

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
16 March 2006 (16.03.2006)

PCT

(10) International Publication Number
WO 2006/028691 A1(51) International Patent Classification⁷: **E21B 43/12**,
34/06, F16K 31/00(21) International Application Number:
PCT/US2005/029829

(22) International Filing Date: 22 August 2005 (22.08.2005)

(25) Filing Language: English

(26) Publication Language: English

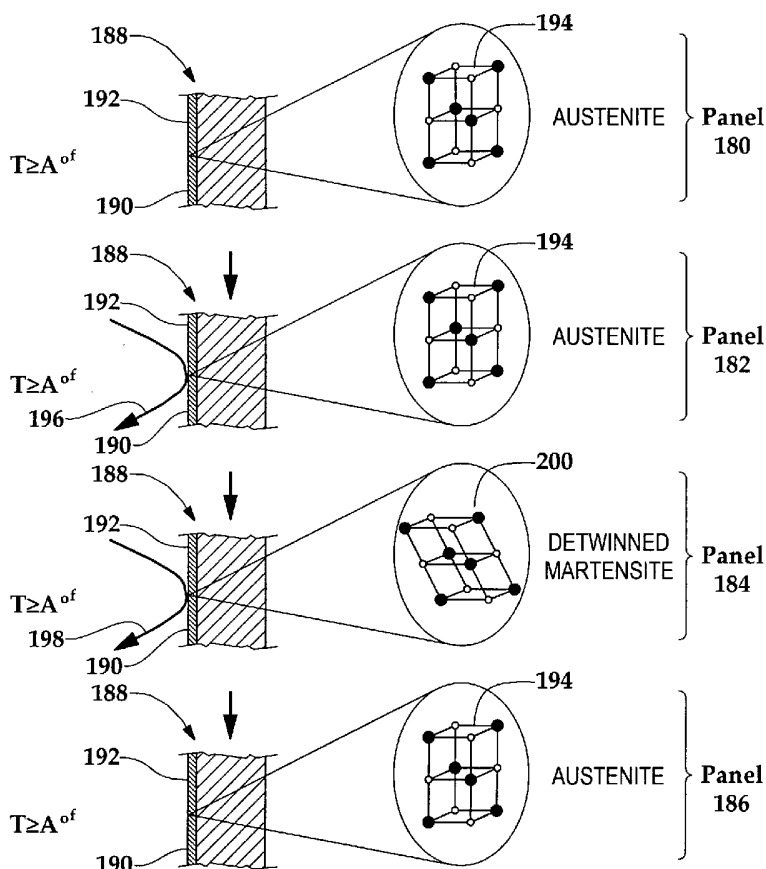
(30) Priority Data:
10/936,279 7 September 2004 (07.09.2004) US(71) Applicant (for all designated States except US): **HAL-
LIBURTON ENERGY SERVICE, INC.** [US/US]; 2901
Beltline Road, Carrollton, TX 75006-5401 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FRIPP, Michael**,
L. [US/US]; 3826 Cemetery Hill Road, Carrollton, TX
75007 (US). **HAMID, Syed** [US/US]; 7539 Bromwich
Court, Dallas, TX 75252 (US). **SCHULTZ, Roger**
[US/US]; 4792 Red Oak Circle, Aubrey, TX 76226 (US).**DAGENAIS, Peter** [US/US]; 4009 Heron Cove Lane,
The Colony, TX 75056 (US). **MICHAEL, Robert, Ken**
[US/US]; 12352 Patmos Lane, Frisco, TX 75034 (US).
SKINNER, Neal [US/US]; 1219 Indian Paint Trail,
Lewisville, TX 75067 (US).(74) Agent: **YOUST, Lawrence, R.**; Danamraj & Youst, P.C.,
5910 N. Central Expressway, Suite 1450, Dallas, TX 75206
(US).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,
KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA,
MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ,
OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL,
SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC,
VN, YU, ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,

[Continued on next page])

(54) Title: SHAPED MEMORY ALLOY FOR EROSION CONTROL OF DOWNHOLE TOOLS



(57) Abstract: A downhole fluid flow control device (188) and method for minimizing erosion are disclosed. The downhole fluid flow control device (188) includes a downhole surface (190) subjectable to an erosive stress (196, 198) which may be a moving fluid or an erosive agent, for example. A shaped memory alloy (192) is integrated with the downhole surface (190) in order to provide erosion resistance by reversibly transforming from an austenitic phase (194) to a martensitic phase (200) in response to the application of the erosive stress (196, 198). Further, the shape memory alloy (192) reversibly transforms from the martensitic phase (200) to the austenitic phase (192) in response to the presence of sufficient heat.



GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SHAPED MEMORY ALLOY FOR EROSION CONTROL OF DOWNHOLE TOOLS

5

TECHNICAL FIELD OF THE INVENTION

The present invention relates, in general, to preventing erosion of downhole tools positioned within a wellbore that traverses a subterranean hydrocarbon bearing formation and, in particular, to downhole tools having a shape memory alloy integrated therein to provide erosion resistance.

10

BACKGROUND OF THE INVENTION

Without limiting the scope of the invention, the background will describe surface controlled, subsurface safety valves, as an example.

15

Surface controlled, subsurface safety valves are commonly used to shut in oil and gas wells in the event of a failure or hazardous condition at the well surface. Such safety valves are typically fitted into the production tubing and operate to block the flow of formation fluid upwardly therethrough. The subsurface safety valve provides automatic shutoff of production flow in response to a variety of out of range safety conditions that can be sensed or indicated at the surface. For example, the safety conditions include a fire on the platform, a high or low flow line temperature or pressure condition or operator override.

20

During production, the subsurface safety valve is typically held open by the application of hydraulic fluid pressure conducted to the subsurface safety valve through an auxiliary control conduit which extends along the tubing string within the annulus between the tubing and the well casing. Flapper type subsurface safety valves utilize a closure plate which is actuated by longitudinal movement of a hydraulically actuated, tubular piston. The

25

flapper valve closure plate is maintained in the valve open position by an operator tube which is extended by the application of hydraulic pressure onto the piston. A pump at the surface pressurizes a reservoir which delivers regulated hydraulic control pressure through the control conduit. Hydraulic fluid is pumped into a variable volume pressure chamber and acts against the piston. When, for example, the production fluid pressure rises above or falls below a preset level, the control pressure is relieved such that the piston and operator tube are retracted to the valve closed position by a return spring. The flapper plate is then rotated to the valve closed position by a torsion spring or tension member in conjunction with fluid forces.

In conventional subsurface safety valves of the type utilizing an upwardly closing flapper plate, the flapper plate is seated against an annular sealing face, either in metal-to-metal contact or metal against an annular elastomeric seal. In one design, the valve seat and the upwardly closing flapper plate each having a sealing surface with a matched spherical radius of curvature. That is, the valve seat is a concave spherical segment and the sealing surface of the flapper plate is a convex spherical segment. In this arrangement, the spherical radius of curvature of the concave valve seat spherical segment is matched with the spherical radius of curvature of the convex spherical segment which defines the sealing surface on the flapper plate. The matching spherical surfaces are lapped together to provide a metal-to-metal seal along the interface between the nested convex and concave sealing surfaces.

It has been found, however, that even when using spherical sealing surfaces leakage may occur. Specifically, erosion of the concave valve seat spherical segment caused by an erosive stress may result in the loss of the ability to create a seal between sealing surfaces. These erosive stresses include moving fluids and erosive agents such as particulate matter. Therefore, a need has arisen for an erosion resistant material that can be used for the sealing surfaces of a subsurface safety valve. Additionally, a need has arisen for such an erosion

resistant material that can withstand erosive stresses such as moving fluids and erosive agents without exhibiting erosive wear.

SUMMARY OF THE INVENTION

5 The present invention disclosed herein comprises a downhole fluid flow control device and method for minimizing erosion that utilize an erosive resistant material for sealing surfaces. In particular, the erosion resistant material comprises a shape memory alloy that is capable of withstanding erosive stresses such as moving fluids and erosive agents without exhibiting excessive erosive wear.

10 In one aspect, the downhole fluid flow control device includes a downhole surface subjectable to an erosive stress which may be a moving fluid or an erosive agent, for example. A shaped memory alloy is integrated with the downhole surface in order to provide erosion resistance by reversibly transforming between an austenitic phase and a martensitic phase in response to the application of the erosive stress. Further, the shape
15 memory alloy reversibly transforms from the martensitic phase to the austenitic phase in response to the application of heat.

In one embodiment, the shape memory alloy reversibly transforms from a martensitic phase to an austenitic phase in response to application of a temperature $\geq A^{of}$. Alternatively, the shape memory alloy may be at a temperature $\geq A^{of}$ and reversibly
20 transform from an austenitic phase to a martensitic phase in response to application of the erosive stress. Thereafter, the shape memory alloy may reversibly transform from the martensitic phase to the austenitic phase in response to removal of the erosive stress.

In one embodiment, the shape memory alloy may include titanium nickel (TiNi) alloys, titanium carbon-titanium nickel (TiC-TiNi) composite alloys, copper zinc (CuZn)
25 alloys, copper zinc aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa) alloys, copper zinc tin (CuZnSn) alloys, copper zinc silicon (CuZnSi) alloys, iron platinum (FePt)

alloys, tribological engineering materials or the like. The shape memory alloy may have pseudoelastic recoverable strain between approximately 1.5% and approximately 8.5% and resistance to chemical corrosion equivalent to a 304-series stainless-steel.

The downhole surface including the shape memory alloy may form a portion of an assembly such as a back-pressure valve, a ball valve, a check valve, a circulation valve, a safety valve, an equalizing valve, a flapper valve, a foot valve, a frac valve, a gas-lift valve, gate valve, an isolation valve, an operating gas-lift valve, an orifice valve, a poppet valve, a reverse-circulating valve, a sliding sleeve, a standing valve, a subsurface safety valve, a traveling valve, a tubing-retrievable safety valve, wireline-retrievable safety valve or the like.

In a further aspect, the present invention is directed to a downhole tool that includes a downhole component having a surface subjectable to erosion. A shaped memory alloy is integrated with the surface in order to resist erosion by reversibly transforming between austenitic and martensitic phases.

In one embodiment, the downhole component may be a crossover, a blast joint, a sand screen, a valve, a nozzle, a choke, a wear surface of a vane, a pump piston, a turbine blade, a flow straightener, a flow mixer, an internal mandrel, a barrel slip, a flow diverter, a seal assembly, a shifting sleeve, a collet, a snap ring, a c-clamp on a ball valve, a landing nipple, a poppet, a rotor, a bearing, a race, a slickline wire, a tubular, a venturi or the like.

In another aspect, the present invention is directed to an oilfield tool that includes a component having a surface subjectable to erosion. A shaped memory alloy is integrated with the surface to provide resistance to erosion by reversibly transforming between austenitic and martensitic phases.

In one embodiment, the oilfield tool may be a casing valve, a master valve, a stabbing valve, a swab valve, a wing valve, a wellhead isolation tool, a pump jack component, a flow line, a vessel or the like.

In a further aspect, the present invention is directed to a method for minimizing erosion in a component. The method includes the steps of disposing the component, which includes a shape memory alloy integrated with a surface of the component, and exposing the shape memory alloy to a downhole stimuli that transforms at least a portion of the shape memory alloy from a first phase to a second phase. The first phase may be an austenitic phase or a martensitic phase and the second phase may be a martensitic phase or austenitic phase, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

Figure 1 is a schematic illustration of an offshore oil and gas platform performing completion operations wherein tools having a shape memory alloy of the present invention are advantageously deployed;

Figure 2 is a schematic illustration of an offshore oil and gas platform performing production operations wherein tools having a shape memory alloy of the present invention are advantageously deployed;

Figure 3A-3B are half sectional views of a subsurface safety valve in the open position utilizing a shape memory alloy of the present invention at its sealing surface;

Figure 4 is a cross sectional view of a flapper closure plate and seat in the valve closed position utilizing a shape memory alloy of the present invention at its sealing surface;

Figure 5 is a stress-temperature phase diagram illustrating phase transitions of a shape memory alloy of the present invention;

Figure 6 is a schematic illustration of a section of a tool having a shape memory alloy of the present invention integrated into a wear surface that is being subjected to an erosive stress and returning to its initial phase upon removal of the erosive stress;

Figure 7 is a schematic illustration of a section of a tool having a shape memory alloy of the present invention integrated into a wear surface that is being subjected to an erosive stress and returning to its initial phase upon application of heat; and

Figure 8 is a schematic illustration of a section of a tool having a shape memory alloy of the present invention integrated into a wear surface that is being subjected to an erosive stress following the application of heat.

DETAILED DESCRIPTION OF THE INVENTION

While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention and do not delimit the scope of the present invention.

Referring initially to figure 1, an offshore oil and gas platform performing completion operations is schematically illustrated and generally designated 10. A semi-submersible platform 12 is centered over a submerged oil and gas formation 14 located below sea floor 16. A subsea conduit 18 extends from deck 20 of platform 12 to wellhead installation 22 including blowout preventers 24. Platform 12 has a hoisting apparatus 26 and a derrick 28 for raising and lowering pipe strings such as completion string 30.

A wellbore 32 extends through the various earth strata including formation 14. A casing 34 is cemented within wellbore 32 by cement 36. Casing 34 has been perforated at formation 14 to create perforations 38 using perforating guns 40 which have been released into the rat hole of wellbore 32. Thereafter, completion string 30 has been lowered to locate

a sand control screen assembly 44 proximate to formation 14 such that a pair of seal assemblies 46 can isolate production from formation 14. Uphole of sand control screen assembly 44 is a cross-over 42 that allows for a treatment operation within the production interval at formation 14 such as a gravel pack, fracture stimulation, frac pack or the like.

5 Uphole of cross-over 42 is a fluid loss control valve 48 that prevents the loss of fluid from within completion string 30 to formation 14 during completion operations to other formations (not pictured) uphole of formation 14.

Also depicted within completion string 30 is a tubing test valve 50 that allows for the periodic pressure testing of completion string 30 during installation thereof. Completion

10 string 30 also includes a plurality of landing nipples, such as landing nipple 52, which is used to receive, for example, wireline set tools such as permanent and temporary bridge plugs as well as other types of flow control devices. A sliding side door valve 54 is also depicted within completion string 30. Sliding side door valve 54 may be used to selectively permit and prevent fluid communication between the interior of completion string 30 and the

15 wellbore annulus. Completion string 30 includes one or more subsurface safety valves, such as safety valve 56, that prevent out of control well conditions from traveling to the surface.

Many of these completion tools, as well as numerous other downhole tools such as drilling tools and production tools, may utilize downhole components having shape memory materials, such as shape memory alloys, phase changing ceramics and phase changing

20 polymers, for example, integrated at wear surfaces. For purposes of explanation and not by way of limitation, however, the shape memory material will be presented as a shape memory alloy. As an example, crossover 42 is subjected to significant volumes of high velocity slurry during treatment operations which commonly result in erosive wear. Utilizing a shape memory alloy of the present invention for these wear surfaces, however, minimizes or

25 prevents such erosive wear. Likewise, the other components through which the slurry is pumped are also subjected to the erosive stress. Accordingly, fluid loss control valve 48,

tubing test valve 50, sliding side door valve 54, subsurface safety valve 56 as well as numerous other valving and flow control devices may utilize shape memory alloy components to minimize or prevent erosive wear, whether the erosive wear is caused by an erosive agent, such as particulars, or friction between components, for example. By way of example, these other devices may include blast joints, sand screens, nozzles, chokes, wear surfaces of vanes, pump pistons, turbine blades, flow straighteners, flow mixers, internal mandrels, barrel slips, flow diverters, shifting sleeves, collets, snap rings, c-clamps on ball valves, landing nipples, poppets, rotors, bearings (e.g., bearing surfaces in journal bearings and thrust bearings), races, slickline wires, tubulars or venturis. As will be explained in further detail hereinbelow, the shape memory alloy components of the downhole tools resist erosion by reversibly transforming from an austenitic phase to a martensitic phase in response to the application of the erosive stress. Rather than wear, shape memory alloy components absorb the stress erosion by reversibly transforming or reversibly transitioning phase.

Referring next to figure 2, offshore oil and gas platform 10 is depicted during production operations. Disposed within casing 34 and extending from wellhead 60 is a production tubing 40. During production, formation fluids enter wellbore 32 through perforations 38 of casing 34 and travel into production tubing string 40 through sand control screen assembly 44 to wellhead 60 that is installed on deck 20. Wellhead 60 includes numerous valves such as lower master valve 61 and upper master valve 63 which provide redundant surface isolation. Additionally, wellhead 60 includes a wing valve 65 and swab valve 67. A flowline 69 connects wellhead 60 to vessel 71 wherein production fluid brought up from formation 14 may be processed. Many of surface production tools may utilize the shape memory alloys of the present invention. For example, in addition to the valves described hereinabove, flowline 69 and vessel 71 may utilize the shape memory alloy of the present invention at wear surfaces such as elbows or other transition regions. Other oilfield

equipment that may utilize the shape memory alloys include casing valves, stabbing valves and pump jack components, for example. In addition, various downhole production tools may also benefit from the shape memory alloy of the present invention such as downhole choke 73, downhole turbine 75, gas lift valve 77, landing nipple 79, subsurface safety valve 56 and the like. Further, although completion and production operations have been depicted in figures 1 and 2, it should be appreciated that the shape memory alloy of the present invention may be utilized with components of drilling operations as well.

Referring now to figures 3A and 3B, subsurface safety valve 56 is illustrated in further detail. Safety valve 56 has a relatively larger production bore and is, therefore, intended for use in high flow rate wells. Safety valve 56 is connected directly in series with production tubing 40. Control conduit 62 provides hydraulic control pressure to longitudinal bore 64 formed in the sidewall of the top connector sub 66. Pressurized hydraulic fluid is delivered through the longitudinal bore 64 into an annular chamber 68 defined by a counterbore 70 which is in communication with an annular undercut 72 formed in the sidewall of the top connector sub 66. An inner housing mandrel 74 is slidably coupled and sealed to the top connector sub 66 by a slip union 76 and seal 78, with the undercut 72 defining an annulus between inner mandrel 74 and the sidewall of top connector sub 66.

A piston 80 is received in slidable, sealed engagement against the internal bore of inner mandrel 74. The undercut annulus 72 opens into a piston chamber 82 in the annulus between the internal bore of a connector sub 86 and the external surface of piston 80. The external radius of an upper sidewall piston section 84 is machined and reduced to define a radial clearance between piston 80 and connector sub 86. An annular sloping surface 88 of piston 80 is acted against by the pressurized hydraulic fluid delivered through control conduit 62. In figures 3A-3B, piston 80 and operator tube 94 are fully extended with the lower shoulder of operator tube 94 engaging an annular face of bottom subconnector 106. In this valve open position, a return spring 96 is fully compressed.

In the illustrated embodiment, a flapper plate 98 is pivotally mounted onto a hinge sub 100 which is threadably connected to the lower end of spring housing 102. A valve seat 104 is confined within a counterbore formed on hinge sub 100. The lower end of safety valve 56 is connected to production tubing 40 by a bottom sub connector 106. The bottom sub connector 106 has a counterbore 108 which defines a valve chamber 110. Thus, the bottom sub connector 106 forms a part of the valve housing enclosure. Flapper plate 98 pivots about pivot pin 112 and is biased to the valve closed position by spring 114. In the valve open position as shown in figures 3A-3B, the spring bias force is overcome and flapper plate 98 is retained in the valve open position by operator tube 94 to permit formation fluid flow up through tubing 40.

During operation, when an out of range condition occurs and subsurface safety valve 56 must be operated from the valve open position to the valve closed position, hydraulic pressure is released from conduit 62 such that return spring 96 acts on the lower end of piston 80 which retracts operator tube 94 longitudinally through valve chamber 110. Flapper closure plate 98 will then rotate through chamber 110 to effectuate the valve closure. Further, it is necessary to have a complete seal between flapper closure plate 98 and valve seat 104, which is subjected to considerable erosive stress in the form of upward moving fluids having particulate matter. Valve seat 104 includes a sealing surface 116 having integrated therewith a shape memory alloy of the present invention in order to resist erosion by absorbing the erosive stresses and reversibly transforming phases.

Referring next to figure 4, therein is depicted the sealing elements of a valve that is generally designated 120. Valve 120 has valve closure member shown as a flapper closure plate 122, which has a convex flapper closure plate sealing surface 124. Additionally, valve 120 includes a valve seat 126 which has concave valve seat sealing surface 128. It should be appreciated that concave sealing surface 128 of valve seat 126 has a radius of curvature that is substantially equal to that of convex flapper closure plate sealing surface 124. As

previously discussed, valve seat 126 includes a shape memory alloy layer 130 in order to resist erosion and maintain the radius of curvature necessary to create an effective seal with flapper closure plate sealing surface 124.

While a particular type of flow control device has been described with respect to figure 4, it should be appreciated that the shape memory alloys of the present invention may be used with other types of valves. For example, the shape memory alloys of the present invention may be utilized with back-pressure valves, ball valves, check valves, circulation valves, equalizing valves, foot valves, frac valves, gas-lift valves, gate valves, isolation valves, orifice valves, poppet valves, reverse-circulating valves, sliding sleeves, standing valves, traveling valves, tubing-retrievable safety valves and wireline-retrievable safety valves, for example. Use of the shape memory alloys of the present invention as the wear surfaces of any of these flow control devices will provide for shape memory effect and superelastic responses to impingement of sand or other particulate matter, thus providing increased wear-resistance.

Referring now to figure 5, therein is depicted a stress-temperature phase diagram illustrating phase transitions of the shape memory alloy of the present invention. The x-axis is temperature (T) and the y-axis is stress (σ). In general, shape memory alloys are metallic alloys that exist in two phases and display both thermal and mechanical memory. By way of example, a titanium nickel (TiNi) shape memory alloy is represented in each of the crystal lattice structure phases. It should be appreciated that other shape memory alloys are within the teachings of the present invention. For example, the shape memory alloy may include titanium carbon-titanium nickel (TiC-TiNi) composite alloys, copper zinc (CuZn) alloys, copper zinc aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa) alloys, copper zinc tin (CuZnSn) alloys, copper zinc silicon (CuZnSi) alloys, iron platinum (FePt) alloys and the like. Additionally, the shape memory may include tribological engineering materials such as nickel (Ni)-based and cobalt (Co)-based tribo-alloys.

An austenitic phase, depicted as austenite 152, is a high-temperature phase in which the shape memory alloy displays a high-symmetry, usually cubic crystal lattice structure. The martensitic phase is a low temperature phase in which the shape memory alloy displays a low-symmetry, monoclinic variant crystal lattice structure. As a low-symmetry lattice structure, martensite includes several variants such as detwinned martensite 154 and twinned martensite 156. A martensitic phase transformation characterizes the phase transformations between martensite and austenite. As those skilled in the art will appreciate, the martensitic phase transformation includes a shear-dominant diffusionless solid-state phase transformation that occurs by nucleation and growth. More specifically, the martensitic phase transformation possesses several well-defined characteristics. The phase transformation is associated with an inelastic deformation of the crystal lattice that results from a cooperative and collective motion of atoms on distances smaller than the lattice parameters. Accordingly, the phase transformation is substantially instantaneous and characterized by an absence of diffusion. Both phases of the shape memory alloy, however, can coexist during the phase transformation. An invariant plane having well defined mutual orientation relationships, which are alloy specific, partitions the phases from one another.

As illustrated in the stress-temperature phase diagram, the austenite-to-martensite phase transformation occurs once the free energy of martensite becomes less than the free energy of austenite at a temperature below a critical temperature T_0 (not illustrated) at which the free energies of the two phases are equal. The phase transformation does not begin exactly at the critical temperature T_0 , however. In the absence of stress, the phase transformation begins at a martensite start temperature, denoted M^{0s} 158, which is less than T_0 , and continues to evolve as the temperature is lowered until a martensite finish temperature, denoted M^{0f} 160, is reached.

Similarly, when the shape memory alloy is heated in the absence of stress from martensite, the martensite-to-austenite phase transformation begins at a austenite start

temperature, denoted A^{0s} 162, and the material is fully austenite at an austenite finish temperature, denoted A^{0f} 164. Hence, the martensite-to-austenite transformations exhibit a hysteresis and a dependence on the direction of the temperature change. Moreover, the difference between the transition temperatures is related to the critical temperature, T_0 , which may be approximated as follows:

$$(M^{0s} + A^{0f})/2$$

Shape memory alloys exhibit the shape memory effect during austenite-to-martensite-to-austenite loading paths. More specifically, when a stress or load is applied to the shape memory alloy, the shape memory alloy is transformed from austenite to martensite. Upon a subsequent heating to a temperature $\geq A^{0f}$, the shape memory alloy returns to austenite. Shape memory alloy also exhibits pseudoelasticity, which is a property that is similar to the shape memory effect and encompasses both superelastic and rubberlike behavior. More particularly, when a stress or load is applied to the shape memory alloy, the shape memory alloy is transformed from austenite to martensite. Upon a subsequent heating to a temperature $\geq A^{0s}$, a partial strain recovery of the shape memory alloy occurs. The phase transformations of the shape memory alloy are the basis for the shape memory effect and pseudoelasticity properties that make the shape memory alloy resistant to erosive stresses.

Additional properties, such as thermal stability and corrosion resistance, of shape memory alloys are presented in the following table wherein a Titanium nickel (TiNi) alloy is presented by way of example:

Table 1: Physical Properties of TiNi

Property	Austenite	Martensite
Melting Temperature, °C	1300	1300
Density, g/cm ³	6.45	6.45
Resistivity, $\mu\Omega/\text{cm}$	Approx. 100	Approx. 70
Thermal Conductivity, W°C/cm	18	8.5
Corrosion Resistance	Similar to 300 series stainless steel or titanium alloys	Similar to 300 series stainless steel or titanium alloys
Yield Strength, Mpa (ksi)	195 to 690 (28 to 100)	70 to 140 (10 to 20)
Ultimate Tensile Strength, Mpa (ksi)	895 (130)	895 (130)
Transformation Temperatures, °C	-200 to 110	-200 to 110
Latent Heat of Transformation, KJ atom/kg (cal atom/g)	167 (40)	167 (40)
Shape Memory Strain	Approx. 1.5 to Approx. 8.5%	Approx. 1.5 to Approx. 8.5%

The properties of the shape memory material may be further influenced by cold working the material which refines the grain size and orients the direction of the grains, thereby improving the crystallographic orientation of the grains and the erosion behavior. Cold working may be done when the material is in a billet form, a partially formed shape (e.g., sheet form) or after the final shaping of the material has been accomplished.

Referring now to figure 6, therein is depicted an austenite-to-martensite-to-austenite shape memory alloy phase transformation in panels 180 through 186. As illustrated in panel 180, a tool 188, such as the downhole fluid flow control device illustrated in figures 3A, 3B and 4, includes a surface 190 having a shape memory material, such as shape memory alloy

"192, integrated therewith." While the shape memory alloy 192 is depicted as a layer on surface 190 for purposes of explanation, it should be appreciated by those skilled in the art that shape memory alloy 192 may form the entire component and not just the surface of tool 188. Initially, an ambient temperature $\geq A^{of}$ is present about tool 188 as indicated by the expression $T \geq A^{of}$. Accordingly, as previously discussed, at temperature $\geq A^{of}$, shape memory alloy 192 is in austenitic phase as represented by austenite 194 in the enlarged representation of shape memory alloy 192. In panel 182, tool 188 and, in particular, shape memory alloy 192 is subjected to an erosive stress as represented by arrow 196. As previously discussed, the erosive stress may be a moving fluid, erosive agent such as particulate matter or mechanical stress that causes erosion by friction. In panel 184, the erosive stress is continuing as indicated by arrow 198. Further, the sustained erosive stress is sufficient to transform the phase of shape memory alloy 192 from austenite 194 to detwinned martensite 200. In particular implementations, it should be appreciated that the sustained erosive stress generates heat which furthers the phase transformation in accordance with the transition diagram presented in figure 5. In panel 186, the erosive stress is concluded and the ambient temperature $\geq A^{of}$ persists proximate to tool 188. The ambient temperature heats shape memory alloy 192 to a temperature $\geq A^{of}$, thereby returning shape memory alloy 192 to austenite 194. Hence, tool 188 having shape memory alloy 192 absorbed erosive stress without exhibiting erosive wear by executing a reversible phase transformation.

Referring now to figure 7, therein is depicted an austenite-to-martensite-to-austenite shape memory alloy phase transformation in panels 200 through 208. As illustrated in panel 200, a tool 210 includes a surface 212 having a shape memory alloy 214 integrated therewith that is subjected to erosion. Initially, shape memory alloy 214 is austenite 216 and shape memory alloy 214 is being subjected to an erosive stress as represented by arrow 218. In panel 202, the erosive stress continues as indicated by arrow 220. The continued stress

transforms shape memory alloy 214 from austenite 216 to detwinned martensite 222. In panel 204, the erosive stress has stopped and shape memory alloy 214 remains in martensitic phase 222. Further, as illustrated, a heat source 224 applies heat 226 to shape memory alloy 214 in order to heat the shape memory alloy and effectuate the martensite-to-austenite transformation. The heat source may be a power generator, friction heater, electric line, fuel generator, resistance heater, radioactive source or other downhole or surface heat source. In panel 208, the temperature of shaped memory alloy 214 has been increased to a temperature $\geq A^{of}$ and martensite 222 has transformed into austenite 216.

Referring now to figure 8, therein is depicted a martensite-to-austenite-to-martensite-to-austenite-to-martensite shape memory alloy phase transformation in panels 230 through 240. More particularly, a tool 242 includes a surface 244 having a shape memory alloy 246 that is subject to erosive stress. Initially, shape memory alloy 246 is detwinned martensite 248 in an environment having a temperature $\leq M^{of}$. In panel 232, a heat source 250 applies heat 252 in order to raise the temperature to a temperature $\geq A^{of}$ and transform detwinned martensite 248 to austenite 254, which is depicted in panel 234. In one embodiment, heat source 250 may be utilized periodically to remove residual stress that accumulates from excessive stress such as erosion.

In addition to heating, it should be appreciated that in certain situations it may be desirable to cool shape memory alloy 246 as well using a refrigerator with thermal cycles or solid state thermoelectric device, for example. In one implementation, a dissolvable component may be used and it may be desirable to erode the component. For example, if the ambient temperature is higher than the phase transformation temperature of the dissolvable component having a shape memory material in accordance with the present invention, the dissolvable component may be cooled to effectuate a phase transformation and the dissolution of the component

Furthermore, in panel 234, tool 242 is subjected to an erosive stress, as indicated by arrow 256, which continues in panel 236, as indicated by arrow 258. The continued erosive stress has transformed the austenite 254 to detwinned martensite 248. In panel 238, the erosive stress has ceased and the temperature of tool 242 is above A^{of} . Hence, the detwinned
5 martensite 248 transforms into austenite 254. In panel 240, the temperature has fallen to less than M^{of} and austenite 254 returns to detwinned martensite 248.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the
10 invention, will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

- 1 1. A downhole fluid flow control device comprising:
2 a downhole surface subjectable to an erosive stress; and
3 a shaped memory alloy integrated with the downhole surface, the shape memory
4 material operable to provide erosion resistance.
- 1 2. The downhole fluid flow control device as recited in claim 1 wherein the
2 shaped memory alloy is operable to reversibly transform between austenitic and martensitic
3 phases responsive to the erosive stress and temperature.
- 1 3. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material reversibly transforms from an austenitic phase to a martensitic phase
3 in response to application of the erosive stress.
- 1 4. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material reversibly phase transforms responsive to erosive stress and
3 temperature.
- 1 5. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material reversibly transforms from a martensitic phase to an austenitic phase
3 in response to application of a temperature $\geq A^{0f}$.
- 1 6. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material is at a temperature $\geq A^{0f}$ and reversibly transforms from an
3 austenitic phase to a martensitic phase in response to application of the erosive stress.

1 7. The downhole fluid flow control device as recited in claim 6 wherein the
2 shape memory material reversibly transforms from the martensitic phase to the austenitic
3 phase in response to removal of the erosive stress.

1 8. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material comprises an alloy selected from the group consisting of titanium
3 nickel (TiNi) alloys, titanium carbon-Titanium nickel (TiC-TiNi) composite alloys, copper
4 zinc (CuZn) alloys, copper zinc aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa)
5 alloys, copper zinc tin (CuZnSn) alloys, copper zinc silicon (CuZnSi) alloys, iron platinum
6 (FePt) alloys and tribological engineering materials.

1 9. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material has pseudoelasticity recoverable strain between approximately 1.5%
3 and approximately 8.5%.

1 10. The downhole fluid flow control device as recited in claim 1 wherein the
2 shape memory material has resistance to chemical corrosion equivalent to a 304-series
3 stainless-steel.

1 11. The downhole fluid flow control device as recited in claim 1 wherein the
2 downhole surface and shape memory material form a portion of an assembly selected from
3 the group consisting of back-pressure valves, ball valves, check valves, circulation valves,
4 safety valves, equalizing valves, flapper valves, foot valves, frac valves, gas-lift valves, gate
5 valves, isolation valves, operating gas-lift valves, orifice valves, poppet valves, reverse-
6 circulating valves, sliding sleeves, standing valves, subsurface safety valves, traveling
7 valves, tubing-retrievable safety valves and wireline-retrievable safety valves.

1 12. The downhole fluid flow control device as recited in claim 1 wherein the
2 erosive stress comprises a moving fluid.

1 13. The downhole fluid flow control device as recited in claim 1 wherein the
2 erosive stress comprises an erosive agent.

1 14. The downhole fluid flow control device as recited in claim 1 wherein the
2 erosive stress comprises friction.

1 15. A downhole tool comprising:
2 a downhole component having a surface subjectable to erosion; and
3 a shaped memory alloy integrated with the surface, the shape memory material
4 operable to resist erosion by reversibly transforming between austenitic and martensitic
5 phases.

1 16. The downhole tool as recited in claim 15 wherein the shape memory material
2 reversibly transforms from an austenitic phase to a martensitic phase in response to
3 application of an erosive stress.

1 17. The downhole tool as recited in claim 15 wherein the shape memory material
2 reversibly transforms from a martensitic phase to an austenitic phase in response to a
3 temperature $\geq A^{0f}$.

1 18. The downhole tool as recited in claim 15 wherein the shape memory material
2 is at a temperature $\geq A^{0f}$ and reversibly transforms from an austenitic phase to a martensitic
3 phase in response to application of an erosive stress.

1 19. The downhole tool as recited in claim 18 wherein the shape memory material
2 reversible transforms from the martensitic phase to the austenitic phase in response to
3 removal of the erosive stress.

1 20. The downhole tool as recited in claim 15 wherein the shape memory material
2 comprises an alloy selected from the group consisting of titanium nickel (TiNi) alloys,
3 titanium carbon-titanium nickel (TiC-TiNi) composite alloys, copper zinc (CuZn) alloys,
4 copper zinc aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa) alloys, copper zinc
5 tin (CuZnSn) alloys, copper zinc silicon (CuZnSi) alloys, iron platinum (FePt) alloys and
6 tribological engineering materials.

1 21. The downhole tool as recited in claim 15 wherein the shape memory material
2 has pseudoelasticity recoverable strain between approximately 1.5% and approximately
3 8.5%.

1 22. The downhole tool as recited in claim 15 wherein the shape memory material
2 has resistance to chemical corrosion equivalent to a 304-series stainless-steel.

1 23. The downhole tool as recited in claim 15 wherein a moving fluid creates an
2 erosive stress.

1 24. The downhole tool as recited in claim 15 wherein an erosive agent creates an
2 erosive stress.

1 25. The downhole tool as recited in claim 15 wherein friction creates an erosive
2 stress.

1 26. The downhole tool as recited in claim 15 wherein the downhole component is
2 selected from the group consisting of crossovers, blast joints, sand screens, valves, nozzles,
3 chokes, wear surfaces of vanes, pump pistons, turbine blades, flow straighteners, flow
4 mixers, internal mandrels, barrel slips, flow diverters, seal assemblies, shifting sleeves,
5 collets, snap rings, c-clamps on ball valves, landing nipples, poppets, rotors, bearings, races,
6 slickline wires, venturis and tubulars.

1 27. An oilfield tool comprising:
2 a component having a surface subjectable to erosion; and
3 a shaped memory alloy integrated with the surface, the shape memory material
4 operable to resist erosion by reversibly transforming between austenitic and martensitic
5 phases.

1 28. The oilfield tool as recited in claim 27 wherein the shape memory material
2 reversibly transforms from an austenitic phase to a martensitic phase in response to
3 application of an erosive stress.

1 29. The oilfield tool as recited in claim 27 wherein the shape memory material
2 reversibly transforms from a martensitic phase to an austenitic phase in response to a
3 temperature $\geq A^{0f}$.

1 30. The oilfield tool as recited in claim 27 wherein the shape memory material is
2 at a temperature $\geq A^{0f}$ and reversibly transforms from an austenitic phase to a martensitic
3 phase in response to application of an erosive stress.

1 31. The oilfield tool as recited in claim 30 wherein the shape memory material
2 reversible transforms from the martensitic phase to the austenitic phase in response to
3 removal of the erosive stress.

1 32. The oilfield tool as recited in claim 27 wherein the shape memory material
2 comprises an alloy selected from the group consisting of titanium nickel (TiNi) alloys,
3 titanium carbon-titanium nickel (TiC-TiNi) composite alloys, copper zinc (CuZn) alloys,
4 copper zinc aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa) alloys, copper zinc
5 tin (CuZnSn) alloys, copper zinc silicon (CuZnSi) alloys, iron platinum (FePt) alloys and
6 tribological engineering materials.

1 33. The oilfield tool as recited in claim 27 wherein the shape memory material
2 has pseudoelasticity recoverable strain between approximately 1.5% and approximately
3 8.5%.

1 34. The oilfield tool as recited in claim 27 wherein the shape memory material
2 has resistance to chemical corrosion equivalent to a 304-series stainless-steel.

1 35. The oilfield tool as recited in claim 27 wherein a moving fluid creates an
2 erosive stress.

1 36. The oilfield tool as recited in claim 27 wherein an erosive agent creates an
2 erosive stress.

1 37. The oilfield tool as recited in claim 27 wherein friction creates an erosive
2 stress.

1 38. The oilfield tool as recited in claim 27 wherein the component is selected
2 from the group consisting of casing valves, master valves, stabbing valves, swab valves,
3 wing valves, wellhead isolation tools, pump jack components, flow lines and vessels.

1 39. A method for controlling erosion in a component comprising the steps of:
2 disposing the component downhole, the component including a shape memory
3 material integrated with a surface of the component; and
4 exposing the shape memory material to a downhole stimuli that transforms at least a
5 portion of the shape memory material from a first phase to a second phase.

1 40. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to particulate impact that transforms the at least a portion of the shape
4 memory material from an austenitic phase to a martensitic phase.

1 41. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to a moving fluid that transforms the at least a portion of the shape
4 memory material from an austenitic phase to a martensitic phase.

1 42. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to an erosive stress that transforms the at least a portion of the shape
4 memory material from an austenitic phase to a martensitic phase.

1 43. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to friction that transforms the at least a portion of the shape memory
4 material from an austenitic phase to a martensitic phase.

1 44. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to temperature $\geq A^{of}$ that transforms the at least a portion of the shape
4 memory material from a martensitic phase to an austenitic phase.

1 45. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to the downhole stimuli further comprises the step of exposing the shape
3 memory material to a temperature $\leq M^{of}$ that transforms the at least a portion of the shape
4 memory material from an austenitic phase to a martensitic phase.

1 46. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to a downhole stimuli further comprises the step of exposing the shape
3 memory material to a combination of temperature and stress that transforms the at least a
4 portion of the shape memory material from the first phase to the second phase.

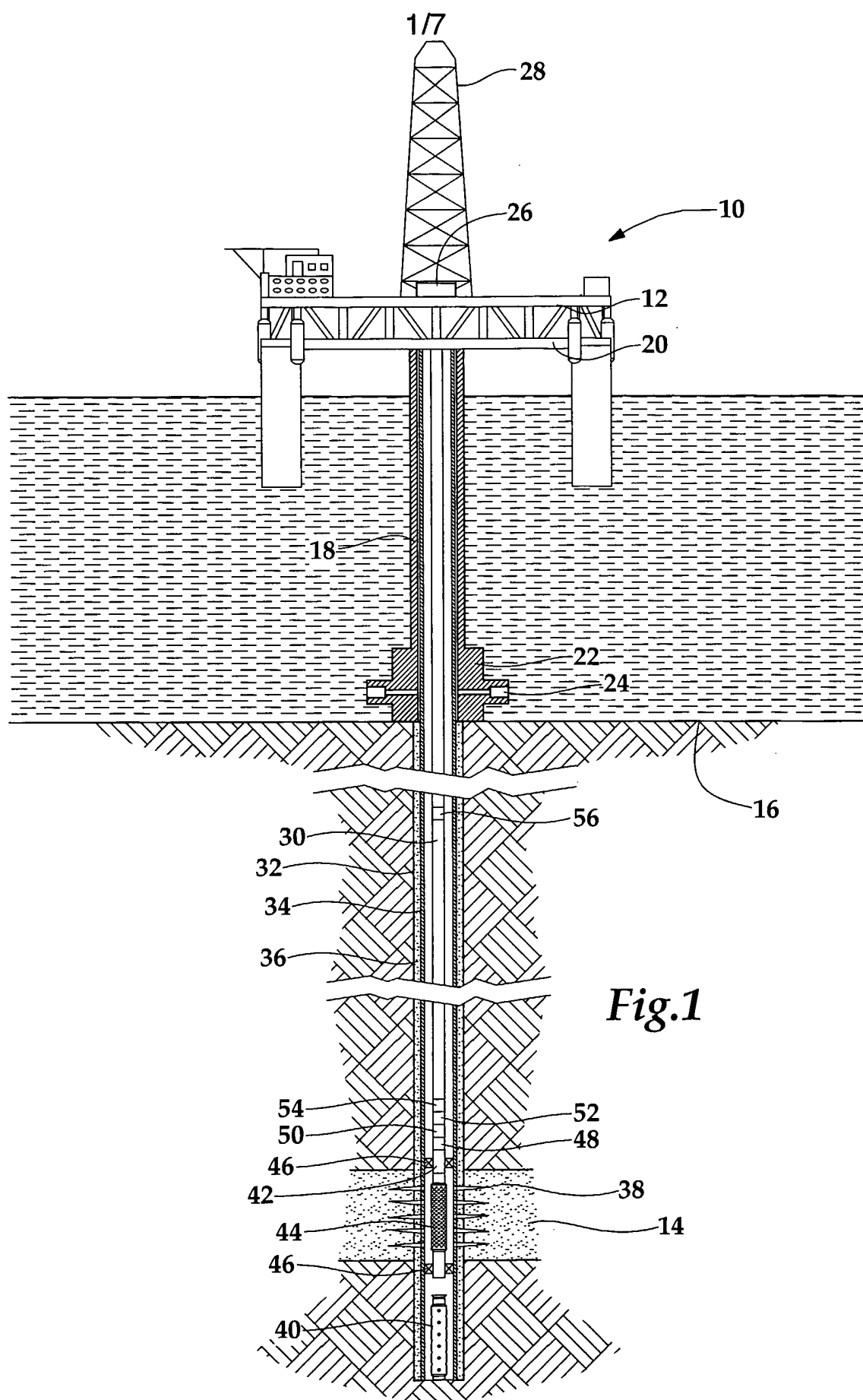
1 47. The method as recited in claim 39 further comprising the step of exposing the
2 shape memory material to another downhole stimuli that transforms the at least a portion of
3 the shape memory material from the second phase to the first phase.

1 48. The method as recited in claim 39 further comprising the step of exposing the
2 shape memory material to temperature $\geq A^{of}$ that transforms the at least a portion of the
3 shape memory material from the second phase to the first phase.

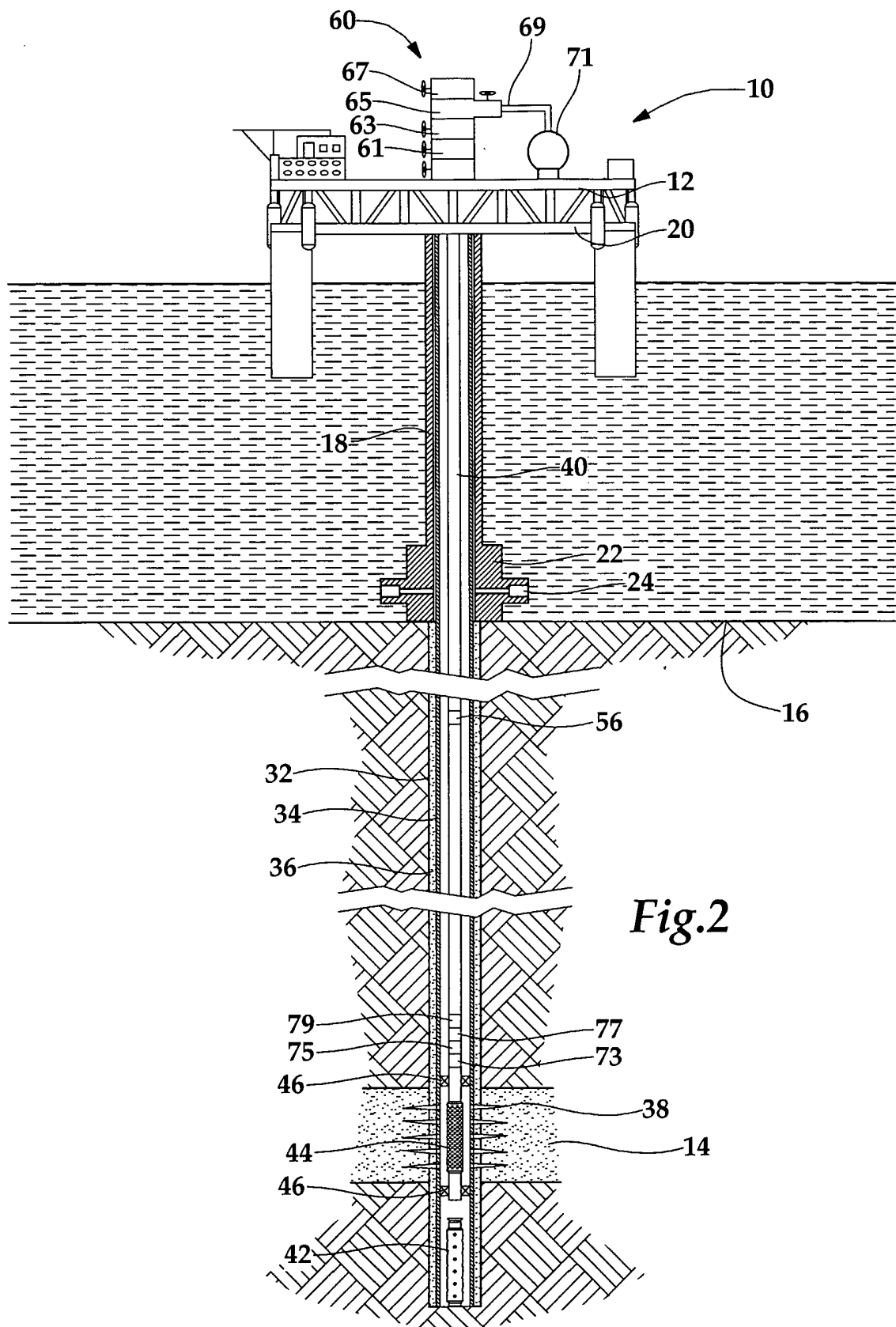
1 49. The method as recited in claim 39 further comprising the step of removing
2 the downhole stimuli to transform the at least a portion of the shape memory material from
3 the second phase to the first phase.

1 50. The method as recited in claim 39 further comprising the step of selecting the
2 shape memory material from the group consisting of titanium nickel (TiNi) alloys, titanium
3 carbon-titanium nickel (TiC-TiNi) composite alloys, copper zinc (CuZn) alloys, copper zinc
4 aluminum (CuZnAl) alloys, copper zinc gallium (CuZnGa) alloys, copper zinc tin (CuZnSn)
5 alloys, copper zinc silicon (CuZnSi) alloys, iron platinum (FePt) alloys and tribological
6 engineering materials.

1 51. The method as recited in claim 39 wherein the step of exposing the shape
2 memory material to a downhole stimuli further comprises the step of displaying
3 pseudoelasticity recoverable strain between approximately 1.5% and approximately 8.5%.



2/7



3/7

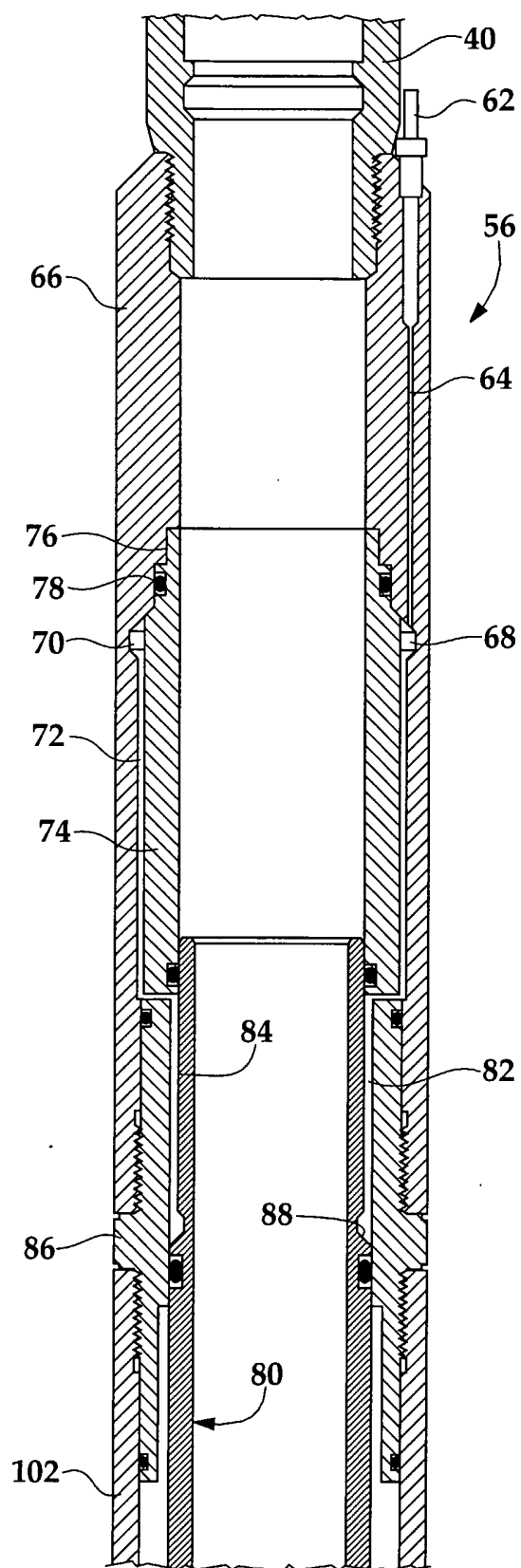


Fig.3A

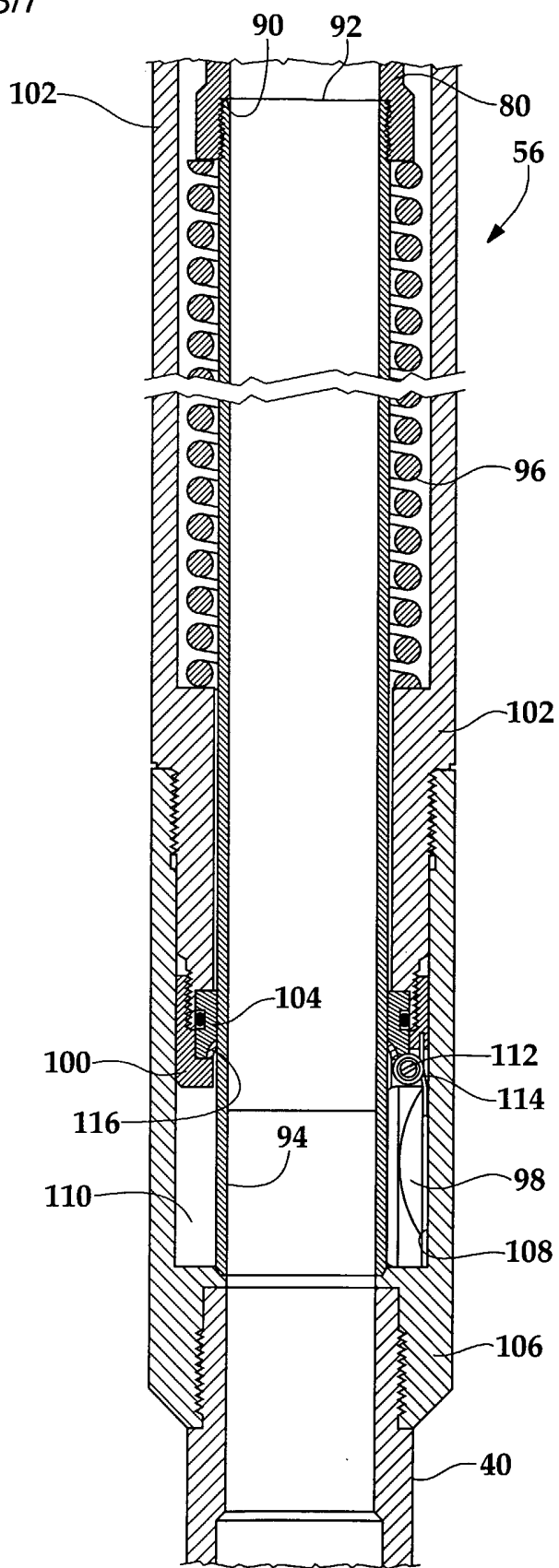


Fig.3B

417

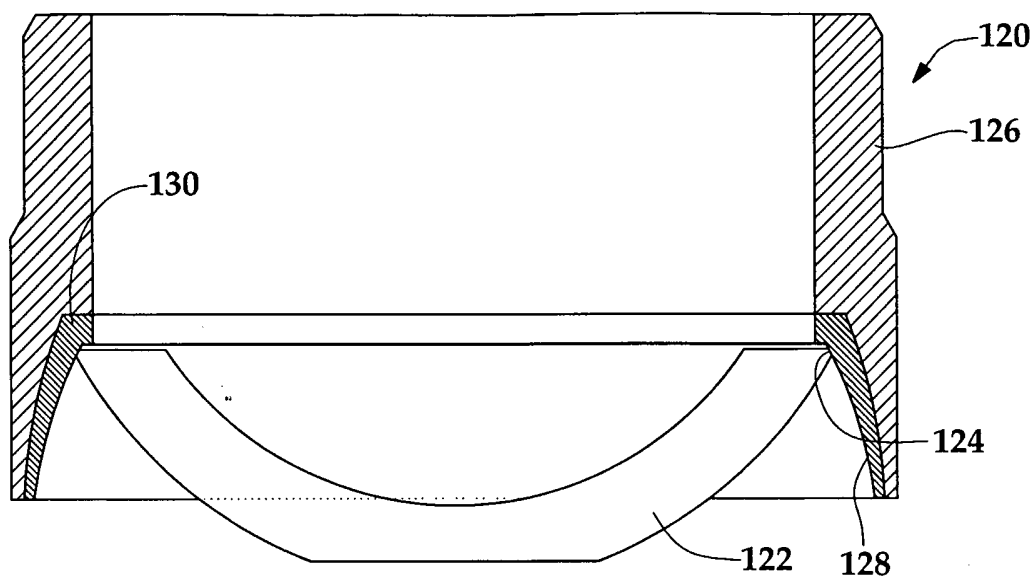
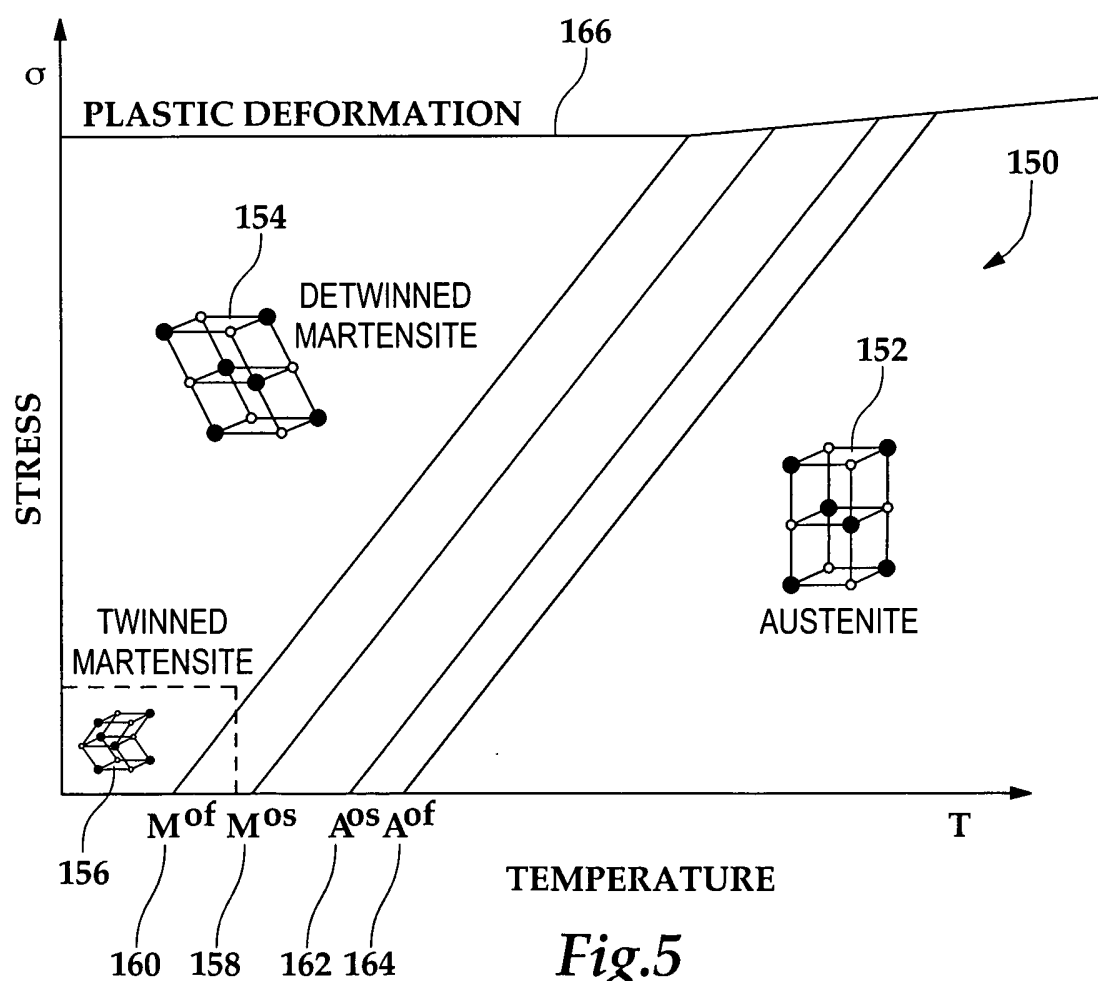
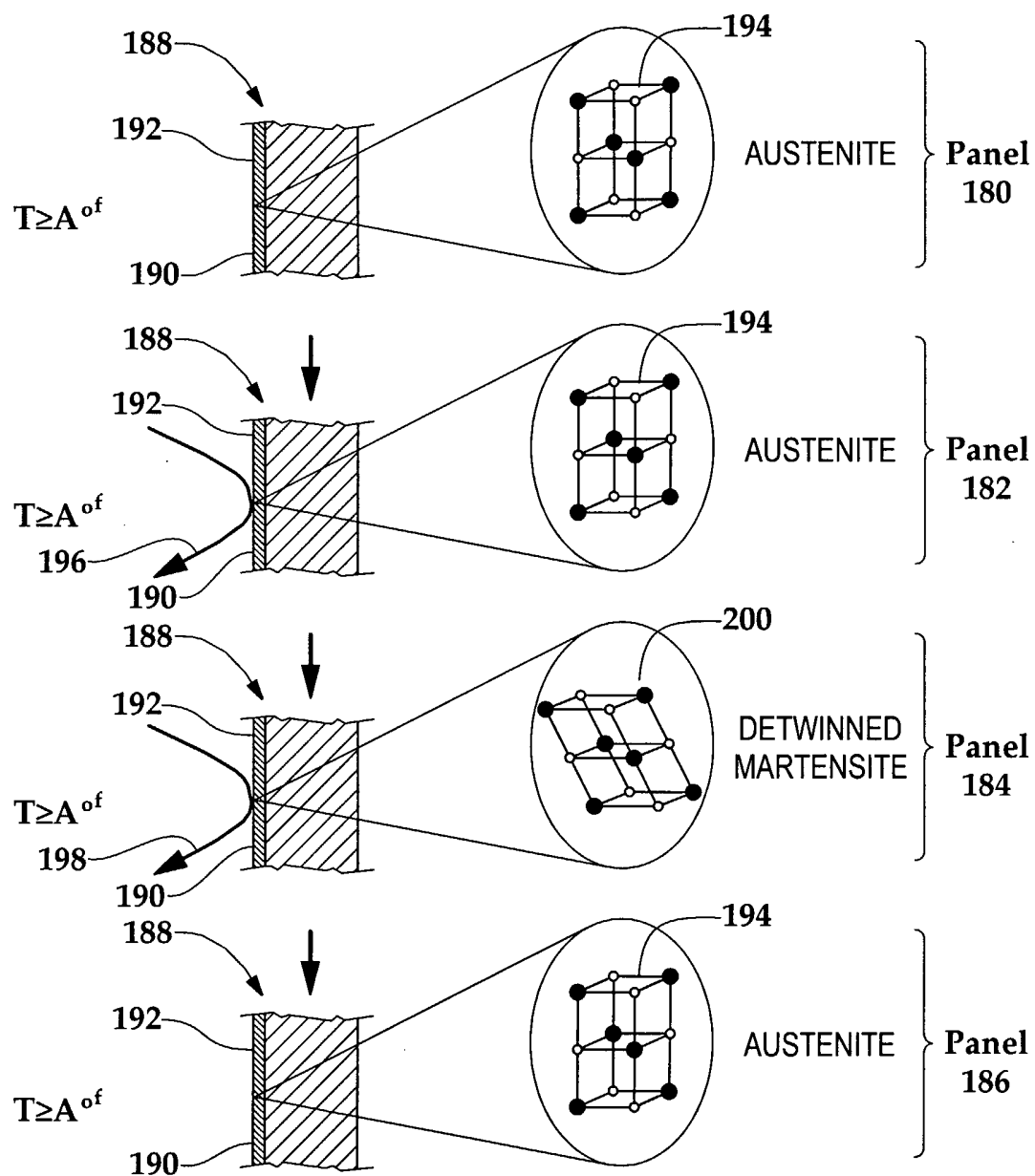


Fig.4



5/7

*Fig.6*

6/7

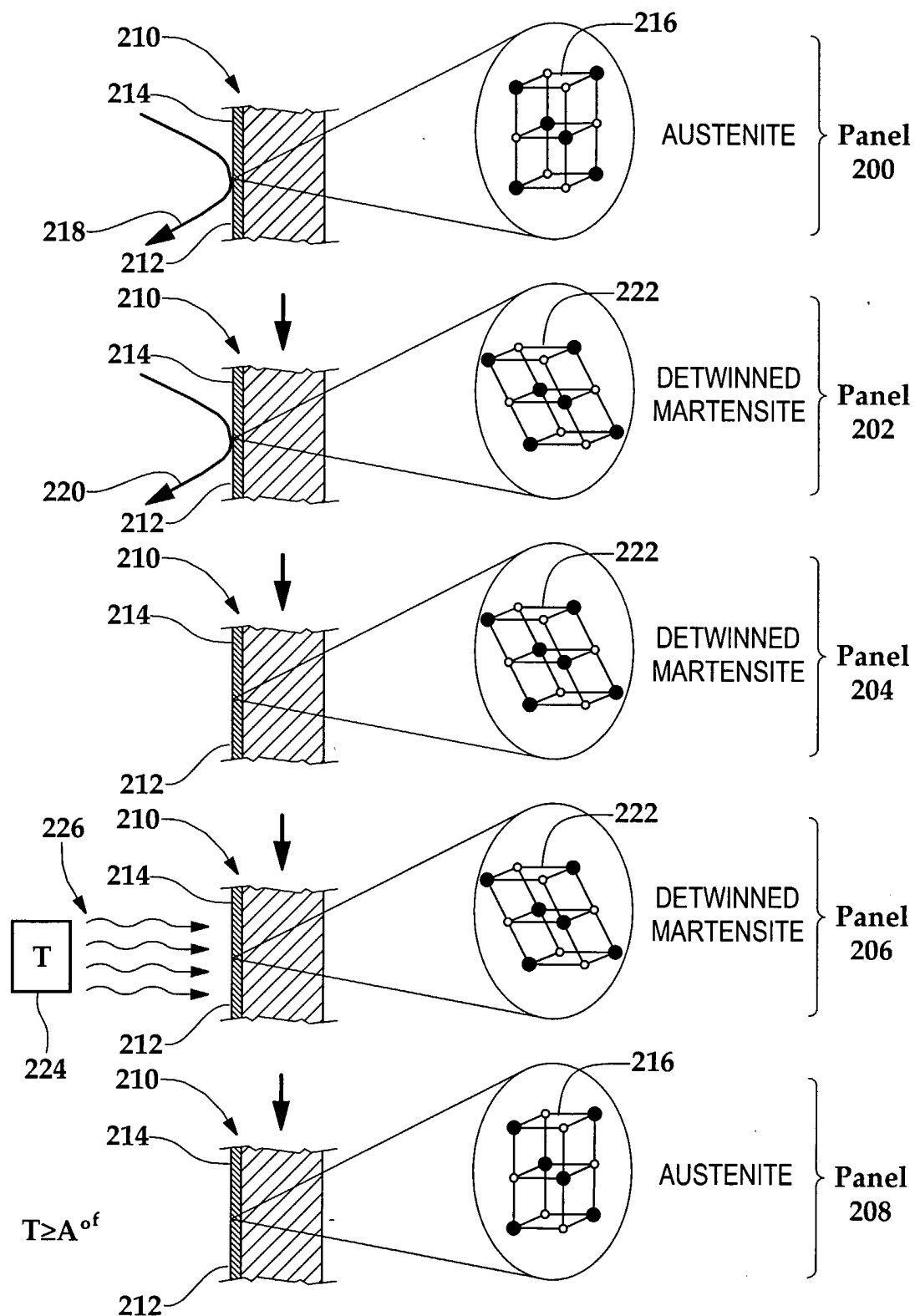
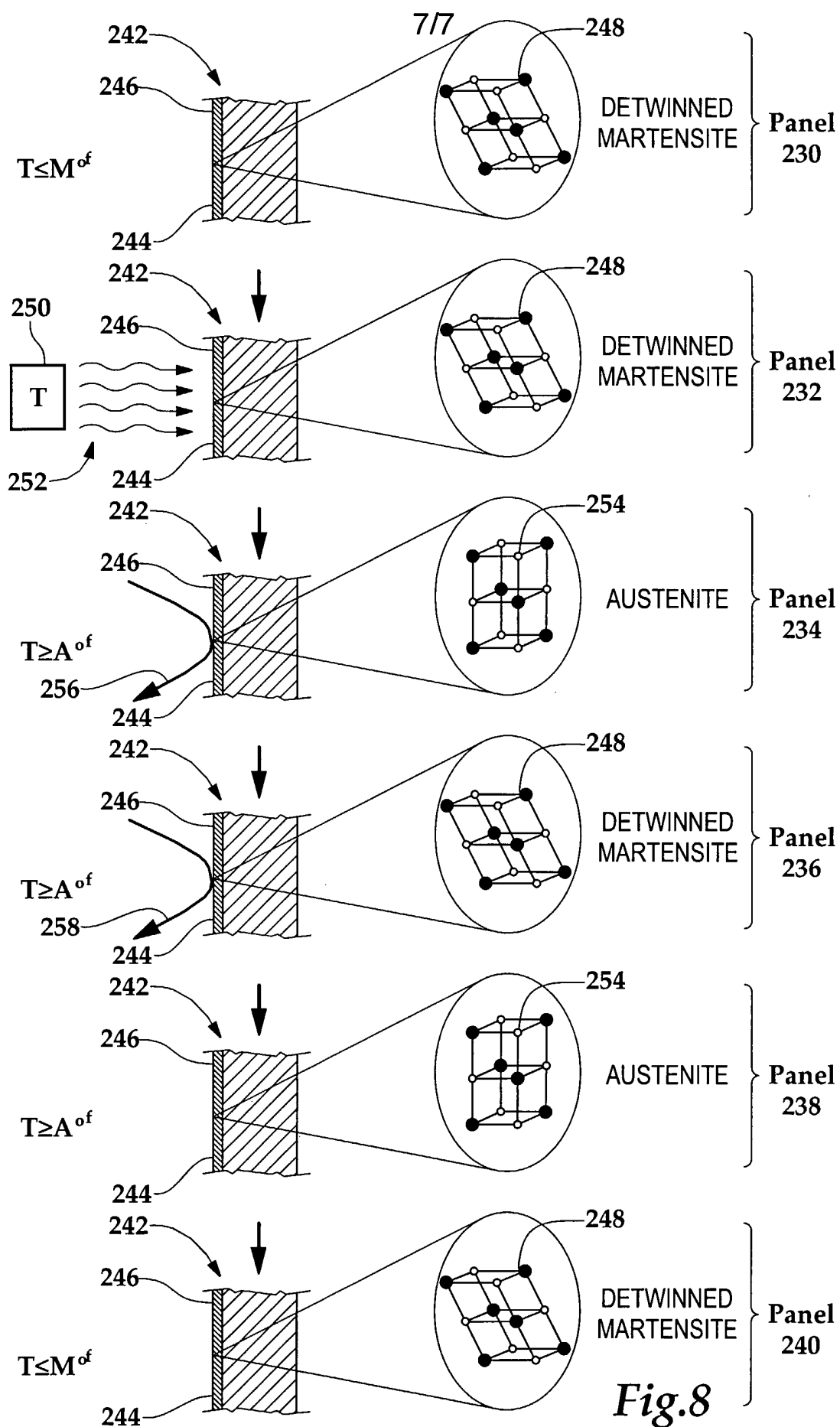


Fig.7



INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/029829

A. CLASSIFICATION OF SUBJECT MATTER
E21B43/12 E21B34/06 F16K31/00

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)
E21B F16K

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 practical, 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.
X	US 2002/108755 A1 (ZISK EDWARD J ET AL) 15 August 2002 (2002-08-15) page 3, paragraph 47; figures 11A,B	1,11-14
Y	the whole document	2-10, 15-51
Y	----- US 5 613 634 A (VERONESI ET AL) 25 March 1997 (1997-03-25) the whole document	2-10, 15-51
A	----- US 2004/050217 A1 (HEIJNEN WILHELMUS HUBERTUS PAULUS MARIA ET AL) 18 March 2004 (2004-03-18) the whole document	1,15,27, 39
A	----- EP 0 841 510 A (MATSUSHITA ELECTRIC WORKS, LTD) 13 May 1998 (1998-05-13) the whole document	1,15,27, 39



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document 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.
- *Z* document member of the same patent family

Date of the actual completion of the international search

29 November 2005

Date of mailing of the international search report

06/12/2005

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Morrish, S

INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US2005/029829

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2002108755	A1	15-08-2002	NONE	
US 5613634	A	25-03-1997	WO 9612994 A1	02-05-1996
US 2004050217	A1	18-03-2004	NONE	
EP 0841510	A	13-05-1998	CN 1182848 A	27-05-1998
			DE 69709529 D1	14-02-2002
			DE 69709529 T2	23-05-2002
			HK 1009476 A1	08-08-2003
			KR 263955 B1	01-09-2000
			TW 386150 B	01-04-2000
			US 5865418 A	02-02-1999