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(54) **THERMAL MANAGEMENT SYSTEM AND METHOD**

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(52) **U.S. Cl.**
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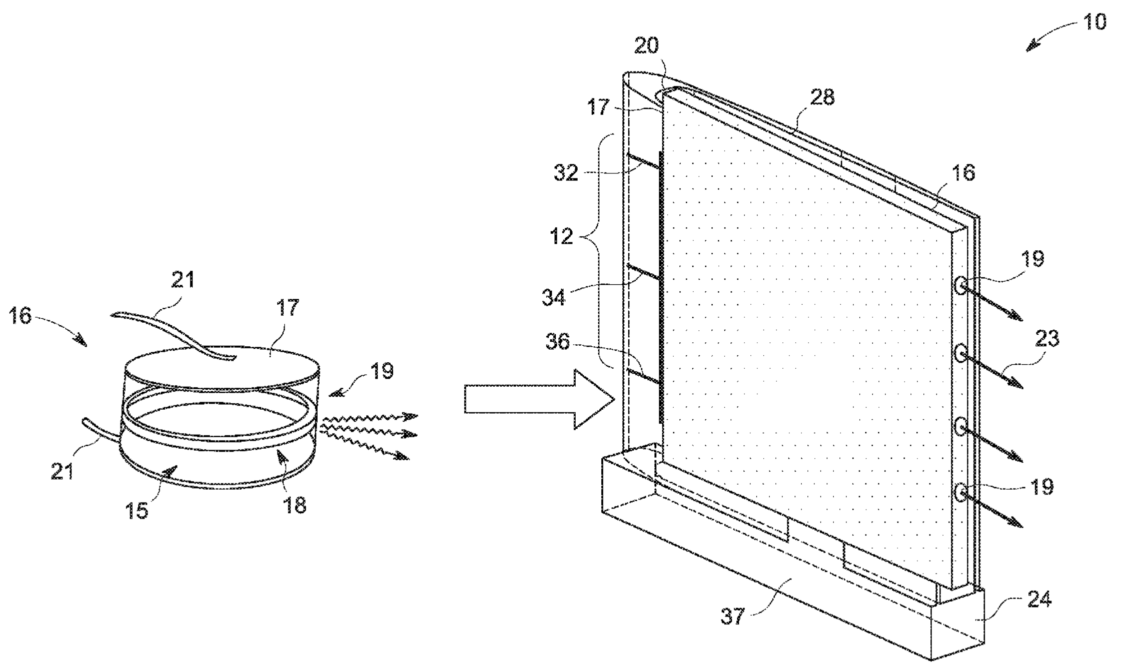
(57) **ABSTRACT**

A thermal management system is provided. The thermal management system includes at least one heat sink including one or more respective fins, wherein the one or more fins include one or more respective cavities. The thermal management system also includes a synthetic jet stack including at least one synthetic jet mounted within each of the respective cavities employing at least one engaging structure to provide a rigid positioning of the synthetic jet stack within the fins, wherein the synthetic jet includes at least one orifice through which a fluid is ejected.



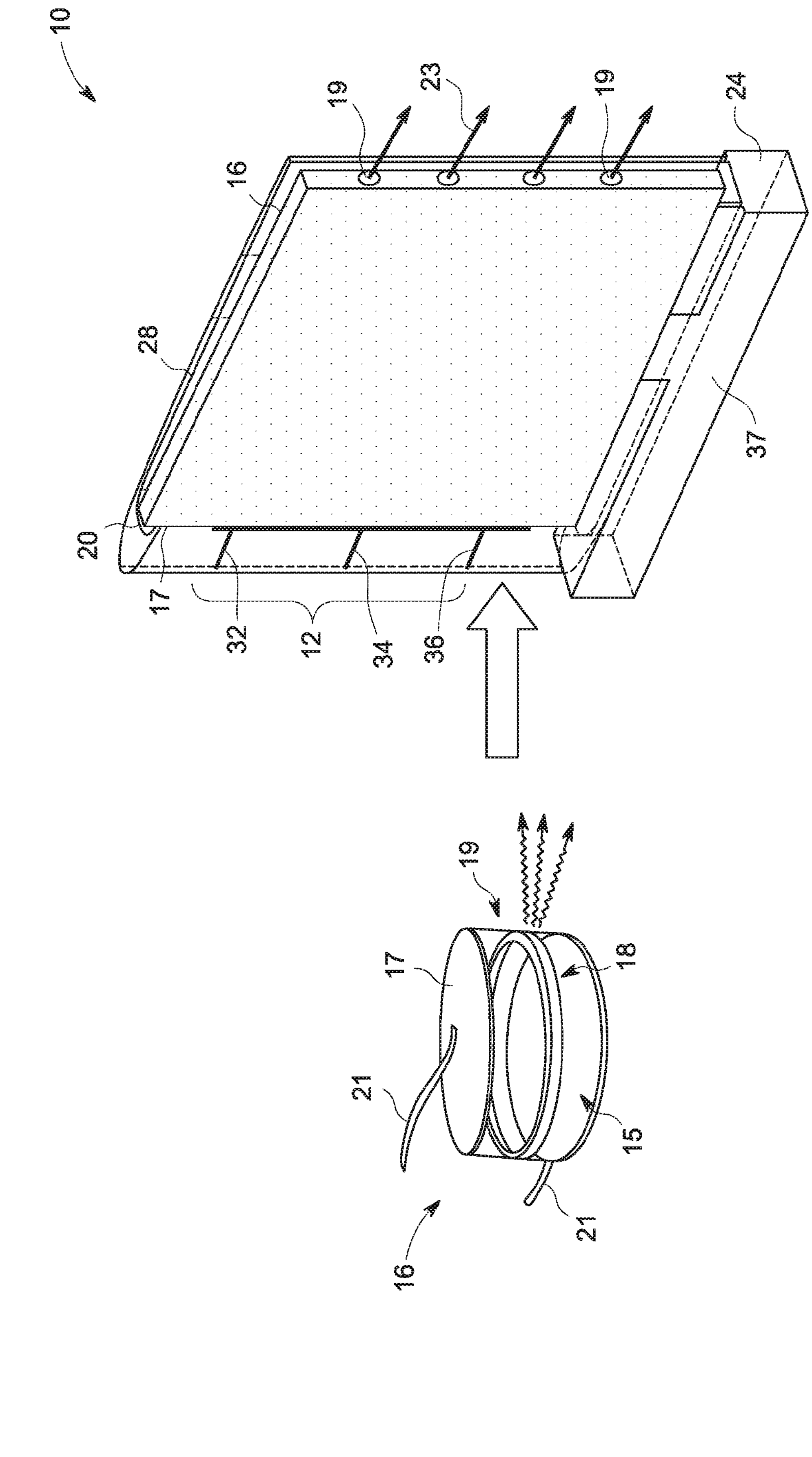


FIG. 1

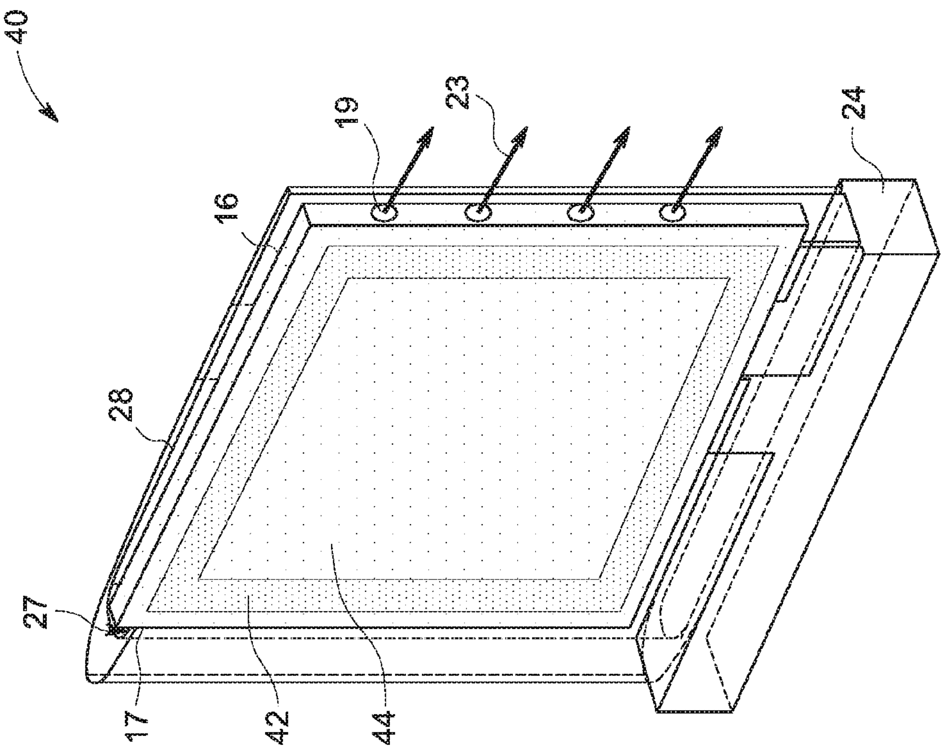


FIG. 2

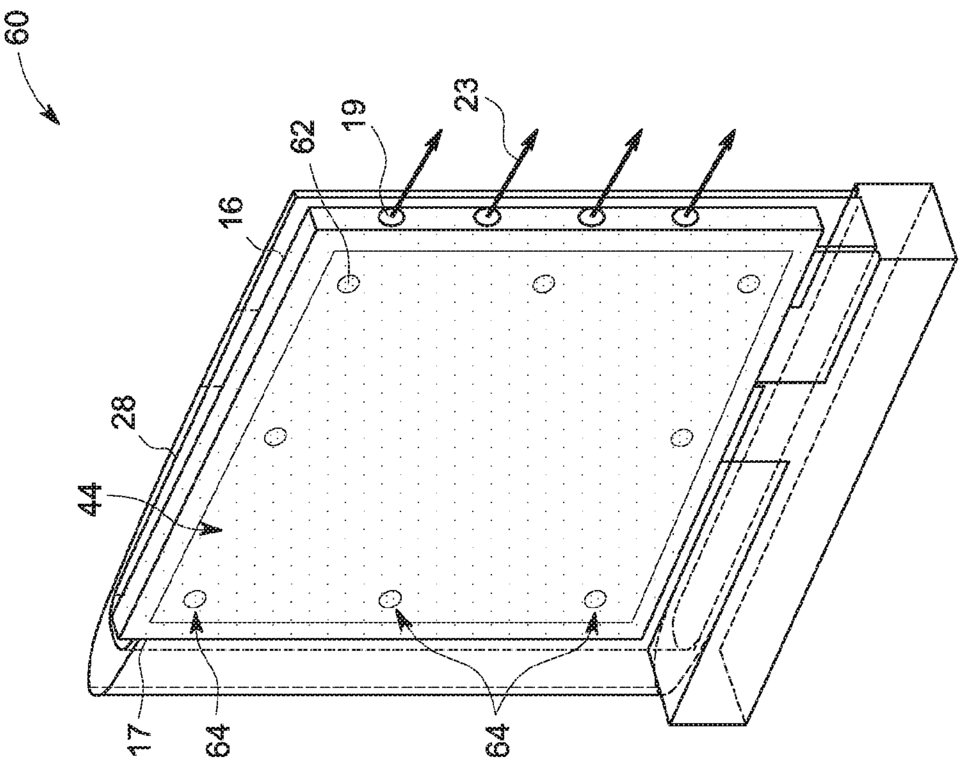


FIG. 3

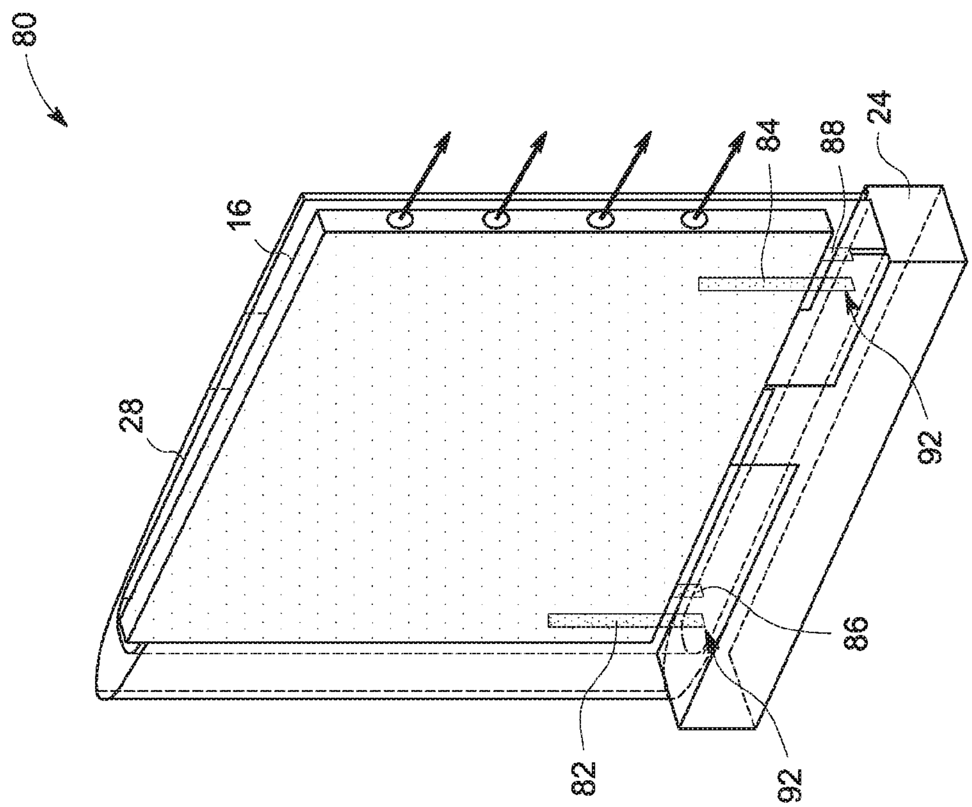


FIG. 4

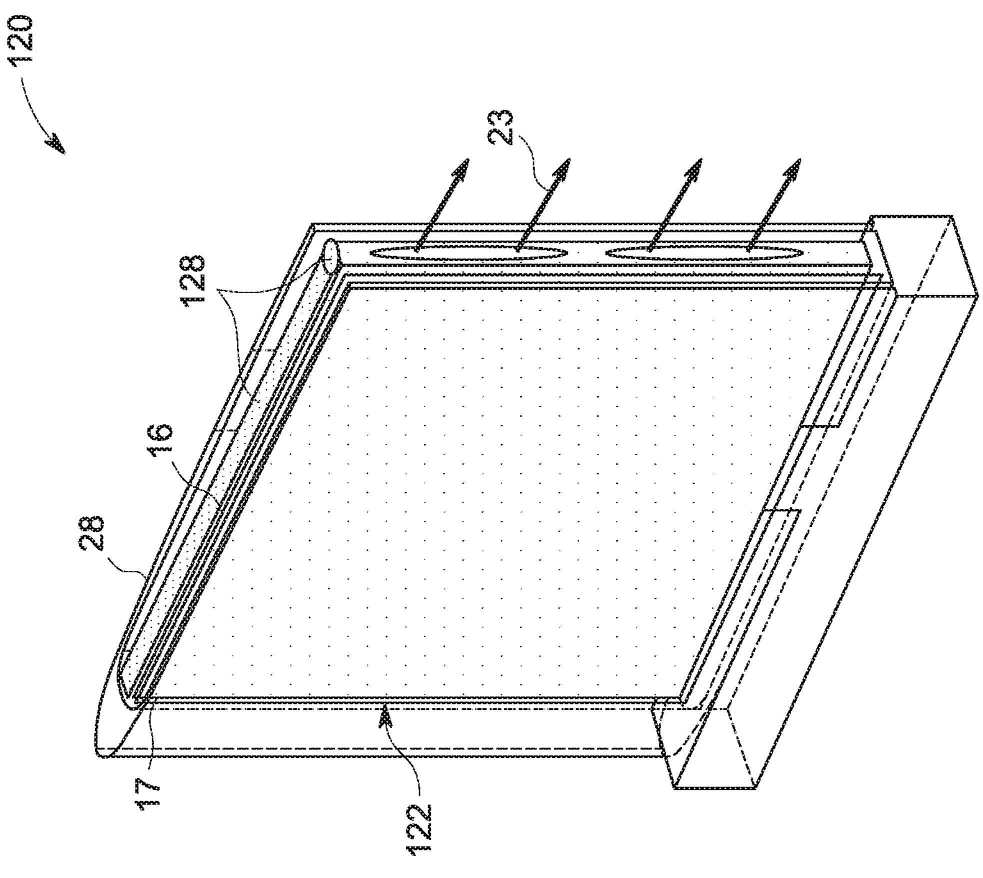


FIG. 5

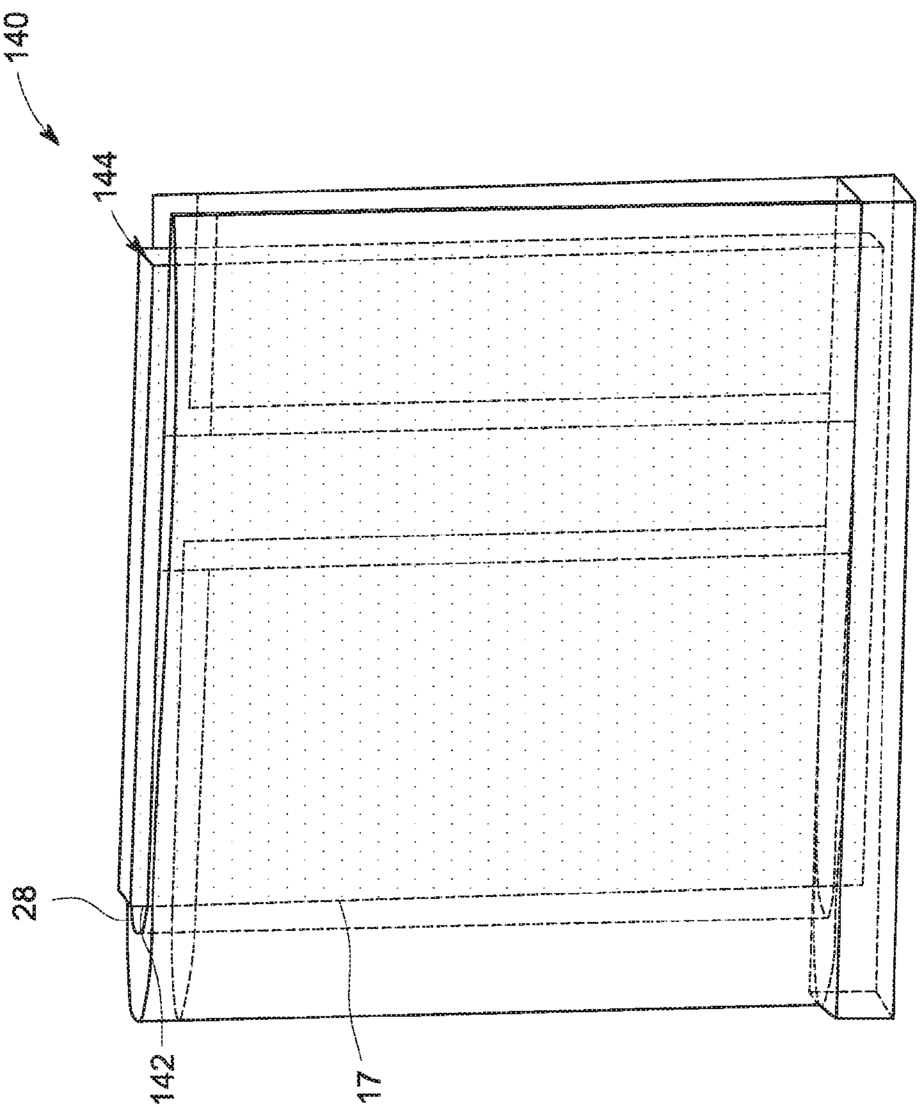


FIG. 6

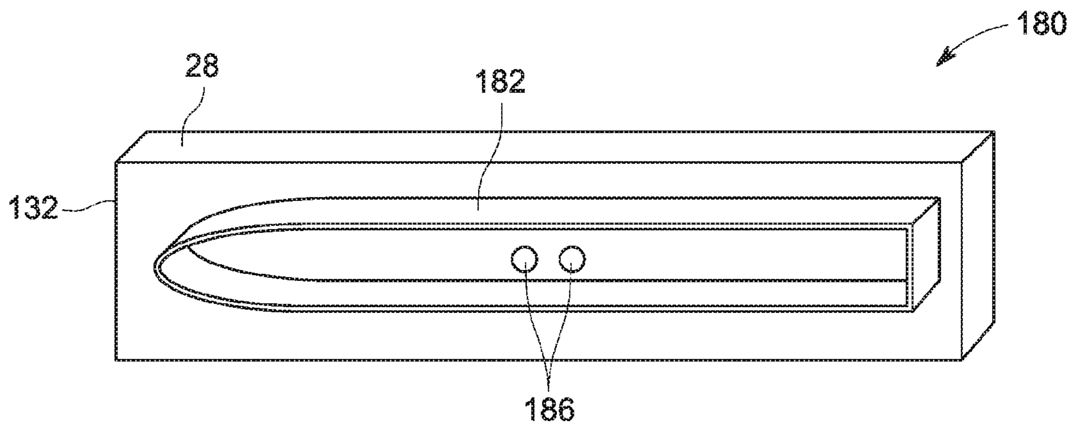

180
28
182
132
186

FIG. 7

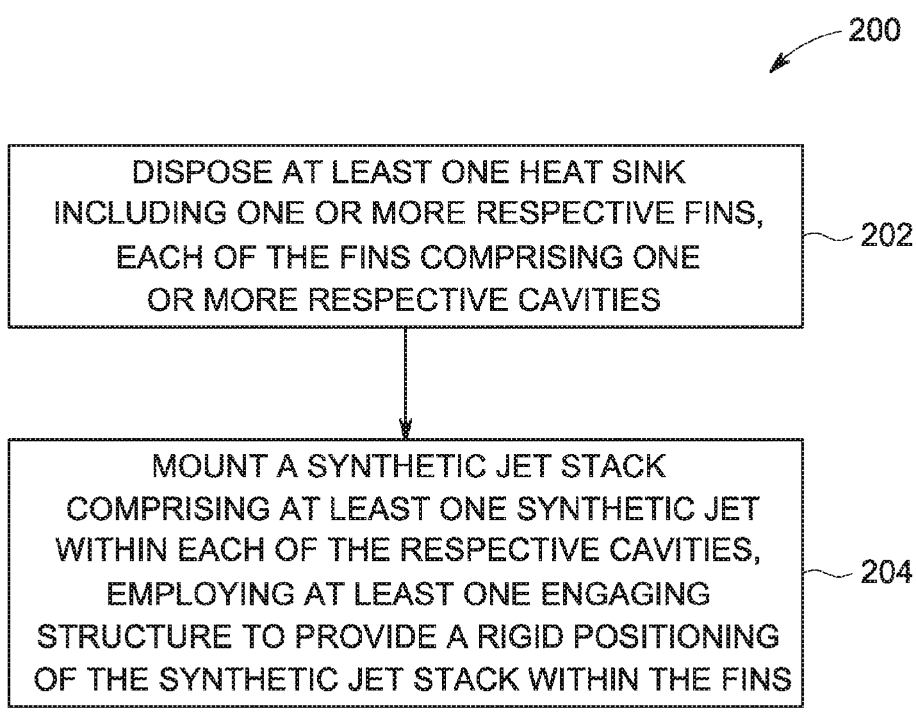

200
DISPOSE AT LEAST ONE HEAT SINK INCLUDING ONE OR MORE RESPECTIVE FINS, EACH OF THE FINS COMPRISING ONE OR MORE RESPECTIVE CAVITIES
202
MOUNT A SYNTHETIC JET STACK COMPRISING AT LEAST ONE SYNTHETIC JET WITHIN EACH OF THE RESPECTIVE CAVITIES, EMPLOYING AT LEAST ONE ENGAGING STRUCTURE TO PROVIDE A RIGID POSITIONING OF THE SYNTHETIC JET STACK WITHIN THE FINS
204

FIG. 8

THERMAL MANAGEMENT SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application is a continuation of, and claims priority to, U.S. patent application Ser. No. 12/911,995, filed Oct. 26, 2010, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] The invention relates generally to thermal management systems, and more particularly, to systems and methods for packaging synthetic jets.

[0003] As the size of semiconductor devices has continued to shrink and circuit densities have increased accordingly, thermal management of these devices has become more challenging. In the past, thermal management in semiconductor devices was often addressed through the use of forced convective air cooling, either alone or in conjunction with various heat sink devices, and was accomplished through the use of fans. However, fan-based cooling systems are undesirable due to the noise attendant to their use. Moreover, the use of fans requires relatively large moving parts, and correspondingly high power inputs, in order to achieve the desired level of heat transfer. As a result of the moving parts, fan reliability is also an issue Furthermore, while fans are adequate for providing global movement of air over electronic devices, they generally provide insufficient localized cooling to provide adequate heat dissipation for the hot spots that typically exist in semiconductor devices and in many types of electronic equipment.

[0004] More recently, thermal management systems have been developed which utilize synthetic jets. Such systems are more energy efficient than comparable fan-based systems, and also offer reduced levels of noise and electromagnetic interference. The use of synthetic jets has proven very efficient in providing localized heat dissipation, and hence can be used to address hot spots in semiconductor devices and electronic equipment. Synthetic jets may be used in conjunction with fan-based systems to provide thermal management systems that afford both global and localized heat dissipation.

[0005] Despite their notable advantages, however, there is a need in the art for further improvements in synthetic jet ejectors. In particular, synthetic jets need to be packaged in fins that provide reduced thermal resistance and steer fluid flow in the jet, for optimal performance. However, such packaging is complex.

[0006] Therefore, there is a need in the art for an optimally packaged thermal management system.

BRIEF DESCRIPTION

[0007] In accordance with an embodiment of the invention, a thermal management system is provided. The thermal management system includes at least one heat sink including one or more respective fins, wherein the one or more fins include one or more respective cavities. The thermal management system also includes a synthetic jet stack including at least one synthetic jet mounted within each of the respective cavities employing at least one engaging structure to provide a rigid positioning of the synthetic jet stack within the fins, wherein the synthetic jet includes at least one orifice through which a fluid is ejected.

[0008] In accordance with another embodiment of the invention, a method for manufacturing a thermal management system is provided. The method includes disposing at least one heat sink comprising one or more respective fins, each of the fins including one or more respective cavities. The method also includes mounting a synthetic jet stack including at least one synthetic jet within each of the respective cavities, employing at least one engaging structure to provide a rigid positioning of the synthetic jet stack within the fins, wherein the synthetic jet includes at least one orifice through which a fluid is ejected.

DRAWINGS

[0009] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0010] FIG. **1** is a cross-sectional view of an exemplary synthetic jet thermal management system including a wire frame in accordance with an embodiment of the invention.

[0011] FIG. **2** is a cross-sectional view of an exemplary synthetic jet thermal management system including a gasket in accordance with an embodiment of the invention.

[0012] FIG. **3** is a cross-sectional view of an exemplary synthetic jet thermal management system including multiple bumps in accordance with an embodiment of the invention.

[0013] FIG. **4** a cross-sectional view of an exemplary synthetic jet thermal management system including multiple locator pins in accordance with an embodiment of the invention.

[0014] FIG. **5** is a cross-sectional view of an exemplary synthetic jet thermal management system including a sheet of non-conductive tape in accordance with an embodiment of the invention.

[0015] FIG. **6** is a cross-sectional view of an exemplary synthetic jet thermal management system including extrusions in accordance with an embodiment of the invention.

[0016] FIG. **7** is a top view of an exemplary synthetic jet thermal management system including a fin cap in accordance with an embodiment of the invention.

[0017] FIG. **8** is a flow chart representing steps in an exemplary method for manufacturing a synthetic jet thermal management system in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0018] As discussed in detail below, embodiments of the invention include systems and methods for packaging synthetic jet embedded fins. The systems and methods include various techniques of mechanically coupling the synthetic fin within the fins to provide high performance cooling. Although embodiments illustrated below include one synthetic jet attached to a single fin, it should be noted that the techniques are applicable to multiple synthetic jets attached to multiple fins and heat sinks.

[0019] FIG. **1** is a cross-sectional view of a thermal management system **10** including a wire frame **12**. A synthetic jet **16** is mounted within a cavity **20** in a heat sink **24** including one or more respective fins **28**. The synthetic jet **16** includes two piezo disks **15**, **17** with an elastomeric wall **18**

between them. In an example, the elastomeric wall is made of silicone material. The elastomeric wall **18** includes at least one orifice **19** for fluid flow. Electrical wires **21** attached to the piezo disk **17** ensure electrical connection to the synthetic jet **16**.

[0020] In the illustrated embodiment, the synthetic jet **16** is inserted into the fin **28** via the wire frame **12**. For example, the wire frame or array of wires includes three wires **32**, **34**, **36** attached to the synthetic jet through holes (not shown) on the fin **28**. Non-limiting example of material used in the wires **32**, **34**, and **36** are copper and aluminum. In another example, the fin is made of aluminum. The synthetic jet **16** also includes multiple orifices **19** through which a fluid **23** is ejected. In one embodiment, the fluid is air. To increase robustness, a slot at a base center **37** of the fin **28** may be opened and a similar wire frame **12** may be employed therein. It will be appreciated that although one heat sink, one fin and synthetic jet is illustrated herein, there may be any number of heat sinks, fins and synthetic jets employed.

[0021] FIG. **2** is a cross-sectional view of a thermal management system **40** including a gasket **42**. The gasket **42** is disposed between an outer surface **44** of the piezo disk **17** (FIG. **1**) and an inner surface **27** of the fin **28**. It should be pointed out that while the piezo disk **17** shown in FIG. **1** is round, it can be any planar shape, including square, as shown in FIG. **2**. The outer surface **44** of the piezo disk **17** bellows in and out within the fin **28**. Similarly, a second gasket is adhesively coupled to the other piezo disk **15** (FIG. **1**). A couple of different manufacturing techniques may be employed for the mechanical coupling of the gasket **42** with the synthetic jet **16** inserted into the fin **28**. In a particular embodiment, the gasket **42** may be manufactured separately and an adhesive is applied on each side of the gasket. The gasket **42** is further attached to the jet **16** that is separately manufactured, with the adhesive on one side that would have enough tact at room temperature and the jet **16** is then inserted into the fin **28**. Furthermore, heat or a chemical is applied to ensure desirable tact to the adhesive on the other side. The thickness of the gasket **42** may be selected based upon a desirable volume required for the piezo disk **17** to bellow back and forth. For example, if a desirable volume required for bellowing is 300 μm, the thickness of the gasket would be at least 300 μm to avoid collision of the jet **16** with the inner surface **27** of the fin **28**. In another embodiment, the gasket **42** is built onto the piezo disk **17** during the manufacturing of the synthetic jet **16** and an adhesive is further applied on an outer gasket material. When the synthetic jet **16** is inserted into the fin **28**, the adhesive is activated either via mechanical pressure, heat, or chemical activation. Subsequently the adhesive bonds the gasket **42** to the inner surface **27** of the fin. In another embodiment, the gasket is dispensed over the synthetic jet and after attachment to the fin, is curing at a specified temperature.

[0022] FIG. **3** is a cross-sectional view of a thermal management system **60** including multiple bumps **62**. The bumps **62** are formed at different locations **64** on an outer surface **44** of the piezo disk **17** (FIG. **1**) of the synthetic jet **16**. Similar shaped dimples (not shown) are formed at the same locations on the inner side **27** of the fin **28** such that the bumps **62** align into respective dimples to provide desirable mechanical coupling of the synthetic jet **16** and the fin **28**. In one embodiment, dimples are formed by drilling holes on the inner side **27** of the fin **28** and later filling the holes with epoxy to establish smooth bumps over the surface. In another embodiment, the bumps are formed by a stamping process via a dye. It will be appreciated that any number of dimples and bumps may be formed.

[0023] FIG. **4** is a cross-sectional view of a thermal management system **80** including multiple locator pins **82**, **84**, **86** and **88**. The locator pins are welded or soldered on an outer surface **44** of the piezo disk **17**. In the illustrated embodiment, two locator pins **82**, **84** and **86**, **88** are welded on each side of the piezo disk respectively. In a particular embodiment, tight fitting holes **92** are drilled in the base/heat sink **24** (FIG. **1**) of the fin **28** to accept the locator pins. The locator pins ensure a tight mechanical coupling between the synthetic jet **16** and the fin **28**. Again, any number of holes and locator pins may be employed.

[0024] FIG. **5** is a cross-sectional view of a thermal management system **120** including sheet **122** of non-conductive tape on a whole area of each surface **44** of the piezo disks **15**, **17**. The sheet **122** electrically separates the synthetic jet **16** from the fin **28** to avoid potential electric shorting of the jet **16** in contact with the metallic inner surface **27** of the fin **28**. A non-limiting example of non-conductive tape is Kapton. Furthermore, a layer **128** of silicone is applied on a top opening **132** of the fin **28** to enclose synthetic jet **16** into the cavity of the fin **28**. The layer **128** ensures secure coupling of the synthetic jet **16** with the fin **28**. A smooth layer **128** also provides an aerodynamic surface for the air flow in the heatsink **24**.

[0025] FIG. **6** is a cross-sectional view of a thermal management system **140** including extruded synthetic jets **142**. The extrusions **144** of the synthetic jet **142** enable top and bottom surfaces of the synthetic jet **142** to fit into external support slots that ensure a rigid attachment with the fin **28**. As illustrated herein, the piezo disks **15**, **17** are elongated above and below (if needed) the slot into which it is fitted. For further robustness, a silicone material (not shown) may be introduced in the extrusion slot to hold the synthetic jet **16**.

[0026] FIG. **7** is a top view of a thermal management system **180** including a fin cap **182**. The fin cap **182** is disposed on a top opening **132** of the fin **28**. The fin cap **182** is designed such that the synthetic jet **16** will be firmly enclosed within the fin **28**, without being in contact with the cap. Through holes **186** may be formed in the fin cap **182** to facilitate a path for electrical connection of the synthetic jet **16**. In the illustrated embodiment, the shape of the fin cap **182** is similar to cross-section of the fin with a concave end. In another embodiment, the shape may be similar to cross-section of the fin with a short extruded wall fitting end. In an embodiment, wherein there are multiple fins, a single fin cap may be employed for each fin, or a top plate including a number of caps may cover all the fins. In an exemplary embodiment, the fin cap **182** is adhesively coupled to the fin via a silicone or epoxy.

[0027] FIG. **8** is a flow chart representing steps in an exemplary method **200** for manufacturing a thermal management system. The method **200** includes disposing at least one heat sink including one or more respective fins, wherein each of the fins includes one or more respective cavities in step **202**. A synthetic jet stack including at least one synthetic jet is mounted in the fin in step **204**, employing at least one engaging structure to provide rigid positioning of the synthetic jet stack within the fins. The synthetic jet includes at least one orifice through which a fluid is ejected. In one embodiment, an engaging structure is employed by attaching an array of wires into each of the at least one synthetic jets to the respective one or more fins. In another embodiment, the engaging structure is employed by adhesively coupling a gasket to an outer surface of the at least one synthetic jet and an inner surface of the fins. In yet another embodiment, the engaging structure is employed by forming multiple bumps on an outer surface of the synthetic jet, and the multiple bumps are disposed upon multiple respective dimples embedded on the surface of the fins.

[0028] In another embodiment, the engaging structure is employed by disposing multiple locator pins on an outer surface of the synthetic jet, and the locator pins are fit into multiple respective holes drilled into the heat sink. In another embodiment, the engaging structure is employed by adhering a sheet of non-conductive tape to each outer surface of the synthetic jets, and a layer of silicone is applied at a top opening side of the fins to enclose the synthetic jets into the cavities. In yet another embodiment, the engaging structure is employed by forming extrusions in the synthetic jets, and the extrusions are fit into multiple external support slots on at least one of a top and a bottom surface of the fins, and a silicone adhesive is applied to the slots to ensure a rigid attachment. In another embodiment, the engaging structure is employed by disposing a fin cap on a top opening of each of the respective fins such that the synthetic jets are rigidly disposed within the fins, wherein the fin cap includes one or more holes to facilitate electrical connection to the synthetic jets. In yet another embodiment, the engaging structure is employed by disposing a top plate comprising multiple fin caps configured to cover each of the fins, such that the synthetic jets are rigidly disposed within the fins, the fin cap including one or more holes to facilitate electrical connection to the synthetic jets.

[0029] The various embodiments of a thermal management system and method described above thus provide a way to achieve a convenient and efficient means of packaging synthetic jet embedded fins. This technique also provides energy efficient cooling of electronic devices. Further, such systems may be employed with low power fans in electronics to provide the desirable high performance cooling.

[0030] It is to be understood that not necessarily all such objects or advantages described above may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the systems and techniques described herein may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0031] Furthermore, the skilled artisan will recognize the interchangeability of various features from different embodiments. Similarly, the various features described, as well as other known equivalents for each feature, can be mixed and matched by one of ordinary skill in this art to construct additional systems and techniques in accordance with principles of this disclosure.

[0032] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

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

1. A thermal management system comprising:

at least one heat sink comprising one or more fins;

at least one synthetic jet mounted within one or more respective cavities of the one or more fins, the at least one synthetic jet comprising at least one orifice through which a fluid is ejected; and

at least one structure that engages the at least one synthetic jet within the one or more respective cavities.

2. The thermal management system of claim **1** wherein the at least one synthetic jet comprises an elastomeric wall positioned between a pair of piezo disks.

3. The thermal management system of claim **1** wherein the at least one synthetic jet comprises a synthetic jet having a plurality of orifices through which fluid is ejected.

4. The thermal management system of claim **1** wherein the at least one structure comprises a gasket positioned between an outer surface of the at least one synthetic jet and an inner surface of the one or more fins.

5. The thermal management system of claim **1** wherein the at least one structure comprises a plurality of mating dimples and bumps formed on an outer surface of the at least one synthetic jet and an inner surface of the at least one fin.

6. The thermal management system of claim **1** wherein the at least one structure comprises a plurality of wires.

7. The thermal management system of claim **1** wherein the at least one structure comprises a plurality of locator pins.

8. The thermal management system of claim **7** wherein the plurality of locator pins are coupled to the at least one synthetic jet and are received within a plurality of openings formed in the heat sink.

9. The thermal management system of claim **1** wherein the at least one structure electrically separates the at least one synthetic jet from the heat sink.

10. The thermal management system of claim **1** further comprising one of a layer of silicone and a fin cap that encloses an opening in a top surface of the one or more fins.

11. The thermal management system of claim **1** wherein the at least one synthetic jet is retained between a slot formed in the heat sink and a fin cap.

12. The thermal management system of claim **1** wherein the one or more fins are c-shaped.

13. A method for manufacturing a thermal management system, the method comprising:

providing a heat sink comprising at least one fin having a cavity formed therein; and

mounting at least one synthetic jet inside the cavity via an engaging structure positioned between the at least one synthetic jet and the heat sink, the at least one synthetic jet comprising at least one orifice through which a fluid is ejected.

14. The method of claim **13** further comprising disposing a gasket between the at least one synthetic jet and an inner surface of the at least one fin.

15. The method of claim **13** further comprising inserting locator pins coupled to the at least one synthetic jet within openings formed in the heat sink.

16. The method of claim **13** further comprising electrically separating the at least one synthetic jet from the heat sink.

17. The method of claim **13** further comprising positioning the at least one synthetic jet within a slot formed in the base of the heat sink.

18. The method of claim **13** further comprising sealing a top surface of the at least one fin with one of a layer of silicone and a fin cap.

19. A thermal management system comprising:

a synthetic jet comprising a pair of piezo disks and at least one orifice through which a fluid is ejected; and

a heat sink fin comprising a cavity that surrounds opposing outward facing surfaces of the pair of piezo disks.

20. The thermal management system of claim **19** wherein the synthetic jet further comprises an elastomeric wall positioned between the pair of piezo disks; and

wherein the at least one orifice is formed in the elastomeric wall.

21. The thermal management system of claim **19** wherein the heat sink fin is c-shaped.

22. The thermal management system of claim **19** further comprising a structure that engages the synthetic jet within the cavity of the heat sink fin.

23. The thermal management system of claim **22** wherein the structure electrically separates the synthetic jet from the heat sink fin.

24. A thermal management system comprising a synthetic jet positioned within an internal cavity of a c-shaped heat sink fin.

25. The thermal management system of claim **24** wherein the synthetic jet comprises at least one orifice positioned to expel fluid in an outward direction relative to the internal cavity.

26. The thermal management system of claim **25** wherein the synthetic jet further comprises an elastomeric wall positioned between a pair of piezo disks, the elastomeric wall having the at least one orifice therein.

27. The thermal management system of claim **24** further comprising an engaging structure coupling the synthetic jet to the c-shaped heat sink fin.

28. The thermal management system of claim **27** wherein the engaging structure electrically separates the synthetic jet from the c-shaped heat sink fin.

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