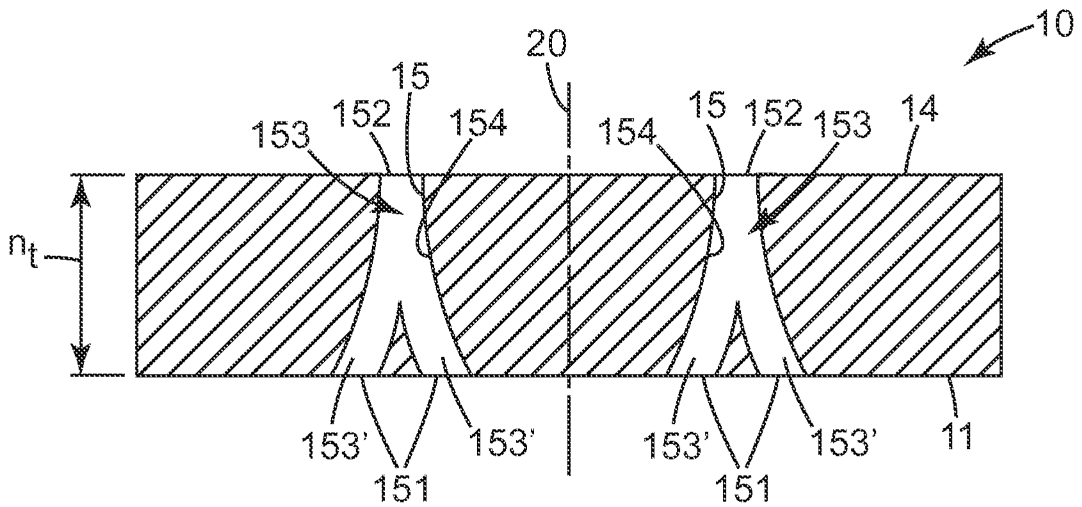

Fig. 2

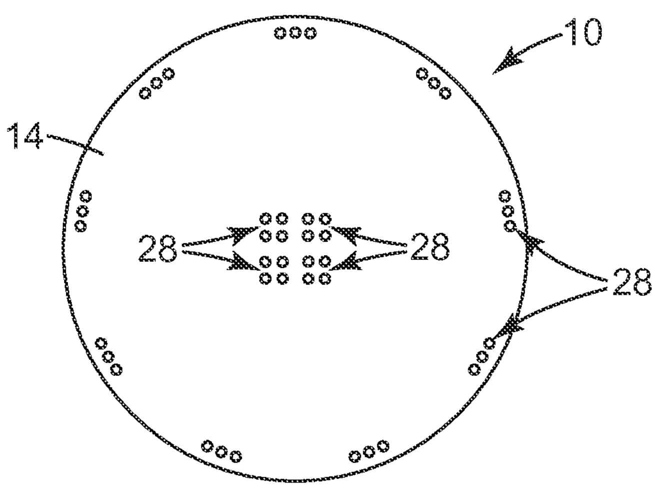

Fig. 3

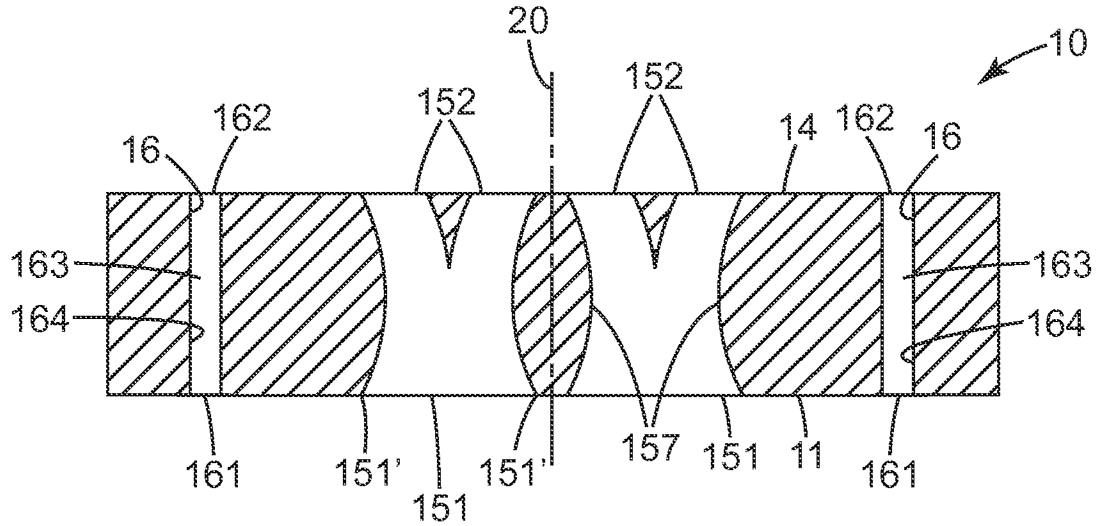
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Fig. 4

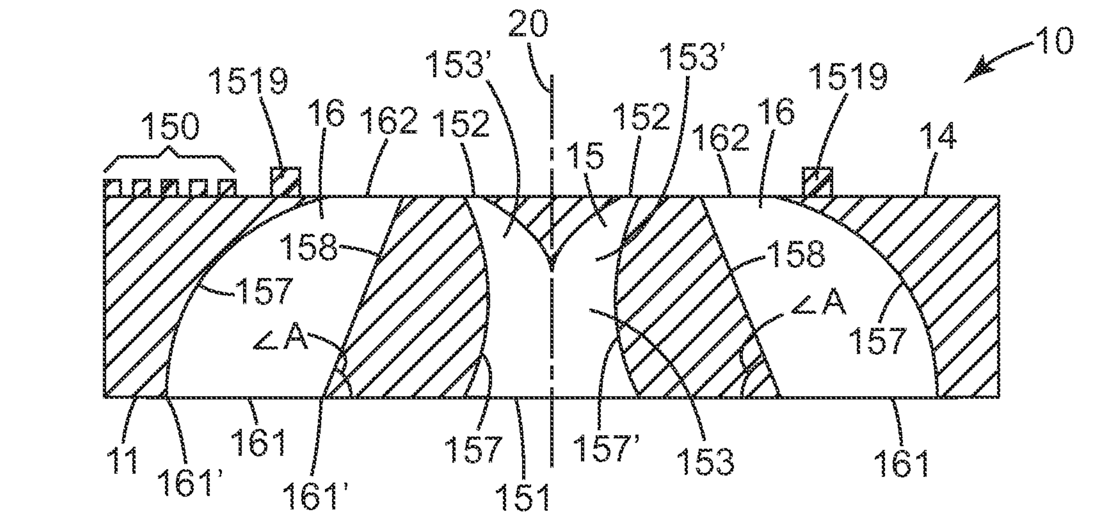
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Fig. 5

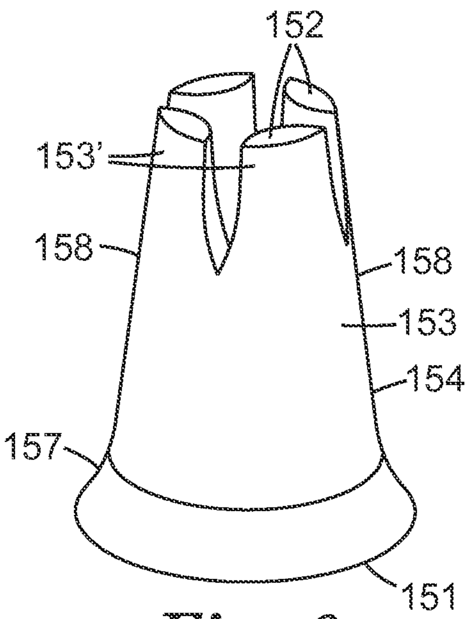

Fig. 6

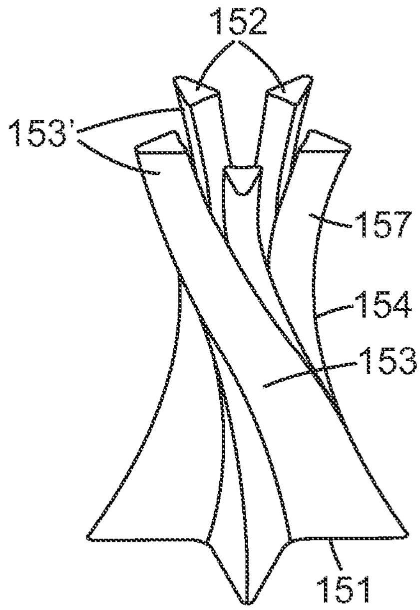

Fig. 7

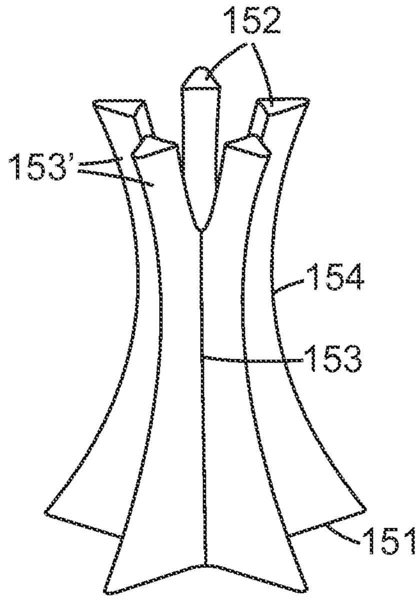

Fig. 8A

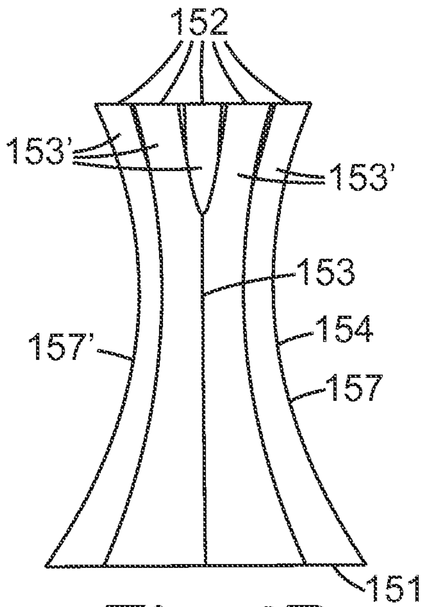

Fig. 8B

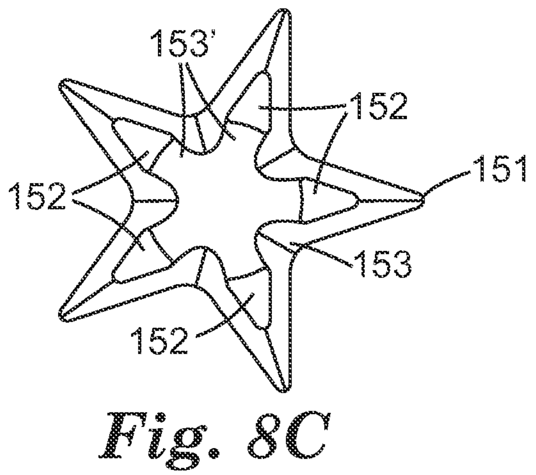

Fig. 8C

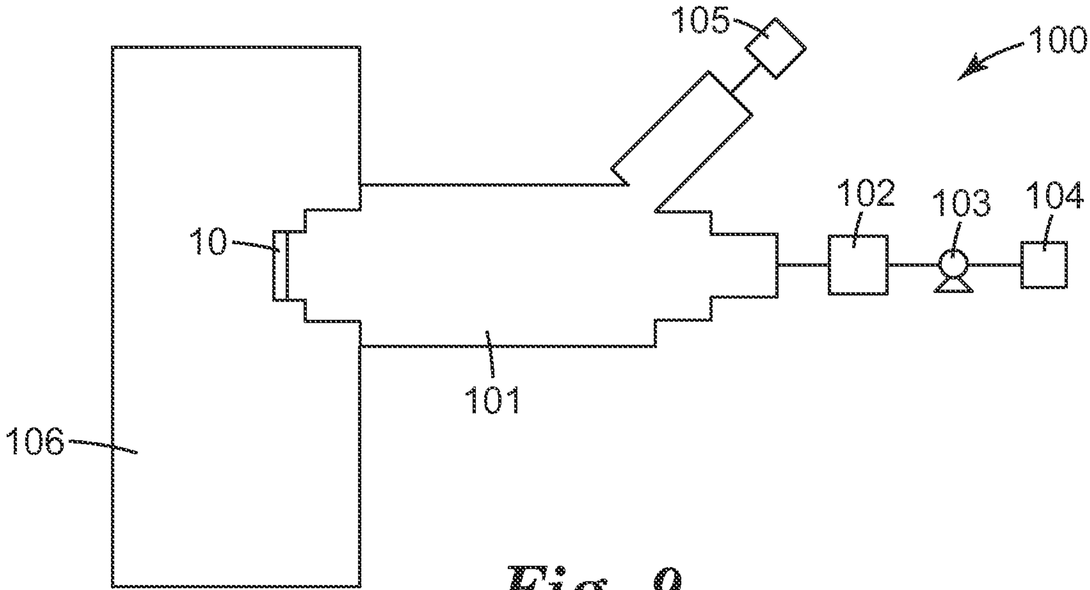
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Fig. 9

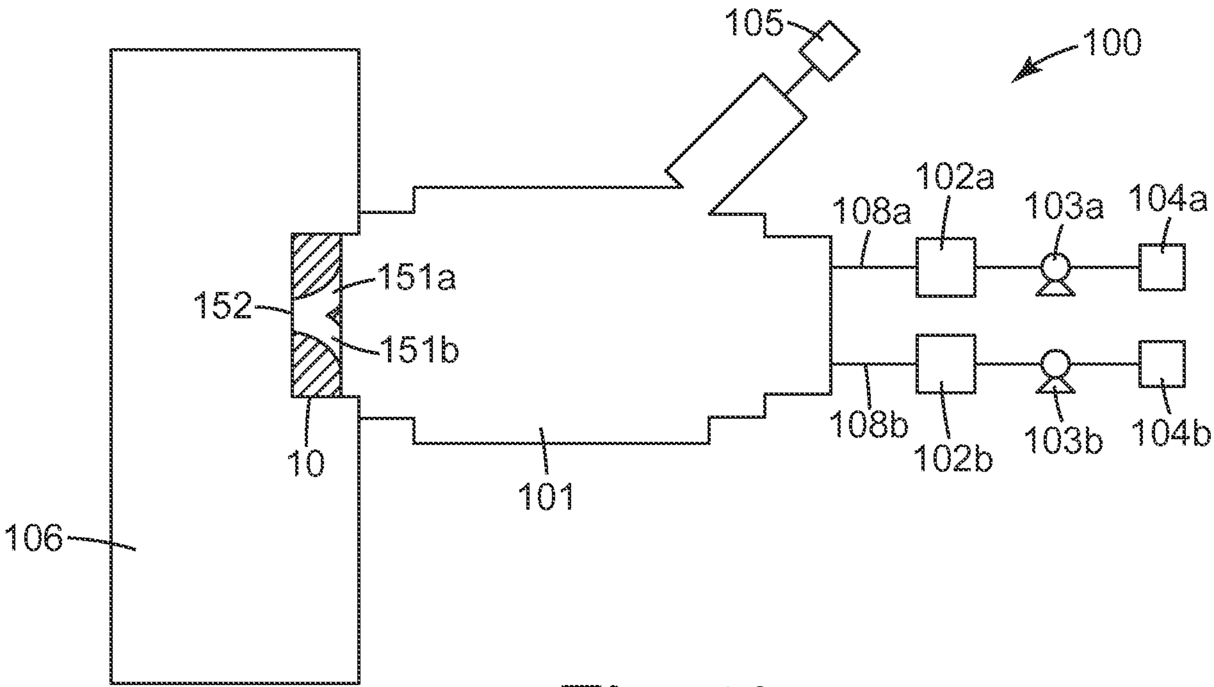
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Fig. 10

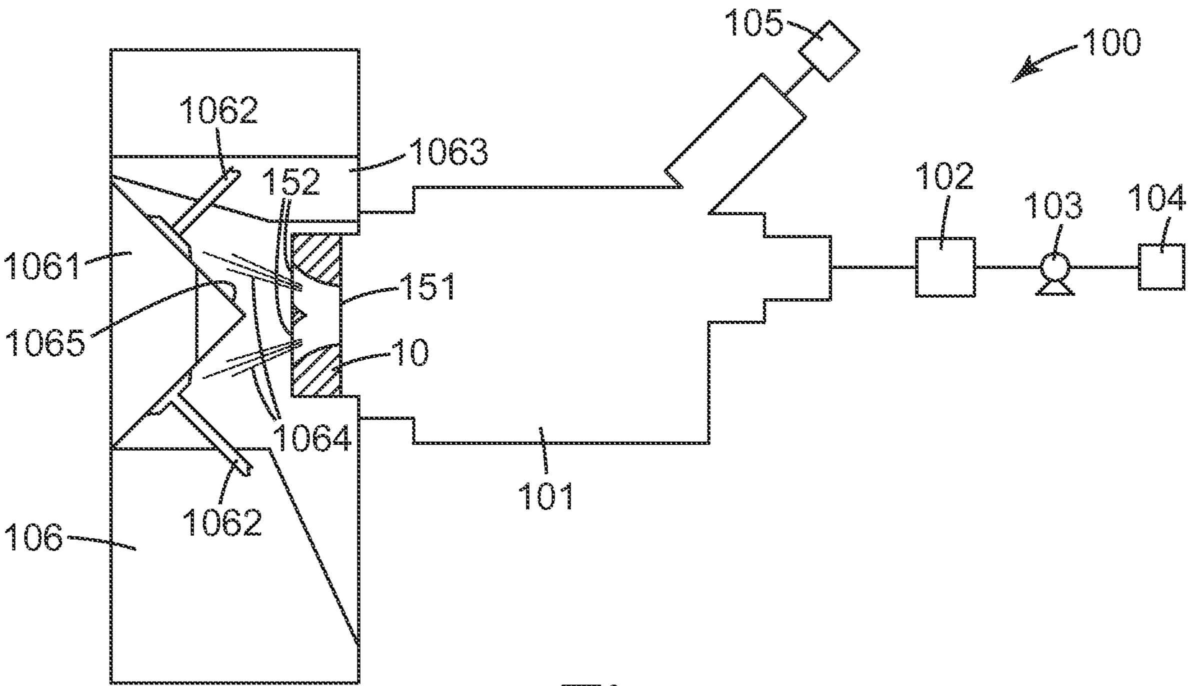
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Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/053198

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M61/18
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

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 2004 005526 A1 (DENSO CORP [JP]) 19 August 2004 (2004-08-19) paragraphs [0095] - [0102], [0122] - [0133]; figures 19-21,29,31 abstract -----	1-15
X	US 2004/104285 A1 (OKAMOTO ATSUYA [JP] ET AL) 3 June 2004 (2004-06-03) paragraphs [0059], [0088], [0092]; figures 5,16,17,18 abstract -----	1-5,7,8, 10,12-15
X	FR 2 872 864 A1 (BOSCH GMBH ROBERT [DE]) 13 January 2006 (2006-01-13) page 4, line 20 - page 5, line 37; figures 2-5 abstract -----	1,3,4, 6-9, 13-15
	-/--	

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

[X] See patent family annex.

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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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 October 2013	14/10/2013

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	Hermens, Sjoerd

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/014607 A1 (3M INNOVATIVE PROPERTIES CO [US]; CARPENTER BARRY S [US]; WILLOUGHBY J) 3 February 2011 (2011-02-03) abstract; figures 9-11	1-3,5,7, 12-15

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/053198

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102004005526 A1	19-08-2004	DE 102004005526 A1	19-08-2004
		US 2004178287 A1	16-09-2004
US 2004104285 A1	03-06-2004	DE 10355707 A1	29-07-2004
		US 2004104285 A1	03-06-2004
		US 2006202063 A1	14-09-2006
FR 2872864 A1	13-01-2006	DE 102004033282 A1	02-02-2006
		FR 2872864 A1	13-01-2006
WO 2011014607 A1	03-02-2011	CN 102575630 A	11-07-2012
		EP 2459867 A1	06-06-2012
		EP 2657510 A1	30-10-2013
		JP 2013501185 A	10-01-2013
		KR 20120046757 A	10-05-2012
		US 2012126038 A1	24-05-2012
		WO 2011014607 A1	03-02-2011