COOLING SYSTEM FOR ELECTRONIC SUBSTRATES

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ABSTRACT

The present invention relates to a cooling system for an electronic substrate comprising a heat transfer fluid (4, 10). The heat transfer fluid (4, 10) is arranged to flow along a path (5, 11, 12) by capillary force.
COOLING SYSTEM FOR ELECTRONIC SUBSTRAVES

FIELD OF THE INVENTION

[0001] The present invention relates to a cooling system for an electronic substrate comprising a heat transfer fluid.

BACKGROUND OF THE INVENTION

[0002] Control of component temperature and temperature gradient is essential for successful operation and reliability of electronic products, such as electronic circuits. As consumer products become smaller with a continuing need for higher heat removal, thermal management will play a crucial role. Thus, novel cooling methods are required to face the demands of the market. The trend towards smaller components imposes an increase in power density, requiring more sophisticated cooling methods than pure radiation or convective cooling with, for instance, fans. Important aspects as noise and reliability limit the use of fan cooling. Therefore, there is a need for advanced cooling methods.

[0003] Liquid cooling is a method already used in portable computers, i.e. laptops. A particular application that requires cooling is solid-state lighting. White light or controllable solid-state lighting requires the use of a multi-chip module wherein several LEDs are placed very close to each other in order to define an optical point source. This design causes high power densities in the silicon submount, in the order 100 W/cm². Liquids are significantly better heat transfer media than air, because their thermal conductivity and thermal capacity are higher (10 to 1000 times better). Forced convection micro channels liquid cooling has proven to be highly efficient in the industrial world (metallic micro channel structures) and in industrial research (silicon micro channel device). The main inconvenience of this technique is that liquid is pumped through the channels by a pump, which makes it less suited for miniaturized and integrated consumer products and electronics.

[0004] O’Connor et al. disclose an example of a cooling system with a pump in US 2002/0039280 A1. The invention by O’Connor et al. concerns a micro fluidic heat exchange system for cooling an electronic component internal to a device, such as a computer. The heat exchange device is substantially in interfacial contact with a heat-generating electronic component and supplies an internal operating fluid to a heat exchange zone. Operating fluids flows into the heat exchange zone at a first fluid temperature that is lower than the component temperature, and then exits the zone at a second fluid temperature higher than the first fluid temperature.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide a cooling system for electronic components that do not utilize a pump. This is achieved with a cooling system according to claim 1. Preferred embodiments are indicated in the dependent claims.

[0006] According to the present invention, a cooling system for an electronic substrate comprises a heat transfer fluid, wherein the heat transfer fluid is arranged to flow along a path by capillary force. Thus, an advantage is that this cooling system does not have moving parts, apart from the heat transfer fluid, and the power consumption is relatively low. This increases the reliability, flexibility and makes it a robust construction compared to systems that require a mechanical pump or piezo-actuated pumps.

[0007] The essential feature of the present invention is the use of a technique to move fluids at a micro scale in order to achieve integrated and compact cooling of an electronic component, for instance a chip submount.

[0008] To facilitate understanding of the technique an example is used where it is desired to dissipate $100$ W/cm² with a temperature drop of $90^\circ$ C. An estimation, as to what the velocity of water should be through a pair of parallel plates, will follow. The heat flux of the system is given by

$$Q = \frac{k}{D} \cdot \Delta T \cdot \text{Nu}$$

where $k$ is the thermal conductivity of water ($0.628$ Wm⁻¹K⁻¹), $D$ is the hydraulic diameter ($10^{-3}$ m) and $\text{Nu}$ is the Nusselt number, which is given by

$$\text{Nu} = C \cdot \text{Re}^{m} \cdot \text{Pr}^{n} \cdot \text{K}$$

where $\text{Re}$ is the Reynolds number and $\text{Pr}$ is the Prandtl number given by

$$\text{Re} = \frac{\rho \cdot v_m \cdot D}{\mu}$$

and

$$\text{Pr} = \frac{C_p \cdot \mu}{k}$$

respectively. $C=1.85$, $m=1/2$, $n=1/3$, $K=0.368$, $C_p=4178$ Jkg⁻¹K⁻¹, $\rho=995$ kg/m³, and $\mu=651 \cdot 10^{-6}$ kgm⁻¹s⁻¹.

$v_m$ is estimated to be in the order of $1$ m/s, which gives, depending on the cross-sectional area, a volumetric flow in the order of $10$ to $100$ μl/s.

[0009] In a preferred embodiment of the present invention the system further comprises an electrode arranged for applying a voltage to the heat transfer fluid for changing the surface tension of the heat transfer fluid. The electrowetting principle allows moving several hundreds of μl/s in a sequence of droplets. Stated in a slightly different way, the energy transport rate $P$ (J/s) is given by

$$P = \frac{\Delta V}{\Delta t} \cdot \rho \cdot C_p \cdot \Delta T$$

where $\Delta V/\Delta t$ is the volumetric flow rate of fluid passing the heat source. For $P=30$ W and $\Delta T=50^\circ$ C, the flow rate will be $140$ μl/s. Electrowetting involves a change of surface tension by electrostatic charges, resulting in a movement of a fluid/liquid meniscus. The movement can be provided in at least two different ways, namely (i) by actuating a fluid/liquid meniscus in one or several channels or slits or (ii) by transporting droplets over a surface.

[0010] The maximum meniscus speed demonstrated by electrowetting is $0.1$ m/s or a little higher. The maximum pressure modulation that can be generated by electrowetting is given by $2\Delta \mu$, where $\Delta \mu$ is the change of surface tension and $R$ the curvature of the meniscus. $\Delta \mu$ can be of the order of $0.1$ N/m. For a curvature of $100$ μm, the maximum pressure is about $2000$ Pa.
To ensure orientational freedom of an electro-wetting device, the gravitational pressure drop in the system has to be lower than the maximum modulation of electrowetting pressure. The gravitational pressure drop equals $Ap_{gl}$, with $I$ the projected length. Maximum orientational freedom can be ensured by using fluids with similar mass density, by minimizing the column heights of one of the fluids, and by using balanced geometries.

It is known that flow velocities of $0.1$ m/s can be reached in channels with a length of $2$ cm and a diameter of $300$ μm. This gives a volumetric flow rate of $7$ μl/s per micro channel. In other words, a volumetric flow rate of $140$ μl/s can be achieved in an actuated-actuated system with about $20$ micro channels.

Preferably, at least one micro channel is connected to a heat transfer fluid reservoir. With fluid reservoirs disposed around the heat source and proper heat sinking of these reservoirs, heat is efficiently removed.

In an embodiment of the present invention the electrode is situated outside the heated region. The actuated-actuated flow generates a transport of energy in the device, from a concentrated heating region to a larger cooling region. Preferably the actuated electrodes are situated outside the heated region, because this will improve the lifetime of the device. Further, the fluid system is preferably a closed system. This will decrease the risk for evaporation and leakage of fluids.

In a further embodiment the cooling system comprises two immiscible fluids with different electrical conductivity, for instance, air/water, water/oil, etc. Actuated actuation requires that an electrode is present in the vicinity of the fluid/fluid meniscus. The electrode generally consists of a material with metallic conductance, coated with an insulating layer. The insulating coating can for example be $1$ μm-$10$ μm of parylene, or $10$ nm-$1$ μm of a fluoropolymer layer, or a combination of such layers.

The different micro channels can be hydrostatically separated from each other or they can join in certain junctions or channels (e.g. common channels or reservoirs). Care should be taken to ensure integrity of the menisci in the micro channels, e.g. to avoid fluid of one type to enter a reservoir for fluid of the second type.

In yet another embodiment the system is arranged such that the fluid is actuated in a bi-directional manner. The fluid flow can be uni-directional or bi-directional. Preferably, the fluid is actuated in a bi-directional manner, so that fluid contact to the heated region can be limited to only one type of fluid. This will improve the lifetime of the device. A bi-directional flow is achieved by applying a pulsating voltage or by reciprocating flow of heat transfer fluid.

In order to reduce the temperature gradient across the device to be cooled the system preferably comprises two sets of micro channels arranged in a counter flow relationship.

SHORT DESCRIPTION OF ACCOMPANYING FIGURES

The present invention will now be further described with reference to the figures showing different embodiments of the invention.

FIG. 1 shows an example of a multi chip module for a solid state lighting application.

FIG. 2 shows an example of droplet flow.

FIG. 3 shows one micro channel for fluid transport between a hot and a cold region.

FIGS. 4a and 4b show a cooling unit with several micro channels connected to a reservoir.

FIG. 5a shows a system according to the invention with ring geometry.

FIG. 5b shows an enlarged view of a portion of the system in FIG. 5a.

FIG. 6a shows a system according to the invention with a counterflow arrangement.

FIG. 6b shows an enlarged view of a portion of the system in FIG. 6a.

FIG. 7a shows a radial system according to the invention.

FIG. 7b shows an enlarged view of a portion of the system in FIG. 7a.

FIG. 8 shows a radial system with channels having non-continuous width.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. 1 shows a general view of a multi chip module with 9 LEDs (light emitting diodes). White light or colour controlled solid state lighting requires the need of a multi chip module where several LEDs 1 are placed very close to each other in order to define an optical point source. This design causes high power densities on the silicon submount 2. By integrating an active liquid cooling droplet based actuated pump in the silicon submount 2, the required cooling can be achieved. In the example shown in FIG. 1 the size of the silicon submount is $5$ mm-$6$ mm and the submount 2 is arranged adjacent to reservoirs/collectors 3. The reservoirs/collectors 3 comprise a heat transfer fluid for removal of the heat energy produced by the LEDs 1.

FIG. 2 the principle of the droplet transport is shown. Heat transfer fluid droplets 4 are flowing in a channel 5 from a reservoir/collector 3. The droplets are made to move by a voltage applied on the fluid via electrodes 6. In this way heat will now be transferred from the silicon submount 2 to the droplets 4. The droplets 4 will subsequently be cooled in a reservoir/collector 3. The energy absorbed by the reservoirs/collectors 3 will subsequently be transferred from the reservoirs/collectors 3 with the help of a separate cooling system (not shown). The heated chip is part of a larger device consisting for example of printed circuit board material, a moulded-interconnect-device (MID), a glass, a metal device, etc. Each of these materials can contain electrodes and channel structures. A hole can be provided so that the silicon chip can be exposed to the heat transfer fluid as well as being electrically interconnected.

In one embodiment of the present invention the heat transfer fluid channel 5 is filled with two fluids. FIG. 3 is a diagrammatic drawing of one micro channel 5 for fluid transport between a hot region 7 and a cold region 8. The electrodes are not drawn. A plug 9 of one of the fluids is used to "push" the other fluid 10 that acts primarily as the heat transfer fluid. The electrodes preferably applies pulsating voltage to the plug 9 such that the plug 9, and consequently the heat transfer fluid 10, is actuated in a bi-directional manner, i.e. a reciprocating flow of the heat transfer fluid, in order to avoid the plug entering the hot region 7. This will improve the lifetime of the device. For this to function, a requirement is that the two fluids are immiscible fluids, for instance a plug of oil in a surplus of water.

FIGS. 4a and 4b illustrates a multi channel system comprising a heat transfer fluid reservoir 3. In FIG. 4a no
voltage is applied and all heat transfer fluid remains in the reservoir. In FIG. 4b a voltage has been applied and the heat transfer fluid has started to flow in the micro channels. When the applied voltage is turned off, the heat transfer fluid returns to the reservoir.

An example of channels made in a "loop" shape can be seen in FIGS. 5a and 5b, the latter being an enlarged view of a portion of the former. The embodiment comprises two reservoirs as heat sinks for the heat transfer fluid. FIG. 6a shows a cooling system according to the invention comprising two reservoirs of heat transfer fluid arranged with separate sets of channels arranged in a countercurrent relationship. This arrangement helps in reducing the temperature gradient across the silicon chip and consequently the lifetime of the silicon chip is increased due to a more even heat load. FIG. 6b is an enlarged view of a portion of the embodiment shown in FIG. 6a.

In FIGS. 7a and 7b, 7b being an enlarged view of a portion of the embodiment in FIG. 7a, is shown an embodiment according to the present invention with radial cooling and the heat source in the centre. Thus, the heat transfer fluid travels from the reservoir in the micro channels towards the centre. Outside the reservoir a heat sink is connected (not shown).

FIG. 8 shows yet another embodiment of a system according to the present invention. The system comprises two reservoirs interconnected with channels. The channel width varies between the two reservoirs for optimising the capillary flow of the heat transfer fluid.

In order to take advantage of the invention the filling of the liquid should be done at the latest stage by a hole/channel in the device. Preferably all micro channels are filled simultaneously, e.g. via filling channels that run perpendicular to the micro channels. Also, the whole liquid device should be entirely sealed after filling. A pressure damper could be included to avoid pressure built up in the set-up. Further, a flexible reservoir can be included (e.g. with a membrane, or a pocket containing an air bubble) to allow expansion and contraction of fluids.

The person skilled in the art realizes that the present invention by no means is limited to the embodiments described above. On the contrary, many modifications and variations are possible within the scope of the appended claims. For example, the shape of the channel systems is not limited to the embodiments in the appended figures.

1. A cooling system for an electronic substrate comprising a heat transfer fluid, characterized in that the heat transfer fluid is arranged to flow along a path by capillary force.

2. A cooling system according to claim 1, wherein the system further comprises:

a) an electrode arranged for applying a voltage to the heat transfer fluid for changing the surface tension of the heat transfer fluid.

3. A cooling system according to claim 1, wherein at least one micro channel is connected to a heat transfer fluid reservoir.

4. A cooling system according to claim 2, wherein the electrode is situated outside the heated region.

5. A cooling system according to claim 1, wherein the fluid system is a closed system.

6. A cooling system according to claim 1, wherein the cooling system comprises two immiscible fluids.

7. A cooling system according to claim 1, wherein the system is arranged such that the fluid is actuated in a bi-directional manner.

8. A cooling system according to claim 1, wherein the system comprises two sets of micro channels arranged in a counter flow relationship.

9. A method for cooling an electronic substrate using a system according to claim 1, by applying a voltage to micro channels comprising a heat transfer fluid such that the surface tension of the heat transfer fluid is changed.

10. A method according to claim 9, wherein a pulsating voltage is applied.

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