What is Claimed:

1. A process for preparing a polarized ~~polymeric composition~~ material comprising the steps of:

a) ~~providing a layer~~ forming a film or sheet of a polarizable polymeric composition, wherein the polarizable polymeric composition comprises a polyhydroxyalkanoate (PHA) based copolymer; and

b) directionally perturbing the ~~layer~~ film or sheet to induce polarization by at least one of:

(i) subjecting the film or sheet cast from solution to calendar rolling,

(ii) subjecting the film or sheet cast from a solution to melt crystallization under shear or pressure,

(iii) mechanically stretching the film or sheet formed from the polarizable polymeric composition in a gel state,

(iv) freezing the polarizable polymeric composition in a gel state to induce shear by crystallization,

(v) applying shear or pressure during molding of the film or sheet, or

(v) applying electrical field during molding of the film or sheet from the polarizable polymeric composition in a melt state;

~~b) optionally polarizing the polymeric composition of the directionally perturbed layer by applying a high electric field which is of less intensity than that which would cause substantial dielectric breakdown of the one or more polymers; and~~

~~c) optionally annealing the polarized polymeric composition of the layer at a temperature less than the melting temperature of the crystals of the polarized polymeric composition, whereby the polarization is retained up to the crystal melting point of the polar crystals of the polymeric composition,~~

wherein the polarized polymeric composition comprises a β-form of the PHA based copolymer, present in an amount ~~of~~ from ~~about~~ 10% to ~~about~~ 99%, as measured by x-ray diffraction.

2. A process for preparing a polarized material comprising the steps of:

a) forming a film or sheet of a polarizable polymeric composition, wherein the polarizable polymeric composition comprises at least one of:

i. a polymer blend of one or more poly[(R)-3-hydroxybutyrate-co-(R)-3-hydroxyhexanoate] (PHBHx) copolymers, each of the one or more PHBHx copolymers having a different comonomer content,

ii. a PHA based copolymer with longer side chain selected from poly(3-hydroxybutyrate-co-3-hydroxyoctanoate) (PHBO) with pentyl side group, poly(3-hydroxybutyrate-co-3-hydroxydecanoate) (PHBD) with heptyl side group, PHBO or PHBD with C15 side group chains, and medium-chain-length branched polyhydroxyalkanoates (mcl-PHA),

iii. a polymer blend of a copolymer of PHBHx and one or more PHA based copolymer with longer side chain, and

iv. a polymer blend comprising polyhydroxyalkanoate (PHA) based copolymer and one or more polymers selected from the group consisting of polyvinylchloride, polymethylacrylate, polymethylmethacrylate, poly(vinylidene cyanide/vinyl acetate) copolymers, vinylidene cyanide/vinyl benzoate copolymers, vinylidene cyanide/isobutylene copolymers, vinylidene cyanide/methyl methacrylate copolymers, vinylidene fluoride copolymer, polyvinylfluoride, polyacrylonitrile, polycarbonate, cellulose, proteins, synthetic polyesters and ethers of cellulose, poly(gamma-methyl-L-glutamate), vinylidene copolymers, Nylon-3, Nylon-5, Nylon-7, Nylon-9, Nylon-11 and blends thereof; and

b) directionally perturbing the film or sheet to induce polarization by at least one of:

(i) subjecting the film or sheet cast from solution to calendar rolling,

(ii) subjecting the film or sheet cast from a solution to melt crystallization under shear or pressure,

(iii) mechanically stretching the film or sheet formed from the polarizable polymeric composition in a gel state,

(iv) freezing the polarizable polymeric composition in a gel state to induce shear by crystallization,

(v) applying shear or pressure during molding of the film or sheet, or

(vi) applying electrical field during molding of the film or sheet from the polarizable polymeric composition in a melt state, or

(vii) in situ polarization during step of forming a film or sheet by electrospinning a ribbon of fibers from a solution of the polarizable polymeric composition in one or more solvents, wherein the each fiber of the electrospun ribbon of fibers comprises a shell formed of β-form and a core formed of α-form;

wherein the polarized polymeric composition comprises a β-form of the PHA based copolymer, present in an amount from 10% to 99%, as measured by x-ray diffraction.

~~2.~~3. The process of claim ~~1~~2, wherein the step of ~~providing a layer~~ forming a film or sheet comprises electrospinning a ribbon of fibers from a solution of the polyhydroxyalkanoate based copolymer in one or more solvents, wherein ~~the~~ each fiber of the electrospun ribbon of fibers comprises a shell formed of β-form and a core formed of α-form.

~~3.~~4. The process of claim 1 or claim 2, wherein the step of ~~providing a layer~~ forming a film or sheet comprises forming ~~a layer~~ the film or sheet from a solution of the polyhydroxyalkanoate based copolymer in one or more solvents.

~~4.~~5. The process of claim 1 or claim 2, wherein the step of ~~providing a layer~~ forming a film or sheet comprises forming ~~a layer~~ the film or sheet from a melted composition of the polyhydroxyalkanoate based copolymer.

~~5.~~6. The process of claim ~~4~~5, wherein the step of directionally perturbing the ~~layer~~ film or sheet comprises calendar rolling, shearing or cold drawing the ~~layer~~ film or sheet after quenching.

~~6.~~7. The process of claim 1 or claim 2, wherein the step of ~~providing a layer~~ forming a film or sheet comprises forming a film from a gel composition of the polyhydroxyalkanoate based copolymer.

~~7.~~8. The process of claim ~~6~~7, wherein the step of directionally perturbing the film comprises drying the gel under shear pressure or freezing gel to induce shear by crystallization of solvent.

~~8.~~ The process of claim 1 or claim 2, wherein the polyhydroxyalkanoate based copolymer comprises at least one monomer unit selected from the group consisting of hydroxybutyrate units, hydroxyhexanoate units, vinyl units, vinylidene units, ethylene units, acrylate units, methacrylate units, Nylon units, carbonate units, acrylonitrile units, cellulose units, units having pendant fluoro, chloro, amide, ester other than ester of acrylate and methacrylate units, cyanide, nitrile other than of acrylonitrile units, or ether groups, protein units and combinations thereof, and~~.~~

9. ~~The process of claim 1~~ wherein the polarizable polymeric composition further comprises one or more polymers selected from the group consisting of polyvinylchloride, polymethylacrylate, polymethylmethacrylate, poly(vinylidene cyanide/vinyl acetate) copolymers, vinylidene cyanide/vinyl benzoate copolymers, vinylidene cyanide/isobutylene copolymers, vinylidene cyanide/methyl methacrylate copolymers, vinylidene fluoride copolymer,

polyvinylfluoride, polyacrylonitrile, polycarbonate, cellulose, proteins, synthetic polyesters and ethers of cellulose, poly(gamma-methyl-L-glutamate), vinylidene copolymers, Nylon-3, Nylon-5, Nylon-7, Nylon-9, Nylon-11 and blends thereof.

10. The process of any one of claims 1 to 9, further comprising polarizing the polymeric composition of the directionally perturbed film or sheet by applying a high electric field which is of less intensity than that which would cause substantial dielectric breakdown of the one or more polymers.

~~10.~~11. The process of claim ~~1~~ 10, wherein the step ~~optionally~~ of polarizing the polymeric composition of the directionally perturbed ~~layer~~ film or sheet is conducted using an electric field of at least 1 MV/cm at a temperature from ~~about~~ 20° C. to ~~about~~ 120° C. for up to ~~about~~ 5 hours.

12. The process of any one of claims 1 to 11, further comprising annealing the polarized polymeric composition of the film or sheet at a temperature less than the melting temperature of the crystals of the polarized polymeric composition, whereby the polarization is retained up to the crystal melting point of the polar crystals of the polymeric composition.

~~11.~~13. The process of claim ~~1~~ 12, wherein the ~~layer~~ film or sheet is annealed at a temperature in the range of from ~~about~~ 125° C~~.~~ to ~~about~~ 150° C~~.~~ for at least one hour.

~~12.~~14. A device comprising a PHA based copolymer layer comprising at least one of (i) a polarized material comprising an electrospun ribbon of fibers of a polyhydroxyalkanoate based copolymer obtained by the process of claim 2, or (ii) a polarized material ~~the polarized polymeric composition~~ obtained by the process of claim ~~1~~12,

wherein the layer is configured to exhibit one or more of a piezoelectric effect, a pyroelectric effect and a ferroelectric effect, wherein ~~each of the electrospun ribbon of fibers and~~ the polarized ~~polymeric composition~~ material comprises a β-form of the PHA based copolymer present in an amount ~~of~~ from ~~about~~ 10% to ~~about~~ 99%, as measured by x-ray diffraction.

~~13.~~15. The ~~polymeric~~ device of claim ~~12~~14, wherein the device is a sensor or an actuator,

wherein the sensor is configured to produce a potential difference or voltage in response to a change in dimension of the PHA based copolymer layer~~,~~.

wherein the change in dimension is caused by a change in one or more of the following properties, humidity, temperature, salinity, nutrient attachment or

infusion and metalloid attachment at a surface of the PHA based copolymer layer, and

wherein the actuator is configured to expand or contract in response to an application of an electrical charge across the PHA based copolymer layer.

~~14. The device of claim 13, wherein the change in dimension is caused by a change in one or more of the following properties, humidity, temperature, salinity, nutrient attachment or infusion and metalloid attachment at a surface of the PHA based copolymer layer.~~

~~15.~~16. The device of claim ~~12~~15, wherein the sensor comprises a plurality of sensor surfaces and/or interfaces, wherein each surface and/or interface is independently configured to monitor one of the following properties, humidity, temperature, salinity, nutrient attachment or infusion and metalloid attachment.

~~16. The device of claim 12, wherein the device is an actuator configured to expand or contract in response to an application of an electrical charge across the PHA based copolymer layer.~~

17. A nanomotor comprising one or more ~~piezoelectric~~ actuators of claim ~~16~~15.

18. A device comprising one or more actuators of claim ~~16~~ 15 configured for placement or implantation near a vascular system component of an animal or a human patient and configured to produce a change in dimension of the PHA based copolymer layer due to heartbeats of the animal or the human patient to generate a potential difference or voltage to operate a monitoring or treatment device.

19. The device of claim 18, wherein the monitoring or treatment ~~or monitoring~~ device comprises a pacemaker, insulin pump, in-situ glucose monitor, or blood pressure monitor~~,~~; and

wherein the vascular system component comprises a vein or artery that beats in a cadence corresponding to heart beats of the patient.

~~19. The device of claim 18, wherein the vascular system component comprises a vein or artery that beats in a cadence corresponding to heart beats of the patient.~~

20. A method comprising:

providing a PHA based copolymer sensor layer configured to monitor one of the following properties, humidity, temperature, salinity, nutrient attachment or infusion and metalloid attachment, wherein the PHA based copolymer sensor layer comprises at least one of an electrospun ribbon of fibers of a

polyhydroxyalkanoate based copolymer or the polarized polymeric composition obtained by the process of any one of claims 1 to 13;

exposing a PHA based copolymer sensor layer to one or more of the said properties, such that the PHA based copolymer sensor layer undergo a change in dimension caused by a change in one or more of the said properties, and

detecting a potential difference or voltage in response to a change in dimension of the PHA based copolymer sensor layer.

TITLE OF THE INVENTION: PIEZOELECTRIC SENSORS COMPRISING ELECTROSPUN POLY[(R)-3-HYDROXYBUTYRATE-CO-(R)-3-HYDROXYHEXANOATE] (PHBHX) NANOFIBERS

ABSTRACT

Disclosed herein is a device comprising a PHA based copolymer layer comprising at least one of an electrospun ribbon of fibers of a polyhydroxyalkanoate based copolymer or the polarized polymeric composition obtained by the process of claim 1, wherein the layer is configured to exhibit one or more of a piezoelectric effect, a pyroelectric effect and a ferroelectric effect, wherein each of the electrospun ribbon of fibers and the polarized polymeric composition comprises a β-form of the PHA based copolymer present in an amount of from about 10% to about 99%, as measured by x-ray diffraction. The device can be configured for use as a sensor, an actuator, a nanomotor, or a biobattery.