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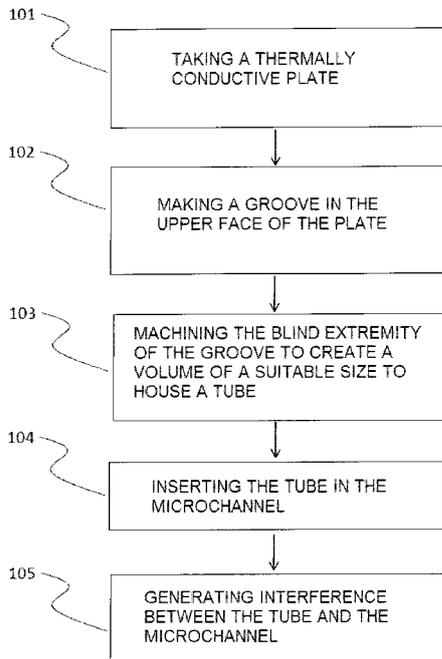
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(54) Title: METHOD FOR PRODUCING A HEAT EXCHANGER AND RELEVANT HEAT EXCHANGER



(57) Abstract: The invention relates to a method for producing a heat exchanger (1), wherein at least one microchannel (3), placed within a plate (2) having an upper face (4) and a lower face (6) and precisely arranged between said upper face (4) and lower face (5) is obtained by making a groove on the upper face (4) of the plate (2), said groove extending between an open extremity facing on the upper face (4) and a blind extremity (32) placed inside the plate (2), and machining the blind extremity (32) of the groove to create a volume of a suitable size to house a tube (10) inserted in the microchannel (3), said tube (10) being fixed inside the microchannel (3) by generating an interference between the tube (10) and the microchannel (3). The invention relates also to a heat exchanger (1) obtained by such method. The heat exchanger (1) according to the present invention is advantageously and preferably applied in nuclear and particle physics systems, such as for example systems for producing radiopharmaceuticals (100), for cooling heat engines, for cooling electronic components and circuits, for producing power targets for medical, energy and basic research applications.

Fig. 1

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“Method for producing a heat exchanger and relevant heat exchanger”

DESCRIPTION

TECHNICAL FIELD

The present invention relates to the field of heat exchangers and to methods for producing them.

More precisely the present invention relates to microchannel heat dissipating systems.

Particularly, the invention relates to a method according to the preamble of claim 1 and to a heat exchanger obtained by such method.

The invention is preferably and advantageously applied for cooling systems producing radionuclides, particularly radiopharmaceuticals, for cooling heat engines, for cooling electronic components and circuits, for producing power targets for medical, energy and basic research applications, and for material treatment.

PRIOR ART

Nowadays in many technological fields it is necessary to dissipate high specific powers (meanings power per unit surface or volume).

For example, in the electronic field, in order to allow the current electronic components to perform their tasks more and more quickly, high-powered integrated circuits have been produced; however such circuits generate such heat fluxes that, if they are not efficiently removed, cause the maximum allowable operating temperatures to be exceeded and the circuits to be consequently damaged.

In this field, it has been known for more than thirty years, to use microchannel heat sinks, that work in a rather simple manner: in the integrated circuits, and more precisely in their thin substrate made of suitable thermally conductive material, microchannels are obtained by mechanical machining operation (having a diameter with a size of few hundreds of micron and close with each other as much as possible) wherein a cooling fluid flows. The heat generated by the electronic component coupled to the heat sink is transferred to the cooling fluid by forced convection with

a high cooling rate, by means of the decrease in the thickness of the thermal boundary layer due to the microscopic dimension of the channels and to the consequent decrease in the convective resistance to heat transfer. By the use of the microchannels, it is possible to operate the heat sinks with high pressures of the cooling fluid, while maintaining the extremely reduced thicknesses of the tubes, in favor also of the convective coefficient of the part of heat thermal conduction.

An example of a microchannel heat sink is described in the European Patent application published with n. EP 1 548 133 A1; particularly such document describes a method for producing a heat exchanger, comprising the steps of:

- forming at least one microchannel inside a plate having an upper face and a lower face, said at least one microchannel extending through the plate between the upper face and the lower one,
- inserting, with radial clearance, a tube into the microchannel so that both tube ends protrude out of the microchannel, and then,
- achieving a press fit of the tube within the microchannel by shrinking the section of the microchannel and/or expanding the section of the tube, such to fix the tube inside the microchannel.

The method described above, providing to make holes instead of fins or grooves starting from a side wall of the plate, has limits regards the geometry of the microchannels, the inter-distances between the microchannels, the maximum dimensions that can be obtained, uniformity of the dimensions and orientation of the microchannels.

Due to technical reasons, by perforating a plate on the side with a micro-tip, it is possible to obtain only micro-holes with a substantially circular section and very short length, it is not possible to obtain inter-distances between the micro-holes lower than 1 mm (with a penetration depth of at least 2 cm), since directionality drops as the perforation goes on, and depending on the type of material, not perfectly equal micro-holes are obtained.

Therefore there is the need of producing heat exchangers with a high heat exchange efficiency, whose microchannels can take several geometries, have uniform

dimensions, keep a constant direction and have a small inter-distance preferably lower than 1 mm.

OBJECTS AND SUMMARY OF THE INVENTION

It is the object of the present invention to overcome the drawbacks of the prior art related to the production of heat exchangers.

Particularly it is the object of the present invention to provide a method for producing heat exchangers with a high efficiency heat exchange allowing microchannels to be formed having different geometries depending on the needs of use.

It is an object of the present invention also to provide a method for producing heat exchangers with microchannels whose dimensions are uniform throughout their length.

It is also an object of the present invention to provide a method for producing microchannel heat exchangers wherein the microchannels have a very small inter-distance with respect to each other, preferably smaller than 1 mm.

It is also an object of the present invention to provide a method for producing microchannel heat exchangers wherein the channels have different shapes ,dimensions and accommodation on the substrate in different geometries.

It is also an object of the present invention to provide a method for producing microchannel heat exchangers by using materials even very different from each other, both for the substrate and for the tube.

These and other objects of the present invention are achieved by a method for producing a heat exchanger and a heat exchanger embodying the characteristics of the annexed claims, which are an integral part of the present description.

In one embodiment, the microchannels are formed in a plate having an upper and a lower face. The method provides to form each microchannel by creating a groove on one face of the plate, for example the upper one. The groove, in a plane orthogonal to the development plane of the groove, will have an open extremity facing the face of the plate and a blind extremity placed inside the plate. In order to form the microchannel, the blind extremity of the groove is machined (simultaneously with or

in a different moment than the generation of the groove) in order to create a volume of a suitable size to house the tube.

This solution provides the advantage of accurately forming the microchannels, since it is not necessary to use a drill with a micro-tip perforating the hole in the development direction of the microchannel.

In a particularly advantageous embodiment the microchannels are made by wire electrical discharge machining of the plate.

The wire electrical discharge machining allows microchannels with sections (in the plane transverse to the development plane) of different shapes, for example polygonal ones, to be obtained. Polygonal sections are particularly efficacious for retaining a tube inserted in the microchannel by pressing it (and therefore in a quite simple manner) in the groove formed on the face of the plate.

On the contrary circular or semicircular sections are particularly efficacious for improving the heat exchange with circular tubes.

The use of the wire electrical discharge machining apparatus allows an almost circular groove to be machined, it being necessary only one open cut for inserting the wire, whose diameter can be up to 1 micron.

In a particularly inexpensive embodiment, that does not require too much expensive apparatuses, the microchannels are formed by milling the plate by using a milling cutter comprising a thin body with a head enlarged towards a free end of the milling cutter. The plate therefore is milled by moving the milling cutter in a plane orthogonal to the upper face of the plate, such that the thin body of the milling cutter creates the groove in the face of the plate while the enlarged head of the milling cutter machines the blind extremity of the groove in order to create the seat for the tube.

At most the thin body may have punctiform dimensions, such that the milling cutter has a conical base.

By this technique it is therefore possible to produce grooves also on non-flat surfaces and with any shape and variable direction.

The invention further relates to a heat exchanger obtained according to the method

such as described and claimed below.

Such heat exchanger, due to the high cooling capacity per cm^2 , can be produced with small dimensions and therefore it can be advantageously put in contact with or integrated with the devices to be cooled. For example in one embodiment the heat exchanger can be integrated with an integrated circuit to be cooled. In this embodiment, therefore, the microchannels and the cooling tubes are made on the same substrate on which the integrated circuit is made.

In one embodiment the heat exchanger is provided with microchannels obtained by means of cuts on the upper face of the plate, said cuts being machined in their blind extremity in order to create a volume of a suitable size to house corresponding micro-tubes that are calendered therein.

In one embodiment, the heat exchanger according to the invention is used in a system for producing radionuclides, precisely for cooling the target on which a beam of particles is irradiated such to generate different elements by nuclear reaction.

Due to the high efficiency of the heat exchanger, it is possible to place it in contact with the target for cooling it, for example by depositing using known methods (rolling, pressure, evaporation, sputtering) the material to be irradiated directly on the substrate of the exchanger (thus it is integrated with the target); thus it is possible to increase the production of radionuclides by operating the system with beams of high specific intensity particles without the thermal power conveyed in the target melting it and by using less material (which usually is a very expensive material). Another advantage deriving from the possibility of dissipating high specific powers is that the concentration of activities is very high, in favor also of the quality of the precursor of the radionuclide produced.

In one embodiment the heat exchanger according to the invention is used for cooling a cylinder head or the cylinder of a combustion engine of a motor vehicle or a motorcycle.

In this manner, namely due to the efficiency of the heat exchange accomplished, it is possible to considerably reduce the dimensions of the engine and to increase its efficiency, consequently reducing the overall dimensions, costs and weight.

In one embodiment, the heat exchanger is applied to a power target for medical applications such as ABNCT (accelerator based neutron capture therapy).

Therefore the present invention relates also to an apparatus for producing radionuclides, a heat engine, particularly a combustion engine, and a power neutron generator (target) for ABNCT comprising one heat exchanger such as described and claimed below.

Further advantageous characteristics of the present invention will be more clear from the following description and from the annexed claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below with reference to non-limiting examples, provided by way of example and not as a limitation in the annexed drawings. These drawings show different aspects and embodiments of the present invention and, where appropriate, reference numerals showing like structures, components, materials and/or elements in different figures are denoted by like reference numerals.

Figure 1 is a flow chart showing the method for producing a heat exchanger according to the present invention;

Figure 2 is a schematic perspective view of the heat exchanger according to one embodiment of the present invention;

Figure 3a is a schematic perspective view of the heat exchanger according to an alternative embodiment of the present invention;

Figures 3b to 3f are alternative profiles of the microchannels of the heat exchanger according to the present invention; and

Figure 4 is a schematic view of an apparatus for producing radionuclides comprising a heat exchanger according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

While the invention is susceptible of various modifications and alternative forms, some disclosed relevant embodiments are shown in the drawings and will be described below in detail.

It should be understood, however, that there is no intention to limit the invention to

the specific embodiments disclosed, but, on the contrary, the intention of the invention is to cover all modifications, alternative constructions and equivalents falling within the scope of the invention as defined in the claims.

Therefore in the description below the use of "for example", "etc", "or", "otherwise" indicates non-exclusive alternatives without limitation unless otherwise defined; the use of "also" means "including, but not limited to" unless otherwise defined; the use of "including/comprising" means "including/comprising but not limited to," unless otherwise defined.

The flow chart of figure 1 allows a method for producing a heat exchanger 1 to be appreciated in its general aspect, for example of the type shown in figures 2 or 3.

According to such method, the heat exchanger 1 is produced starting from a thermally conductive plate 2, that is a block made of a material having a good thermal diffusivity, such as for example a metal (e.g. copper) or diamond, and therefore it is able to properly absorb heat from the devices with which it is put in contact. Such material is preferably thin, thin enough for its mechanical support and for housing micro-tubes.

The plate 2 has an upper face 4 and a lower face 5; the lower face is flat and continuous and therefore it is particularly fit for being placed in contact with a device to be cooled. For example the lower face 5 can be put in contact with a processor or another device to be cooled. The grooves on which the tubes have to be calendered can be also directly produced on the substrate of the electronic device.

The method provides to form a plurality of microchannels 3 developed inside the plate 2 between the upper face 4 and the lower face 5. Such microchannels 3 are intended to receive a respective tube wherein a cooling fluid will flow, with the heat exchanger in use.

Obviously the number of microchannels, their orientation and the number of tubes are not a limitation of the present invention, for example it will be possible to provide a plate 2 with a single microchannel 3 developing along several directions, for example by winding around itself or following broken lines. As an alternative it is possible to provide several microchannels crossing with each other to form a grid

where one or more tubes are housed which do not necessarily occupy each individual microchannel for all its length.

Therefore the method provides to take a thermally conductive plate (step 101), particularly a plate made of a material with a thermal conductivity higher than 300 W/mK.

Then the microchannels 3 are formed by making (step 102) grooves 30 in the upper face 4 of the plate 2. The grooves 30 are cuts made in the upper face of the plate 2 and extending, in a direction perpendicular to the face 4 and precisely from the outside to the inside of the plate, between an open extremity 31 opening on the upper face 4 of the plate 3 and a blind extremity 32 placed inside the plate 2.

In the example of figure 2, each microchannel 3 extends for all the width of the plate 2 therefore opening not only on the upper face 4 of the plate 2 but also on the two side faces (denoted by references 6 and 7) that connect the upper face 4 and lower face 5 of the plate 2. The microchannels 3, in this embodiment, therefore are continuous grooves touching three faces of the plate 2.

The method provides (step 103) to machine the blind extremity 32 of each groove to create a volume with a size suitable to house a tube 10 wherein a cooling fluid will flow intended to remove heat from the plate by convection.

In one embodiment, the tube 10 is preferably a cylindrical microtube, with an inner diameter lower than 500 μm and more preferably ranging from 500 μm to 100 μm . Although the shape and the dimensions of the microtube 10 are not binding for the purposes of the present invention, the cylindrical shape and the small dimensions are particularly advantageous, particularly by using cylindrical microtubes with an inner diameter lower than 500 μm it is possible to improve the heat exchange between the cooling fluid and the plate. In tubes with such dimensions, the movement of the fluid in the microtube allows the fluid layer that tends to adhere on the inner walls of the tube to be broken; this layer (that tends to build in tubes with greater dimensions) is composed of substantially still molecules of fluid, therefore they are not able to transport heat by convection. By breaking such layer, the convective heat transfer capacity and therefore the exchanger performances are improved.

Regardless of physical phenomena, the improvement in the performances of the heat exchanger in this type of tubes is shown by experimental results that, as it is known per se from scientific literature (see e.g. Int. J. Heat Mass Transfer. Vol. 37, No. 2, pp321-332, 1994) denote an improvement in the performances of a heat exchanger when it is provided with this type of tubes.

Then the method provides (step 104) to insert a tube 10 inside the microchannel 3 and then, to generate interference (step 105) between the tube 10 and the microchannel 3 such to fix the tube 10 into the microchannel 3.

The insertion of the tube in the microchannel and the following interference can be accomplished in many ways, for example by thermal expansion of the tube, expansion by pressure or another type described in EP1548133.

In one embodiment, the tube 10 is inserted in the microchannel through the opening 31 of the microchannel 3. In one embodiment the tube 10 has an outer diameter slightly greater than the diameter of the microchannel 3 therefore in order to be inserted it is cooled beforehand with a fluid at a lower temperature, for example liquid nitrogen, such to reduce its outer diameter, then it is inserted through the opening 3, for example by a light pressure. When the temperature of the tube is brought again to room temperature, the tube 10 expands and it interferes with the inner walls of the microchannel 3.

As an alternative to the insertion through the opening in the face 4, after its thermal shrinkage, the tube 10 is lubricated and it slides into the microchannel 3 by inserting it into one of the openings of the microchannel opening on the side faces 6 or 7.

The tube can be inserted in the plate during a wire drawing process after which the tube, once stretched, is made thinner such to enter the microchannel provided that the characteristics of the materials of the plate and of the tube allow this operation.

With reference now to the machining of the microchannel 3 (steps 102 and 103 of the method of figure 1), the groove in the face 4 and the machining of the blind extremity of the groove can be performed in several ways.

In one embodiment, such machining for forming the microchannel is performed by wire electric discharge machining. This technique allows a wire with a length even

more than 1 meter to be used by means of which microchannels 3 with constant dimensions and direction are obtained. Such technique is particularly efficacious for machining plates 2 made of diamond.

By the wire electric discharge machining in the upper part 4 of the plate 2 a cut with a width of 0.2 mm or even less is obtained depending on the dimension of the wire, such to allow the wire to enter in the plate 2.

The microchannels 3 obtained by electric discharge machining preferably have a semicircular profile - in the plane orthogonal to the upper face 4 - such as shown in Figures 2 and 3b; the semicircular profile is preferred since it allows a more effective heat exchange.

Such circular profile however may not be effective if the opening 31 is too large, as a matter of fact, in the case of the insertion of a tube with the outer dimensions greater than the diameter of the groove due to the expansion of the tube, in order to generate the interference with the groove the tube could be lifted from its seat and the contact with the plate would be reduced, with a consequent reduction in the efficiency of the heat exchange.

For this reason, in the embodiment shown in figure 3a the circular profile is obtained deeply in the plate, such that at least 60% and preferably 80% and $\approx 100\%$ (this number never reachable, of course) of the circle inscribing such profile is placed within the plate 2.

In the example of figure 3a, therefore the groove 3 has, in a plane orthogonal to the face 4, a profile composed of a straight channel 33 starting with the opening 31 in the face 4 of the plate and ending in a circular profile 34.

In the preferred embodiment, the straight channel 33 has a null length and the circular profile 34 closes in a way tangent to the face 4 of the plate 2. The circular profile 34 therefore is open only at the opening 31, which can have a width lower than 10 μm and preferably ranging from 1 to 2 μm , such as shown in figure 3f.

By using the wire electric discharge machining, however it is possible to obtain microchannels 3 with several geometries, particularly polygonal shapes such as a square (shown in figure 3d) or a trapezium (shown in figure 3c), depending on needs

of use and on the different shapes of the device to be cooled and/or of the available tube.

As said above, the microchannels can be made with different techniques, for example the microchannel in figure 3a can be obtained in two separate phases, firstly by forming the channel 33, for example by cutting (with a blade or electric discharge machining) or by milling the plate 2, and then by enlarging the blind extremity 32 of the channel 33 made in this manner.

At the same time, the wire drawing of the tube can be used, when it is possible, to create interference between the tube and the groove.

According to another embodiment, the microchannels are formed by milling the plate by using a milling cutter comprising a thin body with a head enlarged towards a free end of the milling cutter. The method provides to mill the plate by a relative movement of the milling cutter in a plane preferably orthogonal to, or substantially orthogonal to, (however not parallel to) the upper face of the plate, such to form a microchannel whose profile in a plane orthogonal to that of the face 4 is shown in figure 3e. The thin body of the milling cutter forms the channel 35 while the enlarged head of the milling cutter, for example a conical head, forms the seat 36 intended to house the tube 10.

Therefore depending on the type of milling cutter used it is possible to obtain different profiles, for example it is possible to obtain microchannels with the profile of figure 3c or that of figure 3d.

Here it has to be noted that unlike the method mentioned above that provides the blind extremity 32 to be machined in a phase different from the machining of the groove, in the case of a milling operation, the machining of the groove 30 and the profiling of its blind extremity 32 have not to follow necessarily different machining moments. For example if the profile of figure 3d is machined by a milling operation, it will be possible to use a cylindrical milling cutter which, starting to mill the plate from a side leading face, for example the face 6, and by moving in the direction of an end side face, for example face 7, will contemporaneously machine the three sides of the square profile of figure 3d. If a microchannel with the profile of figure 3e is

machined by a milling operation, in this case the enlarged head will contact the plate before the thin body of the milling cutter, therefore the seat 36 for the tube 10 will be formed before the channel 35.

Therefore it is clear from the above that for the purposes of the present invention it is important to form a groove along a face of the plate, such groove being characterized by an enlarged blind extremity intended to house the tube 10 where the cooling fluid will flow. The methods and the order for making the several components of the groove can be different and not necessarily limited to those described above.

In order to allow the heat exchanger 1 to work efficiently, during the operation inside each of the tubes 10 a cooling fluid flows, for example a cooling gas or water or a eutectic alloy of tin/indium/gallium; preferably said cooling fluid is liquid metal that, advantageously improves the heat exchange by increasing the performance of the heat exchanger of the invention by at least a factor of 3.

In one embodiment, the heat exchanger 1 therefore is provided also with means (for example a pump and a tank) intended to allow a cooling fluid to flow by force in the tubes 10.

The tubes 10 can be connected with each other in series or in parallel. In the case of a plurality of microchannels it is advantageous to connect them in such a manner that the fluid flows alternately in opposite directions avoiding thermal gradients between the two extremities (6 and 7 in figure 2).

With reference again to Figure 3a, where the heat exchanger 1 according to one embodiment of the present invention is schematically shown, it has to be noted that said heat exchanger 1 comprises;

- a plate 2 in turn comprising:
 - an upper face 4 and a lower face 5
 - at least one microchannel 3 obtained in the plate 2 and extending in the plate 2 between the upper face 4 and the lower face 5,
- a tube 10 inserted in the microchannel 3 and fixed thereto.

The microchannel 3 throughout all its development length has an opening 31 which opens on the upper face 4 of the plate 2 and having such dimensions not to allow the

tube 10 to come out from such opening.

In a preferred embodiment, the plate 2 is made of diamond and the tubes 10 are made of copper. The diamond is a material having a thermal conductivity 20 times higher than the copper and it has a thermal expansion lower than the copper ($3 \cdot 10^{-6} \text{ K}^{-1}$ of the diamond, versus $51 \cdot 10^{-6} \text{ K}^{-1}$ of the copper); therefore in the operating conditions, when the plate absorbs heat from the device to be cooled, the tube 10 expands more than the microchannel 3, improving the thermal contact and therefore the heat exchange. Moreover the diamond, since it is a material with a high thermal diffusivity, allows the heat to be spread very efficaciously, which therefore is transferred to all the tube 10; the diamond allows also a more rigid and strong structure to be obtained.

As an alternative, the tube 10 is made of diamond that, as said above, is a material having several properties.

As an alternative the tube 10 is made of niobium or steel alloys, which allows a liquid metal to be used as the cooling fluid, such to improve the heat exchange.

If it is possible to operate the plate 2 with higher temperature values (particularly exceeding 100°C), it will be possible to use materials of different type for the tube 10, such as graphite, tantalum and tungsten; the same plate 2 can be made of other materials such as fullerenes.

Other materials can also be selected depending on the operating needs, such as the use of chemically aggressive fluids, high thermal stability etc., as it will be clear to the person skilled in the art.

The embodiments shown in the figures described above provide both the microchannels 3 and the corresponding tubes 10 to extend throughout all the length of the plate 2, such that both the ends of the tube 10 protrude outside of the microchannel on opposite side faces of the plate 2. However it is possible to accomplish several different arrangements, for example with both the ends of the tube 10 protruding from the microchannel on the same side face of the plate 2, and also other ones that will be clear to the person skilled in the art.

The heat exchanger 1 according to the present invention can be used in several fields,

where it is necessary to dissipate high specific powers; by way of example and not as a limitation we mention:

- heat sinks for computer CPUs
- power dissipation generally on electronic devices to be miniaturized (the direct use of silicon instead of copper or diamond as the substrate of the plate 2 can be assumed),
- power targets for producing neutrons for "Boron Neutron Capture Therapy-BNCT" with surface deposition of lithium or beryllium,
- production of radionuclides particularly for medical use,
- dissipation in internal combustion engines,
- "beam dump" for particle beams,
- heat dissipation systems for radioactive wastes,
- dissipation systems for concentrator solar photovoltaic system,
- heat transfer systems for solar thermal system,
- cooling systems for tips of welders / laser cutting machines and TIG/MIG machines,
- "plasma-facing components",
- "high heat-load optical components",
- X ray devices, and
- Power Electronics in hybrid vehicles
- Systems for thermally treating materials,
- Cooling devices for laser diode arrays.

A preferred and advantageous application of the heat exchanger 1 according to the present invention is the one schematically shown in Figure 4, showing an apparatus for producing radiopharmaceuticals such as described in the Italian Patent application n. MI2014A000145 to the same applicant.

Said apparatus for producing radiopharmaceuticals, denoted by the reference numeral 100 in Figure 4 comprises:

- a primary accelerator or driver 20
- a target 22, and

- a chemical unit 50.

The primary accelerator 20, preferably an accelerator of the LINAC type (Linear ACcelerator) or cyclotron, produces a beam of particles 21 (for example protons) which is sent on a target 22 where a main reaction takes place such as $X(p,y)Z$, that is a reaction causing a material X to be transformed (induced by protons p with emission of particles y) into a material Z.

In the example of figure 4, the target 22 comprises a heat exchanger 1 of the type described above. In detail, the target 22 comprises a plate 2 on whose lower face 5 the material X (denoted by numeral 220) is deposited, e.g. Nickel or better enriched Nickel, such as Ni-64.

The heat exchanger of figure 4 comprises microtubes 10 placed inside the plate 2 and connected to means 221 for the circulation of the cooling fluid, for example a pump.

During irradiation, the material X gets warm due to the absorbed power; in this phase, means 221 control the circulation of the cooling fluid such to keep the temperature of the target within predetermined values depending on the desired reaction. For example is CU-64 is desired (a radionuclide currently tested as a radiopharmaceutical, but usable also in PET – Positron Emission Tomography – as a marker), a target of Nickel and Nickel-64 is irradiated. Since the melting temperature of the Nickel is about 1450 °C, by using the diamond for the plate 2, it is possible to operate at temperatures of about 800 °C. Finite element conservative calculations denote that in the stationary state, an exchanger made with a copper plate of 2x2 cm dimensions and comprising 13 microtubes wherein water flows as the cooling fluid, is able to keep the surface temperature of the nickel (having a thickness of 0.5 mm) lower than 500 degrees by dissipating a specific power of about 5kw/cm², corresponding to a proton current of 300 μA with an energy of 35 MeV.

Experimental data obtained using a bare copper heat sink, irradiated in vacuum with 2.8 MeV proton beam, has showed that the maximum surface temperature of 100 C has been obtained transferring 3 kW/cm². The cooling fluid used was sanitary water at 10 C inlet temperature and about 3.5 bar of pressure.

After a suitable exposure time, the radiopharmaceutical Z is therefore separated from the material X according to radiochemistry techniques known per se, for example the CU-64 can be separated from the Nickel substrate by ion exchange chromatography.

A further preferred and advantageous application of the heat exchanger 1 according to the present invention is that for cooling heat engines, particularly combustion engines of motor vehicles and motorcycles.

According to such application, a heat engine, particularly a combustion engine, comprises at least one engine block comprising at least one cylinder with a piston intended to slide therein and a cylinder head, which is placed at one end of the engine block, and it is intended to house at least one valve for the intake of fuel in the cylinder. The heat exchanger 1 is placed on the cylinder head or on the engine block such to cool them.

The heat exchanger of the present invention has also a preferred and advantageous application in a BNCT (BORON NEUTRON CAPTURE THERAPY) or ABNCT.

In detail, the heat exchanger is applied on the power target, that is on the target used for producing neutrons. Preferably the heat exchanger is applied on a target composed of a deposit of lithium and it is used for cooling it. Conservative calculations and first experimental evidences have shown that by using as the neutron generator (n) the reaction ${}^7\text{Li}(p,n)$ with a thickness of 50 μm of lithium and proton beam energy of 1.9 meV, it is possible to dissipate a specific power of about 4 kw/cm² while keeping the temperature of the lithium lower than the melting temperature of the lithium 180°C.

From the above description, it is clear how the method for producing a heat exchanger and the relevant heat exchanger described allow the proposed objects to be achieved.

Particularly, advantageously:

- by the method of the present invention it is possible to form microchannels that are also very long, with desired (constant or variable) directions and dimensions and with different geometries (square ones, ellipsoidal ones, semicircular ones, etc), a thing that was not possible with the electrical discharge machining perforation that limited the shape of the microchannel only to the circular section and that prevented perfectly straight holes from being perforated due to mechanical tolerances;
- the constructional method according to the present invention allows heat

exchangers to be made with any dimensions and with very small thicknesses of the walls, thus considerably improving heat conduction properties;

- the use of the liquid metal as the cooling fluid allows a gain of at least a factor of 3 than water since it considerably increases the convective coefficient (defined as $h = \lambda / \text{Nu}$, where λ is the thermal conduction coefficient); the different mode for transferring the heat with respect to water (convection vs thermal conduction) allows high values of h to be obtained also in presence of a laminar motion (low Reynolds number);

- the use of the diamond then provides considerably better performances both as regards heat transfer and mechanical resistance of the object; according to the current experimental data, the heat exchanger of the present invention has performances higher more than one order of magnitude than prior art exchangers for the dissipation of high specific powers;

- the heat exchanger according to the present invention is easy and inexpensive to be produced.

Therefore it is clear for a person skilled in the art that it is possible to make modifications and changes to the solution described with reference to figures 1 to 4, without for this reason departing from the teaching of the present patent and from the scope of protection as defined in the annexed claims.

For example it is clear for the person skilled in the art how it is possible to use materials of the plate 2 and of the tube 10, arrangements of the microchannels 3 and types of cooling fluids different from those mentioned with reference to the shown embodiments depending on the operating conditions and on the devices to be cooled.

It is also clear that, although in the above examples the microchannels 3 are formed through only one face, they can be formed on one or more faces of the plate 2 in order to increase the heat exchange capacity of the exchanger 1. For example the microchannels can be formed on two opposite faces (e.g. faces 4 and 5) or contiguous faces (e.g. faces 4 and 7).

Moreover even if the embodiments described above with reference to figures 1 to 4

provide the opening 33 to remain open, according to one variant, such opening can be closed after forming the microchannel 3, with its blind extremity 32 being shaped. Preferably the opening 33 is closed by means of a thermally conductive material, particularly a metal with a good thermal diffusivity for example a metal, after the tube has been inserted in the microchannel, thus the filling material used for closing the opening 33 further fixes the tube 10 in its seat.

In one embodiment, one or more of the tubes 10 that are inserted in the microchannels 3 are closed at their ends to form a closed circuit within which the cooling fluid can flow. Thus the closed tubes form "heat pipe" able to transfer heat from one end (hot) to another end (cold) of the tube, by the evaporation and condensation of the cooling fluid within the tube itself.

CLAIMS

1. Method for producing a heat exchanger (1), comprising the steps of:

- making at least one microchannel (3) within a plate (2) having an upper face (4) and a lower face (5), said microchannel (3) extending inside the plate (2) between the upper face (4) and the lower face (5),
- inserting (104) a tube (10) inside the microchannel (3) and
- generating (105) interference between the tube (10) and the microchannel (3) so as to fix the tube (10) inside the microchannel (3),

the method being characterized in that the microchannel (3) is made according to the following steps:

- a) making (102) a groove on the upper face (4) of the plate (2), said groove extending between an open extremity (31) facing on the upper face (4) and a blind extremity (32) placed inside the plate (2),
- b) machining (103) the blind extremity (32) of the groove to create a volume of a suitable size to house the tube (10).

2. Method according to claim 1, wherein both the groove according to step a) and the machining of the blind extremity (32) of the groove according to step b) are performed by means of wire electric discharge machining.

3. Method according to claim 1, wherein the microchannel is made by milling the plate using a milling cutter comprising a thin body with an enlarged head towards a free end of the milling cutter, the method providing to mill the plate by means of a relative movement of the milling cutter in a plane orthogonal to the upper face of the plate, so that the thin body of the milling cutter creates the groove referred to in step a) while the enlarged head of the milling cutter performs the machining of step b).

4. Method according to any one of the preceding claims, wherein the tube (10) has a diameter greater than the width of the groove present in the upper face (4) of the

plate, and wherein the tube (10) is inserted into the microchannel (3) through an opening of the groove in a transverse wall of the plate (2), said transverse wall extending between the upper face (4) and the lower face (5) of the plate.

5. Method according to claim 4, wherein a lubricant is used to slide the tube (10) inside the microchannel (3).

6. Method according to any one of claims 1 to 3, wherein the microchannel (3) has, in a plane transverse to the upper face (4), a section in the shape of a polygon (9), and wherein the tube (10) is inserted into the microchannel (3) by pressure through the opening of the groove on the upper face (4) of the plate (2).

7. Method according to any one of the preceding claims, wherein the materials of the plate (2) and of the tube (10) have a high thermal diffusivity and are such that the thermal expansion coefficient of the plate (2) is lower than the tube (10) one.

8. Method according to any one of the preceding claims, wherein the materials of plate (2) and of the tube (10) are such to allow wire drawing of the tube (10) inside the microchannel (3) of the plate (2).

9. Method according to any one of the preceding claims, wherein at least two microchannels (3) are made on two different faces of the plate, each one of said at least two microchannels (3) being provided with an open extremity on a respective face and with a blind extremity placed inside the plate (2).

10. Method according to any one of the preceding claims, wherein the tube (10) is closed at the ends to form a closed circuit within which the cooling fluid can flow.

11. Method according to any one of the preceding claims, further comprising the step of closing the open extremity (33) of the groove by means of thermally conductive

material.

12. Heat exchanger (1) comprising:

- a plate (2), in turn comprising:
 - an upper face (4) and a lower face (5), and
 - at least one microchannel (3) developing inside the plate (2) between the upper face (4) and the lower face (5),
 - a tube (10) inserted inside the microchannel (3) and fixed thereto,
- characterized in that said at least one microchannel (3) has, throughout its development length, an opening (31) which opens on the upper face (4) of the plate (2), and in that the opening has such a dimension that does not allow the tube to come out through said opening.

13. Heat exchanger (1) according to claim 12, wherein the plate (2) is made of silicon and it comprises electronic components.

14. Heat exchanger (1) according to claim 12 or 13, wherein said microchannel (3) has a semicircular profile (7).

15. Heat exchanger (1) according to claim 12 or 13, wherein said microchannel (3) has a polygonal profile (11, 13).

16. Heat exchanger (1) according to any one of claims 12 to 15, wherein said tube (10) is a capillary tube having a diameter of less than 100 μm .

17. Apparatus (100) for the production of radionuclides comprising:

- a primary accelerator (20) to accelerate a beam of particles,
 - a target (22) positioned along a trajectory of said beam of particles,
- characterized in that the target (22) comprises a heat exchanger according to any of claims 12 to 16.

18. Use of the heat exchanger (1) according to any one of claims 12 to 16 for cooling a heat engine, in particular a combustion engine, comprising at least one engine block comprising at least one cylinder with a piston intended to slide therein and a cylinder head, placed at one end of the engine block, and intended to house at least one valve for the intake of fuel into the cylinder, wherein said heat exchanger (1) is positioned on the cylinder head or on the engine block.

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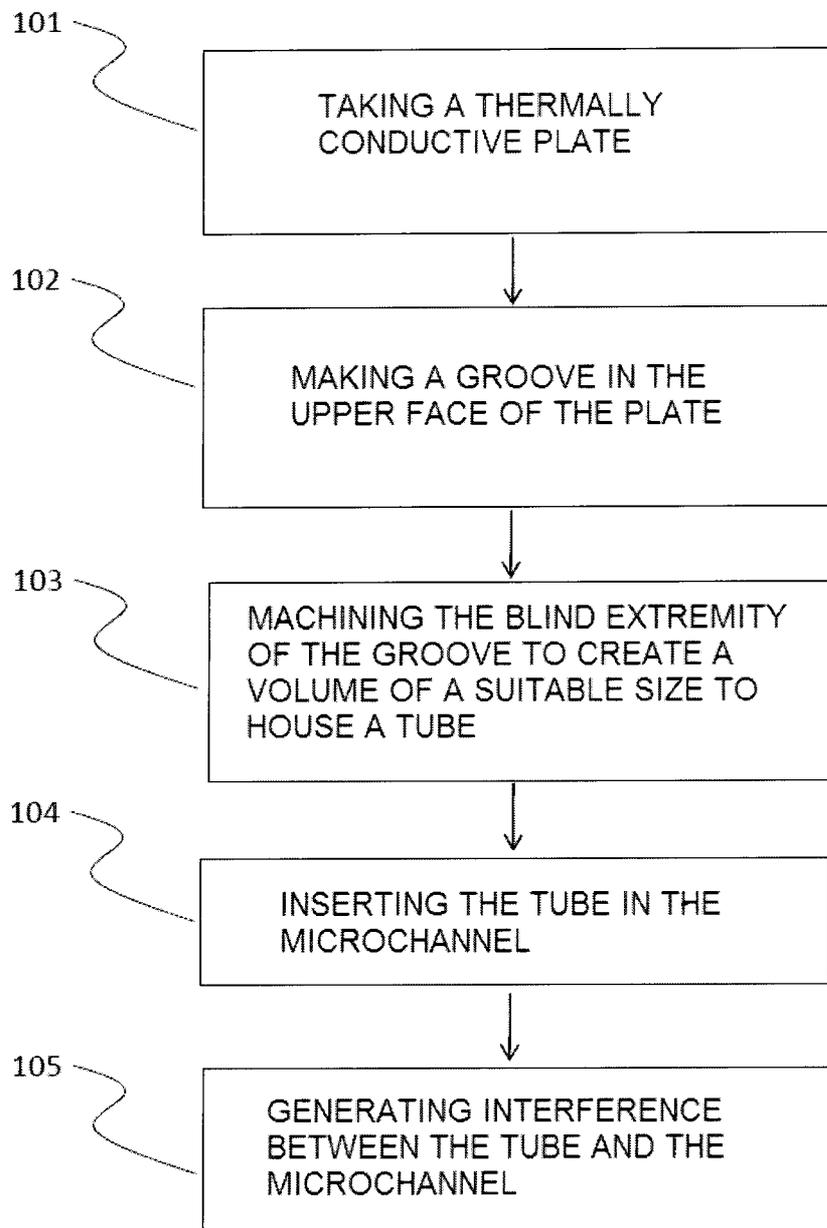


Fig. 1

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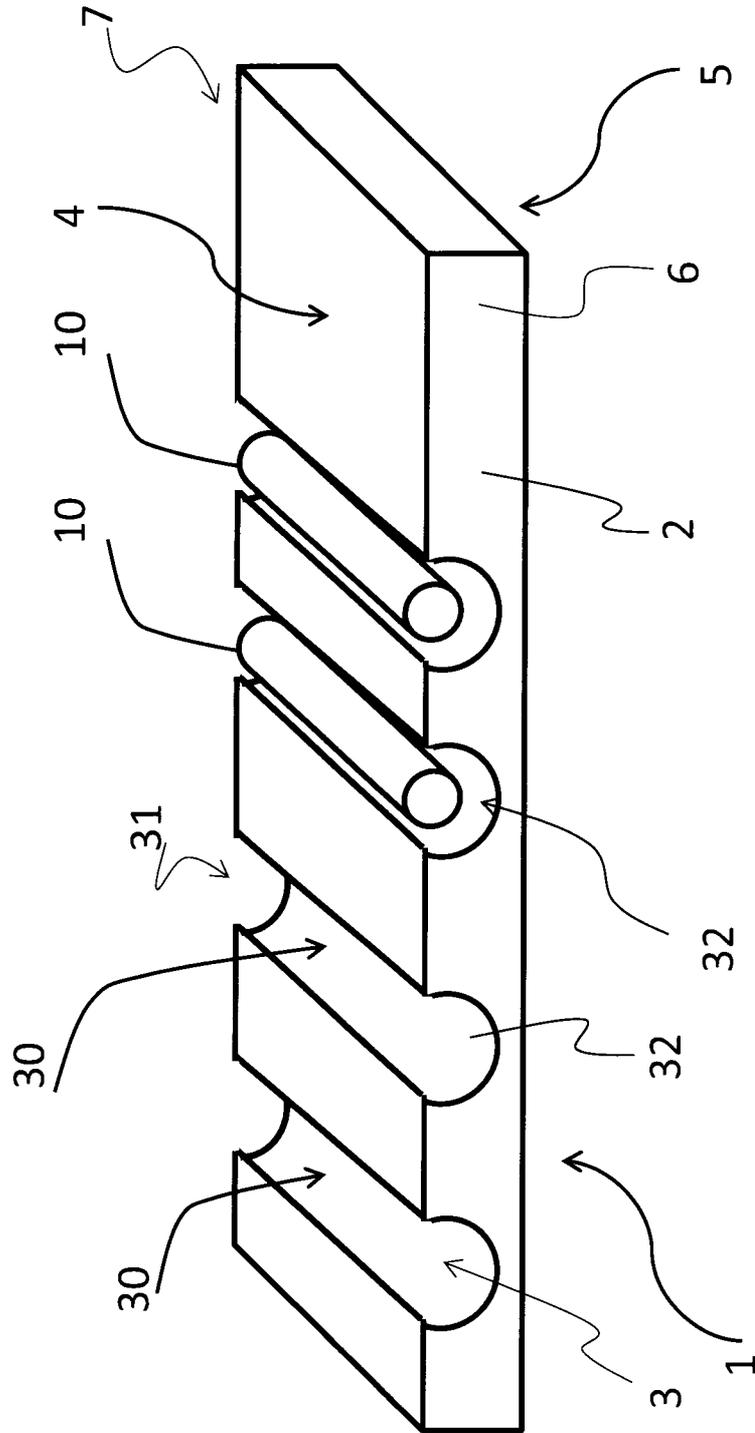


Fig. 2

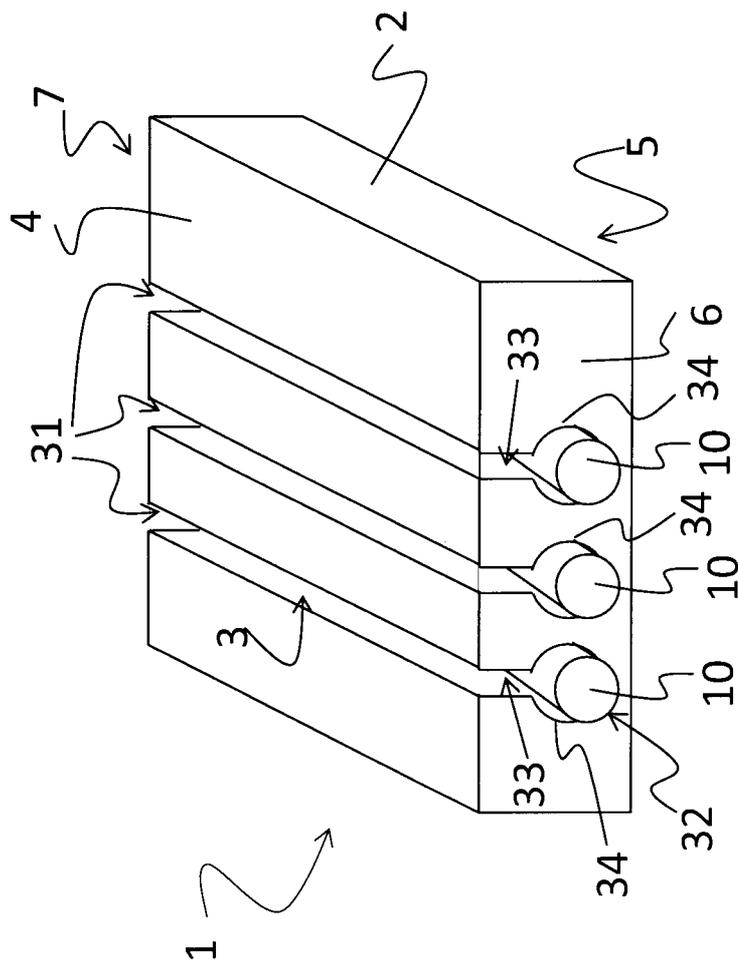


Fig. 3a

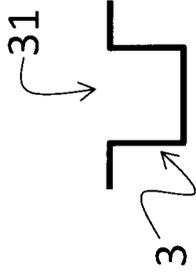


Fig. 3d

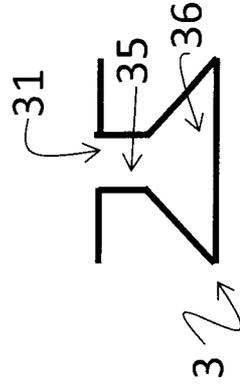


Fig. 3e

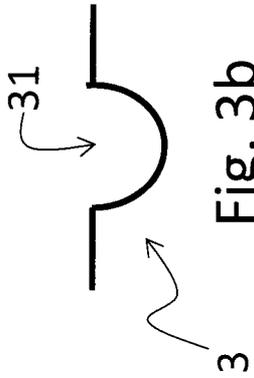


Fig. 3b



Fig. 3c

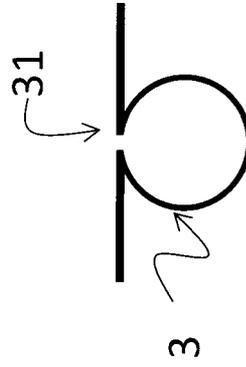


Fig. 3f

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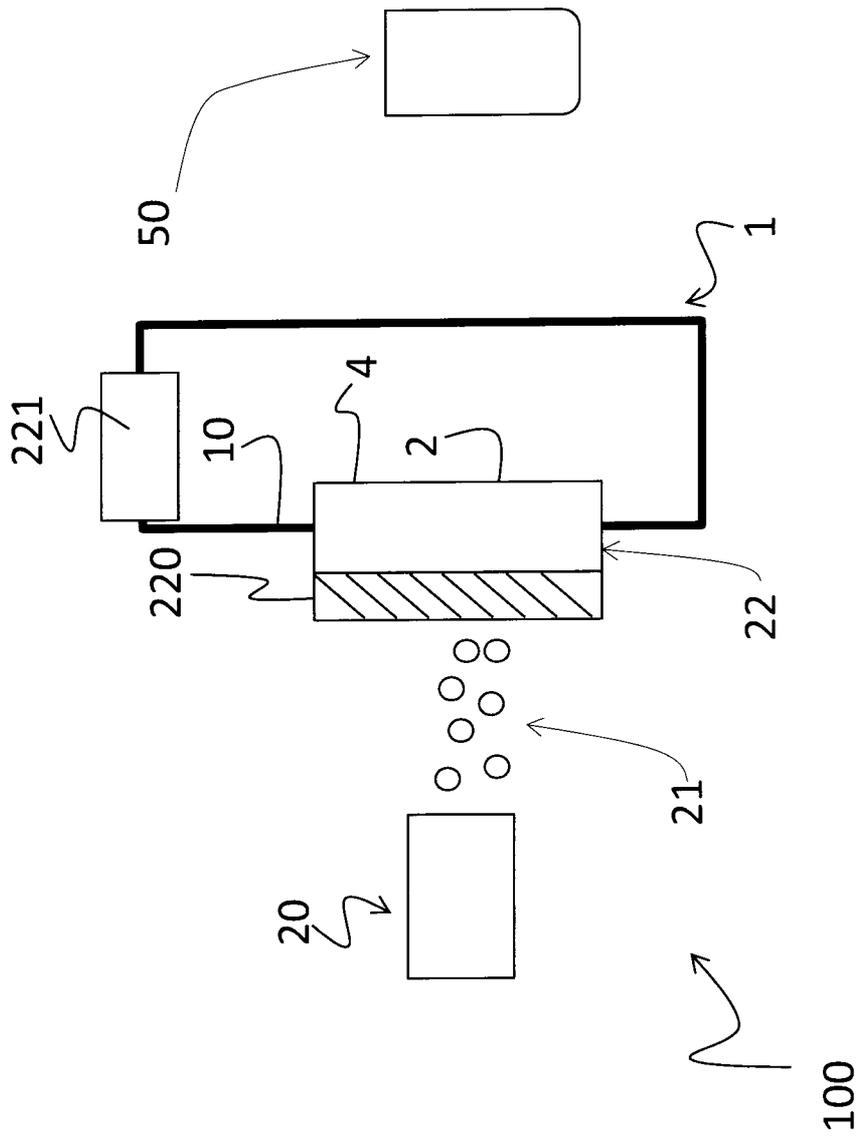


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No PCT/IB2014/067156

A. CLASSIFICATION OF SUBJECT MATTER INV. F28F3/12 H01L23/34 H05K7/20 F28F21/00 G21G1/00 ADD. F01P3/02				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F28F F28D H01L H05K G21G F01P				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	EP 1 548 133 A1 (WURTH PAUL SA [LU]) 29 June 2005 (2005-06-29) cited in the application the whole document -----	1-18		
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.				
* Special categories of cited documents : <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed </td> <td style="width: 50%; border: none; vertical-align: top;"> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family </td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family			
Date of the actual completion of the international search	Date of mailing of the international search report			
24 February 2015	05/03/2015			
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Leclaire, Thomas			

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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