Dec. 16, 1969 N. E. ROGEN ETAL 3,483,748

TEMPERATURE SENSING

Filed May 5, 1967

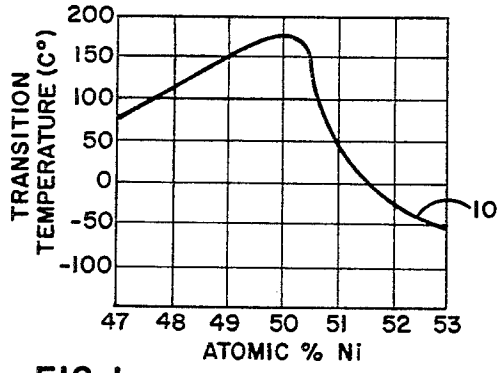
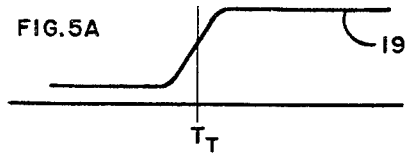
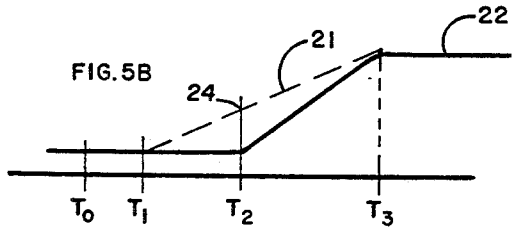


FIG. 1





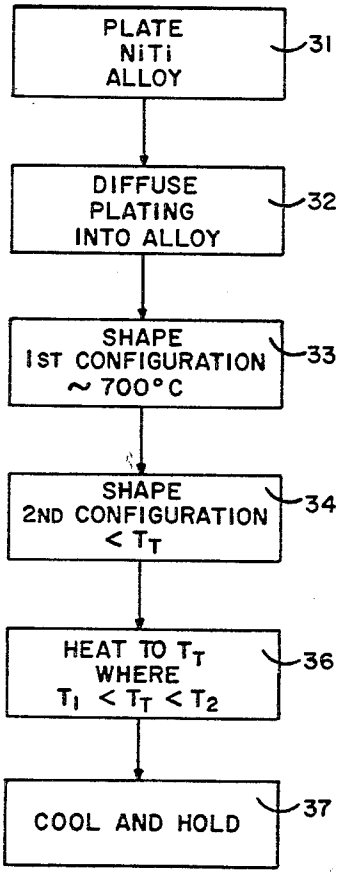


FIG. 2

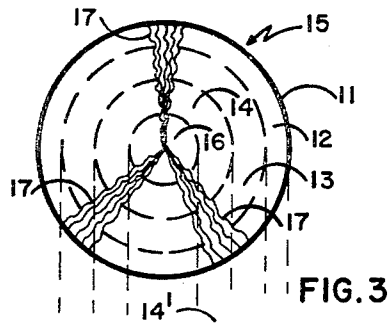


FIG. 3

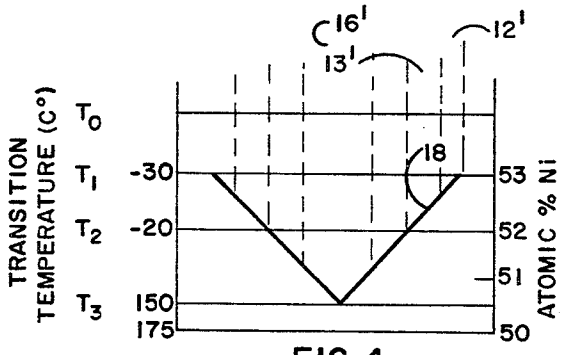


FIG. 4

NEIL E. ROGEN
RUSSELL J. HILL
INVENTORS

BY Charles H Hogan
Abraham Ogman
ATTORNEYS

United States Patent Office 3,483,748 Patented Dec. 16, 1969

3,483,748

TEMPERATURE SENSING

Neil E. Rogen, Newton, and Russell J. Hill, Wilmington, Mass., assignors to Avco Corporation, Cincinnati, Ohio, a corporation of Delaware

Filed May 5, 1967, Ser. No. 636,346
Int. Cl. G01k 5/48
U.S. Cl. 73—339 20 Claims

ABSTRACT OF THE DISCLOSURE

Nickel-titanium alloy compositions in the range of 47 atomic percent to 53 atomic percent are known for use as temperature sensors in the range of —50° C. to 160° C. An article of such an alloy can be made to change from a first configuration to a second configuration when its temperature reaches a transition temperature dependent on the percentages of nickel and titanium. An article is disclosed in which the ratio of nickel to titanium varies as a function of depth into the article, which article would then change its configuration gradually over a range of temperatures. The device may be made responsive to a definite selected temperature within this range by heating the article to this selected temperature and then cooling it.

Cross references

There is a remote relationship between this application and co-pending application "Temperature Indicator Device," Ser. No. 564,372, filed July 11, 1966, and co-pending application "A Temperature Monitor," Ser. No. 615,232, filed Feb. 10, 1967.

Background of the invention

The invention relates broadly to NiTi alloys and more specifically to NiTi alloys in the range of 47 atomic percent to 53 atomic percent nickel. These alloys are treated and discussed in Patent 3,174,851 and the article on page 3232 of volume 36, No. 10 of the Journal of Applied Physics, published in October 1965.

The invention comprises a temperature sensing composition of NiTi alloy having a non-homogeneous composition. The composition of any active increment of said alloy lies within the limitations of 47 atomic percent to 53 atomic percent. Atomic percent is the percentage of atoms of a material present per hundred atoms in an alloy.

Temperature modifying materials in combination with the NiTi alloys are also used in the practice of the invention.

The invention also covers the construction of a novel NiTi sensing alloy and a technique for constructing the non-homogeneous composition by diffusing temperature modifying materials into the basic NiTi alloy.

It is known that NiTi alloy compositions in the range of 47 atomic percent to 53 atomic percent have a peculiar and rather singular characteristic property. When such alloys are formed into a first configuration at or above 700° C. the material acts like a memory device and stores the configuration.

If such heat treated NiTi alloy is now cooled below a transition temperature and its configuration changed to a second configuration, the second configuration will be maintained so long as the temperature of the material does not reach the transition temperature. If the transition temperature is reached the material will change its configuration to the first (stored) configuration.

The transition temperature of the material will vary with the NiTi composition (refer to FIGURE 1). In particular, it will be noted that the transition temperature will vary 100° C. for a half atomic percent variation in the range of 50 to 51 atomic percent NiTi. A very difficult problem is to manufacture an alloy having the exact required composition for a specified transition temperature. This is so for a variety of reasons. It is known that by mixing the desired proportions of nickel and titanium in a molten state and solidifying does not result in the predetermined desired composition. Some of the constituent materials are lost in evaporation, some are oxidized. There is also the problem of homogeneity and contamination, either and both can alter the end composition. In practice, a batch intended to provide a specific atomic percent composition rarely ends up anywhere within the range of percents of interest and usually outside due to the very precise composition tolerances that are necessary for exact reproduction of a specific transition temperature response alloy.

It is an object of the invention to provide a process for constructing a temperature sensing NiTi alloy.

It is another object of the invention to provide a process for constructing a NiTi sensing alloy that contains a non-homogeneous distribution of NiTi.

It is still another object of the invention to provide a NiTi sensor which avoids the limitations and disadvantages of prior sensors of this type.

It is yet another object of the invention to provide a NiTi sensor which will respond to a specific transition temperature in a broad range of transition temperatures.

It is yet another object of the invention to provide a process for taking a NiTi sensing alloy and broadening its temperature response.

The novel features that are considered characteristic of the invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a curve of transition temperatures as a function of the atomic percent of NiTi alloy;

FIGURE 2 is a flow diagram of a process for constructing a temperature sensing NiTi composition and sensors embodying the present invention;

FIGURE 3 is a schematic representation of a cross section of a sensor embodying the present invention;

FIGURE 4 is a curve useful in describing the operation of the FIGURE 3 sensor; and

FIGURES 5*a* and 5*b* are curves useful in explaining the operation of the invention.

Referring to FIGURE 3 of the drawings, there is shown a coated nickel-titanium wire generally designated **15**. The number **11** symbolically designates a coating of preferably nickel, cobalt, titanium or iron. In accordance with the invention the coating is diffused through the nickel titanium element, in this case, the wire **15**, to create or to provide a non-homogeneous distribution composition through the cross section of the wire. The radial lines **17** symbolically indicate the diffusion of the coating **11** into the wire. The thickness across the lines **17** indicate the relative concentration of coating in relation to the surface of the wire.

Referring to FIGURE 4 of the drawings, there is a graphical representation of an assumed non-homogeneous distribution corresponding to the FIGURE 3 representation.

Initially, the wire **15** was assumed to have a 50 atomic percent nickel-titanium formulation. After the coating material was diffused into the wire for a predetermined time, further assumptions were made. The circle **16** corresponding to the center of the wire is assumed to have

a 50.5 to 51 atomic percent nickel while the outside surface of the wire in contact with the coating **11** is assumed to contain 53 atomic percent nickel. A straight line distribution through the wire was also assumed. Accordingly, the composition variation with the annulus **12** is shown to lie between the dotted lines defining the sector **12'** in FIGURE 4. Likewise, annulae **13**, **14** and **16** correspond with sectors **13'**, **14'** and **16'**.

It is clear from FIGURES 1 and 4 that the transition temperature for each of the annulses **13** through **16** will vary in accordance with composition of each sector. For this discussion averages will be used.

It is now proposed to examine the manner by which the usual structure is constructed and used. The flow diagram in FIGURE 2 shows that the first step is to plate the basic nickel titanium alloy. Diffusing nickel or iron or cobalt into the nickel titanium structure has the effect of moving the transition temperature to the right as seen in FIGURE 1. The effect of adding titanium is the equivalent of removing nickel from a nickel titanium alloy or moving from right to left on the abscissas in FIGURE 1.

After the wire or the nickel titanium substrate is coated it is heated to diffuse the coating into the alloy. The variables of time and temperature are adjusted to the shape of the wire, its size, etc.

After the coating has been diffused into the body of the substrate to the desired incident, it is raised in temperature above 700° C. and shaped into a first configuration. At and above approximately 700° C. the first configuration is stored in the material in view of its unique capabilities.

Following the shaping step, at elevated temperatures the material is cooled below the transition temperature. In this case, the material would be cooled below —30° C. since this is required by 53 atomic percent nickel occurring at the surface of the wire. At or below —30° C. the material is shaped into a second configuration and slowly raised in temperature.

It is at this point that the material takes on a unique characteristic. Referring to FIGURE *5a* a homogeneous material when raised in temperature through its transition temperature T_T will undergo a very rapid change in configuration from the second configuration to its first (stored) configuration as depicted by curve **19**.

On the other hand, assuming a non-homogeneous composition of the type previously described, the material starts at a temperature of T_0 or lower. As it is raised in temperature to T_1, the annulus **12** has reached its transition temperature and thus attempts to revert to its first or stored configuration.

There does not occur an abrupt transition to the stored configuration as in the case of a homogeneous material since only a portion of the cross section is at its transition temperature.

A configuration change along curve **21** starts to take place. It continues along curve **21** as the temperature of wire **15** passes through T_2 to T_3 where the transition to the stored first configuration is completed.

Suppose now it is desired to provide a temperature sensor which will be activated precisely at T_2 or —20° C. This can be accomplished by forming a homogeneous nickel titanium wire containing 52 atomic percent nickel. As was previously mentioned this is very difficult to do and often impractical.

Instead utilizing the non-homogeneous configuration just described and discussed one need only raise the temperature of the wire from T_0 to T_2 and then immediately cool the wire below T_2. The wire is then held at a temperature below T_2. In going from T_0 to T_2 those portions of the wire, annulus **12** and annulus **13**, exceed their transition temperatures and the wire is at an intermediate transition point **24** on curve **21**.

When the wire is cooled below T_2 and then reheated there can be no transitional configuration change until the temperature T_2 is reached since those portions of the wire, annulus **12** and annulus **13**, which would ordinarily undergo a configuration change have done so previously. Thus a configuration change begins to take place only after temperature T_2 is reached. The change now proceeds along curve **22** as the temperature of the wire is increased.

In summary, the use of a wire having a non-homogeneous cross sectional composition provides a wide band of transition temperatures. It is possible to accurately adjust the wire or sensing material to a particular transition temperature below which there will be no configuration change and above which a configuration change takes place. The accuracy of the adjustment is determined only by the accuracy of the associated temperature sensing instrumentation.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention.

We claim:

1. A temperature sensing composition comprising nickel titanium wherein the ratio of nickel to titanium is deliberately nonuniform throughout the composition, said ratios lying within the range of 47 to 53 atomic percent nickel whereby said composition has a range of transitional temperatures corresponding to said different nickel titanium ratios.

2. A composition as defined in claim **1** which includes in addition a temperature modifying material in proportion to the nickel and titanium for providing temperature effects equivalent to an alloy consisting of nickel and titanium in the percentage of 47 to 53 atomic percent nickel.

3. A composition as defined in claim **2** where the temperature modifying material is in the class consisting of iron and cobalt.

4. A composition as defined in claim **2** where the atomic percent of one of the materials making up the alloy decreases with the depth from a surface of the alloy.

5. A composition as defined in claim **2** where the atomic percent of the temperature modifying material making up the alloy decreases with the depth from a surface of the alloy.

6. A composition as defined in claim **1** where the atomic percent of one of the materials making up the alloy decreases with the depth from a surface of the alloy.

7. A temperature sensing composition comprising a nickel titanium alloy wherein the ratio of nickel to titanium is deliberately nonuniform throughout the composition, said ratios lying within the range of 47 to 53 atomic percent nickel whereby said composition has a range of transitional temperatures corresponding to said different nickel titanium ratios, the alloy having a stored first configuration and shaped into a second configuration.

8. A sensor as described in claim **7** which includes in addition a temperature modifying material in proportion for providing temperature effects equivalent to that of an alloy consisting of nickel titanium in the range specified.

9. A composition as defined in claim **8** where the temperature modifying material is in the class consisting of iron, cobalt and titanium.

10. A composition as defined in claim **8** where the atomic percent of one of the materials making up the alloy decreases with the depth from a surface of the alloy.

11. A composition as defined in claim **8** where the atomic percent of the temperature modifying material making up the alloy decreases with the depth from a surface of the alloy.

12. A composition as defined in claim **7** where the atomic percent of one of the materials making up the alloy decreases with the depth from a surface of the alloy.

13. A temperature sensing composition comprising a nickel titanium alloy wherein the ratio of nickel to titanium is deliberately nonuniform throughout the composition, said ratios lying within the range of 47 to 53 atomic percent nickel whereby said composition has a range of transitional temperatures corresponding to said different nickel titanium ratios, the alloy having a stored first configuration and shaped into a second configuration, a portion having undergone at least a partial change in configuration from the second configuration toward the stored first configuration.

14. A composition as defined in claim 13 where the atomic percent of one of the materials making up the alloy decreases with the depth from a surface of the alloy.

15. A composition as defined in claim 13 where the atomic percent of the temperature modifying material making up the alloy decreases with the depth from a surface of the alloy.

16. A process for making a nickel titanium sensing composition comprising:

(a) providing a shaped homogeneous alloy of nickel titanium in the range of 47 to 53 atomic percent nickel;

(b) diffusing into the alloy a temperature modifying material such that the temperature modifying material is not evenly distributed through the shape, the proposition of temperature modifying material providing temperature effects equivalent to that of nickel and titanium in the range of 47 to 53 atomic percent nickel.

17. A process as described in claim 16 where the temperature modifying material is taken from the class consisting of nickel, titanium, iron and cobalt.

18. A process as described in claim 16 where the proportion of temperature modifying material diffused into the shaped alloy decrease with depth from a surface.

19. A process for making nickel titanium sensing composition which includes in addition the following steps:

(a) providing a shaped homogeneous alloy of nickel titanium in the range of 47 to 53 atomic percent nickel;

(b) diffusing into the alloy a temperature modifying material such that the temperature modifying material is not evenly distributed through the shape, the proposition of temperature modifying material providing temperature effects equivalent to that of nickel and titanium in the range of 47 to 53 atomic percent nickel;

(d) reducing the temperature below a transition temperature of interest;

(e) changing the shape to a second configuration; and

(f) storing said shaped alloy below the transition temperature.

20. A process as described in claim 19 where the temperature of the second configuration is raised to a transition temperature to cause at least a partial change in configuration from the second configuration toward the stored shape.

References Cited

UNITED STATES PATENTS

3,174,851	3/1965	Buehler	75—170
3,403,238	9/1968	Buehler	73—378.3

LOUIS R. PRINCE, Primary Examiner

D. E. CORR, Assistant Examiner

U.S. Cl. X.R.

116—114.5; 73—378.3

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,483,748 December 16, 1969

Neil E. Rogen et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 27, "proposition" should read -- proportion --. Column 6, line 3, after "making" insert -- a --; line 11, "proposition" should read -- proportion --; Claim 19, after (b) insert -- (c) annealing said shaped alloy at about 700° C. to store said shape; --.

Signed and sealed this 23rd day of June 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents