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Koklu

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(54) **FLUIDIC OSCILLATOR ARRAY FOR SYNCHRONIZED OSCILLATING JET GENERATION**

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F15C 1/22 (2006.01)

(52) **U.S. Cl.**
CPC ***B05B 1/08*** (2013.01); ***F15C 1/22*** (2013.01)

(58) **Field of Classification Search**
CPC B05B 1/08; F15C 1/22
USPC 239/589.1, 555, 589
See application file for complete search history.

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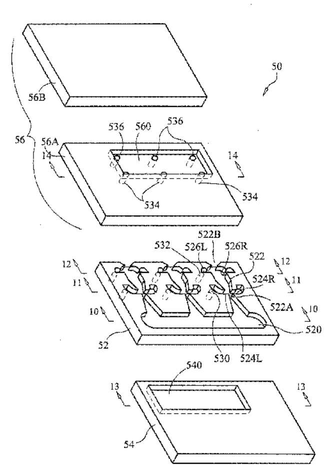
(57) **ABSTRACT**

A fluidic oscillator array includes a plurality of fluidic-oscillator main flow channels. Each main flow channel has an inlet and an outlet. Each main flow channel has first and second control ports disposed at opposing sides thereof, and has a first and a second feedback ports disposed at opposing sides thereof. The feedback ports are located downstream of the control ports with respect to a direction of a fluid flow through the main flow channel. The system also includes a first fluid accumulator in fluid communication with each first control port and each first feedback port, and a second fluid accumulator in fluid communication with each second control port and each second feedback port.

10 Claims, 6 Drawing Sheets



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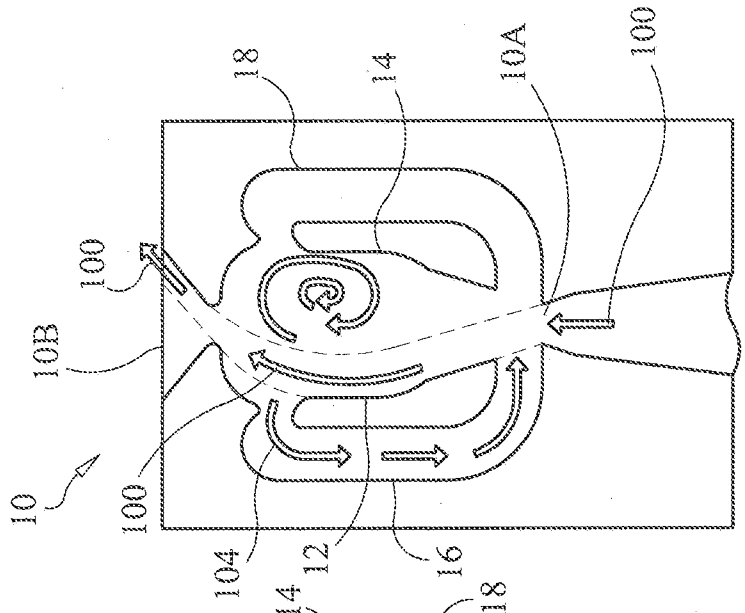

FIG. 1C
PRIOR ART

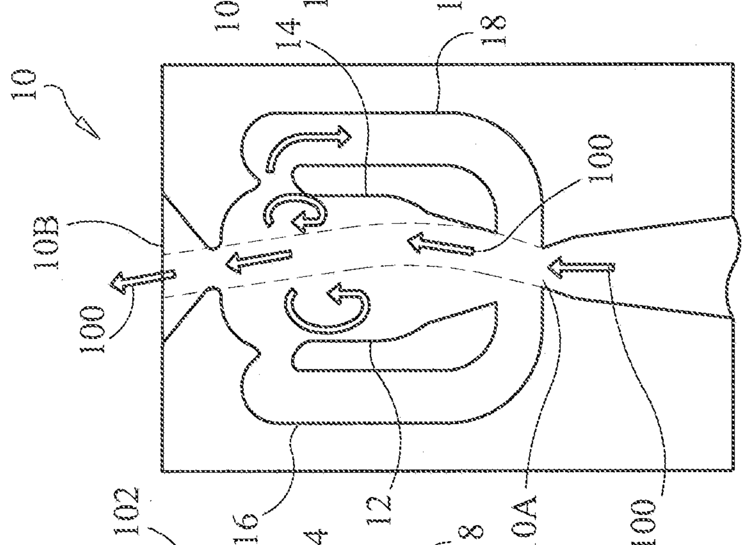

FIG. 1B
PRIOR ART

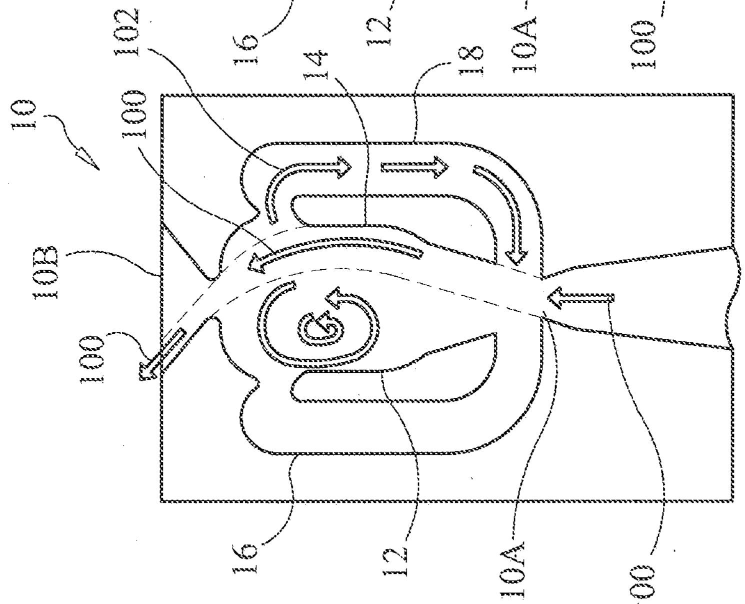

FIG. 1A
PRIOR ART

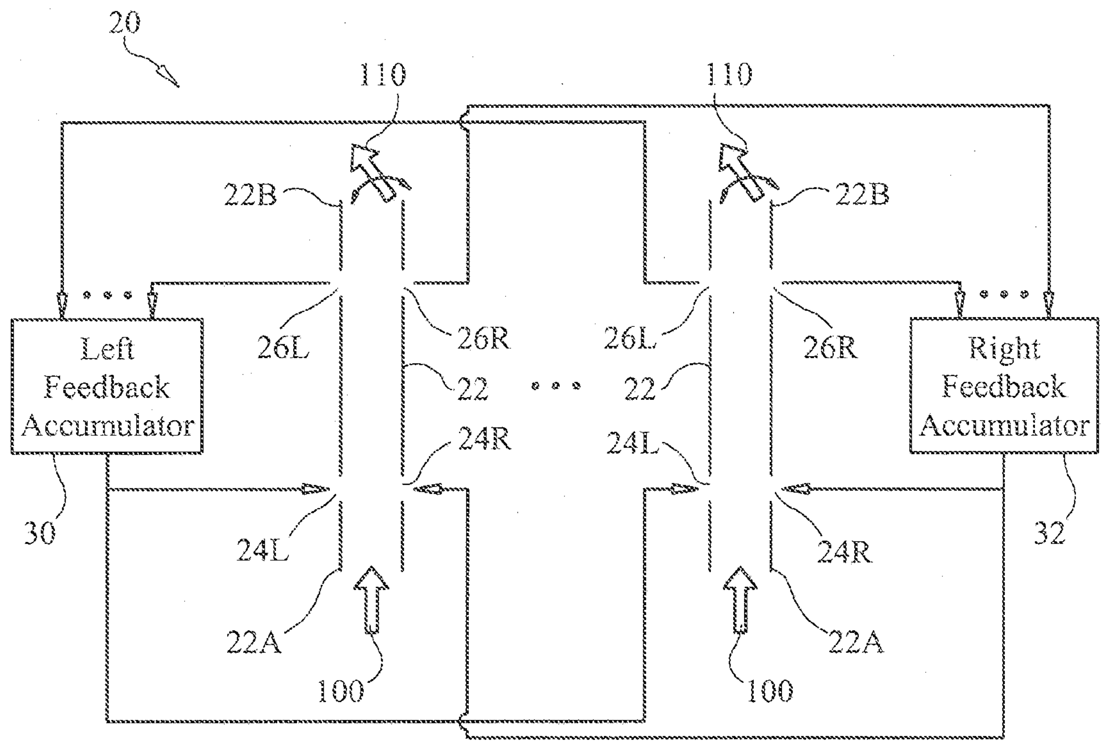
20
110
110
22B
22B
26L
26R
26L
26R
Left Feedback Accumulator
Right Feedback Accumulator
22
22
24R
24L
30
24L
24R
32
22A
22A
100
100

FIG. 2

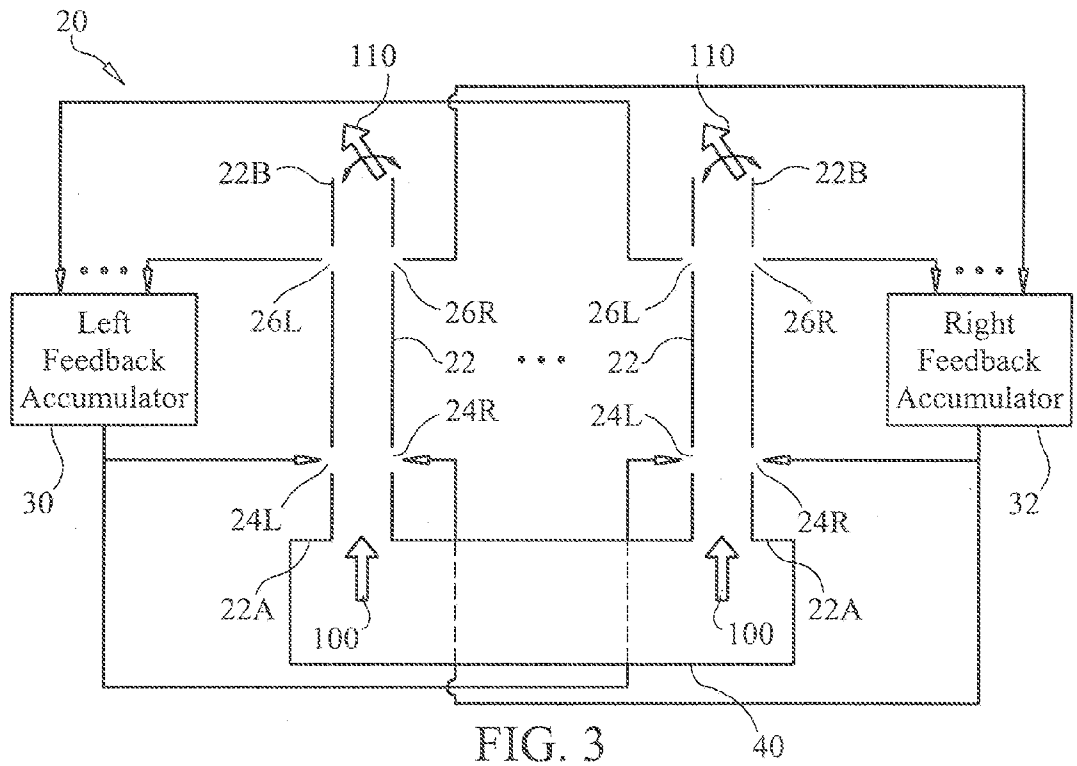
20
110
110
22B
22B
26L
26R
26L
26R
Left Feedback Accumulator
Right Feedback Accumulator
22
22
24R
24L
24L
24R
30
32
22A
22A
100
100
40

FIG. 3

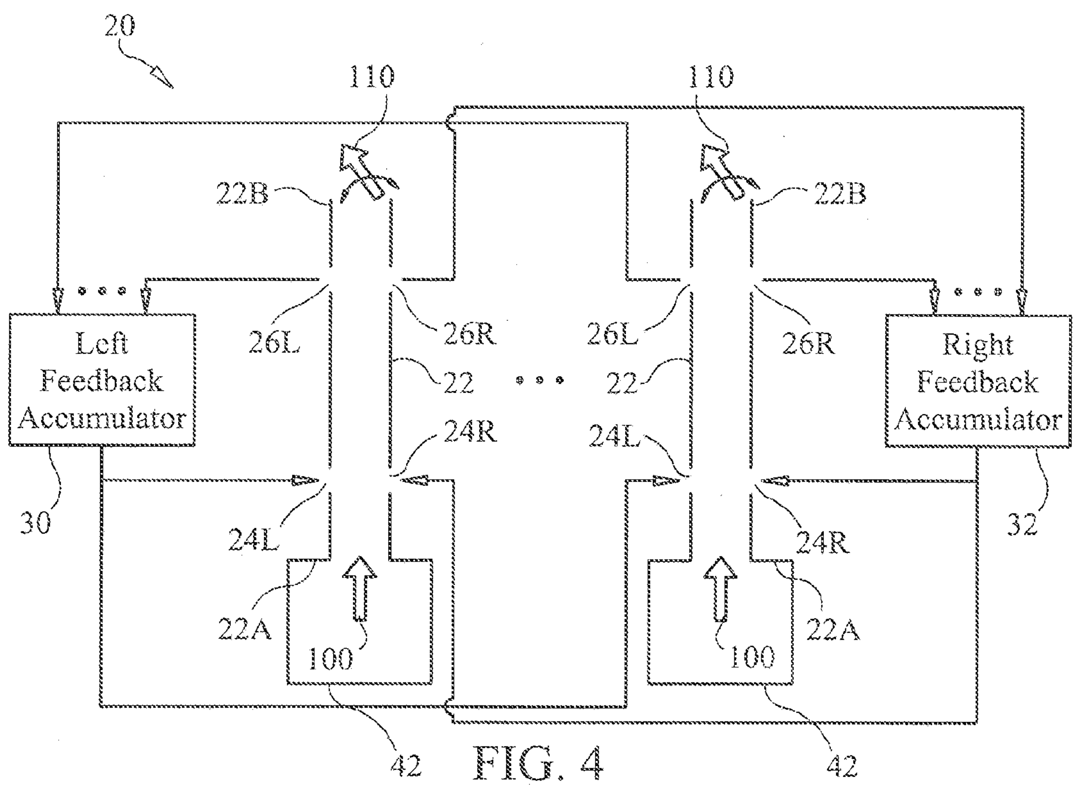
20
110
110
22B
22B
26L
26R
26L
26R
Left Feedback Accumulator
Right Feedback Accumulator
22
22
24R
24L
24L
24R
30
32
22A
22A
100
100
42
42

FIG. 4

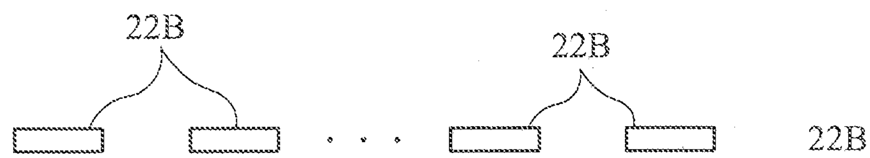

FIG. 5

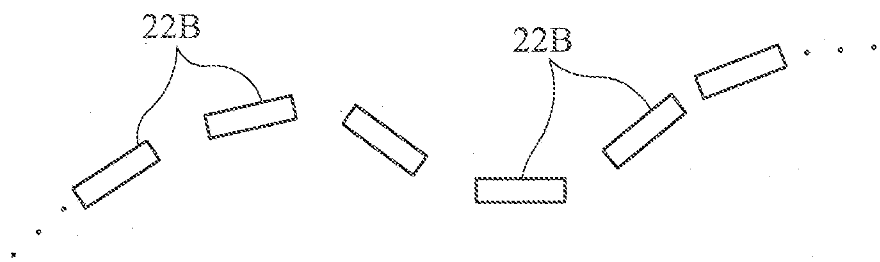

FIG. 6

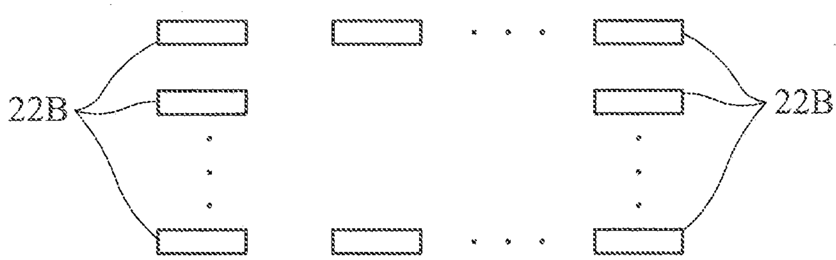

FIG. 7

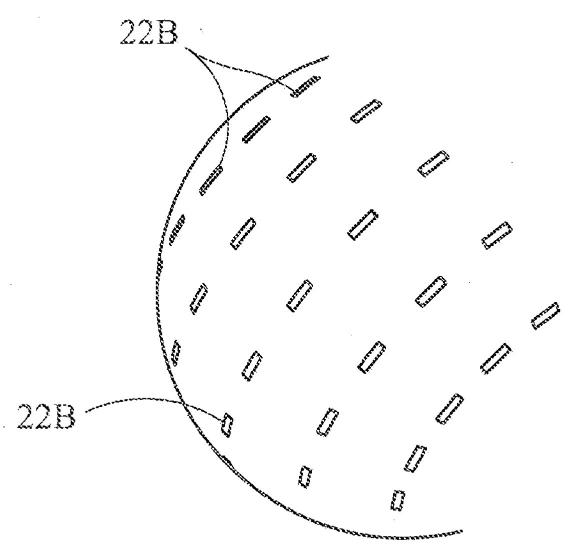

FIG. 8

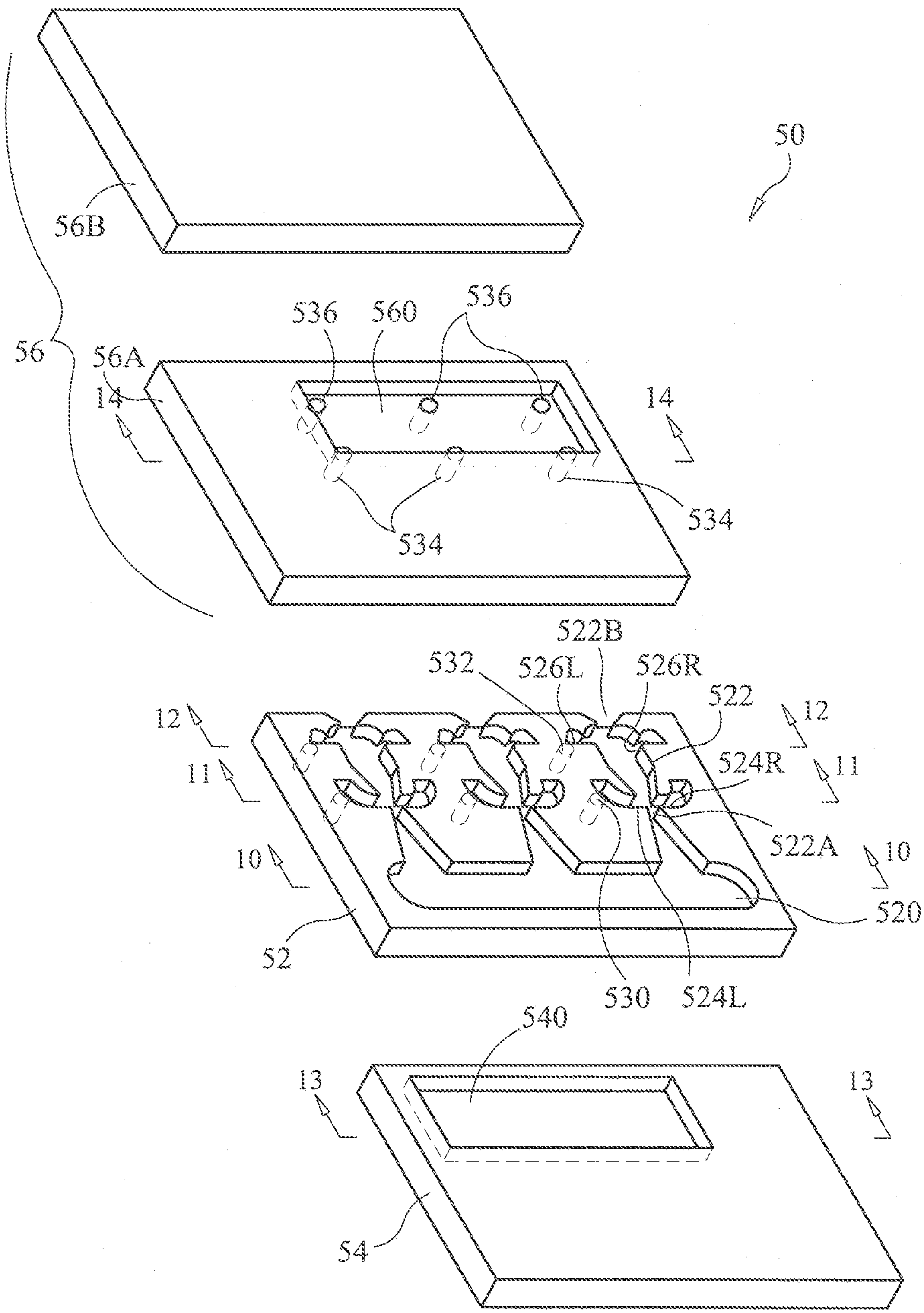
50
56B
56
56A
14
536
560
536
14
534
534
522B
532
526L
526R
522
12
12
11
524R
11
10
522A
10
520
52
530
524L
540
13
13
54

FIG. 9

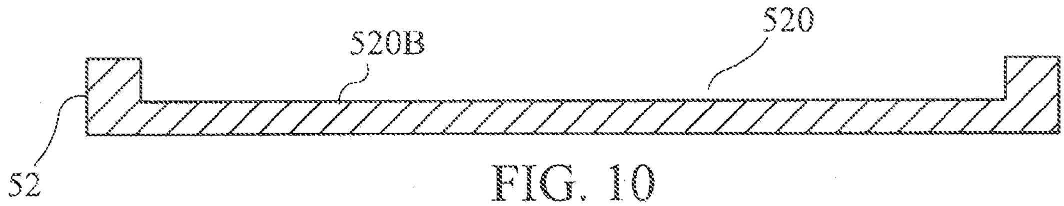

FIG. 10

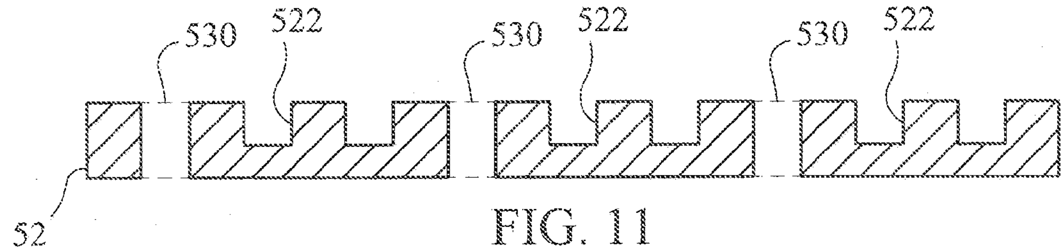

FIG. 11

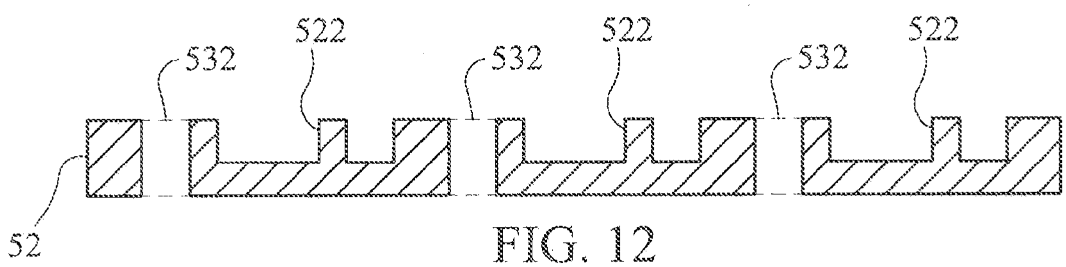

FIG. 12

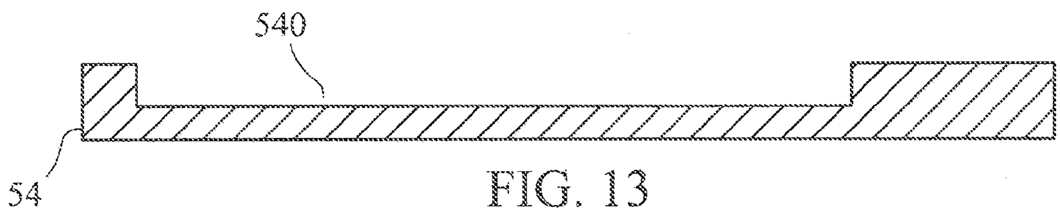

FIG. 13

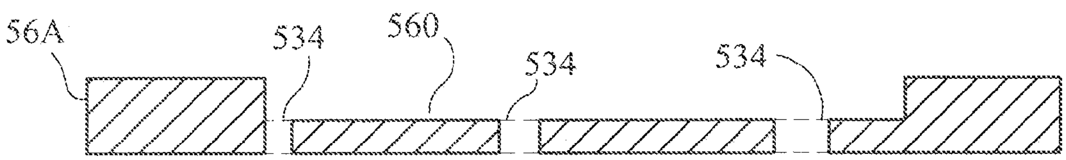

FIG. 14

FLUIDIC OSCILLATOR ARRAY FOR SYNCHRONIZED OSCILLATING JET GENERATION

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS-REFERENCE TO RELATED PATENT APPLICATION

This application is related to co-pending U.S. patent application Ser. No. 13/786,608, titled "Fluidic Oscillator Having Decoupled Frequency and Amplitude Control," filed on the same day as this application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to fluidic oscillators. More specifically, the invention is a fluidic oscillator array that synchronizes the oscillations of the array's output jets.

2. Description of the Related Art

In the 1900s, fluidic oscillators were developed for use as logical function operators. More recently, fluidic oscillators have been proposed for use as active flow control devices where an oscillator's jet output is used to control a fluid flow (e.g., gas or liquid). FIGS. **1A-1C** schematically illustrate the basic operating principles of a fluidic oscillator. Briefly, fluid flow **100** enters a fluidic oscillator **10** at its input **10**A and attaches to either sidewall **12** or **14** (e.g., right sidewall **14** in the illustrated example) due to the Coanda effect as shown in FIG. **1**A. A backflow **102** develops in a right hand side feedback loop **18**. Backflow **102** causes fluid flow **100** to detach from right sidewall **14** (FIG. **1**B) and attach to left sidewall **12** (FIG. **1**C). When fluid flow **100** attaches to left sidewall **12**, a backflow **104** develops in left hand side feedback loop **16** which will force fluid flow **100** to switch back to its initial state shown in FIG. **1**A. As a result of this activity, fluid flow **100** oscillates/sweeps back and forth at the output **10**B of oscillator **10**.

In order to achieve relatively large scale active flow control, a number of fluidic oscillators (such as the one described above) can be arranged such that their output jets are arrayed in an area requiring flow control. One drawback associated with arrays of fluidic oscillators is that each fluidic oscillator output jet will oscillate independently of other output jets. Therefore, the resulting array output tends to be random in nature. While this result can be preferable for mixing applications, it does not provide the result predictability needed for efficient active flow control.

BRIEF SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a fluidic oscillator array.

Another object of the present invention is to provide a fluidic oscillator array whose output jets oscillate in a synchronized fashion.

Still another object of the present invention is to provide an approach that synchronizes oscillating jets without using moving parts and/or electromechanical components.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a fluidic oscillator array includes a plurality of fluidic-oscillator main flow channels. Each main flow channel has an inlet and an outlet wherein a fluid flow is adapted to enter at the inlet and exit at the outlet. Each main flow channel has a first control port and a second control port disposed at opposing sides thereof, and has a first feedback port and a second feedback port disposed at opposing sides thereof. The first feedback port and second feedback port are located downstream of the first control port and second control port, respectively, with respect to a direction of the fluid flow. The system also includes a first fluid accumulator in fluid communication with each first control port and each first feedback port, and a second fluid accumulator in fluid communication with each second control port and each second feedback port.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A-1C** schematically illustrate the operating principles of a fluidic oscillator in accordance with the prior art;

FIG. **2** is a schematic illustration of a fluidic oscillator array that generates synchronized oscillating jets in accordance with an embodiment of the present invention;

FIG. **3** is a schematic illustration of a fluidic oscillator array utilizing a common plenum in accordance with an embodiment of the present invention;

FIG. **4** is a schematic illustration of a fluidic oscillator utilizing a separate plenum for each of the array's oscillators in accordance with another embodiment of the present invention;

FIG. **5** is a head-on view of a linear arrangement of outlet jets for a fluidic oscillator array in accordance with an embodiment of the present invention;

FIG. **6** is a head-on view of a nonlinear arrangement of outlet jets for a fluidic oscillator array in accordance with another embodiment of the present invention;

FIG. **7** is a head-on view of a two-dimensional arrangement of outlet jets for a fluidic oscillator array in accordance with another embodiment of the present invention;

FIG. **8** is a perspective view of a three-dimensional arrangement of outlet jets for a fluidic oscillator array in accordance with another embodiment of the present invention;

FIG. **9** is an exploded perspective view of a multi-layer fluidic oscillator array in accordance with an embodiment of the present invention;

FIG. **10** is a cross-sectional view of the main flow channel layer taken along line **10-10** in FIG. **9**;

FIG. **11** is a cross-sectional view of the main flow channel layer taken along line **11-11** in FIG. **9**;

FIG. **12** is a cross-sectional view of the main flow channel layer taken along line **12-12** in FIG. **9**:

FIG. **13** is a cross-sectional view of the left side accumulator layer taken along line **13-13** in FIG. **9**; and

FIG. **14** is a cross sectional view of the right side accumulator layer taken along line **14-14** in FIG. **9**.

DETAILED DESCRIPTION OF THE INVENTION

Referring again to the drawings and more specifically to FIG. **2**, a fluidic oscillator array for generating synchronized oscillating jets in accordance with an embodiment of the present invention is illustrated schematically and is referenced generally by numeral **20**. Array **20** includes at least two main flow channels **22** configured as the main flow channel of a fluidic oscillator. That is, each main flow channel **22** has an inlet **22**A for receiving a fluid flow **100**, an outlet **22**B through which the fluid flow will exit as an oscillating jet **110**, opposing control polls **24**L/**24**R and opposing feedback ports **26**L/**26**R. The feedback ports **26**L/**26**R are located downstream from control ports **24**L/**24**R with respect to the direction of fluid flow **100**. The particular shape/configuration of each main flow channel **22**, inlet **22**A, and outlet **22**B are not limitations of the present invention.

In the illustrated embodiment, each (left side) feedback port **26**L in array **20** is fluidically coupled to a first feedback accumulator (e.g., enclosed chamber) **30**, while each (right side) feedback port **26**R in array **20** is fluidically coupled to a second feedback accumulator (e.g., enclosed chamber) **32**. Feedback accumulator **30** is fluidically coupled to each (left side) control port **24**L in array **20**. Similarly, feedback accumulator **32** is fluidically coupled to each (right side) control port **24**R in array **20**. By virtue of this construction, as fluid flow **100** moves through main flow channel **22**, the backflow entering each (left side) feedback port **24**L is collected in a single accumulator site before being supplied to the (left side) control ports **26**L. Similarly, the backflow entering each (right side) feedback port **24**R is collected in a single accumulator site before being supplied to the (right side) control ports **26**R. As a result, the sweeping and oscillating jets **110** at outlets **22**B are synchronized in terms of the jets' flow direction at outlets **22**B.

Fluid flow **100** can be individually supplied to the inlet **22**A of each main flow channel **22**. Fluid flow **100** could also be supplied to a common plenum **40** (FIG. **3**) fluidically coupled to all inlets **22**A. Still further, fluid flow **10** could be supplied to a separate/dedicated plenum **42** (FIG. **4**) associated and coupled to a particular one of inlets **22**A. The common plenum (FIG. **3**) embodiment will produce the same oscillation frequency and velocity at each outlet of the array, while the separate plenum (FIG. **4**) embodiment will produce the same oscillation frequency at each outlet of the array but can be used to generate different velocities at the array's outlets. Accordingly, it is to be understood that the method and structure of supplying fluid flow **100** to main flow channels **22** are not limitations of the present invention.

Arrays constructed in accordance with the present invention can arrange outlets **22**B in a variety of geometric configurations without departing from the scope of the present invention. For example, outlets **22**B could be arranged linearly (FIG. **5**), nonlinearly (FIG. **6**), two-dimensionally (FIG. **7**), or three dimensionally (FIG. **8**) in order to satisfy the requirements of a particular application.

A variety of approaches can be used to construct an array's main flow channels and accumulators. By way of example, a layered construction of a fluidic oscillator array **50** is presented in an exploded view in FIG. **9**. Array **50** includes a main flow channel layer **52** disposed between a left side accumulator layer **54**, and a right side accumulator layer **56**. Array **50** is a three-outlet array, but could be constructed to provide two or more than three outlets, in general, fluidic oscillator array **50** is predicated on a conventional fluidic oscillator design with the conventional feedback loops interrupted and then combined as will be described further below.

Main flow channel layer **52** is tray-like in construction with a common plenum **520** and three main flow channels **522** being formed/defined in a partial thickness of layer **52**. This is illustrated in the isolated cross-sectional view of layer **52** shown in FIG. **10** where the base **520**B of plenum **520** is defined within layer **52**. Each main flow channel has an inlet **522**A in fluid communication with plenum **520** and has an outlet **522**B through which a fluid flow will exit. Each main flow channel **522** has a left side control port **524**L, a right side control port **524**R, a left side feedback port **526**L, and a right side feedback port **526**R. For clarity of illustration, these ports are only referenced for one main flow channel **522**. The purpose of the feedback and control ports is analogous to the description provided above for FIG. **2**. Each left side feedback port and control port of a main channel is in fluid communication with a hole in layer **52**. More specifically, each left side control port **524**L is adjacent a hole **530** in layer **52** (FIG. **11**), while each left side feedback port **526**L is adjacent a hole **532** in layer **52** (FIG. **12**).

A left side accumulator is formed when layer **54** is coupled to the underside of layer **52** as illustrated. Layer **54** is also tray-like in construction with an accumulator region **540** being formed in a partial thickness of layer **54** as illustrated in FIG. **13**. Region **540** is sized and positioned to define a contiguous volume that is in fluid communication with all of holes **530** and **532** when layer **54** is coupled to layer **52**. In this way, accumulator region **540** serves as a single collector for fluid exiting left side feedback ports **526**L and as a single source for fluid supplied back to each main channel **522** via left side control ports **524**L.

In a similar fashion, a right side accumulator is formed when layer **56** is coupled to the top side of layer **52** as illustrated. Layer **56** is defined by a formed part **56**A and a solid top cover **56**B. Formed part **56**A is tray-like in construction with an accumulator region **560** being formed in a part al thickness thereof as illustrated in FIG. **14**. Holes **534** and **536** are provided through formed part **56**A with holes **534** providing fluid communication between accumulator region **560** and each right side control port **524**R, and with holes **536** providing fluid communication between accumulator region **560** and each right side feedback port **526**R. In this way, accumulator region **560** serves as a single collector for fluid exiting right side feedback ports **526**R and as a single source for fluid supplied back to each main flow channel **522** via right side control ports **524**R.

The coupling of all left side control ports to the left side accumulator and all right side control ports to the right side accumulator produces a homogeneous sweeping jet output, i.e., all of the output jets move left/right at the same time. However, it is to be understood that the present invention is not limited to the generation of such homogeneous synchronization of weeping jets. That is, it is also possible to configure the present invention to produce heterogeneous synchronization by coupling some of the left side control ports to the right side accumulator and some of the right side control ports to the left side accumulator. For example, in the three-oscillator array used for illustration herein, the control ports of the first and third oscillators could retain the left/right coupling, as described above, while the second (middle) oscillator has its right side control port coupled to the left side accumulator and its left side control port coupled to the right side accumulator. In this way, as the output jets from the first and third oscillators are sweeping to the left, the output jet from the second oscillator would be sweeping to the right, i.e., output jet from the second oscillator would be 180° out-of-phase with respect to the output jets from the first and third oscillators. However, the outputs would remain predictable and synchronous. Other patterns of control port coupling could be used without departing from the scope of the present invention.

The advantages of the present invention are numerous. An array of fluidic oscillators can provide a synchronized oscillating (e.g., sweeping, out-of phase, etc.) output through the use of feedback accumulators. Synchronization is achieved simply and without requiring the addition of any moving parts. The principles of the present invention can be applied to any fluidic oscillator design that is designed to use feedback loops to control output oscillations.

Although the invention has been described relative to specific embodiments thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A fluidic oscillator array, comprising:

a plurality of fluidic-oscillator main flow channels, each of said main flow channels having an inlet and a single outlet wherein a fluid flow is adapted to enter at said inlet and exit at said outlet, each of said main flow channels having a first control port and a second control port disposed at opposing sides thereof, and each of said main flow channels having a first feedback port and a second feedback port disposed at opposing sides thereof wherein all feedback and control ports on the first side of the main flow channels fluidically communicate with a first feedback accumulator, and all feedback and control ports on a second side of the main flow channels fluidically communicate with a second feedback accumulator;

and wherein said first feedback port and said second feedback port are located downstream of said first control port and said second control port, respectively, with respect to a direction of said fluid flow;

and wherein the first feedback accumulator is in fluid communication with each said first control port and each said first feedback port; and

and wherein the second feedback accumulator is in fluid communication with each said second control port and each said second feedback port.

2. A fluidic oscillator array as in claim **1**, further comprising a common plenum in fluid communication with each said inlet.

3. A fluidic oscillator array as in claim **1**, further comprising a plurality of plenums in correspondence with said plurality of main flow channels wherein each of said plenums is in fluid communication with a unique one said inlet.

4. A fluidic oscillator array as in claim **1**, wherein each said outlet is one of a nonlinear array of outlets.

5. A fluidic oscillator array as in claim **1**, wherein each said outlet is one of a two-dimensional array of outlets.

6. A fluidic oscillator array as in claim **1**, wherein each said outlet is one of a three-dimensional array of outlets.

7. A fluidic oscillator array as in claim **1**, wherein said array comprises a layered construction, and wherein said main flow channels are disposed on a first layer of said layered construction, said first feedback accumulator is disposed on a second layer of said layered construction, and said second feedback accumulator is disposed on a third layer of said layered construction.

8. A fluidic oscillator array as in claim **1**, wherein each said outlet is one of a linear array of outlets.

9. A fluidic oscillator array comprising:

a plurality of fluidic-oscillator main flow channels, each of said main flow channels having an inlet and an outlet wherein a fluid flow is adapted to enter at said inlet and exit at said outlet, each of said main flow channels having a first control port and a second control port disposed at opposing sides thereof, and each of said main flow channels having a first feedback port and a second feedback port disposed at opposing sides thereof wherein said first feedback port and said second feedback port are located downstream of said first control port and said second control port, respectively, with respect to a direction of said fluid flow;

a first fluid accumulator in fluid communication with each said first control port and each said first feedback port; and

a second fluid accumulator in fluid communication with each said second control port and each said second feedback port,

wherein said array comprises a layered construction, and wherein said main flow channels are disposed on a first layer of said layered construction, said first fluid accumulator is disposed on a second layer of said layered construction, and said second fluid accumulator is disposed on a third layer of said layered construction.

10. A fluidic oscillator array as in claim **9**, wherein each said outlet is one of a linear array of outlets.

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