

Hybrid 3D Printed Heat Sink

Related Applications

[001] The present invention claims priority to Singapore patent application no. 10202202742X filed on 18 March 2022, the disclosure of which is incorporated in its entirety.

Field of Invention

[002] The present invention relates to hybrid 3D printing of heat sinks. In particular, fins of the heat sinks are fabricated by 3D-printing using laser powder-bed fusion (LPBF) or more generally called selective laser melting (SLM), with the fins being formed of copper or aluminium.

Background

[003] Heat sinks are used to cool down an electric or electronic component to which the heat sinks are thermally connected to. Conventionally, the heat sinks are formed by extrusion; powder metallurgy; machining, such as EDM; and so on.

[004] Extruded heat sinks have simple fin geometry but the fin dimensions are relatively large; the fin dimensions thus place a limit to the surface area available for heat dissipation. Powder metallurgy, as disclosed in patent publication US20050252637, by Hon Hai Precision Industry Co. Ltd., appears to be suitable to produce heat sinks with finer fin geometries. With needs to improve heat sink performance, attempts have been made to fabricate fins by using electro-discharge machining (EDM); however, EDM is a very slow process; EDM is also fraught with manufacturing limitations in that EDM wires often snap. When the EDM machined fins are attached onto a substrate, the attachment interface causes heat flow resistance from the substrate to the fins.

[005] It can thus be seen that there exists a need for a new method for fabricating heat sinks that provide more effective heat dissipation than conventionally available heat sinks. Preferably, such a method is cost effective and suitable for mass production.

Summary

[006] The following presents a simplified summary to provide a basic understanding of the present invention. This summary is not an extensive overview of the present invention, and is not intended to identify key features of the invention. Rather, it is to present some of the inventive concepts of this invention in a generalised form as a prelude to the detailed description that is to follow.

[007] The present invention seeks to provide new heat sinks that provide effective heat dissipation and a new process for fabricating these heat sinks. The new process involves hybrid 3D printing of fins of the heat sink by laser powder-bed fusing or selective laser melting of fin powders on a machined substrate. This new process has been tested and the heat sinks obtained have excellent heat dissipation performance.

[008] In one embodiment, the present invention provides a heat sink comprising: a substrate; and a plurality of fins formed directly on the substrate, with a first layer of each fin being formed directly on the substrate using a laser powder-bed fusing (LPBF) or selective laser melting (SLM) process on a fin powder deposited on the substrate, wherein the fins are built up, layer by layer using laser fusion to reach a predetermined height.

[009] Preferably, the fins are made from CuCrZr, copper alloy powder or pure copper powder, whilst the substrate is machined from a copper-based material. In another embodiment, the fins are made from aluminium or aluminium alloy powder, whilst the substrate is machined from an aluminium-based material.

[0010] Preferably, the fins have a height: thickness ratio range of substantially 4 to 20, and a height: spacing ratio range of substantially 4 to 35.

[0011] Preferably, the fins are configured with a parallelogram cross-sectional shape or geometry. The fins are configured in rows, and a row spacing is substantially equal or greater than an oblique spacing between adjacent fins in a row.

[0012] Preferably, threaded holes are provided on the substrate for mounting a protective cover over or around the fins. Holes are also provided also on the substrate to mount the heat sink to a member that requires heat dissipation.

[0013] In another embodiment, the present invention provides a LPBF or SLM method for hybrid 3D print fabrication of a heat sink, which comprises: forming a substrate using a conventional subtractive machining; forming a powder-bed of a fin powder over the substrate; operating a laser to melt and to fuse particles of the fin powder to build a first layer of the fins directly on the substrate; and adding the fin powder to increase a height of the powder-bed, layer by layer, operating the laser to build up the fins, layer by layer, until the fins reach a predetermined height.

[0014] Preferably, operating the laser to build the fins, layer by layer, comprises generating a pattern of the fin geometry from a CAD or computer system and outputting the pattern to a scanner to direct a laser beam from the laser onto the fin powder. The pattern comprises rows of the fins, with each fin forming a parallelogram shape, and adjacent fins in a row are spaced apart at an oblique side of the parallelogram.

Brief Description of the Drawings

[0015] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0016] FIG. 1 illustrates a structure of a conventional heat sink;

[0017] FIG. 2 illustrates a plan view of a heat sink obtained according to an embodiment of the present invention; FIG. 3 illustrates a profile of fins of the heat sink shown in FIG. 2, whilst FIG. 4 illustrates a side view of the heat sink and FIG. 5 shows a photograph of part of the heat sink;

[0018] FIGs. 6-8 illustrate performances of the above heat sink with a comparative heat sink obtained by EDM wire-cut, whilst FIG. 9 shows thermal properties of a copper-based alloy used in making the above heat sink compared to thermal properties of copper; and

[0019] FIG. 10 illustrates a hybrid 3D printing method for fabricating the above heat sink according to another embodiment of the present invention, whilst FIG. 11 illustrates layer-by-layer building up of the above 3D fin printing.

Detailed Description

[0020] One or more specific and alternative embodiments of the present invention will now be described with reference to the attached drawings. It shall be apparent to one skilled in the art, however, that this invention may be practised without such specific details. Some of the details may not be described at length so as not to obscure the invention.

[0021] FIG. 1 shows a structure of a conventional heat sink **10**. As shown, the conventional heat sink **10** has a plurality of fins **20**. The fins **20** are attached onto a substrate **40** via an attachment interface layer **30** (which may constitute a thermal adhesive, epoxy or solder); alternatively, the fins **20** may be attached onto the substrate **40** with mechanical elements, such as screws, but this creates an interface joint. As discussed in the background, the fins **20** have dimensions that are relatively large and the surface area for heat dissipation is thus limited. Even if heat sink with the fins **20** are EDM wire-cut, such EDM wire-cut heat sink now labelled **10a**, the attachment interface layer **30** or interface joint causes resistance to heat flow from the substrate **40** to the fins **20**.

[0022] Now, referring to FIGs. 2 and 5, which show a heat sink **100** of the present invention according to one embodiment. As shown, the heat sink **100** is made up of a plurality of fins **120** extending from a substrate **140**. In one embodiment, the fins **120** have very fine geometry and are made from a copper alloy powder **122** that is fused and 3D printed to extend directly from a copper-based substrate **140**. In one embodiment, the copper alloy powder **122** is composed of CuCrZr, whilst the substrate **140** is a copper-based material, including a copper alloy. In another embodiment, the fins **120** are made from an aluminium or aluminium alloy powder, whilst the substrate **140** is an aluminum-based material. In both embodiments, the fins **120** are 3D printed directly on the substrate **140** by employing laser powder-bed fusion (LPBF) or, more generally, selective laser melting (SLM) **200** using copper, copper alloy, aluminium or aluminium alloy powder **122**, whilst the substrate **140** is formed by conventional subtractive machining, such as, milling, grinding, and so on; the

heat sink **100** fabrication is thus described as hybrid 3D printing using LPBF or SLM process **200** to form the fins **120** directly on the substrate **140**. It is possible to use other types of copper, copper alloy powder, aluminium, aluminium alloy powder, copper-based and aluminium-based substrates that have excellent thermal conductive properties. The LPBF or SLM **200** is shown in FIG. 10 and it will be clearer after describing the heat sink **100** and its heat performance.

[0023] As shown in FIG. 2, mounting holes H1,H2 are formed on the substrate **140**. Holes H1 (preferably, being threaded) are provided to mount a protective cover around or over the fins **120** when the heat sink **100** is put to use. Holes H2 are provided to mount the heat sink **100** onto an electric or electronic component from which heat is to be dissipated.

[0024] FIG. 3 shows an exploded view of the fins **120** as seen from a top view; in other words, FIG. 3 shows outlines of the fins **120** in plan view. In one embodiment, the fins **120** are parallelogram in shape in the plan or cross-sectional view, with a longitudinal dimension **S**, thickness **T**, oblique spacing **V** and oblique angle α ; the fins **120** are arranged in linear rows in the longitudinal **S** direction but the rows are spaced part with dimension **U**. In one embodiment, dimensions **S**, **T**, **V** and **U** are substantially 1.4, 0.5, 0.3 and 0.5, respectively. It is possible that dimension **S** can vary from substantially 1mm to a few mm, and the oblique angle α can range from about 90 degrees to substantially 10 degrees. The fins **120** dimensions and spacings, or fin geometry, are not numerically limiting but are chosen to depend on a designed heat dissipation performance and/or limitations of the LPBF or SLM process **200**.

[0025] FIG. 4 shows a height projection of the fins **120** shown in FIG. 3. As shown in FIG. 4, the height of the fins **120** is indicated by **Y1**, whilst the thickness of the substrate **140** is indicated by **Y2**. Thickness **Y2** may be selected to minimise any warping from flatness after fabrication of the heat sink. Height dimensions **Y1**, **Y2** can range from substantially about 2 mm to about 10 mm, and also depend on the designed heat dissipation performance and/or limitations of the LPBF or SLM process **200**. From the above dimensions, the fins **120** can be characterised as having a height: thickness ratio of substantially 4 to 20, and a height: spacing ratio of substantially 4 to 35.

[0026] FIGs. 6-8 show heat dissipation and pressure drop performance of the heat sink **100** compared to a comparative heat sink **12** formed entirely by EDM wire-cut. The comparative

heat sink **12** is formed from copper with similar fin and substrate geometries as the heat sink **100** of the present invention. In the comparative study, the two heat sinks **12,100** were separately mounted onto a CPU that was operated at 100% load with various water convection rates. As can be seen from FIG. 6, the hybrid 3D printed heat sink **100** brought the CPU to a lower temperature. However, due to the higher surface roughness of the 3D printed fins **120**, the pressure drop of water flowing over the hybrid 3D printed heat sink **100** is higher compared to that over the heat sink **12** as seen from FIG. 7. Nevertheless, the pressure drop penalty incurred with the hybrid 3D printed heat sink **100** was justified due to its better cooling performance. As can be seen in FIG. 8, the hybrid 3D printed heat sink **100** exhibited higher overall performance when evaluated using the thermal resistance vs pumping power characteristic, against the overall performance of the comparative heat sink **12**.

[0027] FIG. 9 shows some physical properties of the CuCrZr material **122** compared to copper. It is seen that although CuCrZr **122** has a lower thermal conductivity (about 15-23% lower than copper), yet the heat dissipation performance of the heat sink **100** is as effective as the comparative copper heat sink **12**. Inventors believe that melting and fusing the fin powder **122** directly on the substrate **140** by the LPBF or SLM process **200** produce continuous material integrity between the substrate **140** and the fins **120**. Inventors also believe that the minute sizes of the fin powder **122** (substantial range of about 20-70 μm) allow the fin powders **122** to melt and fuse to build up layer-by-layer with continuous material integrity within each of the fins **120**. Continuous material integrity may mean that there are no voids, interfaces or deleterious defects that reduce heat conduction from the substrate **140** to the fins **120** or within the fins **120**.

[0028] Now, referring to FIG. 10 on a schematic of the LPBF or SLM process **200** according to another embodiment of the present invention. The LPBF or SLM process **200** shown is for illustrating and for describing a method to fabricate the heat sink **100**. As illustrated, a machine employing the LPBF or SLM process **200** includes a powder supply station **210** disposed adjacent to a production station **220**. The powder supply station **210** has a supply chamber **212**, which, in use, is filled with the fin powder **122** and a supply piston **214** is operable to feed the fin powder **122** in an upward, step-wise manner. At the production station **220**, the substrate **140** is mounted in a production chamber **222**, which is located above a production piston **224**; the production piston **224** is operable to move downward in

a step-wise manner in coordination with the step-wise movement of the supply piston **214**, as the heat sink **100** is being fabricated. A top of both the powder supply station **210** and the production station **220** are aligned with one another. In a preparation process, the supply piston **214** is stepped up and a blade **240** is operated to scrape across the top of the powder supply chamber **212** over to the production chamber **222** to fill void spaces surrounding the substrate **140** mounted in the production chamber **222**. The preparation process may be repeated several times until the fin powder **122** is deposited to a predetermined height (for eg., 0.05mm) over the substrate **140**, to form a laser powder bed (LPB) in the production chamber **222**; the blade **240** is then brought to a home position towards a far left-hand side of the powder supply station **210**. Any excess fin powder **122** is pushed into an overflow chamber **230**, located adjacent to the production station **220**.

[0029] To form the first layer of the fin **120** directly onto the substrate **140**, the laser member **260** is turned on, the emitted laser beam **262** is reflected and scanned by a scanner **270** to impinge on the fin powder **122**, causing the fin powder **122** to melt and the powder particles to fuse together, as can be seen in FIG. 10. As the laser beam **262** is traversed and controlled by the scanner **270** according to the fin geometry, the melting and fusing of the fin powder **122** forms a first layer of the fins **120** directly on the substrate **140**. To form a second layer, the supply piston **214** is stepped up whilst the production piston **224** is stepped down in a coordinated manner, and the blade **240** is then moved to scrape a layer of the fin powder **122** from the supply chamber **212** over to the production chamber **222**. The SLM process **200** is continued to build up the fins **120**, layer by layer, to the desired height **Y1**, in a manner similar to 3D additive printing. In another configuration of the LPBF or SLM process **200**, it is possible that each layer of the fin **120** be formed by multiple passes of the laser beam **262**, and this depends on the size and power of the laser beam **262**. In addition, the fin geometry can be generated by a CAD or computer system and the output is linked to the scanner **270**, thereby directing the laser beam **262** onto the fin powder **122** and allowing the process **200** to be mechanized or automated.

[0030] FIG. 11 shows three layers of the fins **120** as the LPBF or SLM process **200** continues. As shown, the laser beam **262** produces a molten pool **124** of the fin powder **122** as the laser beam **262** is scanned across the laser powder bed in the production chamber **222**; in FIG. 11, as the laser beam **262** is scanning, the molten pool **124** solidifies to form a third layer **120-3**

of the fin **120**. For illustration, FIG. 11 shows three layers of the fin **120** being built successively, layer by layer.

[0031] The above LPBF or SLM process **200** for fabricating the heat sink **100** has many advantages over known fabrication methods. For example, as described above, the hybrid 3D printed heat sinks **100** have similar or superior cooling performance and higher temperature stability compared to the EDM wire-cut heat sink **12**. The other advantages are: no post-processing is required as compared to conventional 3D printing of metal which required the fabricated part to be removed from the substrate. Without involving any subtractive manufacturing process for forming the fins **120** when compared to EDM wire-cut heat sink **12**, there are savings on materials as no materials are wasted, except for subtractive machining processes for forming the substrate **140**. This hybrid LPBF or SLM process **200** is also a faster process than EDM wire-cut. In addition, this hybrid LPBF or SLM process **200** is suitable for batch fabrication and higher through-put, thus making this hybrid process **200** economical or more productive to produce heat sinks **100** with fine fin geometry and fine spacings.

[0032] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations of variations disclosed in the text description and drawings thereof could be made to the present invention without departing from the scope of the present invention. For example, two or more laser members **260** may be employed to increase the speed of the above hybrid 3D print fabrication. When the hybrid LPBF or SLM process **200** uses aluminium-based fin powder, it is possible to provide a non-oxidising environment around the production chamber **222**.

CLAIMS:

1. A heat sink comprising:
a substrate; and
a plurality of fins, with a first layer of each fin being formed directly on the substrate using a laser powder-bed fusing (LPBF) or selective laser melting (SLM) process on a fin powder deposited on the substrate, wherein the plurality of fins is built up, layer by layer by laser fusion to reach a predetermined height.
2. The heat sink according to claim 1, wherein the fin powder is selected from the following: CuCrZr, pure copper, copper alloys, aluminium or aluminium alloy.
3. The heat sink according to claim 1 or 2, wherein the substrate is machined from a material selected from the following: copper; copper alloy, aluminium or aluminium alloy.
4. The heat sink according to any one of the preceding claims, wherein each of the plurality of fins has a height: thickness ratio range of substantially 4 to 20.
5. The heat sink according to any one of the preceding claims, wherein each of the plurality of fins has a height: spacing ratio range of substantially 4 to 35.
6. The heat sink according to any one of the preceding claims, wherein each of the plurality of fins is configured with a parallelogram cross-sectional shape or geometry.
7. The heat sink according to claim 6, wherein the plurality of fins is configured in rows, wherein a row spacing is substantially equal or greater than an oblique spacing between adjacent fins in a row.
8. The heat sink according to any one of the preceding claims, further comprising a plurality of threaded holes for mounting a protective cover over or around the plurality of fins.
9. The heat sink according to any one of the preceding claims, further comprising a plurality of holes for mounting the substrate to a member that requires heat dissipation.

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10. A laser powder-bed fusing (LPBF) or selective laser melting (SLM) method for hybrid 3D print fabrication of a heat sink, the method comprises:

forming a substrate using a conventional subtractive machining;

forming a powder-bed of a fin powder over the substrate;

operating a laser to melt and to fuse particles of the fin powder to build a first layer of the fins directly on the substrate;

adding the fin powder to increase a height of the powder-bed, layer by layer; and

operating the laser to fuse the fin powder to build up the fins, layer by layer, until the fins reach a predetermined height.

11. The method according to claim 10, wherein operating the laser to build the fins, layer by layer, comprises generating a pattern of the fin geometry from a CAD or computer system and outputting the pattern to a scanner to direct a laser beam from the laser onto the fin powder.

12. The method according to claim 11, wherein the pattern comprises rows of the fins, with each fin forming a parallelogram shape, and adjacent fins in a row are spaced apart at an oblique side of the parallelogram.

13. A heat sink according to any one of claims 1-9 being obtained by the hybrid 3D fabrication method of claims 10-12.