Micro-Structure Cooling Device And Use Thereof

Specification

The invention relates to a cooling device that is characterized by micro-structures (micro-structure cooling device) and that is used for cooling objects by heat-conducting contact. The invention relates in particular to use of the micro-structure cooling device for cooling electronic components, in particular electronic processors such as central processing units (CPUs) and components of power electronics. With regard to manufacturing process, the micro-structured cooling device in accordance with the invention is suitable for mass production in terms of design, structure and assembling method and thus the micro-structure cooling device can be manufactured economically in large numbers.

The continuous increase in the capacity of electronic components, for instance the increase in clock frequencies in microprocessors, also entails increased heat in these components. Component miniaturization further exacerbates this situation. Thermal problems increase, although measures are undertaken to reduce the amount of heat the processors give off. In addition, the increasing packing density of the individual components inside the overall system, such as a server, leads to a situation in which more and more heat must be removed from smaller and smaller spaces. However, the performance and service life of electronic components depend on the maximum values for operating temperature and their fluctuation range. This results in the need for very high-performance, compact cooling systems in order to assure efficient local heat removal.

Currently a modern processor releases for instance 70 Watts in the form of heat on an area of 1 cm^2; this is substantially more heat than a heating element on a kitchen range produces (~ 10 Watts/cm^2). In order to remove this quantity of heat, the most important cooling systems used are cooling bodies, fans, combined

with cooling bodies, heat pipes, Peltier units and liquid cooling. It is to be expected that the amounts of heat to be removed will increase even more in the future.

Currently the most frequently used cooling technique for electronic components is cooling with ambient air. This has proved simple and cost-effective for many applications. This principle is extremely uneconomical for higher heat removal capacities since then air conditioning systems with correspondingly high output are required, which not only drives up capital expenditures and operating costs, but also is problematic in terms of energy and environmental policies.

With the new generation of processors, which produce a great deal of heat, air cooling is also pushing its limits in terms of capacity. Heat removal can still generally be assured by increasing fan power, but this causes an increase in running noise. Today 55 dB is no longer acceptable in commercial and household applications.

The high packing density for processors and other heat-generating components in the smallest possible space, such as for instance in servers, makes air exchange in the housings more difficult, exacerbates the problem of heat concentration and thus leads to an increased risk of electronic components overheating and failing. However, reliability and low-maintenance requirements are primary performance considerations for servers and workstations. In addition, CPUs that operate in the Gigahertz range and electrically operated fans can have reciprocal electromagnetic effects that lead to functional problems with the CPU.

In order to improve the cooling efficiency of the air, electronic components that develop a high amount of heat must generally be provided with cooling bodies. The cooling bodies generally comprise a massive metal core or a metal plate made of copper or aluminum, the top side of which is made for instance by a multi-member structure for surface area enlargement and therefore for better heat distribution. A fan can be mounted on the cooling body. The layout of such cooling

systems is only somewhat adaptable in terms of geometry due to the space required and the weight and is furthermore associated with loud running noise, typically between 40 and 60 dB (c't, 18, p. 122, 2002). The same publication mentions a relatively small ΔT between 30 and 40 K, measured between the maximum CPU temperature and the maximum interior PC temperature in the tested air coolers. For these reasons it is frequently necessary to compromise when using air coolers, which entails both technical and economic disadvantages.

Heat pipes have been commercially available since the 1960's and for the past several years have been increasingly used as high-end cooling systems for the electronics industry. Heat pipes are formed by a passive closed cooling system with which very good heat transfer is attained by a two-phase mechanism in the cooling medium. The heat absorption from the electronic element to be cooled leads to evaporation of the cooling medium in the closed system. The cooling medium then moves through the so-called adiabatic intermediate space in the condensation portion of the heat pipe. There the heat is removed by an additional heat sink. The condensate forms and is then returned to the evaporation area via a meso-porous edge layer. Adjusting this two-phase mechanism is only possible in a very limited temperature range by using specific cooling media and therefore severely restricts the options for employing heat pipes. In addition, the cooling capacity of these systems in comparison to water cooling, for instance, is low.

Peltier cooling units are used as heat pumps for instance in electronics, in air conditioning technology and in medical and laboratory engineering. They are very compact, but they are very expensive and as a rule are not suitable when substantial quantities of heat are to be eliminated locally and cost-effectively. Peltier cooling units furthermore require heat sinks for counter-cooling and an electrical power unit for the power supply. Energy consumption is increased by the amount of additional energy required. For this reason the power requirement of these units is high relative to cooling capacity, so that their use in mass applications is uneconomical.

Water cooling systems made of metal or ceramic materials have the highest cooling capacity in direct comparison to the cooling systems cited above. This is primarily due to the high heat capacity of the water and its low viscosity. Thus recently water coolers made of copper, aluminum and ceramics for cooling microprocessors have been on the market. All of these products today are subject to the high manufacturing costs of non-industrial small batch production. Typical performance data and prices for conventional coolers available on the market are at best for a temperature difference ΔT between CPU and cooling water inlet ($T_{CPU} - T_{cooling\ water\ inlet}$) of 12.5 to 16 K under full load with a cooling medium flow quantity of 3 L/min, if an AMD 2000+ is cooled, for instance, these data being a flow quantity of 1 – 20 L/min, a pressure loss of 25 to 250 mbar maximum, a weight of approx. 200 – 400 g and a component volume between 30 and 100 cm^3. The coolers are designed for the use of aquarium pumps with typical pump capacity of 1 – 3 L/min at a pressure loss of 130 –140 mbar.

In 2002 Innovatek OS GmbH, Stammham, Germany sells water coolers, the innovaCOOL rev 3.0 model at that time being assessed to have the best performance of any coolers available on the market (*e.g.* Chip, October 2002, p. 48).

For coolers for power semiconductors there have been initial attempts to use channel cross-sections smaller than 1 mm^2, as is the case for micro-heat exchangers and micro-reactors, as well.

"*Innovative Chip-Level Cooling*", J. Schulz-Harder, in PCIM Europe, March 2002, pages 27 – 42, describes a water cooling system for power semiconductor circuits. The cooler is produced from copper layers and joined to the semiconductor carrier with ceramic layers using a soldering process by means of eutectic melt. For manufacturing the cooler, the cooling channels in the copper layers are produced by etching similar to printed circuit board manufacturing

techniques. A cooling body through which a liquid flows is formed that has in its interior structure 8 to 10 copper layers with a hexagonal base structure (thickness of each layer is 0.3 mm) and pillars having a diameter of 1.5 mm. It is assumed that a heat quantity of more than 400 Watt/cm^2 can be removed. At a flow quantity of 5 L of water per minute the pressure drop is indicated to be 640 mbar.

Further a similar cooler for the use in cooling electronic components is described in DE 198 53 750 A1. This cooler comprises at least one cooling surface for the electronic components and a stack of cooling layers. The cooling layers are structured such that they form in the interior of the cooler a two-dimensional cooling structure for a cooling medium between an inlet area and an outlet area. The cooling structure comprises branched out flow routes. At least part of the cooling layers is structured such that the ratio or the gradient of the specific hydrodynamic flow resistance between those regions in the cooler which are nearby the cooling surface and those regions in the cooler which are farther away there from rises from the inlet area to the outlet area. For this purpose all the individual cooling layers are designed to be different from each other.

It is clear from this description that these coolers are expensive high-performance components as they are difficult to manufacture.

Furthermore, WO 98/41076 A2 describes an apparatus for cooling electronic components in which capacity can be raised substantially, compared to known coolers, by a heat sink and the heat transfer coefficient and thus the total thermal conductivity are to be substantially improved. In this document it is assumed that the largest pressure loss that the cooling fluid produces when passing through the micro-structured heat sink occurs in the area of the distribution structures and connecting channels. In order to solve this problem, a cooler is suggested that has a plurality of individual layers and that comprises at least one plate with numerous micro-channels and one distribution channel and that furthermore has an intermediate plate with connecting channels and a collection

plate with collection channels. Closed cooling channels result when these plates have been provided together with a cover plate and a base plate. The cooling medium in the cooling channels is introduced through an inlet opening into the micro-structure heat sink and removed from it through an exit opening. The intermediate plate for the cooling medium forms a graded and/or beveled transition structure, through which cross-sectional surface areas of the inlet and/or outlet opening, each of which is a vertical cut to the surface through all individual layers, successively transitions to the cross-sectional surface of the micro-channels. A cooler with cooling channels with a flow cross-section of 0.3 mm x 10 mm is cited as an example. In this cooler, a heat transfer coefficient of 8.5 Watts/$cm^2 \cdot K$ and a pressure loss of 0.5 bar at a flow rate of 500 mL/min is attained, for example. With these performance data, this relatively expensive cooler attains only approximately 10% of the cooling capacity required for an average CPU.

In contrast to micro-reactors and micro-heat exchangers that are already employed in research and development projects and even in initial industrial processes, the problem of the layout of electronic coolers is still completely unresolved since "heat management" in a micro-reactor or micro-heat exchanger is fundamentally different from that in a cooler that has to remove heat from a surface area.

In a reactor, heat that occurs in a flowing medium, *i.e.*, inside the reactor, must be removed or exchanged as rapidly as possible in order to come as close as possible to the ideal of an isothermal process. For this reason, attempts are being made within process engineering limits of a reaction to keep the cross-sections of the channels and the wall thickness between the channels as small as possible. Naturally a reactor must also be optimized in terms of layout, e.g., with respect to flow resistance, flow rate, etc. But the fundamental heat management principle is relatively simple, since heat is transferred from one system ducts for cooling liquid to another one the two systems lying close to each other.

For instance, it has been reported that micro-structure components can be manufactured from individual thin metal sheets (foils) that have a fine structure, the micro-structure (see US 4,516,632 A, for instance; a chemical micro-reactor is described in US 6,409,072 B1, an example disclosing a micro-reactor/heat exchanger comprised of sixty copper plates having a thickness of 125 µm and ducts etched therein which have a width of about 430 µm, a duct depth of 60 µm and a web width of 70 µm). In contrast, in a cooler for electronic components the heat must be removed from a strong, local exterior heat source.

Upon closer inspection, this object, *i.e.*, removing heat from a local highly heated surface, proves to be a very complex problem. The difficulty is that the actual heat source is located outside of the cooler, *i.e.*, much more attention must be given to the heat resistances within the three-dimensional structure of the cooling body through which the fluid flows.

The solution to the problem is now further complicated by additional specific requirements in electronics (for instance, when cooling CPU components) in that the heat must be removed with a minimum requirement for cooling water and a minimum pressure loss in the cooler.

The present inventors have found that increasing the cooling capacity by using increasingly fine structures, *i.e.*, smaller channel cross-sections, is only possible in a limited fashion since then the flow resistance rises too high.

This effect becomes a problem when a large quantity of heat is to be removed via a small surface area without the flow resistance increasing too much. In this case, then, the cooling capacity cannot simply be increased by increasing the flow speed of the cooling medium by applying a higher pressure difference across the cooling device, as is the custom in the prior art.

For application in PCs, servers and workstations, low pressure pumps are typically used that produce, for instance, a pressure of up to approx. 250 mbar. Powerful cooling medium pump systems for conventional micro-reactors that work under elevated initial pressure, for instance 5 bar and more, are not acceptable in this case due to the cost.

Another requirement is that the cooling devices have a shape adapted to the shape of the electronic components, *i.e.*, the surface area of the cooling devices and the mounting area on the component should be at least about the same size.

Finally, for the purposes of mass production, it must be ensured that the manufacturing costs for the fluid cooling devices and the cooling system are not substantially higher than for air cooling.

In summary, it can be concluded that the prior art does not satisfy these requirements or only partially satisfies them. This relates in particular to the requirement for cost-effective mass production for micro-structure components and reducing the high flow resistances in these components. Apart from this, rules for the design or layout of micro-structure cooling devices have not been known hitherto.

The object of the present invention is therefore to provide a cooling device that:

1. has a very high cooling capacity;
2. has a low hydrodynamic flow resistance to the fluid cooling medium;
3. has a shape that is adapted to the electronic component to be cooled;
4. is easy to produce cost-effectively;

5. furthermore the layout of the cooling device should be largely scalable, *i.e.*, it should be adaptable to the requirements at hand in a simple fashion; thus power consumption should increase from 70 Watts/cm^2 to 500 Watts/cm^2;
6. furthermore the cooling device should be optimally adaptable to the overall system in terms of layout, size, volume, assembly, etc.

The foregoing objects are achieved by the micro-structure cooling device in accordance with claim 1 and by the use of the micro-structure cooling device in accordance with claim 24. Preferred embodiments of the invention are provided in the subordinate claims.

The micro-structure cooling device in accordance with the present invention for an object to be cooled, in particular for an electronic component, includes a stack of at least two metal foils (metal sheets) and one base plate that can be brought via a thermal contact surface into thermal contact with the object. The metal foils and the base plate are joined to one another by suitable assembling techniques, preferably soldering. Present in the metal foils are channels in which flows the cooling medium that removes the heat. Assembling the at least two metal foils and the base plate together may preferably be achieved by material fit. Each metal foil may be designed to form a channel plane.

The channels in the metal foils have a width in the range of from 100 to 2,000 µm, preferably in the range of from 200 to 500 µm. In experiments it could be proven that, when all other parameters were maintained, performance of the cooling device decreases sharply starting at a channel width of 800 µm and greater and is no longer advantageous for high performance applications.

The channel depth is in the range of from 25 to 1,000 µm, preferably in the range of from 50 to 400 µm.

At least one of the two geometric variables, channel width or channel depth, should preferably be in the micrometer range. The hydraulic diameter: $4 \cdot A/U$; A = cross-sectional area, U = perimeter (defined in accordance with: "*Technische Strömungslehre*" ("*Technical Fluid Mechanics*"), Kamprath series, Vogel Publishing, W. Bohl, 11th ed., p. 131; Incropera, Frank P. and Dewitt, David P., "*Fundamentals of Heat and Mass Transfer*", 4th ed., John Wiley & Sons, NY, 1996, p. 449) should preferably be in the range of from 200 to 500 µm.

The mean interval between the channels in a metal foil is in the range of from 50 to 1,000 µm, preferably in the range of from 150 to 300 µm. If the cross-section of the channels is rectangular or nearly rectangular, so that a bar is formed between the channels in the metal foil, this interval is characterized as "bar width."

Furthermore, the residual foil thickness through the floor of the channels is in the range of 50 to 300 µm, preferably in the range of from 80 to 120 µm.

The base plate of the cooling device has a thickness in the range of from 200 to 2,000 µm, preferably in the range of from 500 to 1,500 µm.

For each of the foregoing parameters, the parameters particularly satisfy these requirements when they are within the preferred ranges, especially when very high power densities are required. Furthermore, the aforesaid ranges apply for the parameters in particular when copper is used as the base material. **Fig. 1** and **Fig. 2** provide the definitions of the geometric parameters (channel width, channel depth, interval between channels (bar width), residual foil thickness and thickness of the base plate):

It was

1. the perception to first provide fundamental rules and features, *i.e.*, specific geometric data for the optimal layout and design of micro-structured cooling bodies for uniplanar local heat sources, and
2. the need to resolve the special additional problems that are associated with cooling microprocessors (CPUs) and other hot components of electronic computers; in particular, the issues of flow resistance and pressure loss in high performance micro-structure cooling devices, which heretofore have remained unresolved,

that was necessary to find out the solution to the problem outlined above. More specific measures for further optimization of the cooling device according to the present invention are given herein below:

The lower range limits for channel width, channel depth and channel interval (bar width) are largely determined by the requirements for the production process in question. When very small values are set for these geometric parameters, mass production of the cooling device is difficult since the required tolerances cannot be assured. However, production options depend on the technology applied, so that the lower range limits can accommodate even lower values if product engineering is refined.

Use of micro-structuring methods makes it possible to produce much finer channel structures than with conventional technology. In accordance with the invention, the term micro-structure engineering means a manufacturing method in which the highly resolved structures are formed in terms of micrometers, as they can be produced in printed circuit board technology. Such methods include the production of high-resolution structure patterns, such as for instance photo-lithographic process steps. For instance, channels can be produced using dry etching methods or using wet chemical deep etching, depending on the masks used. Mechanical micro-production is also possible (e.g., micro-milling, micro-

stamping, reforming, etc.), whereby methods similar to those for printed circuit boards are preferred.

In that the channel width, channel depth, channel interval (bar width), residual foil thickness and base plate thickness are selected within the given ranges, it is possible to effectively reduce the pressure loss using the inventive design of the micro-structure and to attain the least possible temperature difference between the object to be cooled and the cooling medium at a given cooling capacity (heat transfer capacity). A least possible temperature difference can even be attained when the cooling capacity is high. Optimizing the pressure loss in the cooling device makes it possible to use pumps for feeding the cooling medium that wear less and thus attain a longer service life. In addition, only a low pump capacity is required to circulate the cooling medium, so that the costs for operating the cooling circuit can be minimized, as can the costs for the entire cooling system (cooling device including counter-cooler, fluid lines, pump, power supply for the pump). This also means that the cooling device can be inexpensively industrially mass-produced and that a wide spectrum of cooling capacity can be covered.

The channel width, channel depth, channel interval, residual foil thickness and base plate thickness can be designed in particular with respect to the ratio of cooling capacity to the volume of the micro-structure cooling device and can be optimized, for instance, for an AMD 2000+ CPU.

In comparison to conventional coolers a reduction in temperature difference is achieved if the inventive micro-structure cooling device is used. This reduction effects immediate energy savings in a cooling system and thus effects savings in operating costs. This property is particularly relevant in the case of mainframe computers with a plurality of CPUs, since in this instance several kWatts of heat must be cooled.

The channel width, channel depth, channel interval, residual foil thickness and base plate thickness can also be designed application-specific under the following given operating conditions with respect to pressure loss and/or the cited temperature difference and optimized for instance for an AMD 2000+ CPU:

a. Area power of CPU up to 70 Watts/cm^2;
b. Difference between the temperatures on the thermal contact surface and in the cooling medium flowing into the cooling device of less than 10 K;
c. Flow quantity for the cooling medium through the cooling device in the range of 0.01 to 3 L/min;
d. Pressure loss of less than 100 mbar.

In an identical overall system, a water cooler currently available on the market as a substitute may attain at best a ΔT (between CPU and cooling medium) in the range of 12.5 and 16 K at a flow quantity of from 1 to 3 L/min and at a pressure loss of from 25 to 250 mbar. Under the same conditions, the inventive cooling device requires a ΔT between CPU and cooling medium that is at least 30% lower in order to remove the same quantity of heat as the fluid coolers on the market that have heretofore had the best performance. The inventive cooling device can be oriented toward and adjusted for the pressure loss of the available or preferred pump via layout and design while assuring sufficient capacity.

The inventive micro-structured cooling device thus demonstrates substantially higher capacity with a much smaller ΔT. This relationship is exploited for the high degree of scalability in terms of the capacity of the micro-structure cooling device. In terms of the ratio of interior surface/volume of the cooling device, for known coolers this ratio is much lower than for the inventive cooling devices, by a factor of at least 3, *e.g.*, if measured in [cm]. For a commercial reference cooler this ratio may be 1.13 cm^2/cm^3 and for an inventive prototype it may be as high as 4.8 cm^2/cm^3. In the inventive prototypes the thickness of the cover plate may be

as low as 1 mm and the thickness of the side walls as low as approx. 17 mm. These values may be further optimized depending on production engineering. The following values can be expected under industrial production conditions:

Internal surface/cooler volume:	approx. 12 – 15 cm^2/cm^3
Thickness of the side walls:	less than 2 mm

The aforesaid values for the operating conditions can be even further optimized in particular when using a water/alcohol mixture, in particular a water/ethylene glycol mixture, and very particularly a mixture of 95 vol.% water and 5 vol.% ethylene glycol as cooling medium.

The cooling device according to the present invention can be optimized with respect to the given parameters as follows:

The values for channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may be optimized such that the pressure loss for the cooling medium in the cooling device is minimized.

The values of the channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may also be optimized such that the difference between the temperature of the thermal contact surface and the temperature of the cooling medium flowing in the cooling device is minimized.

The values of the channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may also be adjusted such that a cooling capacity to volume of cooling device ratio, *i.e.*, a "cooling compactness", of at least 2 $Watts/cm^3$ is achieved.

The values of the channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may also be adjusted such that a "cooling capacity per volume and ΔT" of at least 0.1 $W/(cm^3 \cdot K)$ is achieved.

The values of the channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may also be adjusted such that a specific, pressure loss-normalized cooling capacity of at least 0.1 $W/(cm^3 \cdot K \cdot L/min)$ is achieved.

The values of the channel width, the channel depth, the channel interval, the residual foil thickness and the base plate thickness may also be adjusted such that a heat transfer capacity of 200 $Watts/cm^2$ is achieved at a maximum difference in temperature between the thermal contact surface and the cooling medium flowing in the cooling device of 10 K at a flow quantity for the cooling medium through the cooling device in the range of from 0.01 to 3 L/min and at a pressure loss of at most 100 mbar.

The following should be observed for the optimal layout of channel width, channel depth, channel interval, residual foil thickness and base plate thickness:

Given previously gained knowledge about the layout of conventional coolers it is assumed that high heat transfer cannot be attained unless there is a turbulent flow in the coolers (high Reynolds' number), since under these conditions a better heat transfer is achieved between cooling medium and cooling channel wall than by adjusting laminar flow ratios. However, this optimizing measure involves a substantial increase in pressure loss.

A very substantial increase in heat transfer capacity by orders of magnitude, relative to the volume of the component, could be attained by using the micro-structure engineering for manufacturing cooling devices and heat exchangers. An example of this is commercial high performance micro-heat exchangers from the

Karlsruhe Center for Research. In particular the high costs of micro-structure production and the currently very high flow resistances have hindered broad application of micro-structure technology in the past.

The reason for the currently very high flow resistances of the known micro-structured heat exchangers is that an increase in the heat transfer capacity generally leads with a larger cooler, longer channels, and therefore, due to the Hagen Poiseuille Law, to the increase in the flow resistance, which cannot be tolerated for applications in cooling electronic components, however.

It is only the present invention that resolves this problem without this having a negative impact on the heat transfer capacity and it does so by making it possible to optimize, even with regard to the pressure loss in the cooling device, the channel width, channel depth, channel interval, residual foil thickness and base plate thickness.

These measures also make it possible to reduce production costs and therefore also system costs such that micro-structure cooling devices are not only technically superior, but are even economically competitive. The basis for the inventive channel design is that the cross-section of the channels is minimized just enough that a laminar flow is attained in the channels under operating conditions. Turbulences are only tolerated or caused where the flow cross-sections, *i.e.*, the flow resistances, are low. In this manner the pressure loss of a product can be adapted to the application at hand in a simple manner. As a rule the first step is to roughly optimize the geometry (channel width, channel depth and channel interval) within the given ranges by adjusting the surface/volume ratios of the flow channels. A low surface/volume ratio of the micro-structure, e.g., 3000 m^2/m^3 generally means a low flow resistance but also lower heat transfer. At very high values of the surface/volume ratio, *e.g.*, 10,000 – 30,000 m^2/m^3, the flow resistance climbs sharply so that an optimum is attained preferably at mean surface/volume ratios.

As has been emerged, however, optimizing the flow resistance and the surface/volume ratio alone is not sufficient for optimizing capacity. As already explained, in an inventive micro-structure cooling device the heat source is outside of the cooling device and heat is removed via the heat-conducting metal structure and by the cooling medium. The result of this is that the physical structure of the cooling device must be optimized in addition to optimizing the flow conditions.

The object of the invention is therefore also achieved both by the "hydrodynamic factor," which is responsible for the optimum flow conditions, and by the "structure factor," which is established by the design of the cooling device.

The following illustrates the inventive design parameters and their effect on cooling capacity:

It has been turned out that with regard to the aforesaid optimizing criteria, pressure loss and temperature difference, it is particularly beneficial to optimize the ratio of channel width to interval between channels (bar width). A ratio that is too high leads to the heat transfer capacity diminishing. Thus this ratio (width/interval) should preferably be in the range of from 1.5 : 1 to 2.5 : 1. A channel width to residual foil thickness ratio that is too high has a similar effect. The ratio of channel width/residual foil thickness should be in the range of from 2 : 1 to 5 : 1.

Minimizing the residual foil thickness furthermore attains improved heat transmission between the individual layers. The following applies for the base plate thickness: Since the temperature of the object to be cooled as a rule is not constant over the surface area, it could at first appear obvious to design the base plate to be thick in order to achieve homogeneous temperature distribution in the cooling device. On the other hand, heat transfer for the base plate diminishes as thickness increases due to the heat resistance of the metal used.

Thus there is a heat transfer maximum for the inventive base plate thickness, which thickness can be greater or smaller depending on the (desired) temperature difference or layout. In all of the water coolers currently available on the market, the heat is rapidly removed from the heat source by using the thickest possible base plates (e.g., 5 mm) and thus without taking into account the cited optimum. The inventive cooling device, on the other hand, has the minimum necessary residual floor thickness for the corresponding capacity range and thus brings the micro-structure with the cooling medium as close as possible to the heat source. Thus assured are optimized local heat removal with simultaneous substantial reductions in costs due to savings in materials and reduction in mass.

Thus the parameters for the channel geometry (channel width, depth and length) affect pressure loss, *i.e.*, the "hydrodynamic factor", while the channel interval, residual foil thickness and base plate thickness parameters influence the heat transmission of the three-dimensional structure, *i.e.*, the "structure factor." The latter is also highly dependent on the physical arrangement of the channels and flow direction, *i.e.*, the design, as is demonstrated with the design examples presented below. Surprisingly, it has been established that the flow direction in Design B outlined herein below plays a very substantial role. The design principle cannot make full use of its advantages unless the fluid is introduced through the gap in this design. Using appropriate design in the inlet area, the central in-flow generates swirling/turbulence that increases the heat transmission immediately above the heat source before the flow finally fully develops. The pressure loss that results from this and the pressure loss that results during the distribution and in-flow into the channels from both sides of the cooling device having the Design B is compensated by the shortening of the channels and by the doubling of the number of channels compared to Design A described herein below. Since in accordance with the Hagen Poiseuille Law flow speed is proportional to pressure loss (Δp) and by doubling the number of channels the flow speed can be cut in half, Δp can be reduced by 75% maximum by this and by halving the channel length. The channel has a so-called "critical length" beginning with which the laminar flow developed

completely. At first the speed distribution can be described by a nearly rectangular profile. In this case the pressure loss is greater in accordance with the Hagen Poiseuille Law, but the heat transmission is higher. The transition point must thus be optimized with the "inlet effect" so that the pressure loss remains minimized in a controlled manner, but the heat transmission is further increased.

Fundamentally, however, the channel lengths should be as short as possible for each design.

Starting at a "critical Δp" as a minimum, cooling capacity of the cooling device collapses. This minimum can be intentionally pushed even lower using the described design variations.

Furthermore it has proved advantageous that a heat exchange surface created in the channels in the interior of the cooling device is larger than the thermal contact surface on the base plate. For instance, the flow channels in the cooling device can form a more or less dense pattern in a metal foil (cooling plane) and thus define a heat exchange surface in which the heat flowing into the cooling device is absorbed by the cooling medium. The area of this heat exchange surface should be larger than the surface area on the base plate via which the object to be cooled is in direct thermal contact with the cooling device. What this additional optimizing measure achieves is that the heat from the object to be cooled is conducted via the thermal contact surface as directly as possible and completely to the flow channels and thus into the cooling fluid and not for instance into the side walls of the cooling device.

Another influencing variable is the aspect ratio of the channels, *i.e.*, the ratio of channel depth to channel width. Given the same channel cross-section, deep channels (high aspect ratio) clearly have a positive effect on the heat transmission of the cooling device. The aspect ratio in the inventive cooling device depends on

the limits of the etching process being used; the maximum achievable figures are currently in the range of from 1 : 2 to 1 : 3.

Using the described design optimizing, an effective transfer of heat from the object to be cooled to the cooling device and into the cooling medium can be attained, whereby the pressure loss is adjusted to a reasonable range with the inventive adjustment of the hydrodynamic factor as described in the foregoing. If desired, a pressure loss of 100 mbar or less can be attained with a typical heat transfer capacity of approximately 200 Watts/cm^2. Typical characteristic parameters for the cooling device are:

Flow quantity: 0.01 – 3 L/min;
Absolute capacity: 0.02 kWatts – 2 kWatts;
Power density: at least 20 Watts/cm^2;
CPU/fluid temperature difference: less than 10 K.

Additional design parameters that influence the structure factor and that should be used for optimizing are: total number of channels, number of metal foils (channel planes), surface area on the foils, surface area in the channels (heat exchange surface area), channel length, type of material comprising the metal foils, the base plate, a cover plate for closing the cooling device and the joining material for the material-fit joining of the metal foils to one another and to the base plate as well as the selection of the material that is used for creating the thermal contact between the object to be cooled and the cooling device.

The inventive cooling device contains at least two metal foils with flow channels. Preferably the channels are organized into channel planes. Instead of two metal foils, it is also possible to use a single metal foil and additionally one base plate provided with depressions for receiving flow channels. In this case the one of the two metal foils is then called the base plate when it has channels.

The micro-structure cooling device has preferably 2 – 10 planes for the channels. With respect to the foregoing, this means that either 1 – 9 metal foils and additionally one base plate provided with channels or 2 – 10 metal foils and additionally one base plate without channels are provided. For a base plate that contains channels, the condition that the residual foil thickness is in the range of from 50 to 300 µm does not apply. The heat transfer capacity from the object to be cooled to the cooling medium increases with the number of channel planes. However, it has turned out that the heat transfer capacity cannot be increased further, or at least cannot be meaningfully increased further, when there are more than 8 layers with the same geometry. Simply varying the number of layers makes it possible to adjust various ranges of heat transfer capacity of the cooling device and also to intentionally influence manufacturing costs. Since each channel plane increases costs, the product must be designed with the application price/capacity ratio in mind. When using the inventive manufacturing process, the price can be very substantially reduced with sufficient cooler capacity when application-specific design reduces surface areas or volume.

In addition to the metal foils and the base plate, which latter closes the stack to the thermal contact surface for the object to be cooled, the inventive micro-structure cooling device also has a cover plate. The cover plate itself can be a metal foil provided with channels. But it can also be an unstructured cover plate. For manufacturing the micro-structure cooling device, the structured foils are provided with a cover plate and a base plate and joined to form a compact device. Preferably a plurality of openings for the connections of the inlet and outlet areas can be formed by etching, punching or lasering preferably into the cover plate. It is preferred that the cover plate is made of metal, plastic or plastic/injection-molding.

Provided for introducing cooling medium into the cooling device and removing cooling medium from the cooling device are apparatus for connecting tubes, for instance injected, integrated or joined connecting supports. The tube or pipe connecting elements can be directly integrated or variably attached by

screwing on, joining (soldering/brazing), pressing and/or by adhesive. Connected to these connecting supports are fluid lines to the pumps and/or external counter-coolers.

Furthermore, the channels in the metal foils generally run parallel to one another. But this does not mean that they must always run in a straight line. Parallel "snake lines", curved or "star-shaped" channels or the like that do not necessarily run parallel to one another can also be advantageous. This makes it possible to arrange the channels extremely close to one another so that very effective heat transfer is attained between the material of the cooling device (metal foils) and the cooling medium. Also conceivable is any desired three-dimensional arrangement of the channels in which the individual layers are provided with openings.

Furthermore, the micro-structure cooling device can have at least one inlet distribution space and at least one outlet distribution space for the cooling medium.

Design A: The distribution spaces can be arranged such that they are situated at side surfaces in the cooling device opposite one another and extend largely across the entire width of that side surface of the cooling device.

In the first channel design, the channels connect on the inlet side to an inlet distribution space and on the outlet side to an outlet distribution space. Thus in a cooling device structured in this manner cooling medium flows via a first connecting support into the cooling device and then travels into the inlet distribution space. Since the inlet distribution space in this design cuts into all flow channels on one side, the cooling medium can flow from there into the flow channels. Once the cooling medium has traveled through the channels, it reaches the outlet distribution space. From there the cooling medium flows into external cooling lines.

In a second variant, Design B, the metal foils are interrupted at approximately the height of the thermal contact surface by at least one inlet-side distribution chamber. For instance, this distribution chamber can separate the metal foils as a gap, whereby the metal foils are preferably separated at least substantially vertical to their plane. The gap width can be in the range of from 50 to 2,000 µm, for instance. The gap-shaped distribution chamber can pass through the cooling device largely over the entire cross-section vertical to the metal foils. If the thermal contact surface is arranged approximately centrally on the base plate, the distribution chamber also separates the metal foils approximately in the center region. In any case the gap is preferably located in the center region of the cooling device extending upwards from the base plate through the channel planes. What this arrangement achieves is that the cooling medium that flows into the distribution chamber from above (when the base plate is below) also comes into contact with the base plate approximately in the central area in which the thermal contact surface is situated. This produces a flow in this area that leads to increased heat transfer.

Since the channels preferably run in the planes of the metal foils, all of the channels are connected at their one end to the distribution chamber. In one preferred embodiment, two groups of channels are provided that run essentially parallel to one another. Furthermore provided is at least one collection chamber within the cooling device with which all channels are connected at their other end. Two collection chambers can be provided for instance that, as in the case of the first Design A, are arranged on side surfaces opposing one another and that extend essentially across the entire width of each side surface of the cooling device. The collection chambers are preferably connected to one another so that cooling medium can travel from the distribution chamber into the cut-in flow channels and from there into the collection chambers that are joined to one another.

In the case of the Design B, as well, provided are at least one first connecting support that is connected to the collection chambers, as well as at least one second connecting support that is connected to the distribution chamber. The cooling medium can thus be conducted out of an external cooling line via the first connecting support into the distribution chamber and travels from there into the flow channels. The cooling medium is then directed into the collection chambers and from there via the second connecting support out again into an external cooling line.

The dimensions of the inventive cooling device in principle cannot be obtained with industrial production methods conventionally applied for manufacturing cooling systems today.

Therefore for manufacturing the micro-structure cooling device, methods can be used that are analogous to printed circuit board production methods, these methods comprising the individual process steps of photolithography, structuring (preferably etching), metal plating and joining, preferably soldering (DE 197 08 472 A1). The analogy is that a complex three-dimensional structure is produced by stacking and joining micro-structured foils. Component design, structure and joining (soldering) systems are optimized for this method in terms of the ability for mass production and thus make it possible to manufacture the micro-structure cooling devices in large numbers cost-effectively, whereby existing systems can be used that generally do not have to be modified or only require minor modification. The advantages of the described manufacturing method are the use of already existing micro-structuring processes, scalability for industrial mass production and very low costs. This offers the great advantage that technology that has already proved for mass production can be used in a new application for the inventive cooling device and furthermore that the process steps can easily be combined and integrated. Thus, for instance for ensuring force-minimized assembly without additional retaining clips, the cooling device can be mounted directly onto the CPU, preferably by soldering or adhesive.

The following properties are attained with the application of micro-structure engineering for manufacturing the cooling device:

1. Very high, reliable, absolute seal (vacuum seal up to 10^{-9} mbar · L/s) of the micro-channels in the cooling device to the environment, but also between the micro-channels in the device, for optimizing the heat transport by using a complete, fully metal bond;
2. Excellent pressure resistance of the cooling device and strength of the joints between the metal foils and the cover and base plates;
3. Very good resistance to corrosion, adapted to the area of application, using corrosion protection layers applied electrochemically;
4. High temperature resistance;
5. Homogeneous channels that are free of deposits and that are geometrically well defined;
6. Minimal pressure loss for the cooling medium in the cooling device.

For assembling the components, the layer thickness of the soldering system and the process parameters must be carefully coordinated with one another in order also to make possible soldering in the laminating presses. Please refer to DE 197 08 472 A1 as well as "*Handbuch Löttechnik*" ("Manual of Soldering Technology"), I.E. Petrunin, Verlag Technik GmbH, Berlin, 1991), with regard to possible joining methods.

Please refer to the figures for the following explanation of the invention:

Fig. 1: shows a cross-sectional schematic illustration of a structured metal foil;

Fig. 2: shows a cross-sectional schematic illustration of a micro-structure cooler in thermal contact with an electronic component;

Fig. 3: shows a schematic illustration of a micro-structure cooler plane in a first Design A;

Fig. 4: shows a schematic illustration of a micro-structure cooler plane in a second Design B;

Fig. 5a: shows a schematic illustration of a micro-structure cooler in a first Design A with cooling medium connectors pressed in;

Fig. 5b; shows a schematic illustration of a micro-structure cooler in a first Design A with off-set distribution spaces with cooling medium connectors pressed in;

Fig. 5c: shows a schematic illustration of a micro-structure cooler in a first Design A with screw-in cooling medium connectors;

Fig. 5d: a schematic illustration of a micro-structure cooler in a first Design A with screw-in, angled cooling medium connectors;

Fig. 5e: shows a schematic illustration of a micro-structure cooler in a first Design A with offset distribution spaces, with a molded cover plate in the shape of a cover, with screw-in cooling medium connectors and with a base plate that has cooling channels;

Fig. 6: shows a schematic illustration of a micro-structure cooler in a second Design B with cooling medium connectors.

Identical reference numbers have the same meaning in all figures. Please also refer to the attached reference numeral list.

Fig. 1 illustrates individual optimizing parameters on a metal foil **1** that lead to minimizing the pressure loss in the cooler and to minimizing the temperature difference between thermal contact surface and cooling medium flowing into the cooler or for maximizing cooling capacity. The channels are shown as recesses **2** in the metal foil **1** that has not yet been soldered.

Shown are the channel width **b**, channel depth **t**, channel interval (bar width) **s** and residual foil thickness **r**. Also shown is the width **f** of the structured area on the metal foil **1**. **Fig. 2** shows the additional optimizing parameter **g** (base plate thickness).

Fig. 2 illustrates a cooler **3** with thermally contacted CPU processor **4**. The cooler **3** in this case comprises four metal foils **1**, each of which has four cooling channels **2** and bars **9** situated there between. The channels **2** of each metal foil **1** are closed by an adjacent metal foil **1**. The cooling channels **2** of the lowermost metal foil **1** are closed to the CPU processor **4** by a base plate **5**. The base plate **5** also absorbs via a thermal contact surface **6** the heat that the CPU processor **4** develops. For this purpose, the CPU processor **4** is bonded via a joining means with good thermal conductivity (*e.g.*, heat transfer compound, solder, conductive adhesive) **7** to the base plate **5** in the area of the thermal contact surface **6**. The CPU processor **4** is mounted on a CPU carrier plate **8**. The stack of metal foils **1** and base plate **5** is closed by a cover plate **9** situated on top. The base plate thickness **g** is also shown.

Different designs of the channeling in the micro-structure coolers according to the present invention are illustrated in the following:

Design A:

Fig. 3 schematically illustrates a cross-section through a micro-structure cooler at the height of one metal foil **1**. The individual channels **2** in the metal foil **1** are shown. The channels **2** are arranged parallel to one another. The parallel arrangement describes a heat exchange surface that is determined by the width **f** of the channels **2** and the channel length and that is larger than the thermal contact surface of the electronic component. This is attained by selecting a sufficiently long length for the channels **2**. The channels **2** open to an inlet distribution space **10** and to an outlet distribution space **11**. While the channels **2**

are situated only in the plane of one metal foil **1**, the inlet distribution space **10** and the outlet distribution space **11** extend over the entire internal height of the cooler so that the channels **2** of all metal foils **1** in the cooler are connected to the two distribution spaces **10, 11**.

A plurality of such metal foils **1** is soldered to one another, both via the bars **9** of the structured foils **1** and via the edge **12** of the foil **1**. In addition, one of these foils **1** is soldered via the bars **9** and the edge **12** to a base plate **5**. The length of the channels **2** is for instance approximately 20 mm when the surface area of a CPU processor to be cooled is 10 mm x 10 mm. Thus, a 5-mm overhang of the channels **2** over the thermal contact surface for the CPU processor on each side results in a channel length of 20 mm and a width **f** of the heat exchange surface area covered by the channels **2** is also 20 mm.

Fig. 5a illustrates a cross-section of a micro-structure cooler **3**, whereby in this case the connectors for cooling medium that is conducted into and out of the cooler **3** are shown. There is an inlet sleeve **15** and an outlet sleeve **16**. For rapid and cost-effective assembly, rapid plug-in connectors **17** are pressed or screwed into the inlet and outlet sleeves **15, 16**. This makes it possible to attach a tube, for instance with a diameter of 4 or 8 mm.

Fig. 5b illustrates a cross-section of another micro-structure cooler **3**. In this case the connecting sleeve **15** and the rapid plug-in connector **17** pressed into this sleeve are located in the area of the cover plate **9**. The other connecting sleeve **16** with pressed-in rapid plug-in connector **17** is situated to the side in the cover plate **9** projecting over the channel area.

In this case metal foils **1** with cooling channels **2** are used that do not include distribution spaces **10, 11**. On the contrary, the metal foils **1** have exclusively cooling medium channels **2** that are arranged parallel to one another. By assembling a plurality of metal foils **1** with channels **2** into a cooling block, the

cooling channels open at the ends of the cooling block. This cooling block is assembled with the base plate **5** and the cover plate **9** such that hollow spaces form that are adjacent to the ends of the cooling block and into which the channels **2** open. These hollow spaces form the inlet distribution space **10** and the outlet distribution space **11**, respectively. The connecting sleeves **15, 16** with the rapid plug-in connectors open directly into the distribution spaces **10, 11**. The cover plate **9** can be manufactured cost-effectively as a molded part made of plastic. Since the cooling block is largely reduced to the size of the CPU **4**, the manufacturing costs for the cooler **3** can be substantially reduced.

Fig. 5c illustrates another cooler variant. In this case, in contrast to the variant illustrated in **Fig. 5a**, the rapid plug-in connectors **17** for the inlet sleeve **15** and for the outlet sleeve **16** are embodied as screw-in connectors. Otherwise this variant corresponds to the embodiment in **Fig. 5a**.

Fig. 5d illustrates another cooler variant. In this case, in contrast to the embodiment illustrated in **Fig. 5c**, the rapid plug-in connectors **17** for the inlet sleeve **15** and for the outlet sleeve **16** are embodied in an angled shape. This makes possible an alternative assembly of the tube connectors from the side, so that a lower component height can be attained. Additional advantages are that the tubes can be connected force-free and they are also more easily mounted, even under tighter space constraints. Otherwise this variant corresponds to the embodiment in **Fig. 5c**.

In another embodiment of the inventive cooler **3**, in accordance with **Fig. 5e** the cover plate **9** is embodied in the form of a cover, for instance made of plastic. This cover **9** can preferably be manufactured by injection molding. The cover includes the area of the cooling block formed by the cooling channels **2** in the metal foils **1**. Also integrated into the cover **9** are the inlet sleeve **15** and the outlet sleeve **16**, which receive rapid plug-in connectors **17** that can be pressed in.

The cooling block comprising the metal foils **1** provided with cooling channels **2** has approximately the same size as the CPU **4**. The cooling channels **2** in the metal foils **1** open into the inlet distribution space **10** and into the outlet distribution space **11**. The distribution spaces **10, 11** are immediately connected to the inlet sleeve **15** and the outlet sleeve **16**, respectively.

The lowermost metal foil **1** of the cooling block is also the base plate. In this case the base plate thickness **g** satisfies the inventive conditions, *i.e.*, the base plate thickness **g** is in the range of from 200 to 2,000 µm. In contrast, the residual foil thickness **r** for this lowermost metal foil **1** in which cooling channels **2** are also situated does not necessarily have to be set within the inventive range of from 50 to 300 µm. However, the residual foil thickness **r** for the other metal foils is within the inventive range of from 50 to 300 µm.

The CPU **4** is mounted on a carrier plate **8** and is in contact with the cooler **3** via a thermal contact surface **6**. The CPU **4** is set on the carrier plate **8** into a recess in an electrical insulating layer **18**, for instance protective enamel or varnish, and is surrounded thereby, such that the cooler **3** hermetically seals the CPU **4** to the outside.

Design B:

In order to minimize the pressure loss within the micro-structured channels **2** and thus to minimize the necessary flow quantity of the cooling medium with respect to optimizing and making smaller the cooler and the entire cooling system, including a cooling medium pump and the fluid tubes, the metal foils **1** are interrupted approximately at the height of the thermal contact surface by at least one distribution chamber **20** ("splitted channel design"). In **Fig. 4** this distribution chamber **20** is illustrated in one micro-structure cooler plane as a gap that cuts into the channels **2** and the bars **9**. While the channels **2** are only partially taken out of the metal foil **1** illustrated in **Fig. 4** leaving over the residual foil thickness of the

foil, the gap **20** is a slit that runs completely through the metal foil **1**. Overlaying a plurality of such metal foils **1** thus forms channels **2** for receiving the cooling medium that run within the metal foil plane. The distribution chamber **20** formed by the gap, on the other hand, extends over the entire interior of the cooler.

Fig. 4 further illustrates that the channels **2** open into a collection chamber **21**. The collection chamber **21** includes the channel surface area on three sides, so that cooling medium from the distribution chamber **20** can enter the upper channels **2** and the lower channels **2**. The cooling medium exiting the channels **2** again travels into the U-shaped collection chamber **21**. This manner of conducting the cooling medium makes possible excellent cooling capacity. Substantially worse cooling capacity is attained when the cooling medium is conducted in the reverse, *i.e.*, when the cooling medium is introduced from the collection chamber **21** into the channels **2**, from where the cooling medium travels into the distribution chamber **20**.

Just like the distribution chamber **20**, the collection chamber **21** is formed in the metal foil **1** as a continuous recess, so that once a plurality of such foils **1** has been placed one over the other this chamber **21** extends across the entire inner height of the cooler. Just as in the case of the distribution chamber **20**, what this achieves is that the cooling medium is distributed uniformly across all channels **2**.

For conducting the cooling medium out of the cooler, two connecting supports can be provided via which the cooling medium is removed from the distribution chambers **20**. Once the cooling medium has passed through the channels **2**, it travels into the two legs of the collection chamber **21** and is conducted out of the cooler from there.

Fig. 6 is a schematic cross-section of a micro-structure cooler **3** with cooling medium connections. In this case, as well, the reference numbers have the same meanings as in the foregoing.

As in **Fig. 5b**, in this case a structure of the cooler **3** with a cooling block made of metal foils **1** and cooling channels **2** arranged therein is illustrated. The cooling block is approximately the same size as the area of the thermal contact surface of the CPU **4**. Two chambers that form collection chambers **21** result from the cover plate **9** that projects over the channel area in the cooling block and that can preferably be manufactured as an injection molded part made of plastic. These chambers **21** are connected to one another. Furthermore, the metal foils are centrally interrupted corresponding to the arrangement in **Fig. 4** and thus form a distribution chamber **20** that cuts into the cooling channels **2**.

Two connecting sleeves **15, 16** that receive rapid plug-in connectors **17** are in the cover plate **9**. The rapid plug-in connector **17** in the connecting sleeve **15** introduces cooling medium into the cooler **3** and the rapid plug-in connector **16** removes cooling medium from the cooler **3**. Tubes can be connected to the rapid plug-in connectors **17**. The connecting sleeve **15** opens into a distribution channel **22** that opens into the distribution chamber **20**.

Example:

The cooling device according to the present invention having the Design A is compared to a commercially available cooler. For this purpose the two devices are mounted to a computer server For determining the characteristic figures, characteristic data calculated for the computer system are used. In this system, the coolers are measured under otherwise identical conditions (PC, CPU, tube system, pump, radiator, measuring program, etc.).

Various characteristic figures that describe the performance of a cooling device can be defined.

Important factors are:

CPU power	[Watts]
Power/surface area of CPU:	[Watts/cm^2]
Characteristic line for pump delivery:	Flow as function of pressure
Pressure loss in system:	[mbar]

The following characteristic parameters for the cooling device can be represented:

Volume of cooler (without connections):	[cm^3]
Flow quantity of cooling medium:	[L/min]
Temperature difference ΔT between CPU and cooling medium inlet:	
$\Delta T = T_{CPU} - T_{cooling\ medium\ inlet}$	[K]
Temperature difference (for given CPU)/power:	[K/Watts]
Cooling Compactness (cooling capacity/volume):	[Watts/cm^3]
Cooling capacity per volume and ΔT:	[Watts/($cm^3 \cdot K$)]
Cooling capacity per volume and ΔT and flow:	[Watts/($cm^3 \cdot K \cdot$ L/min)]

The various parameters describe important application-relevant properties such as size, performance, efficiency and system requirements.

Important influencing factors are:

CPU power:	approx. 70 Watts
Power/surface area of CPU:	60 Watts/cm^2
Characteristic line for pump delivery:	Eheim pump
Pressure loss in system:	10 – 100 mbar

A) Commercially Available Cooler:

Volume of cooler (without connections):	
W x L x H (5 x 5 x 3.5)	87.5 cm^3
Flow quantity of cooling medium:	2.7 L/min
Temperature difference ΔT between CPU and cooling medium inlet:	
$\Delta T = T_{CPU} - T_{cooling\ medium\ inlet}$	13 K
Temperature difference (for given CPU)/power:	0.186 K/Watts
Cooling Compactness (cooling capacity/volume):	0.8 Watts/cm^3
Cooling capacity per volume and ΔT:	0.062 Watts/($cm^3 \cdot K$)
Cooling capacity per volume and ΔT and flow:	0.023 Watts/($cm^3 \cdot K \cdot$ L/min)
Internal surface area/volume:	approx. 1.13 cm^2/cm^3

B) Inventive cooler in accordance with Design A:

The cooler is built from a base plate (thickness: 1 mm), eight structured foils and a cover plate (thickness: 1 mm) with soldered connecting supports.

Geometry of the structured foils:

Channel length:	16 mm
Channel width:	500 µm
Bar width:	200 µm
Channel depth:	230 µm
Residual floor thickness:	70 µm
Number of channels:	31 channels/foil (structured width: 21.5 mm)

Number of foils: 8

Volume of cooler (without connections):

W x L x H (4.9 x 4.9 x 0.5 cm^3) 12 cm^3

Flow quantity of cooling medium: 1.25 L/min

Temperature difference ΔT between CPU and cooling medium inlet:

$\Delta T = T_{CPU} - T_{cooling\ medium\ inlet}$ 11 K

Temperature difference (for given CPU)/power: 0.157 K/Watts

Cooling Compactness (cooling capacity/volume): 5.8 Watts/cm^3

Cooling capacity per volume and ΔT: 0.53 Watts/($cm^3 \cdot K$)

Cooling capacity per volume and ΔT and flow: 0.42 Watts/($cm^3 \cdot K \cdot$ L/min)

Internal surface area/volume: 4.8 cm^2/cm^3

The results of the comparison tests are given in Table 1.

Table 1:

	Commercially Available Cooler	Inventive cooling device (Design A)	Difference
Temperature difference (for given CPU)/power [K/W]	0.186	0.157	Efficiency improved by 20%
Cooling Compactness [W/cm^3]	0.8	5.8	7.5 times smaller
Cooling capacity per volume and ΔT and flow	0.023	0.42	Improvement by a factor of 20

The characteristic figures clearly demonstrate that the inventive cooling device offers significant advantages in all areas.

Reduction in temperature difference by approx. 20% effects immediate energy savings in a cooling system and thus effects savings in operating costs.

Cooling capacity relative to volume, Δ T and flow is greater by a factor of 20 than for the best market leader and demonstrates that substantially higher packing densities (number of CPUs/volume unit) can be attained with these cooling devices. It should also be noted that the tubing costs (space required and costs for tubing and couplings) are substantially reduced and this leads to better handling (thin tubing instead of thick tubing).

It should be particularly noted that these characteristic figures apply for a component the size of which is currently adapted to the area of the chip carrier and not the CPU itself for technical assembly reasons and, when directly integrated, could increase even further and thus effect even greater differences from existing technologies.

In another comparison test (commercially available cooler vs cooling device according to the present invention having Design B) the performance data for these devices are summarized in Table 2.

Table 2:

	Commercially Available Cooler	**Inventive cooling device (Design B example)**
Weight	312 g	80 g
Volume	80 cm^3	8 cm^3
ΔT	12.5 K	9.4 K
Flow quantity	2.8 L/min.	1.5 L/min.
Cooling medium	Water/glycol 95%/5%	

The comparison tests were conducted under identical conditions for cooling an AMD 2000+ CPU under full load.

It may be easily assessed from these results that the cooling capacity of the cooling device according to the present invention is much more effective than that of the conventional cooler.

It is understood that the examples and embodiments described herein and drawings shown herein are for illustrative purpose only and that various modifications and changes in light thereof as well as combinations of features described in this application will be suggested to persons skilled in the art and are to be included within the spirit and purview of the described invention and within the scope of the appended claims. All publications, patents and patent applications cited herein are hereby incorporated by reference.

Reference Numeral List:

1	Metal foil
2	Channel
3	Micro-structure cooler
4	CPU processor
5	Base plate
6	Thermal contact surface
7	Thermal conductive adhesive
8	CPU carrier plate
9	Cover plate
10	Inlet distribution space
11	Outlet distribution space
12	Edge of metal foil **1**
15	Inlet sleeve
16	Outlet sleeve
17	Rapid plug-in connector
18	Electrical insulating layer
20	Distribution chamber
21	Collection chamber
22	Distribution chamber
b	Channel width
t	Channel depth
s	Channel interval (bar width)
r	Residual foil thickness
f	Width of structured area on the metal foil **1**
g	Base plate thickness

Patent claims:

1. A micro-structure cooling device (**3**) for an object (**4**) to be cooled, said cooling device (**3**) comprising a stack of at least two metal foils (**1**) and one base plate (**5**) that can be brought via a thermal contact surface (**6**) into thermal contact with said object (**4**), said metal foils (**1**) and said base plate (**5**) being joined to one another, the cooling device (**3**) further comprising channels (**2**) for cooling medium in said metal foils (**1**), said channels (**2**) having a width **b** in the range of from 100 to 2,000 µm, a depth **t** in the range of from 25 to 1,000 µm and a mean interval **s** in the range of from 50 to 1,000 µm, a residual foil thickness **r** resulting from said channels (**2**) in said metal foils (**1**) being in the range of from 50 to 300 µm, and said base plate (**5**) having a thickness **g** in the range of from 200 to 2,000 µm.

2. The micro-structure cooling device of claim 1, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being optimized such that the pressure loss for the cooling medium in said cooling device (**3**) is minimized.

3. The micro-structure cooling device of claim 1, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being optimized such that the difference between the temperature of said thermal contact surface (**6**) and the temperature of the cooling medium flowing in said cooling device (**3**) is minimized.

4. The micro-structure cooling device of any one of the preceding claims, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being adjusted such that a cooling capacity to volume of cooling device (**3**) ratio, *i.e.*, a "cooling compactness", of at least 2 Watts/cm^3 is achieved.

5. The micro-structure cooling device of any one of the preceding claims, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being adjusted such that a "cooling capacity per volume and ΔT" of at least 0.1 W/($cm^3 \cdot K$) is achieved.

6. The micro-structure cooling device of any one of the preceding claims, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being adjusted such that a specific, pressure loss-normalized cooling capacity of at least 0.1 W/($cm^3 \cdot K \cdot$ L/min) is achieved.

7. The micro-structure cooling device of any one of the preceding claims, said channel width **b**, said channel depth **t**, said channel interval **s**, said residual foil thickness **r** and said base plate thickness **g** being adjusted such that a heat transfer capacity of 200 Watts/cm^2 is achieved at a maximum difference in temperature between said thermal contact surface (**6**) and the cooling medium flowing in said cooling device (**3**) of 10 K at a flow quantity for the cooling medium through said cooling device (**3**) in the range of from 0.01 to 3 L/min and at a pressure loss of at most 100 mbar.

8. The micro-structure cooling device of any one of the preceding claims, the ratio of said channel width **b** to said mean channel interval **s** being in the range of from 1.5 : 1 to 2.5 : 1.

9. The micro-structure cooling device of any one of the preceding claims, the channel width **b** to residual foil thickness **r** ratio being in the range of from 2 : 1 to 5 : 1.

10. The micro-structure cooling device of any one of the preceding claims, said channel width **b** being in the range of from 200 to 500 µm.

11. The micro-structure cooling device of any one of the preceding claims, said channel depth **t** being in the range of from 50 to 400 µm.

12. The micro-structure cooling device of any one of the preceding claims, said mean channel interval **s** being in the range of from 150 to 300 µm.

13. The micro-structure cooling device of any one of the preceding claims, said residual foil thickness **r** being in the range of from 80 to 120 µm.

14. The micro-structure cooling device of any one of the preceding claims, said thickness **g** of said base plate being in the range of from 500 to 1,500 µm.

15. The micro-structure cooling device of any one of the preceding claims, the area of a heat exchange surface created in said channels (**2**) being larger than said thermal contact surface (**6**).

16. The micro-structure cooling device of any one of the preceding claims, said channels (**2**) in said metal foils (**1**) running largely parallel to one another.

17. The micro-structure cooling device of any one of the preceding claims, further comprising at least one inlet distribution space (**10**) and at least one outlet distribution space (**11**) for the cooling medium.

18. The micro-structure cooling device of claim 17, all channels (**2**) connecting on the inlet side to said inlet distribution space (**10**) and on the outlet side to said outlet distribution space (**11**).

19. The micro-structure cooling device of any one of claims 17 or 18, further comprising at least one first connecting support and least one second connecting support, said at least one first connecting support being connected to said at least one inlet distribution space (**10**) and said at least one second

connecting support being connected to said at least one outlet distribution space (**11**).

20. The micro-structure cooling device of any one of claims 1 to 16, wherein said metal foils (**1**) are interrupted at approximately the height of said thermal contact surface (**6**) by at least one distribution chamber (**20**), wherein all channels (**2**) connect at their one end to said at least one distribution chamber (**20**) and wherein the cooling device (**3**) further comprises at least one collection chamber (**21**) within said cooling device (**3**) to which all channels (**2**) are connected at their other end.

21. The micro-structure cooling device of claim 20, wherein two groups of channels (**2**) are provided that run essentially parallel to one another and wherein at least one collection chamber (**20**) is embodied as a gap between said two groups.

22. The micro-structure cooling device of claim 21, the width of said gap (**20**) being in the range of from 50 to 2,000 µm.

23. The micro-structure cooling device of any one of claims 20 to 22, further comprising at least one first connecting support and at least one second connecting support, said at least one first connecting support being connected to said at least one distribution chamber (**20**) and said at least one second connecting support being connected to said at least one collection chamber (21).

24. A Use of the micro-structure cooling device of any one of claims 1 to 23 for cooling electronic components.

25. The micro-structure cooling device and/or the use thereof substantially as herein described with reference to and as shown in the accompanying drawings.