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(54) **PIEZOELECTRIC GENERATOR AND METHOD OF MANUFACTURING THE SAME**

(71) Applicants: **SAMSUNG ELECTRONICS CO., LTD.**, Suwon-si (KR); **GEORGIA TECH RESEARCH CORPORATION**, Atlanta, GA (US)

(72) Inventors: **Young-jun Park**, Suwon-si (KR); **Zhong-lin Wang**, Atlanta, GA (US); **Sang-min Lee**, Pohang-si (KR)

(73) Assignees: **SAMSUNG ELECTRONICS CO., LTD.**, Suwon-si (KR); **GEORGIA TECH RESEARCH CORPORATION**, Atlanta, GA (US)

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H01L 41/047	(2006.01)

(52) **U.S. Cl.**

CPC ***H02N 2/18*** (2013.01); ***H01L 41/18*** (2013.01); ***H01L 41/317*** (2013.01); *B82Y 40/00* (2013.01); *H01L 41/0477* (2013.01); *Y10S 977/84* (2013.01); *Y10S 977/948* (2013.01); *Y10T 29/42* (2015.01)

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USPC 310/339, 340, 358, 363–366; 29/25.35; 427/100; 977/742, 750, 837
See application file for complete search history.

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Primary Examiner — Thomas Dougherty
(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

Provided are flexible piezoelectric generators and methods of manufacturing the same. The piezoelectric generator includes a first insulation layer disposed on a first electrode, a piezoelectric structure disposed on the first insulation layer, a second insulation layer disposed on the piezoelectric structure, and a second electrode disposed on the second insulation layer.

17 Claims, 6 Drawing Sheets

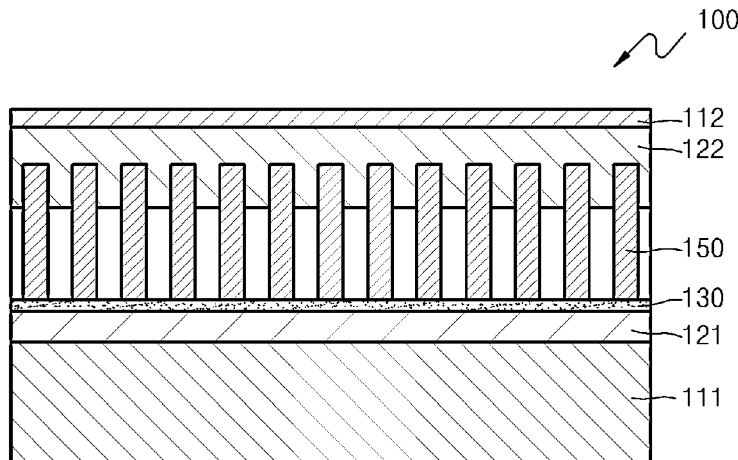

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FIG. 1

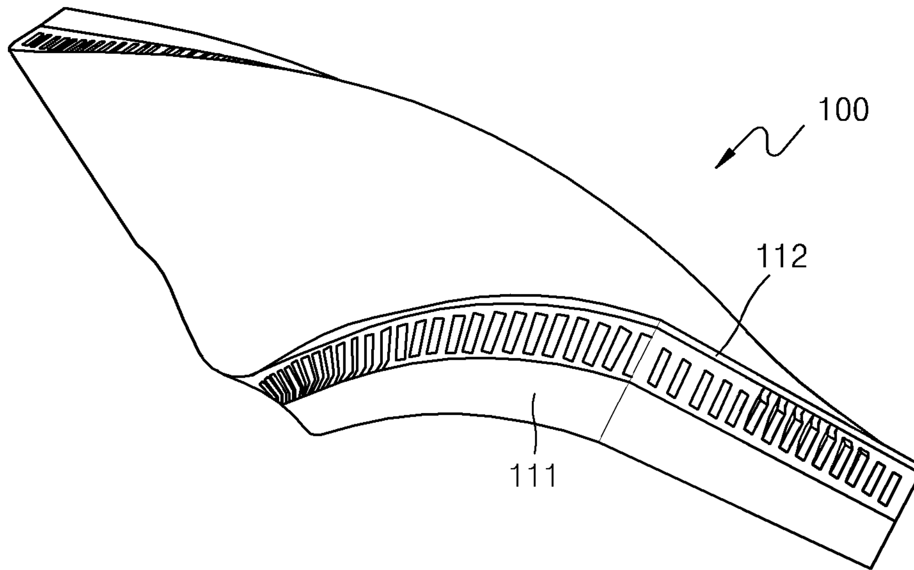


FIG. 2

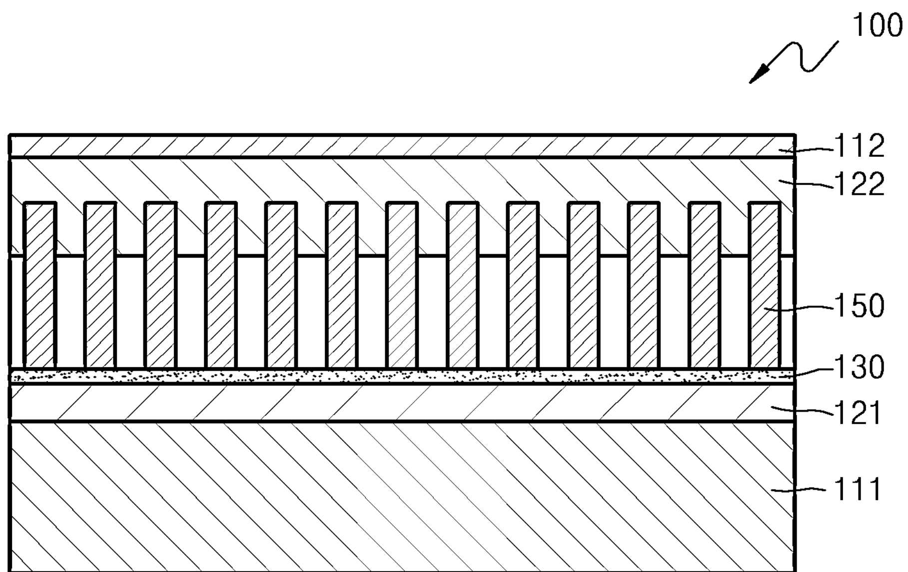


FIG. 3

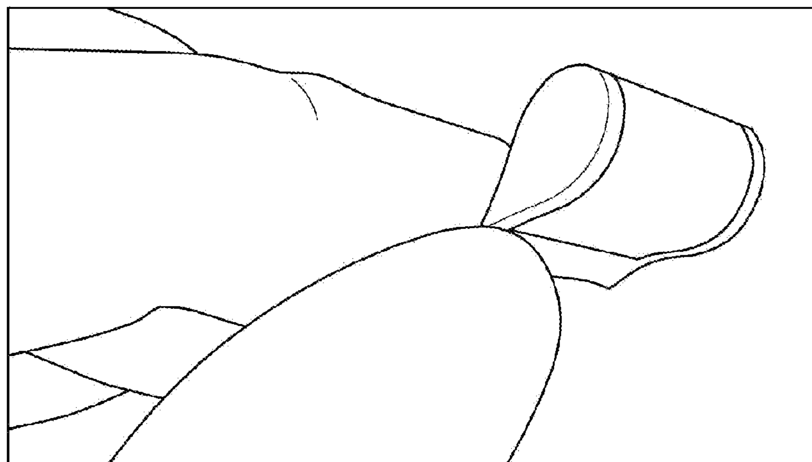


FIG. 4

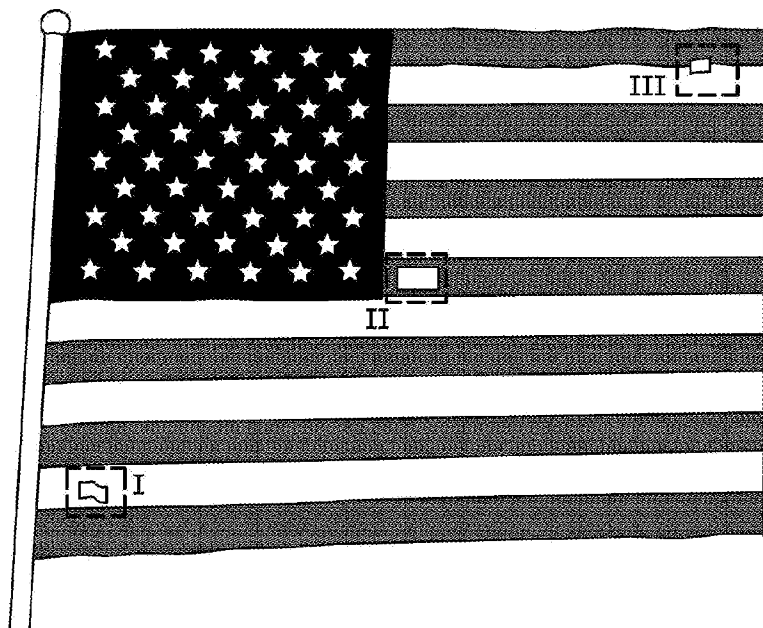


FIG. 5

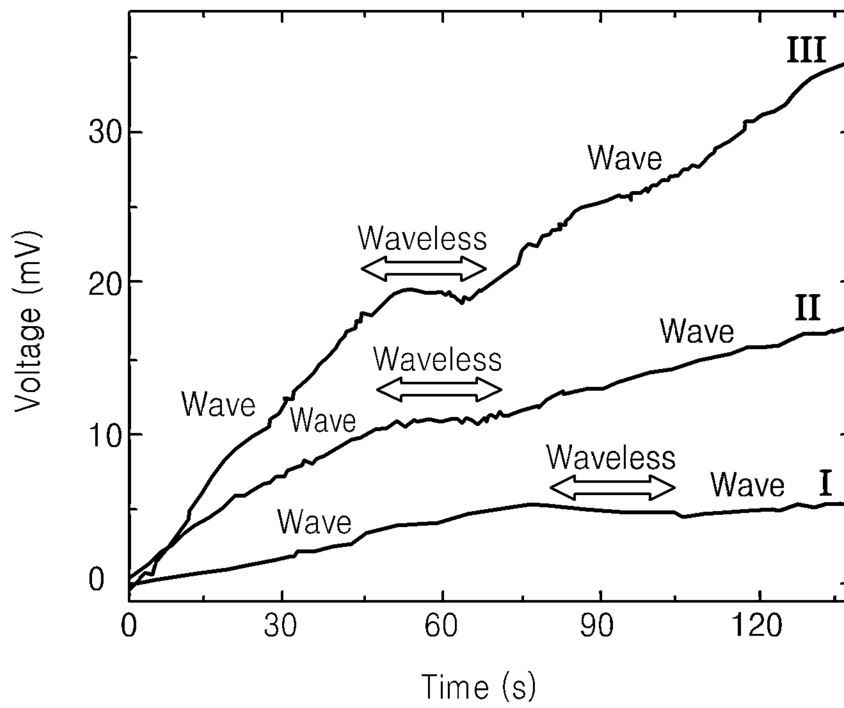


FIG. 6A

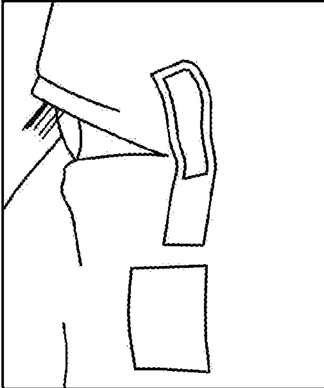


FIG. 6B

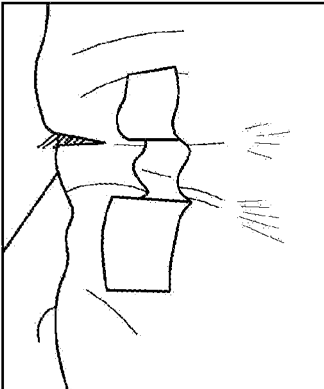


FIG. 7

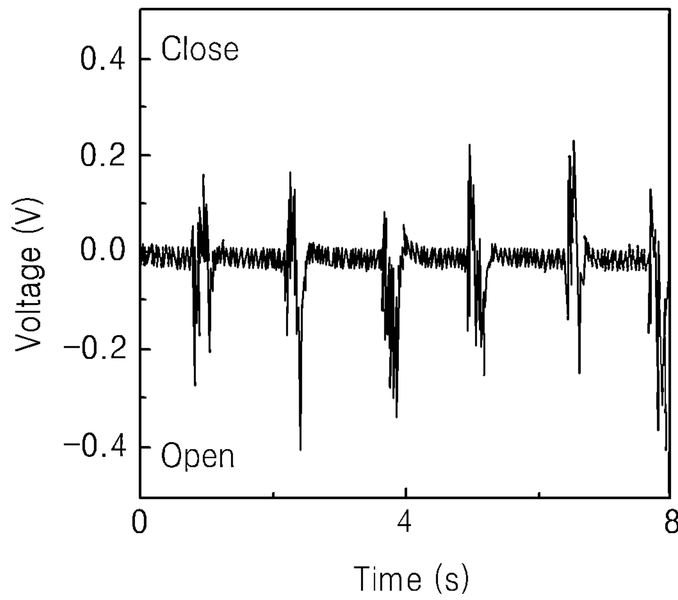


FIG. 8

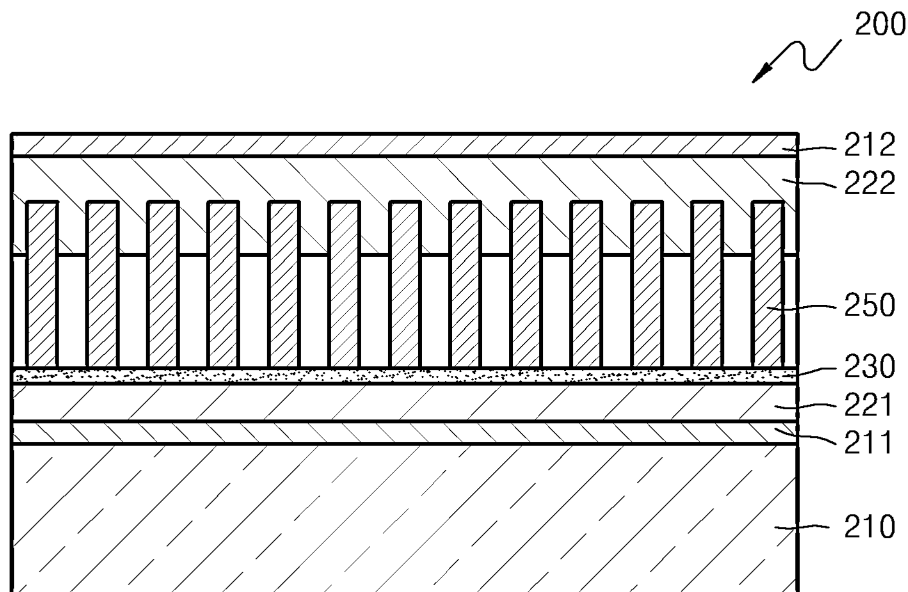


FIG. 9

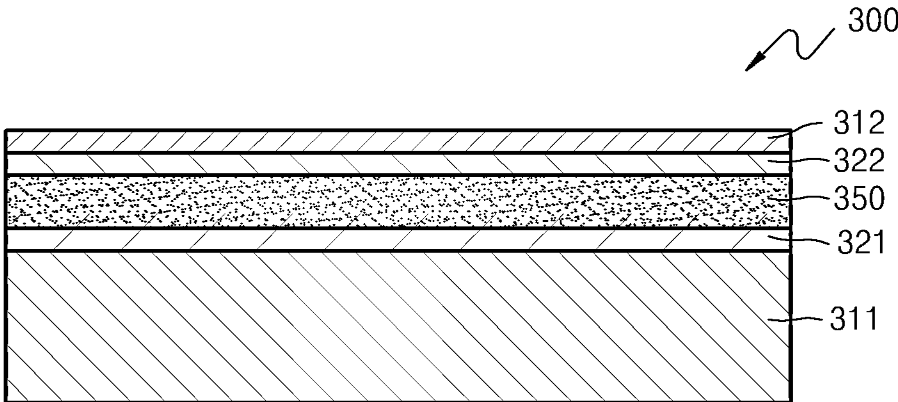
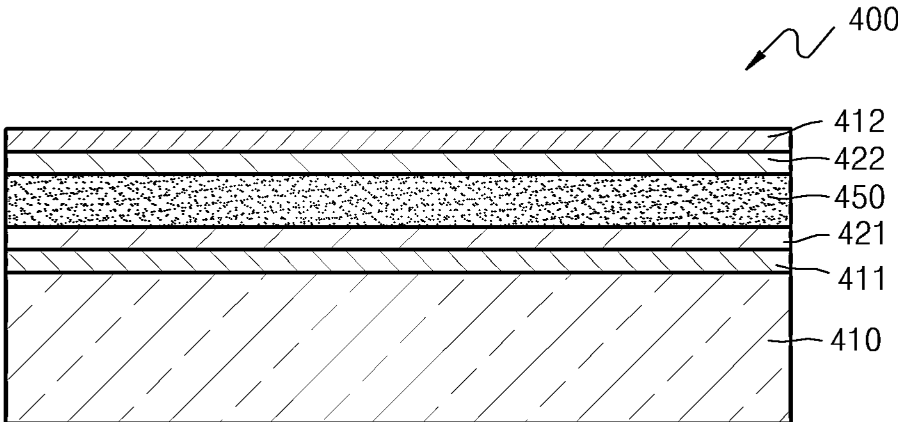


FIG. 10



PIEZOELECTRIC GENERATOR AND METHOD OF MANUFACTURING THE SAME

BACKGROUND

1. Field

The present disclosure relates to generators, and more particularly, to large-area flexible piezoelectric generators and methods of manufacturing the same.

2. Description of the Related Art

Recently, techniques for harvesting energy have received much interest and have been the focus of research. Piezoelectric generators among devices for harvesting energy may be considered as environmentally friendly energy generating devices which may transform mechanical energy generated by vibration existing in a surrounding environment or the motion of the human body into electric energy. Also, research into developing flexible piezoelectric nanogenerators by using nanosystems has been conducted according to the development of nanotechnologies. Such piezoelectric nanogenerators may be used for harvesting electric energy by using mechanical energy generated due to the mechanical motion or vibration in an external environment, such as wind, or the motion of the human body, and may be also used as a sensor for detecting external environmental changes or microscopic motion.

SUMMARY

Exemplary embodiments provide large-area flexible piezoelectric generators and methods of manufacturing the same.

Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

According to an aspect of an embodiment, there is provided a piezoelectric generator including: a first electrode; a first insulation layer disposed on the first electrode; a piezoelectric structure disposed on the first insulation layer; a second insulation layer disposed on the piezoelectric structure; and a second electrode disposed on the second insulation layer.

The first electrode may be a flexible and conductive substrate. Herein, the first electrode may include a metal substrate or a conductive polymer substrate. The metal substrate may include at least one of aluminum (Al), copper (Cu), gold (Au), and silver (Ag). The first electrode may have a thickness of about 500 μm or less.

The first electrode may be disposed on a flexible plastic substrate. Herein, the first electrode may include metal, a conductive polymer, or graphene. The plastic substrate may have a thickness of about 500 μm or less.

The first and the second insulation layers may include a polymer, for example, polymethyl methacrylate (PMMA). The first and the second insulation layers may have a thickness of about 2 μm or less.

The piezoelectric structure may include a plurality of piezoelectric nanowires. The piezoelectric nanowires may include ZnO, $ZnSnO_3$, or SnO. A seed layer may be further disposed between the first insulation layer and the piezoelectric nanowires. The seed layer may include at least one of ZnO, zinc (Zn), $ZnSnO_3$, SnO, tin (Sn), and Au.

The piezoelectric structure may include a piezoelectric thin film. The piezoelectric thin film may include ZnO, $ZnSnO_3$, SnO, $BaTiO_3$, $NaNbO_3$, lead zirconate titanate (PZT), or polyvinylidene fluoride (PVDF).

According to an aspect of another embodiment, there is provided a method of manufacturing a piezoelectric generator includes: preparing a first electrode; coating the first electrode with a first insulation layer; growing piezoelectric nanowires on the first insulation layer by using a hydrothermal process; coating the piezoelectric nanowires with a second insulation layer; and depositing a second electrode on the second insulation layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and/or other aspects will become apparent and more readily appreciated from the following description of embodiments, taken in conjunction with the accompanying drawings of which:

FIG. **1** is a perspective view illustrating a flexible piezoelectric generator according to an exemplary embodiment;

FIG. **2** is a cross-sectional view of the piezoelectric generator illustrated in FIG. **1**;

FIG. **3** is an image of a piezoelectric generator according to the exemplary embodiment manufactured by using an aluminum (Al) foil as an electrode substrate;

FIG. **4** is an image showing piezoelectric generators according to the exemplary embodiment attached to each position (I, II, and III) on a surface of a flag for experiments to identify energy harvesting from wind;

FIG. **5** illustrates energies generated from the piezoelectric generators attached to the each position (I, II, and III) on the surface of the flag illustrated in FIG. **4**;

FIGS. **6**A and **6**B are images showing a piezoelectric generator according to the exemplary embodiment attached to facial skin for experiments to identify detection of the movement of human skin, in which states of eyes open and eyes closed are respectively illustrated;

FIG. **7** illustrates the results of the measurements of skin movement signals detected by the piezoelectric generator attached to the facial skin in FIGS. **6**A and **6**B;

FIG. **8** illustrates a flexible piezoelectric generator according to another exemplary embodiment;

FIG. **9** illustrates a flexible piezoelectric generator according to another exemplary embodiment; and

FIG. **10** illustrates a flexible piezoelectric generator according to another exemplary embodiment.

DETAILED DESCRIPTION

Hereinafter, exemplary embodiments will be described in detail with reference to the accompanying drawings. The present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the invention to those skilled in the art. Like reference numerals in the drawings denote like elements. In the drawings, the thicknesses of layers and regions are exaggerated for clarity. It will also be understood that when a layer is referred to as being "on" another layer or substrate, it can be directly on the other layer or substrate, or intervening layers may also be present. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

FIG. **1** is a perspective view illustrating a flexible piezoelectric generator according to an exemplary embodiment. FIG. **2** is a cross-sectional view of the piezoelectric generator **100** illustrated in FIG. **1**.

Referring to FIGS. **1** and **2**, the piezoelectric generator **100** includes first and second electrodes **111** and **112** disposed by being spaced apart from each other, first and second insulation layers **121** and **122** disposed on the first and second electrodes **111** and **112**, respectively, and a piezoelectric structure disposed between the first and second insulation layers **121** and **122**. The first electrode **111** may be a flexible electrode substrate. That is, the first electrode **111** may be a flexible and conductive substrate. For example, the first electrode **111** may be a metal substrate or a conductive polymer substrate. Herein, the metal substrate, for example, may include at least one of aluminum (Al), copper (Cu), gold (Au), and silver (Ag). However, these are only examples and various metals may be included. The first electrode **111** may have a thickness of about 500 μm or less and, for example, the first electrode **111** may have a thickness of about 50 μm or less. However, the thickness of the first electrode **111** is not limited thereto.

The first insulation layer **121** disposed on the first electrode **111** may act to prevent a short circuit between the first electrode **111** and the second electrode **112**, and uniformly grow piezoelectric nanowires **150** to be later described on the first insulation layer **121**. The first insulation layer **121** may include a flexible material having a high dielectric constant. For example, the first insulation layer **121** may include a polymer such as polymethyl methacrylate (PMMA). However, the material of the first insulation layer **121** is not limited thereto. The first insulation layer **121** may have a thickness of about 2 μm. For example, the first insulation layer **121** may have a thickness of about 200 nm or less. However, the thickness of the first insulation layer **121** is not limited thereto.

A piezoelectric structure is disposed on the first insulation layer **121**. Specifically, the plurality of piezoelectric nanowires **150** are disposed on the first insulation layer **121**. Herein, the piezoelectric nanowires **150** may be arranged perpendicular to or inclined at a predetermined angle with respect to the first insulation layer **121**. The piezoelectric nanowires **150** may include a material generating piezoelectric potential at both ends thereof by deformation. For example, the piezoelectric nanowires **150** may be ZnO nanowires and, in addition, the piezoelectric nanowires **150** may be $ZnSnO_3$ nanowires or SnO nanowires. However, the material of the piezoelectric nanowires **150** is not limited thereto. A seed layer **130** may be further disposed on the first insulation layer **121** having the piezoelectric nanowires **150** formed thereon. The seed layer **130** is provided to facilitate the growth of the piezoelectric nanowires **150** and, for example, may include at least one of ZnO, zinc (Zn), $ZnSnO_3$, SnO, tin (Sn), and Au.

The second insulation layer **122** is disposed on the piezoelectric nanowires **150**. Herein, the second insulation layer **122** may be coated to cover the piezoelectric nanowires **150**. The second insulation layer **122** may also be disposed to fill between the piezoelectric nanowires **150**. FIG. **2** illustrates the exemplary case in which the second insulation layer **122** is disposed to fill between upper portions of the piezoelectric nanowires **150**. Alternatively, the second insulation layer **122** may be disposed to cover the seed layer **130** between the piezoelectric nanowires **150**. The second insulation layer **122** acts to prevent a short circuit between the first electrode **111** and the second electrode **112**. The second insulation layer **122**, as the first insulation layer **121**, may include a polymer, for example, polymethyl methacrylate (PMMA). However, the material of the second insulation layer **122** is not limited thereto. The second insulation layer **122** may have a thickness (specifically, a thickness of the second insulation layer **122** between a top surface of the piezoelectric nanowire **150** and a bottom surface of the second electrode **112**) of about 2 μm, and for example, the second insulation layer **122** may have a thickness of about 200 nm or less. However, the second insulation layer **122** is not limited thereto. The second electrode **112** is disposed on the second insulation layer **122**. Herein, the second electrode **112** may include a conductive material such as metal, graphene, and a conductive polymer.

The foregoing flexible piezoelectric generator **100** may be manufactured by the following exemplary method. First, a first electrode **111** formed of a flexible and conductive substrate, such as a metal substrate or a conductive polymer substrate, is prepared. A first insulation layer **121** is formed on the first electrode **111** by coating with a polymer, for example, PMMA. Thereafter, a seed layer **130** is deposited on the first insulation layer **121** and piezoelectric nanowires **150** are then grown on the seed layer **130** through a hydrothermal process. For example, the piezoelectric nanowires **150** may include ZnO, $ZnSnO_3$, or SnO. The seed layer **130**, for example, may include at least one of ZnO, Zn, $ZnSnO_3$, SnO, Sn, and Au. For example, a growth solution including Zn is prepared and maintained at a predetermined temperature (e.g., about 70° C. to about 100° C.), and the hydrothermal process may then be performed by growing ZnO nanowires through dipping the first electrode **111** having the seed layer **130** and the first insulation layer **121** formed thereon in the growth solution for a predetermined time. A second insulation layer **122** is formed on the grown piezoelectric nanowires **150** by coating with a polymer, for example, PMMA, and a second electrode **112** is then formed by forming a conductive material on the second insulation layer **122**.

As described above, the piezoelectric generator **100** according to the present exemplary embodiment may prevent a short circuit between the first electrode **111** and the second electrode **112** by forming the thin first and second insulation layers **121** and **122** at both ends of the piezoelectric nanowires **150**, may improve power generation performance, and may also be manufactured in a large area.

A method, in which ZnO nanowires are grown on a flexible substrate having a first electrode deposited thereon through a hydrothermal process and the ZnO nanowires are then coated with an insulation layer and a second electrode is deposited, is generally used in order to manufacture a flexible piezoelectric nanogenerator. However, in the case that the ZnO nanowires are grown through a hydrothermal process, since unwanted microscopic particles may be adsorbed, it may be difficult to coat the ZnO nanowires with the insulation layer, and thus, possibility of having a short circuit between the first electrode and the second electrode may be high. In order to prevent a short circuit, a method of increasing a thickness of the insulation layer coated on the ZnO nanowires or a method of only coating the ZnO nanowires having no microscopic particles adsorbed thereon with the insulation layer may be used. However, in the case that the thick insulation layer is formed, since piezoelectric properties (e.g., piezoelectric potential etc.) generated from the ZnO nanowires may not be effectively transferred to the external first and second electrodes, power generation performance may be degraded and a large-area piezoelectric generator may be difficult to be manufactured due to the non-uniform adsorption of the microscopic particles. Meanwhile, in the case that an Al electrode is used as a first electrode for cost reduction purpose, ZnO nanowires may be difficult to be one-dimensionally grown on the first electrode.

In the flexible piezoelectric generator **100** according to the present embodiment, the thin first insulation layer **121** composed of a polymer, such as PMMA, is formed on the first electrode **111** before the hydrothermal process is performed, and thus, a short circuit between the first electrode **111** and the

second electrode **112** may be prevented. Also, even in the case that an inexpensive metal substrate, such as an Al foil, is used as a first electrode **111**, the piezoelectric nanowires **150**, such as ZnO nanowires, may be uniformly grown due to the first insulation layer **121** formed on the Al foil. Therefore, a flexible piezoelectric generator may be realized in which ZnO nanowires having excellent piezoelectric properties are grown in a large area on the first electrode **111** formed of the inexpensive metal substrate. FIG. **3** is an image of a flexible piezoelectric generator according to the exemplary embodiment manufactured by using an Al foil as an electrode substrate.

FIG. **4** is a photograph showing piezoelectric generators according to the exemplary embodiment attached to each position (I, II, and III) on a surface of a flag for experiments to identify energy harvesting from wind. FIG. **5** illustrates energies (i.e., voltages) generated from the piezoelectric generators attached to the each position (I, II, and III) on the surface of the flag illustrated in FIG. **4**. The results illustrated in FIG. **5** present voltages which are generated from the piezoelectric generators attached to the each position (I, II, and III) on the surface of the flag illustrated in FIG. **4** and stored in capacitors when the wind blows and when the wind does not blow. In FIG. **5**, "Wave" denotes a state in which the surface of the flag moves as the wind blows and "Waveless" denotes a state in which the surface of the flag does not move as the wind does not blow. Referring to FIG. **5**, it may be understood that voltages are stored only when the wind blows and amounts of the stored voltages are different according to the positions on the surface of the flag. Specifically, it may be understood that the largest amount of voltage is stored from the piezoelectric generator attached to the position III in which the flag moves with the largest amplitude among the positions (I, II, and III) on the surface of the flag.

FIGS. **6**A and **6**B are images showing a piezoelectric generator according to the exemplary embodiment attached to facial skin for experiments to identify detection of the movement of human skin, in which states of eyes open and eyes closed are respectively illustrated. FIG. **7** illustrates the results of the measurements of skin movement signals detected by the piezoelectric generator attached to the facial skin in FIGS. **6**A and **6**B. Referring to FIG. **7**, it may be understood that the movement of skin may be detected when the signals generated from the piezoelectric generator attached to the facial skin are measured.

FIG. **8** illustrates a piezoelectric generator **200** according to another exemplary embodiment. Hereinafter, features different from those of the foregoing embodiment will be mainly described.

Referring to FIG. **8**, the piezoelectric generator **200** includes a substrate **210**, a first electrode **211** disposed on the substrate **210**, a first insulation layer **221** disposed on the first electrode **211**, a plurality of piezoelectric nanowires **250** arranged on the first insulation layer **221**, a second insulation layer **222** disposed on the piezoelectric nanowires **250**, and a second electrode **212** disposed on the second insulation layer **222**. A flexible plastic substrate may be used as the substrate **210**. Herein, the substrate **210** may have a thickness of about 500 μm or less, and for example, the substrate **210** may have a thickness of about 50 μm or less. However, the thickness of the substrate **210** is not limited thereto. The first electrode **211** including a conductive material is disposed on the substrate **210**. Herein, the first electrode **211** may be formed by depositing predetermined metal on the substrate **210**. The first electrode **211** may be formed of graphene or a conductive polymer.

The first insulation layer **221** is disposed on the first electrode **211**. The first insulation layer **221** may act to prevent a short circuit between the first electrode **211** and the second electrode **212**, and uniformly grow the piezoelectric nanowires **250** on the first insulation layer **221**. The first insulation layer **221** may include a polymer, for example, PMMA. The first insulation layer **221** may have a thickness of about 2 μm, and for example, the first insulation layer **221** may have a thickness of about 200 nm or less. However, the thickness of the first insulation layer **221** is not limited thereto. The plurality of piezoelectric nanowires **250** is disposed on the first insulation layer **221**. The piezoelectric nanowires **250** may be arranged perpendicular to or inclined at a predetermined angle to the first insulation layer **221**. For example, the piezoelectric nanowires **250** may include ZnO, $ZnSnO_3$, or SnO nanowires, but the piezoelectric nanowires **250** are not limited thereto. A seed layer **230** may be further disposed on the first insulation layer **221** having the piezoelectric nanowires **250** formed thereon. The seed layer **230**, for example, may include at least one of ZnO, Zn, $ZnSnO_3$, SnO, Sn, and Au.

The second insulation layer **222** is disposed on the piezoelectric nanowires **250**. Herein, the second insulation layer **222** may be coated to cover the piezoelectric nanowires **250**. The second insulation layer **222** may include a polymer, for example, PMMA, but the second insulation layer **222** is not limited thereto. The second insulation layer **222** may have a thickness of about 2 μm, and for example, the second insulation layer **222** may have a thickness of about 200 nm or less. The second electrode **212** is disposed on the second insulation layer **222**. Herein, the second electrode **212** may include a conductive material such as metal, graphene, and a conductive polymer.

FIG. **9** illustrates a piezoelectric generator **300** according to another exemplary embodiment. Hereinafter, features different from those of the foregoing embodiments will be mainly described.

Referring to FIG. **9**, the piezoelectric generator **300** includes first and second electrodes **311** and **312** disposed by being spaced apart from each other, first and second insulation layers **321** and **322** disposed on the first and second electrodes **311** and **312**, and a piezoelectric structure disposed between the first insulation layer **321** and the second insulation layers **322**. The first electrode **311** may be a flexible electrode substrate. That is, the first electrode **311** may be a flexible and conductive substrate. For example, the first electrode **311** may be a metal substrate or a conductive polymer substrate. Herein, the metal substrate, for example, may include at least one of Al, Cu, Au, and Ag. However, these are only exemplary and various metals may be included. The first electrode **311** may have a thickness of about 500 μm or less and, for example, the first electrode **311** may have a thickness of about 50 μm or less. However, the thickness of the first electrode **311** is not limited thereto.

The first insulation layer **321** is disposed on the first electrode **311**. The first insulation layer **321** may act to prevent a short circuit between the first electrode **311** and the second electrode **312**. The first insulation layer **321** may include a flexible material having a high dielectric constant. For example, the first insulation layer **321** may include a polymer such as PMMA. However, the first insulation layer **321** is not limited thereto. The first insulation layer **321** may have a thickness of about 2 μm, and for example, the first insulation layer **321** may have a thickness of about 200 nm or less. However, the first insulation layer **321** is not limited thereto.

The piezoelectric structure is disposed on the first insulation layer **321**. Specifically, a piezoelectric thin film **350** is formed on the first insulation layer **321**. Herein, the piezo-

electric thin film **350** may include ZnO, $ZnSnO_3$, SnO, $BaTiO_3$, $NaNbO_3$, lead zirconate titanate (PZT), or polyvinylidene fluoride (PVDF). However, the piezoelectric thin film **350** is not limited thereto and may include various piezoelectric materials. The second insulation layer **322** is disposed on the piezoelectric thin film **350**. The second insulation layer **322**, as the first insulation layer **321**, may include a polymer, for example, PMMA. However, the second insulation layer **322** is not limited thereto. The second insulation layer **322** may have a thickness of about 2 μm, and for example, the second insulation layer **322** may have a thickness of about 200 nm or less. However, the second insulation layer **322** is not limited thereto. The second electrode **312** is disposed on the second insulation layer **322**. Herein, the second electrode **312** may include a conductive material such as metal, graphene, and a conductive polymer. When a mechanical force is applied to the flexible piezoelectric generator **300** having the foregoing structure from an external environment, the piezoelectric thin film **350** is deformed, and thus, electric energy may be generated through the first and second electrodes **311** and **312**.

FIG. **10** illustrates a piezoelectric generator **400** according to another exemplary embodiment. Hereinafter, features different from those of the foregoing embodiments will be mainly described.

Referring to FIG. **10**, the piezoelectric generator **400** includes a substrate **410**, a first electrode **411** disposed on the substrate **410**, a first insulation layer **421** disposed on the first electrode **411**, a piezoelectric thin film **450** disposed on the first insulation layer **421**, a second insulation layer **422** disposed on the piezoelectric thin film **450**, and a second electrode **412** disposed on the second insulation layer **422**. A flexible plastic substrate may be used as the substrate **410**. Herein, the substrate **410** may have a thickness of about 500 μm or less, and for example, the substrate **410** may have a thickness of about 50 μm or less. The first electrode **411** including a conductive material is disposed on the substrate **410**. Herein, the first electrode **411** may be formed by depositing predetermined metal on the substrate **410**. The first electrode **411** may be formed of graphene or a conductive polymer.

The first insulation layer **421** is disposed on the first electrode **411**. The first insulation layer **421** may include a polymer, for example, PMMA. The first insulation layer **421** may have a thickness of about 2 μm, and for example, the first insulation layer **421** may have a thickness of about 200 nm or less. However, the first insulation layer **421** is not limited thereto. The piezoelectric thin film **450** is formed on the first insulation layer **421**. The piezoelectric thin film **450** may include ZnO, $ZnSnO_3$, SnO, $BaTiO_3$, $NaNbO_3$, PZT, or PVDF. However, the piezoelectric thin film **450** is not limited thereto and may include various piezoelectric materials.

The second insulation layer **422** is disposed on the piezoelectric thin film **450**. The second insulation layer **422**, as the first insulation layer **421**, may include a polymer, for example, PMMA. However, the second insulation layer **422** is not limited thereto. The second insulation layer **422** may have a thickness of about 2 μm, and for example, the second insulation layer **422** may have a thickness of about 200 nm or less. However, the second insulation layer **422** is not limited thereto. The second electrode **412** is disposed on the second insulation layer **422**. Herein, the second electrode **412** may include a conductive material such as metal, graphene, and a conductive polymer.

The flexible piezoelectric generators according to the foregoing embodiments may prevent a short circuit between the first electrode and the second electrode by forming the thin first and second insulation layers at both ends of the piezoelectric nanowires, may improve power generation performance, and may be manufactured in a large area. That is, the thin first insulation layer formed of a polymer, such as PMMA, is formed on the first electrode before the hydrothermal process is performed, and thus, a short circuit between the first electrode and the second electrode may be prevented. Also, even in the case that an inexpensive metal substrate, such as an Al foil, is used as a first electrode, piezoelectric nanowires, such as ZnO nanowires, may be uniformly grown due to the first insulation layer formed on the Al foil. Therefore, a flexible piezoelectric generator may be realized in which ZnO nanowires having excellent piezoelectric properties are grown in a large area on the first electrode formed of inexpensive metal.

While exemplary embodiments have been particularly shown and described, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the inventive concept as defined by the following claims.

What is claimed is:

1. A piezoelectric generator comprising:

a first electrode;

a first insulation layer disposed on the first electrode;

a piezoelectric structure disposed on the first insulation layer and including a material generating piezoelectric potential at both ends of the piezoelectric structure by deformation;

a second insulation layer disposed on the piezoelectric structure; and

a second electrode disposed on the second insulation layer.

2. The piezoelectric generator of claim **1**, wherein the first electrode is a flexible and conductive substrate.

3. The piezoelectric generator of claim **2**, wherein the first electrode is a metal substrate or a conductive polymer substrate.

4. The piezoelectric generator of claim **3**, wherein the metal substrate comprises at least one of Al (aluminum), Cu (copper), Au (gold), and Ag (silver).

5. The piezoelectric generator of claim **2**, wherein the first electrode has a thickness of about 500 μm or less.

6. The piezoelectric generator of claim **1**, wherein the first electrode is disposed on a flexible plastic substrate.

7. The piezoelectric generator of claim **6**, wherein the first electrode comprises metal, a conductive polymer, or graphene.

8. The piezoelectric generator of claim **6**, wherein the plastic substrate has a thickness of about 500 μm or less.

9. The piezoelectric generator of claim **1**, wherein the first and the second insulation layers comprise a polymer.

10. The piezoelectric generator of claim **9**, wherein the first and the second insulation layers comprise polymethyl methacrylate.

11. The piezoelectric generator of claim **1**, wherein the first and the second insulation layers have a thickness of about 2 μm or less.

12. The piezoelectric generator of claim **1**, wherein the piezoelectric structure comprises a plurality of piezoelectric nanowires.

13. The piezoelectric generator of claim **12**, wherein the piezoelectric nanowires comprise ZnO, $ZnSnO_3$, or SnO.

14. The piezoelectric generator of claim **12**, wherein a seed layer is further disposed between the first insulation layer and the piezoelectric nanowires.

15. The piezoelectric generator of claim **14**, wherein the seed layer comprises at least one of ZnO, Zn, $ZnSnO_3$, SnO, Sn, and Au.

16. The piezoelectric generator of claim **1**, wherein the piezoelectric structure comprises a piezoelectric thin film.

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17. The piezoelectric generator of claim **16**, wherein the piezoelectric thin film comprises ZnO, $ZnSnO_3$, SnO, $BaTiO_3$, $NaNbO_3$, PZT, or PVDF.

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