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(54) Title: MAGNETIC CORE WITH INTEGRATED LIQUID COOLING CHANNEL AND METHOD FOR MAKING MAGNETIC CORE

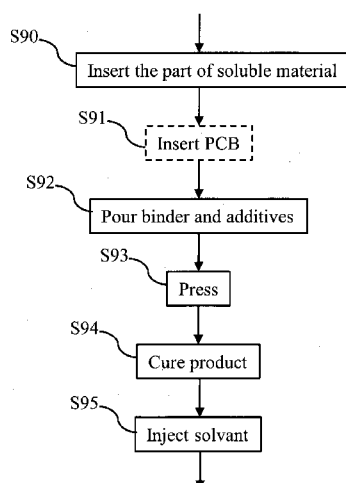


Fig. 9

(57) Abstract: The present invention concerns a magnetic core with an integrated liquid cooling channel and a method to make the same. The method comprises the steps of: - inserting a part of a soluble material that have a shape that corresponds to a liquid cooling channel in a mold, the part of the soluble material having an inner channel, - pouring a mix of magnetic powder, binder and additives in the mold, - pressing the mix of magnetic powder, binder and additives, - curing the pressed mix of magnetic powder, binder and additives, - injecting a solvent in the inner channel in order to dissolve the soluble material.

ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO,
NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW,
SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN,
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[DESCRIPTION]

[Title of Invention]

MAGNETIC CORE WITH INTEGRATED LIQUID COOLING
CHANNEL AND METHOD FOR MAKING MAGNETIC CORE

[Technical Field]

[0001]

The present invention relates generally to a magnetic core with an integrated liquid cooling channel and a method to make the same.

[Background Art]

[0002]

A general trend in power electronics is to increase the power density of converters. This trend is driven by application specific requirements. As an example, in electro mobility applications the increase in power density allows to allocate more space to the passenger compartment and the saved weight helps to extend the range or reduce Co2 emission in the case of Hybrid Electric Vehicle (HEV). In consumer electronic applications, a more compact power converter is the key to miniaturization as it can clearly be seen in smartphone or laptop chargers.

[0003]

Magnetic components such as inductors or transformers have a substantial share of the overall volume of power converters. The volume of magnetic components is closely linked to the switching frequency because the required amount of stored energy in the magnetic core is reduced. So, one answer to the need of high power density is to increase the switching frequency. This solution is also made possible by the advent of components made of Wide Band Gap semiconductor such as Silicon Carbide (SiC) or Gallium Nitride (GaN) whose switching losses are drastically reduced compared to their Silicon counterpart.

[0004]

The volume reduction brought by a higher switching frequency is generally not decreasing the amount of losses in the shrunken device leading to a higher loss density. In addition, the surface available to extract heat from the component is also reduced. This decrease of the available surface is making the heat extraction difficult because heatsinks, independent to their technology, have a fixed heat transfer coefficient. Therefore, with the same amount of heat, a reduced surface generally leads to a higher temperature gradient in the magnetic component.

[0005]

In addition, ensuring a good thermal path from the component to the heatsink is also a challenging task. This is due to two main features of the magnetic core and/or windings. First, a good dimensional accuracy is difficult to obtain during manufacturing of both the core and the windings. Consequently, the heatsink which has usually a controlled flatness and accurate dimensions cannot be tightly assembled with the component. Additional processing steps such as machining, grounding or electro-erosion machining can be done on the component to improve the dimension accuracy but this is strongly impacting the cost. The second limitation is coming from the surface quality of both the heatsink and the heat extraction region on the magnetic component. Most of the time, a thermal interface material is required to fill the void between the two surfaces adding a substantial thermal resistance in the thermal path. Once again, post manufacturing techniques like polishing can improve the matching between the two surfaces but this will again result in a cost increase.

[0006]

Aside from the interface with the heatsink, most of the magnetic materials used in power conversion are poor heat conductors. This low

conductivity is either due to the bulk material characteristics like in ferrite material or because of the layered structure of the core (stack of laminated sheet isolated by a dielectric) giving an anisotropic behavior to the core. Having a low thermal conductivity, despite a good heat transfer coefficient of the cooling system, is also limiting the amount of permissible losses. Indeed, with a low conductivity, a high temperature gradient is generated inside the magnetic core and the hot spot maximal temperature is ruling the level of losses. Commonly used material for magnetic core in power conversion have a rather low maximum operating temperature. This limit is either set by the glass transition temperature of the dielectric use for insulation, or by an inflexion point in the losses versus temperature curve that will lead to a thermal runaway if crossed. Drilling of magnetic core to insert after manufacturing cooling channel can be an option to cool the device. However, magnetic core are either made hard and abrasive material like ferrite or friable material (e.g. amorphous or nanocrystalline) that limit the drilling options and wear out prematurely the tools. Also, the shape of the channel in the drilling axis is restricted to a straight line which can impede the heat extraction capabilities.

[Summary of Invention]

[0007]

The present invention aims to provide a magnetic core with an integrated liquid cooling channel and a method to make the magnetic core.

[0008]

To that end, the present invention concerns a method for making a magnetic core with an integrated liquid cooling channel, characterized in that the method comprises the steps of:

- inserting a part made of a soluble material that have a shape that corresponds to a liquid cooling channel in a mold, the part of the soluble material having an inner channel,

- pouring a mix of magnetic powder, binder and additives in the mold,
- pressing the mix of magnetic powder, binder and additives,
- curing the pressed mix of magnetic powder, binder and additives,
- injecting a solvent in the inner channel in order to dissolve the soluble material.

[0009]

The present invention concerns also a magnetic core comprising a part of a soluble material that have a shape that corresponds to a liquid cooling channel when a solvent is injected in an inner channel of the soluble material.

[0010]

Thus, the heat transfer of the core is increased with a minor increase in the volume of the magnetic core.

[0011]

According to a particular feature, the method further comprises the step of:

- inserting in the mold at least one printed circuit board that comprises a winding.

[0012]

Thus, the present invention enables the realization of compact transformers and inductors.

[0013]

According to a particular feature, the method further comprises the step of:

- coating/plating the part of the soluble material prior to inserting the part of the soluble material in the mold.

[0014]

Thus, the liquid cooling channel is also acting as the windings of the magnetic components combining electrical and thermal functionality.

[0015]

According to a particular feature, the soluble material have a shape of plural turns.

[0016]

Thus, the present invention enables the realization of compact transformers or inductors.

[0017]

According to a particular feature, the soluble material is coated/plated with copper, aluminum or nickel.

[0018]

According to a particular feature, the soluble material is Polyvinyl alcohol, Butenediol Vinyl Alcohol Co-polymer or inorganic salts in a compressed form.

[0019]

The characteristics of the invention will emerge more clearly from a reading of the following description of example embodiments, the said description being produced with reference to the accompanying drawings.

[Brief Description of Drawings]

[0020]

[Fig. 1]

Fig. 1 represents a part made of a soluble material that is used for realizing a magnetic core with an integrated liquid cooling channel according to the invention.

[Fig. 2]

Fig. 2 represents a magnetic core that comprises a soluble material that is used for realizing an integrated liquid cooling channel according to the invention.

[Fig. 3]

Fig. 3 represents a magnetic core with an integrated liquid cooling channel according to the invention.

[Fig. 4]

Fig. 4 represents a magnetic core with an integrated liquid cooling channel that comprises a printed circuit board that comprises a winding according to the invention.

[Fig. 5]

Fig. 5 represents a sectional view of a magnetic core with an integrated liquid cooling channel that comprises a printed circuit board that comprises a winding according to the invention.

[Fig. 6]

Fig. 6 represents a part made of a soluble material that is used for realizing a magnetic core with an integrated liquid cooling channel that further acts as a winding according to the invention.

[Fig. 7]

Fig. 7 represents a magnetic core with an integrated liquid cooling channel that further acts as a winding according to the invention.

[Fig. 8]

Fig. 8 represents an architecture of a device for realizing a magnetic core with an integrated liquid cooling channel according to the invention.

[Fig. 9]

Fig. 9 represents an example of an algorithm for realizing a magnetic core with an integrated liquid cooling channel according to the invention.

[Description of Embodiments]

[0021]

Fig. 1 represents a part made of a soluble material that is used for realizing a magnetic core with an integrated liquid cooling channel according to the invention.

[0022]

The part 10 is made of a specific material, which will be locked in place during the magnetic core manufacturing. Preferably the specific material is soluble into the liquid cooling material which will be used, at least partially, during cooling. For example, the liquid cooling material is water. For example, the specific material is Polyvinyl alcohol (PVA) which can stand a lamination temperature. For example, the specific material is Butenediol Vinyl Alcohol Co-polymer. For example, the specific material is inorganic salts like for example NaCl in a compressed form.

[0023]

The outer shape of the part 10 has to be the exact shape of the desired cooling channel. The inner shape 15 of the part 10 has to match a specific shape for two reasons. The first one is to prime the dissolution of the specific material by allowing the solvent to flow, the second one is to strengthen the hollow shape in order to handle the pressing stage without collapsing. Typical shapes known to help distributing the force, such as honeycomb or gyroid may be used for the internal shape.

[0024]

Fig. 2 represents a magnetic core that comprises a soluble material that is used for realizing an integrated liquid cooling channel according to the invention.

[0025]

The magnetic core 20 is made of a Soft Magnetic Composite (SMC) material. SMC is a well-established type of core in power conversion. It is a mix of a magnetic powder such as iron based powder, nickel based powder and a binder that is fulfilling two requirements. The first one is to electrically isolate each magnetic particle to each other to limit the circulation of eddy current and to restrict the losses associated to this phenomenon. The second one is to

mechanically bind the particles giving the core sufficient strength to be manipulated and integrated in the converter. The multiple isolated magnetic particle approach is distributing the air gap into the whole core's volume. This distribution is helping decreasing the losses due to the fringing effect and a more homogeneous losses distribution can be obtained. SMC permits significant advantages compared to the laminated sheets, such as complex geometries and reduced eddy currents losses. Since SMC are also magnetically isotropic, new types of electrical machines which requires a 3D path of the magnetic flux can be manufactured.

[0026]

A common manufacturing process of SMC is cast molding in which the mix of magnetic powder, binder and optional additives is pressed into a die to shape the core. Post-pressing steps can include drying, infusing liquid, or machining. Extrusion or injection molding are some of the alternatives of cast molding.

[0027]

The mix of magnetic powder and the binder is placed in a mold. Positioning features such as notch or tabs can be machined in the mold and/or in the part 10 to lock part 10 in place.

[0028]

The mix of magnetic powder and the binder is then pressed. One or multiple pressing stages can be done to obtain the required density of the magnetic core 20. In some cases, a unique pressing step is prone to an unbalanced pressure in the material resulting in an inhomogeneous density in the magnetic core 20. Multiple pressing stages allow to even the material step by step. Therefore, insertion of the part should be postponed until the material under the insertion level is properly pressed.

[0029]

Fig. 3 represents a magnetic core with an integrated liquid cooling channel according to the invention.

[0030]

A solvent, like the liquid cooling material, is then injected in the inner channel 15 of the magnetic core disclosed in Fig. 2. As the soluble material 10 is progressively removed from the magnetic core 20, the cooling channel 30 is revealed.

[0031]

Fig. 4 represents a magnetic core with an integrated liquid cooling channel that comprises a printed circuit board that comprises a winding according to the invention.

[0032]

The magnetic core 40 comprises a liquid cooling channel 42 as disclosed in Fig. 3 and further comprises printed circuit boards 41a and 41b that comprise conductive material tracks 45 forming the windings of an inductor or a transformer, the printed circuit boards 41a and 41b are inserted in the mold prior to forming the magnetic core 40. During pressing, or injecting under high pressure, the uncured mix will flow around the printed circuit boards 41a and 41b until all voids are filled.

[0033]

Fig. 5 represents a sectional view of a magnetic core with an integrated liquid cooling channel that comprises a printed circuit board that comprises a winding according to the invention.

[0034]

The magnetic core 40 comprises the liquid cooling channel 42, printed circuit boards 41a and 41b that comprise windings 45.

[0035]

Fig. 6 represents a part made of a soluble material that is used for

realizing a magnetic core with an integrated liquid cooling channel that further acts as a winding according to the invention.

[0036]

The part 60 is made of a soluble material that is used for realizing a magnetic core. The part 60 has a shape that corresponds to the required number of turns in the application in order to produce the targeted magnetic flux.

[0037]

The part 60 may comprise an additional internal channel 67 for priming the flow of a liquid cooling material.

[0038]

The part 60 is coated/plated 65 before insertion in the mold. The plated material could be copper, aluminum or nickel. The purpose of the plating is to protect the channel from abrasion of the coolant and/or to replace the windings.

[0039]

Fig. 7 represents a magnetic core with an integrated liquid cooling channel that further acts as a winding according to the invention.

[0040]

The magnetic core 70 comprises an integrated liquid cooling channel 75 that further acts as a winding according to the invention.

[0041]

Fig. 8 represents an architecture of a device for realizing a magnetic core with an integrated liquid cooling channel according to the invention.

[0042]

The device for realizing a magnetic core with an integrated liquid cooling channel 50 has, for example, an architecture based on components connected together by a bus 801 and a processor 800 controlled by a program as disclosed in Fig. 9.

[0043]

The bus 801 links the processor 800 to a read only memory ROM 802, a random access memory RAM 803 and an input output I/O IF interface 805.

[0044]

The memory 803 contains registers intended to receive variables and the instructions of the program related to the algorithm as disclosed in Fig. 9.

[0045]

The read-only memory, or possibly a Flash memory 802, contains instructions of the programs related to the algorithm as disclosed in Fig. 9, when the device for realizing a magnetic core with an integrated liquid cooling channel 50 is powered on, are loaded to the random access memory 803. Alternatively, the program may also be executed directly from the ROM memory 802.

[0046]

The control performed by the device for realizing a magnetic core with an integrated liquid cooling channel 50 may be implemented in software by execution of a set of instructions or program by a programmable computing machine, such as a PC (*Personal Computer*), a DSP (*Digital Signal Processor*) or a microcontroller; or else implemented in hardware by a machine or a dedicated component, such as an FPGA (*Field-Programmable Gate Array*) or an ASIC (*Application-Specific Integrated Circuit*).

[0047]

In other words, the device for realizing a magnetic core with an integrated liquid cooling channel 50 includes circuitry, or a device including circuitry, causing the device for realizing a magnetic core with an integrated liquid cooling channel 50 to perform the program related to the algorithm as disclosed in Fig. 9.

[0048]

Fig. 9 represents an example of an algorithm for realizing a magnetic

core with an integrated liquid cooling channel according to the invention.

[0049]

At step S90, the part made of a soluble material that is used for realizing a magnetic core with an integrated liquid cooling channel is inserted in a mold. The part made of a soluble material that is used for realizing a magnetic core with an integrated liquid cooling channel is for example as the one disclosed in Fig. 1 or 6. Positioning features such as notch or tabs can be machined in the mold and/or in the inserted parts to lock it in place.

[0050]

Optionally, at step S91, a printed circuit board is inserted in the mold. The printed circuit board is as the one disclosed in reference to Figs. 4 and 5. Positioning features such as notch or tabs can be machined in the mold and/or in the inserted parts to lock it in place.

[0051]

At step S92, the mix of magnetic powder, binder and additives is pour in the mold.

[0052]

At step S93, the mix of magnetic powder, binder and additives is pressed. One or multiple pressing stages can be done to obtain the required density of the core. In some cases, a unique pressing step is prone to an unbalanced pressure in the material resulting in an inhomogeneous density in the core. Multiple pressing stages allow to even the material step by step. Therefore, insertion of the parts may be postponed until the material under the insertion level is properly pressed.

[0053]

At step S94, the pressed mix of magnetic powder, binder and additives is cured. At the end of step, the magnetic core with the part made of a soluble material that is used for realizing a magnetic core with an integrated liquid

cooling channel is released for the mold.

[0054]

At step S95, the solvent is injected in the inner channel 15 of Fig. 1 or 67 in Fig. 6 and dissolution is initiated. As the soluble material is progressively removed from the magnetic core, the cooling channel is revealed.

[0055]

Naturally, many modifications can be made to the embodiments of the invention described above without departing from the scope of the present invention.

[CLAIMS]

[Claim 1]

A method for making a magnetic core with an integrated liquid cooling channel, characterized in that the method comprises the steps of:

- inserting a part of a soluble material that have a shape that corresponds to a liquid cooling channel in a mold, the part of the soluble material having an inner channel,
- pouring a mix of magnetic powder, binder and additives in the mold,
- pressing the mix of magnetic powder, binder and additives,
- curing the pressed mix of magnetic powder, binder and additives,
- injecting a solvent in the inner channel in order to dissolve the soluble material.

[Claim 2]

The method according to claim 1, the method further comprising the step of:

- inserting in the mold at least one printed circuit board that comprises a winding.

[Claim 3]

The method according to claim 1, characterized in that the method further comprises the step of:

- coating/plating the part of the soluble material prior to inserting the part of the soluble material in the mold.

[Claim 4]

The method according to claim 3, characterized in that the soluble material have a shape of plural turns.

[Claim 5]

The method according to claim 3 or 4, characterized in that the soluble material is coated/plated with copper, aluminum or nickel.

[Claim 6]

The method according to any one of the claims 1 to 5, characterized in that the soluble material is Polyvinyl alcohol, Butenediol Vinyl Alcohol Co-polymer or inorganic salts in a compressed form.

[Claim 7]

A magnetic core comprising a part of a soluble material that have a shape that corresponds to a liquid cooling channel when a solvent is injected in an inner channel of the soluble material.

[Claim 8]

The magnetic core according to claim 7, wherein the soluble material is Polyvinyl alcohol, Butenediol Vinyl Alcohol Co-polymer or inorganic salts in a compressed form.

[Claim 9]

The magnetic core according to claim 7, wherein the part of the soluble material is coated or plated.

[Claim 10]

The magnetic core according to claim 9, wherein the soluble material is coated/plated with copper, aluminum or nickel.

[Claim 11]

The magnetic core according to claim 9, wherein the soluble material have a shape of plural turns.

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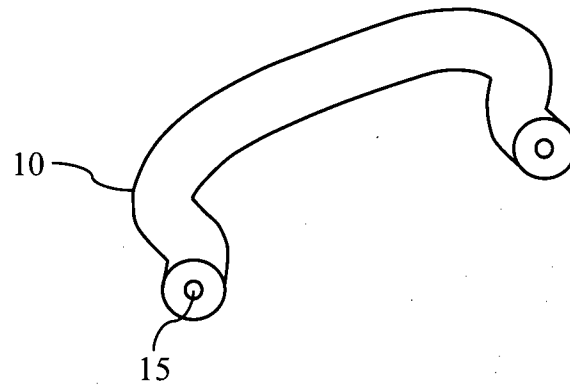


Fig. 1

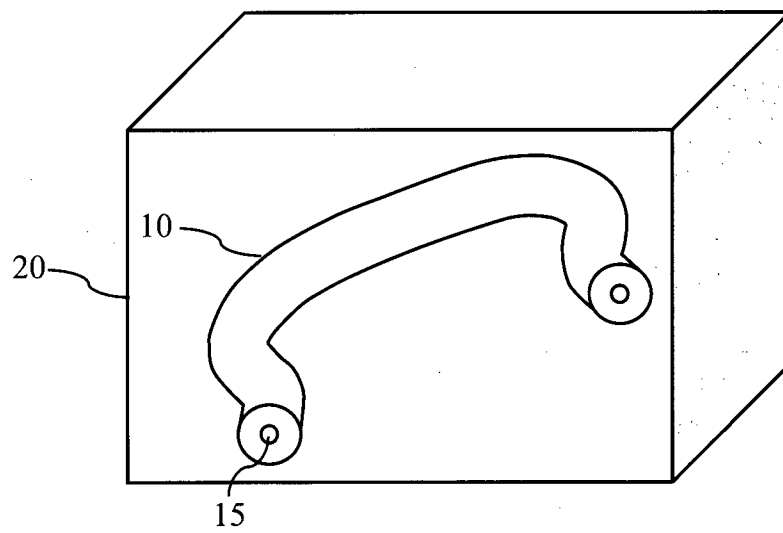


Fig. 2

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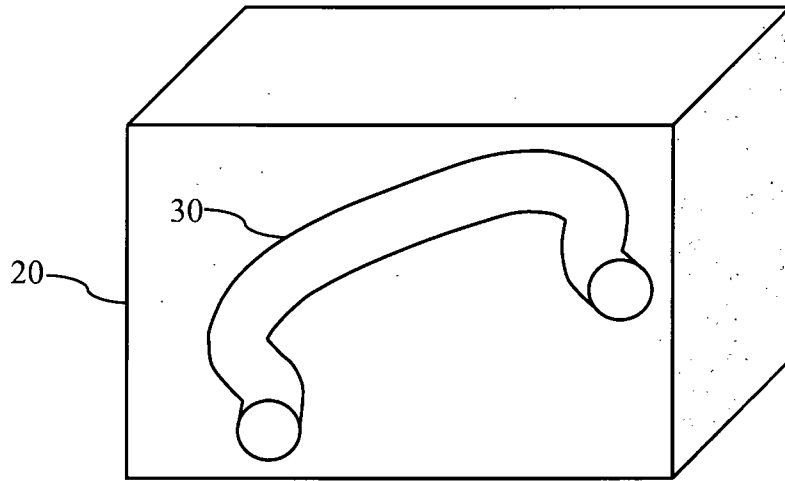


Fig. 3

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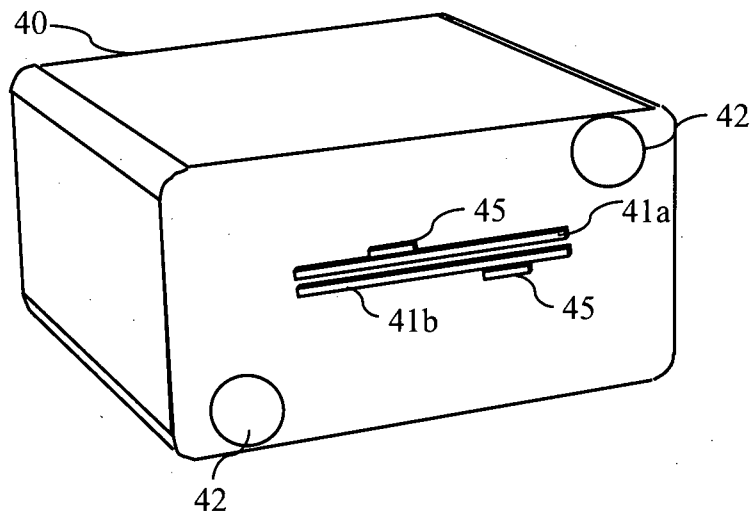


Fig. 4

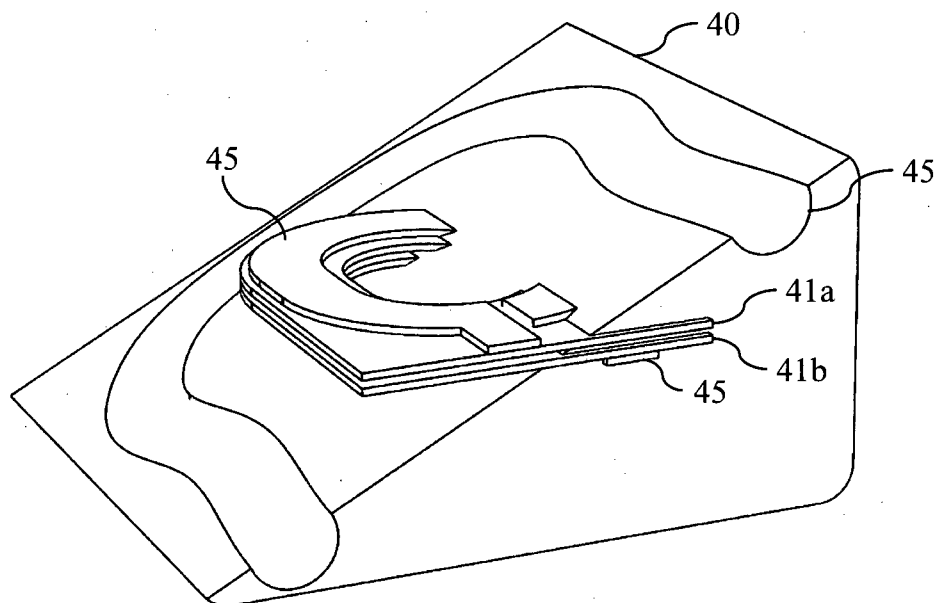


Fig. 5

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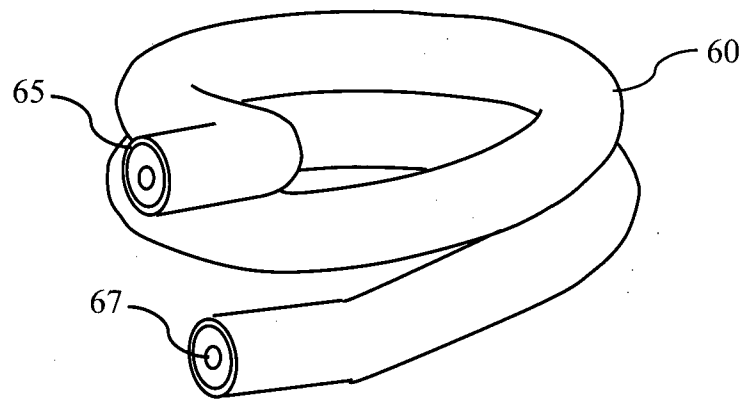


Fig. 6

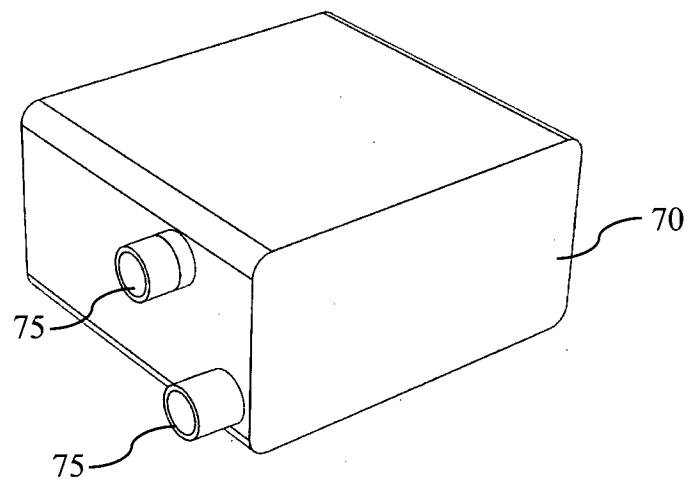


Fig. 7

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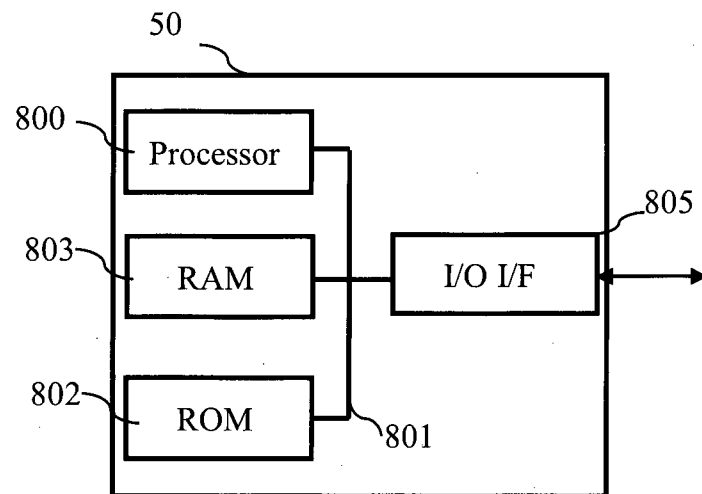


Fig. 8

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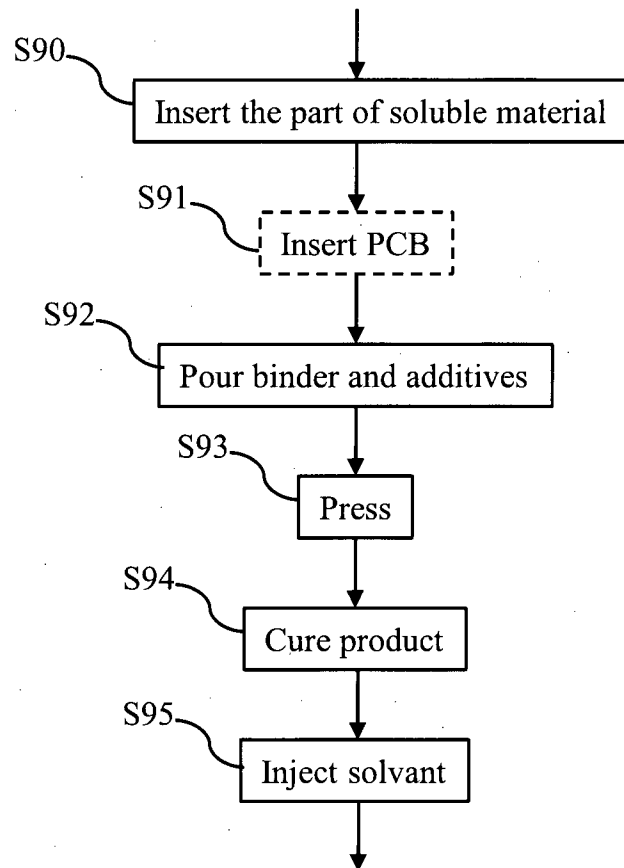


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No

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A. CLASSIFICATION OF SUBJECT MATTER		
INV.	H01F41/02 H01F27/10	H01F17/00 H01F27/28
	H01F17/04 B22C9/00	H01F3/08 H01F27/255
ADD.		
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) H01F B22C		
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	DE 20 2017 101659 U1 (VACON OY [FI]) 19 April 2017 (2017-04-19) figures 3,4a,4b corresponding description -----	1-11
A	US 2019/333676 A1 (SHIN JONGWON [US] ET AL) 31 October 2019 (2019-10-31) figures 1b,2a,2b,4a-d corresponding description -----	1-11
A	US 2007/295715 A1 (SAKA KENJI [JP] ET AL) 27 December 2007 (2007-12-27) figures 1-8 corresponding description -----	1-11
A	US 2017/154720 A1 (OHKUBO HITOSHI [JP] ET AL) 1 June 2017 (2017-06-01) figures 1-4 corresponding description -----	1-11
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Date of the actual completion of the international search 13 August 2021		Date of mailing of the international search report 23/08/2021
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 Weisser, Wolfgang

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 202017101659 U1	19-04-2017	CN 207199448 U DE 202017101659 U1	06-04-2018 19-04-2017
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