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(54) **Downhole tool cooling system and method**

(57) Present embodiments relate to systems and methods for cooling electronics components 40 of downhole tools 42. More specifically, the downhole tool includes a multi-chip module 40 (MCM) coupled to a thermoelectric cooling (TEC) system 56. The TEC system 56 may reduce a temperature of the MCM using, for example, the Peltier effect.

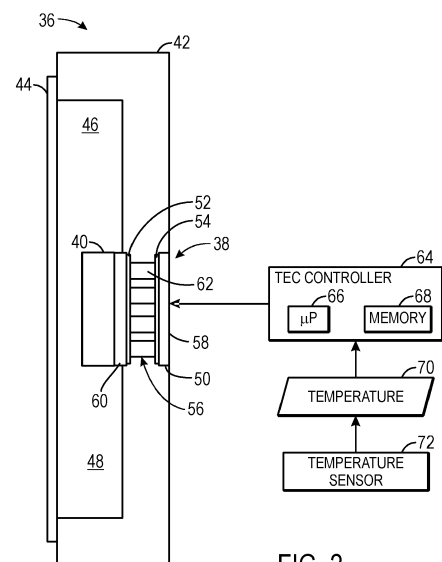


FIG. 2

Description

BACKGROUND

[0001] The present disclosure relates generally to systems and methods for improving the operability of downhole tools for drilling operations.

[0002] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

[0003] A drill bit attached to a long string of drill pipe, generally referred to as the drill string, may be used to drill a borehole for an oil and/or gas well. In addition to the drill bit, the drill string may also include a variety of downhole tools to measure or log properties of the surrounding rock formation or the conditions in the borehole. These tools often operate in high temperature and pressure conditions. Unfortunately, the high temperature conditions may reduce the operability or lifespan of the electronics components within the downhole tools. For example, overheating of the downhole tools may weaken certain joints or induce electro-erosion of the electronics components. Thus, it is now recognized that it may be desirable to prevent the downhole tools from overheating during operation of the drilling system in order to improve the efficiency and operability of these tools.

SUMMARY

[0004] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0005] Present embodiments relate to systems and methods for cooling electronics components of downhole tools. More specifically, the downhole tool includes a multi-chip module (MCM) coupled to a thermoelectric cooling (TEC) system. The TEC system may reduce a temperature of the MCM using, for example, the Peltier effect.

[0006] In a first embodiment, a system includes a housing, an integrated circuit hermetically sealed within the housing, and a thermoelectric cooling (TEC) system coupled to the housing. The TEC system may reduce a temperature of the integrated circuit. In addition, the TEC includes a thermoelectric cooling module with a plurality of alternating p-type and n-type semiconductors, a first thermal interface material (TIM) coupled to a first end of the thermoelectric cooling module, and a second TIM coupled to a second end of the thermoelectric cooling

module.

[0007] In a second embodiment, a method includes lowering a downhole tool into a borehole. The method also includes detecting a temperature of the downhole tool using a sensor. Furthermore, at least electronics component of the downhole tool is actively cooled using a first thermoelectric cooling system based on the detected temperature.

[0008] In a third embodiment, a drilling system includes a downhole tool and an electronics assembly. The downhole tool may measure one or more parameters related to the drilling system, a rock formation, or both. The electronics assembly may adjust operation of the drilling system based on the one or more parameters. In addition, the electronics assembly includes a housing, a multi-chip module disposed within the housing, and a thermoelectric cooling system coupled to the housing. The thermoelectric cooling system may reduce a temperature of the multi-chip module.

[0009] Various refinements of the features noted above may exist in relation to various aspects of the present disclosure. Further features may also be incorporated in these various aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to one or more of the illustrated embodiments may be incorporated into any of the above-described aspects of the present disclosure alone or in any combination. Again, the brief summary presented above is intended only to familiarize the reader with certain aspects and contexts of embodiments of the present disclosure without limitation to the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

[0011] FIG. 1 is a schematic diagram of a drilling system that employs a downhole tool having an electronics assembly equipped with a thermoelectric cooling (TEC) system, in accordance with an embodiment;

[0012] FIG. 2 is a schematic diagram of the electronics assembly of FIG. 1, illustrating a multi-chip module coupled to the TEC system, in accordance with an embodiment;

[0013] FIG. 3 is a schematic diagram of the electronics assembly of FIG. 1, illustrating a the TEC system coupled to a housing of the electronics assembly, in accordance with an embodiment; and

[0014] FIG. 4 is a flowchart of a method to actively cool a multi-chip module using the TEC system of FIG. 1, in accordance with an embodiment.

DETAILED DESCRIPTION

[0015] One or more specific embodiments of the

present disclosure will be described below. These described embodiments are only examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0016] When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0017] As mentioned above, the present disclosure is directed toward systems and methods for cooling electronics components within downhole tools of drilling systems. The downhole tools may include, for example, logging-while-drilling (LWD) tools, measurement-while-drilling (MWD) tools, steering tools, and/or other tools to communicate with drilling operators at the surface. Because the downhole tools may operate in high-temperature conditions, a thermoelectric cooling (TEC) system may be used to reduce a temperature of the electronics components within the downhole tools, thereby improving the operability and/or efficiency of the downhole tools in boreholes of great depths and/or high temperatures. For example, the TEC system may include a TEC module with a plurality of alternating n-type and p-type semiconductors. When an electric current is applied to the TEC module, one end (e.g., a hot plate) of the TEC module increases in temperature and another end (e.g., a cold plate) decreases in temperature. Thus, the electronics component may be coupled to the cold plate in order to remove heat from the electronics component. The hot plate may expel the removed heat to a heat sink.

[0018] Turning now to the figures, FIG. 1 illustrates a drilling system 10 that may benefit from the TEC system described above. As shown, the drilling system 10 includes a drill string 12 used to drill a borehole 14 into a rock formation 16. A drill collar 18 of the drill string 12 encloses the various components of the drill string 12. Drilling fluid 20 from a reservoir 22 at the surface 24 may be driven into the drill string 12 by a pump 26. The hy-

draulic power of the drilling fluid 20 causes a drill bit 28 to rotate, cutting into the rock formation 16. The cuttings from the rock formation 16 and the returning drilling fluid 20 exit the drill string 12 through a space 30. The drilling fluid 20 thereafter may be recycled and pumped, once again, into the drill string 12.

[0019] A variety of information relating to the rock formation 16 and/or the state of drilling of the borehole 14 may be gathered while the drill string 12 drills the borehole 14. For instance, a measurement-while-drilling (MWD) tool 32 may measure certain drilling parameters, such as the temperature, pressure, orientation of the drilling tool, and so forth. Likewise, a logging-while-drilling (LWD) tool 34 may measure the physical properties of the rock formation 16, such as density, porosity, resistivity, and so forth. The MWD tool 32 and the LWD tool may be lowered into the borehole 14 to gather the information at various depths within the rock formation 16.

[0020] As illustrated, the MWD tool 32 and the LWD tool 34 may include electronics components stored within an electronics assembly 36. The electronics components may perform calculations or otherwise control operation of the tools 32 and 34. As better illustrated by FIGS. 2 and 3, the electronics assembly 36 includes a TEC system 38 to remove heat from the electronics components, thereby enabling the drilling tools 32 and 34 to operate in harsher conditions, and in turn, drill deeper into the rock formation 16.

[0021] Although FIG. 1 illustrates the TEC system 38 used in the drilling system 10, the TEC system 38 may be used in any suitable downhole tools with any suitable means of conveyance. For example, the TEC system 38 may be used in downhole tools carried by wireline or coiled tubing, to name just a few examples.

[0022] FIG. 2 illustrates an embodiment of the electronics assembly 36 having an electronics component 40 disposed within a housing 42. In general, the electronics component 40 may be a single chip module, a multi-chip module (MCM), or any other suitable form of integrated circuit related to the operation of the drilling tools 32 and 34. For example, an MCM may include a plurality of dies disposed on a unifying substrate, thereby simplifying procurement and installation of the MCM.

[0023] The housing 42 includes a cover frame 44, which defines a space 46 where the electronics component 40 resides. Furthermore, the housing 42 hermetically seals the space 46, which helps to thermally insulate the electronics component 40 from the ambient temperature of the rock formation 16. In certain embodiments, the space 46 may be filled with an inert gas 48, such as nitrogen or argon. The inert gas protects the electronics component 40 by inhibiting humidity, corrosion, and/or electro-erosion within the space 46. Additionally or alternatively, the space 46 may be placed under full or partial vacuum conditions. In a similar manner, the vacuum condition inhibits humidity and corrosion, thereby improving the operability of the electronics component 40.

[0024] As noted earlier, the electronics assembly 36

may operate at depths corresponding to high ambient temperatures (e.g., greater than 200 degrees Celsius). Accordingly, the material of the housing 42 may be selected in order to withstand these high temperatures, while still maintaining operability with the TEC system 38. In a presently contemplated embodiment, the housing 42 may include a high-temperature co-fired ceramic (HTCC), such as a combination of aluminum oxide, tungsten, and molybdenum.

[0025] The TEC system 38 is coupled to the housing 42 at one or more junctions 50. In certain embodiments, the TEC system 38 may be glued (e.g., with a high thermal conductivity epoxy) or soldered to the housing 42. In configurations where the TEC system 38 is soldered to the housing 42, it may be desirable to select a soldering material with a coefficient of thermal expansion (CTE) similar to a CTE of the TEC system 38. For example, plates 52 and 54 of the TEC system 38 may include alumina having a CTE of approximately 6.5 millimeters per meter per degree Kelvin (mm/m-K). Accordingly, the solder may include MoCu15 (7 mm/m-K), WCu10 (5.6 to 8.3 mm/m-K), or any other suitable alloy.

[0026] The junctions 50, whether glued or soldered, may be exposed to high temperature conditions. In order to maintain the integrity of the junctions 50, it is desirable to maintain a temperature of the junctions 50 below a temperature threshold (e.g., 210 degrees Celsius). As will be appreciated, the temperature threshold is generally based on the material of the junction 50. The TEC system 38 may be used to cool the junctions 50 as well as the electronics component 40 in order to improve the operability of the electronics assembly 36, as discussed further below.

[0027] The TEC system 38 includes a TEC module 56 coupled to two thermal interface materials (TIM) 58 and 60. The TIMs 58 and 60 absorb or dampen thermal expansion of the TEC module 56 and the junctions 50. As a result, the TIMs 58 and 60 inhibit the formation of cracks in the junctions 50 and within the TEC system 38, thereby improving the mechanical integrity of the TEC system 38. The TIMs 58 and 60 are generally metallic or metalloid and may include, for example, silicon. In addition, the geometry of the TIMs 58 and 60 may be designed based on certain parameters of the TEC system 38. For example, the dimensions of the TEC system 38 may be smaller than the dimensions of the housing 42. In certain embodiments, the TEC system 38 may have a generally rectangular (e.g., square) shape with a width of less than 20 millimeters and a thickness of less than 3 millimeters. The varying sizes of the TEC system 38 may correspond to a cooling rate in a range of approximately 0.5 Watts to approximately 10. Watts. Furthermore, in applications where a greater amount of cooling is desired, the TIMs 58 and 60 may have a greater thickness or length than in the embodiment illustrated by FIG. 2

[0028] In the embodiment shown in FIG. 2, the electronics component 40 is directly coupled to the TIM 60, which may enable efficient cooling of the electronics com-

ponent 40. However, in other embodiments, due to space constraints or other design considerations, the geometry of the electronics assembly 36 may vary. For example, as shown in FIG. 3, the electronics component 40 may be coupled to the housing 42, which is subsequently coupled to the TIM 60. Notably, the electronics component 40 is not in direct contact with the TIM 60. As illustrated, the TEC system 38 dissipates heat directly from the housing 42. The cooled housing 42 subsequently removes heat from the electronics component 40. This design may be desirable, for example, when a larger TEC system 38 is desired for a greater amount of cooling. In other words, because the junction 50 between the housing 42 and the TEC system 38 has a greater surface area, a greater cooling rate may be achieved. In the embodiment illustrated in FIG. 3, the thickness of the TEC system 38 may be less than 4 millimeters.

[0029] Furthermore, it should be noted that the electronics assembly 36 may include a varying number of electronics components 40 and/or TEC systems 38. For example, a single electronics component 40 may be cooled using two or more TEC systems 38. Additionally or alternatively, a single TEC system 38 may cool two or more electronics components 40. Thus, the electronics assembly 36 may include 1, 2, 3, 4, or more electronics components 40 individually or collectively coupled to 1, 2, 3, 4, or more TEC systems 38.

[0030] Turning back to FIG. 2, the TEC module 56 between the TIMs 58 and 60 is illustrated. The TEC module 56 includes the plates 52 and 54 and a plurality of pellets 62 (e.g., semiconductors) disposed therebetween. In certain embodiments, the pellets 62 may alternate between n-type and p-type semiconductors. Furthermore, the design of the pellets 62 may be based on the ambient temperature of the rock formation 16, among other considerations. For example, for operating conditions near 200 degrees Celsius, the pellets 62 may include bismuth telluride.

[0031] When a current is applied to the TEC module 56, the plate 52 (e.g., cold plate) absorbs heat from the electronics component 40, while the plate 54 (e.g., hot plate) expels the absorbed heat according to the Peltier effect. As a result, heat is removed from the electronics component 40 and the junctions 50, thereby enabling the electronics assembly 36 to operate at depths within the rock formation 16 that have higher ambient temperatures. In certain embodiments, it may be desirable to control the rate of cooling of the electronics assembly 36 or to actively enable or disable the application of current to the TEC module 56. Accordingly, a TEC controller 64 may be communicatively coupled to the TEC system 38 in order to control the application of current to TEC module 56.

[0032] As shown, the TEC controller 64 includes one or more processors 66 and/or other data processing circuitry, such as memory 68, to execute instructions to enable cooling of the electronics assembly 36. These instructions may be encoded in software programs that are

executed by the processor 66. For example, the processor 66 may determine when cooling the electronics component 40 is desirable based on a temperature 70 detected by a temperature sensor 72. These instructions may be stored in a tangible, non-transitory, computer-readable medium, such as the memory 68. The memory 68 may include, for example, random-access memory, read-only memory, rewriteable memory, hard drives, optical discs, and/or the like. In certain embodiments, various temperature thresholds may be stored within the memory 68 to be later accessed by the processor 66. The operation of the TEC controller 64 is discussed below with respect to FIG. 4.

[0033] FIG. 4 illustrates an embodiment of a method 74 to enable operation of the drilling system 10 at depths corresponding to higher ambient temperatures. The drilling system 10 may drill (block 76) to a high-temperature depth. For example, the ambient temperature around the tip of the drill collar 18 may be greater than 200 degrees Celsius. The temperature sensor 72 detects (block 78) the temperature 70 and communicates the temperature 70 to the TEC controller 64. The TEC controller 64 determines (block 80) if the temperature is appropriate by, for example, comparing the detected temperature 70 to a temperature threshold. As mentioned earlier, the temperature threshold may be stored on the memory 68 and may be based on the material of the junction 50 and/or the design temperature of the electronics component 40. If the detected temperature 70 is greater than the temperature threshold or the temperature 70 is otherwise inappropriate, the TEC controller 64 activates (block 82) the TEC system 38 to cool the electronics assembly 36 by applying a current to the TEC module 56.

[0034] A myriad of different temperatures 70 may be detected (block 78) by the temperature sensor 72. For example, the temperature sensor 72 may detect (block 78) an ambient temperature of the reservoir rock 16, a temperature of the electronics component 40, a temperature of the junction 50, a temperature differential between the cold plate 52 and the hot plate 54 of the TEC module 56, or any combination thereof. Furthermore, the temperature threshold of block 80 may vary depending on the type of temperature detected by the temperature sensor 72.

[0035] For example, the TEC controller 64 may maintain a temperature of the junction 50 below a first temperature threshold (e.g., 210 degrees Celsius) using the TEC system 38. As will be appreciated, the cooling effect of the TEC system 38 is not instantaneous. In order to ensure that the temperature 70 of the junction 50 is maintained below the first temperature threshold (e.g., 210 degrees Celsius), the TEC controller 64 may activate (block 82) the TEC system 38 when the temperature 70 of the junction 50 exceeds a second temperature threshold (e.g., 200 degrees Celsius).

[0036] In a similar manner, the TEC controller 64 may maintain a temperature differential (e.g., less than a 40 degree difference) between the ambient temperature 70

of the reservoir rock and the temperature 70 of the electronics component 40, or a temperature differential (e.g., less than a 10 degree difference) between the hot and cold plates 52 and 54 of the TEC module 56, or both.

[0037] In configurations with multiple TEC systems 38 used to cool an individual electronics component 40 or junction 50, the TEC systems 38 may be activated (block 82) independently and at different temperature thresholds. For example, the TEC controller 64 may control two TEC systems 38 to maintain a temperature differential (e.g., less than a 40 degree difference) between the ambient temperature 70 and the temperature 70 of the electronics component 40. At a first temperature threshold (e.g., a 20 degree difference), the TEC controller 64 may activate (block 82) the first TEC system 38. Then, when a second temperature threshold is exceeded (e.g., a 30 degree difference), the TEC controller 64 may activate (block 82) the second TEC system 38. Such a configuration may generally improve the efficiency of the TEC systems 38.

[0038] Indeed, the multiple TEC systems 38 may be designed with varying sizes and cooling rates. For example, the first TEC system 38 may remove approximately 1 watt (W) of heat using 1 amp (A), and the second TEC system 38 may remove approximately 2 W using 2 A. The TEC controller 64 may independently activate (block 82) the TEC systems 38 to achieve a desired cooling rate. More specifically, the TEC system 38 may activate (block 82) the first TEC system 38 and disable the second TEC system 38 for a cooling rate of 1 W, activate (block 82) the second TEC system 38 and disable the first TEC system 38 for a cooling rate of 2 W, or activate (block 82) both TEC systems 38 for a cooling rate of 3 W.

[0039] Furthermore, when activating (block 82) the TEC systems 38, the TEC controller 64 may be designed to apply a constant current or a variable current to the TEC module 56. For example, constant current applications may be easier to design, whereas variable current applications may provide more flexibility to operate the TEC system 38. In certain embodiments, the TEC controller 64 may apply a greater or lesser amount of current depending on the proximity of the temperature 70 to the various temperature thresholds. For example, the TEC controller 64 may maintain a temperature differential (e.g., less than a 10 degree difference) between the hot plate 54 and the cold plate 52 of the TEC module 56. The TEC controller 64 may increase the amount of current applied to the TEC module 56 as the temperature 70 approaches a first temperature threshold (e.g., an 8 degree difference), thereby increasing the amount of cooling to the electronics assembly 36.

[0040] Technical effects of the disclosed embodiments include systems and methods for active cooling of the electronics components 40 within the downhole tools 32 and 34 of the drilling system 10, thereby enabling operation in high-temperature and/or high-depth environments. In particular, the TEC system 38 is coupled to the electronics component 40 either directly or indirectly

through the housing 42 of the electronics assembly 36. The TEC controller 64 controls application of current to the TEC system 38 in order to control the temperature of the electronics component 40, the junction 50, or both. [0041] The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

Claims

1. A system comprising:

a housing;
an integrated circuit disposed within the housing, wherein the housing is configured to hermetically seal the integrated circuit; and
a thermoelectric cooling system coupled to the housing and configured to reduce a temperature of the integrated circuit, wherein the thermoelectric cooling system comprises:

a thermoelectric cooling module having a plurality of alternating p-type and n-type semiconductors;
a first thermal interface material coupled to a first plate of the thermoelectric cooling module; and
a second thermal interface material coupled to a second plate of the thermoelectric cooling module.

2. The system of claim 1, wherein a surface of the first thermal interface material is coupled to the integrated circuit.

3. The system of claim 1, wherein a surface of the first thermal interface material is coupled to the housing and is not in direct contact with the integrated circuit.

4. The system of claim 3, wherein the integrated circuit is disposed on the housing and is not in direct contact with the first thermal interface material.

5. The system of claim 1, wherein the integrated circuit comprises a multi-chip module comprising a plurality of dies disposed on a substrate.

6. The system of claim 5, wherein the housing contains an inert gas configured to reduce electro-erosion of the integrated circuit, the thermoelectric cooling system, or both.

7. The system of claim 1, comprising:

a sensor configured to detect an ambient temperature; and
a controller configured to selectively enable or disable the thermoelectric cooling system based on the detected ambient temperature.

8. The system of claim 7, wherein the controller is configured to maintain a temperature difference of at least 40 degrees Celsius between the ambient temperature and the temperature of the integrated circuit.

9. A method, comprising:

lowering a downhole tool into a borehole;
detecting a temperature of the downhole tool using a sensor; and
actively cooling at least one electronics component of the downhole tool using a first thermoelectric cooling system based on the temperature.

10. The method of claim 9, wherein actively cooling the at least one electronics component comprises:

comparing the temperature to a first temperature threshold; and
activating the first thermoelectric cooling system to actively cool the at least one electronics component when the detected temperature is above the first temperature threshold.

11. The method of claim 10, comprising:

comparing the temperature to a second temperature threshold; and
activating a second thermoelectric cooling system to actively cool the at least one electronics component when the detected temperature is above the second temperature threshold, wherein the second temperature threshold is greater than the first temperature threshold.

12. The method of claim 9, wherein the temperature comprises an ambient temperature, a temperature of the at least one electronics component, a temperature of a junction, a temperature difference between a hot plate and a cold plate of the first thermoelectric cooling system, or any combination thereof.

13. The method of claim 12, wherein lowering the downhole tool comprises drilling to a depth corresponding to the ambient temperature in a range greater than 200 degrees Celsius.

14. The method of claim 13, comprising maintaining a

temperature difference of at least 40 degrees Celsius between the ambient temperature and the temperature of the at least one electronics component.

15. The method of claim 9, wherein the at least one electronics component comprises first and second electronics components, and wherein the method comprises actively cooling both of the first and second electronics components using the first thermoelectric cooling system based on the temperature.

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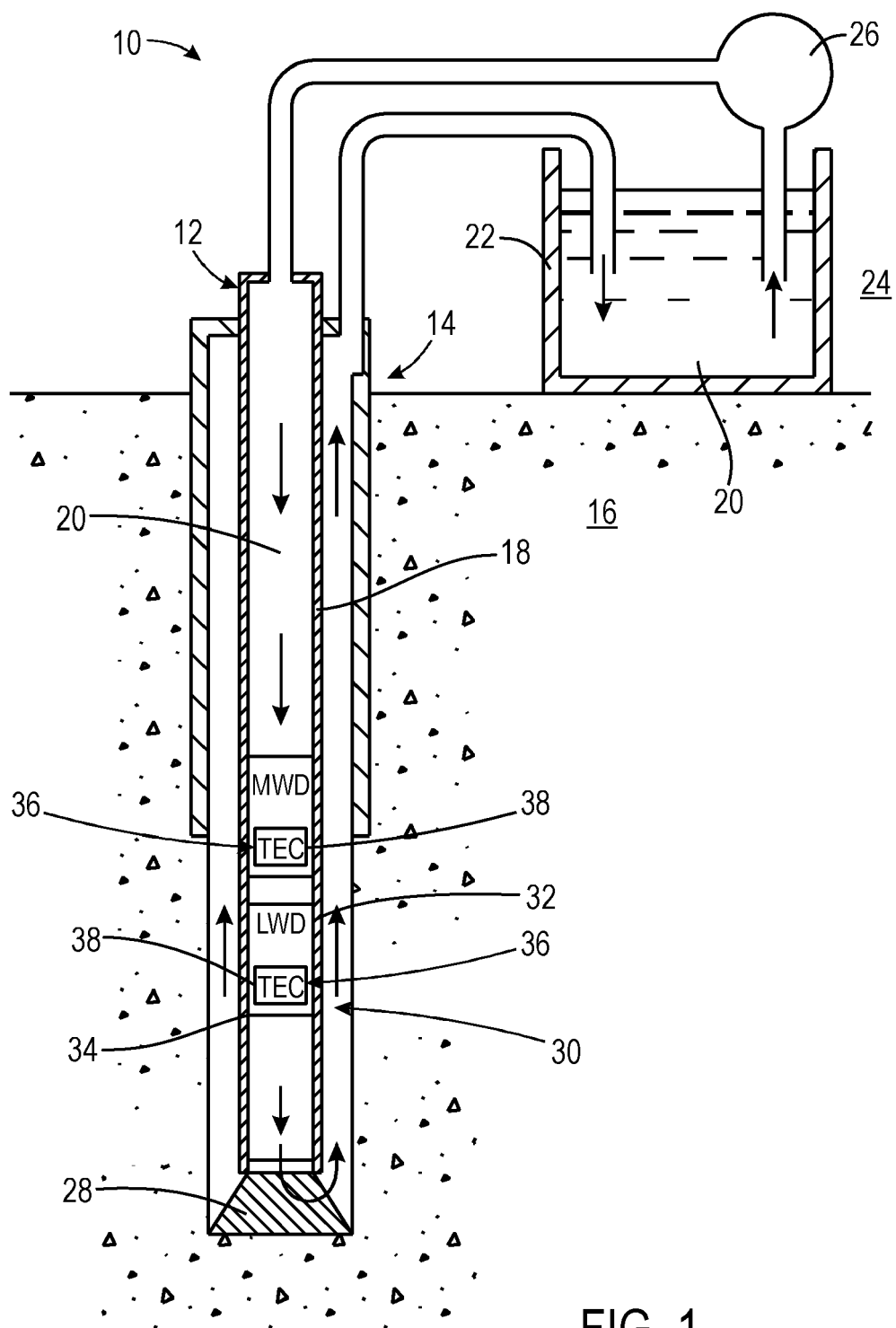


FIG. 1

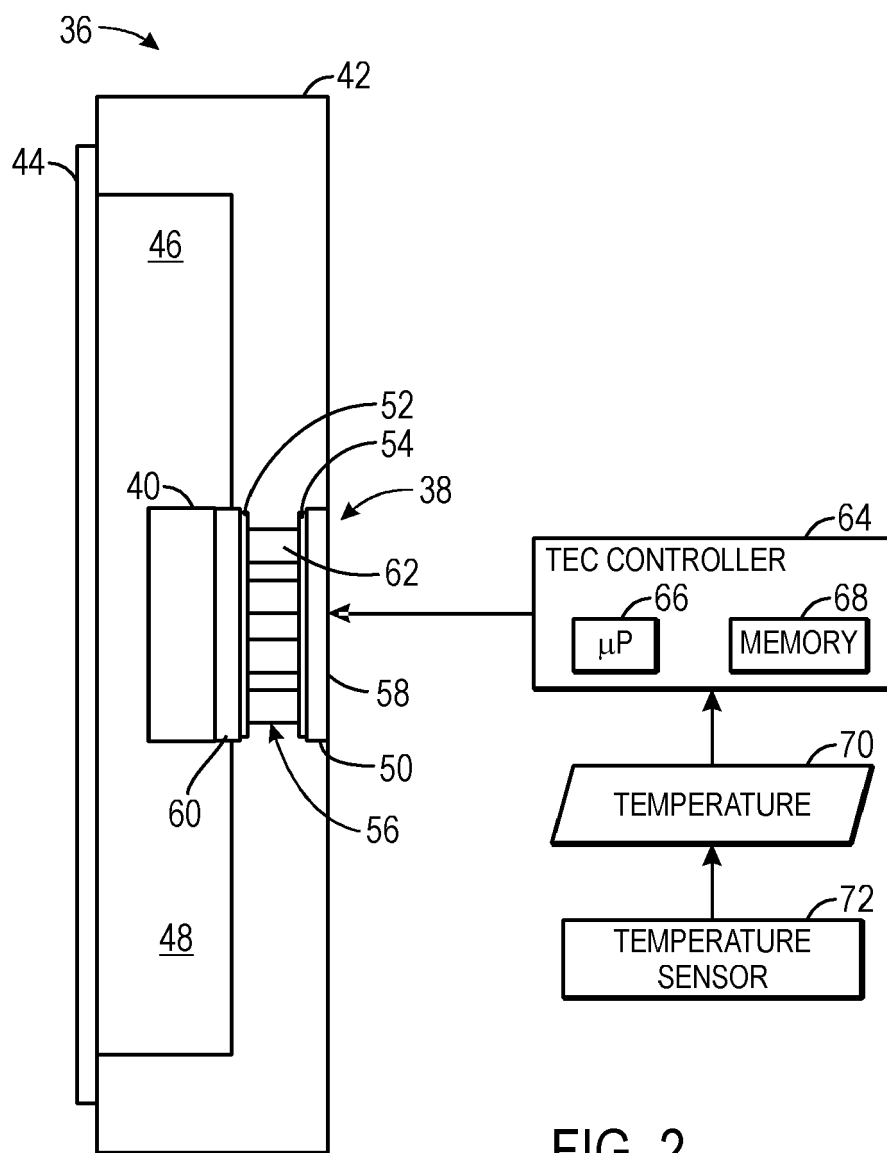


FIG. 2

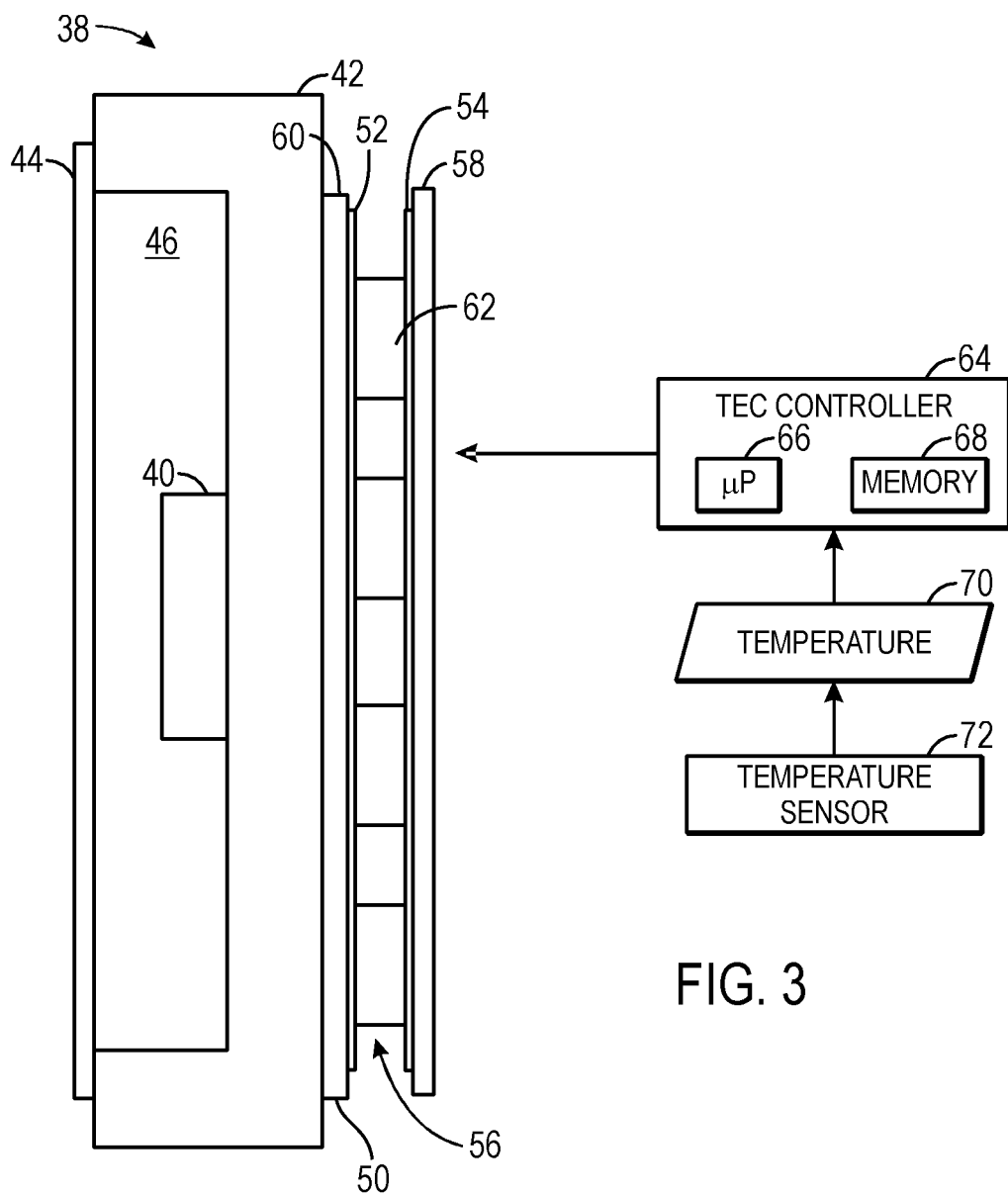


FIG. 3

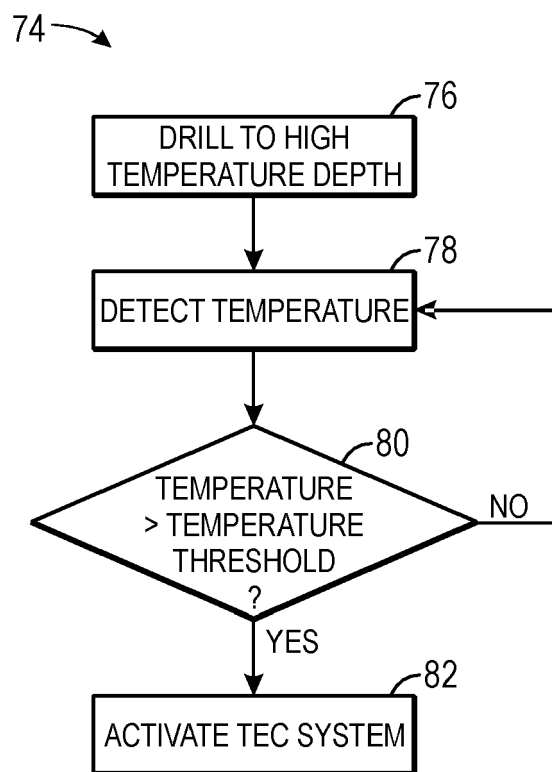


FIG. 4



EUROPEAN SEARCH REPORT

Application Number
EP 12 30 6530

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Place of search Munich		Date of completion of the search 4 April 2013	Examiner Schneiderbauer, K
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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