

HEAT AND ENERGY EXCHANGE

DESCRIPTION

[001] This application claims priority to U.S. Provisional Application No. 61/347,446, filed May 23, 2010, the contents of which are incorporated herein by reference. This application is related to co-pending U.S. Application No. 12/585,981, filed September 30, 2009, the contents of which are incorporated by reference, and which itself claims the benefit of U.S. Provisional Application No. 61/101,227, filed September 30, 2008.

Field

[002] Materials, components, and methods consistent with the present disclosure are directed to the fabrication and use of micro-scale channels with a fluid, where the micro-scale channels are arranged according to certain macroscopic configurations so as to at least partially control the temperature and flow of the fluid.

Background

[003] A volume of fluid, such as air, can be characterized by a temperature and pressure. When considered as a collection of constituent particles, comprising, for example, molecules of oxygen and nitrogen, the volume of fluid at a given temperature can also be characterized as a distribution of constituent particle speeds. This distribution can be characterized, generally, by an average speed which is understood to bear a relationship with the temperature of the fluid (as a gas, for example).

[004] Accordingly, the internal thermal energy of a fluid can provide a source of energy for applications related to heating, cooling, and the generation of fluid flow.

SUMMARY

[005] In one aspect, embodiments can provide a system that utilizes one or more micro-scale channels (a “micro channel”) configured to accommodate the flow of a fluid, and where the walls of the micro channel and the constituent particles in the fluid are configured such that collisions between the constituent particles and the walls of the micro channel are substantially specular. Moreover the micro channel can be arranged in a macroscopic configuration to provide at least one wall with at least a first wall portion that is at least approximately planar, a second wall portion that is at least approximately planar, a third wall portion that is approximately planar, a first intermediate wall portion, and a second intermediate wall portion, where a boundary of the first wall portion is contiguous with a first boundary of the first intermediate wall portion, a first boundary of the second wall portion is contiguous with a second boundary of the first intermediate wall portion, a second boundary of the second wall portion is contiguous with a first boundary of the second intermediate wall portion, and a boundary of the third wall portion is contiguous with a second boundary of the second intermediate wall portion, such that the first wall portion, the first intermediate wall portion, the second wall portion, the second intermediate wall portion, and the third wall portion form a contiguous wall of a portion of the micro channel. Further still, embodiments can provide that a first normal to the approximate plane defined by the first wall portion is not parallel to a second normal to the approximate plane defined by the second wall portion, and is also not parallel to a third normal to the approximate plane defined by the third wall portion, and where the second normal is also not parallel to the third normal. Further still, embodiments can provide that the angle offset between the first normal and the second normal is less than 90 degrees, and is approximately the same as the angle offset between the second normal and the third normal. Where the separation between the first wall portion and the second wall portion is at least N times the largest width of the micro channel over that separation (where N can be an integer), the angle offset between the first normal and the second normal can be less than $N/10$ degrees. Likewise, where the separation between the second wall portion and the third wall portion is at least N times the largest width of the micro channel over that separation, the angle offset between the second normal

and the third normal can be less than $N/10$ degrees. For example purposes only, where the separation between the first wall portion and the second wall portion (and the separation between the second wall portion and the third wall portion) is at least twenty-five times the largest width of the micro channel over that separation, the angle offset between the first normal and the second normal (and the second normal and the third normal) can be less than 2.5 degrees. Likewise, for example purposes only, where the separation between the first wall portion and the second wall portion is at least fifty times the largest width of the micro channel over that separation, the angle offset between the first normal and the second normal can be less than 5 degrees.

[006] In another aspect, embodiments can provide for the manipulation of flow and temperature of a volume of fluid, where the fluid can comprise molecules, and can allow for the population of molecular vibrational levels through enhanced heating of a volume of the fluid. Where such vibrationally-excited molecules are allowed to relax, embodiments can allow for the creation and manipulation of electromagnetic radiation emitted thereby.

[007] In a further aspect, embodiments can provide for the manipulation of flow and temperature of a volume of fluid, and can provide for practical applications ranging from heating and cooling, refrigeration, electricity generation, coherent and non-coherent light emission, gas pumping, plasma and particle beam production, particle beam acceleration, chemical processes, and others.

[008] Additional objects and advantages of the disclosure will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of embodiments consistent with the disclosure. The objects and advantages can be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[009] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[010] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of the disclosure and together with the description, serve to explain the principles of the disclosure.

[011] Figure 1 depicts an exemplary heat exchange system consistent with the present disclosure;

[012] Figure 2 is an exemplary view of the micro channels within an accelerating element of the system of FIG. 1;

[013] Figure 3 is an exemplary illustration of a specular collision consistent with the present disclosure;

[014] Figure 4 is an exemplary view of the micro channels within a decelerating element of the system of FIG. 1;

[015] Figure 5 depicts an exemplary view of an interface and a connection channel connecting an accelerating element and a decelerating element of the system of FIG. 1; and

[016] Figure 6 depicts exemplary normal vectors to the walls of the micro channels and the angular offsets within an accelerating element of the system of FIG. 1.

DESCRIPTION OF THE EMBODIMENTS

[017] Reference will now be made in detail to the present embodiment (exemplary embodiment) of the disclosure, characteristics of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[018] FIG. 1 depicts a view of exemplary heat exchange system 100 consistent with the present disclosure. Pump 150 is configured to generate and/or maintain a flow of fluid (such as air, for example) from channel 152 to channel 151. Arrow 118 indicates an exemplary fluid flow into channel 151, and arrow 128 indicates an exemplary fluid flow from channel 152.

[019] In general, consistent with the present disclosure, sub-system 110 can include a plurality of accelerating elements 115, where each accelerating element 115 includes micro channels (to be described further below) in fluid communication with channel 151. Further, sub-system 120 can include a plurality of decelerating elements 125, where each decelerating element 125 also includes micro channels (to be described further below) in fluid communication with channel 152. Further still, consistent with an exemplary embodiment of the present disclosure, there can be a one-to-one correspondence between each of micro channel of each accelerating element 115 and each of micro channel of each decelerating element 125, where the one-to-one correspondence can be realized by ensuring that the micro channel of each accelerating element 115 is in fluid communication with a micro channel of a decelerating element 125 through interface 130.

[020] In a preferred embodiment, each pair of accelerating element 115 and decelerating element 125 can transfer 100 watts from the cold side (accelerating element 115) to the hot side (decelerating element 125). The dimensions of such an accelerating element 115 within such a 100 watt pair of accelerating and decelerating elements can be 100 millimeters by 100 millimeters. In a further embodiment, an additional heat exchange element (not shown) may be affixed to each accelerating element 115 and decelerating element 125. In an embodiment consistent with the disclosure, the additional heat exchange element can be substantially planar (such as accelerating element 115 and decelerating element 125 are planar) and serve to conduct heat away from decelerating element 125 into the ambient air (by providing additional surface area to dissipate such energy) or serve to conduct heat to accelerating element 115 from the ambient air (again, by providing provide additional surface area for cooling purposes). The additional heat exchange element can be 100 millimeters by 100 millimeters, thereby making the dimensions of the combined accelerating element 115 and additional heat exchange element 100 millimeters by 200 millimeters, and making the dimensions of the combined decelerating element 125 and additional heat exchange element 100 millimeters by 200 millimeters in one embodiment. In the embodiment depicted in FIG. 1, with twenty (20) such pairs of accelerating element 115 and decelerating element 125 depicted, system 100 can be

capable of transferring 2 kilowatts from sub-system 110 to sub-system 120. In a further preferred embodiment, with 35 such pairs capable of transferring 3.5 kilowatts from a cold side to a hot side, the height, H , of a 3.5 kilowatt system can be approximately 300 millimeters. Where interface 130 is 10 millimeters wide (and taking into account the additional heat exchange elements described above), the overall dimensions of such a 3.5 kilowatt system can be 300 millimeters by 210 millimeters by 200 millimeters. Further, the exemplary diameter of channel 151 and channel 152 can be 25 millimeters or more. Furthermore, in such an exemplary 3.5 kilowatt system, where the fluid is air, pump 150 can be a 300-500 watt air pump. Further still, in such an exemplary embodiment, the air to be circulated through system 100 can be drawn from the immediate environment of system 100.

[021] Channel 151 is in fluid communication with channel 152 through a plurality of micro channels within the plurality of accelerating elements 115, interface 130, and decelerating elements 125. Arrow 138 depicts the flow of fluid from accelerating element 115 to decelerating element 125 through interface 130.

[022] FIG. 2 is a schematic view of micro channel 210 within an exemplary accelerating element 115 of FIG. 1. Channel 151 is depicted as an opening in accelerating element 115, and in fluid communication with micro channel 210. The scale of micro channel 210 as depicted in FIG. 2 is for illustration purposes. Micro channel 210 can be engineered to be small (*i.e.*, with an internal surface area that may be as small as approximately $3\text{e-}11\text{ m}^2$ per linear micron to $6\text{e-}10\text{ m}^2$ per linear micron in a preferred embodiment; which can correspond, respectively, to a channel with an approximate diameter of 9 microns to 180 microns). As depicted in FIG. 2 in an exemplary embodiment, micro channel 210 is approximately confined to a planar region (*i.e.*, accelerating element 115) and exhibits a spiral such that a fluid entering from channel 151 enters micro channel 210, describing arcs of increasing radius until the fluid enters entering linear channel 220. In a preferred embodiment, the total length of micro channel 210 from channel 151 until reaching linear channel 220 can be approximately 10 mm to more than 1 meter. Further still, as discussed above, in a preferred embodiment where accelerating element 115 is one of a 100 watt pair of accelerating and decelerating elements, the width W can be 100 millimeters.

[023] Furthermore, in a preferred embodiment, the walls of micro channel 210 can be substantially specular, FIG. 3 depicts a portion of FIG. 2 in more detail. Specifically, arrow 325 represents a velocity component of constituent particle 310 before constituent particle 310 collides with wall 305. (Wall 305 is an enlarged view of an exemplary wall of micro channel 210, and constituent particle 310 corresponds to a constituent particle in an exemplary fluid flowing through micro channel 210 according to a preferred embodiment.) Normal 306 represents an axis that is perpendicular to the plane defined by wall 305. Arrow 335 represents a velocity component of constituent particle 310 after constituent particle 310 collides with wall 305. As used herein, a specular collision between constituent particle 310 and wall 305 is a collision in which the velocity component of constituent particle 310 parallel to plane 302 determined by local portion 301 of wall 305 proximal to the collision between constituent particle 310 and wall 305, is substantially the same before and after the collision. Moreover, during a specular collision, the speed of constituent particle 310 associated with the velocity component perpendicular to the plane of wall 305 can be substantially the same before and after the collision. One skilled in the art should appreciate that the term “specular collision” as used herein should not be interpreted to apply to elastic collisions only. Rather, because there can be a transfer of energy (on the average) between wall 305 of the micro channel and a plurality constituent particles 310, it is understood that any one particular specular collision between constituent particle 310 and wall 305 can increase or decrease the kinetic energy of constituent particle 310 relative to the kinetic energy it possessed prior to the collision. For example, if there is a transfer of energy from wall 305 to constituent particle 310, then one would expect that the acute angle between constituent particle 310 and the plane parallel to wall 305 would be larger after the collision than before the collision. Likewise, if there is a transfer of energy from constituent particle 310 to wall 305, then one would expect that the acute angle between constituent particle 310 and the plane parallel to wall 305 would be smaller after the collision than before the collision. Furthermore, where the temperature of the fluid comprising a plurality of constituent particles is different from the temperature of the wall, there can be a transfer of internal energy from the fluid to the wall, or from the wall to the fluid

(depending upon which is at the higher temperature). Where the collisions between a plurality of constituent particles 310 and wall 305 are substantially specular as used herein, a transfer of energy from a fluid flowing through micro channel 210 to wall 305 or from wall 305 to the fluid flowing through micro channel 210 can occur predominantly through the average change in the speed of constituent particle 310 associated with the change in its velocity component perpendicular to the plane of wall 305 during the collision. One should also appreciate that such a change in the velocity component of constituent particle 310 during the collision can change the overall speed of constituent particle 310 as a result of the collision process.

[024] In an embodiment consistent with the present disclosure, the surface of the walls of micro channel 210 can include any suitable material configured for specular collisions, such as silicon, tungsten, gold, platinum, and diamond. Such a surface may be deposited onto micro channel 210 using any of a variety of MEMs fabrication techniques, including, but not limited to, sputtering and evaporative deposition. Furthermore, consistent with the present disclosure, diamond smooth films with grains as small as 100 nm and 20nm Ra roughness can be grown onto channel walls. In one embodiment, diamond can be preferable as a result of its melting point (*i.e.*, approx. 4000 K at one atmosphere) and as a result of its hardness (*i.e.*, a10 in Mohs scale for hardness). Consistent with further embodiments of the present disclosure, the surface of the walls of micro channel 210 can also include tungsten carbide, glass and pyrolytic graphite—in part at least because of its high thermal conductivity of 1700 W/mK. Micro channel 210 can also include a diamond nanoparticle film on pyrolytic graphite substrate.

[025] FIG. 4 is a schematic view of micro channel 410 within an exemplary decelerating element 125 of FIG. 1. Channel 152 is depicted as an opening in decelerating element 125, and in fluid communication with micro channel 410. Again, the scale of micro channel 410 as depicted in FIG. 4 is for illustration purposes. Micro channel 410 can be engineered to be small (*i.e.*, with an internal surface area that may be as small as approximately $3\text{e-}11\text{ m}^2$ per linear micron to $6\text{e-}10\text{ m}^2$ per linear micron in a preferred embodiment, which can correspond, respectively, to a channel with an approximate diameter of 9 microns to 180 microns). As depicted in FIG. 4 in

an exemplary embodiment, micro channel 410 is approximately confined to a planar region (i.e., accelerating element 125) and exhibits a spiral such that a fluid entering from linear channel 420 enters micro channel 410, describing arcs of decreasing radius until the fluid enters entering channel 152. In a preferred embodiment, the total length of micro channel 410 from linear channel 420 until reaching channel 152 can be approximately 10 mm to more than 1 meter. Further still, as discussed above, in a preferred embodiment where decelerating element 125 is one of a 100 watt pair of accelerating and decelerating elements, the width W can be 100 millimeters. Furthermore, in a preferred embodiment, the walls of micro channel 410 can be substantially specular.

[026] In an embodiment consistent with the present disclosure, the surface of the walls of micro channel 410 can include any suitable material configured for specular collisions, such as silicon, tungsten, gold, platinum, and diamond. Such a surface may be deposited onto micro channel 410 using any of a variety of MEMs fabrication techniques, including, but not limited to, sputtering and evaporative deposition. Furthermore, consistent with the present disclosure, diamond smooth films with grains as small as 100 nm and 20nm Ra roughness can be grown onto channel walls. In one embodiment, diamond can be preferable as a result of its melting point (i.e., approx. 4000 K at one atmosphere) and as a result of its hardness (i.e., a10 in Mohs scale for hardness). Consistent with further embodiments of the present disclosure, the surface of the walls of micro channel 410 can also include tungsten carbide, glass and pyrolytic graphite—in part at least because of its high thermal conductivity of 1700 W/mK. Micro channel 410 can also include a diamond nanoparticle film on pyrolytic graphite substrate

[027] FIG. 5 depicts connection 510 between linear channel 220 and linear channel 420 through interface 130.

[028] In a preferred embodiment, where the fluid is air, channel 151 can be kept at a relatively high pressure, and channel 152 can be kept at a relatively low pressure, so as to allow for the flow of fluid through the plurality of accelerating elements 115 and decelerating elements 125. In a preferred embodiment, the channel

151 can exhibit a pressure of approximately 1 atm or more, and channel 152 can exhibit a pressure that is approximately 0.528 of the pressure of channel 151.

[029] Turning to FIG. 6, which depicts an expanded view of micro channel 210, fluid that is at the inner portion of micro channel 210 (*i.e.*, proximal to inflow opening 601) can be induced to flow through spirals of increasing radii through the use of a pressure differential as discussed above. Where the temperature of the fluid at inflow opening 601 is T_1 , then the constituent particles (such as constituent particle 310 in FIG. 3) can be represented by a distribution of speeds, the average speed of which is proportional to temperature.

[030] Where the throat of inflow opening 601 is small (for example, anywhere from $0.01\mu\text{m}^2$ to $500\mu\text{m}^2$ where the fluid is air), then the constituent particles of a fluid moving through inflow opening 601 into micro channel 210 can exhibit a velocity that has its component parallel to direction 650 larger than its component perpendicular to direction 650. Consequently, the fluid passing through micro channel 210 acquires a flow velocity that is predominantly parallel to direction 650. The kinetic energy that is associated with the flow of fluid in direction 650 is drawn from the internal thermal energy of fluid, which was at T_1 before it entered inflow opening 601. Conservation of energy dictates that, because a portion of the original thermal energy of fluid at T_1 has been converted to kinetic energy of flow for fluid passing through micro channel 210, the temperature of fluid (in a frame that is stationary with the velocity of flow) in micro channel 210 can be lower than T_1 , which we will designate as T_2 . Where T_2 is also less than the temperature of wall 610 (which we will designate as T_w) of micro channel 210, then the fluid in micro channel 210 can cool the material comprising accelerating element 115.

[031] Micro channel 210, consistent with an embodiment of the present disclosure is configured to enhance the effect this temperature change has on the fluid passing through micro channel 210 in at least three ways. Specifically, where wall 610 and the constituent particles in the fluid are configured such that collisions between wall 610 and the constituent particles are substantially specular, then such collisions—which are a means of transferring energy between wall 610 and the fluid—will have a minimal effect on the overall flow of fluid through micro channel

210. In other words, where the collision between the constituent particle and wall 610 is such that the velocity of the constituent particle is equally likely to be in any direction away from wall 610 (*i.e.*, a non-specular collision), then a plurality of such collisions will have the effect of slowing down the flow of the fluid, which will also likely have the effect of raising the internal temperature of the fluid in micro channel 210. Micro channel 210, consistent with an embodiment of the present disclosure, is configured to enhance the effect of cooling by selectively avoiding the effect of non-specular collisions.

[032] In addition, because the outer wall of micro channel 210 is configured as a generally increasing spiral, the specular scattering of a constituent particle off of successive portions of the wall of micro channel 210 (such as portions 610, 615, and 620), can convert a portion of the velocity component which was perpendicular to the direction of flow through micro channel 210 (*i.e.*, a radial velocity component) to a component parallel to the direction of flow through micro channel 210. Because the spiral grows larger along the path of micro channel 210, the constituent particles can undergo less and less collisions with the wall (along the path of micro channel 210) as the fluid travels towards linear channel 220.

[033] Moreover, because micro channel 210 is engineered to be small (*i.e.*, with an internal surface area that may be as small as approximately $3\text{e-}11\text{ m}^2$ per linear micron to $6\text{e-}10\text{ m}^2$ per linear micron in a preferred embodiment), then the ratio of the surface area presented by the wall of micro channel 210 to a given volume of fluid in any region within micro channel 210 is relatively large (*i.e.*, where the volume of the fluid enclosed by the above surface is approximately $8\text{e-}17\text{ m}^3$ per linear micron to $3\text{e-}15\text{ m}^3$ per linear micron). Because the surface area presented by the wall of micro channel 210 to a volume of fluid is a primary means of energy exchange between the walls and the fluid 115, this can tend to maximize the overall energy exchange interaction between the fluid and micro channel 210.

[034] For example, as shown in FIG. 6, a constituent particle can enter inflow opening 601 with a component predominantly parallel to direction 650, and undergoes a specular collision with local region 610 of the wall of micro channel 210, and acquires a velocity component in direction 651. The constituent particle may now

undergo a specular collision with local region 615 of the wall of micro channel 210, and acquires a velocity component in direction 652. The constituent particle can undergo a specular collision with local region 620 of the wall of micro channel 210, and acquire a further velocity component along the general direction of micro channel 210.

[035] Angle β corresponds to the angular offset between normal 625 and normal 630. Angle α corresponds to the angular offset between normal 630 and normal 635. In a preferred embodiment, where the separation between the first wall portion and the second wall portion is at least N times the largest width of the micro channel over that separation (where N can be an integer), the angle offset between the first normal and the second normal can be less than $N/10$ degrees. Likewise, where the separation between the second wall portion and the third wall portion is at least N times the largest width of the micro channel over that separation, the angle offset between the second normal and the third normal can be less than $N/10$ degrees. For example, preferably where the separation between the first wall portion and the second wall portion (and the separation between the second wall portion and the third wall portion) is at least twenty-five times the largest width of the micro channel over that separation, the angle offset between the first normal and the second normal (and the second normal and the third normal) is less than 2.5 degrees. Likewise, preferably where the separation between the local region 610 and local region 615 is at least fifty times the largest width of micro channel 210 over that separation, the angle offset between normal 625 and normal 630 can be less than 5 degrees. Similarly, where the separation between local region 615 and local region 620 is at least fifty times the largest width of micro channel 210 over that separation, the angle offset between normal 630 and normal 635 can be less than 5 degrees.

[036] In this manner, accelerating element 115 can be cooled by the passage of a fluid, where the fluid is configured to exhibit specular collisions with the walls of micro channel 210. Moreover, a fluid passing through accelerating element 115 can be accelerated: *i.e.*, when the fluid arrives at linear channel 220, the velocity components of the fluid's constituent particles are predominantly along the direction of linear channel 220 leading to connection 510.

[037] Recapping somewhat, and consistent with the present disclosure, the translational kinetic energy (TKE) of the constituent particles in a fluid (*i.e.*, molecules in a molecular beam) can be reduced by collisions with a surface. The percentage of TKE transferred from the fluid to the surface can be dependent upon the velocity of the fluid, the smoothness of the surface, the internal kinetic energy of the constituent particles in the fluid and the kinetic energy density of the surface.

[038] A fluid (as a molecular beam) with a particular root mean square (RMS) velocity and a constant average angle of incidence can transfer more energy to a smooth surface with a lower kinetic energy density than to the same surface when it is placed at a higher energy density. If the energy density of the surface is sufficiently high with respect to the energy density of an impinging molecular beam no energy will be transferred from the beam to the surface.

[039] Surface collisions that result in a net energy transfer to the surface can reduce the internal kinetic energy level of constituent particles in the fluid. When the internal energy level of a molecule has been reduced sufficiently (such as through vibrational energy levels) it can emit one or more photons at a frequency that is commensurate with the reduced internal energy level.

[040] The same principle of operation can apply to decelerating element 125, where micro channel 410 is configured as a spiral that presents successively smaller radii to a fluid passing from linear channel 420 to channel 152. In this manner, a high velocity fluid arriving from connection 510 to linear channel 420 can undergo more and more collisions with the wall (along the path of micro channel 210) as the fluid travels towards channel 152.

[041] As with accelerating element 115 and micro channel 210, the walls of micro channel 410 in decelerating element 125 are configured to cause the constituent particles in the fluid passing through micro channel 410 to undergo specular collisions.

[042] In addition, where the constituent particles of the fluid are molecules (and, for example, where the fluid is a gas), then certain vibrational states of the constituent particles may be populated as a result of the increase in temperature that is achieved near the inner opening between micro channel 410 and channel 152.

[043] Consistent with the present disclosure, a molecular beam in a MEMS device (such as accelerating element 115 and decelerating element 125) that can be used for cooling electronics, refrigeration, air conditioning and other applications can exhibit high RMS velocities. A molecular beam composed of room air with an RMS velocity of 2,000 meters per second has the translational kinetic energy of still air at over 4,000 K, a temperature that is well beyond the melting point of most materials. A refrigeration system's hot-side heat exchanger preferably would have the ability to extract precise quantities of both translational and internal kinetic energy from the accelerated molecular beam without damage to a heat exchanger composed of conventional materials, such as aluminum and thermally conductive plastics with a melting point of only 933 K or less.

[044] A gradual reduction in the translational kinetic energy level of a fast molecular beam with a high energy density relative to that of the surface allows for energy transfer to the surface to occur over an extended surface length. This is a desirable method of extracting the energy from a molecular beam when a more concentrated extraction would damage the channel or raise the temperature of a device beyond practical limits. With this gradual energy extraction approach, a hot side heat exchanger in a refrigeration system that is made of aluminum with a melting point of 933 K can be used to transfer extracted energy from a high energy molecular beam with an RMS velocity of 2,000 m/s or more to the outside environment without damaging the channels of the heat exchange device and not overheating any portion of the outer surface of the heat exchanger device. With a gradual kinetic energy extraction methodology, virtually any conformal channel material including ceramics and thermally conductive polymers can be used as channels and thermal packaging in hot-side heat exchanger applications.

[045] As described herein, when a molecular beam experiences a series of surface collisions with an arc of gradually decreasing radius, translational and internal kinetic energy is extracted gradually. A variety of MEMS device channel designs can permit a molecular beam to experience such a series of collisions with an arc of gradually decreasing radius. For example, channels configured as spirals with an initially large radii that gradually reduce over length to a smaller radii, and a spiraling

molecular beam progressing through an attenuated channel using the centrifugal force of the spiral motion to remain in close proximity to the surface at all diameters of the channel are two examples of such designs. Any gradual energy extraction design would serve to facilitate the conversion of the beams kinetic energy to infrared and optical wavelengths of light even when the average energy content of the beam, if abruptly slowed or stopped could produce higher frequency emissions. For applications requiring higher frequency emissions, designs that facilitate more abrupt energy extraction methods can of course be applied and are within the scope of this disclosure.

[046] An equation describing the approximate transfer of energy from the translational energy of a molecular beam to a collision surface temperature can be derived through kinetic theory. In the equation $(3kT)/2 = (mv^2)/2$, k is Boltzmann's Constant, T is temperature in Kelvins, m is mass and v is velocity. Because energy increases with the square of the velocity, the quantity of kinetic energy that can be transferred to a surface by slowing a faster beam by one meter per second can be more than the quantity that can be transferred to the same surface by a slower molecular beam with the same reduction in velocity. The local temperature of the collision surfaces and thermal path that extends to the outer surfaces can be controlled with complementary collision angles with known velocity ranges of a molecular beam.

[047] A heat exchanger consistent with the present disclosure that gradually absorbs the kinetic energy from a high energy molecular beam can be heated as kinetic energy from the molecular beam is absorbed by the heat exchanger's inner channel surfaces. Provided that there is a sufficiently conductive thermal path between the inner channel surfaces and the outer surfaces of the heat exchanger, the heat exchanger and molecular beam channel surfaces can be maintained with any desired ΔT (change in temperature) with the ambient surroundings with conventional means of heat transfer from the heat exchanger to the ambient environment. Heat exchangers that evenly extract energy from a molecular beam along a channel surface can very nearly approximate nearly isothermal conditions.

[048] Energy extracted from an equilibrated molecular beam can be used to precisely quantize the modes of energy in a channel cavity. Emissions of light with a

predictable energy are provided by Plank's radiation formula that is equal to Planck's constant times the frequency. Plank's radiation formula can be used to calculate the average energy of any desired frequency of light emitted from a MEMS device channel.

[049] Continuous coherent spontaneous emission can also occur when a collimated and equilibrated molecular beam transfers highly resolved quantities of energy to the surface of a channel. Channel transparency to the emitted frequency of light can allow for the light to escape the channel for practical purposes that include any laser application and conversion of light energy to electric current as would occur by a photodiode array in the flux path of the photonic emissions from the channels. The voltage of the current can be related to the bandgap energy of the channel material. Coherent emissions can permit photodiodes with a narrow bandwidth to efficiently convert extracted energy from a molecular beam to an electric current of a desired voltage.

[050] Coherent and in-phase emissions from several channels can be readily achieved from a series of parallel channel surfaces on a MEMS device using ultra-flat wafer surfaces. Energy density of coherent emissions can be accomplished with sub-micron gaps between parallel channels. MEMS devices with optically and UV transparent channels with excellent optical homogeneity can be fabricated using a variety of materials. Silicon can provide suitable transparent optical homogeneity to some infrared frequencies, as can germanium and Amtir. Sapphire, yttria, and yttrium alumina garnet provide excellent optical transmission of infrared as well. Optical glass can be used for UV and optical wavelengths.

[051] In a preferred embodiment, the architecture or micro channel 210 and micro channel 410 can reduce pumping power requirements. Due at least in part to such architecture, the values associated with the coefficient of performance ("COP") can be 10 or higher.

[052] In a further embodiment consistent with this disclosure, values of COP can be 10 or higher by operating at different pressures. For example, in an exemplary embodiment, the power required per constituent particle (or molecule) is a function of the pressure ratio, and not the pressure. For exemplary systems 100 that operate at

higher pressures, but that are configured to exhibit the same pressure ratio, a pumping cost per constituent particle will remain the same, but a higher density flow if constituent particles (i.e., a higher density molecular beam) can provide higher heat transfer rates and could produce a COP of 10 or more.

[053] Materials and components consistent with the present disclosure, such as the exemplary devices described above, offers solutions to all of the problems that have been identified

[054] Other embodiments consistent with the disclosure will be apparent to those skilled in the art from consideration of the specification and practice of the embodiments disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

WHAT IS CLAIMED IS:

1) An apparatus for heat exchange comprising:

a micro channel comprising a wall portion; and

a gas comprising a constituent particle;

wherein the micro channel is configured to accommodate a flow of the gas in a first direction substantially perpendicular to a cross section of the micro channel and wherein said gas does not condense to a liquid throughout said flow;

wherein the wall portion and the constituent particle are configured such that collisions between the constituent particle and the wall portion are substantially specular; and

wherein the wall portion comprises at least a first wall portion, a second wall portion, a third wall portion, a first intermediate wall portion, and a second intermediate wall portion;

wherein a boundary of the first wall portion is contiguous with a first boundary of the first intermediate wall portion, a first boundary of the second wall portion is contiguous with a second boundary of the first intermediate wall portion, a second boundary of the second wall portion is contiguous with a first boundary of the second intermediate wall portion, and a boundary of the third wall portion is contiguous with a second boundary of the second intermediate wall portion, such that the first wall portion, the first intermediate wall portion, the second wall portion, the second intermediate wall portion, and the third wall portion form a contiguous portion of the wall of the micro channel;

wherein a first normal to the first wall portion is not parallel to a second normal to the second wall portion, and is also not parallel to a third normal to the third wall portion, and where the second normal is also not parallel to the third normal;

wherein an angle offset between the first normal and the second normal is less than 90 degrees, and is approximately the same as an angle offset between the second normal and the third normal;

wherein the largest width of the micro channel is 180 microns;

wherein a separation between the first wall portion and the second wall portion is at least an integer N times the largest width of the micro channel over that separation; and

wherein the angle offset between the first normal and the second normal is less than M degrees where M equals $N/10$.

- 2) The apparatus of claim 1 wherein N is selected from at least one of: twenty-five and fifty.
- 3) The apparatus of claim 1 wherein the gas comprises air.
- 4) The apparatus of claim 1 wherein the micro channel is substantially confined to a planar region.
- 5) The apparatus of claim 1 wherein a path of the micro channel is a spiral with an inner portion and an outer portion, wherein a radius of the outer portion is greater than a radius of the inner portion.
- 6) The apparatus of claim 1, wherein at least a portion of the micro channel is configured with an internal surface area between approximately 3×10^{-11} m² per linear micron to 6×10^{-10} m² per linear micron.
- 7) The apparatus of claim 1 wherein the wall portion further comprises a coating material deposited on a substrate.
- 8) The apparatus of claim 7 wherein the substrate comprises copper.
- 9) The apparatus of claim 7 wherein the coating material comprises tungsten.

- 10) The apparatus of claim 1 wherein the wall portion is manufactured to be generally smooth.
- 11) A method for heat exchange, comprising:
- providing a micro channel comprising a wall portion;
- providing a gas comprising a constituent particle; and
- inducing a flow of the gas adjacent to the wall portion;
- wherein the micro channel is configured to accommodate the flow of the gas in a first direction substantially perpendicular to a cross section of the micro channel and wherein said gas does not condense to a liquid throughout said flow;
- wherein the wall portion and the constituent particle are configured such that collisions between the constituent particle and the wall portion are substantially specular; and
- wherein the wall portion comprises at least a first wall portion, a second wall portion, a third wall portion, a first intermediate wall portion, and a second intermediate wall portion;
- wherein a boundary of the first wall portion is contiguous with a first boundary of the first intermediate wall portion, a first boundary of the second wall portion is contiguous with a second boundary of the first intermediate wall portion, a second boundary of the second wall portion is contiguous with a first boundary of the second intermediate wall portion, and a boundary of the third wall portion is contiguous with a second boundary of the second intermediate wall portion, such that the first wall portion, the first intermediate wall portion, the second wall portion, the second intermediate wall portion, and the third wall portion form a contiguous portion of the wall of the micro channel;

wherein a first normal to the first wall portion is not parallel to a second normal to the second wall portion, and is also not parallel to a third normal to the third wall portion, and where the second normal is also not parallel to the third normal;

wherein an angle offset between the first normal and the second normal is less than 90 degrees, and is approximately the same as an angle offset between the second normal and the third normal;

wherein a largest width of the micro channel is 180 microns;

wherein a separation between the first wall portion and the second wall portion is at least an integer N times the largest width of the micro channel over that separation; and

wherein the angle offset between the first normal and the second normal is less than M degrees where M equals $N/10$.

12) The method of claim 11 wherein N is selected from at least one of: twenty-five and fifty.

13) The method of claim 11 wherein:

the step of providing a micro channel comprising a wall portion comprises:

providing the wall portion at a first temperature at a first time; and wherein

a portion of the fluid flows through the micro channel during a period of time between the first time and a second time later than the first time; and wherein

the wall portion exhibits a second temperature that is less than the first temperature at the second time.

14) The method of claim 11 wherein the gas comprises air.

- 15) The method of claim 11 wherein a path of the micro channel is a spiral with an inner portion and an outer portion, where a radius of the outer portion is greater than a radius of the inner portion.
- 16) The method of claim 11 further comprising, providing a heat exchange element conductively affixed to the wall portion.
- 17) The method of claim 11, wherein at least a portion of the micro channel is configured with an internal surface area between approximately 3×10^{-11} m² per linear micron to 6×10^{-10} m² per linear micron.
- 18) The method of claim 11 wherein providing a micro channel comprising a wall portion further comprises: depositing a material on a surface of the micro channel using at least one of: sputtering and evaporative deposition.
- 19) The method of claim 18 wherein the surface is copper.
- 20) The method of claim 18 wherein the material is tungsten.
- 21) The apparatus of claim 1 wherein the flow of gas in the micro channel is from the inner portion to the outer portion.
- 22) The apparatus of claim 1 wherein the flow of gas in the micro channel is from the outer portion to the inner portion.
- 23) A system for heat exchange comprising:

an accelerating element comprising the apparatus of claim 21;

a decelerating element comprising the apparatus of claim 22; and

an interface comprising a micro channel in fluid communication with the micro channel of the accelerating element and the micro channel of the decelerating element;

wherein the gas of the accelerating element comprises a first portion of the gas at substantially a first pressure and the gas of the decelerating element comprises a second portion of the gas at substantially a second pressure that is less than the first pressure.

- 24) The system of claim 23, wherein the accelerating element and the decelerating element are configured to transfer heat energy from the accelerating element to the decelerating element at a rate of at least 100 watts.
- 25) The system of claim 23, wherein each of the accelerating element and the decelerating element are approximately 100 millimeters by 100 millimeters.