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(54) Modular photochemical flow reactor system

Modulares photochemisches Strömungsreaktorsystem

Système modulaire de réacteurs photochimiques

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Description

FIELD

[0001] The present disclosure relates to flow reactors and flow processes performed therewith, in particular to a modular, flexible, and high-throughput photochemical flow reactor system.

BACKGROUND

[0002] The present inventors and/or their colleagues have previously developed flow reactors for performing chemical reactions. These flow reactors may typically employ fluidic modules that may take the form of a multilayer glass structure. A representation of one embodiment of such a fluidic module 20 is shown in Figure 1 in perspective view. In Figures 2 and 3 in cross sectional views are shown representations of certain features of additional embodiments of such fluidic modules 20. Fluidic modules 20 of the type(s) shown in Figures 1-3 in general has a planar form and first and second major surfaces 22, 24 (with surface 24 underneath the module 20 in the perspective view of Figure 1). Reactants or process fluids circulate inside "microchannels", channels of generally millimeter or sub-millimeter scale defined within a generally planar process fluid layer 30. The module 20 further includes two outer planar thermal control fluid layers 40 for containing flowing thermal control fluid, with the process fluid layer 30 positioned between the two thermal control fluid layers 40.

[0003] Inlet and outlet process fluid ports 32 allow supplying and removing process fluid (one of the ports 32, the outlet port in this case, is not visible in Figure 1 because it is on the downward facing major surface 24, opposite the upward facing port 32). Inlet and outlet thermal fluid ports 42 allow supplying and removing thermal control fluid. All of the inlet and outlet ports 32, 42 are located on one of the first and second major surfaces at one or more edges thereof (at edge 26 in the case of the embodiment of Figure 1), leaving a free surface area 22F (and corresponding free surface area 24F, underneath and not visible in Figure 1) free of inlet and outlet ports.

[0004] Scale-up from lab scale to production scale processes is enabled by a range of various sizes of fluidic modules 20. To provide adequate residence time, for a given required flow rate, a certain amount of internal volume is required. Increased total internal volume, when needed, is provided by connecting several fluidic modules 20 in series to form a reactor. A reactor is therefore typically composed of several fluidic modules 20. Each fluidic module 20 can have specific function, like preheating, premixing, mixing, providing residence time, quenching, and so forth. Given that the modules 20 may be formed of glass, photochemistry is a potentially useful application, since glass is at least partially transparent to wavelengths of interest for photochemistry in the UV and visible spectra.

[0005] Numerous prior art documents disclose photochemical reactors. Patent application US 2012/0228236 discloses a photochemical fluid treatment reactor with direct illumination by LED arrays. The LED light source can be mounted onto fluid-cooled heatsink blocks. The heatsink can be configured to use the treated fluid as its coolant. No cooling of the fluid during its illumination is disclosed. Patent application US 2010/0255458 discloses different embodiments of bioreactors with light distributing elements. Patent application US 2013/0102069 discloses a bioreactor using a light emitting diode (LED) lighting system to at least partly provide light for an algae. Patent application US 2014/0050630 discloses a microreactor for photoreactions. Patent application US 2012/0091489 is concerned with a light-emitting device.

SUMMARY

[0006] The invention relates to a modular photochemical reactor system comprising a plurality of fluidic modules, each having a planar form with first and second major surfaces, each of said first and second major surfaces having a free surface area free of inlet and outlet ports, and each comprising: i) a central planar process fluid layer for containing flowing process fluid, ii) two outer planar thermal control fluid layers for containing flowing thermal control fluid; said central planar process fluid layer and said two outer planar thermal control fluid layers being arranged between said first and second major surfaces and being at least partially radiation-transparent to at least some wavelengths in the UV and/or visible spectrum. The system further comprises a plurality of illumination modules, each having a planar form with first and second major surfaces, and each comprising at least a first array of semiconductor emitters, said emitters capable of emitting at visible and/or UV wavelengths, positioned to emit from or through the first major surface to the free surface area of one of the first and second major surfaces of a fluidic module, wherein said first array of semiconductor emitters comprises at least a first emitter and a second emitter, the first emitter capable of emitting at a first center wavelength and the second emitter capable of emitting at a second center wavelength, said first and second center wavelengths differing from each other. Said fluidic modules and said illumination modules are arranged so that at least some of said fluidic modules are able to benefit from irradiation from said illumination modules.

[0007] Use of semiconductor emitters, desirably LEDs, allows for sharply defined wavelengths to be employed with the potential of increasing the yield of a reaction or decreasing the production of undesired byproducts that may be fostered by undesired wavelengths present in sources having a broader spectrum. Providing at least first and second emitters differing in center wavelength allows easy experimentation and optimization between the two wavelengths as well as potentially increased performance for reactions that may benefit from light at more than one wavelength.

[0008] The resulting reactor assembled from the disclosed system is both flexibly reconfigurable and compact, while well-isolating the thermal output of the emitters from the reactant or process fluids. The present system and reactor formed therefrom also provides the ability to switch illumination wavelengths, or, more generally, to alter the spectral composition of the illumination without disassembly of the reactor, such that reaction testing and characterization are more easily accomplished.

[0009] Other variations and specific advantages are discussed or will be apparent from the description below. The foregoing general description and the following detailed description represent specific embodiments, and are intended to provide an overview or framework for understanding the nature and character of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Figure 1 is a perspective view of an embodiment of a fluidic module useful within the presently disclosed system.

Figures 2 and 3 are a cross sectional views of additional embodiments of fluidic modules useful within the presently disclosed system.

Figure 4 is an expanded assembly perspective view of an embodiment of an illumination module useful within the presently disclosed system.

Figures 5A and 5B are schematic cross-sectional views of additional embodiments of illumination modules useful within the presently disclosed system.

Figure 6 is a perspective view of an embodiment of a support frame or core of an illumination module useful within the presently disclosed system.

Figures 7A and 7B are schematic plan view representations of alternative embodiments of emitter arrays of an illumination module useful within the presently disclosed system.

Figure 8 is a perspective view of an embodiment of a partially assembled reactor comprised of components of the presently disclosed system.

Figure 9 is a perspective view of the reactor of Figure 8 with some additional components included.

DETAILED DESCRIPTION

[0011] A modular photochemical reactor system 10 as shown in perspective view in Figure 9 comprises a plurality of fluidic modules 20, the fluidic modules 20 of said plurality each having a planar form as seen in Figure 1, with first and second major surfaces 22, 24. Each fluidic module 20 of said plurality comprises, also as seen in Figure 1, and additionally in Figures 2 and 3, a central planar process fluid layer 30 for containing flowing process fluid, and two outer planar thermal control fluid layers 40 for containing flowing thermal control fluid. The process fluid layer 30 is positioned between the two thermal control fluid layers 40. The process fluid layer 30 and the two thermal control fluid layers 40 are all at least partially radiation-transparent to at least some wavelengths in the UV and/or visible spectrum. In operation of the fluidic modules 20, substantially transparent thermal control fluids such as water or ethanol may desirably be used.

[0012] Each fluidic module 20 of said plurality further comprises inlet and outlet process fluid ports 32 for supplying and removing process fluid and inlet and outlet thermal fluid ports 42 for supplying and removing thermal control fluid, the inlet and outlet fluid ports 32 located either 1) on one of the first and second major surfaces 22, 24 at one or more edges 26 thereof, or 2) on a surface 28 of the fluidic module 20 other than the first and second major surfaces 22, 24 thereof, in either case leaving a free surface area 22F, 24F of the first and second major surfaces 22, 24 free of inlet and outlet ports, said free surface area 22F, 24F comprising at least 50% of the total area of the respective first or second major surface 22, 24, desirably at least 75%.

[0013] The modular photochemical reactor system 10 as shown in perspective view in Figure 9 further comprises a plurality of illumination modules 50 such as those shown in the embodiments of the perspective view of Figure 4 and cross sectional views of Figures 5A and 5B. The illumination modules 50 of said plurality each have a planar form with first and second major surfaces 52, 54, and each comprise at least a first array 60 of semiconductor emitters 70, said emitters 70 capable of emitting at visible and/or UV wavelengths, positioned to emit from or through the first major surface 52. Further, said first array 60 of semiconductor emitters 70 comprises at least a first emitter 72 and a second emitter 74, with the first emitter 72 capable of emitting at a first center wavelength and the second emitter 74 capable of emitting at a second center wavelength, where said first and second center wavelengths differ from each other.

[0014] More details of one embodiment of an illumination module are shown in the exploded perspective view of Figure 4. A support frame or core 90 of the illumination module 50 includes inlet and outlet ports 94 for supplying cooling fluid to the illumination module 50. The core 90 together with a gasket 64 and lid 66, when assembled and fastened together in the order shown, form a heat exchanger 96 for cooling the emitters 70 of the array 60 of emitters 70. The emitters 70 are mounted (such as by soldering or other mounting process or structure) on a mounting sheet 71, which is attached to the lid 66. Alternatively, as in the additional embodiments shown in cross section in Figures 5A and 5B, the mounting sheet 71 for the emitters 70 may itself function as a lid to cover fluid channels in the core 90, such that a separate lid 66 as in the embodiment of Figure 4 is not used. A light shield or frame 97 may be attached so as to surround the array 60 on the sides thereof, and a protective window 98 may be mounted to the shield 97. The protective window may be of quartz, glass, or any other desirably transparent material relative to the wavelength(s) employed by the illumination module 50, and may optionally include a roughened structure or similar optical feature so as to function as an optical diffuser to even out the illumination provided by the illumination module 50. As another optional alternative, the window 98 and frame 97 may also cooperate to form a hermetic seal over the array 60, and the sealed volume may be filled with an inert gas such as argon or low-reactivity gas such as nitrogen. This would serve to protect the emitters from any airborne chemical or chemicals otherwise present on or near the protective window 98.

[0015] Figures 5A and 5B are schematic cross-sectional views of additional embodiments of illumination modules 50. In Figure 5A it may be more clearly seen (than in Figure 4) that an illumination module 50 according to the present disclosure may desirably include both a first array (of emitters 70) 60 and a second array (of emitters 70) 80, on opposing first and second major surfaces 52, 54 of the illumination module 50. A single core 90 may have two sides each with a surface for supporting each of the two arrays 60, 80. The array(s) may be retained by a clip or ledge 62. As illustrated generally in Figure 5B, the presently disclosed system also desirably includes illumination modules 50 having only one array 60, rather than two arrays 60, 80 as in Figure 5A.

[0016] Figure 6 shows a perspective view of an embodiment of a core 90, including a support surface 91 for the emitter array 60 or the lid 66, into which support surface are recessed channels 93 for containing flowing cooling fluid.

[0017] Figures 7A and 7B are schematic plan view representations of alternative embodiments of emitter arrays 60 (and 80) of an illumination module 50 such as those in Figures 4, 5A and 5B. In the embodiment of Figure 7A, the emitters 70 are in the form of individually packaged emitters (or individually packaged LEDs) 78, while in the embodiment of Figure 7B the emitters 70 are in the form of groups 79 of emitters (such as "multi-chip" LEDs) (of different types 72,74,76), at least two types minimum, packaged together. In both embodiments, there is at least a first emitter 72 and a second emitter 74, with the second emitter 74 having a second center wavelength differing from a first center wavelength of the first emitter 72. Optionally, the array 60 (or 80) may further comprise at least a third emitter 76 capable of emitting at a third center wavelength, with the third center wavelength differing from each of the first and second center wavelengths. More than three different emitters or types of emitters may also be employed. Also, grouped emitters (or groups of emitters) 79 may be used within the same array as individual emitters.

[0018] Regardless of the number of different types and whether they are packaged together, it is also desirable that the various different types of emitters 72, 74, 76 be independently controllable by switch or controller or receiver 100, through respective control and/or power lines 102a, 102b, 102c (labeled generally 102. Preferably, the various sub-arrays of emitters, each formed by the emitters of the same wavelength, are independently controllable by switch or controller or receiver. The emitters of the same wavelength or center wavelength on an array are desirably controlled collectively. Independent control over the various wavelengths allows for easy reaction characterization or other experimentation or reaction control involving use of various wavelengths, without having to disassemble the reactor or any components.

[0019] The emitters 70 are desirably LEDs. According to an embodiment, the array comprises a Printed Circuit Board on which the emitters are mounted. In addition, they are desirably capable of providing at least 40 mW/cm2 homogeneous irradiation to the free surface area 22F, 24F of the first or second major surface 22, 24 of a fluidic module 20, more desirably at least 50 mW/cm2. The LEDs may be high power LEDs, or their density on the array may be sufficient to achieve the desired irradiation. A desired degree of homogeneity of irradiation may be achieved through the density of LEDs on the array, or through an optical diffuser.

[0020] Figures 8 and 9 show perspective views illustrating an embodiment of certain ways in which the system 10 of the present disclosure may be assembled into a reactor 12. In figures 8 and 9, fluidic modules 20 and illumination modules 50 are supported on a reactor support or mount 104, in this case in the form of a beam. Alternatively, the fluidic modules 20 and the illumination modules 50 may be supported on 2 separate supports or mounts, and the illumination modules 50 and their support or mount may be slid in and out of the reactor in order to ease the maintenance of the system. Illumination modules 50 in these embodiments include both two-sided illumination modules 50a and single-sided illumination modules 50b. In Figure 8 the reactor 12 is shown without the fluidic modules 20 included. Figure 9 shows the position of multiple fluidic modules 20 between the radiative faces of the illumination modules 50.

[0021] Reactors 12 formed of the system 10 are both flexibly reconfigurable and compact, while well-isolating the thermal output of the emitters from the reactant or process fluids, first because of the use of semiconductor emitters such as LEDs in which energy conversion efficiency is reasonably high, in contrast to lamps and other similar sources, and second because of the use of heat exchanger 96 which is capable of extracting even as much as multiple hundred watts, and third because the process fluid layer 30 of the fluidic module 20 is surrounded on both sides by a thermal control fluid layer 40 through which incoming illumination arrives, providing thereby significant isolation from any heat generated by or at the emitters 70. Reactors 12 formed of the system 10 also enable LED emitters to be operated at low temperature (below room temperature and fluidic module operating temperature), through the use of heat exchangers 96, resulting in increased emitted intensity and increased LED lifetime.

[0022] The present system and reactor formed therefrom also provides the ability to switch illumination wavelengths, or, more generally, to alter the spectral composition of the illumination without disassembly of the reactor, such that reaction testing and characterization are more easily accomplished. It is advantageous to be able to perform photochemical reactions in a flow reactor that is compact yet flexible in both reactor structure or design as well as in the radiation supplied. Light wavelength of interest is mainly near UV and violet light between 300 and 450 nm, but other UV or visible wavelengths may also be of interest.

[0023] Having the working fluid layer 30 illuminated from both sides of fluidic modules 20, through the thermal control layers 40 not only helps provide thermal isolation, but also delivers a large amount of illumination to the process fluid and may allow more uniform penetration through the depth of the process channel, relative to illuminating on only one major surface of the fluidic module 20.

[0024] It should be noted that not all fluidic modules 20 in a given reactor will necessarily require or benefit from irradiation, accordingly, some fluidic modules may not be illuminated within the same reactor in which some others are. In other words, the illumination is scalable independently or together with the number of fluidic modules.

[0025] Different kind of chemistries can be therefore performed with same lighting solution, without any change of equipment, without any maintenance. This is not equipment specific to 1 single wavelength.

[0026] By the use of spectrally narrower light from semiconductor sources, chemistries can be better understood and therefore optimized. Accurate wavelength of the semiconductor sources allows getting more product selectivity. Lifetime of the light source should also be long.

[0027] The methods and/or devices disclosed herein are generally useful in performing any process that involves mixing, separation, extraction, crystallization, precipitation, or otherwise processing fluids or mixtures of fluids, including multiphase mixtures of fluids-and including fluids or mixtures of fluids including multiphase mixtures of fluids that also contain solids-within a microstructure. The processing may include a physical process, a chemical reaction defined as a process that results in the interconversion of organic, inorganic, or both organic and inorganic species, and desirably includes a chemical, physical, or biological process or reaction favored in the presence of light, of whatever wavelength, i.e., photoreactions, whether photosensitized, photoinitiated (as in photoinitiated radical reactions), photoactivated, photocatalytic, photosynthetic, or other).. A non-limiting list of light-assisted or light-favored reactions of potential interest includes photoisomerizations, rearrangements, photoreductions, cyclizations, 2+2 cycloadditions, 4+2 cycloadditions, 4+4 cycloadditions, 1,3-dipolar cycloadditions, sigmatropic shifts (which could result in cyclisation), photooxidation, photocleavage of protecting groups or linkers, photohalogenations (phtochlorinations, photobrominations), photosulfochlorinations, photosulfoxidations, photopolymerizations, photonitrosations, photodecarboxylations, photosynthesis of previtamin D, decomposition of azo-compounds, Norrish type reactions, Barton type reactions. Further, the following non-limiting list of reactions may be performed with the disclosed methods and/or devices: oxidation; reduction; substitution; elimination; addition; ligand exchange; metal exchange; and ion exchange. More specifically, reactions of any of the following non-limiting list may be performed with the disclosed methods and/or devices: polymerisation; alkylation; dealkylation; nitration; peroxidation; sulfoxidation; epoxidation; ammoxidation; hydrogenation; dehydrogenation; organometallic reactions; precious metal chemistry/ homogeneous catalyst reactions; carbonylation; thiocarbonylation; alkoxylation; halogenation; dehydrohalogenation; dehalogenation; hydroformylation; carboxylation; decarboxylation; amination; arylation; peptide coupling; aldol condensation; cyclocondensation; dehydrocyclization; esterification; amidation; heterocyclic synthesis; dehydration; alcoholysis; hydrolysis; ammonolysis; etherification; enzymatic synthesis; ketalization; saponification; isomerisation; quaternization; formylation; phase transfer reactions; silylations; nitrile synthesis; phosphorylation; ozonolysis; azide chemistry; metathesis; hydrosilylation; coupling reactions; and enzymatic reactions..

[0028] The foregoing description provides exemplary embodiments to facilitate an understanding of the nature and character of the claims. It will be apparent to those skilled in the art that various modifications to these embodiments can be made without departing from the scope of the appending claims.

Claims

1. A modular photochemical reactor system (10) comprising:

   a plurality of fluidic modules (20) each having a planar form with first and second major surfaces (22,24), each of said first and second major surfaces (22,24) having a free surface area (22F,24F) free of inlet and outlet ports, and each having i) a central planar process fluid layer (30) and ii) two outer planar thermal control fluid layers (40) for containing flowing thermal control fluid, said central planar process fluid layer (30) and said two outer planar thermal control fluid layers (40) being arranged between said first and second major surfaces (22,24) and being at least partially radiation-transparent to at least some wavelengths in the UV and/or visible spectrum ; and

   a plurality of illumination modules (50), each having a planar form with first and second major surfaces (52,54), and each comprising at least a first array (60) of semiconductor emitters (70), said emitters (70) capable of emitting at visible and/or UV wavelengths, positioned to emit from or through the first major surface (52) to the free surface area (22F or 24F) of one of the first and second major surfaces (22,24) of a fluidic module (20), wherein said first array (60) of semiconductor emitters (70) comprises at least a first emitter (72) and a second emitter (74), the first emitter (72) capable of emitting at a first center wavelength and the second emitter (74) capable of emitting at a second center wavelength, said first and second center wavelengths differing from each other.

2. The system (10) according to claim 1 wherein said first array (60) further comprises at least a third emitter (76) capable of emitting at a third center wavelength, said third center wavelength differing from each of the first and second center wavelengths.

3. The system (10) according to either of claims 1 and 2 wherein the emitters (70) comprise individually packaged emitters (78).

4. The system (10) according to any of claims 1-3 wherein the emitters (70) comprise emitters packaged in groups (79) and wherein said groups (79) contain at least one first emitter (72) and at least one second emitter (74).

5. The system (10) according to any of claims 1-4 wherein said at least one first emitter (72) within said first array (60) is connected to a first power or control line (102a) and said at least one second emitter (74) within said first array (60) is connected to a second power or control line (102b).

6. The system (10) according to any of claims 1-5 wherein the plurality of illumination modules (50) comprises at least one illumination module (50a) which itself further comprises a second array (80) of semiconductor emitters (70) capable of emitting at visible and/or UV wavelengths and positioned to emit from or through the second major surface (54), said second array (80) of semiconductor emitters (70) comprising at least a first emitter (72) and a second emitter (74).

7. The system (10) according to claim 6 wherein said at least one illumination module (50a) of said plurality of illumination modules (50) further comprises a heat exchanger (96) including a cooling fluid passage (92) therein having inlet and outlet ports (94), the heat exchanger (96) being in thermal contact with the emitters (70) of the first array (60) and with the emitters (70) of the second array (80).

8. The system (10) according to any of claims 1-5 wherein said illumination modules (50) of said plurality each further comprise a heat exchanger (96) including a cooling fluid passage (92) therein having inlet and outlet ports (94), the heat exchanger (96) being in thermal contact with the emitters (70) of the first array (60).

9. The system (10) according to any of claim 1-8, wherein the emitters (70) are LEDs.

10. The system (10) according to claim 9 wherein the LEDs are capable of providing at least of 40 mW/cm2 to the free surface area (22F,24F) of the first or second major surface (22,24) of a fluidic module (20).

Patentansprüche

1. Modulares photochemisches Reaktorsystem (10) umfassend:

mehrere fluidische Module (20), von denen jedes eine planare Form mit ersten und zweiten Hauptflächen (22,24) aufweist, wobei jede der ersten und zweiten Hauptflächen (22,24) einen freien Oberflächenbereich (22F,24F) aufweist, der frei von Einlass- und Auslassöffnungen ist, und jedes i) eine mittlere planare Prozessfluidschicht (30) und ii) zwei äußere planare Wärmeregulierungfluidschichten (40) zum Halten von fließendem Wärmeregulierungfluid aufweist, wobei die mittlere planare Prozessfluidschicht (30) und die zwei äußeren planaren Wärmeregulierfluidschichten (40) zwischen den ersten und zweiten Hauptflächen (22,24) angeordnet sind und mindestens teilweise strahlungsdurchlässig für mindestens einige Wellenlängen im UV- und/oder sichtbaren Spektrum sind, und

mehrere Beleuchtungsmodule (50), von denen jedes eine planare Form mit ersten und zweiten Hauptflächen (52,54) aufweist und jedes mindestens eine erste Anordnung (60) von Halbleiteremittern (70) umfasst, wobei die Emitter (70) fähig sind, bei sichtbaren und/oder UV- Wellenlängen zu emittieren, und zum Emittieren von der oder durch die erste Hauptfläche (52) zu dem freien Oberflächenbereich (22F oder 24F) einer der ersten und zweiten Hauptflächen (22,24) eines fluidischen Moduls (20) positioniert sind, wobei die erste Anordnung (60) von Halbleiteremittern (70) mindestens einen ersten Emitter (72) und einen zweiten Emitter (74) umfasst, wobei der erste Emitter (72) fähig ist, bei einer ersten mittleren Wellenlänge zu emittieren, und der zweite Emitter (74) fähig ist, bei einer mittleren zweiten Wellenlänge zu emittieren, wobei die ersten und zweiten mittleren Wellenlängen voneinander verschieden sind.

2. System (10) nach Anspruch 1, wobei die erste Anordnung (60) ferner mindestens einen dritten Emitter (76) umfasst, der fähig ist, bei einer dritten mittleren Wellenlänge zu emittieren, wobei die dritte mittlere Wellenlänge von jeder der ersten und zweiten mittleren Wellenlängen verschieden ist.

3. System (10) nach einem der Ansprüche 1 und 2, wobei die Emitter (70) einzeln gepackte Emitter (78) umfassen.

4. System (10) nach einem der Ansprüche 1 - 3, wobei die Emitter (70) Emitter umfassen, die in Gruppen (79) gepackt sind, und wobei die Gruppen (79) mindestens einen ersten Emitter (72) und mindestens einen zweiten Emitter (74) enthalten.

5. System (10) nach einem der Ansprüche 1 - 4, wobei mindestens ein erster Emitter (72) innerhalb der ersten Anordnung (60) an eine erste Starkstrom- oder Steuerleitung (102a) angeschlossen ist und der mindestens eine zweite Emitter (74) innerhalb der ersten Anordnung (60) an die Starkstrom- oder Steuerleitung (102b) angeschlossen ist.

6. System (10) nach einem der Ansprüche 1 - 5, wobei die mehreren Beleuchtungsmodule (50) mindestens ein Beleuchtungsmodul (50a) umfassen, das selbst ferner eine zweite Anordnung (80) von Halbleiteremittern (70) umfasst, die fähig sind, bei sichtbaren und/oder UV- Wellenlängen zu emittieren, und die positioniert sind, um aus der oder durch die zweite Hauptfläche (54) zu emittieren, wobei die zweite Anordnung (80) von Halbleiteremittern (70) mindestens einen ersten Emitter (72) und einen zweiten Emitter (74) umfasst.

7. System (10) nach Anspruch 6, wobei das mindestens eine Beleuchtungsmodul (50a) der mehreren Beleuchtungsmodule (50) ferner einen Wärmetauscher (96) umfasst, der einen Kühlfluiddurchgang (92) umfasst, der darin Einlass- und Auslassöffnungen (94) aufweist, wobei der Wärmetauscher (96) in Wärmekontakt mit den Emittern (70) der ersten Anordnung (60) und mit den Emittern (70) der zweiten Anordnung (80) steht.

8. System (10) nach einem der Ansprüche 1 - 5, wobei jedes der mehreren Beleuchtungsmodule (50) ferner einen Wärmetauscher (96) umfasst, der einen Kühlfluiddurchgang (92) umfasst, der darin mit Einlass- und Auslassöffnungen (94) aufweist, wobei der Wärmetauscher (96) in Wärmekontakt mit den Emittern (70) der ersten Anordnung (60) steht.

9. System (10) nach einem der Ansprüche 1 - 8, wobei die Emitter (70) LEDs sind.

10. System (10) nach Anspruch 9, wobei die LEDs fähig sind, mindestens 40 mW/cm^2 zu dem freien Oberflächenbereich (22F, 24F) der ersten oder zweiten Hauptfläche (22,24) eines fluidischen Moduls (20) bereitzustellen.

Revendications

1. Système de réacteur photochimique modulaire (10) comprenant :

   plusieurs modules fluidiques (20) ayant chacun une forme plane avec de première et seconde surfaces principales (22, 24), chacune desdites première et seconde surfaces principales (22, 24) présentant une zone de surface libre (22F, 24F) exempte d'orifices d'entrée et de sortie, et ayant chacune i) une couche de fluide de procédé plane centrale (30) et ii) deux couches de fluide de contrôle thermique planes externes (40) pour contenir un fluide de contrôle thermique en écoulement, ladite couche de fluide de procédé plane centrale (30) et lesdites deux couches de fluide de contrôle thermique planes externes (40) étant disposées entre lesdites première et seconde surfaces principales (22, 24) et étant au moins partiellement transparentes au rayonnement à au moins certaines longueurs d'onde dans le spectre des UV et/ou du visible ; et

   plusieurs modules d'illumination (50), ayant chacun une forme plane avec de première et seconde surfaces principales (52, 54), et comprenant chacun au moins une première rangée (60) d'émetteurs à semiconducteurs (70), lesdits émetteurs (70) capables d'émettre aux longueurs d'onde du visible et/ou des UV, positionnés pour émettre à partir de ou à travers la première surface principale (52) vers la première zone de surface libre (22F ou 24F) de l'une des première et seconde surfaces principales (22, 24) d'un module fluidique (20), dans lequel ladite première rangée (60) d'émetteurs à semiconducteurs (70) comprend au moins un premier émetteur (72) et un second émetteur (74), le premier émetteur (72) capable d'émettre à une première longueur d'onde centrale et le second émetteur (74) capable d'émettre à une seconde longueur d'onde centrale, lesdites première et seconde longueurs d'onde centrales étant différentes l'une de l'autre.

2. Système (10) selon la revendication 1, dans lequel ladite première rangée (60) comprend en outre au moins un troisième émetteur (76) capable d'émettre

à une troisième longueur d'onde centrale, ladite troisième longueur d'onde centrale étant différente de chacune des première et seconde longueurs d'onde centrales.

3. Système (10) selon l'une quelconque des revendications 1 et 2, dans lequel les émetteurs (70) comprennent des émetteurs individuellement emballés (78).

4. Système (10) selon l'une quelconque des revendications 1-3, dans lequel les émetteurs (70) comprennent des émetteurs emballés en groupes (79) et dans lequel lesdits groupes (79) contiennent au moins un premier émetteur (72) et au moins un second émetteur (74).

5. Système (10) selon l'une quelconque des revendications 1-4, dans lequel ledit au moins un premier émetteur (72) dans ladite première rangée (60) est connecté à une première ligne électrique ou de contrôle (102a) et ledit au moins un second émetteur (74) dans ladite première rangée (60) est connecté à une seconde ligne électrique ou de contrôle (102b).

6. Système (10) selon l'une quelconque des revendications 1-5, dans lequel les plusieurs modules d'illumination (50) comprennent au moins un module d'illumination (50a) qui comprend lui-même de plus une seconde rangée (80) d'émetteurs à semiconducteurs (70) capables d'émettre aux longueurs d'onde du visible et/ou des UV et positionnés pour émettre à partir de ou à travers la seconde surface principale (54), ladite seconde rangée (80) d'émetteurs à semiconducteurs (70) comprenant au moins un premier émetteur (72) et un second émetteur (74).

7. Système (10) selon la revendication 6, dans lequel ledit au moins un module d'illumination (50a) desdits plusieurs modules d'illumination (50) comprend en outre un échangeur de chaleur (96) incluant un passage de fluide réfrigérant (92) dans celui-ci présentant des orifices d'entrée et de sortie (94), l'échangeur de chaleur (96) étant en contact thermique avec les émetteurs (70) de la première rangée (60) et avec les émetteurs (70) de la seconde rangée (80).

8. Système (10) selon l'une quelconque des revendications 1-5, dans lequel lesdits modules d'illumination (50) desdits plusieurs comprennent de plus chacun un échangeur de chaleur (96) incluant un passage de fluide réfrigérant (92) dans celui-ci présentant des orifices d'entrée et de sortie (94), l'échangeur de chaleur (96) étant en contact thermique avec les émetteurs (70) de la première rangée (60).

9. Système (10) selon l'une quelconque des revendications 1-8, dans lequel les émetteurs (70) sont des LED.

10. Système (10) selon la revendication 9, dans lequel les LED sont capables de fournir au moins 40 mW/cm^2 à la zone de surface libre (22F, 24F) des première ou seconde surfaces principales (22, 24) d'un module fluidique (20).

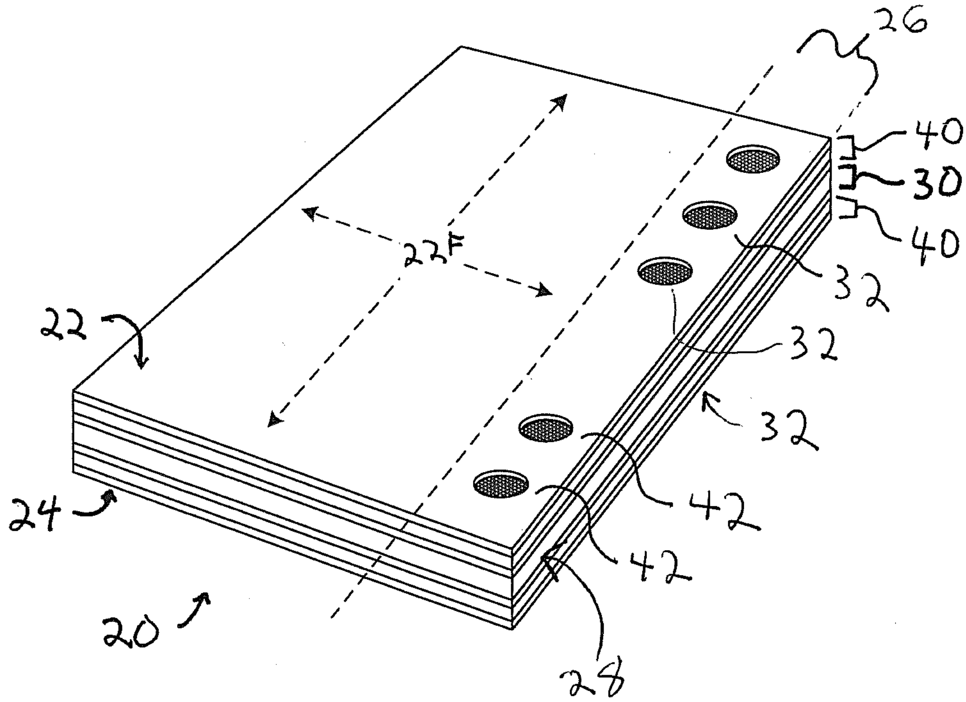

Figure 1

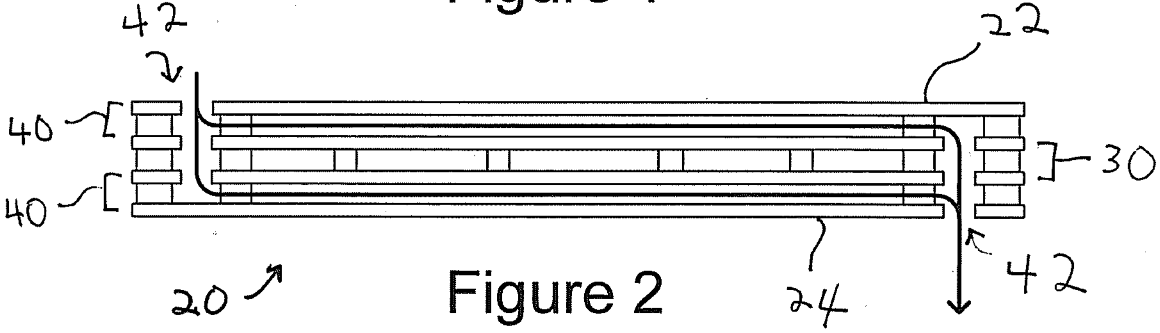

Figure 2

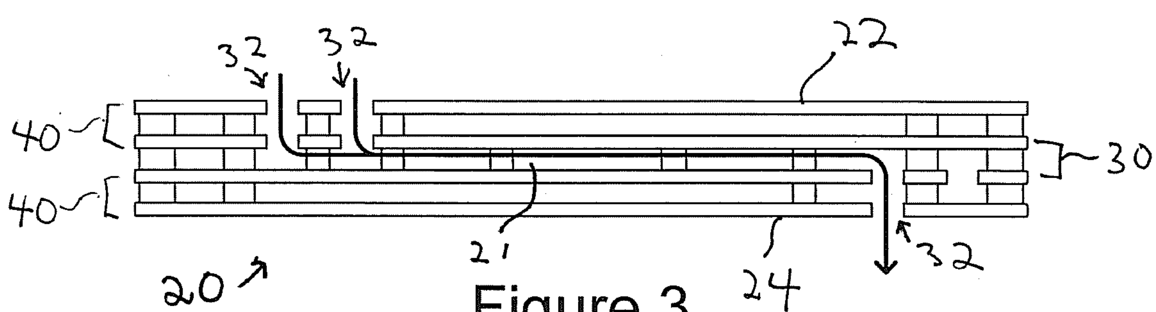

Figure 3

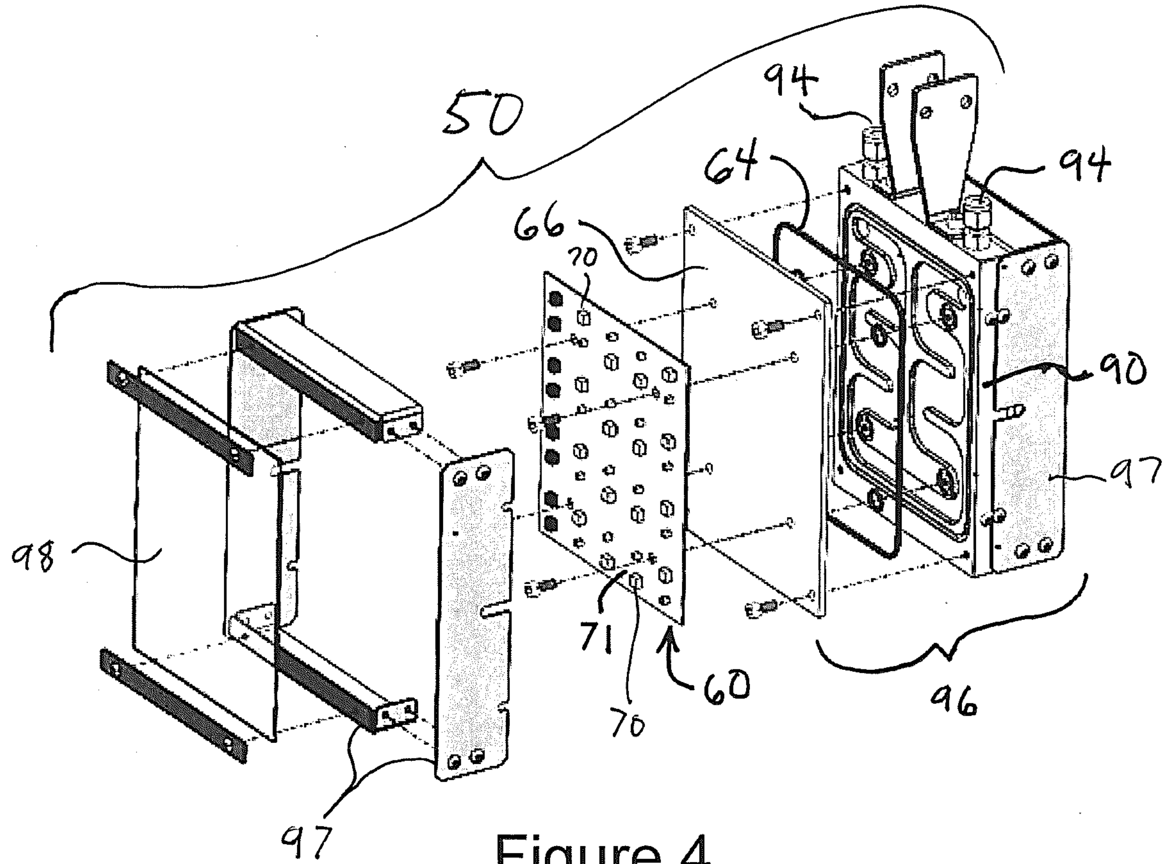

Figure 4

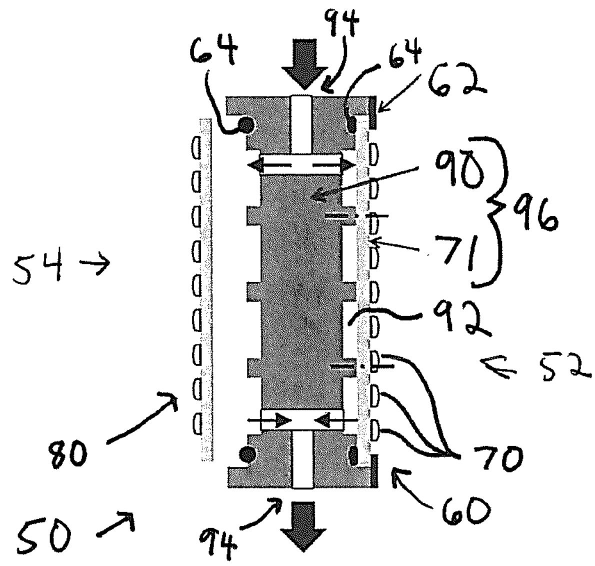

Figure 5A

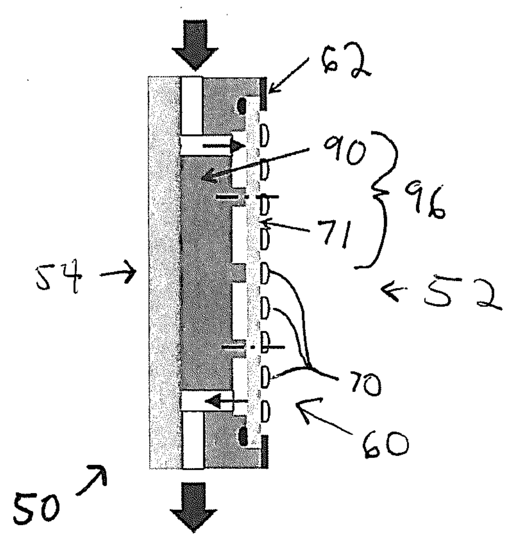

Figure 5B

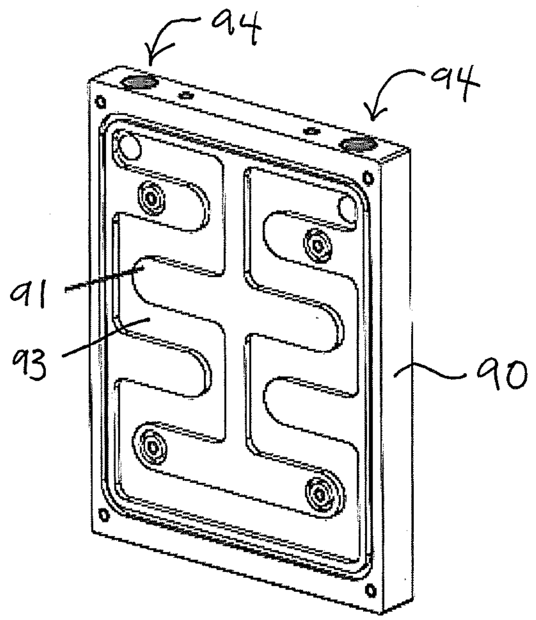

Figure 6

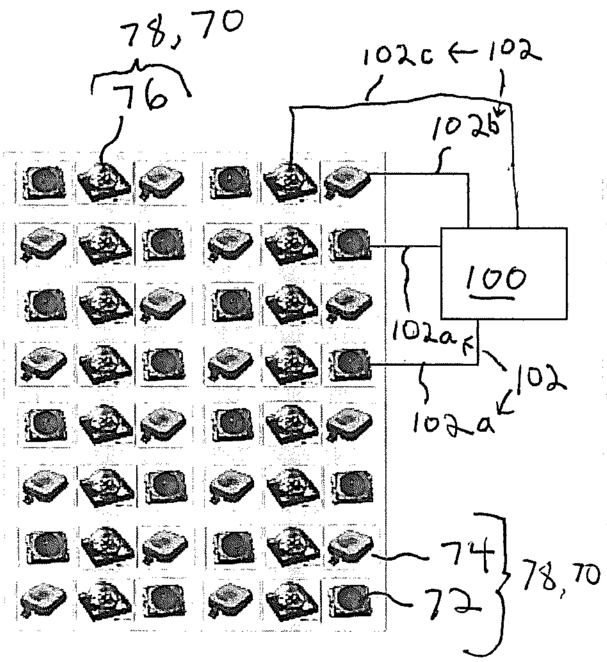

Figure 7A

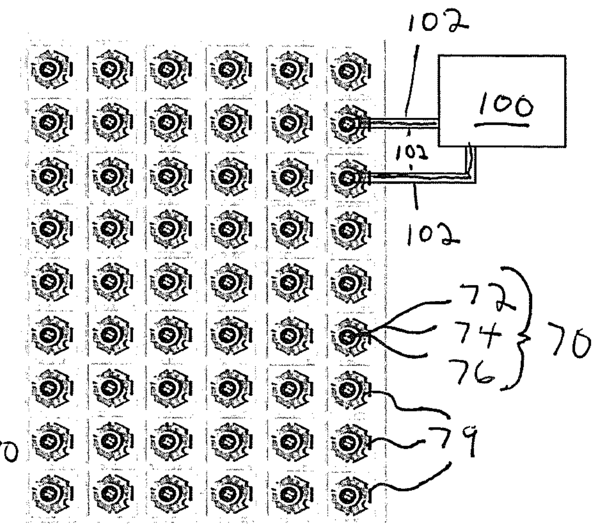

Figure 7B

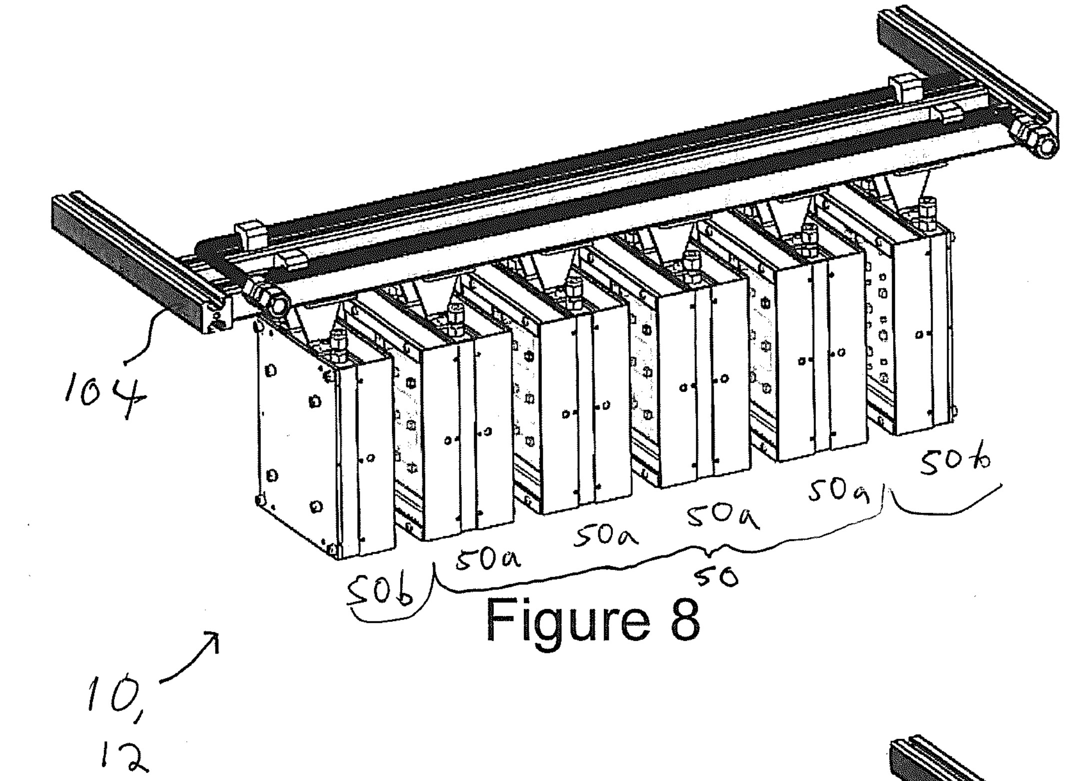

Figure 8

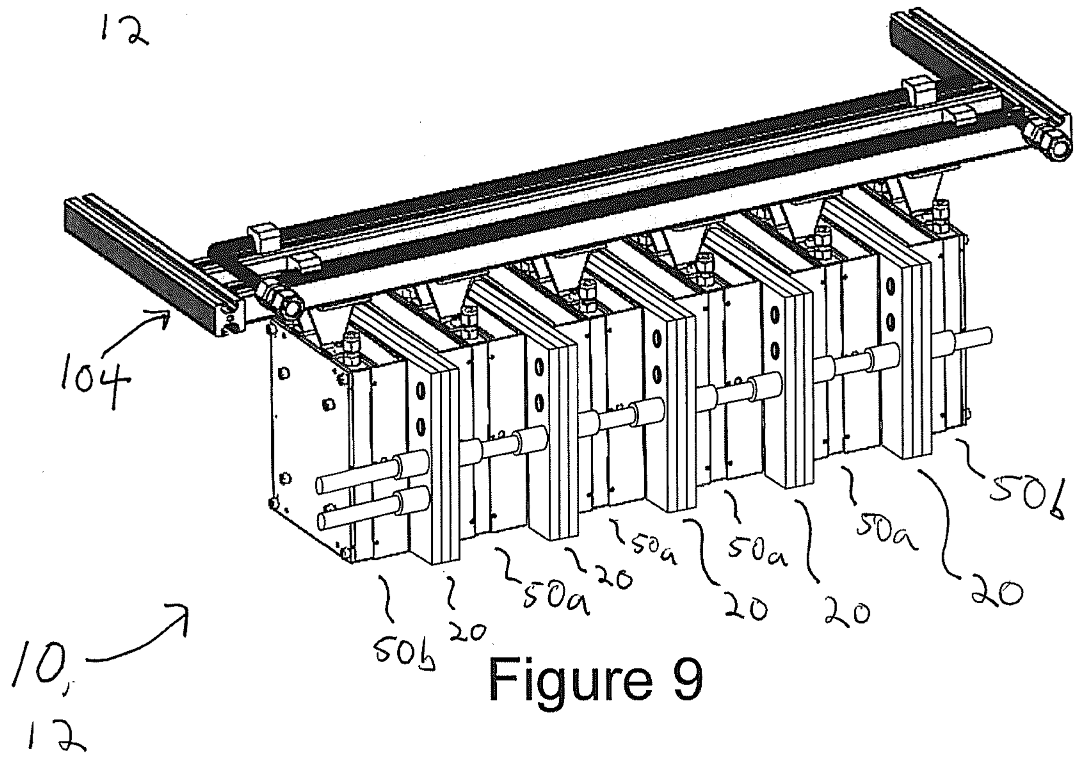

Figure 9

REFERENCES CITED IN THE DESCRIPTION

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