SMA to switch back to its Austenitic phase in so doing recovering its starting shape and higher modulus.

[0044] Ferromagnetic SMA's (FSMA's), which are a subclass of SMAs, may also be used in the present invention. These materials behave like conventional SMA materials that have a stress or thermally induced phase transformation between martensite and austenite. Additionally FSMA's are ferromagnetic and have strong magnetocrystalline anisotropy, which permit an external magnetic field to influence the orientation/ fraction of field aligned martensitic variants. When the magnetic field is removed, the material may exhibit complete two-way, partial two-way or one-way shape memory. For partial or one-way shape memory, an external stimulus, temperature, magnetic field or stress may permit the material to return to its starting state. Perfect two-way shape memory may be used for proportional control of shape with continuous power supplied. External magnetic fields are generally produced via soft-magnetic core electromagnets in automotive applications, though a pair of Helmholtz coils may also be used for fast response.

[0045] Generally, SMP's are co-polymers comprising at least two different units which may be described as defining different segments within the co-polymer, each segment contributing differently to the elastic modulus properties and thermal transition temperatures of the material. "Segment" refers to a block, graft, or sequence of the same or similar monomer or oligomer units which are copolymerized to form a continuous cross-linked interpenetrating network of these segments. These segments may be crystalline or amorphous materials and therefore may be generally classified as a hard segment(s) or a soft segment(s), wherein the hard segment generally has a higher glass transition temperature (T_g) or melting point than the soft segment.

[0046] Each segment then contributes to the overall flexural modulus properties of the shape memory polymer (SMP) and the thermal transitions thereof, the hard segments tending to increase and the soft segments tending to decrease both the flexural modulus properties and the temperatures associated with their changes. When multiple segments are used, multiple thermal transition temperatures may be observed, wherein the thermal transition temperatures of the copolymer may be approximated as weighted averages of the thermal transition temperatures of its comprising segments.

[0047] The previously defined or permanent shape of an SMP can be set by melting or processing the polymer at a temperature higher than the highest thermal transition temperature for the shape memory polymer or its melting point, followed by cooling below that thermal transition temperature. The temperature necessary to set the permanent shape is preferably between about 100° C. to about 300° C. A temporary shape can be set by heating the material to a temperature higher than any T_g or thermal transition temperature of the shape memory polymer, but lower than the highest T_g or its melting point. The temporary shape is set by applying an external stress or load while processing the material above the T_g, but below the highest thermal transition temperature or melting point of the shape memory material followed by cooling to fix the shape.

[0048] The material can then be reverted to the permanent shape by heating the material, with the stress or load removed, above its T_g but below the highest thermal transition temperature or melting point. Thus, by combining multiple soft segments it is possible to demonstrate multiple temporary shapes and with multiple hard segments it may be possible to demonstrate multiple permanent shapes. Similarly using a layered or composite approach, a combination of multiple SMP's will demonstrate transitions between multiple temporary and permanent shapes.

[0049] At the soft segment transition temperature (also termed "first transition temperature"), the temporary shape of the shape memory polymer is set followed by cooling of the shape memory polymer, while still under load, to lock in the temporary shape. The temporary shape is maintained as long as it remains below the soft segment transition temperature. The permanent shape is regained when the shape memory polymer fibers are once again brought to or above the transition temperature of the soft segment. Repeating the heating, shaping, and cooling steps can reset the temporary shape. The soft segment transition temperature can be chosen for a particular application by modifying the structure and composition of the polymer. Transition temperatures of the soft segment range from about −63° C. to above about 160° C.

[0050] Shape memory polymers may contain more than two transition temperatures. A shape memory polymer composition comprising a hard segment and two soft segments can have three transition temperatures: the highest transition temperature for the hard segment and a transition temperature for each soft segment.

[0051] Most shape memory polymers exhibit a "one-way" effect, wherein the shape memory polymer exhibits one permanent shape. Upon heating the shape memory polymer above the first transition temperature with the stress or load removed, the permanent shape is achieved and the shape will not revert back to the temporary shape without the use of outside forces.

[0052] As an alternative, some shape memory polymer compositions can be prepared to exhibit a "two-way" effect. These systems consist of at least two polymer components. For example, one component could be a first cross-linked polymer while the other component is a different cross-linked polymer. The components are combined by layer techniques, or are interpenetrating networks, wherein two components are cross-linked but not to each other. By changing the temperature, the shape memory polymer changes its shape in the direction of the first permanent shape of the second permanent shape. Each of the permanent shapes belongs to one component of the shape memory polymer. The two permanent shapes are always in equilibrium between both shapes. The temperature dependence of the shape is caused by the fact that the mechanical properties of one component ("component A") are almost independent from the temperature in the temperature interval of interest. The mechanical properties of the other component ("component B") depend on the temperature. In one embodiment, component B becomes stronger at low temperatures compared to component A, while component A is stronger at high temperatures and determines the actual shape. A two-way memory device can be prepared by setting the permanent shape of component A ("first permanent shape"); deforming the device into the permanent shape of component B ("second permanent shape") and fixing the permanent shape of component B while applying a stress to the component.

[0053] SMP can be configured in many different forms and shapes. The temperature needed for permanent shape recovery can be set at any temperature between about −63° C. and about 160° C. or above. It should be apparent to those skilled in the art that engineering the composition and structure of the polymer itself can allow for the choice of the selected tem-