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(54) **SYSTEMS, METHODS, AND APPARATUSES FOR ACTIVE THERMAL MANAGEMENT OF ULTRASOUND TRANSDUCERS**

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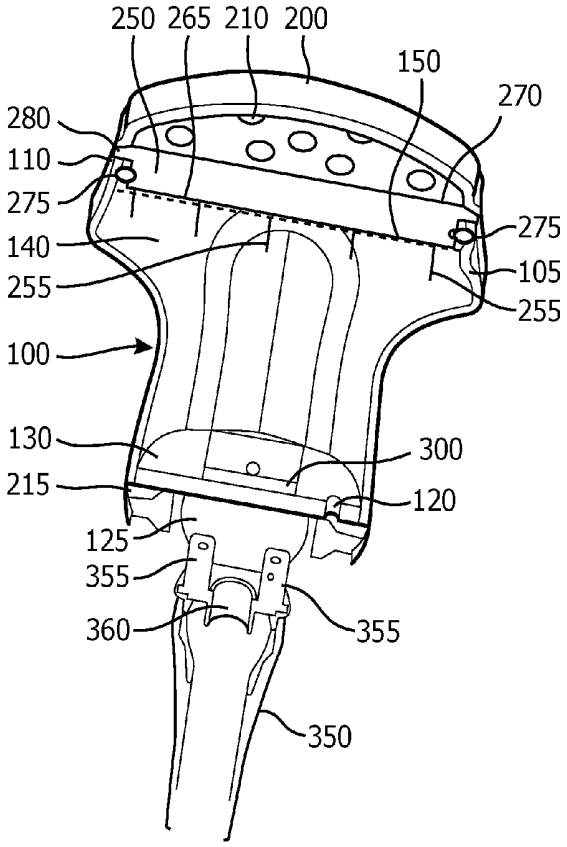
(57) **ABSTRACT**

An ultrasound probe including an active thermal management system is disclosed. The active thermal management system may include a fluid chamber coupled to a transducer assembly of the ultrasound probe. The fluid chamber may include a coolant that may dissipate heat from the transducer assembly. The active thermal management system may further include a heat sink coupled to the fluid chamber and thermal management system. The heat sink may include fins that extend into the coolant. The coolant may be a liquid or a gas. The coolant may be circulated within the fluid chamber by a circulation device. The circulation device may be a pump, a fan, or an impeller. An ultrasound probe may further include a window that forms an enclosure over the lens of the transducer assembly. The enclosure may be fluidly coupled to the fluid chamber and filled with coolant to dissipate heat from the lens.



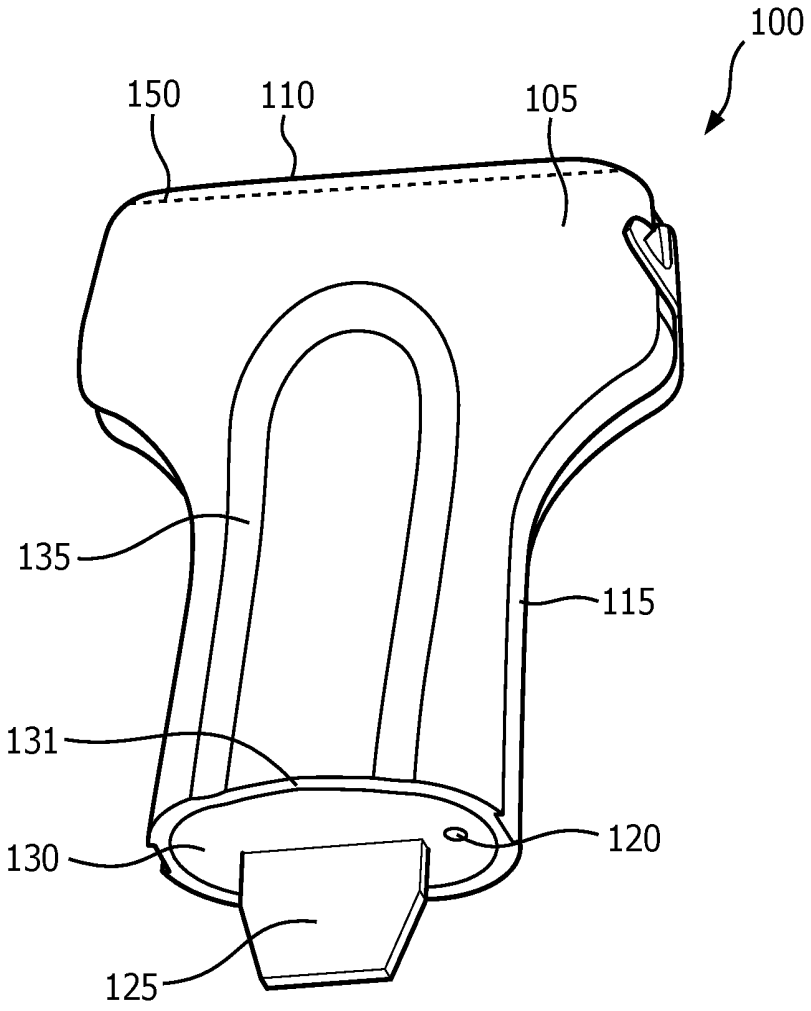


FIG. 1

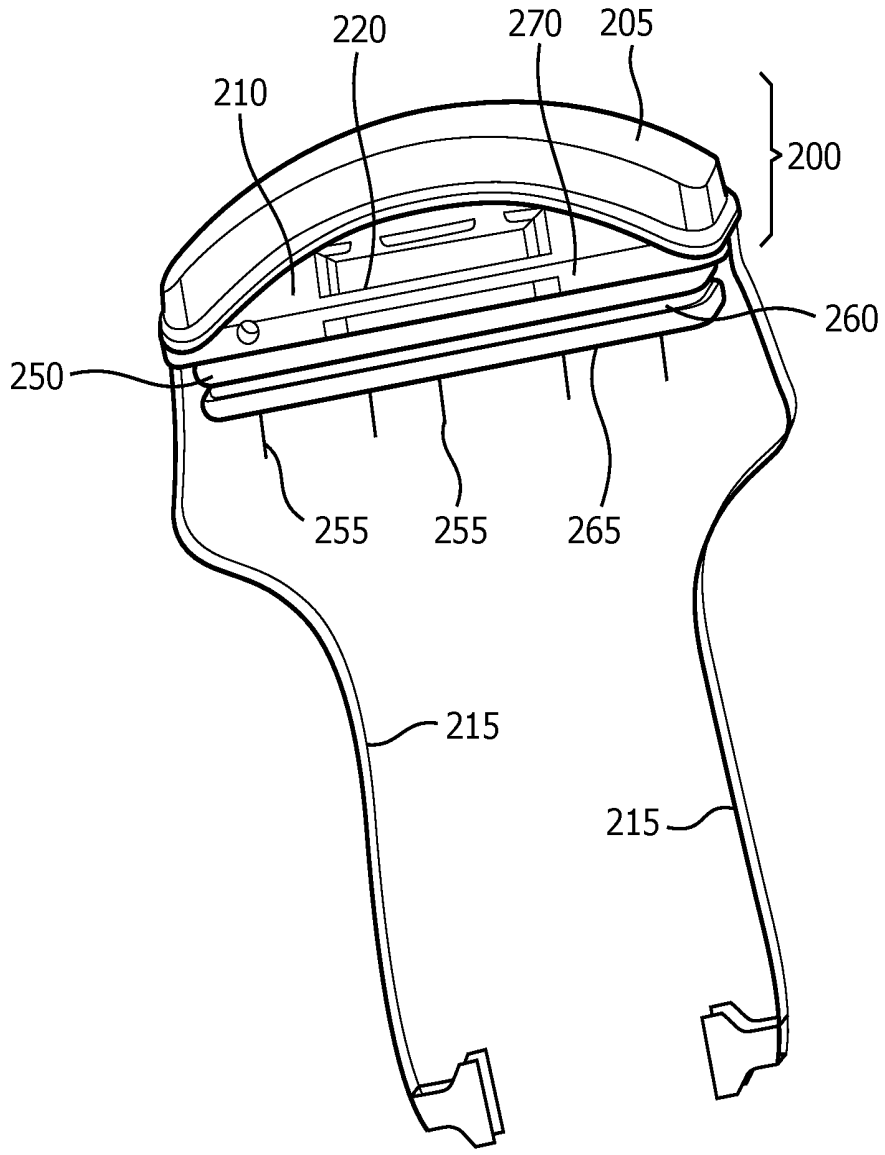
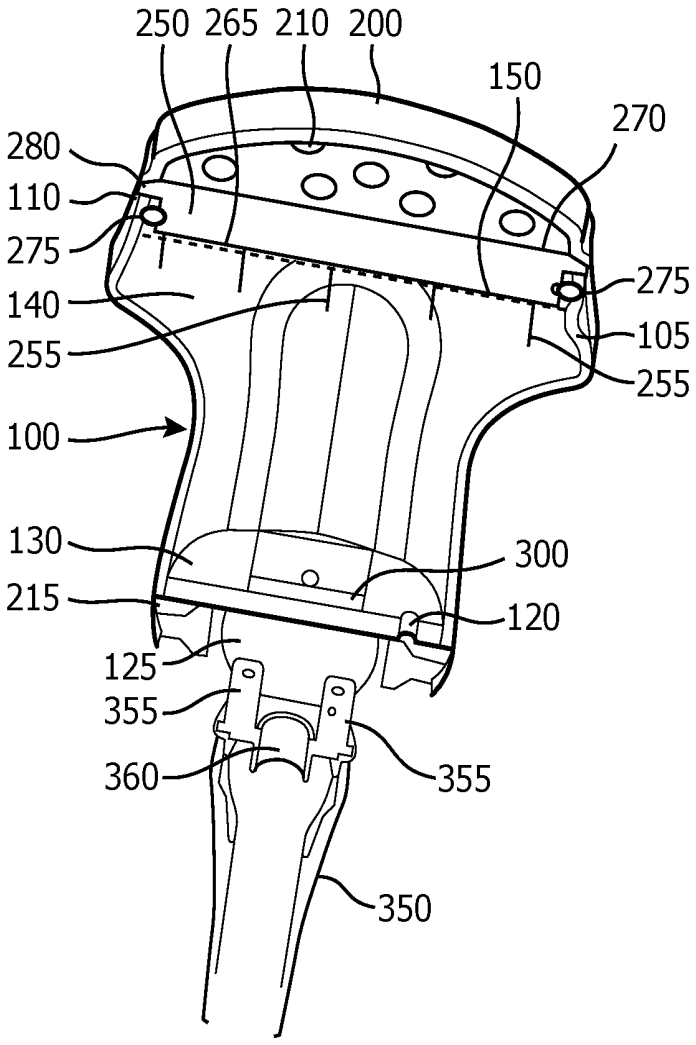


FIG. 2


250
265
210
200
150
270
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110
275
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355
350

FIG. 3

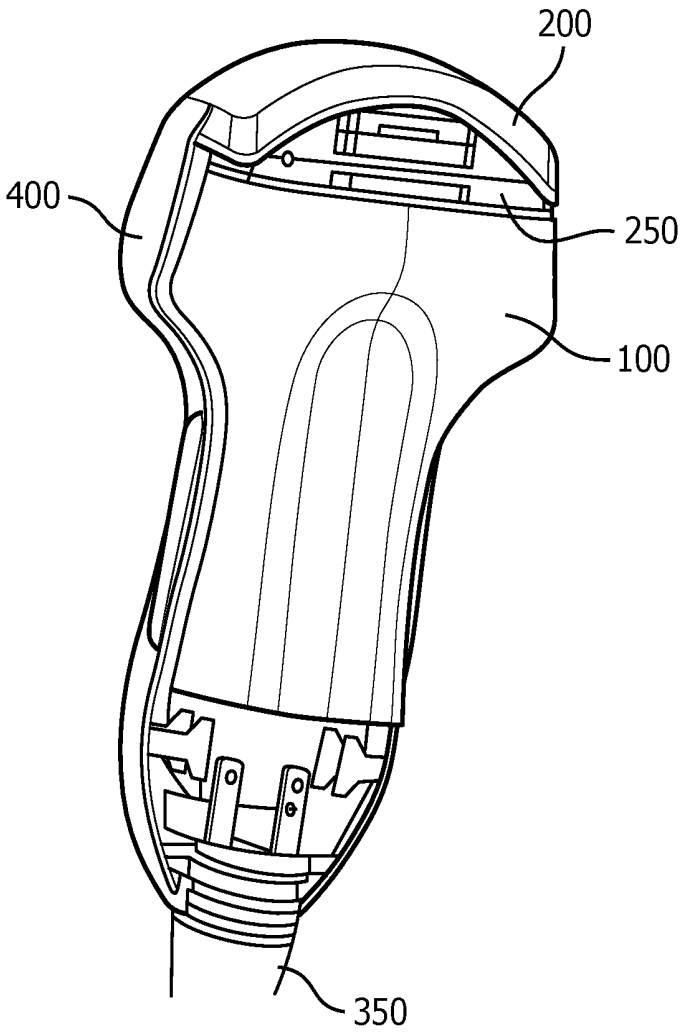

FIG. 4

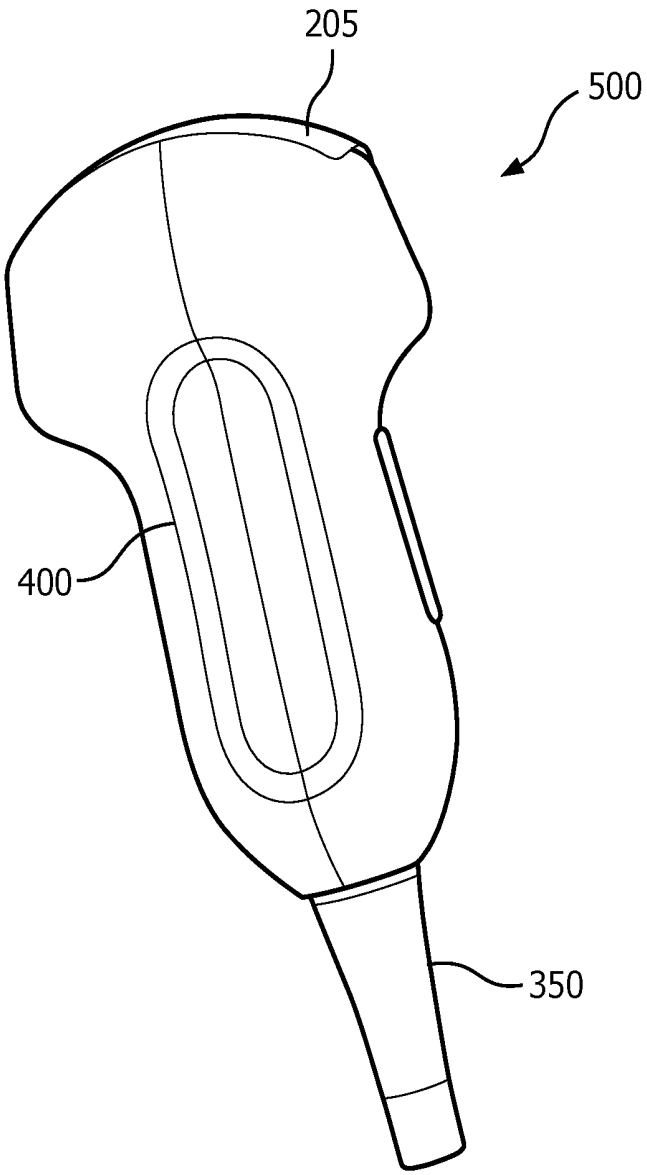

FIG. 5

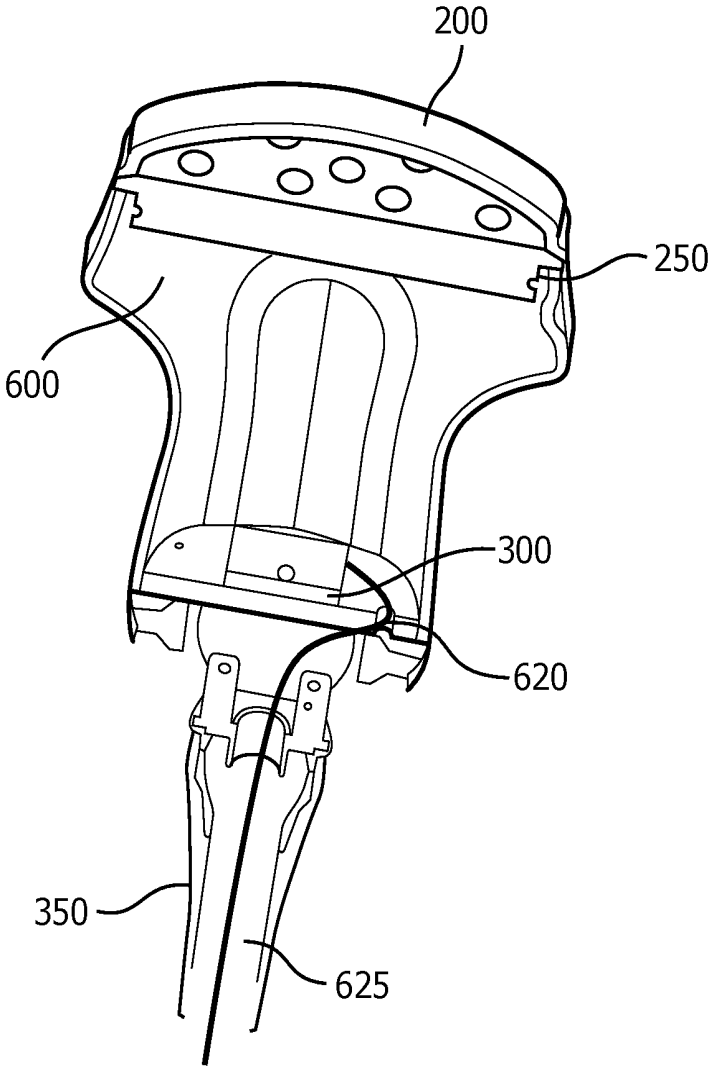

FIG. 6

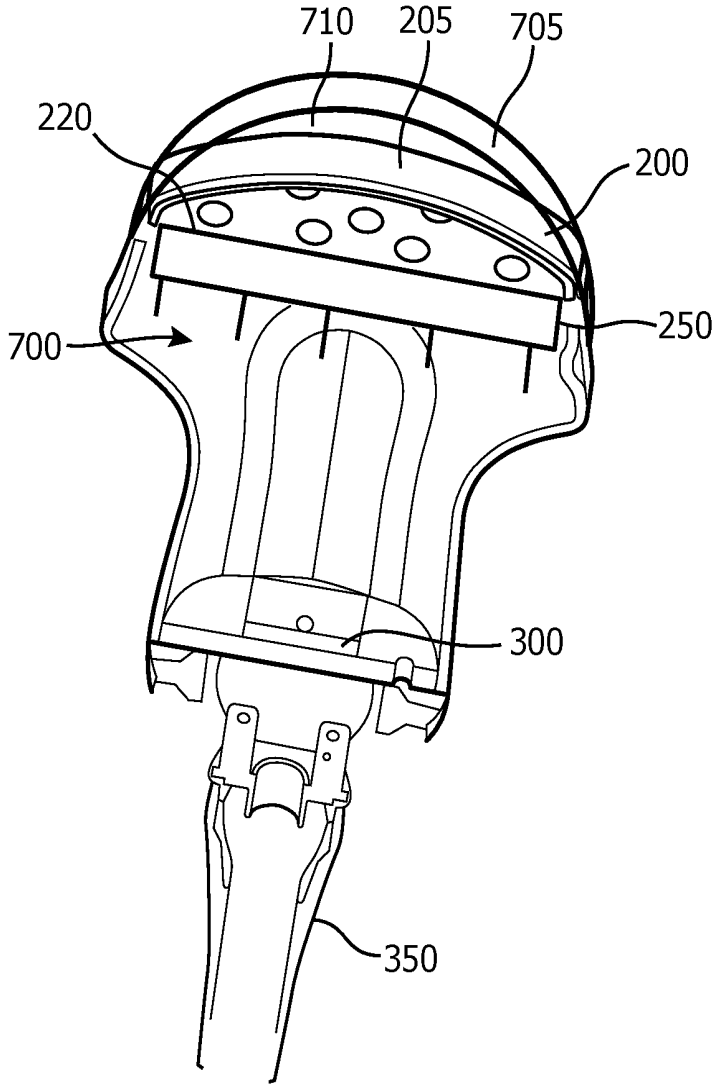

FIG. 7

SYSTEMS, METHODS, AND APPARATUSES FOR ACTIVE THERMAL MANAGEMENT OF ULTRASOUND TRANSDUCERS

BACKGROUND

[0001] Ultrasound transducer arrays produce ultrasound waves for a variety of applications such as imaging, cleaning, and therapeutic treatment of tissue. Many ultrasound transducers convert electrical energy into ultrasound waves, and heat may be produced as a byproduct of the conversion. The heat may require dissipation to avoid damaging the transducer and/or a surface with which the ultrasound transducer is in contact. For example, a medical ultrasound transducer may burn the skin of a patient if heat produced by the transducer is not dissipated adequately.

[0002] Ultrasound transducers may have active and/or passive thermal management systems. Passive systems may include materials that draw heat away from the transducer. For example, an ultrasound probe may include a backing material below the transducer that may dissipate heat away from the transducer surface. However, current passive thermal management systems may not be adequate for new, higher power ultrasound applications such as shear wave imaging.

[0003] Active thermal management systems may include, for example, circulating liquid coolants pumped via conduits adjacent to the transducer array. Coolants may be provided to the conduits via a reservoir within the ultrasound probe or external to the ultrasound probe. Active thermal management systems may be capable of rapidly dissipating heat, active systems may decrease ultrasound probe reliability. For example, a liquid coolant based thermal management system may require circulation tubing and a circulation pump. However, with some liquid coolant based systems, the tubing and pump may be prone to leakage over time as the elements are flexed during use of the ultrasound probe. Leakage of the liquid coolant may damage the internal components of the ultrasound probe and/or reduce the effectiveness of the active thermal management system.

SUMMARY

[0004] An example ultrasound probe according to an embodiment of the disclosure may include a transducer assembly including a transducer and a fluid chamber coupled to the transducer assembly and may be configured to dissipate heat from the transducer assembly, the fluid chamber may include an outer shell having an upper surface and a lower surface, wherein the upper surface may be proximate to the transducer assembly and the lower surface may be distal to the transducer assembly, and a hollow interior may be configured to contain a fluid coolant.

[0005] An example active thermal management system for an ultrasound probe according to an embodiment of the disclosure may include a fluid chamber that may be configured to couple to a transducer assembly of the ultrasound probe and may be further configured to dissipate heat from the transducer assembly, the fluid chamber may include an outer shell having an upper surface and a lower surface, wherein the upper surface may be proximate to the transducer assembly and the lower surface may be distal to the transducer assembly, a hollow interior that may be configured to contain a fluid coolant, a circulation device that may be configured to circulate the fluid coolant, and a sealed port through the outer shell, wherein the sealed port may be configured to allow electrical coupling of a power source to the circulation device.

[0006] A second example ultrasound probe according to an embodiment of the disclosure may include a transducer assembly that may include a lens having a top surface and a bottom surface and a transducer stack coupled to the bottom surface of the lens. The ultrasound probe may also include a fluid chamber that may at least partially enclose the transducer assembly, the fluid chamber may include an outer shell having an upper rim and a lower surface, wherein the upper rim may be proximate to the transducer assembly and the lower surface may be distal to the transducer assembly, a hollow interior that may be configured to contain a fluid coolant, the fluid coolant may be configured to dissipate heat from the transducer assembly, a circulation device that may be configured to circulate the fluid coolant, and a sealed port through the outer shell, wherein the sealed port may be configured to allow electrical coupling of a power source to the circulation device. The ultrasound probe may further include a window coupled to the upper rim of the fluid chamber, the window may be configured to be above and offset from the lens to form an enclosure between the window and the top surface of the lens in fluid communication with the fluid chamber, wherein the fluid coolant may fill the enclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic illustration of a fluid chamber according to an embodiment of the disclosure.

[0008] FIG. **2** is a schematic illustration of a transducer assembly and heat sink according to an embodiment of the disclosure.

[0009] FIG. **3** is a schematic illustration of a cross sectional view of a fluid chamber, heat sink, and transducer assembly according to an embodiment of the disclosure.

[0010] FIG. **4** is a schematic illustration of a side view of a fluid chamber, heat sink, transducer assembly, cable assembly, and a portion of a probe housing according to an embodiment of the disclosure.

[0011] FIG. **5** is a schematic illustration of an ultrasound probe according to an embodiment of the disclosure.

[0012] FIG. **6** is a schematic illustration of a cross sectional view of an alternative fluid chamber, heat sink, and transducer assembly according to an embodiment of the disclosure.

[0013] FIG. **7** is a schematic illustration of a cross sectional view of an alternative fluid chamber, heat sink, and transducer assembly according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0014] The following description of certain exemplary embodiments is merely exemplary in nature and is in no way intended to limit the invention or its applications or uses. In the following detailed description of embodiments of the present systems and methods, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the described systems and methods may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the presently disclosed systems and methods, and it is to be

understood that other embodiments may be utilized and that structural and logical changes may be made without departing from the spirit and scope of the present system.

[0015] The following detailed description is therefore not to be taken in a limiting sense, and the scope of the present system is defined only by the appended claims. The leading digit(s) of the reference numbers in the figures herein typically correspond to the figure number, with the exception that identical components which appear in multiple figures are identified by the same reference numbers. Moreover, for the purpose of clarity, detailed descriptions of certain features will not be discussed when they would be apparent to those with skill in the art so as not to obscure the description of the present system.

[0016] An ultrasound probe may be used for imaging, medical therapy, or other applications. The ultrasound probe includes an ultrasound transducer to produce and receive ultrasound signals (e.g., waves, pulses, sequences). The transducer may be included in a transducer assembly. The transducer may generate heat as it produces and/or receives ultrasound signals. If the temperature of the transducer increases above a threshold temperature, the transducer may be damaged and/or a patient may be injured. For example, supporting electronic components of the transducer assembly may melt and become inoperable or a patient being imaged may suffer a burn on the skin.

[0017] To manage the increase in temperature of the transducer, the probe may include an active thermal management system to dissipate the heat generated by the transducer. The active thermal management system may include a fluid chamber filled with a fluid coolant. A circulation device may be included within the fluid chamber to circulate and/or agitate the coolant throughout the fluid chamber. The fluid chamber may be coupled to the transducer assembly and/or a heat sink coupled to the transducer assembly. Coupling the fluid chamber to the transducer assembly and/or heat sink may allow heat dissipation without the use of tubing and/or other conduits. This may reduce or eliminate potential leakage of coolant in the probe.

[0018] Coupling the fluid chamber to the transducer assembly and/or heat sink without the use of tubing and/or other conduits may facilitate assembly of an ultrasound probe. For example, the fluid chamber may be a separate modular unit that may be installed in an ultrasound probe during assembly. In some embodiments, the modular unit may include the fluid chamber and a heat sink. In some embodiments, the modular unit may be configured to be press fit into another ultrasound probe component, for example, a probe frame, a transducer assembly, and/or a probe housing. In some embodiments, the modular unit may be configured to be snap fit into a resilient ultrasound probe component. This may reduce or eliminate fasteners used to install the modular unit. In some embodiments, the modular unit may facilitate retrofitting of existing ultrasound probes with an active thermal management system.

[0019] The fluid chamber may be embedded in and/or partially enclosed by an ultrasound probe frame. The probe frame may be used to provide support for a transducer assembly, printed circuit boards, and/or other probe components. In some embodiments, the fluid chamber may replace the probe frame.

[0020] The coolant in the fluid chamber may dissipate heat from the transducer assembly and/or heat sink and distribute the heat throughout the coolant and fluid chamber. The heat may be dissipated from the fluid chamber to a probe housing and/or to the air surrounding the probe. The coolant and fluid chamber may dissipate the heat over a wide area. This may prevent the occurrence of "hot spots," that is, localized sections of the ultrasound probe that have a greater temperature than the surrounding probe. Hot spots may damage other portions of the ultrasound probe and/or make the ultrasound probe uncomfortable or dangerous to handle by a user.

[0021] FIG. **1** is a schematic illustration of a fluid chamber **100** according to an embodiment of the disclosure. The fluid chamber **100** may be used in an active thermal management system in an ultrasound probe. The fluid chamber **100** may include an outer shell **105** with a hollow interior (not shown). The hollow interior may be filled with a coolant **150**. The outer shell **105** may comprise molded plastic, metal, and/or another material impermeable to the coolant **150**. The outer shell **105** may be formed as a single integral unit or as multiple components coupled together to form the outer shell **105**. For example, the outer shell **105** may include two injection-molded halves coupled together by epoxy or other coupling method that is impermeable to the coolant. The outer shell **105** may be contoured to fit within the interior of a hand-held ultrasound probe. For example, as shown in FIG. **1**, the outer shell **105** may have a three dimensional "T" shape, where the wide portion of the "T" may be proximate a transducer assembly and/or heat sink. In other examples, the outer shell **105** may be a cylinder, a rectangular prism, or an ovoid. Other shapes of the outer shell **105** may also be used.

[0022] The outer shell **105** may include grooves **115** to accommodate electrical components of the ultrasound probe. For example, the grooves **115** may accommodate printed circuit boards (PCBs) and/or flexible circuits of the ultrasound probe (neither shown). The outer shell **105** may include additional grooves **135** that may promote intimate connection with an interior surface of a probe housing (not shown). For example, the probe housing may include grooves to promote a non-slip grip for a sonographer. The additional grooves **135** may be configured to receive the grooves of the probe housing's inner surface. In another example, the probe housing may include grooves on the inner surface that mate with the additional grooves **135** to facilitate alignment of the outer shell **105** and the probe housing during probe assembly. In some embodiments, the additional grooves **135** may be omitted.

[0023] The outer shell **105** may include a bottom surface **130**. The bottom surface **130** may be flat as illustrated in FIG. **1**. In some embodiments, the bottom surface **130** may be contoured to accommodate the shape of the interior of the ultrasound probe. The bottom surface may include a tang **125**. The tang **125** may extend perpendicularly from the bottom surface **130**. The tang **125** may be located in the center of the bottom surface **130** as illustrated in FIG. **1**. In some embodiments, the tang **125** may extend from an edge of the bottom surface **130**, for example, edge **131**. In some embodiments, multiple tangs may be present. The tang **125** may be trapezoidal, square, half-circle, or another shape. The shape of the tang **125** may be chosen based at least in part, on the shape of the interior of the ultrasound probe. The tang **125** may facilitate mechanical coupling between the fluid chamber **100** and a bend relief ferrule (not shown) of the ultrasound probe. The tang **125** may further facilitate

thermal coupling between a cable assembly (not shown) of the probe and the fluid chamber **100**.

[0024] The bottom surface **130** may include a sealed port **120**. The sealed port **120** may be impermeable to fluid and/or only permit fluid flow in a single direction. The sealed port **120** may facilitate electrical coupling between a power source and a circulation device (neither shown) located in the interior of the fluid chamber **100**. The sealed port **120** may facilitate filling of the fluid chamber **100** with a coolant. In some embodiments, the sealed port may be used to incorporate a fluid expansion chamber and/or bladder to compensate a change in fluid volume, for example, due to temperature change. In some embodiments, the bottom surface **130** may include multiple sealed ports. Separate sealed ports may be used for electrical coupling and filling of the fluid chamber **100**. In some embodiments, the sealed port **120** may be located on another surface of the outer shell **105**. For example, the sealed port **120** may be located in the groove **115**. The sealed port **120** may be implemented with rubber, silicone, and/or other suitable fluid-impermeable material.

[0025] The outer shell **105** may include an upper surface **110**. The upper surface **110** may be sized to match the dimensions of a heat sink and/or a portion of a transducer assembly (neither shown). In some embodiments, the upper surface **110** is a closed surface of the outer shell **105**. In some embodiments, the upper surface **110** may include an upper rim defining a periphery of an opening of the fluid chamber **100**. When the upper surface **110** is open, the coolant of the fluid chamber **100** may come into direct contact with a portion of the heat sink and/or a portion of the transducer assembly.

[0026] FIG. **2** is a schematic illustration of a transducer assembly **200** and heat sink **250** according to an embodiment of the disclosure. The transducer assembly **200** and/or heat sink **250** may be used in combination with a fluid chamber, such as fluid chamber **100** illustrated in FIG. **1**. The transducer assembly **200** may include a lens **205**, a transducer stack **210**, and one or more flexible circuits **215**. The lens **205** may be coupled to an upper surface of the transducer stack **210**. The lens **205** may acoustically couple the transducer stack **210** to an object to be imaged. The transducer stack **210** may include one or more ultrasound transducer elements. The transducer stack **210** may include supporting electronic components for the transducer elements. For example, electrical coupling to a power supply, control signals, data signals, and/or other circuits. The flexible circuits **215** may be coupled to a lower surface and/or edge of the transducer stack **210**. The flexible circuits **215** may electrically couple transducer elements and/or other electronic components of the transducer stack **210** to additional electronic components in an ultrasound probe or components of an ultrasound imaging system (not shown). The flexible circuits **215** may provide electrical power and/or communication between the transducer stack **210** and other components.

[0027] The heat sink **250** may be a rectangular plate having an upper surface **270** and a lower surface **265** parallel to the upper surface **270**. The upper surface **270** of a heat sink **250** may be positioned against the lower surface **220** of the transducer assembly **200**. In some embodiments, the lower surface **220** may be a lower surface of an acoustic backing included in the transducer assembly **200**. The heat sink **250** may be coupled to the transducer assembly **200** by fasteners (e.g., screws), adhesives (e.g., epoxy), and/or compression. In some embodiments, a thermally conductive laminate may be applied to the upper surface **270** of the heat sink and/or the lower surface **220** of the transducer assembly **200** to increase heat transfer from the transducer assembly **200** to the heat sink **250**. The upper surface **270** of the heat sink **250** may be contoured to be flush against the lower surface **220** of the transducer assembly **200**. The upper surface **270** of the heat sink **250** may be sized to cover the lower surface **220** of the transducer assembly. In some embodiments, the upper surface **270** of the heat sink **250** may be sized to cover a portion of the lower surface **220** of the transducer assembly. The heat sink **250** may be implemented with aluminum, another metal, and/or another heat conducting material.

[0028] In some embodiments, the heat sink **250** includes a gland **260** extending around a periphery of the heat sink **250**. The gland **260** may be configured to accept an O-ring (not shown). The O-ring may facilitate the formation of a fluid-impermeable coupling between the heat sink **250** and a fluid chamber (not shown), such as fluid chamber **100** illustrated in FIG. **1**. The O-ring may engage an inner surface of an outer shell of the fluid chamber and/or an upper rim of the outer shell. In some embodiments, the O-ring and gland **260** may be omitted. For example, if an upper surface of the outer shell is closed, the heat sink **250** may be coupled to the outer shell by compression, a thermal laminate, and/or other coupling method. In some embodiments, if the upper surface of the outer shell is closed, the heat sink **250** may be omitted, and the transducer assembly **200** may be coupled to the upper surface of the fluid chamber.

[0029] In some embodiments, a lower surface **265** of the heat sink **250** may include one or more fins **255** extending from the lower surface **265**. The fins **255** may extend perpendicularly from the lower surface or at another angle. The fins **255** may be parallel to one another or intersect. The fins **255** may form straight lines or another pattern (e.g., waves, concentric circles, zig-zags). In some embodiments, the pattern formed by the fins **255** may be chosen to induce a desired circulation pattern of a fluid in contact with the fins **255**. The fins **255** may be in contact with an upper surface of a fluid chamber. If the upper surface of the fluid chamber is open, the fins **255** may extend into the interior of the fluid chamber. The fins **255** may contact a coolant within the fluid chamber. In some embodiments, the fins **255** are omitted, and the lower surface **265** of the heat sink **250** is flat or contoured to be flush against the upper surface of the fluid chamber.

[0030] FIG. **3** is a schematic illustration of a cross sectional view of a fluid chamber **100**, heat sink **250**, and transducer assembly **200** according to an embodiment of the disclosure. The transducer assembly **200** may be in contact with the heat sink **250**. The transducer assembly **200** may also be in contact with the fluid chamber **100** in some embodiments. The heat sink **250** may be in contact with the fluid chamber **100**. The flexible circuits **215** of the transducer assembly **200** may extend on either side of the heat sink **250** and extend on either side of the fluid chamber **100**. The flexible circuits **215** may extend through grooves (not shown) of the outer shell **105** of the fluid chamber **100**. For example, the flexible circuits **215** may extend through grooves **115** illustrated in FIG. **1**. In some embodiments, the flexible circuits **215** extend beyond the fluid chamber **100** as shown in FIG. **3**. The flexible circuits **215** may couple to one

or more PCB's (not shown), a cable assembly **350**, and/or other ultrasound probe component.

[0031] As shown in FIG. **3**, in some embodiments, the heat sink **250** may be at least partially enclosed by the fluid chamber **100**. The heat sink **250** may be press fit into the fluid chamber **100**. An O-ring **275** around a periphery of the heat sink **250** may engage an inner surface **140** of the fluid chamber **100** to form a fluid-impermeable seal. The O-ring **275** may be positioned within a gland (not shown), such as gland **260** illustrated in FIG. **2**. The O-ring **275** may be implemented with rubber, silicone, and/or other fluid-impermeable, resilient material.

[0032] In some embodiments, the heat sink **250** may include a flange **280** that extends around and beyond a periphery of the heat sink **250** proximate the upper surface **270**. The flange **280** may be between the O-ring **275** and the upper surface **270**. The flange **280** may contact an upper surface and/or rim **110** of the fluid chamber **100**. The flange **280** may act as a stop to prevent the heat sink **250** from being fully enclosed by the fluid chamber **100**. The engagement of the flange **280** and upper surface and/or rim **110** of the fluid chamber **100** may enhance the fluid-impermeable seal formed by the O-ring **275** and the inner surface **140**. In some embodiments, the flange **280** may extend from the heat sink **250** to be flush with the outer surface of the outer shell **105**. In some embodiments, the flange **280** may extend beyond the outer shell **105**. In some embodiments, the flange **280** may be omitted. For example, the O-ring **275** may act as a stop to prevent the heat sink **250** from being fully enclosed by the fluid chamber **100**. In another example, the sides of the heat sink **250** may be tapered so that the lower surface **265** has a smaller area than the upper surface **270**. The area of the upper surface **270** may be greater than an area of an opening of the fluid chamber **100**.

[0033] The lower surface **265** of the heat sink **250** may be in contact with a coolant **150** in the fluid chamber **100**. The coolant **150** may dissipate heat from the lower surface **265**. As described previously in reference to FIG. **2**, the lower surface **265** may include fins **255** that extend into the coolant **150**. The fins **255** may increase the surface area of the heat sink **250** in contact with the coolant **150**. This may increase heat transfer between the heat sink **250** and the coolant. In some embodiments, the fins **255** may be omitted, and the lower surface **265** may be in contact with and/or submerged in the coolant.

[0034] The coolant **150** may be a non-electrically conductive coolant, for example mineral oil or silicone oil. In some embodiments, the coolant **150** is an electrically conductive coolant, for example, water or propylene glycol. In some embodiments, the coolant **150** is a gas such as air, nitrogen, or helium. Other coolants may be used. A mixture of coolants may be used.

[0035] The coolant **150** may fully fill the fluid chamber **100**. This may facilitate heat dissipation throughout the fluid chamber **100**. In some embodiments, the coolant **150** may not fully fill the fluid chamber **100**. The coolant **150** may dissipate heat throughout the fluid chamber **100**, even when it does not fully fill the fluid chamber **100**. The coolant **150** may or may not expand and/or contract over the temperature range of the ultrasound probe. If the coolant **150** expands and/or contracts over the temperature range, a compliant compensation bladder (not shown) may be included in the fluid chamber **100**. In some embodiments, the compensation bladder may be coupled to a sealed port, which may be similar to sealed port **120**, which may allow contraction and expansion of the compensation bladder. The compensation bladder may be implemented using rubber, a polymer, and/or another coolant-impermeable elastic material.

[0036] The coolant **150** may be circulated to increase heat dissipation from the heat sink **250** to the coolant **150**. The coolant **150** may be circulated by manual agitation of the fluid chamber **100**. For example, a sonographer may agitate the fluid chamber **100** to provide sufficient coolant circulation by moving an ultrasound probe including the fluid chamber **100** during an exam. In some embodiments, the fluid chamber **100** may include a circulation device **300**. As shown in FIG. **3**, the circulation device **300** may be coupled to the bottom surface **130** of the fluid chamber **100** in some embodiments. However, the circulation device **300** may be coupled to another portion of the inner surface **140** of the fluid chamber **100**. Electrical coupling may be provided to the circulation device by sealed port **120**. In some embodiments, the circulation device **300** may be a piezoelectric pump that circulates the coolant within the fluid chamber. In some embodiments, the piezoelectric pump may be parylene coated. Other pump types may also be used. In some embodiments, the circulation device **300** may be an impeller. In some embodiments, the circulation device **300** may be a fan. The circulation device **300** may circulate the coolant **150** within the fluid chamber **100** during operation of the ultrasound probe. In some embodiments, the circulation device **300** may continue to circulate the coolant **150** for a period of time after the ultrasound transducer has been used to dissipate remaining heat from the heat sink **250** and/or transducer assembly **200**.

[0037] In some embodiments, the operation of the circulation device **300** may be based, at least in part, on signals received from one or more sensors (not shown). For example, a temperature sensor may be included with the fluid chamber **100**, transducer assembly **200**, and/or heat sink **250**. The circulation device **300** and/or a circulation device controller (not shown) may be programmed to increase circulation of the coolant **150** when the temperature sensor detects a temperature above a threshold temperature. In another example, an accelerometer may be included in the ultrasound probe. The circulation device **300** and/or a circulation device controller may be programmed to circulate the coolant **150** when the accelerometer detects the ultrasound probe is not being moved by the sonographer to adequately agitate the coolant **150**.

[0038] Still referring to FIG. **3**, tabs **355** may couple to tang **125** to couple the fluid chamber **100** to a bend relief ferrule **360** of a cable assembly **350**. The tabs **355** may be coupled to the tang **125** using a fastener (e.g. screw), soldering, and/or other coupling method. The tabs **355** and relief ferrule **360** may be implemented using metal and/or plastic. In some embodiments, the tabs **355** and relief ferrule **360** may dissipate heat from the tang **125** to the cable assembly **350**. The cable assembly **350** may provide power to the fluid chamber **100**, flexible circuits **215**, and/or other ultrasound probe components. The cable assembly **350** may also receive and transmit data and/or control signals to the fluid chamber **100**, flexible circuits **215**, and/or other ultrasound probe components. The cable assembly **350** may couple the ultrasound probe components to an ultrasound imaging system (not shown).

[0039] In an alternative embodiment, the lower surface **265** of the heat sink **250** may be in contact with the upper

surface **110** of the fluid chamber **100** (not shown in FIG. **3**). The O-ring **275**, gland **265**, and flange **280** of the heat sink **250** may be omitted. The lower surface **265** may be flush with the upper surface **110**. In some embodiments, a thermal laminate may be applied to the lower surface **265** and/or upper surface **110** to reduce thermal resistance. Heat may be dissipated from the transducer assembly **200** through the heat sink **250** to the upper surface **110**. The coolant **150** may dissipate heat from the upper surface **110** throughout the fluid chamber **100**. The closed fluid chamber **100** may provide resistance to leakage of coolant **150** in the ultrasound probe.

[0040] FIG. **4** is a schematic illustration of a side view of a fluid chamber **100**, heat sink **250**, transducer assembly **200**, cable assembly **350**, and a portion of a probe housing **400** according to an embodiment of the disclosure. The probe housing **400** may enclose the fluid chamber **100**, heat sink **250**, at least a portion of the transducer assembly **200**, and at least a portion of the cable assembly **350**. The probe housing **400** may conform to the outer surface of the fluid chamber **100**. In some embodiments, the probe housing **400** may dissipate heat from the outer surface of the fluid chamber **100** to the air surrounding an ultrasound probe. In some embodiments, the probe housing **400** may include a heat spreader (not shown) on an inner surface of the probe housing that is in contact with the outer surface of the fluid chamber **100**. The heat spreader may reduce thermal resistance between the probe housing **400** and the fluid chamber **100**. In some embodiments, the heat spreader may include a thermal interface material between the heat spreader and the fluid chamber **100**.

[0041] FIG. **5** is a schematic illustration of an ultrasound probe **500** according to an embodiment of the disclosure. The probe housing **400** may enclose all of the components of the probe except for the lens **205** and a portion of the cable assembly **350**. In some embodiments, the probe housing **400** is a thermoplastic shell. In some embodiments, the probe housing **400** is omitted, and a robust finish is applied to the exterior of the fluid chamber **100** which may act as a handle for the probe.

[0042] FIG. **6** is a schematic illustration of a cross sectional view of an alternative fluid chamber **600**, heat sink **250**, and transducer assembly **200** according to an embodiment of the disclosure. In the embodiment illustrated in FIG. **6**, the coolant is a gas, for example, air. The circulation device **300** may be a fan, an air pump, and/or another suitable gas circulator. The circulation device **300** may be included in a zero insertion force (ZIF) enclosure in some embodiments. Other connector types may also be used. Power may be provided via the cable assembly **350** via port **620**. Gas may also pass through port **620** into the fluid chamber **600**. The gas may be circulated by the circulation device **300** to dissipate heat from the heat sink **250**. The heat sink **250** may be configured similarly to the heat sinks previously described with reference to FIGS. **2-4**. In some embodiments, the fluid chamber **600** may include multiple ports to allow passage of gas into and out of the fluid chamber **600**. In some embodiments, the ports may include a mesh, filter, and/or barrier material to prevent moisture and/or debris from passing through the ports. In some embodiments, the fluid chamber **600** may be omitted and gas may circulate within a probe housing.

[0043] In some embodiments, gas may be provided to the circulation device **300** by a tube **625**. The tube **625** may be coupled to the circulation device **300** and pass through the port **620** and into the cable assembly **350**. The distal end (not shown) of the tube **625** may be coupled to an air supply. The gas supply may be filtered to reduce introducing dust and/or other contaminants into the ultrasound probe. The gas supply may be chilled which may increase heat dissipation from the heat sink **250**. After circulation by the circulation device **300**, the gas may be exhausted via port **620** and/or additional ports in the fluid chamber **600**. The gas may exit the ultrasound probe via interstitial areas of the cable assembly. In some embodiments, gas may be exhausted via a separate exhaust tube (not shown). The separate exhaust tube may pass through port **620** or a separate port. The distal end of the exhaust tube may be coupled to the gas supply.

[0044] In some embodiments, pressurized gas may be provided to the fluid chamber **600** by tube **625**. The circulation device **300** may be omitted when pressurized gas is utilized. The pressure of the gas may provide for circulation of the gas within the fluid chamber **600**.

[0045] FIG. **7** is a schematic illustration of a cross sectional view of an alternative fluid chamber **700**, heat sink **250**, and transducer assembly **200** according to an embodiment of the disclosure. The fluid chamber **700** may extend to enclose a portion of the transducer assembly **200**. A window **705** may be coupled to the fluid chamber **700** and/or probe housing (not shown) and offset over the lens **205** to form an enclosure **710**. The window **705** may be contoured to match a contour of lens **205**. The window **705** may be contoured to provide an enclosure **710** of a desired shape and/or volume, for example, a dome. The window **705** may be plastic and/or other fluid-impermeable material that provides acoustical coupling to a subject. The window **705** may be acoustically transparent. The enclosure **710** may be fluidly coupled to the fluid chamber **700**. Coolant may fill the fluid chamber **700** and the enclosure **710**. The coolant may dissipate heat from the lens **205**. The coolant may provide acoustical coupling between the window **705** and the lens **205**. In some embodiments, the heat sink **250** may be omitted, and the coolant may dissipate heat from the lower surface **220** of the transducer assembly **200**.

[0046] Although the present system has been described with reference to an ultrasound imaging system, the present system may be extended to other ultrasound transducers. Additionally, the present system may be used to obtain and/or record image information related to, but not limited to renal, testicular, prostate, breast, ovarian, uterine, thyroid, hepatic, lung, musculoskeletal, splenic, nervous, cardiac, arterial and vascular systems, as well as other imaging applications related to ultrasound-guided interventions and other interventions which may be guided by real-time medical imaging. Further, the present system may also include one or more elements which may be used with non-ultrasound imaging systems with or without real-time imaging components so that they may provide features and advantages of the present system.

[0047] Further, the present methods, systems, and apparatuses may be applied to existing imaging systems such as, for example, ultrasonic imaging systems. Suitable ultrasonic imaging systems may include a Philips® ultrasound system which may, for example, support a conventional broadband linear array transducer that may be suitable for small-parts imaging.

[0048] Certain additional advantages and features of this invention may be apparent to those skilled in the art upon

studying the disclosure, or may be experienced by persons employing the novel system and method of the present invention, chief of which is thermal dissipation in ultrasound transducers and method of operation thereof is provided. Another advantage of the present systems and method is that conventional medical image systems may be easily upgraded to incorporate the features and advantages of the present systems, devices, and methods.

[0049] Of course, it is to be appreciated that any one of the above embodiments or processes may be combined with one or more other embodiments and/or processes or be separated and/or performed amongst separate devices or device portions in accordance with the present systems, devices and methods.

[0050] Finally, the above-discussion is intended to be merely illustrative of the present system and should not be construed as limiting the appended claims to any particular embodiment or group of embodiments. Thus, while the present system has been described in particular detail with reference to exemplary embodiments, it should also be appreciated that numerous modifications and alternative embodiments may be devised by those having ordinary skill in the art without departing from the broader and intended spirit and scope of the present system as set forth in the claims that follow. Accordingly, the specification and drawings are to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims.

1. An ultrasound probe comprising:
- a transducer assembly including a transducer; and
- a fluid chamber coupled to the transducer assembly and configured to dissipate heat from the transducer assembly, the fluid chamber comprising:
  - an outer shell having a first surface and a second surface, wherein the first surface is proximate to the transducer assembly and the second surface is distal to the transducer assembly; and
  - a hollow interior configured to contain a fluid coolant, wherein the fluid chamber is configured to receive and seal the fluid coolant within the hollow interior.

2. The ultrasound probe of claim **1**, further comprising a heat sink configured to dissipate heat from the transducer assembly to the fluid chamber, the heat sink comprising:
- a surface coupled to the second surface of the transducer assembly;
- a different surface in contact with the fluid chamber;
- a gland around a periphery of the heat sink; and
- an O-ring disposed in the gland.

3. The ultrasound probe of claim **2**, wherein the O-ring is configured to engage the hollow interior to form a fluid-impermeable seal.

4. The ultrasound probe of claim **2**, wherein the different surface includes a fin extending from the lower surface into the fluid chamber.

5. The ultrasound probe of claim **2**, wherein the heat sink further includes a flange around the periphery proximate the surface coupled to the second surface, the flange configured to contact a rim of the first surface of the outer shell.

6. The ultrasound probe of claim **1**, further comprising:
- a circulation device located within the hollow interior and configured to circulate the fluid coolant within the hollow interior of the fluid chamber; and
- a sealed port through the outer shell, wherein the sealed port is configured to allow electrical coupling of a power source to the circulation device.

7. The ultrasound probe of claim **1**, wherein the fluid chamber further comprises a tang extending from the second surface, wherein the tang is configured to couple the fluid chamber to a cable assembly.

8. The ultrasound probe of claim **1**, further comprising a probe housing configured to enclose the fluid chamber and at least a portion of the transducer assembly.

9. The ultrasound probe of claim **1**, wherein the fluid chamber includes grooves in the outer shell configured to accept a flexible circuit coupled to the transducer assembly.

10. An active thermal management system for an ultrasound probe, the active thermal management system comprising:
- a fluid chamber configured to couple to a transducer assembly of the ultrasound probe and configured to dissipate heat from the transducer assembly, the fluid chamber comprising:
  - an outer shell having a first surface and a second surface, wherein the first surface is proximate to the transducer assembly and the second surface is distal to the transducer assembly;
  - a hollow interior configured to contain a fluid coolant;
  - a circulation device located within the hollow interior and configured to circulate the fluid coolant within the hollow interior; and
  - a sealed port through the outer shell, wherein the sealed port is configured to allow electrical coupling of a power source to the circulation device and wherein the sealed port is further configured to seal the fluid coolant within the hollow interior.

11. The active thermal management system of claim **10**, wherein the circulation device comprises a pump or an impeller.

12. The active thermal management system of claim **10**, further comprising a temperature sensor coupled to the fluid chamber and configured to detect a temperature of the fluid chamber.

13. The active thermal management system of claim **10**, further comprising a controller configured to increase circulation of the coolant by the circulation device when the temperature sensor detects a temperature above a threshold temperature.

14. The active thermal management system of claim **10**, wherein the fluid coolant comprises a liquid, a gas, or a mixture thereof.

15. The active thermal management system of claim **10**, wherein the circulation device comprises a fan.

* * * * *

专利名称(译)	用于超声换能器的主动热管理的系统，方法和设备		
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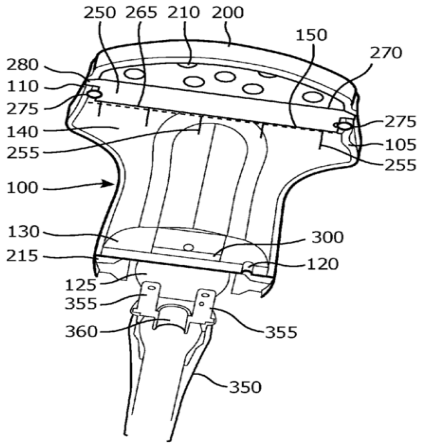
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