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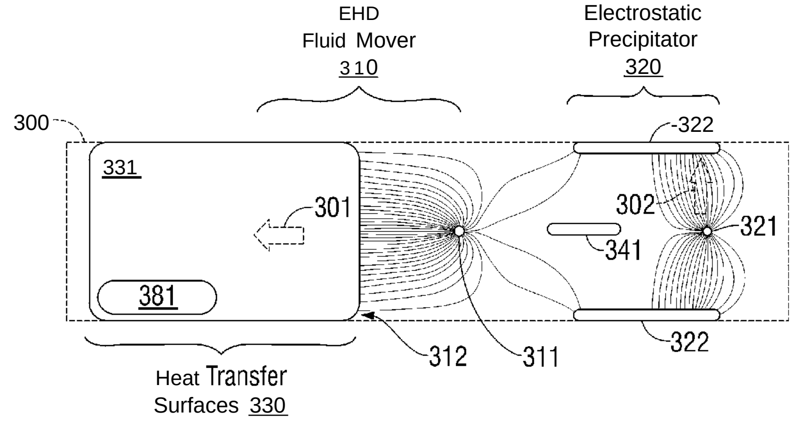

FIG. 3A

(57) Abstract: Electrostatic precipitation is performed upstream of collector electrode surfaces toward which a downstream EHD fluid mover accelerates fluid flow. In this way, the upstream electrostatic precipitator (ESP) acts as a pre-filter (with low flow-impedance) and can reduce accumulation of otherwise detrimental materials on downstream electrodes and/or arcing. In some cases, pre-filtering by an upstream electrostatic precipitator may also reduce accumulation of otherwise detrimental materials on downstream heat transfer surfaces and/or ozone catalytic or reactive surfaces/materials. In some embodiments, an EHD fluid mover with an ESP pre-filter is used in a thermal management system to dissipate heat generated by a thermal source.

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ELECTROSTATIC PRECIPITATOR PRE-FILTER FOR ELECTROHYDRODYNAMIC FLUID MOVER

BACKGROUND

Field

[1001] The present application relates to thermal management, and more particularly, to micro-scale cooling devices that use electrohydrodynamic (EHD, also known as electro-fluid-dynamic, EFD) technology to generate ions and electrical fields to control the movement of fluids, such as air, as part of a heat transfer solution.

Related Art

[1002] Devices built to exploit ionic movement of a fluid are variously referred to in the literature as ionic wind machines, electric wind machines, corona wind pumps, electro-fluid-dynamic (EFD) devices, electrohydrodynamic (EHD) thrusters, EHD gas pumps and EHD fluid or air movers. Some aspects of the technology have also been exploited in devices referred to as electrostatic air cleaners or electrostatic precipitators.

[1003] When employed as part of a thermal management solution, an ion flow fluid mover may result in improved cooling efficiency with reduced vibrations, power consumption, electronic device temperatures and/or noise generation. These attributes may reduce overall lifetime costs, device size or volume, and in some cases may improve system performance or user experience.

[1004] However, in many EHD devices and/or operating environments, detrimental materials such as silica dendrites, surface contaminants, particulate or other debris may accumulate or form on electrode surfaces and may decrease the performance, efficiency and lifetime of such devices. Build-up of such detrimental materials can decrease power efficiency, cause sparking or reduce spark-over voltage and contribute to device failure. In general, detrimental material build up may affect any number of surfaces including emitter and/or collector electrode surfaces involved in the motivation of fluid flow. In some cases, detrimental material build up on EHD device surfaces can interfere with ozone (O_3) catalytic or reactive techniques employed to reduce ozone concentrations or even contribute, e.g., through sparking, to ozone production.

[1005] Accordingly, improved techniques are desired for reducing and/or mitigating detrimental material build up on EHD device surfaces, particularly emitter and/or collector electrode surfaces involved in the motivation of fluid flow.

SUMMARY

[1006] In the present application, some aspects of embodiments illustrated and described herein are referred to as electrohydrodynamic fluid accelerator devices, also referred to as "EHD devices," "EHD fluid accelerators," "EHD fluid movers," and the like. In some cases, such devices are suitable for use as a component in a thermal management solution to dissipate heat generated by an electronic circuit, amongst other things. For concreteness, some embodiments are described relative to particular EHD device configurations in which a corona discharge at or proximate to an emitter electrode operates to generate ions that are accelerated in the presence of electrical fields, thereby motivating fluid flow. While corona discharge-type devices provide a useful descriptive context, it will be understood (based on the present description) that other ion generation techniques may also be employed. For example, in some embodiments, techniques such as silent discharge, AC discharge, dielectric barrier discharge (DBD), or the like, may be used to generate ions that are in turn accelerated in the presence of electrical fields and motivate fluid flow.

[1007] Also in the present application, some aspects of the embodiments illustrated and described herein are referred to as electrostatic filters, electrostatic precipitators, electrostatic precipitator (ESP) devices, and the like. Configured as described herein, such devices can be used to reduce particulates entrained in a fluid flow, and which might otherwise flow toward and accumulate on emitter and/or collector surfaces of a downstream EHD device. Again for concreteness, some embodiments are described herein relative to constituent ESP device configurations in which a corona discharge at or proximate to an emitter electrode operates to generate ions that impart charge to particulates such that, in the presence of an electric field, the charged particulates are driven toward collection surfaces. Typically, orientation of the charged particulate driving electric field is transverse to fluid flow.

[1008] As before, corona discharge-type devices provide a useful descriptive context, it will be understood (based on the present description) that other ion generation techniques may also be employed. Techniques such as silent discharge, AC discharge, dielectric barrier discharge (DBD), or the like, may also be employed to generate ions that, in turn, impart charge to entrained particulates and thereby facilitate filtration or precipitation the charged particulates from the fluid flow.

[1009] Thus, EHD devices may be employed to motivate ESP pre-filtered flow of air in a thermal management system, such as when employed to exhaust heat dissipated by integrated circuits in computing devices and electronics. For example, in devices such as laptop computers, compact scale, flexible form factor and absence of moving parts can provide design and user advantages over conventional forced air cooling technologies that rely exclusively on fans or blowers. EHD device solutions with ESP pre-filtration can operate silently (or at least comparatively so) with reduced volume and mass. In some cases, products incorporating EHD device solutions with ESP pre-filtration may be thinner and lighter than those employing conventional forced air cooling technologies. Furthermore, flexible form factors of EHD and ESP devices can facilitate compelling product designs and, in some cases, may provide functional benefits. More specifically, it has been discovered that, in some EHD device configurations, upstream pre-filtration of a fluid flow using an electrostatic filter or precipitator may reduce accumulation of detrimental material on electrode surfaces of the downstream EHD device.

[1010] In some embodiments of the present invention, an apparatus includes a fluid flow path, an electrohydrodynamic (EHD) fluid mover introduced in the fluid flow path and operable to motivate fluid flow therealong and an electrostatic precipitator. The electrostatic precipitator precedes the EHD fluid mover in the fluid flow path and is operable to prevent a substantial amount of particulate matter otherwise entrained in the fluid flow from reaching at least the collector electrode surfaces of the EHD fluid mover. In some embodiments, heat transfer surfaces are introduced in the fluid flow path downstream of the electrostatic precipitator to transfer heat to or from the fluid flow.

[101 1] In some embodiments, the EHD fluid mover is configured to generate, when energized, net ion flow in a primary direction, while the electrostatic precipitator is configured to generate, when energized, ion flow in directions substantially unaligned with the primary direction. In some embodiments, collector electrode surfaces of the EHD fluid mover and of the electrostatic precipitator are respectively positioned such that, when energized, magnitude of ion current to collector surfaces of the EHD fluid mover substantially exceeds that to the collector surfaces of the electrostatic precipitator. In some embodiments, collector electrode surfaces of the EHD fluid mover and of the electrostatic precipitator are respectively coupled between supply voltages such that, when energized, magnitude of ion current to collector surfaces of the EHD fluid mover substantially exceeds that to the collector surfaces of the electrostatic precipitator.

[1012] In some embodiments, the EHD fluid mover and electrostatic precipitator have separate emitter electrode surfaces. For example, the emitter electrode surfaces of the EHD fluid mover may be positioned relative to the collector electrode surfaces thereof to, when energized, generate a net ion flow in substantial alignment with a direction of the motivated fluid flow. In contrast, the emitter electrode surfaces of the electrostatic precipitator may be positioned relative to collector electrode surfaces of the electrostatic precipitator to, when energized, generate a substantial majority of ion flows in one or more directions that are substantially orthogonal to the motivated fluid flow.

[1013] In some embodiments, one or more repelling electrodes may be provided, wherein at least some of the surfaces thereof are positioned between the emitter electrode surfaces of the EHD fluid mover and upstream collector electrode surfaces of the electrostatic precipitator. In some embodiments, at least some of surfaces of the one or more repelling electrodes are positioned between the emitter electrode surfaces of the electrostatic precipitator and downstream collector electrode surfaces of the EHD fluid mover.

[1014] In some embodiments, the electrostatic fluid mover and electrostatic precipitator share at least one emitter electrode. When energized, magnitude of ion current from the emitter electrode to collector surfaces of the EHD fluid mover substantially exceeds that to collector surfaces of the electrostatic precipitator. In some embodiments, ion current to the collector surfaces of the EHD fluid mover is at least 10 times greater than that to the collector surfaces of the electrostatic precipitator.

[1015] In some embodiments in accordance with the present invention, a method includes (i) motivating fluid flow using an electrohydrodynamic (EHD) fluid mover introduced in a fluid flow path; and (ii) upstream of the electrohydrodynamic (EHD) fluid mover, electrostatically precipitating from the fluid flow a substantial amount of particulate matter otherwise entrained therein and thereby preventing the electrostatically precipitated particulate matter from reaching collector electrode surfaces of the EHD fluid mover. In some embodiments, the method further includes transferring heat to or from the fluid flow using heat transfer surfaces introduced in the fluid flow path downstream of the electrostatic precipitating.

[1016] In some embodiments, the method includes energizing at least a first emitter electrode to generate ions that, in a first portion of an electric field, are driven toward collection surfaces of the electrohydrodynamic (EHD) fluid mover; and energizing at least a second emitter electrode, upstream of the first emitter electrode, to generate ions that, in a second portion of the electric field, are driven toward collection surfaces of an electrostatic precipitator. In some embodiments, the method further includes repelling at least some of the ions generated at the first emitter electrode away from paths toward collection surfaces of an electrostatic precipitator.

[1017] In some embodiments, the method includes energizing a shared emitter electrode to generate ions that, in a first portion of an electric field, are driven toward collection surfaces of the electrohydrodynamic (EHD) fluid mover and which, in a second portion of the electric field, are driven toward collection surfaces of an electrostatic precipitator. In some embodiments, the method includes positioning of the respective collection surfaces of the EHD fluid mover and of the electrostatic precipitator, relative to the shared emitter electrode, is such that when the shared emitter is energized, magnitude of ion current to the collection surfaces of the EHD fluid mover substantially exceeds that to the collection surfaces of the electrostatic precipitator. In some embodiments, the method includes positioning of the respective collection surfaces of the EHD fluid mover and of the electrostatic precipitator, relative to the shared emitter electrode, is such that when the shared emitter is energized, magnitude of ion current to the collection surfaces of the EHD fluid mover substantially exceeds that to the collection surfaces of the electrostatic precipitator.

[1018] In some embodiments in accordance with the present invention, an apparatus includes an enclosure and a thermal management assembly for use in cooling one or more devices within the enclosure. The thermal management assembly defines a flow path for conveyance of air between ventilated boundary portions of the enclosure. The thermal management assembly includes an electrohydrodynamic (EHD) fluid mover introduced in the flow path and operable to motivate air flow past heat transfer surfaces thermally coupled to the one or more devices within the enclosure and an electrostatic precipitator preceding the EHD fluid mover in the flow path. The electrostatic precipitator operable to prevent a substantial amount of particulate matter otherwise entrained in the air flow from reaching the EHD fluid mover.

[1019] In some embodiments, a repelling electrode is positioned between an emitter electrode of the EHD fluid mover and collection surfaces of the electrostatic precipitator. In some embodiments, a collector electrode of the electrostatic precipitator allows the air flow to transit therethrough.

[1020] In some embodiments, the apparatus is configured to cool the one or more devices and is embodied as a handheld mobile phone or personal digital assistant, as a laptop, netbook, pad-type or desktop computer, as a digital book reader, media player or gaming device, or as a projector, television or video display panel. In some embodiments, the apparatus is configured to provide ambient heating or cooling in a volume external to the enclosure.

[1021] Building on the foregoing, we present a variety of ESP pre-filtered embodiments of EHD devices. In some embodiments, collector electrodes of the EHD device are themselves thermally coupled to a heat source such that at least some surfaces thereof act as fins of a heat exchanger. In some embodiments, the EHD device motivates flow of a fluid (typically air) past a heat exchanger that is thermally integrated with the collector electrodes. In some embodiments, multiple EHD device instances are ganged and/or staged so as to increase volume of flow, pressure or both. These and other embodiments will be understood with reference to the description that follows and with respect to the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[1022] The description of illustrative embodiments will be understood when read in connection with the accompanying drawings. Drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the structural and fabrication principles of the described embodiments.

[1023] **FIG. 1** is a graphical depiction of certain basic principles of corona-induced electrohydrodynamic (EHD) fluid flow.

[1024] **FIG. 2** is a cross-sectional view of an illustrative electrostatic precipitator configuration in which generated ions charge particulates entrained in a fluid flow and, in the presence of an electric filed, drive the charged particulates from the fluid flow toward collection surfaces.

[1025] **FIG. 3A** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which a repelling electrode tends to shape electric fields emanating from distinct emitter electrode surfaces employed in EHD device and electrostatic precipitator portions, respectively. **FIG. 3B** depicts a perspective view consistent with the arrangement of **FIG. 3A.**

[1026] **FIG. 4A** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which a shared emitter electrode is employed to generate ions for respective EHD device and an electrostatic precipitator portions thereof. **FIG. 4B** depicts a perspective view consistent with the arrangement of **FIG. 4A.**

[1027] **FIG. 5A** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which a repelling electrode is employed together with an alternative EHD collector electrode geometry. **FIG. 5B** depicts a perspective view consistent with the arrangement of **FIG. 5A.**

[1028] **FIG. 6A** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which a repelling electrode is employed together with distinct heat transfer and EHD collector electrode surfaces. **FIG. 6B** depicts a perspective view consistent with the arrangement of **FIG. 6A.**

[1029] **FIG. 7** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which electrostatic precipitator portions are ganged and corresponding repelling electrodes are provided.

[1030] **FIG. 8** depicts a side cross-sectional view consistent with certain thermal management system embodiments in which a repelling electrode is employed together with distinct heat transfer and EHD collector electrode surfaces.

[1031] **FIGS. 9A** and **9B** depict respective (and illustrative) voltage source coupling circuits overlaid on a side cross-sectional view of a low-profile variation on the arrangement with repelling electrode illustrated in **FIGS. 6A** and **6B.** **FIG. 9A** depicts a voltage source shared amongst emitter and repelling electrodes, while **FIG. 9B** depicts a configuration in which plural voltage sources are provided to facilitate independent control over the various electrodes.

[1032] **FIG. 10** depicts a side cross-sectional view of a further variation with a shared emitter electrode, in which an illustrative voltage source coupling circuit is again overlaid.

[1033] **FIG. 11** depicts a consumer electronics device configuration in which a display (typically of a touch screen variety) dominates a major surface expanse and in which low-profile and/or flexible form factor thermal management system embodiments may provide active cooling and/or moderation of spatially varied thermal loads.

[1034] **FIG. 12A** depicts a side cross-sectional view consistent with certain compact embodiments of a thermal management system in which a shared emitter electrode is employed. **FIG. 12B** depicts a perspective view consistent with the arrangement of **FIG. 12A.**

[1035] **FIG. 13** is an additional consumer electronics device illustration in which low-profile and/or flexible form factor thermal management system embodiments such as illustrated in **FIGS. 12A** and **12B** may provide active cooling and/or moderation of spatially varied thermal loads.

[1036] **FIGS. 14A** and **14B** depict alternative side cross-sectional views consistent with certain embodiments of a thermal management system in which a shared emitter electrode is employed. **FIG. 14B** depicts a variation in which a repelling electrode is employed. **FIG. 14C** depicts a perspective view consistent with the arrangement of **FIG. 14A.**

[1037] Use of the same reference symbols in different drawings indicates similar or identical items.

DETAILED DESCRIPTION

[1038] Some embodiments of thermal management systems described herein employ EHD fluid mover devices to motivate flow of a fluid, typically air, based on acceleration of ions generated as a result of corona discharge. Likewise, ions generated by corona discharge are also used in some embodiments to charge entrained particulates and electrostatically precipitate them from the fluid (e.g., air) flow. Other embodiments may employ other ion generation mechanisms for either or both of the EHD fluid motivation and electrostatic precipitation and will nonetheless be understood in the descriptive context herein which emphasizes corona discharge as an illustrative mechanism. In each case, electrostatic precipitation is performed upstream of collector electrode surfaces toward which a downstream EHD fluid mover accelerates fluid flow. In this way, the upstream electrostatic precipitator acts as a *pre-filter* (with low flow-impedance) and can at least reduce accumulation of otherwise detrimental materials on downstream electrodes and/or arcing. In some cases, pre-filtering by an upstream electrostatic precipitator may also reduce accumulation of otherwise detrimental materials on downstream heat transfer surfaces and/or ozone catalytic or reactive surfaces/materials.

[1039] In form-factors envisioned for some thermal management system embodiments *{e.g.,* on the order 2-5 mm in height and <10 mm flow path through the ESP pre-filter and EHD fluid mover), field shaping techniques are employed to allow the EHD fluid mover and ESP pre-filter portions of a solution to operate in close proximity to one another along the flow path. In some embodiments, one or more repelling electrodes are interposed between an emitter electrode of one portion and collector electrodes of the other. In some embodiments, distances to a shared emitter and differences in the operating voltages of respective collector electrode surfaces are selected to allow net downstream ion-motivated fluid acceleration to dominate, while still allowing entrained particulate, which accumulates significant charge in the upstream ESP pre-filter portion to *counter flow* back toward upstream collectors of the ESP pre-filter.

[1040] In general, downstream heat transfer surfaces may include purpose-built structures such as arrays of heat transfer fins introduced in the EHD motivated fluid flow and thermally coupled to thermal sources using heat pipes, heat spreaders or the like. In some cases, EHD motivated fluid flow may itself be directed over thermal sources such that heat transfer surfaces downstream of the electrostatic precipitator pre-filter may include surfaces of the thermal sources themselves. Even when purpose-built, heat transfer surfaces may be integral, or monolithically formed, with collector electrodes of an EHD fluid mover.

[1041] While in some situations or embodiments, heat evolved by electrical assemblies (e.g., microprocessors, graphics units, RF or optical communications, displays or illuminators, etc.) and/or other components can be transferred to the fluid flow and exhausted, in others, substantial portions of the motivated fluid flow need not transit a ventilation boundary of an enclosure. Instead, in some situations or embodiments, particularly at handheld consumer electronic device form factors that place thermal sources closely proximate to exterior surfaces, active circulation of fluid (e.g., air) within a sealed (or partially sealed) enclosure may be desirable even without substantial mass transport across a ventilation boundary.

[1042] Typically, when a thermal management system is integrated into an operational environment, heat transfer paths (often implemented as heat pipes or using other technologies) are provided to transfer heat from where it is dissipated (or generated) to a location (or locations) within the enclosure where air flow motivated by an EHD device (or devices) flows over heat transfer surfaces. Of course, while some embodiments may be fully integrated in an operational system (such as a handheld mobile phone or personal digital assistant; a laptop, netbook, pad-type or desktop computer; a digital book reader, media player or gaming device; or a projector, television or video display device, etc.), other embodiments may take the form of subassemblies.

[1043] Although much of the description herein focuses on systems in which waste heat is transferred to an EHD motivated flow, based on the description herein, persons of ordinary skill in the art will also appreciate heating and/or cooling system embodiments in which a primary operational goal may be thermal transfer of heat into or from an EHD motivated flow. In such embodiments, heat transfer surfaces may be heated or cooled using any of a variety of conventional techniques including Peltier effects, evaporative cooling, closed-cycle heat pumps, resistive heating, etc.

[1044] In general, a variety of scales, geometries and other design variations are envisioned for EHD fluid mover, ESP and (if provided) heat transfer surfaces, together with a variety of positional interrelationships between emitter and collector electrodes of a given EHD or ESP device portion. For concreteness of description, we focus on certain illustrative embodiments and certain illustrative surface profiles and positional interrelationships with other components. For example, in much of the description herein, plural planar collector electrodes are arranged in a parallel, spaced-apart array proximate to a corona discharge wire-type emitter electrode that is displaced from leading surfaces of the respective collector electrodes. In some embodiments, planar portions of the collector electrodes are oriented generally orthogonally to the longitudinal extent of a corona discharge wire. In other embodiments, orientation of collector electrodes is such that leading surfaces thereof are generally parallel to the longitudinal extent of a corona discharge wire.

[1045] Although embodiments of the present invention are not limited thereto, much of the description herein is consistent with geometries, air flows, and heat transfer paths typical of mobile, handheld consumer electronics such as pad-type computers, mobile phones, and laptops and will be understood in view of that descriptive context. Of course, the described embodiments are merely illustrative and, notwithstanding the particular context in which any particular embodiment is introduced, persons of ordinary skill in the art having benefit of the present description will appreciate a wide range of design variations and exploitations for the developed techniques and configurations. Indeed, EHD device technologies present significant opportunities for adapting structures, geometries, scale, flow paths, controls and placement to meet thermal management challenges in a wide range of applications and systems. Moreover, reference to particular materials, dimensions, electrical field strengths, exciting voltages, currents and/or waveforms, packaging or form factors, thermal conditions, loads or heat transfer conditions and/or system designs or applications is merely illustrative. In view of the foregoing and without limitation on the range of designs encompassed within the scope of the appended claims, we now describe certain illustrative embodiments.

Electrohydrodynamic (EHD) Fluid Acceleration, Generally

[1046] Basic principles of electrohydrodynamic (EHD) fluid flow are well understood in the art and, in this regard, an article by Jewell-Larsen, N. et al., entitled "Modeling of corona-induced electrohydrodynamic flow with COMSOL multiphysics" (in the *Proceedings of the ESA Annual Meeting on Electrostatics 2008)* (hereafter, "the Jewell-Larsen Modeling article"), provides a useful summary. Likewise, U.S. Patent 6,504,308, filed October 14,1999, naming Krichtafovitch et al. and entitled "Electrostatic Fluid Accelerator" describes certain electrode and high voltage power supply configurations useful in some EHD devices. U.S. Patent 6,504,308, together with sections I (Introduction), II (Background), and III (Numerical Modeling) of the Jewell-Larsen Modeling article are hereby incorporated by reference herein for all that they teach.

[1047] Note that the simple illustration of corona-induced electrohydrodynamic fluid flow shown in **FIG. 1** (which has been adapted from the Jewell-Larsen Modeling article and discussed above) includes shapes for first electrode **10** and second electrode **12** that are particular to the simple illustration thereof. Likewise, the electrode configurations illustrated in U.S. Patent 6,504,308 and aspects of the power supply design are particular thereto. Accordingly, such illustrations, while generally useful for context, are not intended to limit the range of possible electrode or high voltage power supply designs in any particular embodiment of the present invention.

[1048] EHD fluid mover and, indeed, electrostatic precipitator (ESP) designs described herein can include one or more corona discharge-type emitter electrodes. In general, such corona discharge electrodes include a portion (or portions) that exhibit(s) a small radius of curvature and may take the form of a wire, rod, edge or point(s). Other shapes for the corona discharge electrode are also possible; for example, the corona discharge electrode may take the shape of barbed wire, wide metallic strips, and serrated plates or non-serrated plates having sharp or thin parts that facilitate ion production at the portion of the electrode with the small radius of curvature when high voltage is applied. In general, corona discharge electrodes may be fabricated in a wide range of materials. For example, in some embodiments, compositions such as described in U.S. Patent 7,157,704, filed December 2, 2003, entitled "Corona Discharge Electrode and Method of Operating the Same" and naming Krichtafovitch et al. as inventors may be employed. U.S. Patent 7,157,704 is incorporated herein for the limited purpose of describing materials for some emitter electrodes that may be employed in some corona discharge-type embodiments. In general, a high voltage power supply creates the electric field between corona discharge electrodes and collector electrodes.

[1049] EHD fluid mover portions of embodiments described herein include ion collection surfaces positioned downstream of one or more corona discharge electrodes. Often, ion collection surfaces of an EHD fluid mover portion include leading surfaces of generally planar collector electrodes extending downstream of the corona discharge electrode(s). In some cases, such generally planar collector electrodes may do double-duty as heat transfer surfaces. In some cases, a fluid permeable ion collection surface may be provided. ESP portions of embodiments described herein likewise include ion collection surfaces, typically configured as generally planar collector electrodes positioned across from, or even upstream of, corona discharge electrodes in the fluid flow motivated by a downstream EHD fluid mover. As such, the ESP portion positioned upstream of an EHD fluid mover portions acts as a pre-filter for the downstream EHD fluid mover.

[1050] In general, collector electrode surfaces may be fabricated of any suitable metal material, such as aluminum or copper. Alternatively, as disclosed in US Patent 6,91 9,698 to Krichtafovitch, collector electrodes (referred to therein as "accelerating" electrodes) may be formed of a body of high resistivity material that readily conducts a corona current, but for which a result voltage drop along current paths through the body of high resistivity collector electrode material provides a reduction of surface potential, thereby damping or limiting an incipient sparking event. Examples of such relatively high resistance materials include carbon filled plastic, silicon, gallium arsenide, indium phosphide, boron nitride, silicon carbide, and cadmium selenide. US Patent 6,919,698 is incorporated herein for the limited purpose of describing materials for some collector electrodes that may be employed in some embodiments. Note that in some embodiments described herein, a surface conditioning or coating of high resistivity material (as contrasted with bulk high resistivity) may be employed.

[1051] Configurations described and illustrated herein typically include first collector electrodes that constitute the dominant ion collection surfaces for EHD fluid mover operation together with second collector electrodes that constitute the dominant ion collection surfaces for electrostatic precipitation. In general, the number of, the distances between, and even the orientation of such collector electrodes and surfaces shown in various of the drawings are merely exemplary. Indeed, numbers, distances and orientations may vary from what is shown according to design factors, voltages employed and the type of fluid being pre-filtered and moved. In general, the distance between an emitter electrode (including corona discharge-type emitter electrodes) and corresponding collector electrode surfaces is referred to as the "gap" or "air gap" and may vary from what is shown according to design choices, voltages employed and the type of fluid being pre-filtered and moved.

[1052] Various embodiments described herein may be implemented in a repeated adjacent plural configuration in order, for example, to improve fluid flow efficiency, or to fit into a specific space (or distribute amongst available spaces) within an enclosure. Likewise, design variations of one EHD fluid mover or ESP portion described herein may be mixed and matched with another design variation in a plural adjacent configuration. Furthermore, while single stage configurations are emphasized for clarity of description, it is understood that any one of the EHD fluid mover or ESP portions described herein may also be replicated two or more stages sequentially disposed along a desired fluid flow direction. In operation, each individual EHD fluid mover stage may be operated simultaneously and synchronously with the others in order to produce increased volume and pressure of fluid flow in the desired direction, thereby sequentially accelerating a fluid through the multiple stages. ESP portions may likewise be staged to increase efficacy of pre-filtering.

[1053] Synchronous operation of a multi-stage EHD device is defined herein to mean that a single power supply, or multiple synchronized and phase-controlled power supplies, provide high voltage power to each EHD device stage such that both the phase and amplitude of the electric power applied to the same type of electrodes in each stage *(i.e.,* the corona discharge electrodes or the collector electrodes) are aligned in time. US Patent 6,727,657, entitled "Electrostatic Fluid Accelerator for and a Method of Controlling a Fluid Flow" provides a discussion of the configuration and operation of several embodiments of a multi-stage EHD device, including computing an effective inter-stage distance and exemplary designs for a high voltage power supply for powering neighboring EHD device stages with respective synchronous and syn-phased voltages. US Patent 6,727,657 is incorporated by reference herein in its entirety for all that it teaches.

Electrostatic Precipitator (ESP) Pre-filter Configurations

[1054] Electrostatic precipitators are well understood in the art and have been used in industrial and consumer devices alike. Indeed, the use of industrial-scale electrostatic precipitators in air pollution controls to remove particles from a flowing gas by electric field force dates back to the early 20th century. Conventional electrostatic precipitator (ESP) designs include those of a wire and plate type wherein equally spaced corona wires (often of negative polarity) are centered between grounded plates (or collecting electrodes) and are kept at a voltage high enough to support corona discharge. Ions generated by the corona discharge are driven toward the grounded plates by the electrostatic field and, in the process, collide with particles entrained in a fluid flow through the ESP. These particles acquire electric charges of the same polarity as that of the corona. As a result, the charged particles move toward the grounded plates under the influence of the electrostatic field and typically adhere thereto.

[1055] **FIG. 2** is a cross-sectional view of an illustrative electrostatic precipitator configuration in which ions generated at corona discharge-type emitter electrodes **221** charge particulates **203** entrained in a fluid flow **201** and, in the presence of the illustrated electric fields (from emitter electrodes **221** to collector electrodes **222),** drive **(202)** the charged particulates **203** from the fluid flow toward collector electrodes **222.** Electrostatic precipitators can be highly efficient filtration devices that minimally impede flow of fluids such as air, and yet effectively remove fine particulate matter such as dust and smoke from the air flow. Experience with ESP designs and modeling thereof confirm that electrostatic forces experienced by charged particulates **203** easily overcome momentum of the particulate entrained in the fluid flow **201 .** *See* Lei, Wang, and Wufro, *EHD Turbulent Flow and Monte-Carlo Simulation for Particle Charging and Tracing in a Wire-Plate Electrostatic Precipitator,* Journal of Electrostatics 66 130-141 (2008) for a detailed analysis of the operative forces. Ions (and for that matter, the aforementioned charged particles) also collide with the fluid molecules and transfer momentum to them. In this way, an electric field is produced in the ESP that tends to contribute to a force vector that, in the illustrated configuration of **FIG. 2**, is aligned with arrow **202.** Such forces are, of course, orthogonal to the dominant flow **201** of air forced through the ESP by other means.

[1056] **FIGS. 3A** and **3B** depict respective views of a thermal management assembly **300** in which a corona discharge wire-type emitter electrode **311** and leading collector electrode surfaces **312** of an array of generally planar heat transfer fins **331**, which are energizable in accord with aforementioned principles of electrohydrodynamic (EHD) fluid acceleration, constitute an EHD fluid mover **310.** In particular, **FIG. 3A** depicts a side cross-sectional view of the thermal management assembly with electric field line annotations, while **FIG. 3B** depicts a perspective view consistent with **FIG. 3A.**

[1057] EHD fluid mover **310** is operable to motivate fluid flow through thermal management assembly **300** and over heat transfer surfaces **330.** As will be understood by persons of ordinary skill in the art, heat transfer fins **331** do double-duty as collector electrodes in the illustrated configuration. More particularly, the fins present leading collector electrode surfaces **312** that (i) collect the flux of ions generated at emitter electrode **311** and (ii) establish the downstream orientation of the electric field in which the generated ions are accelerated to establish a downstream net flow **301** through thermal management assembly **300.**

[1058] In addition to EHD fluid mover **310** portion, **FIGS. 3A** and **3B** depict an electrostatic precipitator (ESP) **320** portion upstream of EHD fluid mover **310** in a pre-filter configuration. Ions generated at corona discharge-type emitter electrode **321** charge particulates entrained in flow **301** at locations upstream of the fluid mover **310** that actually motivates the dominant net flow. In the presence of the illustrated electric fields (from emitter electrode **321** to collector electrodes **322),** the charged particulates are driven from the dominant downstream fluid flow toward exposed surfaces of collector electrodes **322** where they typically adhere.

[1059] By removing these entrained particulates (or at least a substantial portion thereof) from the flow, the illustrated configuration tends to reduce accumulation of at least some detrimental materials on downstream electrodes of fluid mover 310. In some cases or embodiments, use of ESP 320 portion as a pre-filter may increase operating lifetime of emitter electrode 311 and/or collector electrode surfaces 312, reduce or eliminate electrode cleaning cycles, or both. In some cases or embodiments, use of ESP 320 portion as a pre-filter may reduce susceptibility of fluid mover 310 to arcing (from emitter electrode 311 to leading collector electrode surfaces 312), thereby reducing ozone generation and/or allowing electrode surfaces of fluid mover 310 to operate at voltage differentials closer to a breakdown voltage of the air or fluid upon which the applied electrostatic forces operate. In some cases or embodiments, pre-filtering by upstream ESP 320 portion may also reduce accumulation of otherwise detrimental materials on downstream heat transfer surfaces 330 and/or ozone catalytic or reactive surfaces/materials, thereby maintaining ozone reduction/sequestration efficacy and/or heat transfer performance of the pertinent surfaces.

[1060] Commonly owned, co-pending U.S. Patent Application No. 12/772,008, filed April 30, 2010, entitled "Collector-Radiator Structure for an Electrohydrodynamic Cooling System," and naming Jewell-Larsen et al. as inventors describes a variety of surface conditionings that may be applied to collector electrode surfaces and/or heat transfer surfaces of an EHD fluid mover. In particular, techniques are described to selectively condition respective surfaces by (amongst other things) providing ion bombardment robustness for collector electrode surfaces and by facilitating ozone abatement by coating (or otherwise conditioning) heat transfer surfaces with an ozone reducing material such as a manganese dioxide (MnO_2) catalyst. Application No. 12/772,008 is incorporated herein by reference and surface conditionings described therein may be provided for corresponding surfaces of the various thermal management assemblies described herein.

[1061] A repelling electrode **341**, positioned as shown in **FIGS. 3A** and **3B**, allows EHD fluid mover **310** and ESP **320** portions to be placed in close proximity to one another, as can be desirable in some of the small-form-factor embodiments of thermal management assemblies described herein. For example, in some embodiments, when repelling electrode **341** is charged to a potential that approximates the respective operating potentials of emitter electrodes **311** and **321**, localized field shaping tends to reduce the attractiveness of ion flow paths from emitter electrode **311** toward collector electrodes **322** of ESP **320** portion (on the one hand) and from emitter electrode **321** toward leading collector electrode surfaces **312** of EHD fluid mover **310** (on the other). As a result, EHD fluid mover **310** and ESP **320** portions can operate with desired ion flow paths despite close physical proximity of emitter electrodes to collector electrodes of the adjacent structure to which ion flow is disfavored.

[1062] In some embodiments, repelling electrode **341** may be coupled to a same power supply terminal as emitter electrodes **311** and **321**. Based on generally larger radii of curvature on surfaces thereof (as compared with emitter electrodes **311** and **321**), repelling electrode **341** does not itself contribute to corona discharge. Instead, repelling electrode **341** shapes electrical fields as generally illustrated in **FIG. 3A.** In embodiments where emitter electrodes **321** and **311** are coupled to a same current supply, repelling electrode **341** may be positioned (relative to the respective emitter electrodes) such that emitter electrodes **321** and **311** operate at approximately the same potential. In some such embodiments, ion current from emitter electrode **311** can be expected to substantially exceed that from emitter electrode **321**, e.g., by a ratio of approximately 10::1 . In some embodiments, repelling electrode **341** need not be directly connected to a power supply terminal, but rather, may be allowed to float to a potential approaching that of emitter electrode **311** and/or emitter electrode **321** based on charge accumulating thereon.

[1063] In the illustrated configuration of thermal management assembly **300**, a heat pipe **381** is illustrated. Heat pipe **381** is optional, but when included, defines part of a heat transfer path from thermal sources of an electronic device (e.g., a handheld mobile phone or personal digital assistant; a laptop, netbook or pad-type computer; a digital book reader, media player or gaming device; or display panel and/or a television) for which thermal management is provided. Although specific thermal sources are not specifically illustrated in **FIGS. 3A** and **3B,** heat evolved by any of a variety of components, including processors (e.g., CPUs and/or GPUs), radio frequency (RF) or optical transceivers and/or illumination sources for a display device, may be conveyed to heat transfer fins **331** via heat pipe **381** or any other suitable heat transfer pathway.

[1064] **FIGS. 4A** and **4B** depict an alternative embodiment in which a shared emitter electrode is employed to generate ions for respective EHD fluid mover **410** and an electrostatic precipitator (ESP) **420** portions of a thermal management assembly **400.** In particular, **FIG. 4A** depicts a side cross-sectional view of thermal management assembly **400** with illustrative electric field line annotations, while **FIG. 4B** depicts a perspective view consistent with **FIG. 4A.**

[1065] As before, an EHD fluid mover **410** portion is operable to motivate fluid flow through a thermal management assembly and over heat transfer surfaces (here, constituent fins **431** of heat transfer surfaces **430).** In the illustrated configuration, the fins present leading collector electrode surfaces **412** that collect a portion of the ion flux generated at emitter electrode **411** and establish the downstream orientation of an electric field in which a portion of generated ions are accelerated to provide a downstream net flow **401** through thermal management assembly **400.**

[1066] In contrast with embodiment(s) illustrated and described above with reference to **FIGS. 3A** and **3B,** embodiments now described with reference to **FIGS. 4A** and **4B** need not employ a repelling electrode interposed between EHD fluid mover **410** and ESP **420** portions of the thermal management assembly. Instead, a *shared* emitter electrode **411** generates a flux of ions from which a generally greater portion are accelerated downstream toward leading collector electrode surfaces 412 and from which a generally *lesser* portion travel in a counter flow direction (*see* arrow 402), colliding with and charging particulates entrained in the fluid flow. In turn, the charged particulates are driven, in the presence of the illustrated electric fields (from shared emitter electrode 411 to collector electrodes 422) and again in a counter flow direction generally consistent with arrow 402, toward exposed surfaces of collector electrodes 422 where they typically adhere.

[1067] As before, the electrostatic precipitator, here ESP 420 portion, is upstream of the EHD fluid mover, here EHD fluid mover 410 portion, in a pre-filter configuration. By removing the entrained particulates (or at least a substantial portion thereof) from the flow, the illustrated configuration tends to reduce accumulation of at least some detrimental materials on electrodes of fluid mover 410 portion and on heat transfer surfaces 430. In some cases or embodiments, such removal may increase operating lifetime of shared emitter electrode 411 and/or collector electrode surfaces 412, reduce or eliminate electrode cleaning cycles, or both. In some cases or embodiments, use of ESP 420 portion as a pre-filter may reduce susceptibility of fluid mover 410 portion to arcing (e.g., from shared emitter electrode 411 to leading collector electrode surfaces 412), thereby reducing ozone generation and/or allowing electrode surfaces of fluid mover 410 portion to operate at voltage gradients across the relevant air gap, which are closer to a breakdown voltage of the air or fluid upon which the applied electrostatic forces operate. In some cases or embodiments, pre-filtering by upstream ESP 420 portion may also reduce accumulation of otherwise detrimental materials on downstream heat transfer surfaces 430 and/or ozone catalytic or reactive surfaces/materials, thereby maintaining ozone reduction/sequestration efficacy and/or heat transfer performance of the pertinent surfaces.

[1068] As illustrated and described above, thermal management assembly 400 need not employ a repelling electrode to shape electrical fields. Instead, other design features or operating conditions ensure that net fluid flow 401, which is motivated downstream by fluid mover 410 portion, dominates counter flows 402 in upstream ESP 420 portion. For example, in some embodiments, supply voltages are selected to establish greater voltage differential between emitter electrode **411** and leading collector electrode surfaces **412** than between emitter electrode **411** and collector electrodes **422.** In some embodiments, distances between emitter electrode **411** and respective collector electrode surfaces of EHD fluid mover **410** and ESP **420** portions are selected to provide higher field strength in the EHD fluid mover **410** portion than in the ESP **420** portions. In some embodiments, both supply voltages and emitter to collector distances are manipulated to provide dominant net fluid flow **(401)** in the downstream direction, while still providing electromotive force vectors (e.g., as indicated by arrows **402)** for particulates that become charged by ions in the upstream pre-filter portion (ESP **420)** of the thermal management assembly to be driven toward (and adhere to) collector electrodes **422.**

[1069] Positioned as shown in **FIGS. 4A** and **4B,** EHD fluid mover **410** and ESP **420** portions are in close proximity to one another, as can be desirable in some of the small-form-factor embodiments of thermal management assemblies described herein. Given the illustrated geometries and assuming equivalent potentials at respective collector electrodes, the combination of a first air gap of about 2 mm between emitter electrode **411** and leading collector electrode surfaces **412** and a larger second air gap of about 4 mm to a nearest surface of collector electrodes **422** can be sufficient to provide dominant net fluid flow **(401)** in the downstream direction, while still providing sufficient electromotive force to drive charged particulates toward collector electrodes **422.** In general, given the illustrated geometries and equivalent collector potentials, air gap ratios greater than about 1::1 .5, but less than about 1::10, provide sufficient EHD fluid mover dominance, while still achieving suitable collection efficiencies given flow rates, particle sizes and particulate loads characteristic of typical implementations and operating environments.

[1070] In some embodiments, air gaps are comparable but electrodes are energized to provide a greater electric field strength across the first air gap between shared emitter electrode **411** and leading collector electrode surfaces **412** and to provide a lesser electric field strength across the second air gap between shared emitter electrode **411** and collector electrodes **422.** For example, voltages at respective collector electrodes may be selected to achieve electric field strengths between shared emitter electrode **411** and respective collector electrode surfaces such that ion currents of about 300 μA across the first air gap and about 30 μA across the second air gap are provided. Such ion current ratios, when biased in favor of the EHD fluid mover, are typically to provide dominant net fluid flow **(401)** in the downstream direction, while still providing sufficient electromotive force to drive charged particulates toward collector electrodes **422.** In general, given geometries such as illustrated but with equivalent air gaps, ion current ratios greater than about 2::1 , but less than about 20::1 , provide sufficient EHD fluid mover dominance, while still achieving suitable collection efficiencies given flow rates, particle sizes and particulate loads characteristic of typical implementations and operating environments.

[1071] Of course, both the dimensional (air gap) ratio and the electric field strengths (with corresponding ion current ratios) may be varied to achieve flow and filtration goals in a given design. For example, in some embodiments in accord with geometries illustrated in **FIGS. 4A** and **4B,** a first-to-second air gap ratio of about 1::1 .5 and a EHD portion to ESP portion current ratio of about 10::1 may be selected to provide sufficient EHD fluid mover dominance, while still achieving suitable collection efficiencies given flow rates, particle sizes and particulate loads characteristic of typical implementations and operating environments.

[1072] As before, a heat pipe is depicted with thermal management assembly **400.** Heat pipe **481** provides a thermal transfer path from thermal sources of an electronic device (e.g., a handheld mobile phone or personal digital assistant; a laptop, netbook or pad-type computer; a digital book reader, media player or gaming device; or display panel and/or a television) for which thermal management is provided. Although specific thermal sources are not specifically illustrated in **FIGS. 4A** and **4B,** heat evolved by any of a variety of components, including processors (e.g., CPUs and/or

GPUs), radio frequency (RF) or optical transceivers and/or illumination sources for a display device, may be conveyed to heat transfer fins **431** via heat pipe **481** or any other suitable thermal transfer pathway.

[1073] **FIGS. 5A** and **5B** depict respective views of a thermal management assembly **500** in which a repelling electrode **541** facilitates closely proximate placement of EHD fluid mover **510** and ESP **520** portions, wherein ESP **520** is configured as an upstream pre-filter. **FIG. 5A** depicts a side cross-sectional view of thermal management assembly **500** with electric field line annotations, while **FIG. 5B** depicts a perspective view consistent with **FIG. 5A.**

[1074] An emitter electrode **511** (here of a corona discharge wire type) and leading collector electrode surfaces **512** of an array of generally planar heat transfer surfaces **530,** which are energizable in accord with aforementioned principles of electrohydrodynamic (EHD) fluid acceleration, constitute the EHD fluid mover (here, EHD fluid mover **510).** However, in contrast with some embodiments previously illustrated and described, generally planar surfaces that do double duty as collector electrodes and as heat transfer surfaces are oriented with a major lateral extent aligned with the longitudinal extent of corona discharge wire-type emitter electrode **511** and to provide generally curved array of leading ion collection surfaces. Notwithstanding these variations in EHD fluid mover configuration, design of ESP **520** portion and operation thereof as a pre-filter are largely analogous to the design and operation of ESP **320** portion, previously described (recall **FIG. 3).**

[1075] Operation of repelling electrode **541** to shape the electric field emanating from distinct emitter electrode surfaces employed in respective EHD device and electrostatic precipitator portions is analogous to that described above with reference to repelling electrode **341** . Note that while **FIGS. 5A** and **5B** illustrate a repelling electrode configuration, based on the description herein persons of ordinary skill in the art will appreciate variations analogous to those illustrated and described with reference to **FIGS. 4A** and **4B,** wherein a shared emitter is employed and dimensional (e.g., air gap) and/or voltage ratios selections provide dominant net fluid flow in the downstream direction, while still providing sufficient electromotive force to drive charged particulates upstream toward collector electrodes.

[1076] **FIGS. 6A** and **6B** depict respective views of still another embodiment in which a thermal management assembly **600** includes an ESP **620** configured as an upstream pre-filter for an EHD fluid mover **610.** **FIG. 6A** depicts a side cross-sectional view, while **FIG. 6B** depicts a perspective view consistent with the arrangement of **FIG. 6A.** In the illustrated embodiment, heat transfer surfaces **630** and EHD collector electrode surfaces **614** are provided using separate (or separable) structures that allow respective surfaces to be conditioned or otherwise specialized to their respective roles. U.S. Patent Application No. 12/772,008, filed April 30, 2010, which has been incorporated herein by reference herein, describes coatings (and other surface conditioning) suitable for the respective surfaces.

[1077] As before, the illustrated configuration includes a repelling electrode (here, repelling electrode **641)** that facilitates closely proximate placement of EHD fluid mover **610** and ESP **620** portions, though (also as before), based on the description herein persons of ordinary skill in the art will appreciate variations in which a shared emitter is employed and dimensional (e.g., air gap) and/or voltage ratios selections provide dominant net fluid flow in the downstream direction, while still providing sufficient electromotive force to drive charged particulates upstream toward collector electrodes.

[1078] An emitter electrode **611** (here of a corona discharge wire type) and collector electrodes **614** (including leading surfaces **612** thereof) are energizable in accord with aforementioned principles of electrohydrodynamic (EHD) fluid acceleration, to act as an EHD fluid mover (here, EHD fluid mover **610).** Although, four (4) collector electrodes **614** are illustrated in a configuration that presents emitter electrode **611** with a generally-curved profile of leading surfaces **612,** both that number and the presented profile are matters of design choice. In some variations on the illustrated embodiment, larger or smaller numbers of collector electrodes **614** may be provided. Likewise, more or less pronounced curvature may be presented. Indeed, in some extremely low-profile embodiments, a mere pair of collector electrodes (akin to the outmost instances of collector electrodes **614** illustrated) without additional laterally displaced collector electrode surfaces positioned therebetween may (in conjunction with an emitter electrode) provide the EHD fluid mover portion of a thermal management assembly.

[1079] Design of ESP **620** portion, and operation thereof as a pre-filter, are largely analogous to the design and operation of ESP portions described and illustrated with respect to **FIGS. 3** and **5**, above. As before, repelling electrode **641** tends to shape electric fields emanating from distinct emitter electrode surfaces employed in respective EHD fluid mover **(610)** and ESP **(620)** portions. Design and operation of repelling electrode **641** is likewise analogous to that described and illustrated with respect to **FIGS. 3** and **5**, above.

[1080] **FIGS. 12A** and **12B** depict respective views of still another embodiment in which a thermal management assembly includes an electrostatic precipitator portion configured as an upstream pre-filter for an EHD fluid mover. As with the embodiment(s) previously described with respect to thermal management assembly **400** (recall **FIGS. 4A** and **4B),** thermal management assembly **1200** includes a shared emitter electrode (here emitter electrode **1211)** that supplies ion current to respective collector electrode of both electrostatic precipitator **1220** and EHD fluid mover **1210** portions of the assembly. Unlike the prior embodiment, a fluid inflow (typically air) transits a collector electrode **1222** positioned at a ventilation boundary. As will be appreciated by persons of ordinary skill in the art with access to the present description, collector electrode **1222** may be formed as an electrostatically smooth mesh, grid, grille, with perforations or slots, etc. to allow fluid to transit therethrough.

[1081] The illustrated electrode geometry facilitates an extremely low-profile design in which closely spaced collector electrodes **1214** of EHD fluid **1210** mover allow thermal management assembly **1200** to contribute less than about 2-3 mm to stacking height of components within an enclosure. In addition, the illustrated electrode geometry allows a compact flow path in which flow **1201** is motivated between ventilation boundaries (IN and OUT) positioned at adjacent rather than opposing-end (or sides) of an enclosure. In some implementations in accord with **FIGS. 12A** and **12B,** ESP pre-filtered, EHD fluid accelerator-motivated air flows past heat transfer surfaces may be achieved with a total inlet-to-outlet flow path of less than about 5 mm. In some extremely thin-form factor consumer electronics embodiments (such as for laptops, netbooks or pad computers; for handheld phones, book readers, or media players; and/or for televisions or other flat panel displays) a collector electrode positioned at a bottom-, top-, front- or back-surface inlet ventilation boundary may act as an ESP pre-filter collection surface with an edge outlet ventilation boundary.

[1082] As before, an EHD fluid mover **1210** portion is operable to motivate fluid flow through the thermal management assembly and over heat transfer surfaces (here, constituent fins **1231** of heat transfer surfaces **1230).** As with configurations described above with reference to **FIGS. 4A** and **4B,** EHD fluid mover **1210** and ESP **1220** portions of the thermal management assembly are closely packed without an interposed repelling electrode. Instead, shared emitter electrode **121 1** generates a flux of ions from which a generally *greater* portion are accelerated downstream toward collector electrodes **1214** and from which a generally *lesser* portion travel in a counter flow direction *(see* arrow **1202),** colliding with and charging particulates entrained in the fluid flow. In turn, the charged particulates are driven (in the presence of an applied electric field) from shared emitter electrode **121 1** to collector electrode **1222** in a counter flow direction generally consistent with arrow **1202,** back toward exposed surfaces of collector electrode **1222** where they typically adhere.

[1083] Electrostatic precipitator **1220** portion is upstream of EHD fluid mover **1210** portion in a pre-filter configuration. By removing the entrained particulates (or at least a substantial portion thereof) from the flow, the illustrated configuration tends to reduce accumulation of at least some detrimental materials on electrodes of fluid mover **1210** portion and on heat transfer surfaces 1230. In some cases or embodiments, such removal may increase operating lifetime of shared emitter electrode 1211 and/or collector electrodes 1214, reduce or eliminate electrode cleaning cycles, or both. In some cases or embodiments, use of ESP 1220 portion as a pre-filter may reduce susceptibility of fluid mover 1210 portion to arcing (e.g., from shared emitter electrode 1211 to surfaces of collector electrodes 1214), thereby reducing ozone generation and/or allowing electrode surfaces of fluid mover 1210 portion to operate at voltage gradients across the relevant air gap, which are closer to a breakdown voltage of the air or fluid upon which the applied electrostatic forces operate. In some cases or embodiments, pre-filtering by upstream ESP 1220 portion may also reduce accumulation of otherwise detrimental materials on downstream heat transfer surfaces 1230 and/or ozone catalytic or reactive surfaces/materials, thereby maintaining ozone reduction/sequestration efficacy and/or heat transfer performance of the pertinent surfaces.

[1084] As illustrated and described above, thermal management assembly 1200 need not employ a repelling electrode to shape electrical fields. Instead, other design features or operating conditions ensure that ion currents in fluid mover 1210 portion (and the associated net downstream fluid flow 1201 motivated thereby) dominate ion currents in upstream ESP 1220 portion, for example by a ratio of about 10::1 . As previously explained (and depending on flow rates, particle sizes and particulate loads), even ion current ratios of 20::1 may provide sufficient ion flux in upstream ESP 1220 portion to provide a suitable level of particulate collection.

[1085] Accordingly, in some embodiments, supply voltages are selected to establish greater voltage between emitter electrode 1211 and collector electrodes 1214 than between emitter electrode 1211 and collector electrode 1222. In some embodiments, distances between emitter electrode 1211 and respective collector electrode surfaces of EHD fluid mover 1210 and ESP 1220 portions are selected to provide higher field strength in the EHD fluid mover 1210 portion than in the ESP 1220 portion. In some embodiments, both supply voltages and emitter to collector distances are manipulated to provide dominant net fluid flow **(1201)** in the downstream direction, while still providing electromotive force vectors (e.g., as indicated by arrows **1202)** for particulates that become charged by ions in the upstream pre-filter portion (ESP **1220)** of the thermal management assembly to be driven toward (and adhere to) collector electrode **1222.**

[1086] Positioned as shown in **FIGS. 12A** and **12B,** EHD fluid mover **1210** and ESP **1220** portions are in close proximity to one another, as can be desirable in some of the small-form-factor embodiments of thermal management assemblies described herein. Given the illustrated geometries and assuming equivalent potentials at respective collector electrodes, the combination of a first air gap of about 1 mm between emitter electrode **121 1** and collector electrodes **1214** and a larger second air gap of about 2 mm to a nearest surface of collector electrode **1222** can be sufficient to provide dominant net fluid flow **(1201)** in the downstream direction, while still providing sufficient electromotive force to drive charged particulates toward collector electrode **1222.** In general, given the illustrated geometries and equivalent collector potentials, air gap ratios as low as about 1::1 .5 can provide sufficient EHD fluid mover dominance.

[1087] In some embodiments, air gaps are comparable but electrodes are energized to provide greater electric field strength across the first air gap between shared emitter electrode **121 1** and leading collector electrode **1214** and to provide a lesser electric field strength across the second air gap between shared emitter electrode **121 1** and collector electrode **1222.** For example, voltages at respective collector electrodes may be selected to achieve electric field strengths between shared emitter electrode **121 1** and respective collector electrode surfaces such that ion currents of about 300 µA across the first air gap and about 30 µA across the second air gap are provided. Such ion current ratios, when biased in favor of the EHD fluid mover, are typically to provide dominant net fluid flow **(1201)** in the downstream direction, while still providing sufficient electromotive force to drive charged particulates toward collector electrode **1222.** In general, given geometries such as illustrated but with equivalent air gaps, ion current ratios greater than about 2::1 , but less than about 20::1 , provide sufficient EHD fluid mover dominance, while still achieving suitable collection efficiencies given flow rates, particle sizes and particulate loads characteristic of typical implementations and operating environments.

[1088] **FIGS. 14A, 14B** and **14C** depict respective views of still further embodiments in which a thermal management assembly includes an electrostatic precipitator portion configured as an upstream pre-filter for an EHD fluid mover. **FIG. 14B** depicts a variation in which a repelling electrode is employed, while **FIG. 14C** depicts a perspective view consistent with the arrangement of **FIG. 14A.** As with the embodiment(s) previously described with respect to thermal management assembly **1200** (recall **FIGS. 12A** and **12B),** thermal management assembly **1400** includes a shared emitter electrode (here emitter electrode **1411)** that supplies ion current to respective collector electrodes of electrostatic precipitator **1420** and EHD fluid mover **1410.** Collector electrodes **1414** of EHD fluid mover **1410** are analogous to those previously explained relative to **FIG. 12A,** and as before, a fluid inflow (typically air) transits a collector electrode **1422** positioned at a ventilation boundary. In general, collector electrode **1422** may be formed as an electrostatically smooth mesh, grid or grille with perforations or slots to allow fluid to transit therethrough or as an ion collection surface proximate to such a mesh, grid or grille.

[1089] In some cases, the illustrated electrode geometry facilitates an extremely low-profile design in which closely spaced collector electrodes **1414** of EHD fluid **1410** mover allow thermal management assembly **1400** to contribute less than about 2-3 mm to stacking height of components within an enclosure. As one example, the illustrated electrode geometry allows a flow path in which flow **1401** is motivated between ventilation boundaries (IN and OUT) positioned at opposing-ends (or sides) of an enclosure. Of course, persons of skill in the art having benefit of the present disclosure will appreciate that flow paths may include a turn or turns (e.g., a 90 degree turn to a sidewall or 180 degree "U" turn) and/or more complex ducting, if desired, of varied lengths between upstream collector electrode **1422** of electrostatic precipitator **1420** and EHD fluid mover **1410.** In some embodiments, collector electrode **1422** may be positioned at (or adjacent) a convenient bottom-, top-, front- or back-surface inlet ventilation boundary.

[1090] In some implementations in accord with **FIG. 14A** or **14B,** ESP pre-filtered, EHD fluid accelerator-motivated air flows past constituent fins **1431** of heat transfer surfaces **1430.** As with other embodiments described herein, EHD fluid mover **1410** and ESP **1420** portions of the thermal management assembly may optionally include an interposed repelling electrode **1441** such as illustrated in **FIG. 14B.** With or without a repelling electrode, shared emitter electrode **1411** generates a flux of ions from which a generally *greater* portion are accelerated downstream toward collector electrodes **1414** and from which a generally *lesser* portion travel or migrate in a counter flow direction, colliding with and charging particulates entrained in the fluid flow. The charged particulates are, in turn, electrostatically motivated in a counter flow direction generally consistent with arrow **1402,** back toward exposed surfaces of collector electrode **1422** where they typically adhere. While a repelling electrode (such as repelling electrode **1441)** may contribute to the disparity between downstream and counterflow (i.e., upstream) ion fluxes, so to may dimensional factors and/or voltages established between respective electrodes of the electrostatic precipitator **1420** and EHD fluid mover **1410** portions during operation.

[1091] **FIG. 7** depicts a side cross-sectional view consistent with still another thermal management system embodiment in which electrostatic precipitator elements are ganged and provided in an upstream pre-filter configuration. Corresponding repelling electrodes are also provided. Emitter electrode **711** and collector electrodes **714** (including leading surfaces **712** thereof) are again energizable in accord with aforementioned principles of electrohydrodynamic (EHD) fluid acceleration to act as an EHD fluid mover (here, EHD fluid mover **710).** As before, separate (or separable) heat transfer surfaces **730** and EHD collector electrode surfaces **714** allow respective surfaces to be conditioned or otherwise specialized to their respective roles. Likewise, both the number of collector electrodes and the profile of leading surfaces presented thereby are matters of design choice and subject to variation.

[1092] Though illustrated in a ganged configuration, operation of ESP 720 portion and, more particularly, operation of its constituent emitter (721) and collector (722) electrode surfaces as a pre-filter, is analogous to that of the ESP portions and electrodes previously illustrated and described herein. Persons of ordinary skill in the art will readily understand operation of the individual elements of ESP 720 portion based on the illustration and foregoing description. Multiple repelling electrode instances 741 are provided and positioned to disfavor upstream ion flow from emitter electrode 711. In this way, a substantial entirety of the generated ions are driven from emitter electrode 711 toward surfaces of collector electrodes 714, thereby motivating the illustrated net flow 701 in the downstream direction.

[1093] FIG. 8 depicts a side cross-sectional view consistent with still another thermal management system embodiment in which an electrostatic precipitator is provided in an upstream pre-filter configuration. As in previously illustrated embodiments, close proximity of EHD fluid mover and ESP pre-filter portions is facilitated using a repelling electrode positioned therebetween, although (again as before) based on the description herein persons of ordinary skill in the art will appreciate variations in which a shared emitter is employed and dimensional (e.g., air gap) and/or voltage ratios selections provide dominant net fluid flow in the downstream direction, while still providing sufficient electromotive force to drive charged particulates upstream toward collector electrodes.

[1094] Collector electrodes 814 are again separate (or separable) from heat transfer surfaces 830 and, as before, respective surfaces to be conditioned or otherwise specialized to their respective roles. As before, emitter electrode 811 and collector electrodes 814 (including curved leading surfaces 812 thereof) are again energizable in accord with aforementioned principles of electrohydrodynamic (EHD) fluid acceleration to act as an EHD fluid mover (here, EHD fluid mover 810). In the illustrated embodiment, collector electrodes **814** are generally planar and arrayed in a manner analogous to the heat transfer fins previously described. Although some embodiments in accord with **FIG. 8** may provide substantially equal numbers of heat transfer fins **831** and collector electrodes **814** aligned one behind the other, other embodiments may vary relative numbers and alignment.

[1095] **FIGS. 9A** and **9B** depict respective (and illustrative) voltage source coupling circuits overlaid on a side cross-sectional view of a low-profile variation on the arrangement with repelling electrode illustrated in **FIGS. 6A** and **6B.** Operation of the illustrated configurations, when energized, will be understood based on the prior description. More particularly, **FIG. 9A** depicts a voltage source shared amongst emitter and repelling electrodes, while **FIG. 9B** depicts a configuration in which plural voltage sources are provided to facilitate independent control over the various electrodes.

[1096] Referring first to **FIG. 9A,** emitter electrodes **911** and **921** are both coupled to a terminal of supply **991** and energized to positive high voltage (illustratively +3.5 KV, although specific voltage and, indeed, any supply voltage waveforms may be matters of design choice), while collector electrodes **914** and **922** are respectively coupled to an opposing terminal of supply **991 .** *See* previously incorporated U.S. Patent 6,508,308 for a description of suitable designs for supply **991** . In the illustrated configuration, that opposing terminal (and collector electrodes **914)** are at "ground" potential, while resistive path **992** signifies that collector electrodes **914** and **922** need not operate at the same potential. In some cases or embodiments, it may be desirable to, over time, change voltage between emitter electrode **911** and collector electrodes **922,** such as in correspondence with particulate buildup on collection surfaces. For example, initially, it may be desirable to increase voltage to accommodate voltage drop across accumulated particulate. At some point, accumulated particulate and/or the aforementioned increased voltage may adversely affect sparking and it may be desirable to reduce voltage accordingly.

[1097] In the illustrated configuration, repelling electrode **941** is coupled to the same positive high voltage potential as emitter electrodes **911** and **921**; although, as previously indicated, other designs are possible including a floating repelling electrode without direct connection to the illustrated supply voltage terminal.

[1098] Of course, EHD fluid mover **910** and ESP **920** portions need not share a single supply. Indeed, suitable emitter-to-collector voltages may result from other supply configurations, including separate supplies for EHD fluid mover and ESP portions **(910** and **920).** In this regard, **FIG. 9B** depicts a configuration in which separate voltage sources are provided to facilitate coordinated control over the various electrodes. For example, independently variable sources may allow particularized control over ion currents in EHD fluid mover portion **910** and ESP portions **920.** In some embodiments, independently variable sources may facilitate some of the aforementioned accommodations in ESP portions **920** that may be made in correspondence with accumulated particulate on collector electrodes thereof. In some embodiments, controlled changes to repelling electrode **941** voltage may be used to vary impedance across the air gaps (particularly that between emitter electrode **921** and collector electrodes **922)** thereby controlling a ratio of ion currents in the respective portions.

[1099] **FIG. 10** depicts a side cross-sectional view of a further variation with a shared emitter electrode, in which an illustrative voltage source coupling circuit is again overlaid. Operation of the illustrated configuration, when energized, will be understood with reference to the prior description of **FIGS. 4A** and **4B.**

[1100] Referring to **FIG. 10,** shared emitter electrode **1011** is coupled to a terminal of supply **1091** and energized to positive high voltage (illustratively +3.5 KV, although specific voltage and, indeed, any supply voltage waveforms may be matters of design choice), while collector electrode **1014** is coupled to an opposing terminal of supply **1091**. Collector electrodes **1022** are coupled to a supply terminal (depicted illustratively as a lesser included supply **1093)**

that results in a lesser voltage across the air gap between shared emitter electrode **1011** and collector electrodes **1022.** As before, in some cases or embodiments, it may be desirable to, over time, change voltage between emitter and collector electrodes (here, emitter electrode **1011** and collector electrodes **1022)** in correspondence with particulate buildup on collection surfaces. In the illustrated embodiment, field shaping is achieved (without use of an interposed repelling electrode) based at least in part on the greater and lesser voltages which energize EHD fluid mover **1010** and ESP **1020** portions, respectively. Collector electrodes **1014** are at "ground" potential in the illustrated configuration. Of course, other configurations may place other surfaces (e.g., collector electrodes **1022)** at "ground" potential, if desirable.

[1101] As previously described, some shared emitter embodiments may achieve desired field shaping without substantial variation of the respective collector electrode voltages. In such embodiments, collector electrode **1014** (of EHD fluid mover **1010)** and collector electrodes **1022** (of ESP **1020)** may be coupled to like supply voltages. As before, previously incorporated US Patent 6,508,308 includes a description of suitable designs for supply **1091, 1093.** Finally, EHD fluid mover **1010** and ESP **1020** portions need not share a single, multi-tap supply. Indeed, suitable emitter-to-collector voltages may result from other supply configurations, including separate supplies for EHD fluid mover and ESP portions **(1010** and **1020)** which provide the desired greater and lesser voltages across respective air gaps.

[1102] **FIG. 11** depicts a consumer electronics device **1101** configuration in which a display (typically of a touch screen variety) dominates a major surface expanse and in which low-profile and/or flexible form factor thermal management system **1102** embodiments may provide active cooling and/or moderation of spatially varied thermal loads. Such loads may include processor (e.g., CPU or GPU) integrated circuits, radio-frequency (RF) or optical transceiver electronics and/or display illumination devices. In general, any of the thermal management systems embodiments and design variations described herein may be integrated in consumer electronics device **1101** as thermal management system **1102.** In the illustration of **FIG. 11,** air flow motivated by and through thermal management system **1102** enters and exits through respective side-edge ventilation boundaries. Although **FIG. 11** illustrates a particular opposing side-edge configuration, other flow topologies and ventilation boundary configurations may be employed consistent with thermal, physical and even aesthetic design factors.

[1103] **FIG. 13** is additional consumer electronics device illustration in which low-profile and/or flexible form factor thermal management system embodiments such as illustrated in **FIGS. 12A** and **12B** may provide active cooling and/or moderation of spatially varied thermal loads. In the illustration of **FIG. 13,** air flow motivated by and through thermal management system **1302** enters and exits through respective bottom surface and edge-positioned ventilation boundaries. As before, other flow topologies and ventilation boundary configurations may be employed consistent with thermal, physical and even aesthetic design factors.

Other Embodiments

[1104] While the techniques and implementations of the EHD fluid mover and ESP pre-filter portions discussed herein have been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the appended claims. In addition, many modifications may be made to adapt a particular situation or material to the teachings without departing from the essential scope thereof. Therefore, the particular embodiments, implementations and techniques disclosed herein, some of which indicate the best mode contemplated for carrying out these embodiments, implementations and techniques, are not intended to limit the scope of the appended claims.

WHAT IS CLAIMED IS:

1. An apparatus comprising:

a fluid flow path;

an electrohydrodynamic (EHD) fluid mover (310, 410, 510, 610, 710, 810, 910, 1010, 1210, 1410) introduced in the fluid flow path and operable to motivate fluid flow therealong; and

an electrostatic precipitator (320, 420, 520, 620, 720, 820, 920, 1020, 1220, 1420) preceding the EHD fluid mover in the fluid flow path, the electrostatic precipitator operable to prevent a substantial amount of particulate matter otherwise entrained in the fluid flow from reaching at least collector electrode surfaces of the EHD fluid mover.

2. The apparatus of claim 1, further comprising:

heat transfer surfaces (330, 430, 530, 630, 730, 830, 930, 1030, 1230, 1430) introduced in the fluid flow path downstream of the electrostatic precipitator to transfer heat to or from the fluid flow.

3. The apparatus of claim 2,

wherein at least a substantial portion of the heat transfer surfaces are downstream of an emitter electrode of the EHD fluid mover.

4. The apparatus of claim 2,

wherein at least a substantial portion of the heat transfer surfaces are downstream of the collector electrode surfaces of the EHD fluid mover.

5. The apparatus of claim 3,

wherein, during operation, at least a leading portion of the heat transfer surfaces constitute the collector electrode surfaces of the EHD fluid mover.

6. The apparatus of claim 1,

the EHD fluid mover configured to generate, when energized, net ion flow in a primary direction; and

the electrostatic precipitator configured to generate, when energized, ion flow in directions substantially unaligned with the primary direction.

7. The apparatus of claim 1,

wherein collector electrode surfaces (331, 431, 531, 614, 714, 814, 914, 1014, 1214, 1414) of the EHD fluid mover and of the electrostatic precipitator are respectively positioned such that, when energized, magnitude of ion current to collector surfaces of the EHD fluid mover substantially exceeds that to the collector surfaces (322, 422, 522, 622, 722, 822, 922, 1022, 1222, 1422) of the electrostatic precipitator.

8. The apparatus of claim 1,

wherein collector electrode surfaces (331, 431, 531, 614, 714, 814, 914, 1014, 1214, 1414) of the EHD fluid mover and of the electrostatic precipitator are respectively coupled between supply voltages such that, when energized, magnitude of ion current to collector surfaces of the EHD fluid mover substantially exceeds that to the collector surfaces (322, 422, 522, 622, 722, 822, 922, 1022, 1222, 1422) of the electrostatic precipitator.

9. The apparatus of claim 1,

wherein ion current to respective collector electrode surfaces of the EHD fluid mover and of the electrostatic precipitator is from one or more emitter electrodes energized to positive high voltage; and

wherein the collector electrode surfaces of the EHD fluid mover and the collector electrode surfaces of the electrostatic precipitator are each coupled to ground.

10. The apparatus of claim 1,

wherein ion current to respective collector electrode surfaces of the EHD fluid mover and of the electrostatic precipitator is from one or more emitter electrodes energized to positive high voltage;

wherein the collector electrode surfaces of the EHD fluid mover are coupled to ground; and

wherein the collector electrode surfaces of the electrostatic precipitator are coupled to provide an operating voltage off of ground.

11. The apparatus of claim 10,

wherein the operating voltage for the collector electrode surfaces of the electrostatic precipitator is variable and thereby accommodates accumulation of particulate matter thereon.

12. The apparatus of claim 1, further comprising:

at least some emitter electrode surfaces that exhibit surface features sized or shaped to, when energized, generate ions through a corona discharge effect.

13. The apparatus of claim 1,

wherein collector electrode surfaces of the EHD fluid mover and of the electrostatic precipitator are coupled to ground.

14. The apparatus of claim 1,

wherein at least some collector electrode surfaces (1222, 1422) of the electrostatic precipitator are formed as a mesh, grid, or grille with perforations or slots to allow the fluid flow to transit therethrough.

15. The apparatus of claim 1,

the EHD fluid mover and electrostatic precipitator having separate emitter electrode surfaces,

wherein the emitter electrode surfaces (311, 411, 511, 611, 711, 811, 911, 1011, 1211, 1411) of the EHD fluid mover are positioned relative to the collector electrode surfaces thereof to, when energized, generate a net ion flow in substantial alignment with a direction of the motivated fluid flow, and

wherein the emitter electrode surfaces (321 , 411, 521 , 621 , 721 , 821 , 921 , 1011, 1211, 1411) of the electrostatic precipitator are positioned relative to collector electrode surfaces of the electrostatic precipitator to, when energized, generate a substantial majority of ion flows in one or more directions that are substantially orthogonal to the motivated fluid flow.

16. The apparatus of claim 15, further comprising:

one or more repelling electrodes (341 , 541 , 641 , 741 , 841 , 941 , 1441), wherein at least some of the surfaces thereof are positioned between the emitter electrode surfaces of the EHD fluid mover and upstream collector electrode surfaces of the electrostatic precipitator.

17. The apparatus of claim 16,

wherein at least some of surfaces of the one or more repelling electrodes are positioned between the emitter electrode surfaces of the electrostatic precipitator and downstream collector electrode surfaces of the EHD fluid mover.

18. The apparatus of claim 1,

the electrostatic fluid mover and electrostatic precipitator sharing at least one emitter electrode,

wherein, when energized, magnitude of ion current from the emitter electrode to collector surfaces of the EHD fluid mover substantially exceeds that to collector surfaces of the electrostatic precipitator.

19. The apparatus of claim 18,

wherein ion current to the collector surfaces of the EHD fluid mover is at least 10 times greater than that to the collector surfaces of the electrostatic precipitator.

20. A method comprising:

motivating fluid flow using an electrohydrodynamic (EHD) fluid mover (310, 410, 510, 610, 710, 810, 910, 1010, 1210, 1410) introduced in a fluid flow path; and

upstream of the electrohydrodynamic (EHD) fluid mover, electrostatically precipitating from the fluid flow a substantial amount of particulate matter otherwise entrained therein and thereby preventing the electrostatically precipitated particulate matter from reaching collector electrode surfaces of the EHD fluid mover.

21. The method of claim 20, further comprising:

transferring heat to or from the fluid flow using heat transfer surfaces (330, 430, 530, 630, 730, 830, 930, 1030, 1230, 1430) introduced in the fluid flow path downstream of the electrostatic precipitating.

22. The method of claim 20, further comprising:

energizing at least a first emitter electrode (311, 511, 611, 711, 811, 911) to generate ions that, in a first portion of an electric field, are driven toward collection surfaces of the electrohydrodynamic (EHD) fluid mover; and

energizing at least a second emitter electrode (321, 521, 621, 721, 821, 921), upstream of the first emitter electrode, to generate ions that, in a second portion of the electric field, are driven toward collection surfaces of an electrostatic precipitator.

23. The method of claim 22, further comprising:
repelling at least some of the ions generated at the first emitter electrode away from paths toward collection surfaces of an electrostatic precipitator.

24. The method of claim 20, further comprising:
energizing a shared emitter electrode (411, 1011, 1211, 1411) to generate ions that, in a first portion of an electric field, are driven toward collection surfaces of the electrohydrodynamic (EHD) fluid mover and which, in a second portion of the electric field, are driven toward collection surfaces of an electrostatic precipitator.

25. The method of claim 24,
wherein positioning of the respective collection surfaces of the EHD fluid mover and of the electrostatic precipitator, relative to the shared emitter electrode, is such that when the shared emitter is energized, magnitude of ion current to the collection surfaces of the EHD fluid mover substantially exceeds that to the collection surfaces of the electrostatic precipitator.

26. The method of claim 24, further comprising:
coupling respective collection surfaces of the EHD fluid mover and of the electrostatic precipitator between supply voltages such that, when the shared emitter is energized, magnitude of ion current to collection surfaces of the EHD fluid mover substantially exceeds that to the collection surfaces of the electrostatic precipitator.

27. An apparatus comprising:
an enclosure;
a thermal management assembly (300, 400, 500, 600, 700, 800, 1200, 1400) for use transferring heat to or from one or more devices

within the enclosure, the thermal management assembly defining a flow path for conveyance of air between ventilated boundary portions of the enclosure, the thermal management assembly including an electrohydrodynamic (EHD) fluid mover (310, 410, 510, 610, 710, 810, 910, 1010, 1210, 1410) introduced in the flow path and operable to motivate air flow past heat transfer surfaces thermally coupled to the one or more devices within the enclosure; and

an electrostatic precipitator (320, 420, 520, 620, 720, 820, 920, 1020, 1220, 1420) preceding the EHD fluid mover in the flow path, the electrostatic precipitator operable to prevent a substantial amount of particulate matter otherwise entrained in the air flow from reaching the EHD fluid mover.

28. The apparatus of claim 27, further comprising:

a repelling electrode (341, 541, 641, 741, 841, 941, 1441) between an emitter electrode of the EHD fluid mover and collection surfaces of the electrostatic precipitator.

29. The apparatus of claim 27, further comprising:

a collector electrode (1222, 1422) of the electrostatic precipitator formed and positioned at an inlet one of the ventilation boundaries to allow the air flow to transit therethrough.

30. The apparatus of claim 27,

configured to cool the one or more devices; and

embodied as one or more of a handheld mobile phone or personal digital assistant; a laptop, netbook, pad-type or desktop computer; a digital book reader, media player or gaming device; and a projector, television or video display panel.

31. The apparatus of claim 27, configured to provide ambient heating or cooling in a volume external to the enclosure.

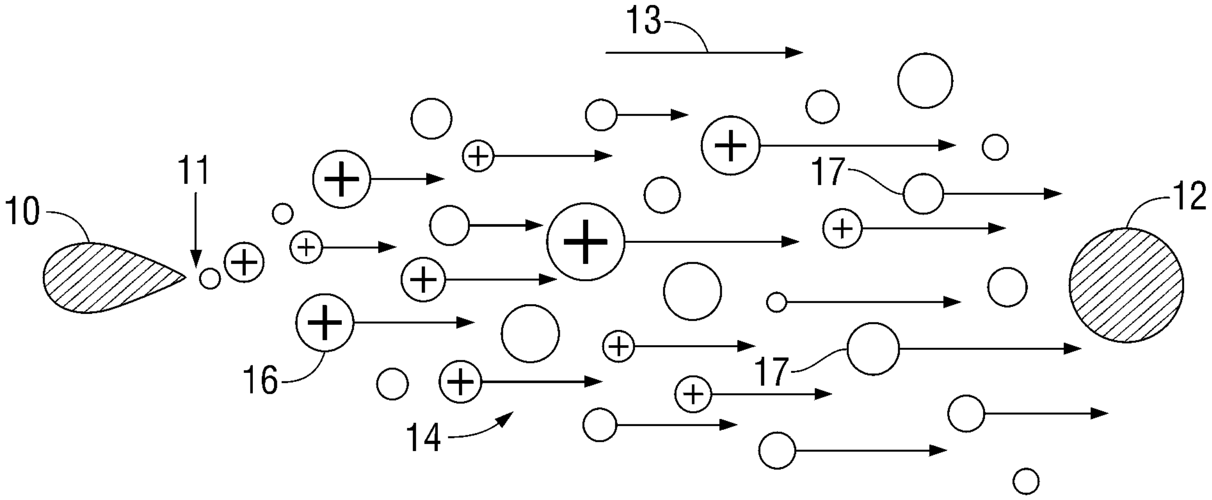

FIG. 1

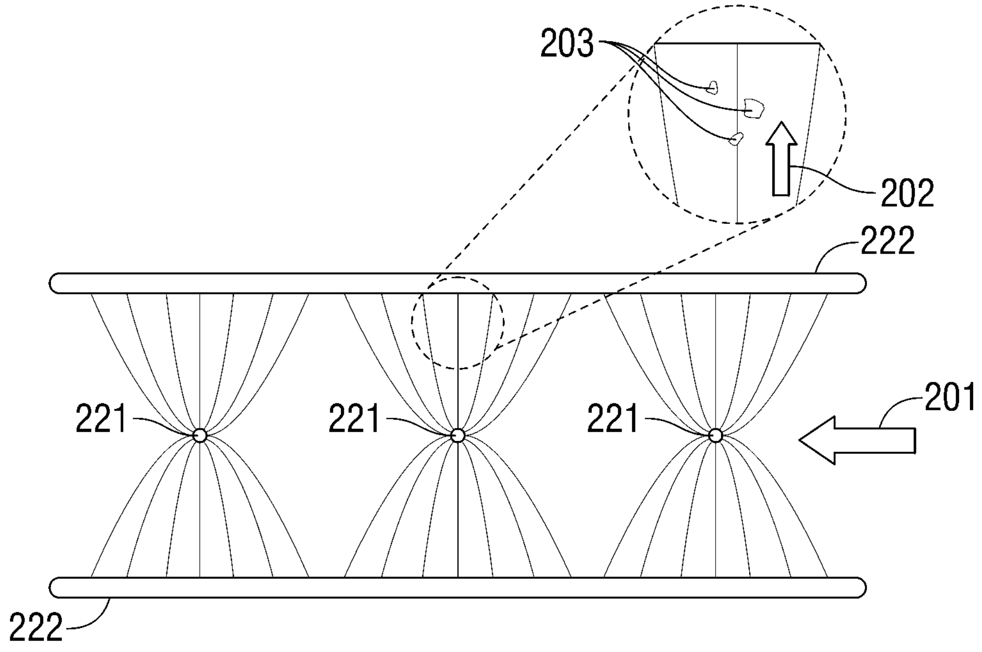

FIG. 2

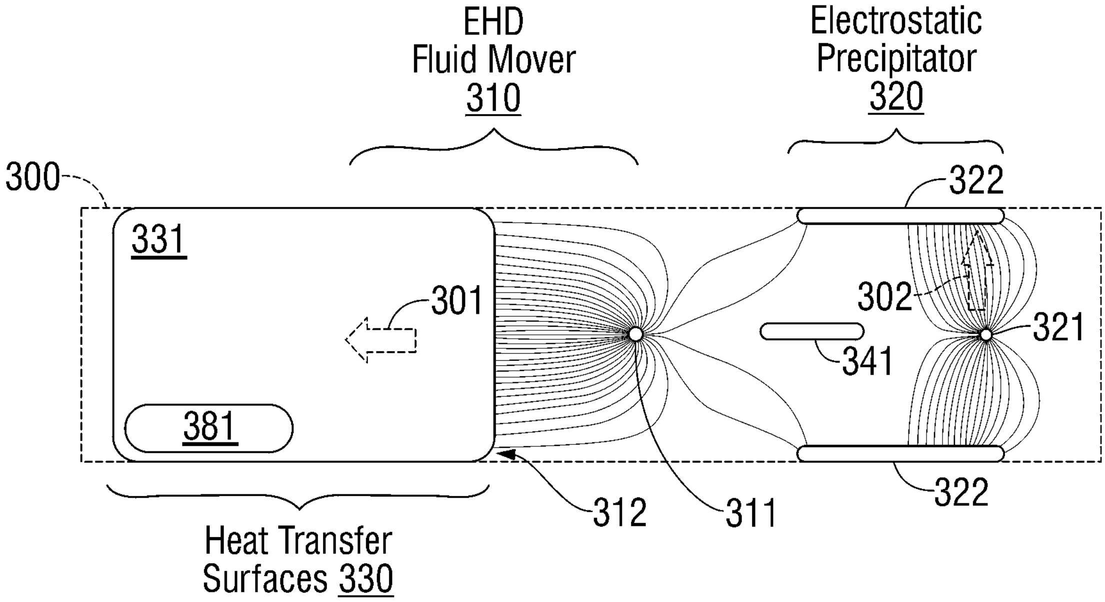
EHD
Fluid Mover
310
Electrostatic
Precipitator
320
300
322
331
301
302
321
341
381
322
312
311
Heat Transfer
Surfaces 330

FIG. 3A

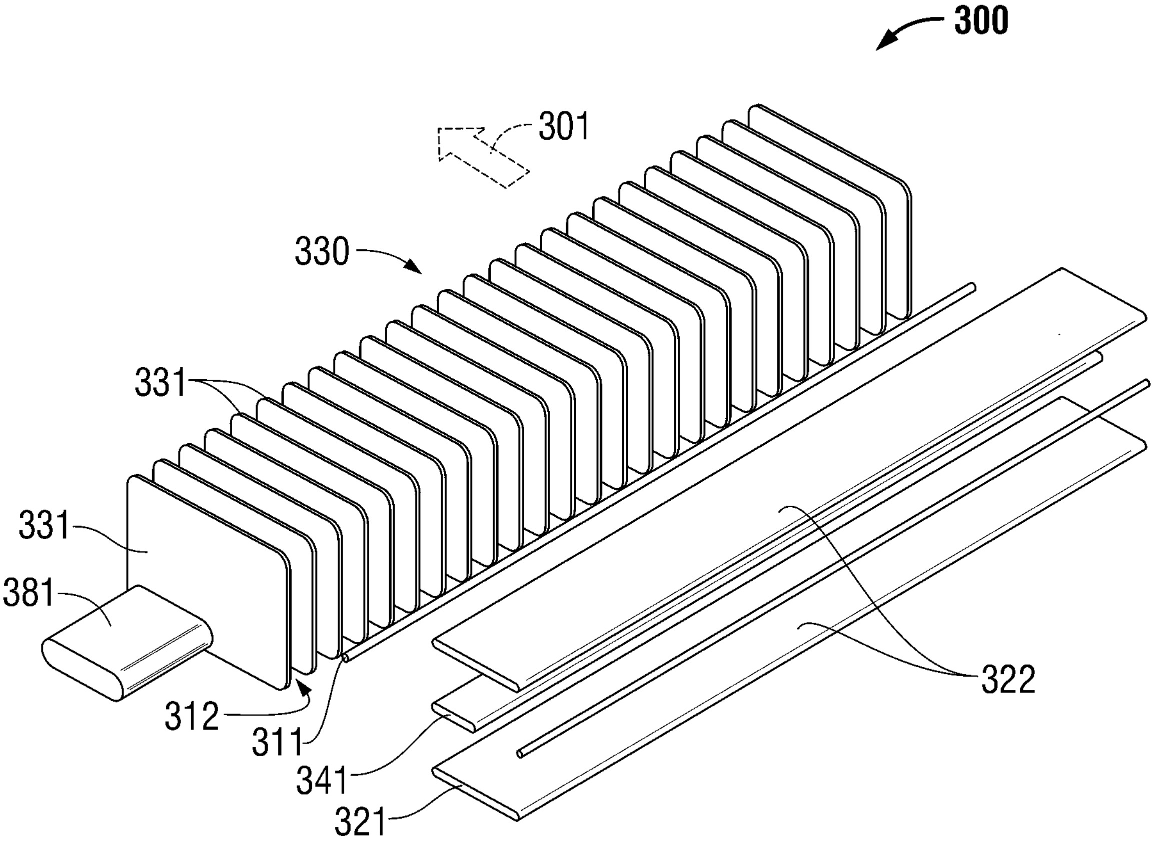
300
301
330
331
331
381
312
311
341
321
322

FIG. 3B

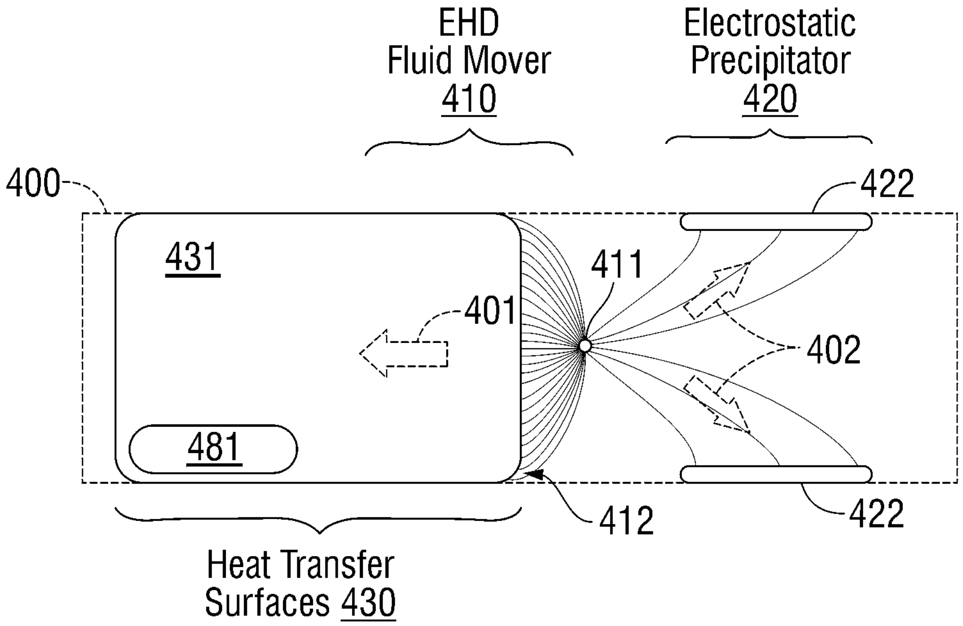
EHD
Fluid Mover
410
Electrostatic
Precipitator
420
400
422
431
411
401
402
481
412
422
Heat Transfer
Surfaces 430

FIG. 4A

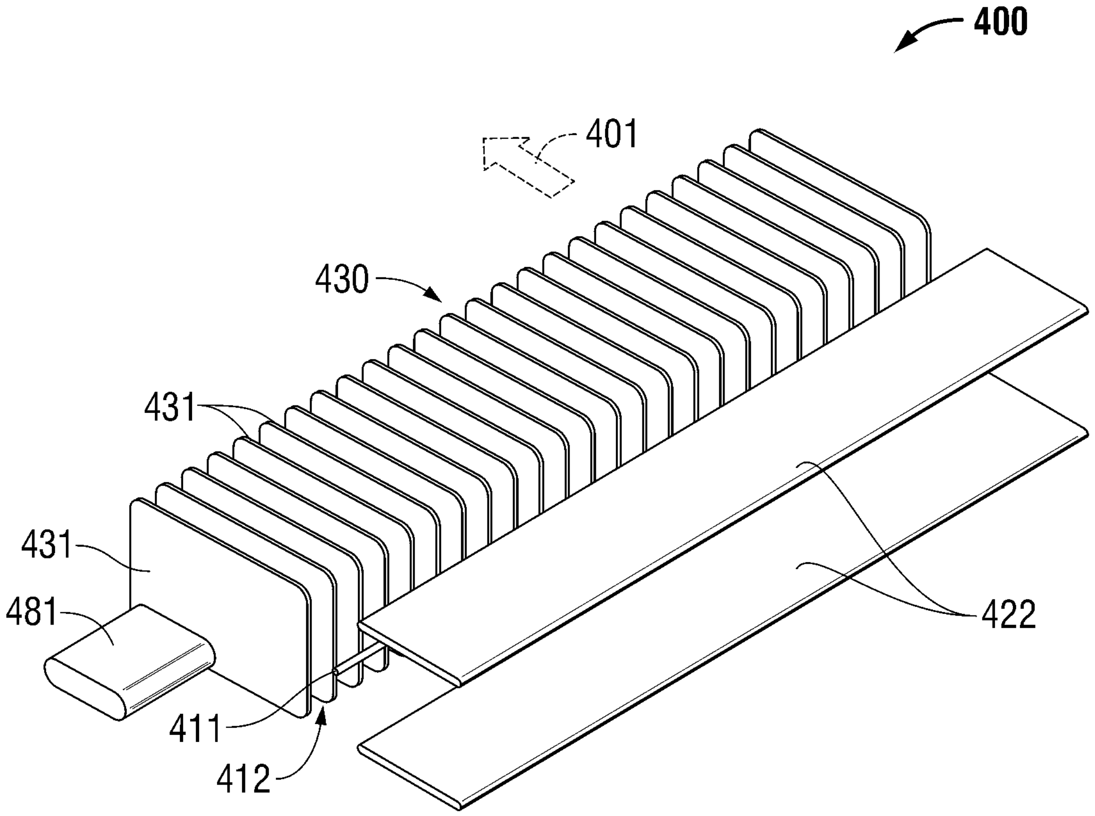
400
401
430
431
431
481
411
412
422

FIG. 4B

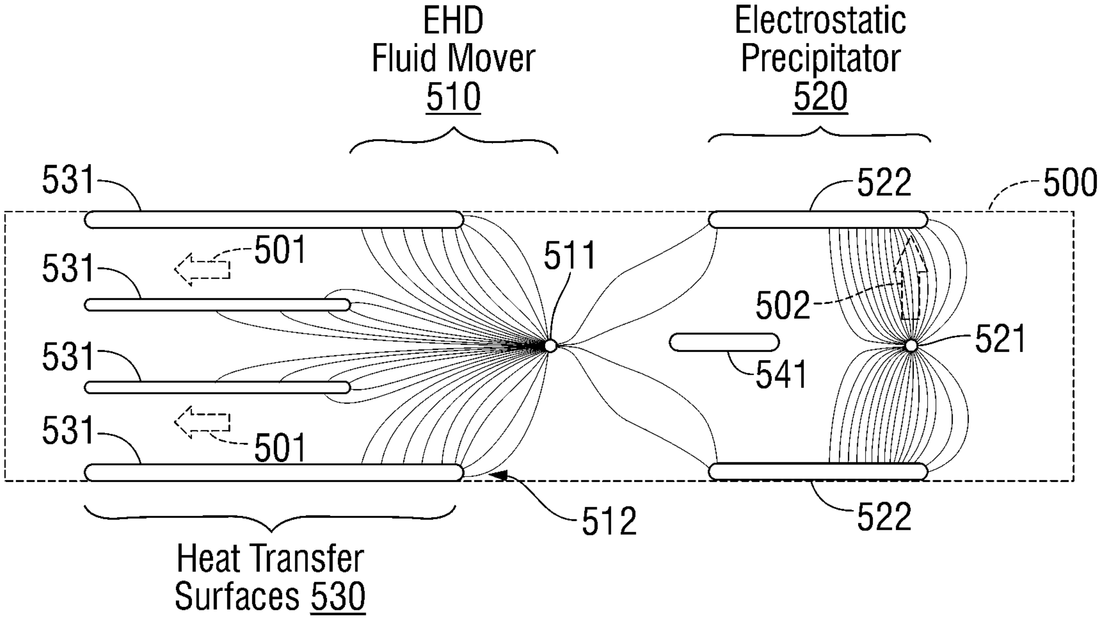
EHD
Fluid Mover
510
Electrostatic
Precipitator
520
531
531
531
531
501
501
511
502
521
522
522
541
512
500
Heat Transfer
Surfaces 530

FIG. 5A

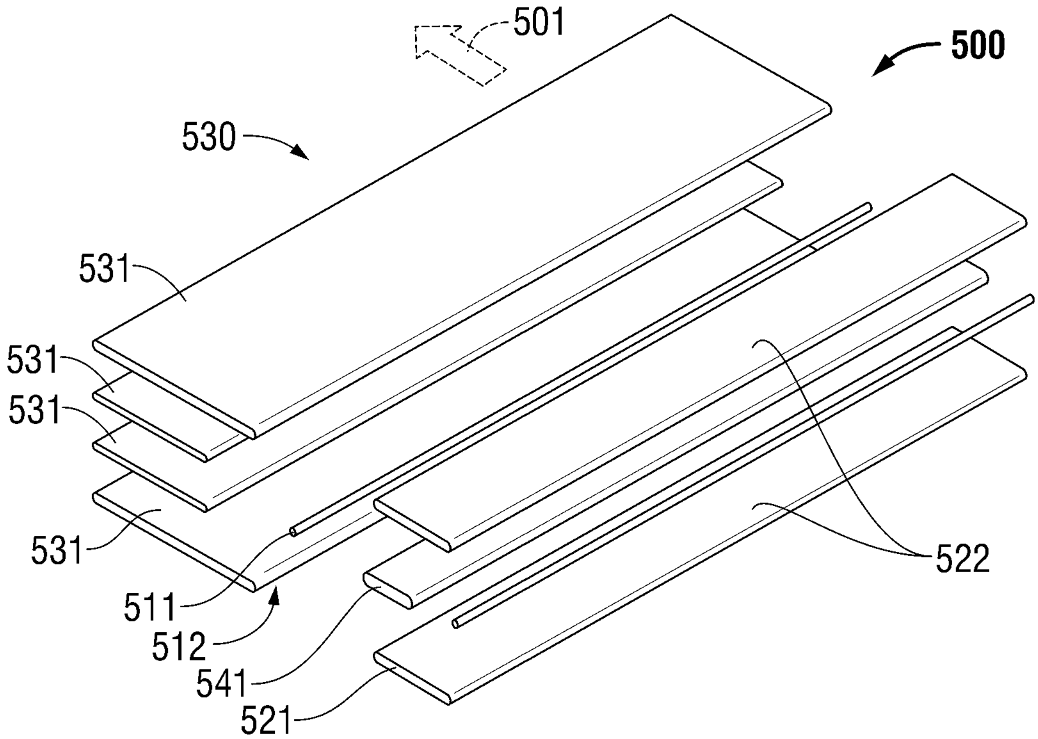
501
500
530
531
531
531
531
511
512
541
521
522

FIG. 5B

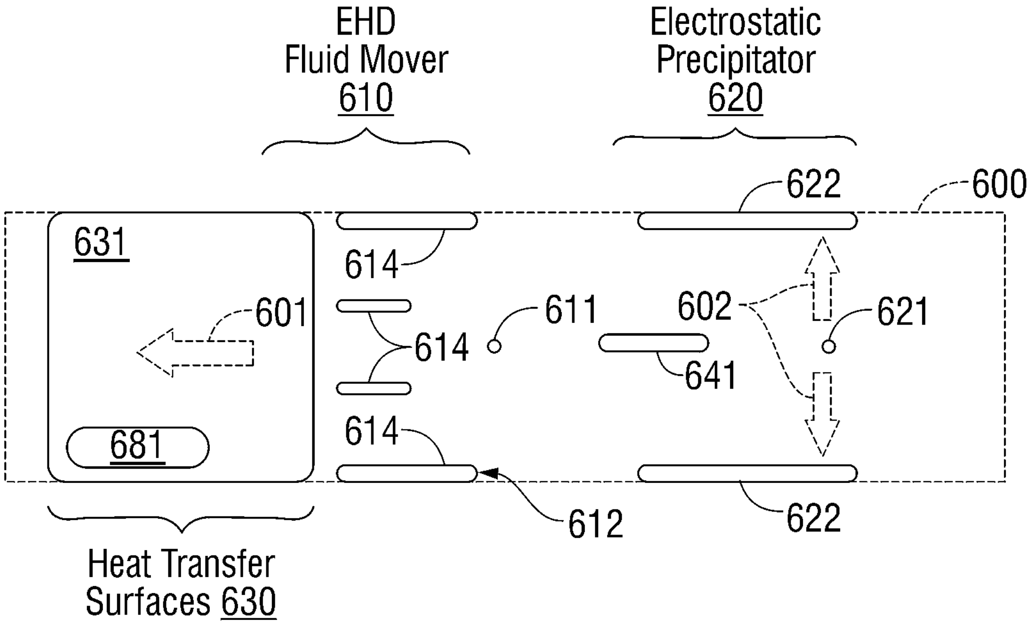
EHD
Fluid Mover
610
Electrostatic
Precipitator
620
622
600
631
614
601
614
611
602
621
641
681
614
612
622
Heat Transfer
Surfaces 630

FIG. 6A

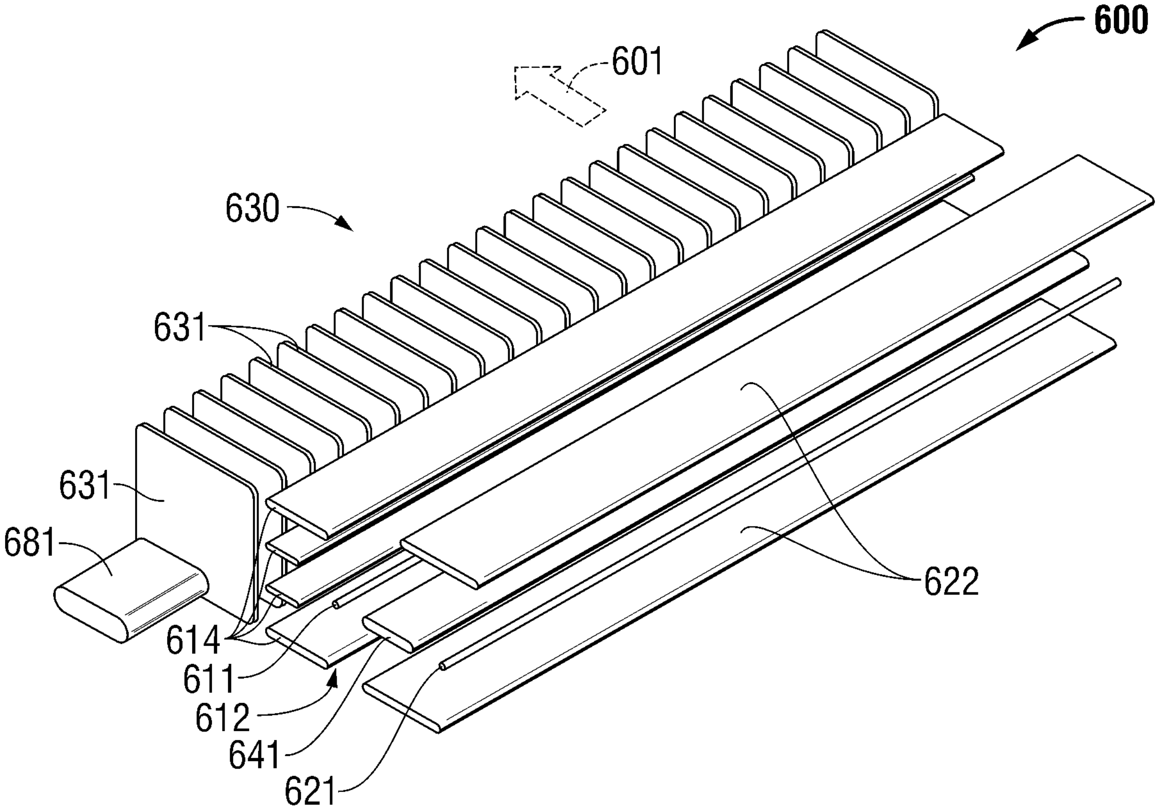
600
601
630
631
631
681
614
611
612
641
621
622

FIG. 6B

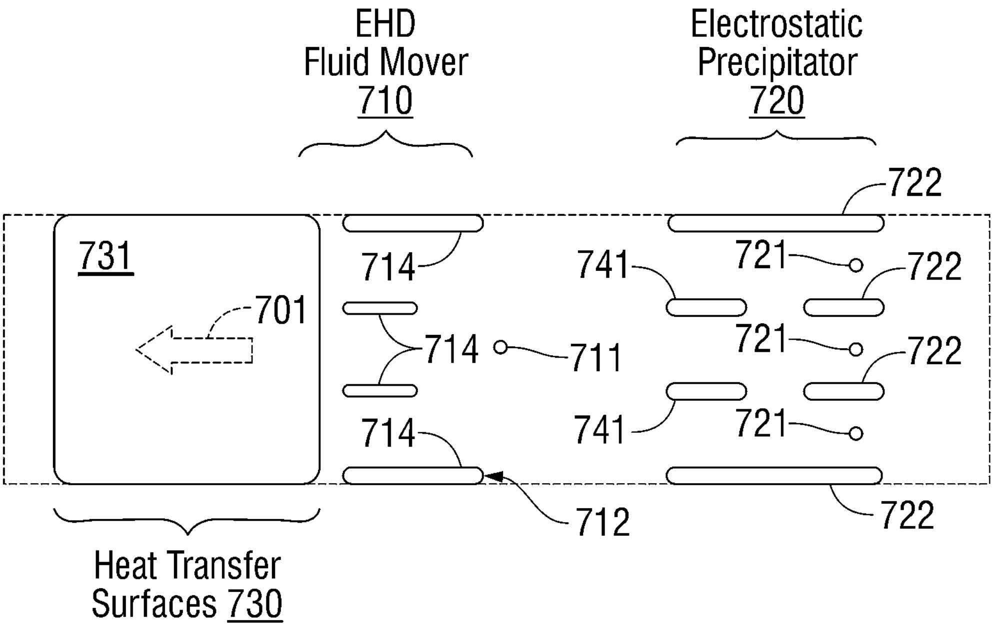
EHD
Fluid Mover
710
Electrostatic
Precipitator
720
722
731
714
741
721
722
701
714
711
721
722
741
721
714
712
722
Heat Transfer
Surfaces 730

FIG. 7

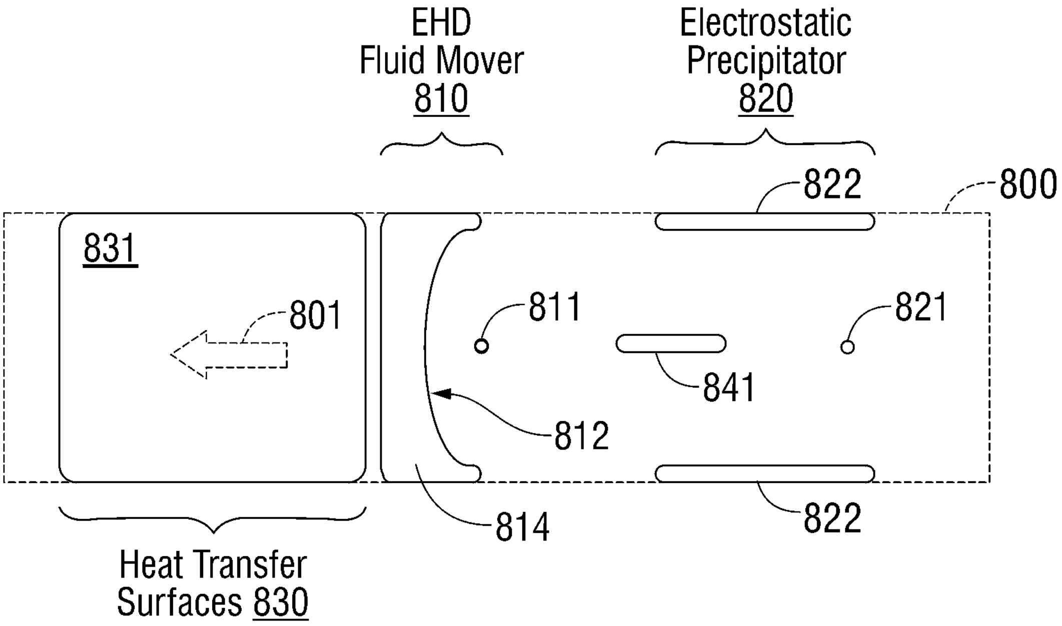
EHD
Fluid Mover
810
Electrostatic
Precipitator
820
822
800
831
801
811
821
841
812
814
822
Heat Transfer
Surfaces 830

FIG. 8

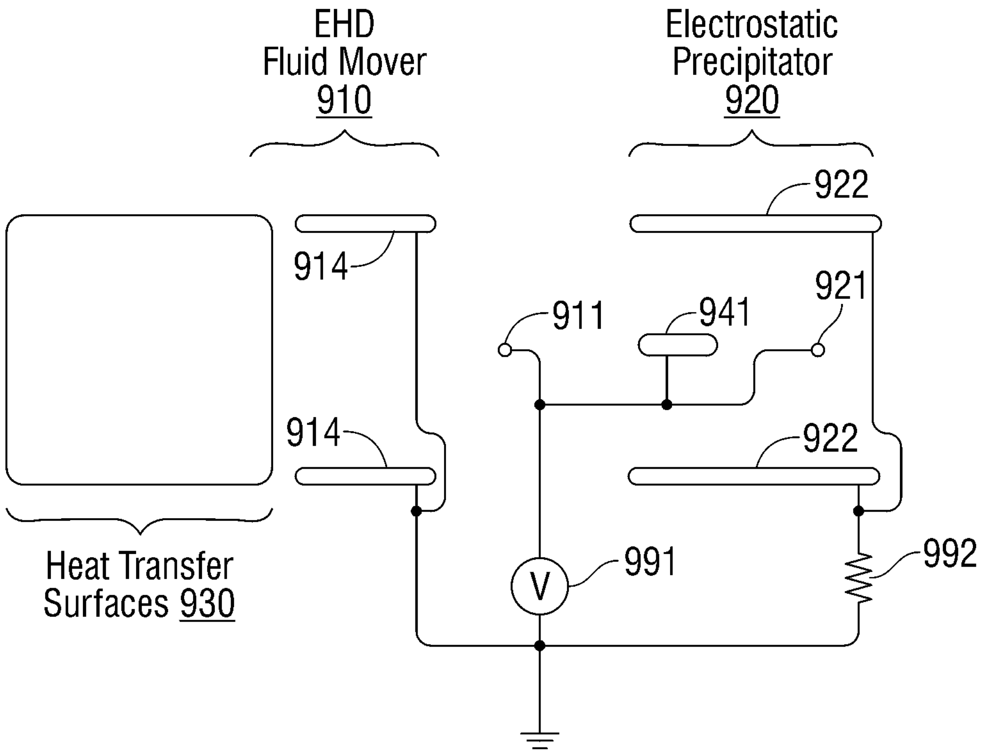
EHD
Fluid Mover
910
Electrostatic
Precipitator
920
922
914
921
911
941
914
922
991
992
V
Heat Transfer
Surfaces 930

FIG. 9A

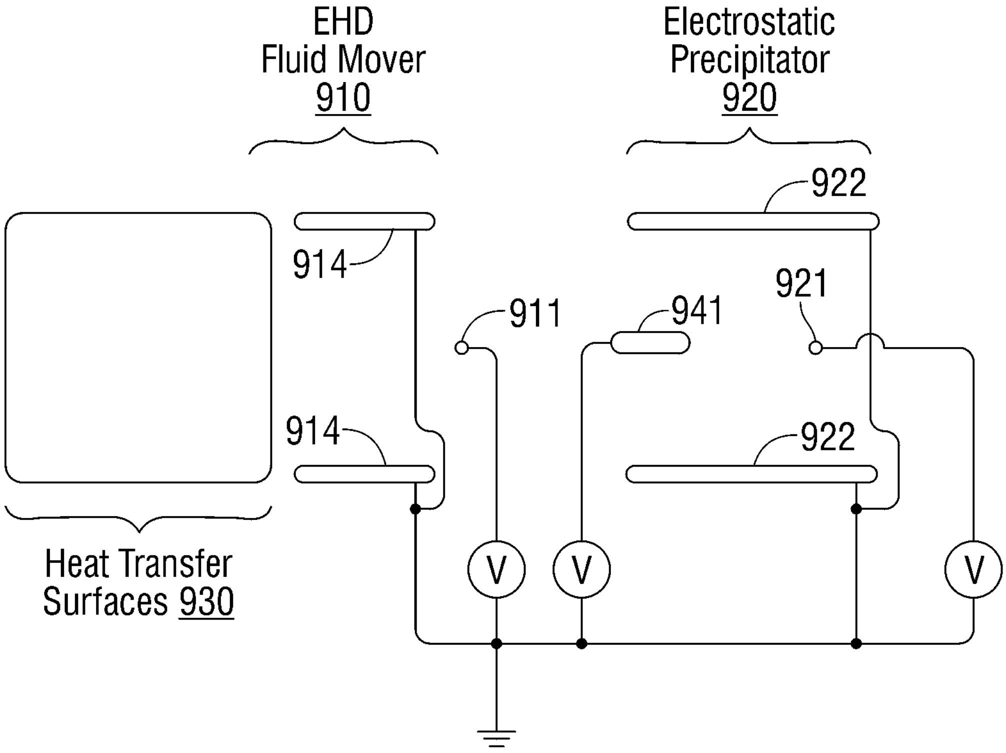
EHD
Fluid Mover
910
Electrostatic
Precipitator
920
922
914
921
911
941
914
922
V
V
V
Heat Transfer
Surfaces 930

FIG. 9B

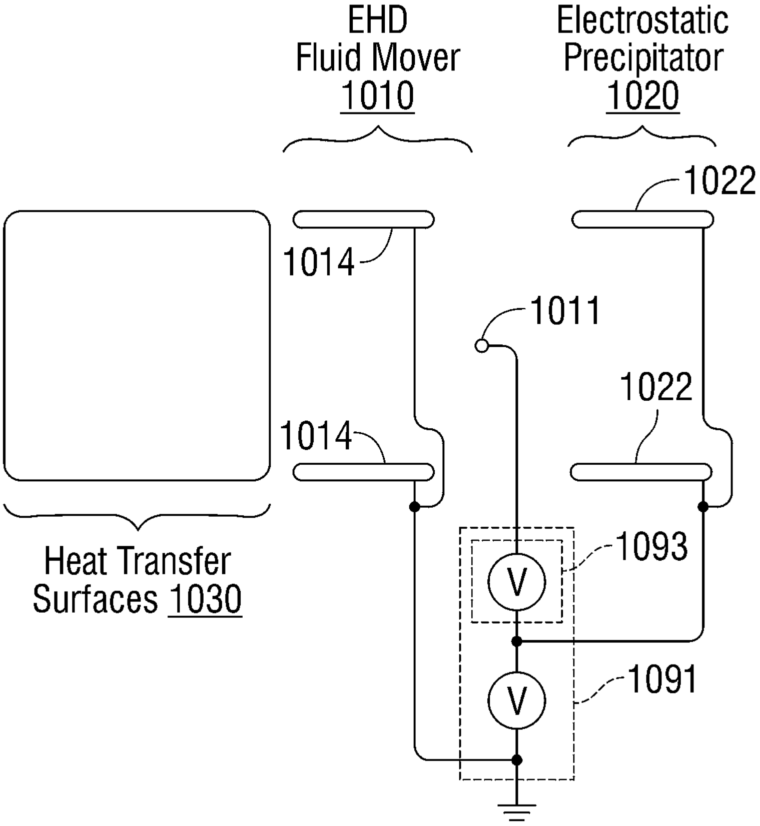
EHD
Fluid Mover
1010
Electrostatic
Precipitator
1020
1022
1014
1011
1022
1014
1093
1091
V
V
Heat Transfer
Surfaces 1030

FIG. 10

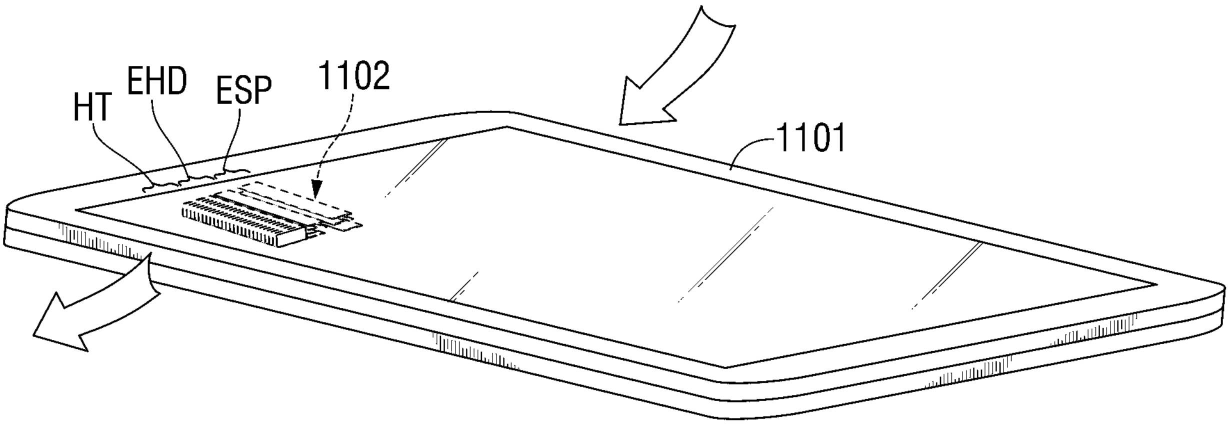
HT
EHD
ESP
1102
1101

FIG. 11

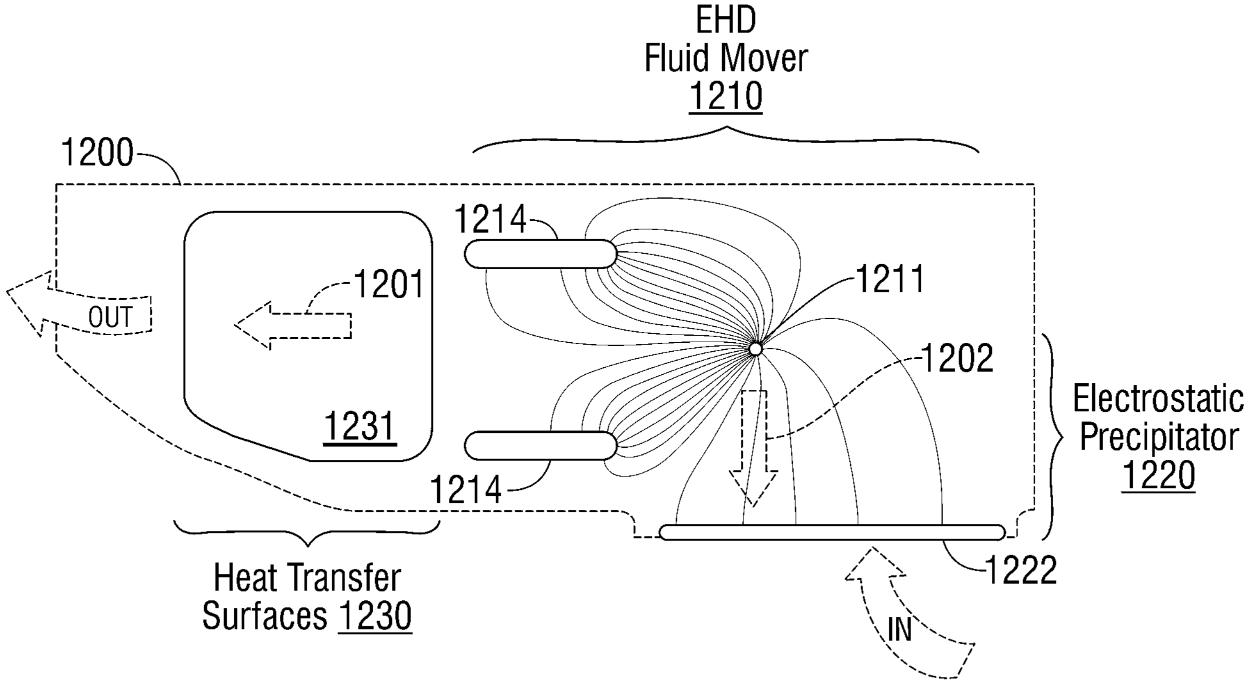

FIG. 12A

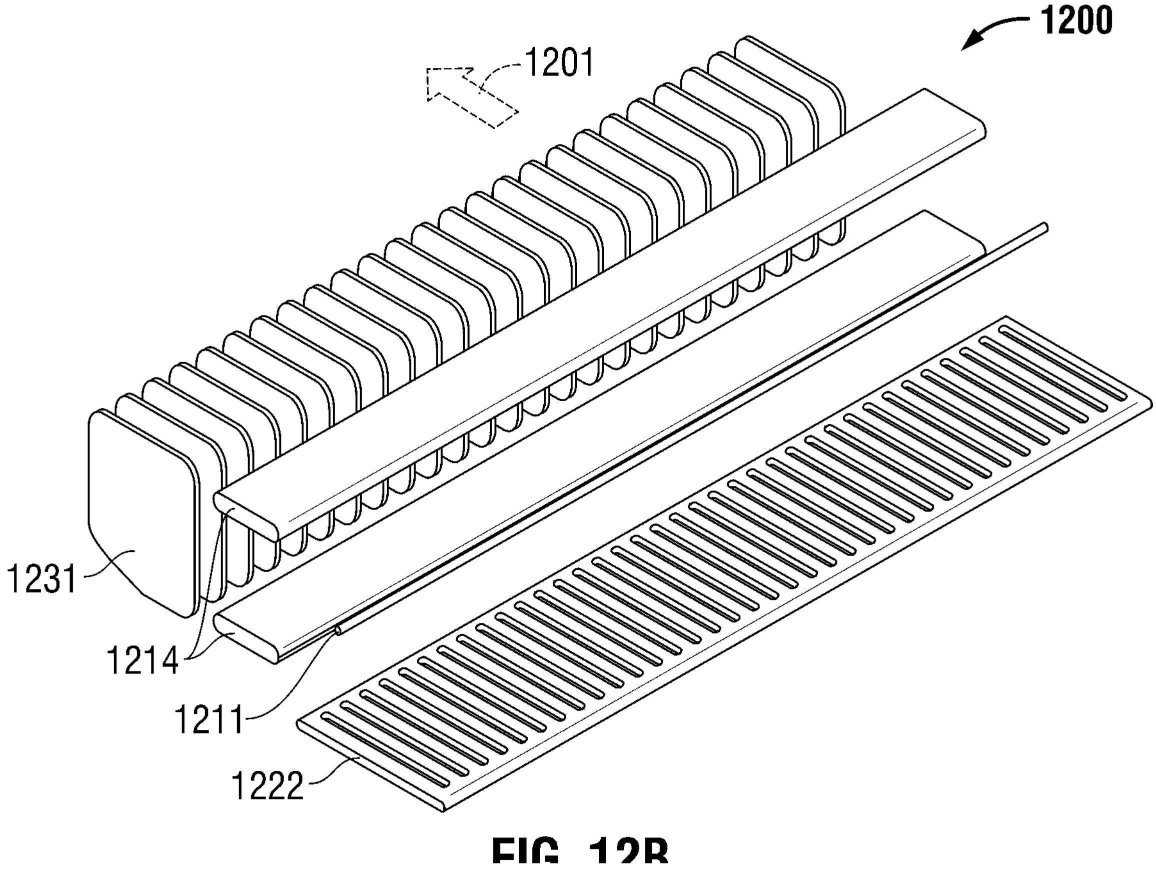

FIG. 12B

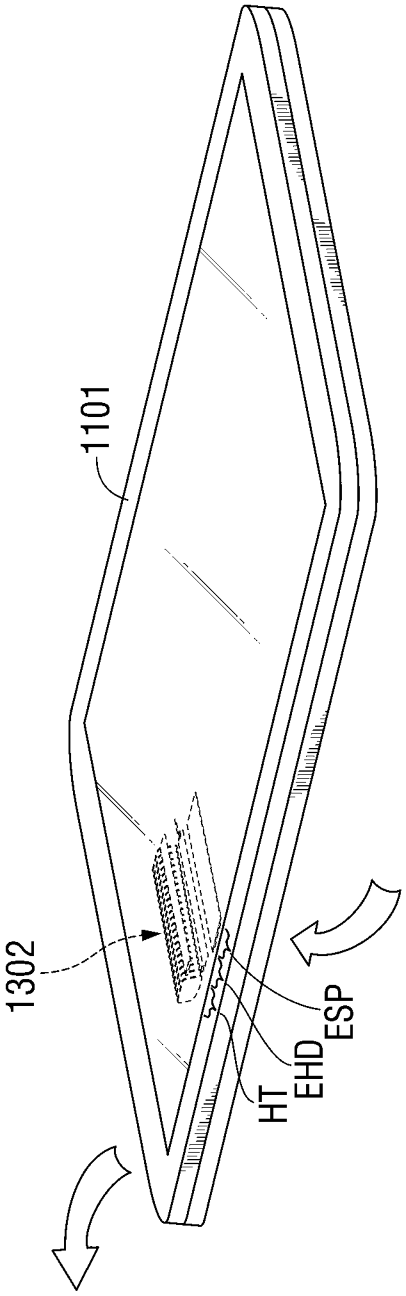

FIG. 13

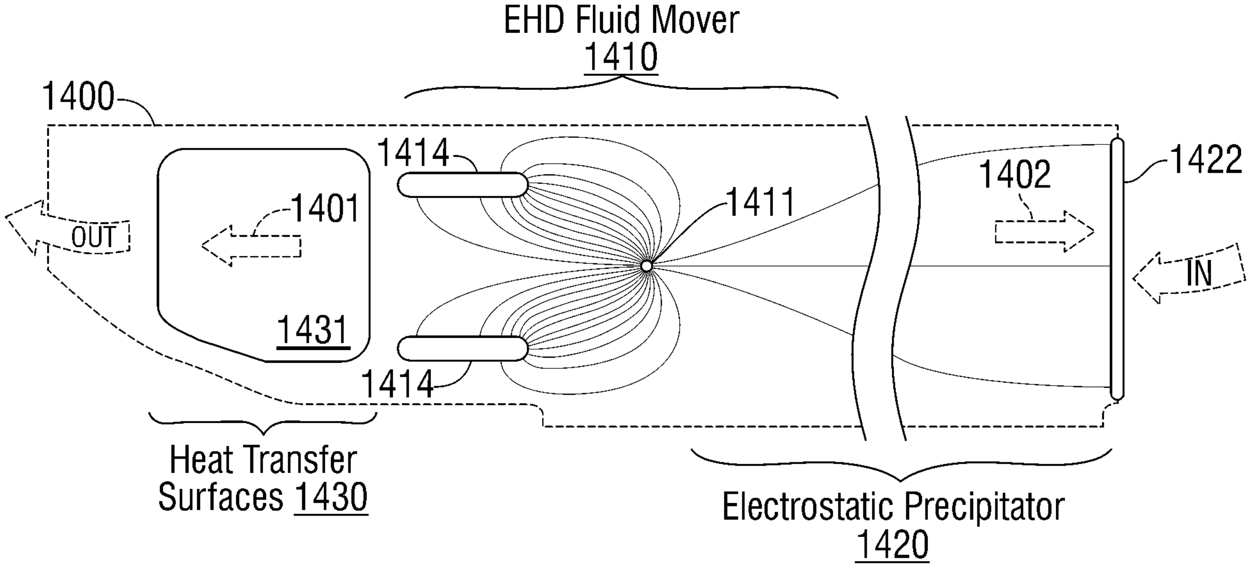

FIG. 14A

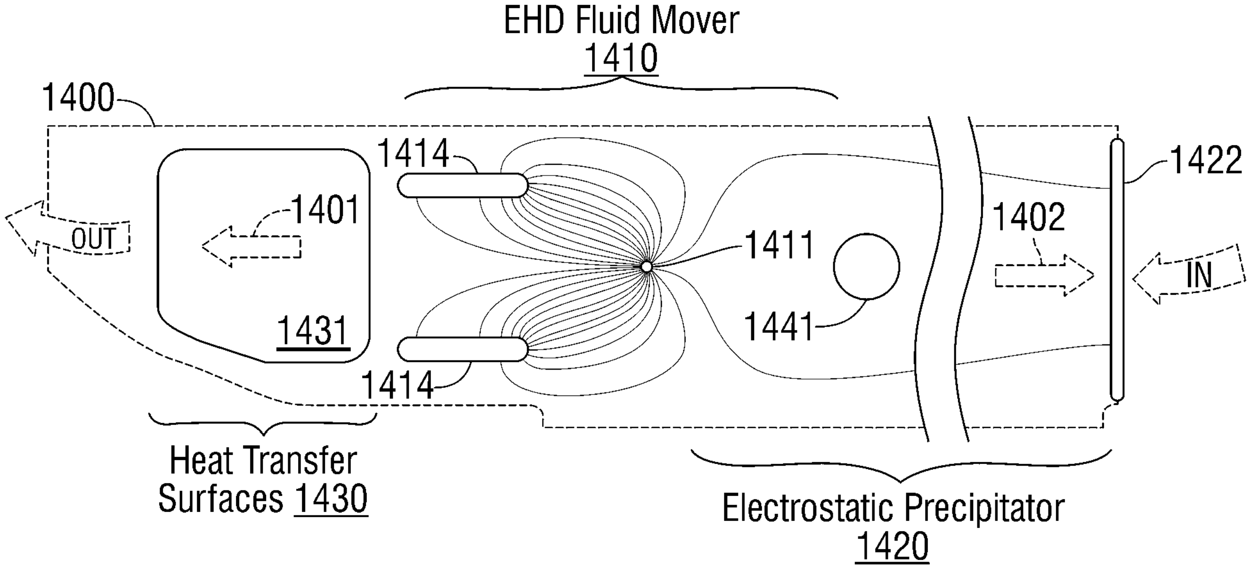

FIG. 14B

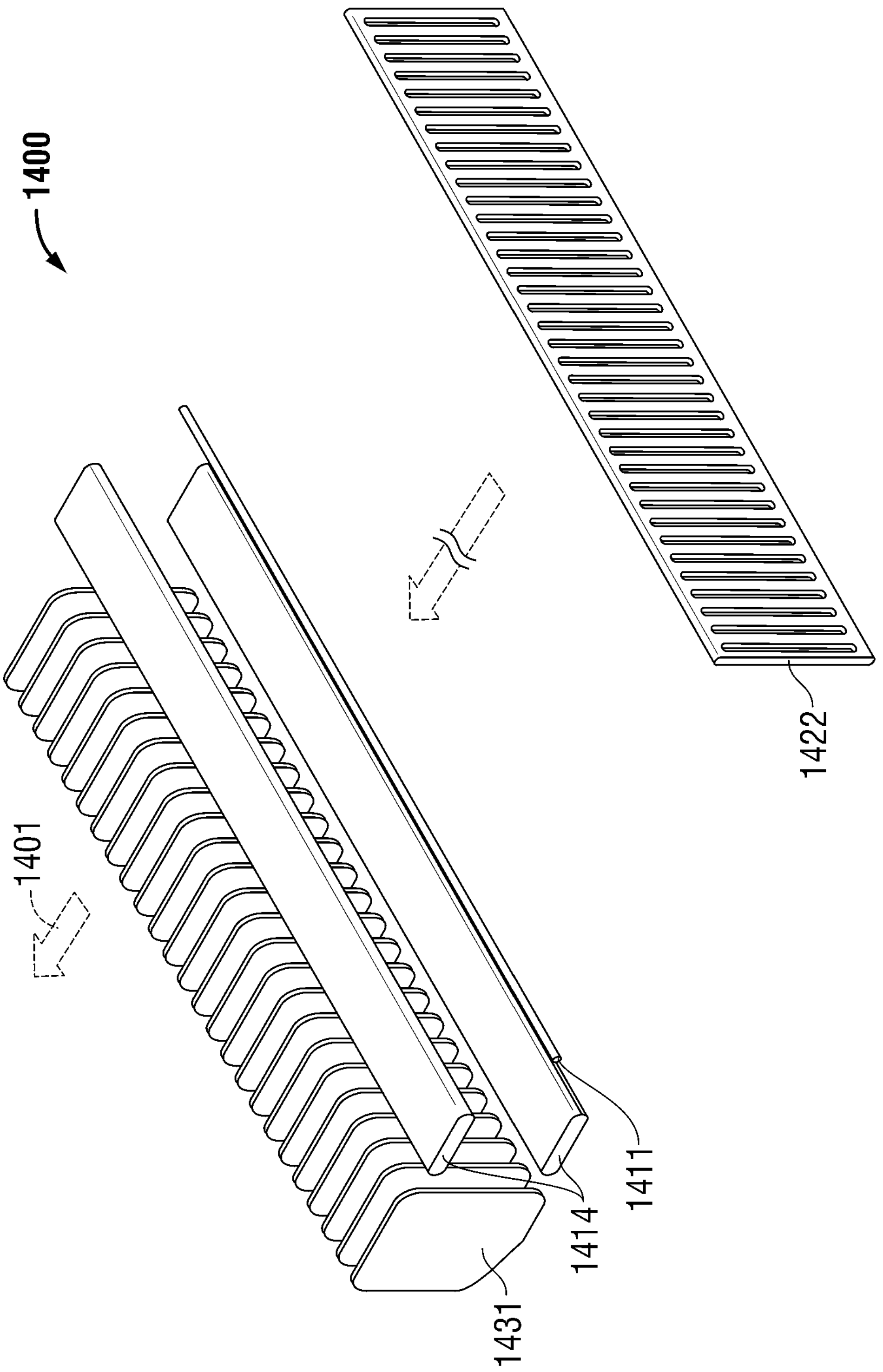

FIG. 14C

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/040212

A. CLASSIFICATION OF SUBJECT MATTER

INV. B93C3/02 B03C3/45

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)

B03C

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 practical, 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	JP 61 149257 A (MATSUSHITA ELECTRIC IND CO LTD) 7 July 1986 (1986-07-07) abstract; figure 1 -----	1-26
X	US 6 544 485 B1 (TAYLOR CHARLES E [US]) 8 April 2003 (2003-04-08) figure 2E -----	1-26
X	US 2003/090209 A1 (KRICHTAFOVITCH IGOR A [US] ET AL) 15 May 2003 (2003-05-15) figure 7 -----	1,20
X	JP 10 314621 A (SANYO ELECTRIC CO) 2 December 1998 (1998-12-02) paragraphs [0039], [0040], [0045] ----- -/--	1,20

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search 11 August 2011	Date of mailing of the international search report 19/08/2011
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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/040212

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 643 745 A (SAKAKIBARA NOBUYOSHI [JP] ET AL) 17 February 1987 (1987-02-17) figure 7 -----	1-26
A	US 3 558 286 A (GOURDINE MEREDITH C) 26 January 1971 (1971-01-26) column 3, line 10 - line 15 -----	1-26
A	US 4 789 801 A (LEE JIMMY L [US]) 6 December 1988 (1988-12-06) figure 3 -----	1-26
A	US 2007/137480 Al (BERGERON VANCE [FR] ET AL) 21 June 2007 (2007-06-21) paragraphs [0034], [0035] -----	1-26
Y	W0 2008/057362 A2 (KR0N0S ADVANCED TECHNOLOGIES I [US]; KRICHTAF0VITCH IGOR A [US]; G0R0B) 15 May 2008 (2008-05-15) figure 5 -----	27-31
Y	KR 100 905 722 Bl (K I C A INC [KR]) 1 July 2009 (2009-07-01) paragraph [0061] -----	27-31
Y	US 2005/116166 Al (KRICHTAFOVITCH IGOR A [US] ET AL) 2 June 2005 (2005-06-02) paragraph [0113] -----	27-31
Y	DE 199 05 680 Al (H0ELTER HEINZ [DE]) 17 August 2000 (2000-08-17) claim 2 -----	27-31
A	JP 2006 035194 A (MITSUBISHI HEAVY IND LTD) 9 February 2006 (2006-02-09) paragraph [0035] -----	1,20,27

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2011/040212

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP 61149257	A	07-07-1986	NONE		
US 6544485	Bl	08-04-2003	CN 1375336	A	23-10-2002
			HK 1050149	Al	19-05-2006
			US 2003072697	Al	17-04-2003
			US 2003147786	Al	07-08-2003
			US 2003147783	Al	07-08-2003
			US 2003159918	Al	28-08-2003
			US 2003165410	Al	04-09-2003
US 2003090209	Al	15-05-2003	US 6504308	Bl	07-01-2003
JP 10314621	A	02-12-1998	JP 3670799	B2	13-07-2005
US 4643745	A	17-02-1987	JP 1745415	C	25-03-1993
			JP 4027906	B	13-05-1992
			JP 60132661	A	15-07-1985
US 3558286	A	26-01-1971	NONE		
US 4789801	A	06-12-1988	NONE		
US 2007137480	Al	21-06-2007	NONE		
WO 2008057362	A2	15-05-2008	US 2010051709	Al	04-03-2010
KR 100905722	Bl	01-07-2009	NONE		
US 2005116166	Al	02-06-2005	AU 2004296485	Al	23-06-2005
			CA 2547951	Al	23-06-2005
			CN 1918685	A	21-02-2007
			EP 1695368	A2	30-08-2006
			HK 1099961	Al	23-07-2010
			JP 4714155	B2	29-06-2011
			JP 2007513484	A	24-05-2007
			MX PA06006296	A	23-08-2006
			NZ 547475	A	30-04-2008
			W0 2005057613	A2	23-06-2005
DE 19905680	Al	17-08-2000	NONE		
JP 2006035194	A	09-02-2006	NONE		